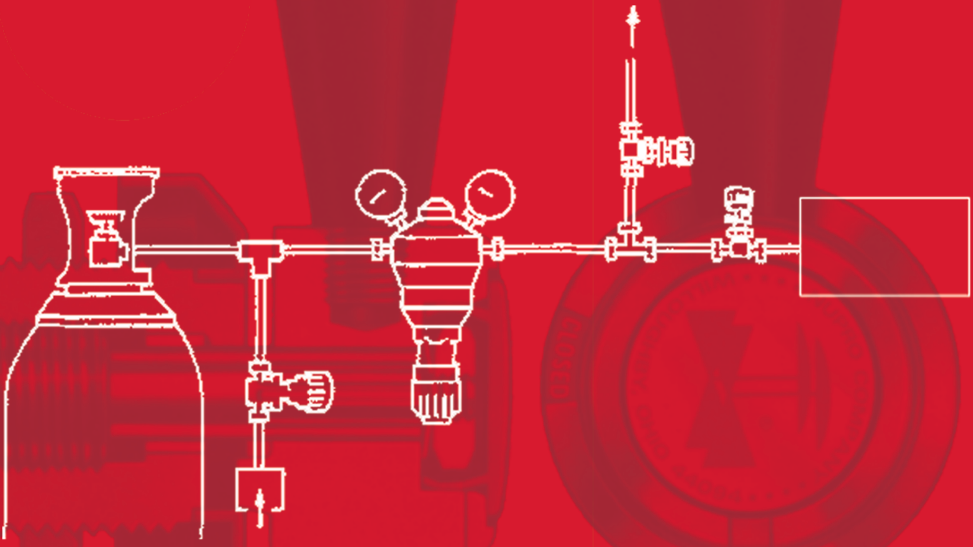
Helmut Schön

Handbook of Purified Gases



Springer

Handbook of Purified Gases

Helmut Schön

Handbook of Purified Gases

Springer

Helmut Schön
Leipzig
Germany

ISBN 978-3-540-32598-7 ISBN 978-3-540-32599-4 (eBook)
DOI 10.1007/978-3-540-32599-4

Library of Congress Control Number: 2014951880

Springer Heidelberg New York Dordrecht London

Printed on acid-free paper

Springer-Verlag GmbH Berlin Heidelberg is part of Springer Science+Business Media
(www.springer.com)

Foreword to the English Edition

The German Version of the Handbook of purified Gases was first published in 2005. There has been a great take up from colleges and specialists, so this positive resonance encouraged me to provide an English version of the book. In respect to the advances in technology and the more global approach it soon became evident to me that there will be an revision and enhancement for the handbook. Hints and helpful suggestions from expert colleagues representing more than 50 different companies and institutions were taken into account and I would like to express my very grateful thanks to all concerned.

Special thanks goes to the following people; without their help this book would not lay in your hands:

The Bavarian translation office which took the challenge of translation this very technical handbook with elaborateness, thereby reviewing every chapter thoroughly. Geoff Holford as native speaker war particularly helpful in this process.

Bill Heintz, formerly and currently working for Linde AG and briefly for PRAXAIR Inc., gave me as highly qualified US engineer very useful and important information about the technical requirements in the USA.

Jos Swinnen from Belgian Praxair in Brussels made significant contributions to ensure coherency applicability in European countries.

Special thanks to both gentleman for proof reading every chapter and their provision for all multinational aspects.

The experienced chemist Anette Nieczorawski from Praxair Germany in Berlin and expert engineer Peter Titschinski from special gases manufacturing plant of Linde AG Germany in Unterschleißheim (Munich) reviewed and adopted the data sheets in the annex of this book.

Unfortunately I had a stroke in December 2007 and it became significantly more difficult to me to work on the finalization of the handbook. The above mentioned experts gave me extensive support, especially Goeff Holford, as my son, the chemist Dr. Oliver Schön.

Last but not least I would like to thank Springer publishing house for the excellent support.

Leipzig in Germany, Dr. rer. nat. Helmut Schön
July 2014

Contents

1 Introduction

Technical gases are used in almost every field of industry, science and medicine and also as a means of control by government authorities and institutions. They are regarded as indispensable means of assistance. After World War II there have been two dominant directions of development: variety and purity. Both are closely connected with the modern technologies of the late 20th century

Due to the rapid progress of the semiconductor industry in the 70s the gases arsine, monosilane and diborane, formerley of interest for scientists, gained particular significance, previously they had only been of interest to scientists. There was a similar development in the 90s with nitrogen trifluoride and octafluorcyclobutane (RC318). There was also a steady increase in the amount of exotic components in gas mixtures. The number of substances, gases and liquids currently used in mixtures is estimated to be approx. 200. An example is the addition of a small quantity of halothane, a liquid anaesthetic, to nitrogen in order to control the air in hospital operating rooms.

Regarding the development of the purity of the gas, it is useful to look into the past. According to the book by Müller and Gnauck, published in 1965 and considered to be the latest monograph about purest gases in the German speaking area a gas is defined as purest if the total impurities are less than 100 ppm. (Riedel 1981) dealt with the principles of the purity of gases, (Schön 1985) reported on the already established quality of 99.99999% for helium, argon, hydrogen and monosilane. Already today there is large-scale production of gases with total impurities less than 0.1 ppm and a supply without loss of quality for the consumer. However, this does not mean that there is no possibility of further improvement. Roughly speaking, each decade sees an increase in purity by the power of ten. This development is and has been a fundamental prerequisite for the miniaturisation of electronic and mechanic components in the semiconductor and other related industries. It is reasonable to expect this trend to continue.

H. Schön, *Handbook of Purified Gases*,
DOI: 10.1007/978-3-540-32599-4_1

1.1 Definition of Purity

Purity G_R is identical with the content of gases and usually indicated in percentage. As in the first approach this indication means a mathematical relation only, a reference to volume, masses or the amount of substances is indispensable.

With reference to the standard conditions (chap. 1.2.3) and metrological certainty (chap. 7.1) it is advantageous to have purity data in relation to the amount of substances. A code designation is the so called point notation.

- N_2 with $G_R \geq 99.99$ mol-% is N_2 4.0
- Ar with $G_R \geq 99.9995$ mol-% is Ar 5.5

Point notation: The number of "9"s stands to the left of the point; the following digit after the point. Thus: 5.9 = 6.0.

Definition of purity by measuring the contents *via* chemical or physical absolute measuring systems shows a meaningful result under 2.0 only. As concentration C as result of analysis contains an error ΔC itself, O_2 2.0 and $\Delta C = 1$ %- rel. would result in $G_R = C = (99 \pm 1)$ volume- %. Higher percentage purity cannot be characterized herewith.

An acceptable alternative could be the measurement of concentration C_i % of impurity 1 –n which results in mol- or vol.-percentage.

$$G_R = 100.00000 - \sum_{i=1}^{n} C_i \tag{1.1-1}$$

Due to the low concentration of impurities the percentage data is only used for determination of G_R in eq.(1.1-1) or higher contents in gas mixtures. For practical reasons smaller units like ppm (part per million: $1 : 10^6$) ppb (part per billion: $1 : 10^9$) and ppt (part per trillion: $1 : 10^{12}$) have put through in the English-speaking areas. These are also related to volume, mass or mol. Exceptions are the water- and oil contents, which are mostly given in mg / m^3 or by the number of particles (chapter 7.5).

Unless otherwise mentioned, details about the extent of impurity refer to the observed limits. The definition whether an impurity lies within the limit is analytically less demanding than the determination of the quality level (in Ar: $C_{N2} = 124$ ppb ± 10 %-rel.). Such determination, however, is indispensable if the highest grade gas is being used as calibration gas for analytical comparison at the same time.

With given data "Xe 5.0" or "Xe 5.5" in the light bulb industry for example, the user must also be informed about the data of impurity which has been limited by the manufacturer regarding his product acc. to eq. (1.1-1). This is being demonstrated in the example of Xe. The following table T1.1-1 might give an idea of the requirements which are necessary for the extraction from air separation plants with further stages by means of adsorption, catalytic transformation, distillation and getter as well as for the analytical proof of purity.

Enrichment of Xe must be performed with approx. 10^1 to 10^6 ppm thus by factor 10^7. Progressive industrialization provokes an increase of pollutant concentration in the atmosphere, which on the one hand can only be proved by means of enrichment techniques and on the other hand regionally quite different.

The physical characteristic features of the last mentioned three gases in the following table are close to that of Xe, therefore a large scale of enrichment is to noticed too. As the physical-chemical actions in high-performance bulbs react very sensitively against these connections and lead to a reduction of working life a special cleaning method to remove detrimental impurities must be developed and applied.

Table T1.1-1 Specification of Xe 5.5 for incandescent bulbs

Gasart	**Limit concentration (volume parts)**	**Concentration (volume) in dry air**
Xe	> 99.9995 %	0.09 ppm
H_2	< 0.5 ppm	0.5 – 1 ppm
O_2	< 0.5 ppm	20.95 %
N_2	< 0.5 ppm	78.08 %
Ar	< 0.5 ppm	0.93 %
Kr	< 1.0 ppm	1.1 ppm
H_2O	< 1.0 ppm	1 – 3 %
CO_2	< 0.2 ppm	350 – 400 ppm
C_nH_m in summa	< 0.2 ppm	< 5 ppm
N_2O	< 0.5 ppm	< 1 ppm
C_2F_6	< 0.1 ppm	< 0.01 ppm
SF_6	< 0.1 ppm	< 0.01 ppm
ClF_5C_2 (R115)	< 0.1 ppm	< 0.01 ppm

Beside point notation there have always been designations which should either only indicate purity (Ar special clean) or point out a particularly low impurity. (N_2 CO-free). Theses impurities have some special account for the user and have sometimes been designated “signal impurities”. This designation can also express a purposeful user warranty (AsH_3 LED = Arsine, suitable for the production of light-emitting diodes). In cases like these a careful specification of impurities ought to be done too.

Referring to the concentrations which gets smaller is the question whether we are approaching the physical limits. Let us regard 1 ppt = 1 particle in 10^{12} particles. Under normal conditions in 1 ml there are approx. $2{,}7 \cdot 10^{19}$ atoms or molecules, 1 ppt = 27 million particles in 1 ml.[1] This is still enough for a statistical observation, it must, however, be considered that the collision probability e.g. against a wall or active centres in catalysers drops considerably so that conversions or bonding get slower and rarer.

---

[1] From the Avogadro constant $6.022 \cdot 10^{22}$ particles per Mol

Because of a concentration below 10 ppm of O_2 and SiH_4 in N_2 can be kept for weeks whereas reaction in the percentage-range ensues fast and explosion like. New methods are required to obtain further success in the development of purity.

1.2 Graduation of Gases

The designations „technical gases", „industrial gases", "speciality gases", "semiconductor gases", "doping gases", "calibration gases", "laser gases", "pure gases", or similar are not standardized and used by gas producers according to different critical ranges. In common "industrial gases" and "medical gases" are considered as generic terms.

1.2.1 Graduation According to Physical Data

A solid body has a definite shape and thus a definite cubature, a liquid doesn't have a definite shape but a definite cubature. It fills a basin which it is poured into only up to its cubature. Gas has neither a definite shape nor a definite cubature, and can therefore fill every given space. Gas is a state of aggregation which each substance can achieve given the necessary temperature. This is at atmospheric pressure always the case when the temperature of ebullition T_{bp} is obtained. Even at $T < T_{bp}$, however, a part of the substance is gaseous, and in this case one speaks of temperature-dependant vapour pressure above a liquid or a solid body.

The pure gases dealt with in this book are compressed gases , which are mostly filled and transported in gas cylinders. Stationary pressure tanks are partially used for storage purposes. Graduation is done due to critical temperatures of the compresses and under pressure liquefied gases together with those under pressure with solvents dissolved gases. The filling density (factor) f_{fill} regulates the maximum mass to be filled in relation to the volume of the container (geometric volume V_{geom}).

Graduation of gases is done according to (ADR 2005). Significant for USA is (DOT 2005), with only minor difference compared to (ADR 2005). Class 2: gases are valid for both regulations. Gases are defined to be substances

a) with a vapour pressure $p_D > 3$ bar at a temperature of +50°C (122°F) or
b) being totally gaseous at a temperature of +20°C (68°F) and a pressure of 1013.25 mbar (= 14.7 psia).

Further distinctive features are:

- Compressed gas (non liquefied compressed gas): A gas which is for transportation purposes packaged under pressure at –50°C (–58°F) and totally gaseous. This category includes all gases with a $T_{Cri} \leq -50°C$ (Fig. 1 – ADR).

- Fig 2: liquefied compressed gas. a gas which is packaged under pressure for transportation purpose at a temperature of > –50°C (–58°F) and partially liquefied (fig 2 – ADR). Further difference is made between
  - high pressure liquefied gas with $-50 < T_{Cri} \leq +65°C$ (149°F) or
  - low pressure liquefied gas with $T_{Cri} > +65°C$.
- Cryogenic liquefied gases like LN_2 for example (Fig. 3 – ADR).
- Compressed gases in solution like C_2H_2 (Fig. 4 – ADR).
- Low pressure cans (small packages with a volume about 1 l and working pressure below 20 bar), (Fig. 5 –ADR).
- Other objects under pressure (Fig. 6 – ADR)
- Gases not under pressure which have to follow particular regulations, e.g. gas samples (Fig. 7 – ADR).

The following table (T1.2.1-1) gives an overview regarding solid, liquid and gaseous substances.

Table 1.2.1-1: Physical Data of different Substances: T_{Cri} critical temperature, p_D vapour-pressure.

Substance	**Chemical Formula**	**T_{Cri} [^{0}C]**	**p_D/20 °C [bar]**	**p_D/50 °C [bar]**	**Consistence**
gold	Au	?	$\sim 10^{-59}$	$\sim 10^{-52}$	solid
mercury	Hg	1460	1.6×10^{-6}	1.7×10^{-5}	liquid
water	H_2O	374	0.023	0.123	liquid
ethanol	C_2H_5OH	244	0.058	0.299	liquid
silicon tetrachloride	$SiCl_4$	234	0.26	0.6	liquid
trichlorofluoro-methane (R11)	CCl_3F	198	0.87	2.6	liquid
hydrogen fluoride	HF	188	1.08	2.74	low press. liq.
nitrogen dioxide	NO_2	158	0.96	3.48	low press. liq.
dichlorodifluoro-methane (R12)	CCl_2F_2	112	5.66	12	low press. liq.
bromotriflioro-methan (R13B1)	$CBrF_3$	67	14.4	28	low press. liq.
carbon dioxide	CO_2	31	57.3	gaseous	high. press. liq.
xenon	Xe	16.6	gaseous	gaseous	high. press. liq.
silicon tetrafluoride	SiF_4	–14.1	gaseous	gaseous	high. press. liq.
tetrafluor-methane (R14)	CF_4	–45.6	gaseous	gaseous	high. press. liq.
methane	CH_4	–82,5	gaseous	gaseous	gaseous
oxygen	O_2	–119	gaseous	gaseous	gaseous
nitrogen	N_2	–147	gaseous	gaseous	gaseous
helium-3	He-3	–270	gaseous	gaseous	gaseous

Among compressed gases there are pure gases and gas mixtures. The latter may also contain liquid components.

Appropriate gases and gas mixtures are, as liquids, stored and transported at very low temperature. Examples: O_2,, H_2, He and CO_2. Relevant advice is to be found among manufacturing methods.

An important characteristic feature is the combustibility of gases. A gas is denoted combustible if, together with air it has an ignition range (explosion range). This is indicated at a temperature of 20°C and a minimum pressure of 1,013 bar regarding an inflammable mixture. If the concentration of oxygen compared to the approx. 21 volume-% of the air differs or another oxidizing agent e.g. nitrons oxide (N_2O) is being used, the limits of inflammation may change considerably. Many substances which do not burn or hardly burn in air, may burn particularly well in pure oxygen.

If the ignition point of a gas is below 100°C it is indicated as pyrophoric. Typical samples are monosilane (S_iH_4), phosphine (PH_3) and diborane (B_2H_6).

In regard to physical features the stable and radioactive isotopes must be observed. Many of the gases consist of isotopic mixtures; a few gaseous isotopes have only gained technical and scientific account.

With hydrogen three isotopes are known. The normal hydrogen ${}^{1}_{1}H_2$ is produced commercially, it contains approx. 0.01 volume-% heavy hydrogen, deuterium ${}^{2}_{1}H_2 = D_2$. Deuterium is available in trade as origin (independent) gas with enrichments > 99.8 atom-%. From nuclear plants emerges the radioactive tritium ${}^{3}_{1}H_2$, which is incorporated and replaces the ${}^{1}_{1}H_2$ in the human body by means of organic bonding. Therefore the use of tritium is restricted to special laboratories. With helium both stable isotopes ${}^{3}_{2}He$ and ${}^{4}_{2}He$ differ considerably at low temperatures only because of their quantum-mechanical characteristics.

Often used as tracers in the biological process are the stable isotopes ${}^{15}_{7}N_2$ and ${}^{18}_{8}O_2$. Short forms are C-13, N15 and O-18.

Regarding krypton the red spectral line of the stable isotope ${}^{85}_{36}Kr$ was used in the 60s to connect the primary metre to the wavelength. The radioactive isotope ${}^{86}_{36}Kr$ develops from core reactions in the decay chains and its concentration rises in the atmosphere, similar is the radioactive ${}^{133}_{54}Xe$. For both a radioactivity of approx. 120 Becquerel (B_q) per m^3 of air is calculated. Kr and Xe are not incorporate, e.g. they don't remain in the human body after being breathed in (inhaled). The half-life value t_{HW} and the kind of radiation for radioactive isotopes are:

- ${}^{3}_{1}H_2$: very soft ß-radiator, $t_{HW} = 12.3$ a
- ${}^{85}_{36}Kr$: ß-radiator, with a quota of 1 % ß-radiation. $t_{HW} = 10.8$ a
- ${}^{133}_{54}Xe$: ß-radiator, $t_{HW} = 5.25$ a

1.2.2 Graduation According to Other Characteristics

Chemical instability is an important feature. Typical examples are vinyl fluoride C_2H_3F (R 1141), ethylene oxide C_2H_4O and the well known acetylene C_2H_2.

- R 1141 tends to polymerisation which spontaneously appears at temperatures of over 100°C: the gas bottle must be of suitable material.
- Ethylene oxide serves for sterilization of medical devices; it also tends to polymerise and can only be used with mixtures of nitrogen.
- Acetylene is dissolved in acetone, which is in turn is held in a porous spongy solid.

Corrosion of the material of the container is a further safety issue feature. Examples: fluorine F_2, hydrogen chloride HCI, carbon monoxide CO and hydrogen-sulphide H_2S. In order to avoid corrosion some measures are necessary:

- High purity, particularly low moisture, reduction of chemical reactions at an inside container welds.
- High quality container material (e.g. electro polished stainless steel)
- With fluorine passivating treatment inside the container has to done.

The classification of toxicity of the pure gases is regulated in different documents. The comparison of the safety regulations for working places to those for storage and transportation unfortunately shows significant differences.

1.2.3 Standard Conditions

The international definition of a normal state for pressure measuring was determined in Paris on 04/10/1927 by the General Conference for Weights and Measurements. Thus an atmosphere (atm) is the pressure which a mercury column of 760 mm high pursues at 0°C onto a cm². As a result of this conference three different units of pressure were being used in many European countries between 1927–1970/80s:

- Physical standard specification: 760 mmHg (Torr) and 0°C, physical atmosphere 1 atm = 1013.25 mbar.
- Technical standard specification: 735.56 mm Hg and 20°C, technical atmosphere 1 at = 980.67 mbar.
- Physical standardized system cgs (centimetres, gram, second): 1 bar = 1 dyn $\cdot\text{cm}^{-2}$ = 1000 mbar (used in the field of meteorology)

Today the international valid “Systeme international d’unites”, mostly defined as SI-System, was introduced in 1960 claiming 6 basic units: meter, kilogram, second, Ampere, Kelvin and Candela and completed in 1971 with the basic unit mol.

The valid unit for the pressure of the power of one Newton on an m² is Pascal.

$$1\ \text{Pa} = 1\ \text{N} \cdot \text{m}^{-2} = 1\ \text{kg} \cdot \text{m}^{-2} \cdot \text{s}^{-2}$$

The bar is a derived, but in relation to the SI – System valid unit

$$1\ \text{bar} = 1000\ \text{mbar} = 10^5\ \text{Pa}\ .$$

The unit atm is used quite rarely, whereas in the U.S.A., atm is still frequently used. Conversion tables regarding the different units incl. Britannic ones are to be found among the tables in the appendix [2].

Many producers of technical gases indicate user-made standard operating condition of 1 bar at 15°C for their products. In the U.S.A. the standard operating condition at 70°F (= 21.1°C) and 1.01325 bar (= 14.696 psia) is often used. In Canada 15°C and 1.01325 bar are being used.

Pressure indications are only complete if it is visible whether it is to be considered as absolute or as super pressure. In this book a single pressure indication without suffix is always absolute. If necessary, "a" or "(a)" for absolute are will be added. If super pressure is being meant, "g" or "(g)" (gauge) will be used.

Faced with the conference in 1927 normal pressure has not changed, it reads p_{stand} = 1013.25 mbar. Thus, for example the boiling temperature T_{bp} must be indicated with this kind of pressure. As to be taken from the data sheets, point 9, other measurements have also been related to 1 bar. Furthermore the standard operating temperatures have been chosen differently, which has let to a certain non-uniformity. Norm temperature as before, is T_{stand} = 273.15 K = 0°C. Norm condition is mostly defined by "STP" (Standard Temperature and Pressure).

Regarding the volume percent most of gas producers take the ideal case. Based on the inquiries about concentration in mass-% an ideal and uniform Mol-volume of V_{STP} = 22.41383 $\text{dm}^3 \cdot \text{mol}^{-1}$ at norm condition or of 23.95797 $\text{dm}^3 \cdot \text{mol}^{-1}$ at standard operating condition of 15°C and 1 bar is being taken. Valid for standard operating condition in U.S.A. is a mol-volume of 24.14605 dm^3 or 0.85284 ft^3. These are also defined as SCF (Standard Cubic Foot).

1.3 Regulations and Standard Publications

In principle the regulations can be divided into:

- International regulations
- European rules. In regard to the widespread trading area regulations in the U.S.A. it was to be adapted.
- National rules.

---

[2] An introduction to the British Gravitational System and English Engineering System: (Thorncroft)

Throughout the United Europe common regulations become more and more popular. It has always been a task of the member countries to transfer European rule into national rule by means of regulations and law. This might be done by a direct international adaption of texts, but may as well be carried out by amending the particular rules of the single country accordingly. These measures are fluid and demand a period of several years. As long as there are no new rules, however, the previous form of rule is valid in principle.

International regulations:

- UN numbers or UN Ids: four-digit numbers that identify dangerous goods, hazardous substances and articles. The numbers are assigned by the United Nations Committee of Experts on the Transport of Dangerous Goods. They are published as part of their "Recommendations of the Transport of Dangerous Goods", also known as "Orange Book".
- NA numbers (North America), also known as (DOT 2005) numbers are issued by the United States Department of Transportation and are identical to UN numbers.
- Railway: (RID 2005)
- Aviation: (IACO 2005) and (IATA 2005)

European Regulations:

- Road: (ADR 2005)
- Inland Navigation (Rhine): (ADNR 2005)
- Pressure Equipment Directive: (97/23 EC 1997)
- Explosion Protection Directive: (94/9/EC 1994), also known as ATEX
- Minimum Safety and Health Requirements for the Use of Work Equipments by worker at work: (2001/45/EC)

US Regulations:

- As mentioned before (DOT 2005)
- Safety in laboratories: (OSHA 2005)

Encyclopedial publications about the most important technologies are (Römpp 1996-99), (Ullmann 1990-92), (Winnacker and Küchler 2003-05) and (Lide DL 2003-04).

There are only a few standard publications which directly refer to the area of technical gases. As already mentioned some earlier publications are "German Monographie" by (Müller, Gnauck 1965), the English-German book "Gases" by (Gerling, Holz & Co. 1996), the German "Paperback edition Technical Gases" by (Drews 1973), the German booklet "Technical Gases" by (Verannemann 1987) as well as the English monographic "Industrial Gases" by (Downie 1997).

A large collection of material data are offered in "Encyclopédie des Gaz" by (L'Air Liquide 1976) and the "Handbook of Compresses Gases" by (CGA 1999). Particularly for semiconductor gases a closer look into "Matheson Gas Data Book" by (Yaws 1001) is in particular recommended. The most popular publication in the German speaking area is the "gases Handbook" by (Messer Griesheim 1989) and the successor (Air Liquid 2005). A lot of information can also be gathered from special gas catalogues and safety data sheets by Linde, Messer, Matheson Trigas and L'Air Liquide companies.

Most of the physical, chemical and safety related data have been compared to the specifications in well known German publications by (D'Ans-Lax 1983–98), (Landolt-Börnstein from 1951), (Gmelin from 1979), (Kühn and Birett 2003) and (Hommel 2005). In the chapters about production, cleaning, analyses etc. reference to standard publications is directly made.

2 Introduction to the Physics of Gases

In physical textbooks and especially in thermodynamic textbooks there are more or less detailed explanations with the most important equations. For a more in-depth study the monograph from (Atkins 2006) is recommended as detailed as well as the German handbook from (Messer Griesheim 1989) and the monograph from (Hering et al. 1999).

2.1 The Ideal Gas

Since it has been possible to examine gases using physical methods two questions have always been of interest:

- How do the pressure p and the volume V of an enclosed quantity of gas behave at a constant temperature T (isothermal state change)?
- How does the volume of a gas behave at changing temperatures but constant pressure (isobaric state change)?

The answers can be found in Boyle-Mariotte's Law (17th century) according to the equation.

$$p \cdot V = \text{constant} = k \qquad (2.1\text{-}1)$$

with k as a constant and in Gay-Lussac's Law (around 1800)

$$V_{T1} = V_{T0} \cdot \left(1 + \alpha \cdot \Delta T_{1-0}\right) \qquad (2.1\text{-}2)$$

with a constant p for the states 0 and 1, and with the temperature difference $\Delta T_{1-0} = T_1 - T_0$ and α as the (spatial) expansion coefficient of gas. α was determined by experiment and is found to be in a borderline case $p \to 0$ as 1/(273.15) K. A gas with this borderline case is described as ideal.

All known gases show no ideal behaviour, rather, they are so called "real gases". The above mentioned Eqs. for the ideal gas can be used, if the temperatures are clearly above the melting point or the triple point and/or the pressure or the differences in pressure are small. The monoatomic He as the lightest inert gas comes closest to this ideal behaviour which is why it is used in gas thermometers.

The analogous equation (2.1-2) also applies to the behaviour of pressure at a constant geometric volume (isometric state change).

$$p_{T1} = p_{T0}(1 + \alpha \cdot \Delta T_{1-0}) \qquad (2.1\text{-}3)$$

H. Schön, *Handbook of Purified Gases*,
DOI: 10.1007/978-3-540-32599-4_2

Example E2.1-1: Calculating pressure with varying temperature.

At 15°C the pressure of the gas cylinder is determined to 198 bar gauge-pressure, thus the absolute pressure is 199 bar. A temperature of 35°C is expected, consequently $\Delta T = 20°C$. By approximation

$$p_{T35} = 199(1 + \frac{1}{273.15} 20) = 213.6[\mathrm{bar}]$$

The equations (2.1-2 and -3) assume a very simple form when V_{T0} is equal to V_0 for 0°C. Taking $\alpha = (273.15\ \mathrm{K})^{-1} = (T_{stand})^{-1}$ into consideration one obtain

$$V_1 = V_0 \frac{T_1}{T_{stand}} \quad \text{and} \quad p_1 = p_0 \frac{T_1}{T_{stand}} \tag{2.1-4}$$

with T in K or more generally

$$\frac{V}{T} = k_1 \quad \text{and} \quad \frac{p}{T} = k_2 \tag{2.1-5}$$

2.1.1 State Equations

The combination of Boyle-Mariotte's Law and Gay-Lussac's Law produces the state equation for the ideal gas.

$$\frac{p \cdot V}{T} = k \tag{2.1-1}$$

where k indicates a specific constant in each case. With a fixed but arbitrary mass M of an ideal gas for two states 1 and 2 and the standard condition this equation is therefore valid.

$$\frac{p_1 \cdot V_1}{T_1} = \frac{p_2 \cdot V_2}{T_2} = \frac{p_{stand} \cdot V_{T-stand}}{T_{stand}} \tag{2.1.1-2}$$

with $V_{T\text{-}stand}$ the volumes for V_1 and V_2 under standard conditions. By introducing the experimentally measured density of the real gas G at standard conditions $\varphi_{G,STP}$ and the specific gas constant R_G a simplification is obtained.

$$V_{G,T-stand} = \frac{M_G}{\varphi_{G,STP}} = V_{G,STP} \tag{2.1.1-3}$$

$$\frac{p \cdot V}{T} = \frac{M_G \cdot p_{stand}}{T_{stand} \cdot \varphi_{G,STP}} \tag{2.1.1-4}$$

$$R_G = \frac{p_{G,stand}}{T_{stand} \cdot \varphi_{G,STP}} \tag{2.1.1-5}$$

$$p \cdot V = M \cdot R_G \cdot T \tag{2.1.1-6}$$

Example E2.1.1-1: Calculating R_G *for Ar* (R_{Ar}) *with a density* $\varphi_{Ar,STP} = 1{,}784\ kg \cdot m^{-3}$.

$$R_{Ar} = \frac{101325}{273.15 \cdot 1.784} = 207.9 \left[J \cdot kg^{-1} \cdot K^{-1} \right]$$

From the equations (2.1-10 and -11) one can derive a formula to calculate the density when R_G is known.

$$\varphi_{G,T,p} = \frac{M_G}{V_G} = \frac{p}{T \cdot R_G} \qquad (2.1.1\text{-}7)$$

Example E2.1.1-2: Calculating the density φ_{Ar} *at 15°C (=288.15 K) and 1 bar (=*10^5 *Pa) using* R_{Ar} *from Example E2.1.1-1.*

$$\varphi_{Ar} = \frac{10^5}{288.15 \cdot 207.9} = 1.669 \left[kg \cdot m^{-3} \right]$$

If it is necessary to start from a different point than $\varphi_{G,STP}$ one can use a formula which can also be derived from the equation (2.1.1-2). This also applies in idealized conditions, i.e. for small pressure and temperature differences.

$$\varphi_{G,T2,p2} = \varphi_{G,T1,p1} \frac{p_2 \cdot T_1}{p_1 \cdot T_2} \qquad (2.1.1\text{-}8)$$

The specific gas constant can also be formed for mixtures. The basis is Dalton's Law (1807): The pressure p of an ideal gas mixture consists of the sum of the partial pressure p_i of the n individual gases.

$$p = \sum_{i=1}^{n} p_i \qquad (2.1.1\text{-}9)$$

Thus one obtains the equation (2.1.1-6) for the individual gas i and the number n

$$p_i \cdot V = M_i \cdot R_i \cdot T \qquad \text{and} \qquad p \cdot V = \sum_{i=1}^{n} (M_i \cdot R_i) \cdot T$$

The specific gas constant R_{1-n} can be represented as

$$R_{1-n} = \frac{\sum_{i=1}^{n} M_i \cdot R_i}{\sum_{i=1}^{n} M_i} \qquad \text{and} \qquad M = \sum_{i=1}^{n} M_i$$

$$p \cdot V = M \cdot R_{1-n} \cdot T \qquad (2.1.1\text{-}10)$$

The gases can be compared with each other using the molar volume. According to Avogadro’s Principle (1811) different gases contain the identical number of molecules at the same pressure and the same temperature and the same volume.

The molar volume $V_{G,Mol}$ is the volume that the molar mass $M_{G,Mol}$ of a gas adopts. The molar volume of an ideal gas at standard conditions is the V_{STP} from paragraph 1.2.3.

With ν as the number of moles in the mass M_G of the gas G, partly also referred to as fractions one obtains

$$M_G = \nu \cdot M_{G,Mol} \qquad (2.1.1\text{-}11)$$

$\varphi_{G,STP}$ from equation (2.1.1-3) can be expressed through $V_{G,Mol,STP}$ at standard condition as

$$\varphi_{G,s\tan d} = \frac{M_{G,Mol}}{V_{G,Mol,STP}} \qquad (2.1.1\text{-}12)$$

The $\varphi_{G,Mol}$ is usually referred to as molar density (at standard condition). However the $V_{G,Mol,STP}$ for an ideal gas is the V_{STP} from chapter 1.2.3. Thus one can introduce a universal molar gas constant R_{Mol} . It is combined with the specific gas constant *via* the molar masses.

$$R_{Mol} = \frac{p_{s\tan d}}{T_{s\tan d} \cdot V_{STP}} = M_{G,Mol} \cdot R_G \qquad (2.1.1\text{-}13)$$

$$= 8.31441\left[J \cdot mol^{-1} \cdot K^{-1}\right] = 8.31441 \cdot 10^{-2}\left[bar \cdot m^3 \cdot kmol^{-1} \cdot K^{-1}\right]$$

From the equation (2.1.1-6) $p \cdot V = M \cdot R_G \cdot T$ and the equations (2.1.1-11) as well as (2.1.1-13) follows the Clapeyronish State Equation (mid. 19th century).

$$p \cdot V = \nu \cdot R_{Mol} \cdot T \qquad (2.1.1\text{-}14)$$

For 1 ν, i.e. 1 mole, the following equation is valid

$$p \cdot V_{Mol} = R_{Mol} \cdot T \qquad (2.1.1\text{-}15)$$

Thus a new equation for the density is aquired.

Omitting the index G and introducing the molar density φ_{Mol} one obtains

$$\varphi_{G,T,p} = \frac{M}{V} = \frac{p \cdot M_{Mol}}{R_{Mol} \cdot T} \qquad (2.1.1\text{-}16)$$

$$\varphi_{Mol} = \frac{1}{V_{Mol}} = \frac{p}{R_{Mol} \cdot T} \qquad (2.1.1\text{-}17)$$

The Boltzmann constant $k_{Boltzmann}$ (around 1900) is used for state equations. Here R_{Mol} is reduced to a single molecule (or atom in the case of the noble gases). The molar volume contains $6.0221367 \cdot 10^{23}$ particles. This number is referred to as Avogadro or Loschmidtish Number.

$$k_{Boltzmann} = \frac{R_{Mol}}{k_{Avogadro}} \qquad (2.1.1\text{-}18)$$

$k_{Boltzmann}$ is $1.380658 \cdot 10^{-23}$ J · K^{-1}. Thus instead of the equation (2.1.1-15) we obtain

$$p \cdot V_{Mol} = k_{Boltzmann} \cdot k_{Avogadro} \cdot T \qquad (2.1.1\text{-}19)$$

This equation is valid for one mole. Therefore the counterpart for the equation (2.1.1-14) with the number of particles $n_{particle}$ in volume V is the equation

$$p \cdot V = k_{Boltzmann} \cdot n_{particle} \cdot T \qquad (2.1.1\text{-}20)$$

$$n_{particle} = \nu \cdot k_{Avogadro} \qquad (2.1.1\text{-}21)$$

2.1.2 Kinetic Gas Theory

Two concepts are associated with the ideal gas and form the basis of the kinetic gas theory:

- Molecules are so small that their own volume is negligible in comparison with the dimension of the container.
- No forces act between the molecules except those of the completely elastic collisions with each other.

Amongst other things the kinetic gas theory provides us with the equation for the average velocity v_m of a molecule or an atom using the root mean square statistical method. It is therefore called the RMS value.

$$v_{m,G} = \sqrt{\frac{3 \cdot R_{Mol} \cdot T}{M_{G,Mol}}} \qquad (2.1.2\text{-}1)$$

As there is a dependency of the gas G on the molar mass the velocity is referred to as $v_{m,G}$.

Example E2.1.2-1: Calculating the molecular velocity of hydrogen and sulphur hexafluoride at a room temperature of 20°C.
The specifications are $M_{H2,Mol} = 2.0 \cdot 10^{-3}$ *kg · mol*$^{-1}$, $M_{SF6,Mol} = 146.05 \cdot 10^{-3}$ *kg · mol*$^{-1}$, $T = 293.15$ *K. The* $R_{Mol} = 0.0831441$ *bar · m*$^{-3}$ *· kmol*$^{-1}$ *· K*$^{-1}$ *from the equation 2.1.1-13 needs to be adjusted: 1 bar =* 10^{+5} *kg · m*$^{-1}$ *· s*$^{-2}$*, 1 kmol =* 10^3 *mol,* $R_{Mol} = 8.31441$ *kg · m*^{2} *· s*$^{-2}$ *· mol*$^{-1}$ *· K*$^{-1}$*.*

$$v_{m,H2} = \sqrt{\frac{3 \cdot 8.31441 \cdot 293.15}{2.016 \cdot 10^{-3}}} = 1904.5 \quad \left[m \cdot s^{-1}\right]$$

$$v_{m,SF6} = \sqrt{\frac{3 \cdot 8.31441 \cdot 293.15}{146.05 \cdot 10^{-3}}} = 223.8 \quad \left[m \cdot s^{-1}\right]$$

The average velocity which has been introduced here $v_{m,G}$ is only one of several common ways of determining the average value. It is important to mention Maxwell distribution and probability distribution when determining the average value.

$$v_{m,G,Maxwell} = \sqrt{\frac{8}{3 \cdot \pi}} \; v_{m,G} = 0.9212 \cdot v_{m,G} \qquad (2.1.2\text{-}2)$$

$$v_{m,G,probability} = \sqrt{\frac{2}{3}}\ v_{m,G} = 0.8165 \cdot v_{m,G} \tag{2.1.2-3}$$

The diffusion which will be dealt with in chapter 2.2.3 is directly proportional to $v_{m,Maxwell}$. Therefore there may be significant differences in the reaction times of chemical syntheses, adsorption and catalysis depending on the mass of the gases.

The kinetic gas theory provides us with another important factor: The mean free path of a molecule or an atom which was first introduced by Clausius in 1858. It is the path which a molecule travels between two collisions. We refer to the average value as $s_{particle}$.

$$s_{particle} = \frac{k_{Boltzmann} \cdot T}{\sqrt{2} \cdot \pi \cdot p \cdot d^2} = \frac{R_{Mol} \cdot T}{\sqrt{2} \cdot \pi \cdot p \cdot d^2 \cdot k_{Avogadro}} \tag{2.1.2-4}$$

with the diameter d of the particle.

2.1.3 Enthalpy

From thermodynamics we introduce the properties of state quantities U for the internal thermodynamic energy of a system and H as enthalpy, both are measured in Joules J. The enthalpy is the sum of the internal energy and the product $p \cdot V$ meaning the work which is done by a gas, e.g. when it drives a piston.

$$H = U + p \cdot V \tag{2.1.3-1}$$

We need this equation to calculate the heat capacity. This is defined as the heat quantity which is needed to heat a specific quantity of a material by 1 K. If 1 kg is used we talk about the specific heat capacity. If we refer to one mole then it is the molar heat capacity. The equation symbol is the lower case c. Now we need to differentiate between the c_V at constant volume and the c_p at constant pressure.

If we have a container with rigid walls (constant V) and heat the gas in it, then p increases and thus also the internal energy U. c_v is therefore defined as the differential quotient of U with respect to the temperature

$$c_V = \left(\frac{dU}{dT}\right)_V \tag{2.1.3-2}$$

This only applies to the ideal gas (which is not intended to be proven here!)

$$c_V = \left(\frac{dU}{dT}\right)_V = \left(\frac{dU}{dT}\right)_p$$

Looking at a container with a moving piston an increase in temperature will lead to an increase in volume with the pressure remaining the same. The increase in volume, however, necessitates further derivation. Thus we must use enthalpy for the definition of c_p.

$$c_p = \left(\frac{dH}{dT}\right)_p \tag{2.1.3-3}$$

We ascertain the difference and put $p\ V = \nu\ R_{Mol}\ T$ into the equation (2.1.3-1) and differentiate according to T

$$c_p - c_V = \left(\frac{dH}{dT}\right)_p - \left(\frac{dU}{dT}\right)_V = \left(\frac{dH}{dT}\right)_p - \left(\frac{dU}{dT}\right)_p$$

$$\left(\frac{dH}{dT}\right)_p = \left(\frac{dU}{dT}\right)_p + \nu \cdot R_{Mol}$$

$$c_p - c_V = \nu \cdot R_{Mol}$$

and with reference to moles

$$c_{p,Mol} - c_{V,Mol} = R_{Mol} \tag{2.1.3-4}$$

This is the known equation for the difference of the heat capacities which can also be calculated individually from the kinetic gas theory. For a monoatomic ideal gas which has three degrees of freedom as to translation of its atoms (vibration in three directions without rotation) the following applies:

$$c_{p,Mol} = \frac{5}{2} R_{Mol} \qquad \text{and} \qquad c_{V,Mol} = \frac{3}{2} R_{Mol}$$

The heat capacities of ideal gases do not depend on temperature, thus they only give an approximation of the correct values for real gases. For diatomic gases like N_2 and O_2 $c_{p,Mol} = (7/2) \cdot R_{Mol}$ and $c_{v,Mol} = (5/2) \cdot R_{Mol}$ apply. For molecules like H_2O with three degrees of freedom in translation and rotation they are $c_{p,Mol} = (8/2) \cdot R_{Mol}$ and $c_{v,Mol} = (6/2) \cdot R_{Mol}$. The proportion ε of both heat capacities will be required in chapter 2.2.3 for the adiabatic expansion:

$$\varepsilon = \frac{c_{p,Mol}}{c_{V,Mol}} \tag{2.1.3-5}$$

ε equals 5/3 for a monatomic and 7/5 for a diatomic ideal gas.

2.2 The Real Gas

The real gas is differentiated from the ideal gas because the forces between the molecules or atoms as well as their own volume cannot be neglected. This causes a number of consequences.

The gases can be liquefied under suitable conditions and also transformed into solid phase. Therefore the critical point with T_{Cri} and p_{Cri} and density φ_{Cri} is important. However when $T > T_{Cri}$, one cannot achieve liquefaction even at high pressure. At the triple point all three thermodynamic phases exist simultaneously, illustrated in P2.2-1 explains this.

The vapour-pressure curve separates the gaseous from the liquid phase, the sublimation curve separates the gaseous from the solid, and the melting-pressure curve separates the liquid from the solid. Thus these curves are called phase separation curves. The melting point T_{mp} is obtained from the intersection point of the isobars at $p_{stand} = 1.01325$ bars with the vapour-pressure curve.

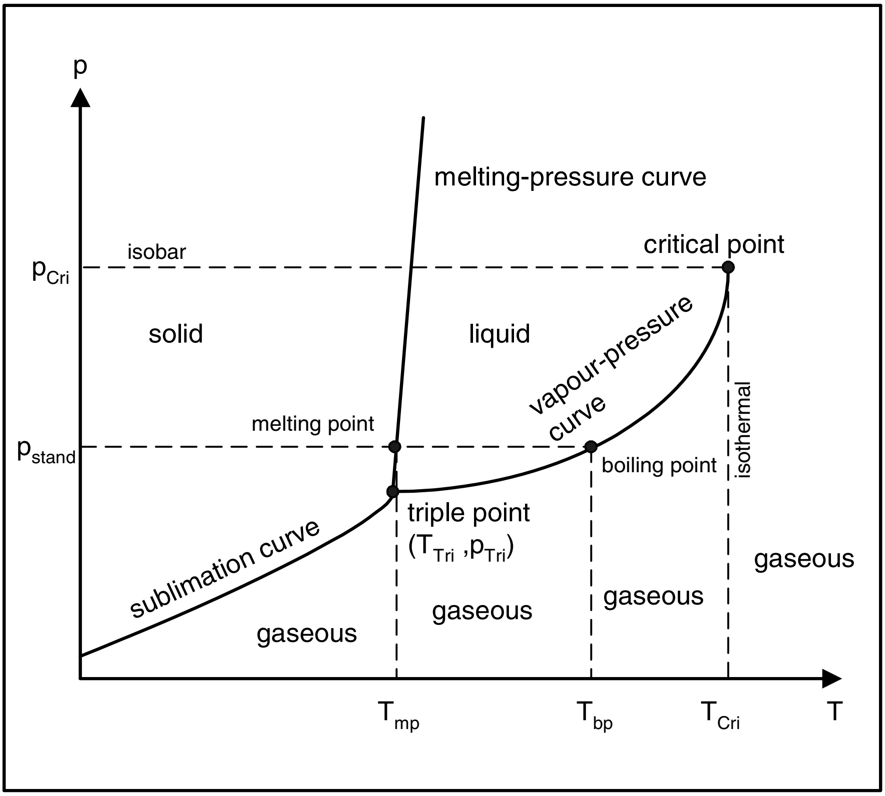


Illustration P2.2-1: T, p – diagram of the real gas in schematic depiction.

In order to obtain the melting point at p_{stand} we must differentiate between two cases.

- The pressure p_{Tri} at the triple point is below p_{stand} as shown in P2.2.1. Thus the melting point at the intersection curve of the isobars p_{stand} with the melting pressure curve, this results in the melting point T_{mp} which is always close to the triple temperature T_{Tri} . This is also adverted to gases which boil at a low temperature He, N_2, H_2, O_2 or Ar, a typical example is Xe with $p_{Tri} = 0.8167$ bar $< p_{stand}$.

- If $p_{Tri} > p_{stand}$, then the sublimation point is the one at the intersection point of the isobars p_{stand} with the sublimation curve, thus we can give a sublimation temperature T_{Subl} which is close to the triple temperature. A typical example is CO_2 with $p_{Tri} = 5.185$ bar. These relationships imply that the release of CO_2 causes the formation of some carbon dioxide snow. In order to avoid this e.g. when mixing it with other gases attention must be paid to the fact that the expansion pressure is not smaller than p_{Tri} (5.2 bar abs. for CO_2) or that the expansion takes place isothermally.

2.2.1 Equations of State

In his dissertation in 1873 Van der Waals introduced an equation which reflects the liquefaction of real gases qualitatively and corrects the ideal gas equation quantitatively. With reference to mole this equation is

$$\left(p + \frac{a}{V_{G,Mol}^2}\right)\left(V_{G,Mol} - b\right) = R_{Mol}T \qquad (2.2.1\text{-}1)$$

For a = 0 and b = 0 one obtains the state equation of the ideal gas. The correcting factor $a/(V_{G,Mol})^2$ is referred to as the internal pressure and takes into consideration the intermolecular attraction force. The constant b stands for the molecules' own volume. The following table expresses the experimentally ascertained numerical values for a and b for some selected gases. The larger these values become the greater is the deviation from the ideal behaviour.

Table T2.2.1-1:. Numerical values of the constants in van der Waals' equation.

Gas	**a in 10^3 [$N \cdot m^4 \cdot kmol^{-2}$]**	**b in 10^{-2} [$m^3 \cdot kmol^{-1}$]**
He	3.47	2.38
H_2	24.86	2.67
Air	136	3.66
CH_4	230	4.31
CO_2	366	4.28
C_3H_8	937	9.03
C_4H_{10}	1389	11.64

There are a large number of additional state equations which are built up similarly. Thus we achieve a good approximation especially in the boundary area to liquefaction. For the calculation and use of such data please refer to the previous work of (Baumer 1983) and especially the comprehensive work of (Poling et al. 2001). The dependence of the intermolecular forces can be represented with a compression factor Z (Atkins 2006). An ideal gas has Z = 1. If $Z > 1$ then the gas is compressed more heavily than an ideal gas. Z is also referred to as a real gas factor, there is a dependency on pressure and temperature.

$$Z_{p,T} = \frac{p \cdot V_{Mol}}{R \cdot T} \tag{2.2.1-2}$$

$$Z_{p,T} = \frac{V_{real}}{V_{ideal}} \tag{2.2.1-3}$$

For $Z_{p,T} < 1$ the real molar volume is smaller than the ideal. This means that in a pressurised container there is more gas than would be expected according to the ideal equation. With $Z_{p,T} > 1$ it is vice versa. The dependency of Z on p and T can be so extreme that for a gas both $Z_{p,T} < 1$ and $Z_{p,T} > 1$ are possible. For N_2 $Z = 0.9752$ for $p = 120$ bar and $T = -10°C$, and $Z = 1.0711$ for $p = 200$ bar and $T = +50°C$. $Z_{p,T}$ is represented as a polynomial of the pressure p. The polynomial is an infinite mathematical series according to increasing powers of p.

$$Z_{p,T} = 1 + \beta \cdot p + \gamma \cdot p^2 + \ldots \tag{2.2.1-4}$$

with the β, γ, ... as virial coefficients dependent on temperature which has to be determined experimentally. The word virial is derived from the Latin vis = power, plural vires/virium and is intended to draw attention to the intermolecular forces. For reasons of simplification the first virial coefficient was set = 1, in most cases the series is terminated after the first power of p. As well as the development of powers of p it is also possible to obtain polynomials for the molar density and the molar volume with different virial coefficients. The second virial coefficients are easily transferable with each other. Using equation (2.1.1-16) we obtain

$$p = \varphi_{Mol} \cdot R_{Mol} \cdot T = \frac{R_{Mol} \cdot T}{V_{Mol}} \tag{2.2.1-5}$$

$$Z_{p,T} = 1 + \beta^* \cdot \varphi_{Mol} + \gamma^* \cdot \varphi_{Mol}^2 + \ldots \tag{2.2.1-6}$$

With

$$\beta^* = \beta \cdot R_{Mol} \cdot T \tag{2.2.1-7}$$

$$Z_{p,T} = 1 + \frac{\beta^*}{V_{Mol}} + \frac{\gamma^*}{V_{Mol}^2} \tag{2.2.1-8}$$

Using the real gas factor it is now possible to calculate volumes, densities and pressures much more accurately than with the ideal gas laws. Using the equation (2.1.1-14) we convert to (2.2.1-3)

$$Z_{p,T} = \frac{V_{Mol} \cdot p}{R_{Mol} \cdot T} \tag{2.2.1-9}$$

For the density we obtain

$$\varphi_{p,T} = \frac{M_{Mol} \cdot p}{Z_{p,T} \cdot R_{Mol} \cdot T} \tag{2.2.1-10}$$

For the comparison of two states we form the quotients of the two Z.

$$\frac{Z_{p1,T1}}{Z_{p2,T2}} = \frac{\nu_2 \cdot V_1 \cdot p_1 \cdot T_2}{\nu_1 \cdot V_2 \cdot p_2 \cdot T_1} = \frac{\nu_2 \cdot \varphi_2 \cdot M_1 \cdot p_1 \cdot T_2}{\nu_1 \cdot \varphi_1 \cdot M_2 \cdot p_2 \cdot T_1} \qquad (2.2.1\text{-}11)$$

Most calculations can be carried out using this equation.

Example E2.2.1-1: Calculating the gas volume of N_2 *at* $p = 200$ *bar and 15°C in a 50 litre cylinder (*$V_{geom} = 0.05\ m^3$*).*

The $Z_{p,T}$ *can be taken from the table T10.6-1 including the necessary interpolation at 1.050. If one dispenses with a p, T point of reference then one assumes that there is* V_{geom} *0.05* m^3 *of gas at 1 bar. Thus there are* V_{ideal} *at 200 bar*

$$V_{ideal} = \frac{p}{1\,\text{bar}} V_{geom} = 200 \cdot 0.05 = 10\left[m^3\right]$$

From equation 2.2.1-3 we obtain a V_{real}

$$V_{real} = \frac{V_{ideal}}{Z_{p,T}} = \frac{10}{1.050} = 9.522\left[m^3\right]$$

As already mentioned in paragraph 1.2.3 many manufacturers of industrial gases prefer the operating conditions 15°C and 1 bar. In this case it is necessary to calculate a $Z_{reference}$. As in most cases the density for the point of reference is known accurately enough so that we can use equation (2.2.1-10) with the necessary conversion.

$$Z_{reference} = \frac{M_{Mol} \cdot p_{reference}}{\varphi_{reference} \cdot R_{Mol} \cdot T_{reference}}$$

From the data sheet N_2 we obtain $M_{Mol} = 28.0134$ kg, $\varphi_{p=1bar,T=15} = 1.170\ kg \cdot m^{-3}$. In addition $T = 288.15$ K and $R_{Mol} = 0.0831441\ bar \cdot m^3 \cdot kmol^{-1} \cdot K^{-1}$.

$$Z_{reference} = 0.99938$$

The very small deviation from 1.0000 shows that the operating conditions vary only a small amount from the standard state and this is marginal for many calculations. We now have to determine the volume of gas $V_{reference}$ at the point of reference which would result at the expansion from 200 bar. For this we use the equation (2.2.1-11). In addition we can simplify because of the number ν of the moles and the T being the same in both states, $p_{reference} = 1$ bar.

$$\frac{Z_{reference}}{Z_{p,T}} = \frac{V_{reference}}{p \cdot V_{geom}}$$

$$V_{reference} = \frac{Z_{reference}}{Z_{p,T}} p \cdot V_{geom} = \frac{0.99938}{1.0502} 200 \cdot 10 = 9.516\left[m^3\right]$$

Then we should introduce a calculation which cannot be immediately solved with the equation (2.2.1-11) but requires the use of two virial coefficients.

Example E2.2.1-2: From a pressurised gas cylinder filled with CH_4 *with* V_1 = *50 litres volume and* p_1 = *200 bar with stable temperature* $T = T_1 = T_2$ =*20°C = 293.15 K in a container with* V_2 = *200 litres pressure equalization takes place. We are determined to find* p_2 .

The new total volume is $V_{1+2} = V_1 + V_2$, $v_1 = v_2$. *According to the equations (2.2.1-11) and (2.2.1-4) but only with the linear element* $\beta \cdot p$ *we obtain:*

$$\frac{Z_{p1,T}}{Z_{p2,T}} = \frac{V_1 \cdot p_1}{V_{1+2} \cdot p_2} = \frac{1+\beta \cdot p_1}{1+\beta \cdot p_2} \qquad (2.2.1\text{-}12)$$

It is possible to ascertain $Z_{p1,T}$ *as 0.813 from table T10.6-1 ,* p_2 *and* $Z_{p2,T=293}$ *cannot be determined from the equation (2.2.1-11). Thus we use the two virial coefficients and solve the above-mentioned equation according to* p_2 .

$$p_2 = \frac{V_1 \cdot p_1}{V_{1+2} + \beta \cdot p_1 \left(V_{1+2} - V_1\right)} \qquad (2.2.1\text{-}12)$$

The second virial coefficient β *at 20°C is taken to be* $-1.93 \cdot 10^{-3}$ bar^{-1} *including interpolation from the data sheet in chapter 9.*

$$p_2 = \frac{200 \cdot 0.05}{0.25 - 1.93 \cdot 10^{-3} \cdot 200(0.25 - 0.05)} = 57.8[\text{bar}]$$

The result deviates significantly from the ideal calculation (= 40 bar).

2.2.2 The Liquefied Gas

If a substance is in a gaseous state then its internal energy determined by the temperature is greater than the intermolecular (attracting) forces. If the temperature is lowered by removing heat from the outside then depending on the pressure at one particular temperature the intermolecular forces prevail and liquefaction takes place. At p_{stand} = 1013.25 mbar this point is referred to as boiling point T_{bp}. In order to change the state of aggregation it is necessary to supply energy in the form of heat (evaporation) or withdraw energy (liquefaction). This amount of energy corresponds with the enthalpy of evaporation or with heat of vaporization ΔH_{evap} in $kJ \cdot kg^{-1}$ mostly given at T_{bp} . The enthalpy of evaporation depends on the temperature and can be calculated as T between T_{Tri} and T_{Cri} according to Watson's formula for a particular temperature T using $\Delta H_{bp,evap}$ at T_{bp} .

$$\Delta H_{T,evap} = \Delta H_{bp,evap} \left(\frac{1 - T \cdot T_{Cri}^{-1}}{1 - T_{bp} \cdot T_{Cri}^{-1}} \right)^{0.38} \qquad (2.2.2\text{-}1)$$

When the state of aggregation changes from solid to liquid there is a corresponding melting heat at T_{mp}.

Example E2.2.2-1: 3 m · h^{-1} are to be removed from a propane gas cylinder in a gaseous state at T = 20°C = 293.15 K. How much electrical energy has to be used for the water bath?

First of all, one will ask why it is necessary to have additional heating. The cylinder contains liquid propane, the gaseous propane in the upper part of the cylinder is used and must replenished by evaporation. When removing small amounts of the substance, the amount of heat supplied by the surrounding air is sufficient to achieve more evaporation if the cylinder cools slightly. If larger amounts are removed the cylinder will cool significantly which could lead to the propane changing to the solid state of aggregation. In this case a water bath controlled by a thermostat is the appropriate means. One should use T_{Cri} =369.85 K, T_{bp} = 231.08 K and $\Delta H_{bp,evap}$ = 425.4 kJ · kg^{-1} from the propane data sheet.

$$\Delta H_{T=293,evap} = 425.4\left(\frac{1-\dfrac{293.15}{369.85}}{1-\dfrac{231.08}{369.85}}\right)^{0.38} = 339.3\left[kJ\cdot kg^{-1}\right]$$

As 1 kJ = 1 kWs (kilowatt second) the energy E for 3 kg per 1 hour (= 3600 s) is shown in usual kWh as

$$E = \frac{3\cdot 339.3}{3600} = 0.283\left[kWh\right]$$

An important physical characteristic of the gas which has been liquefied under pressure is the vapour pressure p_D which is dependent on the temperature. The vapour pressures in the temperature range from −10 to +20°C are given in the data sheets as a means of orientation. The state equations for the transitional borderline between liquid and gaseous was historically derived from Clausius and Clapeyron’s (19th century) mole-based differential equation.

$$\frac{dp_D}{dT} = \frac{\Delta H_{Mol,evap}}{\left(V_{Mol,D} - V_{Mol,liq}\right)T} \tag{2.2.2-2}$$

As the molar volume $V_{Mol,liq}$ in a liquid is very small, it can be neglected it in comparison to the molar volume $V_{Mol,D}$ of the vapor. One uses the ideal state equation again.

$$V_{Mol,D} = R_{Mol}\cdot T\cdot p_D^{-1}$$

$$\frac{dp_D}{p_D} = d\ln p_D = \frac{\Delta H_{Mol,evap}}{R_{Mol}\cdot T^2}dT \tag{2.2.2-3}$$

We will dispense with the mathematical method of integration and obtain as a solution for states 1 and 2.

$$\ln\left(\frac{p_2}{p_1}\right) = -\frac{\Delta H_{Mol,evap}}{R_{Mol}}\left(\frac{1}{T_2}-\frac{1}{T_1}\right) \tag{2.2.2-4}$$

As the enthalpy of evaporation depends on the temperature there are various approximations for Eq. (2.2.2-4). Most frequently the following Eq. is applied using the decade logarithm (lg). A to F are constants which depend on the type of gas. They have to be ascertained experimentally (see Table T10.5-1).

$$\lg p_D = A + \frac{B}{C+T} + D \cdot T + E \cdot T^2 + F \cdot \lg T \tag{2.2.2-5}$$

If not indicated otherwise, such Eqs. are always valid between the triple temperature and the critical temperature.

If a liquefied gas is in a pressurised container it is often necessary to know the volume proportion of the liquid phase and the gaseous phase at temperature T. With the geometric volumes V_{geom} and the contained mass M we obtain the Eqs.

$$V_{geom} = V_{gas} + V_{liq} \qquad \text{and} \qquad M = M_{gas} + M_{liq}$$

In order to calculate the densities depending on T are needed and in the gaseous state also on p_D. The densities are inserted into the Eq. for M.

$$M = \varphi_{gas} \cdot V_{gas} + \varphi_{liq} \cdot V_{liq}$$

$$V_{gas} = \frac{M - \varphi_{liq} \cdot V_{liq}}{\varphi_{gas}} \qquad \text{and} \qquad V_{liq} = V_{geom} - V_{gas}$$

After further steps, one obtains

$$V_{liq} = \frac{M - \varphi_{gas} \cdot V_{geom}}{\varphi_{liq} - \varphi_{gas}} \tag{2.2.2-6}$$

Example E2.2.2-2: According to (ADR 2005) *a pressurised gas cylinder with a test pressure of 190 bar (g) can be filled with CO_2 with a filling factor f_{fill} of 0.66 kg/l. The filling is to be effected with cold CO_2 at 258 K (approx. −15°C). Later on the cylinder is due to be transported at 298 K (approx. +25°C). How large is the V_{liq} at both temperatures?*

CO_2 has been checked thoroughly and there are tables for the material data on the vapour pressure curve (T10.4-8). For 258 K we take the vapour pressure p_D = 22.8 bar (abs.), $\varphi_{liq} = 1.009\ kg \cdot l^{-1}$, $\varphi_{gas} = 60.505\ kg \cdot m^{-3}$, and for 298 K is p_D = 64.09 bar, $\varphi_{liq} = 0.7137\ kg \cdot l^{-1}$, $\varphi_{gas} = 240.68\ kg \cdot m^{-3}$. V_{geom} is 10 litres, as well as $M = f_{fill} \cdot V_{geom} = 6.6\ kg$.

$$V_{liq,258K} = \frac{6.6 - 0.0605 \cdot 10}{1.009 - 0.0605} = 6.32[l]$$

and

$$V_{liq,298K} = \frac{6.6 - 0.24068 \cdot 10}{0.7137 - 0.24068} = 8.86[l]$$

As the temperature increases the density of the liquid falls and it takes up more and more volume. The filling factors are calculated so that at the maximum permitted temperature range for the pressurised gas cylinders of –20 to +70°C the pressure can't be higher than the tested one. If the container has been overfilled there is a great safety risk of the liquid filling the whole container and expanding through heat. In this case we do not consider the vapour pressure p_D any longer but we must use the pressure of the incompressible liquid which can rise over 1000 bar with a temperature increase of only a few K. This then leads to the destruction of the cylinder with usually significant damage to personnel and equipment.

For this reason the filling of liquefied gases is only allowed through gravimetric weighing. Accompanying measures require detailed written reports as well as an additional weighing by a second person. If an overfilling is discovered the excess amount has to be discharged immediately.

2.2.3 Diverse Properties

This section introduces the concept of adiabatic (isenthalpic) expansion. This means the expansion of a gas without the transfer of heat, thus not isothermally, e.g. in a system isolated from heat. The real gas combats the adiabatic expansion through cooling by using its internal energy to compensate for the intermolecular attraction forces. This effect was discovered by Joule and Thomson, later to be Lord Kelvin, in the 19th century. Thus there is the possibility of cooling and liquefying a gas with, if possible, isothermal compression and subsequent resultant adiabatic expansion. This was the basis of the first liquefaction of air by Carl von Linde in 1876.

One must be advised that the Joule-Thomson effect has an inversion temperature dependent on the type of gas. Above this temperature heating occurs during expansion, the so-called inverse Joule-Thomson effect. Thus H_2 has to be initially pre-cooled by liquid N_2 (–196°C) before the liquefaction is possible.

The resultant new pressure p_2 from the adiabatic expansion of volume V_1 at pressure p_1 into the total volume V_2 can be calculated, considering Eq. (2.1-25), using the formula

$$p_2 = \left(\frac{V_1}{V_2}\right)^{\varepsilon} \cdot p_1 \qquad \text{with} \qquad \varepsilon = \frac{c_{p,\mathrm{Mol}}}{c_{V,\mathrm{Mol}}} \tag{2.2.3-1}$$

For the temperature T_2 after expansion is defined as

$$T_2 = \left(\frac{V_1}{V_2}\right)^{\phi} \cdot T_1 \qquad \text{with} \qquad \phi = R_{\mathrm{Mol}} \cdot c_{p,\mathrm{Mol}}^{-1} \tag{2.2.3-2}$$

Example E2.2.3-1: Calculating the pressure p_2 and temperature T_2 after the adiabatic expansion of N_2 with V_1, $p_1 = 30$ bar and $T_1 = 293.5$ in a $V_2 = 3\ V_1$.

Ideally apply $c_{p,Mol} = (7/2) \cdot R_{Mol}$ *and* $\varepsilon = 7/5$. $R_{Mol} = 8.31441\ J \cdot mol^{-1} \cdot K^{-1}$

$$c_{p,Mol} = \frac{7}{2} 8.31441 = 29.10 \left[J \cdot mol^{-1} \cdot K^{-1} \right] \qquad \phi = \frac{8.31441}{29.10} = 0.2857$$

$$p_2 = \left(\frac{1}{3} \right)^{7/5} 30 = 6.44 [bar] \qquad T_2 = \left(\frac{1}{3} \right)^{0.2857} \cdot 293.15 = 214.17 [K]$$

We compare the ideal molar heat capacity with the measured value of the specific heat capacity $c_{p,kg} = 1.040\ kJ \cdot kg^{-1} \cdot K^{-1} = 1.040\ J \cdot g^{-1} \cdot K^{-1}$ as per data sheet N_2.

$$c_{p,kg} = c_{p,Mol} \cdot M_{Mol}^{-1} = \frac{7 \cdot R_{Mol}}{2 \cdot M_{Mol}} \tag{2.2.3-3}$$

$$c_{p,kg} = \frac{7 \cdot 8.31441}{2 \cdot 28.0134} = 1.039 \left[kJ \cdot kg^{-1} \cdot K^{-1} \right]$$

One can see that the deviation of the ideal calculation from the measured value of 0.1 % rel. is very small. However, one must be aware of the fact that for N_2 c_p and c_v depend significantly on pressure and temperature. These values have to be determined empirically and can be read out of standard tables (Messer 1989).

We are now considering the so-called transport phenomena of gases. This means the movement of particles (diffusion), energy (thermal conductivity) and impulse (viscosity). The differential equations which describe these properties are all constructed similarly.

Fick's first law adverts to diffusion

$$Q_V = \frac{dV}{dt} = -D \cdot A \frac{dC}{dx} \tag{2.2.3-4}$$

Q_V is the flow-rate of the volume or the mass (= dM/dt), t the time, and A the area contemplated, through which the diffusion is effected. X is the direction considered and D the diffusion constants in $m^2 \cdot s^{-1}$.

For the thermal conductivity the function of the energy flow dE/dt on the temperature gradients dT/dx is shown.

$$\frac{dE}{dt} = -\lambda \cdot A \frac{dT}{dx} \tag{2.2.3-5}$$

λ is the heat conductivity coefficient in $W \cdot m^{-1} \cdot K^{-1}$, often simply referred to as thermal conductivity.

To understand viscosity we must consider the internal friction of a gas. If two adjacent layers of gas move with different speeds then particles move from one layer to the other. The layers become interlocked; this causes the faster layer to slow down and vice versa. To maintain the difference in speeds, the internal friction force $F_{friction}$ has to be generated. As the force is equal to the derivation of impulse I_{mv} over the time we obtain

$$F_{friction} = \frac{dI_{mv}}{dt} = -\eta \cdot A \frac{dv}{dx} \tag{2.2.3-6}$$

with dv/dx as speed gradient and η the dynamic viscosity coefficient in $kg \cdot m^{-1} \cdot s^{-1}$ or $N \cdot s \cdot m^{-2}$. To a certain extent we define a deviating kinematic viscosity when we consider the density.

$$\eta^* = \frac{\eta}{\varphi}\left[m^2 \cdot s^{-1}\right] \tag{2.2.3-7}$$

For the ideal gas the coefficients of transport phenomena are calculated *via* the kinetic gas theory. As the diffusion coefficient D plays a central role both for permeation (chap. 3.1.4) and for homogenisation (chap. 5.1.3) a short introduction is required. Without proof and with the help of Eqs. (2.1.2-1), (2.1.2-2) and (2.1.2-4) the diffusion coefficient ($m^2 \cdot s^{-1}$) is shown to be

$$D = \frac{1}{3} v_{m,Maxwell} \cdot s_{particle} = \frac{1}{3}\sqrt{\frac{8}{3 \cdot \pi}}\sqrt{\frac{3 \cdot R_{Mol} \cdot T}{M_{Mol}}}\,\frac{R_{Mol} \cdot T}{\sqrt{2} \cdot \pi \cdot p \cdot 4 \cdot r^2 \cdot k_{Avogadro}}$$

$$D = \frac{\sqrt{R^3_{Mol}}}{6 \cdot \sqrt{\pi^3} \cdot k_{Avogadro}}\sqrt{\frac{T^3}{M_{Mol}}}\,\frac{1}{p \cdot r^2} \tag{2.2.3-8}$$

Here d = 2 r was fixed with r as the particle radius. With respect to D the following dependencies are important:

- Inversely proportional to the pressure, i.e. as the pressure increases the diffusion decreases.
- Inversely proportional to the root of the molar mass as well as to the square of the particle radius. Small particles and particles with little mass diffuse more quickly.
- Proportional to $T^{3/2}$ and therefore an increase in temperature encourages diffusion.

The D from Eq (2.2.3-8) only applies for the so-called self diffusion in the cylinder containing only the observed gas. For the diffusion of two gases 1 and 2 in each other a binary diffusion coefficient applies. The extended formula, also provided without proof, is then:

$$D_{1,2} = \frac{\sqrt{R^3_{Mol}}}{6 \cdot \sqrt{\pi^3} k_{Avogadro}}\sqrt{\frac{T^3 \cdot \left(M_{Mol,1} + M_{Mol,2}\right)}{M_{Mol,1} \cdot M_{Mol,2}}}\,\frac{1}{p \cdot \left(r_1 + r_2\right)^2} \tag{2.2.3-9}$$

For the real gases the dependency of the individual coefficients of p and T differ from the ideal calculation. The empirical data mostly serve a mathematical representation in the form of a series expansion based on p or T, similar to that for the real gas factor.

For flammable gases the so-called burning values (energy values) and heating values are interesting. The energy value H_{energy} is defined as the energy per kg, mole or m^3 which is produced by complete combustion in pure O_2. After combustion the remains are exclusively gaseous CO_2, N_2, and SO_2 as well as liquid H_2O. For the heating value H_{heat} burning takes place in the air, it is $H_{heat} < H_{energy}$. After combustion the H_2O remnants are gaseous.

Let us now look at the solubility of gases in liquids. The simplest case is provided by atmospheric air over water. If we consider the main components N_2, O_2 and Ar there is a thermodynamic system of 8 phases. Water forms the liquid phase with the vapour pressure $p_{D,H2O}$ as a function of T. N_2, O_2 and Ar each have a phase of which is soluble in water with the proportional amounts of substance $C_{v,G,sol}$

$$C_{\nu,G,sol} = \frac{\nu_{G,sol}}{\nu_{liq} + \nu_{G,sol}} \qquad (2.2.3\text{-}8)$$

and the partial pressures exerted above the water p_{N2}, p_{O2} and p_{Ar}. $\nu_{G,sol}$ is the number of the moles of the gases dissolved in the liquid, ν_{liq} is the number of the moles of the liquid. For small solubilities and pressures Henry's Law applies. $p_{G,sat}$ is the saturation vapour pressure of the gas G.

$$p_{G,sat} = \delta_{Henry,G} \cdot C_{\nu,G,sol} \qquad (2.2.3\text{-}9)$$

Henry's coefficient δ_{Henry} has the dimension of a pressure. The Law describes the proportionality of the concentration in the liquid and the pressure above the liquid. To differentiate from the normal vapour pressure of a liquid this can also be referred to as saturation vapour pressure p_{sat} of the soluble phase and is dependent on T. In practice however the technical solubility coefficient δ_{techn} has prevailed.

$$\delta_{techn} = \frac{V_{G,STP}}{M_{sol}} \left[l \cdot kg^{-1} \right] \qquad (2.2.3\text{-}10)$$

δ_{techn} shows how many litres of gases at normal state are dissolved per kg liquid at p and T. For the amount of $p_{G,sat}$ we will use Dalton's Law in our example and thus apply ideal behaviour.

One uses more rarely

$$\delta^*_{techn} = \frac{V_{G,STP}}{M_{G,sol} \cdot p_{G,sat}} \left[l \cdot kg^{-1} \cdot bar^{-1} \right] \qquad (2.2.3\text{-}11)$$

2.3 Gas Mixtures

In this book we predominantly describe gas mixtures in pressurised cylinders. The manufacture is described in chapter 5. Gas mixtures close to atmospheric pressure, as required by the user, are mentioned briefly in chapter 8.2. In the case of the pure gases it became clear in the previous chapters that the real behaviour leads to a great deal of effort as far as the calculating is concerned. This is even more noticeable with the gas mixtures. The "triangular relationship" volume – pressure – temperature can be avoided if we can revert to the mass of the gases. One while dealing with densities in the area of only a few grams per litre very accurate scales are necessary. At the end of the seventies single-pan scales achieved accuracies better than 0.1% rel., thus the triumph of the gravimetric production of gas mixtures and especially calibration gases could not be sterned. This trend was connected with the use of the relationship of the amounts of substance C_ν which we have already introduced as the number of moles. This leads to the fraction of molar concentration, the character of which is obviously a concentration.

$$C_{\nu,j} = \frac{\nu_j}{\sum_{i=1}^{n} \nu_i} \qquad (2.3\text{-}1)$$

The designation as the fraction of the molar concentration was chosen because this information is most frequently used on the analytical certificate for a gas mixture. In addition, the definitions for the volume and mass fractions apply which are however often used without misunderstanding as the volume and mass concentration

$$C_{V,j} = \frac{V_j}{\sum_{i=1}^{n} V_i} \qquad (2.3\text{-}2)$$

$$C_{M,j} = \frac{M_j}{\sum_{i=1}^{n} M_i} \qquad (2.3\text{-}3)$$

The conversion of the different kinds of concentration with each other can be found in Table T2.3-1. It is complicated because the density φ depends on both p and T and has to be calculated from tables or by using virial coefficients.

Table T2.3-1: Conversion of the different kinds of concentration

	$C_{\nu,j}$	$C_{V,j}$	$C_{M,j}$
$C_{\nu,j} = \frac{\nu_j}{\sum_{i=1}^{n} \nu_i}$	—	$= \frac{\frac{\varphi_j \cdot C_{V,j}}{M_j}}{\sum_{i=1}^{N} \frac{\varphi_i \cdot C_{V,i}}{M_i}}$	$= \frac{\frac{C_{M,j}}{M_j}}{\sum_{i=1}^{n} \frac{C_{M,i}}{M_i}}$
$C_{V,j} = \frac{V_j}{\sum_{i=1}^{n} V_i}$	$= \frac{\frac{C_{\nu,j} \cdot M_j}{\varphi_j}}{\sum_{i=1}^{n} \frac{C_{\nu,i} \cdot M_i}{\varphi_i}}$	—	$= \frac{\frac{C_{M,j}}{\varphi_j}}{\sum_{i=1}^{n} \frac{C_{M,i}}{\varphi_i}}$
$C_{M,j} = \frac{M_j}{\sum_{i=1}^{n} M_i}$	$= \frac{M_j \cdot C_{\nu,j}}{\sum_{i=1}^{n} M_i \cdot C_{\nu,i}}$	$= \frac{\varphi_j \cdot C_{V,j}}{\sum_{i=1}^{n} \varphi_i \cdot C_{V,i}}$	—

To calculate the composition of a calibration gas we introduce the ideal density of a gas.

$$\varphi_{G,\mathrm{ideal}} = \frac{M_{G,\mathrm{Mol}}}{V_{\mathrm{STP}}} = \frac{M_i}{V_i} \tag{2.3-4}$$

Example E2.3-1: Calculating the composition of a test gas with 1% N_2, 2% Ar in H_2 for 2 m^3 in a 10-litre cylinder.

The total volume is $V = 2\ m^3$, the supposed concentrations and the fraction of molar concentration $C_{N2} = 1 \cdot 10^{-2}$, $C_{Ar} = 2 \cdot 10^{-2}$ and $C_{H2} = 0.97$. The partial volumes are correspondingly shown to be

$$V_i = C_i \cdot V \qquad \textit{and} \qquad V = \sum V_i = 2\left[m^3\right]$$

From this: $V_{N2} = 0.02\ m^3$, $V_{Ar} = 0.04\ m^3$ and $V_{H2} = 1.94\ m^3$, which are idealised volumes can be calculated. From the data sheets we take the ideal densities as $\varphi_{N2} = 1.250\ kg \cdot m^{-3}$, $\varphi_{Ar} = 1.782\ kg \cdot m^{-3}$ and $\varphi_{H2} = 0.090\ kg \cdot m^{-3}$. The masses which have to be weighed are therefore provided by the formula $M_i = \varphi_i \cdot V_i$.

Table T2.3-2: Example of the composition of a calibration gas

gas	concentration [%]	mass [g]	partial volume $[m^3]$
N_2	1	25.0	0.02
Ar	2	71.3	0.04
H_2	to 100	174.6	1.94

It still needs to be proven that one is not dealing with the volume concentration but with the desired concentration of the fraction of the molar concentration.

$$C_j = \frac{V_j}{\sum\limits_{i=1}^{n} V_i} = \frac{\dfrac{M_j}{\varphi_j}}{\sum\limits_{i=1}^{n} \dfrac{M_i}{\varphi_i}} = \frac{\dfrac{M_j \cdot V_{STP}}{M_{j,Mol}}}{\sum\limits_{i=1}^{n} \dfrac{M_i \cdot V_{STP}}{M_{i,Mol}}} = \frac{V_{STP}}{V_{STP}} \frac{\nu_j}{\sum\limits_{i=1}^{n} \nu_i} = \frac{\nu_j}{\sum\limits_{i=1}^{n} \nu_i}$$

Example E2.3-2: Pressure in the gas cylinder T=15°C for the mixture as per Example E 2.3-1

For these small fractions it should be calculated by using the ideal gas law. For N_2 it is

$$p_{N2} = \frac{p_{1bar} \cdot V_{N2}}{V_{geom}} = \frac{0.02}{0.01} = 2[\text{bar}]$$

and analogous with $p_{Ar} = 4$ bar. For H_2 the ideal calculation is added up to 194 bar. Nevertheless, it is necessary to carry out the calculation of pressure with the real gas factor. Analogous to Example E2.2.1-2 one proceeds:

$$\frac{V_1 \cdot p_1}{V_2 \cdot p_2} = \frac{1 + \beta \cdot p_1}{1 + \beta \cdot p_2}$$

$V_1 = 1.94\ m^3$, $p_1 = 1$ bar, $V_2 = 0.01\ m^3$, $\beta = 0.595 \cdot 10^{-3}\ bar^{-1}$ are inserted into the equation and from the data sheet we take

$$p_2 = \frac{V_1 \cdot p_1}{V_2 + \beta \cdot p_1 (V_2 - V_1)} = \frac{1.94 \cdot 1}{0.01 + 0.595 \cdot 10^{-3} \cdot 1(0.01 - 1.94)} = 219.2[\text{bar}]$$

Altogether for the gas mixture a pressure of 225.2 bar is obtained which is not acceptable for the normal cylinder with an operating pressure of 200 bar. Therefore one reduces the volume from 2 m^3 in the ratio 200/225.2 to approximately 1.77 m^3 and calculate the composition again.

For the real gases and their mixtures we have carried out only relatively simple calculations. The handbooks of (Messer 1989) and (Air Liquide 2005) are recommended for more detailed study.

2.4 Moisture Content

Of all the impurities in the purest gases moisture has a special position. For most users the omnipresent water is a very disturbing substance, the limit concentration which must be achieved a moves continually into the lower ppb range. Water is often a basic prerequisite for chemical reactions. Thus dry oxygen does not cause the internal wall of the steel cylinder to rust but with a moisture content of as little as 50 ppm severe rusting can be expected. CO_2 and HCl (anhydrous inorganic acids) in connection with liquid water in the steel cylinder cause corrosions negatively which effect safety. The strongly polarised H_2O molecule bonds with almost every means of adsorption and can be removed, e.g. by heating.

First of all one must differentiate between two marginal cases in the gas cylinder. If water is present in liquid form the vapour pressure $p_{D,H2O}$ which is dependent on the temperature is established. The concentration relation for removing the water is shown by the Eq.

$$C_{H2O} = \frac{p_{D,H2O}}{\sum_{i=1}^{n} p_i} \tag{2.4-1}$$

When p_i is the pressure of all n gases in the cylinder. The concentration increases sharply at the end of the removal. Liquid water in a gas cylinder is a terrible mistake by the filling company and is caused by inadequate preparation of the cylinder. For the purest gases this case is not relevant.

If only gaseous water i.e. water vapour with the partial pressure p_{H2O} is in the cylinder then the types of concentration according to section 2.3 apply. The concentration, e.g. on the basis of the partial pressure (ideal calculation) remains constant during the removal.

$$C_{H2O} = \frac{p_{H2O}}{\sum_{i=1}^{n} p_i} = k \tag{2.4-2}$$

If water vapour has been adsorbed on the internal wall of the gas cylinder then there is a saturation pressure $p_{Ads,sat}$ for this adsorbed phase. If the partial pressure decreases to the level of the saturation one during the removal then there is an increase in concentration as the water vapour is supplied from the adsorbed phase.

(Schön 1999) reported about a special case of the concentration relation. If there are small amounts of oil (glyceride) in the cylinder, e.g. because the cylinder has been filled using compressors which have been lubricated, then a film of water can be formed, which is covered by a layer of oil, which is only a few molecules thick. In these cases for the concentration relation the following Eq. applies

$$C_{H2O} = C_{H2O}^{(A)} \left(\frac{p^{(A)}}{p} \right)^{k} \tag{2.4-3}$$

with (A) as the designation of the initial value and k is a constant which depends on the geometry of the pressurised container and the temperature. Strangely enough the maximum value is 37.2°C which has given rise to the speculation that the human brain is thermostatically set at this value.

Measuring moisture content (humidity) takes place in meteorology in the temperature range surrounding us as well as in the extreme conditions of the upper atmosphere. To achieve this dew point is often determined (wet mirror method). Thus we are dealing with vapour pressures above water e.g. 6.11 mbar at 0°C which correspond to a concentration of 0.603 volume-% at 1013.25 mbar in the air. The range which is of interest for the purest gases is the one with few ppm or ppb. As the wet mirror method has also been used successfully in this area the vapour pressures over ice are relevant.

The phase borderline solid-gaseous is described mathematically similarly to Clausius and Clapeyron's differential equations (Egs 2.2.2-2 and -3) ΔH_{Subl} is the sublimation enthalpy.

$$\frac{d \ln p_{D,Subl}}{dT} = \frac{\Delta H_{Mol,Subl}}{R_{Mol} \cdot T^2} \tag{2.4-4}$$

The evaporation enthalpy is dependent on the temperature, as it is with sublimation. The concept of the sublimation point is connected with the pressure of 1013.25 mbar. When measuring moisture sublimation points at other pressures they are referred to as frost point.

For the following discussion, documents used were kindly provided by the PTB (Physikalisch-Technische Bundesanstalt, Germany) in Brunswick. (Sonntag 1998) gave an overview of the historical development of the formulas for the dependence of vapour pressure on the temperature. To calculate it over water or ice one often uses the Magnus formula with T in ^{0}C, (Magnus 1844).

$$p_D(T) = p_{D,0C} \cdot \exp \frac{k_1 \cdot T}{k_2 + T} \tag{2.4-5}$$

One can obtain more recent values k_1 and k_2 of the Magnus' formula from (Weber 2002) work, $p_{D,0C}$ is the vapour pressure at 0°C.

(Sonntag 1990) gave a more exact Eq. with a series expansion, T in K and p_D in hPa.

$$\begin{aligned} \ln p_D = &-\frac{6024.5282}{T} + 24.7219 + 1.0613868 \cdot 10^{-2} \cdot T \\ &-\frac{1.3198825}{10^5 \cdot T^2} - 0.49382577 \cdot \ln T \end{aligned} \tag{2.4-6}$$

Table T2.4-1 uses Eq (2.4-6) and contrasts:

- The temperature at the phase borderline solid – gaseous, the frost point temperature T_{Frost}, sometimes also referred to the phase borderline liquid gaseous, called the dew point temperature.
- The pressure $p_{D,Subl}$, the saturation vapour pressure of the solid phase
- The fraction of the amount of substance in ppm (p assumed to be ideal, $p_{D,Subl}$ in mbar)

$$C_{v,H2O} = \frac{p_{D,Subl}}{\left(\sum_{i=1}^{n} p_i\right)_{=1013\text{mbar}}} 10^6 \,[\text{ppm}] \tag{2.4-7}$$

– The absolute moisture concentration

$$C_{abs,H2O} = \frac{M_{H2O}}{\sum_{i=1}^{n} V_i} \left[g \cdot m^{-3} \right] \qquad (2.4\text{-}8)$$

The relationship between the types of concentrations applies with an ideal calculation and under normal conditions, $C_{v,H2O}$ in ppm:

$$\begin{aligned} C_{abs,H2O} &= \frac{M_{Mol,H2O}}{V_{Norm}} C_{v,H2O} \cdot 10^{-6} = \frac{18.0152}{22.41383} C_{v,H2O} \cdot 10^{-3} \\ &= 0.80375 \cdot C_{v,H2O} \cdot 10^{-3} \left[g \cdot m^{-3} \right] \end{aligned} \qquad (2.4\text{-}9)$$

Table T2.4-1: Frost point temperature, moisture fractions and absolute moisture concentration for selected values in the temperature range from 0 to –120°C. Interim values can be taken from Table T10.7-1.

T_{Frost} in [°C] at 1013.25 mbar	$p_{D,Subl}$ in [mbar]	$C_{v,H2O}$ in [ppm] at 1013.25 mbar	$C_{abs,H2O}$ [mg · m^{-3}] STP
0	6.1115	6031.6210	4844.7
–10	2.5983	2564.3326	2059.7
–20	1.0324	1018.8904	818.4
–30	0.3800	375.0246	301.2
–40	0.1284	126.6910	101.8
–50	0.03936	38.8433	31.20
–60	0.01081	10.6656	8.567
–70	0.002615	2.5812	2.073
–80	$547.2 \cdot 10^{-6}$	0.54009	0.434
–90	$96.7 \cdot 10^{-6}$	0.09544	0.0767
–100	$14.0 \cdot 10^{-6}$	0.01384	0.0111
–110	$1.61 \cdot 10^{-6}$	0.001588	0.00128
–120	$0.140 \cdot 10^{-6}$	0.000138	0.000111

2.5 Leak Rate

With requirements for the purity of gases it was critically necessary to improve technical equipment with regards to leak tightness. In 1961[1] something was classified leak proof if it did not produce any bubbles when tested with a soap solution. Besides this test there was already the ultra-high vacuum technique used in which the concept of the leak rate was well established. This was determined for a

---

[1] In 1961 the author started his work at the Ostberliner Technische Gase Werken.

geometric volume V_{geom} by evacuating it separating it from the vacuum pump and measuring the increase in pressure Δp after a time t. We call this the vacuum leak rate L_{vac} .

$$L_{vac} = \frac{\Delta p \cdot V_{geom}}{t} \left[mbar \cdot l \cdot s^{-1} \right] \tag{2.5-1}$$

In the pressure technique the relationships are different. The cylinder is under a pressure p and the escaping amount of gas $Q_V = dV/dt$ at STP is measured. It is called the pressure leak rate L_p .

$$L_p = Q_V = \frac{V}{t} \left[cm^3 \cdot s^{-1} \right] \tag{2.5-2}$$

If neglecting the small corrections (e.g. cm^3 at STP) one obtains

$$1 \cdot mbar \cdot liter \cdot s^{-1} \cong 1 \cdot cm^3 \cdot s^{-1} \tag{2.5-3}$$

It is important to realize that the pressure leak rate L_p depends on the internal pressure of the container in question. This becomes clear when one looks at the Eq. for the relationships between the flows. One differentiates between two borderline cases.

The flow through a capillary with radius r and length l is referred to as laminar flow. The Hagen-Poisseuille's law of 1839/40 applies. p_1 is the pressure in the container, p_2 the atmospheric pressure under normal circumstances.

$$Q_{V,H-P} = \frac{\pi \cdot r^4}{8 \cdot \eta \cdot l} (p_1 - p_2) = \frac{\pi \cdot r^4}{8 \cdot \eta \cdot l} p_{1,(g)} \tag{2.5-4}$$

The other extreme case is easiest to show with an orifice plate with A as the area of the opening. According to Knudsen the molecular flow is given

$$Q_{V,Knudsen} = A \sqrt{\frac{R_{Mol} \cdot T}{2\pi \cdot M_{Mol}}} \frac{p_1 - p_2}{p_2} = A \sqrt{\frac{R_{Mol} \cdot T}{2\pi \cdot M_{Mol}}} p_{1,(g)} \tag{2.5-5}$$

with $p_2 = 1$ bar.

Both kinds of flow express the relationship of the pressure difference between the container pressure and atmospheric one. Consequently, the pressure leak rate has to be supplemented by information about the pressure.

Vacuum and pressure leak rate can not be calculated from each other with any great accuracy. The rule of thumb is

$$L_p \approx p \cdot L_{vac} \tag{2.5-6}$$

Many manufacturers of leak-test mass spectrometers give $L_p = 100\ L_{vac}$ without specifying p.

When considering the container pressure one peculiarity of the leak must be mentioned. At high pressures the form of the pressure containers is changed, sometimes leaks only occur at this stage. Thus it makes sense to check an industrial gas plant for leak tightness at the pressure production.

Eqs. 2.5-4 and -5 show the dependence on the type of gas. From the example of selected gases in Table T2.5-1 one can view the sometimes considerable differences, the Q_V for He were randomly fixed = 1. It is not possible to give a simple relationship of the leak rate to the density because the exact type of leak is normally unknown and is additionaly a combination.

Table T2.5-1: The dependence of leak volume flow rate on the type of gas and flow.

gas	**η in $[Ns \cdot m^{-2}] \cdot 10^{-6}$**	**M_{Mol} in [kg]**	**Q_V Hagen-Poisselle**	**Q_V Knudsen**
He	19.2	4.00	1	1
H_2	8.92	2.02	2.20	1.40
N_2	17.9	28.01	1.10	0.38
Ar	22.8	39.95	0.86	0.32
CF_4	17.4	8.00	1.13	0.21
Xe	23.0	131.30	0.86	0.17

In general the leak rate serves as a measure of leak tightness and thus the quality e.g. of a component, it can however also be used to estimate volume flows.

Example E2.5-1: In a 50 litre gas cylinder with 200 bar (gauge pressure) He a leak rate of $5 \cdot 10^{-3}\ cm^3 \cdot s^{-1}$ *is measured at the point where the valve is screwed in. By how many bars has the pressure in the bottle fallen after 2 years (a)?*

$$V = L_{p=200bar} \cdot t_{2a} = 5 \cdot 10^{-3} \cdot 60 \cdot 60 \cdot 24 \cdot 365 \cdot 2 = 315.360[cm^3] = 0.3154[m^3]$$

We continue to calculate perfectly using the relatively small amount of ideal gas. In 2 years the volume has decreased from 10 to 9.684 m^3 *. Then the pressure is (A) = beginning*

$$p^{(A)} \cdot V_{geom} = 0.05 \cdot 200 = 10\left[m^3\right]$$

$$\Delta p^{(2a)} \cdot V_{geom} = 0.05 \cdot p_{2a} = 9.684\left[m^3\right]$$

$$p^{(2a)} = \frac{9.684 \cdot 200}{10} = 193.7\left[bar\right]$$

If the filling company gives a 2-year guarantee, there must be complaint about this decrease in pressure. In most cases a tolerance of ± 5 bar is guaranteed.

Example E2.5-2: With a pipeline plant Ar 6.0 is supplied to different customers at a pressure of 6 bar (gauge pressure). The pipeline plant contains 40 sealing components in the pipes and fittings. The volumetric flow is 10 $m^3 \cdot h^{-1}$*. The fraction of air in*

the Ar should not be increased by more than 0.1 ppm by leakage. How large can the leak rate for the individual sealing element be?
Using $C_{air} = 0{,}1 \cdot 10^{-6}$ *and* $Q_V = 10\ m^3 \cdot h^{-1}$ *we obtain*

$$Q_{air} = L_{total} = C_{air} \cdot Q_V = 0.1 \cdot 10^{-6} \cdot 10$$

$$= 10^{-6}\left[m^3 \cdot h^{-1}\right] = 10^{-6}\,\frac{10^{-6}}{60 \cdot 60} = 2.8 \cdot 10^{-4}\left[cm^3 \cdot s^{-1}\right]$$

$$L_{single} = \frac{L_{total}}{40} = 7 \cdot 10^{-6}\left[cm^3 \cdot s^1\right]$$

Now there is a justified question: How can air get into a system which is operating at an gauge pressure of 6 bar. The answer: The flow through a leak is dependent on the partial pressure. The outside one is the atmospheric pressure of air, inside it is virtually = 0. This may seem paradoxical but even for an Ar supply pipe at a pressure of 250 or even 400 bar it is true that leaks cause the Ar to flow to the outside but air to the inside. If the volumetric flow of Ar is very large it is hardly noticeable. At times of less usage, e.g. during weekends the following phenomenon occurs: When the plant is put into operation at the beginning of the week a relatively high content of O_2 *and* N_2*, is found which slowly decreases again. It is hardly possible to deal with this mathematically.*

Searching for leaks and establishing specification limits are described in chapter 4.

3 Manufacturing and Purification

Very different methods are used to manufacture a gas

- Separating a mixture of different gases. Typical examples are separating air to obtain O_2, N_2, Ar, Kr or Xe or the separation of CO_2 in the large-scale chemical industry.
- Using natural resources such as producing CO_2 from geological sources.
- Special syntheses such as C_2H_2 or AsH_3 .

In most cases using one method does not achieve the desired purity so it is necessary to take further steps. The path to obtaining a very pure gas is always a combination of several manufacturing and cleaning processes.

Furthermore, the quantity flow rates vary enormously according to the requirements of the different gases. There is no terminology for the classification which is why the following table is provided for a rough guide. We give the volumetric flow rate Q_V as a derivative dV/dt at STP. Another possibility is the mass flow of the derivative $Q_M = dM/dt$.

Table T3-1: Overview of different volumetric flow rates and the appropriate working methods.

Q_V in $[m^3 \cdot h^{-1}]$	Working method	Examples
< 0.1	laboratory	adsorptive purification of NO for calibration mixtures
0.1 – 10	batch	distillation of Kr and Xe
$10 - 10^4$	industrial	carbide synthesis of C_2H_2 combustion gas synthesis of HCl-gas
$> 10^4$	large scale	H_2 by steam reforming air separation

With many of these processes there is a dependency on the physical or chemical reactions of the volumetric flow rates in relation to the dimensions of the containers or pipes. Only when the flow is below certain values it is possible to obtain reliable results of distillation, adsorption or catalysis.

Three different technical and physical concepts are commonly used to characterise the volume.

Linear velocity v_{lin} with A as the cross sectional area of the container or pipe which is assumed to be empty can be obtained from the Eq.

$$v_{lin} = \frac{Q_V \cdot p_{=1bar}}{A \cdot p} \tag{3-1}$$

H. Schön, *Handbook of Purified Gases*,
DOI: 10.1007/978-3-540-32599-4_3

One must be aware of the inversely proportional dependence on pressure p abs. The higher the pressure, the smaller and more advantageous is v_{lin}, which is normally given in $m \cdot s^{-1}$.

The dwell time t_{dwell} gives the period of time, in which an impurity caused by sorption can be kept in the container. We use s for the internal length of the container with $V_{geom} = A \cdot s$ which is valid exactly only for the cylinder. Thus we obtain the Eq.

$$t_{dwell} = \frac{s}{v_{lin}} = \frac{A \cdot s \cdot p_{abs.}}{Q_V \cdot p_{=1bar}} \tag{3-2}$$

With the gaseous hourly space velocity (GHSV) v_V we get a further specific value for the permitted gas flow in use. The unit is h^{-1}.

$$v_V = \frac{Q_V \cdot p_{=1bar}}{V_{geom} \cdot p_{abs.}} \left[h^{-1}\right] \tag{3-3}$$

The information provided by manufacturers of zeolites or catalysts normally refers only to atmospheric pressure. Further details will be dealt with in the section "heterogeneous catalysis". A comparison with Eq. (3-2) shows that t_{dwell} and v_V behave reciprocally to one another:

$$t_{dwell}\left[s\right] = \frac{3.6 \cdot 10^3}{v_V\left[h^{-1}\right]} \tag{3-4}$$

Example E3.1-1: From a cylinder bundle 25 $m^3 \cdot h^{-1}$ *CO is taken, purified through an adsorption bed to remove (adsorber) iron pentacarbonyl and then recompressed. In the beginning the pressure falls in the adsorption bed from 200 bar to* p_{min} *whereby* $v_{lin} \leq 0.25\ m \cdot s^{-1}$ *is still achieved. The adsorption bed is cylindrical with the internal dimensions: diameter of 12 cm and length s of 90 cm* ($V_{geom} \approx 10$ *liter).* p_{min} *and the appropriate* t_{dwell} *have to be calculated.*

All sizes are adjusted to m and s and Eq. (3-1) is adapted

$$Q_V = 25\left[m^3 \cdot h^{-1}\right] = \frac{25}{60 \cdot 60} = 6.94 \cdot 10^{-3}\left[m^3 \cdot s^{-1}\right]$$

$$A = r^2 \cdot \pi = (0.06)^2 \cdot 3.14 = 1.13 \cdot 10^{-2}\left[m^2\right] \quad \text{and} \quad s = 90[cm] = 0.9[m]$$

$$p_{min} = \frac{Q_V}{A \cdot v_{lin}} = \frac{6.94 \cdot 10^{-3}}{1.13 \cdot 10^{-2} \cdot 0.25} = 2.46\left[bar(abs.)\right]$$

$$t_{dwell} = \frac{s}{v_{lin}} = \frac{0,9}{0.25} = 3.6[s]$$

This approximate calculation shows that the adsorption bed at the chosen Q_V can cope with relatively small pressures. A reducing valve is added to the adsorption bed which provides an initial pressure of 200 bar and a secondary pressure appropriate to the suction of the compressor.

The chosen adsorption bed has the favourable ratios of diameter to length between 1:5 and 1:10.

Example E3.1-2: The task is to test a catalyst to remove hydrocarbons from oxygen in a laboratory. The manufacturer of the catalyst gives a GHSV of $v_V = 5000\ h^{-1}$*. In the laboratory there is a stainless steel container with a volume of 20 ml. One has to calculate the gas flow* Q_V*, the test mixture and the dwell time.*

With $V_{geom} = 20[\mathrm{ml}] = 20 \cdot 10^{-6}\left[\mathrm{m}^3\right]$ *using Eq. (3-3) one calculates*

$$Q_V = V_{geom} \cdot v_V = 20 \cdot 10^{-6} \cdot 5000 = 0.1\left[\mathrm{m}^3 \cdot \mathrm{h}^{-1}\right]$$

This is the amount of the test mixture per hour. According to Eq. (3-4)

$$t_{dwell} = \frac{3600}{5000} = 0.72[\mathrm{s}]$$

Our example shows that small amounts in the catalyser can cope with relatively large amounts of substance in a very short time.

The particle size of the adsorption bed, catalysts, etc. is important when experimenting on a smaller scale. It should be a maximum of 10% of the diameter of the container. If this cannot be obtained, an appropriate reduction by milling or sieving has to be done.

Downie's monograph of 1997 provides a good overview of the technologies for the industrial production of gases. General information to the processes and production plants can be obtained from the following handbooks: (Lide 2003-04), (Kirk-Othmer 2001) and (Hirschberg 1999).

3.1 Physical Processes

Physical processes include the inter-related distillation and rectification, physisorption and chemisorption, permeation and the methods of isotope separation. Gas washing (purification) with physical or chemical reaction is dealt with in section 3.2.

3.1.1 Distillation

Distillation is used to remove small amounts of impurities in liquefied gases as well as to separate these gases from liquids. One looks at the basis for mixtures of liquefied gases, i.e. the components are all present in a liquid form at the temperature in question. The aim is to distribute the components in the liquid and then the gaseous phase. For the gaseous phase one uses the known (ideal) law of Dalton (Eq. 2.1.1-9), in which the mole concentration (amount-of-substance fraction, material fraction) $C_{v,gas,i}$ is inserted for to the component i.

$$p = \sum_{i=1}^{n} p_i = \sum_{i=1}^{n} C_{v,gas,i} \cdot p \qquad (3.1.1\text{-}1)$$

with

$$\sum_{i=1}^{n} C_{v,gas,i} = 1$$

and

$$C_{v,gas,j} = \frac{v_{gas,j}}{\sum_{i=1}^{n} v_{gas,i}}$$

There is a similar law for the mole concentration of the liquid phase, namely Raoult's law of 1882:

$$p = \sum_{i=1}^{n} C_{v,liq,i} \cdot p_{D,i} \qquad (3.1.1\text{-}2)$$

with $p_{D,i}$, the vapour pressure of the pure component i and

$$C_{v,liq,j} = \frac{v_{liq,j}}{\sum_{i=1}^{n} v_{liq,i}}$$

By combining Eqs. (3.1.1-1 and -2) one obtains

$$p_j = C_{v,liq,j} \cdot p_{D,j} = C_{v,gas,j} \cdot p \qquad (3.1.1\text{-}3)$$

or for two components with indices 1 and 2

$$\frac{C_{v,liq,1}}{C_{v,gas,1}} = \frac{C_{v,liq,2}}{C_{v,gas,2}} \frac{p_{D,2}}{p_{D,1}} \qquad (3.1.1\text{-}4)$$

Taking $p_{D,2} < p_{D,1}$ as an example one obtains

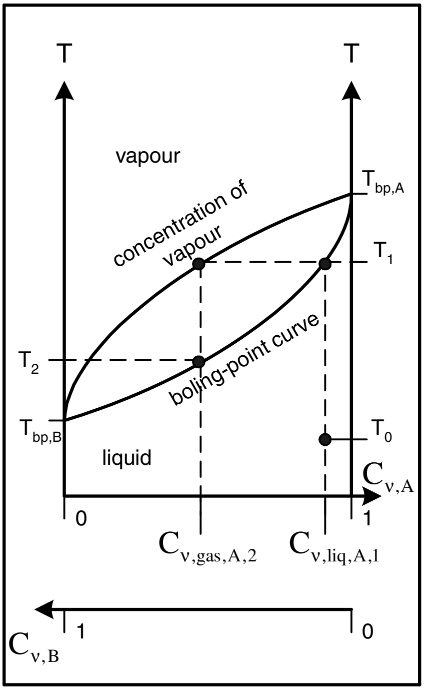
$$\frac{C_{v,liq,2}}{C_{v,gas,2}} > \frac{C_{v,liq,1}}{C_{v,gas,1}}$$

This result agrees with the consideration that there should be more components with less vapour pressure in the liquid phase.

The ideal equation introduced here has narrow limits. It is accurate as far as possible only for mixtures in which the boiling points are not too far apart.

3.1.1.1 Separation of Liquefied Gases

The explanation of distillation can be most easily effected with a binary mixture with the substances A and B, whereby the boiling point $T_{bp,A} > T_{bp,B}$ is and, $p_{D,A} < p_{D,B}$ are valid. Thus, component B with the lower boiling point is the more volatile and becomes more concentrated in the vapour. The boiling point of the mixture lies between both T_{bp} and depends on the composition. The relationships are mostly represented in the boiling-point diagram (T-C_v-diagram) and the related pressure diagram (p-C_v-diagram), see illustrations P3.1.1.1-1 and -2.



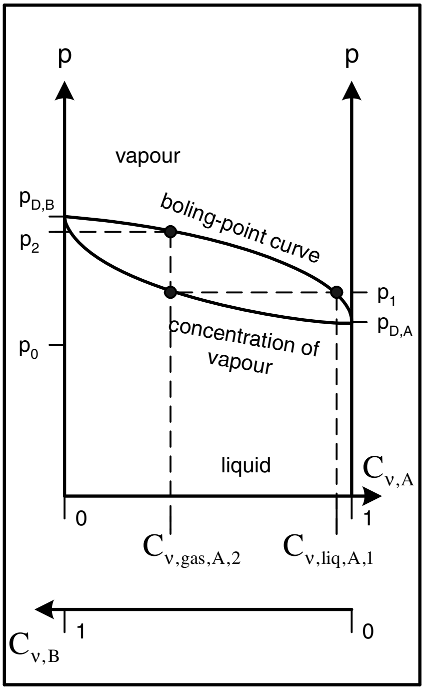


Illustration P3.1.1.1-1(left): Boiling-point diagram of a binary (ideal) liquid mixture.
Illustration P3.1.1.1-2(right): Related concentration-pressure diagram

The liquid to be distilled has the temperature T_0 and the mole concentration is $C_{v,liq,A,1}$ (= $1 - C_{v,liq,B,1}$). By heating the boiling-point temperature T_1 is reached on the boiling-point curve. The distilled vapour is normally liquefied in a subsequent condenser and has the composition $C_{v,gas,A,2}$ according to the horizontal line to the upper curve which is also referred to as the dew-point curve. The intersection point of the vertical line with the boiling curve indicates the boiling point for the condensed mixture.

Example E3.1.1.1-1: Simple distillation from "cylinder to cylinder"

According to illustration P3.3.1.1-3 the mixture which is to be distilled is in gas container 1, which is maintained at the temperature T_1 in a water bath. The path of the distilled vapour is highlighted in dark black. The first fraction can be e.g. disposed of as a waste gas or otherwise removed. Or it can be collected in one of the cylinders 3 or 4 after cooling in the condenser at temperature T_2 and subsequent liquefaction. Cylinder 2 is available on a set of scales in order to measure the fraction required. Thus, cylinder 2 can be filled so that it is ready to be delivered. The remainder in cylinder 1, the so-called heavies, either remains where it is or is also transferred to one of the cylinders 3 or 4 by heating and cooling. It is recommended to monitor the process of distillation with frequent analyses and thus maintain the correct separation of the fractions.

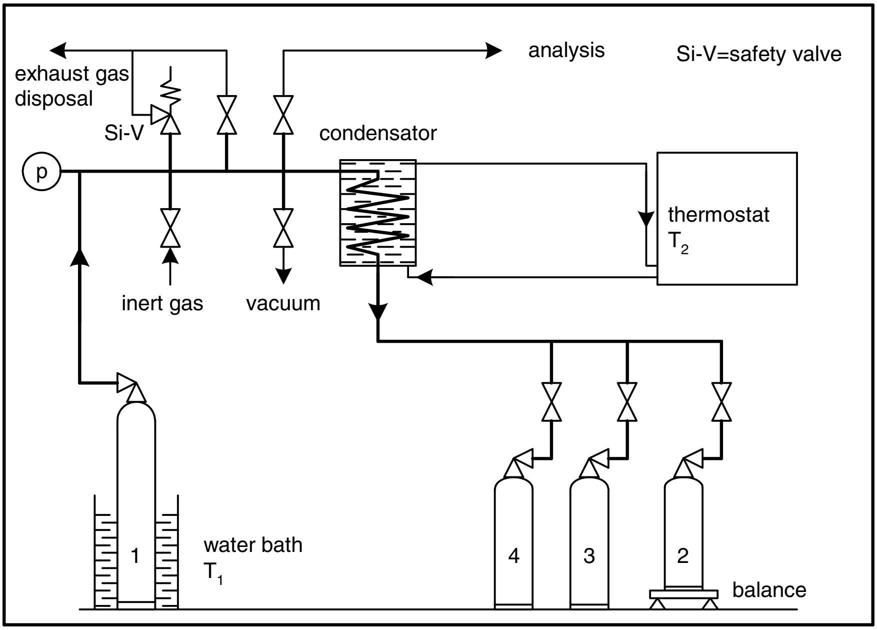


Illustration P3.1.1.1-3: Schematic depiction of distillation from cylinder to cylinder. Only absolutely essential fittings are included.

It is important to begin the process with cylinders 2, 3 and 4 in an evacuated state. A flow only occurs, when the pressure in cylinder 1 is higher than in the cylinders to be filled. This is achieved by flowing cold liquefied gas from the condenser into these cylinders. If partially filled cylinders are used at the beginning, these have to be pre-cooled, e.g. by keeping them in a fridge at –20°C.

The safety valve is absolutely essential because a liquefied gas can become enclosed within the circuit. For this construction it is also recommended to use a pressure indicator as well as lines for purging with inert gas and for evacuation.

This demonstration assumes ideal conditions. However, real gases behave in a way which deviates both positively and negatively from Raoult's Law. In both cases there may be spots in the boiling-point diagram at which the liquid and the gaseous phase have exactly the same composition. This is referred to as azeotropic mixtures. By using simple distillation it is not possible to achieve any separation at these points. Standard reference books will provide more detailed information, especially about the remaining options.

3.1.1.2 Removing Inert Impurities

If impurities with a low boiling point have to be removed from liquefied gases then distillation is often the only feasible method.

With nitrogen at room temperature for example it is not a question of vapour pressure (above a liquid phase) where the laws of solubility apply which were described in section 2.2.3, and not Raoult's Law, although this can still provide relevant information by using the following trick:

Example E 3.1.1.2-1: Liquid CO_2 *shows a concentration of* N_2 *at 50 ppm which has to be reduced by half. Which of the temperatures* $T_1 = -20°C$ *or* $T_2 = +20°C$ *is more suitable for the distillation? This question is synonymous with the question at which temperature the* N_2 *concentration is higher in the gaseous phase.*

We start at Eq. 3.1.1-4 and observe the N_2 *as if vapour pressure is present at* T_1 *and* T_2*. To simplify things, we neglect the small v.*

$$\frac{C_{\text{liq,N2,T1}}}{C_{\text{gas,N2,T1}}} = \frac{C_{\text{liq,CO2,T1}}}{C_{\text{gas,CO2,T1}}} \frac{p_{\text{D,CO2,T1}}}{p_{\text{D,N2,T1}}} = \Omega_{\text{T1}}$$

$$\frac{C_{\text{liq,N2,T2}}}{C_{\text{gas,N2,T2}}} = \frac{C_{\text{liq,CO2,T2}}}{C_{\text{gas,CO2,T2}}} \frac{p_{\text{D,CO2,T2}}}{p_{\text{D,N2,T2}}} = \Omega_{\text{T2}}$$

The mole concentrations of the CO_2 *are all near 1.00. The values for the imaginary vapour pressure of the* N_2 *are calculated according to the equation in Table T10.5-1, even though this only applies as far down to the boiling point of* N_2 *at –196°C. For both temperatures one obtains pressures between 26 and 27 bar. For our estimation we include*

$$p_{\text{D,N2,T1}} = p_{\text{D,N2,T2}}$$

The vapour pressures of the CO_2 *are taken from Table T10.4-8*

$$p_{\text{D,CO2,-20}} = 19.6[\text{bar}] \quad \textit{and} \quad p_{\text{D,CO2,+20}} = 57.1[\text{bar}]$$

One forms the relationship

$$\frac{\Omega_{-20}}{\Omega_{+20}} = \frac{\dfrac{C_{liq,N2,-20}}{C_{gas,N2,-20}}}{\dfrac{C_{liq,N2,+20}}{C_{gas,N2,+20}}} \frac{p_{D,CO2,-20}}{p_{D,CO2,+20}} \cong \frac{19,6}{57,1} = 0,34$$

then the following is easily obtained

$$\frac{C_{liq,N2,-20}}{C_{liq,N2,+20}} = 0,34 \frac{C_{gas,N2,-20}}{C_{gas,N2,+20}} \qquad \frac{C_{gas,N2,-20}}{C_{gas,N2,+20}} \gg \frac{C_{liq,N2,-20}}{C_{liq,N2,+20}}$$

Thus, we expect a higher concentration in the gaseous phase at the lower temperature and therefore a more favourable distillation. This estimation agrees with the results of analyses and therefore applies for almost all similar combinations. Nevertheless one should consider using an analytical control.

Finally, two practical tips: if the distillation takes place directly in the CO_2 tank it is appropriate to use an amount of distillation of 0.1% per h, referring to the tank filling. After about 100 hours one can achieve a required relative reduction of the N_2 concentration of 10 to 20%, the CO_2 loss is about 10%. The distillation procedure should take place as isobaric as possible; therefore it is advantageous if one uses a tank with a heating system which also maintains a constant pressure.

3.1.2 Rectification

The distillation and the related increased concentration of the fractions obtained by condensation in irregular steps are very time-consuming. Especially in the large scale chemical industry but also in air separation ways have been sought to design the operation continuously. This has been achieved by rectification where the steps of distillation and condensation follow one another.

The essential point about rectification is the counter flow of vapour and liquid. This can be seen in more detail with the continuous rectification as shown in I3.1.2-1.

As with distillation, evaporation takes place. This is effected at the bottom of a rectification column by the evaporator (reboiler). The vapour coming out at the head of the column is liquefied in the condenser and returned into the column as reflux. In the middle section of the column there are trays or random packing which achieve an intensive contact between vapour and liquid. An exchange of material and heat between both. The heavier liquid components are condensed from the vapour and returned downwards takes place *via* reflux. Conversely the lighter volatile components of the reflux are evaporated and driven to the head. As a result of these processes of enrichment and depletion the products in the head and the bottom have different compositions.

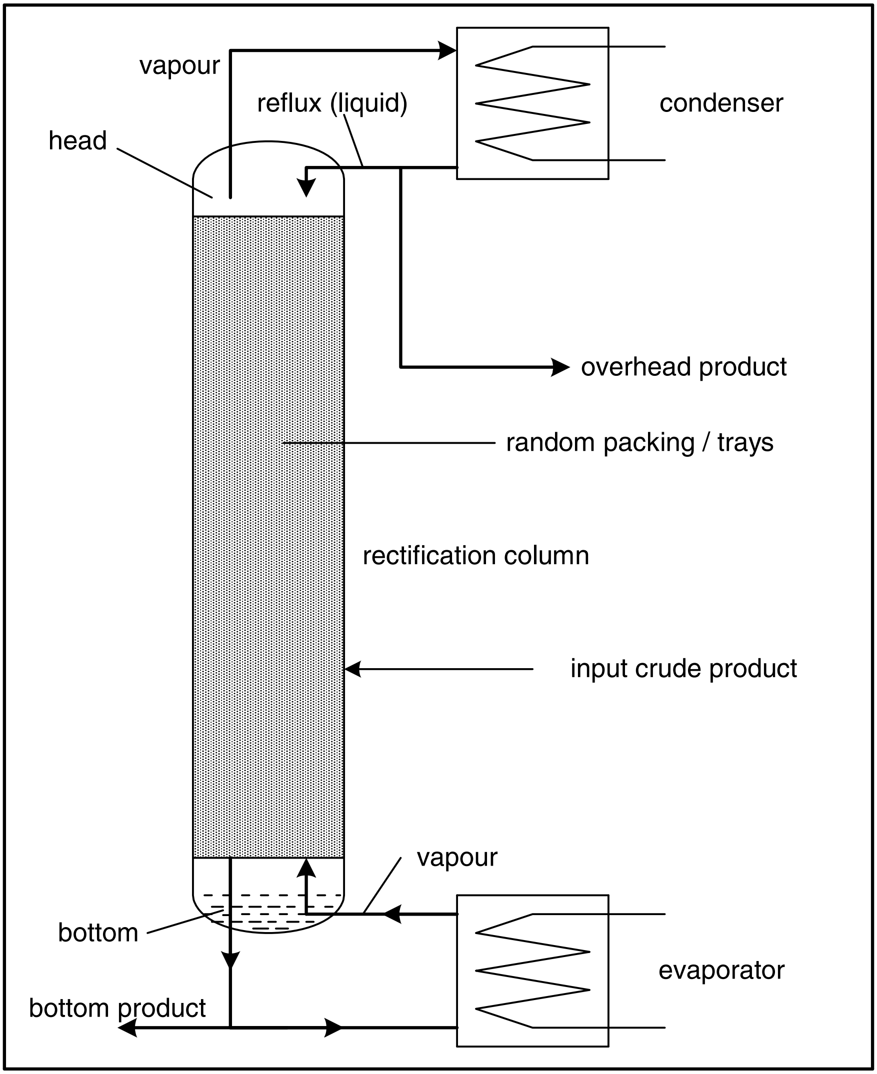


Illustration P3.1.2-1: Schematic of a continuous rectification.

The raw product is continuously added. The one of the head is removed parallel to the reflux, the product of the bottom is removed parallel to the inflow of the evaporator.

The cross section area A or the diameter d of a column, which is assumed to be empty is calculated in connection with Eq. (3-1).

$$A = \frac{d^2 \cdot \pi}{4} = \frac{Q_D \cdot p_{=1\text{bar}}}{v_{\text{lin},D} \cdot p} \qquad (3.1.2\text{-}1)$$

Q_D is the volume flow of the vapour in the column which is given by the performance of the evaporator $v_{lin,D}$ is the permissible linear speed of the vapour at atmospheric pressure. In order to calculate these partially empirical data are necessary, see (Lide 2003-04), (Kirschbaum 1969) und (Sattler 2001). One mostly uses the Eq.

$$v_{lin,D} = k_{v-lin} \cdot \sqrt{\frac{\varphi_{liq} - \varphi_D}{\varphi_D}} \tag{3.1.2-2}$$

with φ_{liq} as density of the reflux and φ_D that of the rising vapour. Several models have been published for the constant $k_{v\text{-}lin}$. $k_{v\text{-}lin} = 0{,}107\ m \cdot s^{-1}$ is often used.

Example E3.1.2-1: a 50% mixture of C_3H_8 / i-C_4H_{10} is rectified at approx. 37°C. The diameter of the column has to be approximated when the volume of gas produced by the evaporator is 10 $m^3 \cdot h^{-1}$.

From Tables T10.4-7 and T10.4-13 one takes

- i-C_4H_{10} : $\varphi_{liq} = 535\ kg \cdot m^{-3}$, $\varphi_{gas} = 12.57\ kg \cdot m^{-3}$, $p_D = 4.8$ bar abs.
- C_3H_8 : $\varphi_{liq} = 473\ kg \cdot m^{-3}$, $\varphi_{gas} = 27.93\ kg \cdot m^{-3}$, $p_D = 12.72$ bar abs.

For the calculation we determine the average from the 50%-point of the densities and the total of the vapour pressures.

$$\varphi_{liq} = 504\ kg \cdot m^{-3}, \quad \varphi_{gas} = 20.25\ kg \cdot m^{-3}, \quad p = 17.6\ bar$$

$$v_{lin,D} = 0.107 \cdot \sqrt{\frac{504 - 20.25}{20.25}} = 0.523\left[m \cdot s^{-1}\right] = 1883\left[m \cdot h^{-1}\right]$$

Eq. 3.1.2-1 is solved using d

$$d = \sqrt{\frac{4 \cdot Q_D \cdot p_{=1bar}}{v_{lin,D} \cdot \pi \cdot p}} = \sqrt{\frac{4 \cdot 10 \cdot 1}{1883 \cdot \pi \cdot 17.6}} = 0.0196[m] = 19.6[mm]$$

The column has a small diameter. It is appropriate to use a 50% increase for this “pencil column”. This reduces the effect of the wall interaction such as decreased exchange of material.

In addition, we look at the quantity flow per time using Illustration I3.1.2-1. We also add the following terms:

Q_{input} : input crude product
Q_{head} : overhead product
Q_{bottom} : bottom product (heavies)
Q_{reflux} : reflux quantity per time, reflux flow
Q_D : vapour quantity per time

The following reference applies:

$$Q_{input} - Q_{bottom} = Q_D = Q_{reflux} - Q_{head} \tag{3.1.2-3}$$

From the amount of reflux and the head product the external reflux ratio Ψ_{ext} is calculated. This provides information about the efficiency of the column.

$$\Psi_{ext} = \frac{Q_{reflux}}{Q_{head}} \qquad (3.1.2\text{-}4)$$

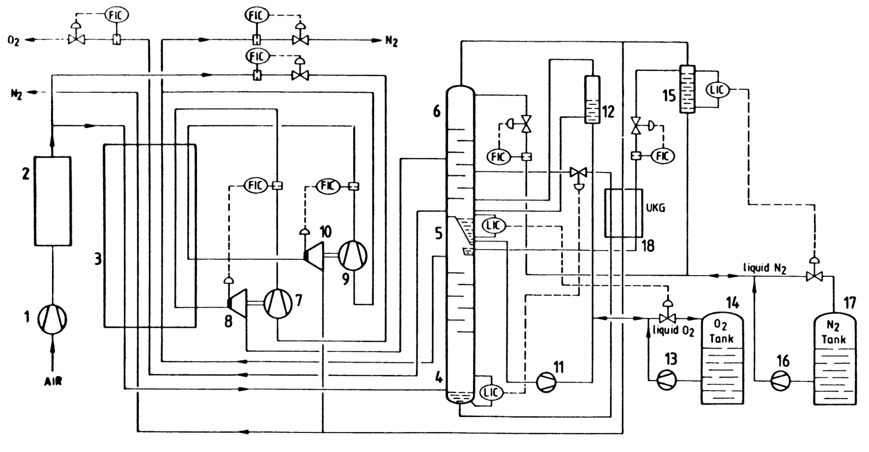
In general the following applies: the greater the purity of the head product, the bigger the reflux ratio and the taller the column. Often the internal reflux ratio Ψ_{int} is formed:

$$\Psi_{int} = \frac{Q_{reflux}}{Q_{D}} \qquad (3.1.2\text{-}5)$$

The internal reflux ratio is constant when the product removal is restricted to the head and the bottom.

The height of the column depends on the so-called number of plates, also referred to as the number of distillation stages. Calculating these values is often done by using McCabe-Thiele's graphic procedure; relevant technical reference books are available.

Example E1.2-2 : Air separation plant (or as they are often called, Air Sepation Unit ASU) to provide varying amounts of oxygen according to (Rhode 1984). *Although this publication is more than 3 decades old it nevertheless shows all the elements which are also required in a similar plant today in an equal form.*



1 air compressor
2 air purification
3 heat exchanger
4 pressure column
5 main condenser
6 upper column
7 turbine-booster 1
8 expansion-turbine 1
9 turbine-booster 2
10 expansion-turbine 2
11 O_2-pump 1
12 O_2-separator
13 O_2-pump 2
14 O_2-tank
15 N_2-separator
16 N_2-pump
17 N_2-tank
18 subcooler

Illustration P3.1.2-2: Schematic plan of an air separation plant (ASU).

Description of the processes: Atmospheric air is sucked in by compressor 1, compressed to approx. 6 bars and freed of undesirable constituents such as water, carbon dioxide and hazardous hydrocarbons in a drying and cleaning system 2 (molecular sieve adsorber station). The air flow is divided into two parts, the main flow which passes through heat exchangers 3 to pressure column 4 and a secondary flow, compressed in turbine booster 7, which likewise flows through exchangers 3 to the expansion turbine 8 and, following expansion, is fed into the upper column. The main air flow fed into the pressure column is pre-separated into pure nitrogen and rich liquid, which is being further separated, together with the branch stream of air coming from turbine 8, in the upper column into pure oxygen and on impure nitrogen fraction. The pure nitrogen recovered in the pressure column serves are runback into columns 4 and 6 and as liquid or gaseous nitrogen product. To this extent, the process corresponds to a normal ASU.

The variability of the plant results from 2 different operational modes. In the case of operation the 22,000 standard $m^3 \cdot h^{-1}$ *of oxygen that can produced from the air supplied, is drawn from the unit, the nitrogen turbine 10 is operated at medium capacity in addition to the air expansion turbine 8. For this purpose, compressed nitrogen is taken from the top of pressure column 4, heated in heat exchanger 3 in counter-current to the entering gases and passes to turbine booster 9. The quantity of compressed nitrogen is drawn off upstream from turbine booster 9. The gaseous nitrogen is compressed to a higher pressure in turbine booster 9, passed via heat exchangers 3 to the nitrogen expansion turbine 10 and expanded, while performing work, into the low-pressure nitrogen line coming from the upper column.*

If oxygen demand increases to a level higher than 22,000 standard $m^3 \cdot h^{-1}$ *(e.g. 33,000 standard* $m^3 \cdot h^{-1}$*) the nitrogen quantity is abated reducing the flow through turbine 10. This gaseous nitrogen is now no longer taken from pressure column 4. It liquefies, at the same time evaporating the equivalent quantity of oxygen from the main condenser 5. The liquefied* N_2 *is passed to the nitrogen tank. The oxygen flow rising from condenser 5 is drawn off as an additional product.*

3.1.3 Adsorption

Bonding gases to solid surfaces is called adsorption. One differentiates between physisorption, also referred to as physical adsorption, and chemisorption. The bonded thermodynamic phase is the adsorbate, it has a saturation vapour pressure $p_{D,Ads}$. The physisorption is determined by the bonding of the adsorbat using the weak Van-der-Waals-forces. In the case of solid objects with highly energetic surfaces, especially metals and ionic compounds, the adsorption does not remain at the level of physical adsorption but a chemical bonding takes place. As a result of this the forces of heteropolar interactions are significantly stronger than with physisorption.

Adsorption is an exothermic process. Energy is released in the form of heat. The enthalpy of physisorption is about the same as the heat of evaporation. With chemisorption there are significantly higher energy values. The boundary between the two is often regarded as 40 kJ · mol^{-1}.

For adsorption adsorbents with large porous surfaces are necessary, molecular sieves and activated carbons are most frequently used. However, other materials are also employed, e.g. porous glasses for suitable resorption coated with suitable metals or acids. The pore diameter d_{Pore} is decisive as to whether a gas can be bonded or not. d_{Pore} is given in nm, before the introduction of the SI units, the Angström unit was used

$$1\left[\overset{\circ}{\mathrm{A}}\right] = 10^{-8}\,[\mathrm{cm}] = 0{,}1\,[\mathrm{nm}] \qquad (3.1.3\text{-}1)$$

Classification according to pore size:

submicropores	$d_{Pore} < 0{,}4$ nm
micropores	$d_{Pore} = 0{,}4 - 2$ nm
mesopores	$d_{Pore} = 2 - 50$ nm
macropores	$d_{Pore} > 50$ nm

In contrast to this there is the critical molecular diameter d_{Cri}.

This shows whether a molecule fits in the pore diameter. The geometrical form is a significant factor as to whether a substance is adsorbable. An Ar molecule is mainly spherical with d = 2 r, to which the critical diameter corresponds. On the other hand n-butane is oblong, the critical diameter here is the largest of all possible molecular cross sections, which can be put vertically into the molecular axis. This is understandable if the n-butane molecule is to be placed into a narrow, straight or suitably fitted pore.

Table T3.1.3-1 shows the critical molecular diameter of some selected substances. The published values vary slightly and are dependent on the method used. For this reason the numbers have more exploratory nature.

Many substances have approximately the same critical diameter but nevertheless the possibilities of adsorption are very different and depend on the polarity and the resultant atomic forces. Water is regarded as one of the easiest bondable substances. Adsorption is often the best way to remove water.

Table T3.1.3-1: Critical atomic and molecular diameters

substance	**d_{Cri} in [nm]**	**substance**	**d_{Cri} in [nm]**
helium	0.20	krypton	0.41
hydrogen	0.24	ethane	0.42
neon	0.26	methanol	0.42 (0.36)
water	0.28	ethanol	0.42
ammonia	0.29	propane	0.43
carbon dioxide	0.33	n-butane	0.43
hydrogen chloride	0.33	n-hexane	0.48
acetylene	0.33	R12	0.49
oxygen	0.35	R22	0.49
nitrogen	0.36	xenon	0.49
hydrogen sulphide	0.36	i-butane	0.51
sulphur dioxide	0.36	thiophene	0.53
carbon monoxide	0.37	benzene	0.58 (0.68)
methane	0.38	toluene	0.58
methyl mercaptan	0.38	p-xylene	0.59
ethyl mercaptane	0.38	carbon tetrachloride	0.59
argon	0.38	cyclohexane	0.60
ethylene	0.39	m-xylene	0.63
propylene	0.40	o-xylene	0.66
butene-1	0.40	chloroform	0.69
1,3 butadiene	0.40	triethylamine	0.78

3.1.3.1 Isotherms and Capacity

Adsorption of gas molecules or atoms takes place on the surface of the adsorbent. It is usually a monomolecular resorption (layer) with the coverage Γ_G which is between 0 and 1 and is dimensionless. The adsorption isotherm for the single combination gas – adsorbent describes the relationship between the coverage Γ_G and the saturation vapour pressure $p_{D,Ads,G}$ of the adsorbate. Several empirical attempts are known.

Freundlich's isotherm is

$$\Gamma_G = k_1 \cdot \sqrt[n]{p_{D,Ads,G}} \tag{3.1.3.1-1}$$

with k_1 and n as constants independent of temperature.

Langmuir's (1918) isotherm is

$$\Gamma_G = \frac{k_2 \cdot \Gamma_{Max,G} \cdot p_{D,Ads,G}}{1 + k_2 \cdot p_{D,Ads,G}} \tag{3.1.3.1-2}$$

with the constants k_2 and $\Gamma_{Max,G}$ as the maximum possible monomolecular coverage. Sattler's comprehensive work of 2001 is recommended for further details, especially the Brunauer-Emmet-Teller-isotherm (BET isotherm) for multi-layered coverage.

Now one considers the borderline case of a very small $p_{D,Ads,G}$ as is the case with trace impurities. Then the denominator in Eq. (3.1.3.1-2) approaches 1.

$$\Gamma_G = k_2 \cdot \Gamma_{Max,G} \cdot p_{D,Ads,G} \tag{3.1.3.1-3}$$

This Eq. is referred to as the Henry isotherm. The coverage is proportional to the saturation vapour pressure. Freundlich's isotherm assumes the same form with $n = 1$.

For the further application the (dynamic) adsorption capacity $K_{AM,G}$ is necessary.

$$K_{AM,G} = \frac{M_{Ads,G}}{M_{AM}} 100[\%] \tag{3.1.3.1-4}$$

with $M_{Ads,G}$ as the adsorbable mass of the gas G, thus the amount of the adsorbat and M_{AM} the mass of the adsorbent. $K_{AM,G}$ depends both on the temperature and the $p_{D,Ads,G}$. In general, the following points apply:

- With decreasing temperature adsorption is improved, $K_{AM,G}$ increases.
- With a smaller $p_{D,Ads,G}$, $K_{AM,G}$ decreases. Therefore a high pressure p (abs.) of the gas to be purified is advantageous. The partial pressure p_G of the impurity G is:

$$p_G = C_{v,G} \cdot p \tag{3.1.3.1-5}$$

where $C_{v,G}$ is the molar concentration. An adsorption only takes place when

$$p_G > p_{D,Ads,G} \tag{3.1.3.1-6}$$

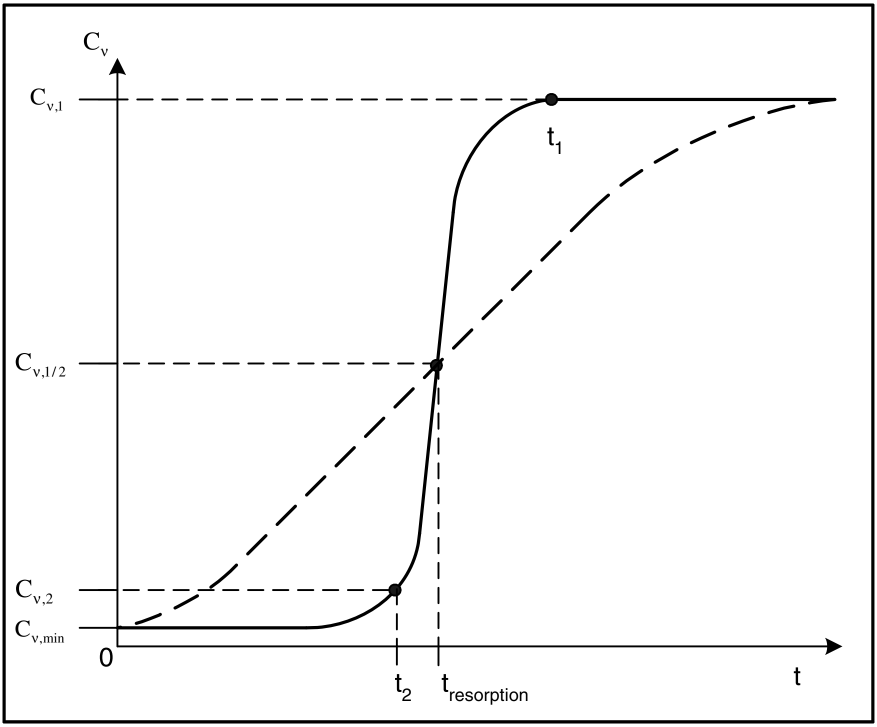


Illustration P3.1.3.1-1: Breakthrough curves

The adsorption capacity is determined by experimentation to obtain the breakthrough curve. A schematic representation can be found in Illustration P3.1.3.1-1

The gas 1 which is to be purified has molar the concentration $C_{v,1}$ and the purified gas 2 should not exceed $C_{v,2}$. C_v is measured during the adsorption time. At the beginning of the adsorption one determines a very small concentration $C_{v,min}$ which can often be neglected. The curve has the shape of an S, the steeper it is, the better the adsorber works. The coverage time $t_{resorption}$ is usually calculated at

$$C_{v,1/2} = \frac{1}{2}\left(C_{v,1} - C_{v,min}\right)$$

The adsorbed amount of the gas G and the adsorption capacity are then

$$M_{Ads,G} = Q_{M,G} \cdot t_{resorption} = C_{v,1/2} \cdot \varphi_G \cdot Q_V \cdot T \qquad (3.1.3.1\text{-}7)$$

$$K_{AM,G} = \frac{C_{v,1/2} \cdot \varphi_G \cdot Q_V \cdot t_{resorption}}{M_{AM,G}} 100[\%] \qquad (3.1.3.1\text{-}8)$$

A more exact definition of the capacity is obtained by using t_2 instead of $t_{resorption}$. In this case it is possible to avoid the concentration of the gas leaving the purifier, exceeding the desired value $C_{v,2}$. This can be clearly seen by the dashed breakthrough curve. This reaches the value $C_{v,2}$ after a relatively short coverage time.

Example E3.1.3.1-1: In a service pipeline at 10 bar (g) Ar and a daily consumption of 12 m^3 one has to apply a post-drying process. The moisture concentration has an average volume of C_V = 2.55 ppm which corresponds to a dew point of about –70 ^{0}C. This is to be reduced to a value below 0.1 ppm. How large does an adsorber have to be to only be changed every 3 months?

Calculation of the amount of the adsorbat to be taken up.

$$M_{Ads,H2O} = C_{abs,H2O} \cdot Q_V \cdot t \tag{3.1.3.1-9}$$

$Q_V = 12\ m^3 \cdot d^{-1}$, $t = 91$ d, from Table T2.4-1 one takes for $C_{V,H2O}$ a $C_{abs,H2O} = 1.96\ mg \cdot m^{-3} = 1.96 \cdot 10^{-3}\ g \cdot m^{-3}$

$$M_{Ads,H2O} = 12 \cdot 91 \cdot 1.96 \cdot 10^{-3} = 2.14[g]$$

$K_{AM,H2O}$ is assumed to be 0.01%. As a comparison: when removing water from atmospheric air one expects a $K_{AM,H2O} \geq 10\%$. One still has to compare the partial pressures of the water before and after adsorption.

$$M_{AM} = \frac{M_{Ads,H2O}}{K_{AM,H2O}} = \frac{2.14 \cdot 100}{0.01} = 21400[g] = 21.4[kg]$$

The geometrical volume of the adsorber with the assumed mean density $\varphi_{bulk} = 0.8\ kg \cdot dm^{-3}$ is

$$V_{geom} = \frac{M_{AM}}{\varphi_{bulk}} \tag{3.1.3.1-10}$$

$$V_{geom} = \frac{21.4}{0.8} = 26.75\left[dm^3\right]$$

An adsorber of this volume already has a total weight of up to 50 kg. Changing by hand is still just feasible. The adsorbent can be exchanged and regenerated externally. If larger amounts are to be adsorbed, fixed manifolds with installed regeneration are necessary, see the following chapter.

Information about adsorption capacity and mean density are provided by the adsorbent manufacturers.

3.1.3.2 Molecular Sieves and Silica Gels

Molecular sieves are a generic term for porous substances with adsorbing characteristics. The main concern is attached to the group of aluminium silicate substances of natural or artificial origin (1940). Their structure is three-dimensional consisting of reticulated AlO_4 – tetrahedrons, which are connected by common

O atoms. The network of long channels contains both water molecules and alkali ions which can be exchanged by other cations. The collective formula of the crystallographic unit cells is

$$M_{x/Va}\left[(AlO_2)_x\,(SiO_2)_y\right]\cdot zH_2O \tag{3.1.3.2-1}$$

with the cation $M_{x/Va}$ and its valence number Va. The sum (x+y) is the number of tetrahedrons in the unit cell, the quotient y/x is greater than 1. The number of water molecules is characterised by z.

The principle of adsorption consists of removing the bonded water by heating (desorption), so that the free places can be occupied, not only by water.

The number of zeolites known today is very large. Breck's 1991 and Kast's 1988 papers provide a good overview. The technically most interesting zeolites are of type A and X. The first type A is still quoted in Angström, other types have random or mineralogical names.

Table T3.1.3.2-1: Overview of the most important molecular sieves. Type 13X is sometimes also referred to as 10A..

Molecular sieve	Structure of crystallographic cell	Pore size in [nm]
3A	$K_{12}[(AlO_2)(SiO_2)]_{12}$	0.33
4A	$Na_{12}[(AlO_2)(SiO_2)]_{12}$	0.39
5A	$Ca_6[(AlO_2)(SiO_2)]_{12}$	0.43
13X	$Na_{86}[(AlO_2)_{86}(SiO_2)_{106}]$	0.79

Type A has a cage (void) with a diameter of about 1.2 nm which is accessible for molecules *via* 6 pore openings (windows). The size of the pore openings depends on the type of the cations. A characteristic structure of zeolite X is the "super cage" with a diameter of about 1.3 nm. Compared with type A this type has a more complex and significantly larger unit cell. This can be clearly seen type X when comparing the amounts of bonded water per unit cell: 27 molecules of water with 4A while 264 can be inserted into 13X.

Molecular penetration into the zeolites is a very elastic process. It is generally assumed that the molecules can be about 0.05 nm bigger than the given free diameter (crystallographic diameter) of the pores. This process takes time as shown in the linear velocity v_{lin}. If the manufacturers of the molecular sieves do not provide any information to the contrary, one uses v_{lin} from 0.1 to 0.25 $m \cdot s^{-1}$.

Table T3.1.3.2-2: Examples for usage of molecular sieves in large-scale industry compiled according to documents of the firm Grace GmbH in Worms.

Type	Bulk density in [kg · m^{-3}]	Natural gas industry	Chemical industry
3A	700 – 720	Natural gas drying with H_2S conversion to COS less than 5%	Ethylene drying, water contents of less 0.1 vpm* Propylene drying in liquid phase
4A	700 – 730	Removal of CO_2 and H_2O to less than 1 vpm* prior to liquefaction	Hydrogen and air/nitrogen drying Removal of chlorides for catalyst protection.
5A	700	Removal of H_2S and mercaptans to pipeline specification	Ethylene purification, removal of CO_2 down less than 1 vpm*
13X	620 – 650	Removal of sulphur compounds, LNG** sweetening	Removal of H_2O and CO_2 prior to air separation. Removal of sulphur compounds in liquid C_3H_8 and C_4H_{10}

* 1vpm = 1 ppm (volume) ** LNG = Liquefied Natural Gas

It is not worth carrying out a desorption (regeneration) with every charged adsorbent, especially with chemisorption there are irreversible bonds which require the removal and the need of fresh material. Regeneration however is typical for the molecular sieve, it occurs with:

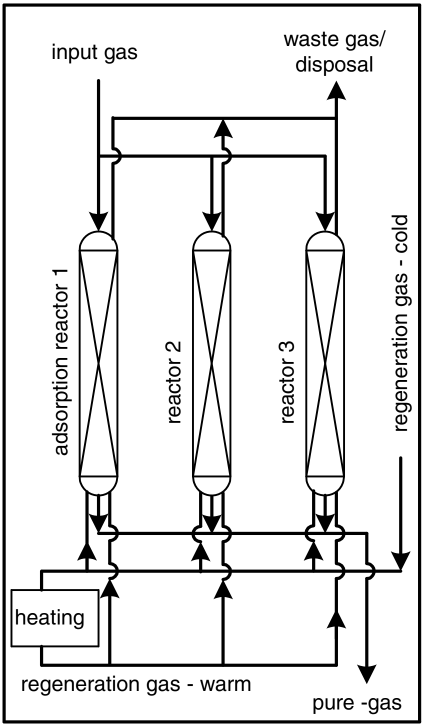
- Heating
- decrease in pressure
- flushing with a non-adsorbable gas, this use is rare.
- adsorption of a more easily adsorbable substance. This is often a problem if several impurities have to be bonded.

Thermal regeneration is carried out by drying a gas at low overpressure, as explained in Illustration P3.1.3.2-1. For continuous handling adsorbers 1 to 3 can be used operating cyclically at the following stages of work:

(1.) Loading with the gas to be cleaned: adsorber 1, from top to bottom.
(2.) Desorption with a heated regenerating gas in the opposite direction of the adsorption: adsorber 2, from bottom to top.
(3.) Cooling with a regenerating gas: adsorber 3, from top to bottom.

Regeneration by pressure decrease is used in the process of Pressure Swing Adsorption (PSA). The principle is represented in illustration P3.1.3.2-2.

The gas to be purified is put into adsorber vessel 1 at as high a pressure p_1 as possible. At the same time the parallel adsorber vessel 2 is in a state of almost zero



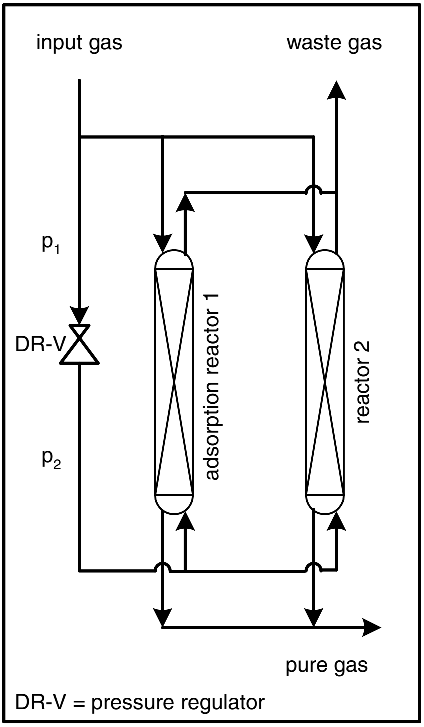


Illustration P3.1.3.2-1 (left): Schematic representation of a system for drying with thermal regeneration

Illustration P3.1.3.2-2 (right): Schematic representation of a PSA system.

pressure (p_2). Desorption is possible because of the different adsorption capacities at p_1 and p_2. Expanded gas is used to transport the desorbed impurities, away from adsorber vessel 2.

Compared to thermal desorption with loading and desorption times in the region of hours, the PSA times take only minutes. In addition one must also consider that the loading capacities with the PSA are significantly lower, whereas the loading frequency is higher. For an overview of the multiple uses of PSA see (Riquarts and Leitgeb 1985).

Regeneration by removal with a non-adsorbable gas, e.g. He is confined to special cases. Desorption by adsorption of a more easily adsorbable gas is to be considered in the case of multi-component mixtures, as the following example shows.

Example E3.1.3.2-1: Adsorption of CO_2 and H_2O from atmospheric air. Partial pressures $p_{CO2} = 0.4$ mbar, $p_{H2O} = 8$ mbar, relevant adsorption capacities $K_{Ads,CO2} = 2\%$, $K_{Ads,H2O} = 10\%$. Further specifications: $Q_V = 100\ m^3 \cdot h^{-1}$ and $M_{Ads} = 20$ kg. The loading times are to be calculated.

$$Q_{V,G} = \frac{p_{G,mbar}}{1000} Q_{V,total} = C_{v,G} \cdot Q_{V,total} \qquad (3.1.3.2\text{-}1)$$

$$Q_{V,CO2} = \frac{0.4}{1000} 100 = 0.04 \left[m^3 \cdot h^{-1} \right] \qquad Q_{V,H2O} = \frac{8}{1000} 100 = 0.8 \left[m^3 \cdot h^{-1} \right]$$

Transfer to Q_M *with* $\varphi_{CO2} = 1.848\ kg \cdot m^{-3}$ *according to the data sheet and* $\varphi_{H2O} = 0{,}8\ kg \cdot m^{-3}$*, for more exact values see (D´Ans-Lax 1983–98)*

$$Q_{M,G} = \varphi_G \cdot Q_{V,G} \qquad (3.1.3.2\text{-}2)$$

$$Q_{M,CO2} = 1.848 \cdot 0.04 = 0.074 \left[kg \cdot h^{-1} \right] \qquad Q_{M,H2O} = 0.8 \cdot 0.8 = 0.64 \left[kg \cdot h^{-1} \right]$$

The adsorbed amount $M_{Ads,G}$ *and the time* t_G *are related by*

$$M_{Ads,G} = Q_{M,G} \cdot t_G \qquad (3.1.3.2\text{-}3)$$

By using the Eq. (3.1.3.1-4) one obtains

$$K_{Ads,G} = \frac{M_{Ads,G} \cdot 100}{M_{AM}} = \frac{Q_{M,G} \cdot t_G \cdot 100}{M_{AM}} [\%]$$

$$t_G = \frac{K_{Ads,G} \cdot M_{AM}}{Q_{M,G} \cdot 100} \qquad (3.1.3.2\text{-}4)$$

$$t_{CO2} = \frac{2 \cdot 20}{0.074 \cdot 100} = 5.4 [h] \qquad t_{H2O} = \frac{10 \cdot 20}{0.64 \cdot 100} = 3.13 [h]$$

This result shows independent of different adsorption processes that the loading process must be finished at the latest after t_{CO2}*. However, as the* CO_2*- and* H_2O*-molecules are competing for every free space, the water with the higher adsorption capacity displaces the* CO_2 *before* t_{CO2} *is reached. For detailed information about the calculation please refer to* (Sattler 2001). *Experimental confirmation is always appropriate.*

In practice, a significant amount of the water is removed by condensation at temperatures below 0°C before the adsorption. Another possibility is to pre-use silica gel (see below).

Molecular sieves are normally not suitable for drying acidic gases like HCl or gas mixtures with acidic components. For this purpose acid resistant molecular sieves have been developed, primarily in sizes 3A and 4A.

Another also very promising development are the so-called hydrophobic (water-repellent) molecular sieves. Unlike the standard hydrophilic types, the presence of moisture is no competition for the adsorption sites.

Finally, a different very often used adsorbent which must be considered is silicagel, a porous, amorphous form of silica SiO_2. Although it has the same chemical composition as sand, silica gel is radically different to other SiO_2-based materials, due to its unique internal structure. It is composed of vast network of interconnected microscopic pores. As opposed to zeolites, silica gels have larger pores with a wide range of diameters – typically between 0.5 and 30 nm – and do not allow for the separation of molecules solely dependent on their size. Important features are:

- Chemically inert, no metals or cations present.
- Chemically stable in acidic, neutral and mildly basic environments.
- Synthesised with an average pore sizes of about 2 nm known as narrow pore silica gels.
- Adsorption occurs due to the van der Waals interaction and capillary condensation at high humidities. The adsorption force is less than for zeolites, resulting in a lower adsorption capacity at low concentrations of adsorbates.
- At higher concentrations of adsorbates, the adsorption capacity is higher than for zeolites, due to the higher internal pore volume.

3.1.3.3 Activated Carbon

Activated carbons are micro-porous forms of carbons of different origin. The most common starting points for their manufacture are lignites and anthracites, but in addition charcoal from somewhat exotic materials, such as coconuts and exotic woods are used. There are two methods of producing the porous structure.

Coke with its very small pores is used for activation by water vapour. Using vapour at approx. 1000°C carbon is removed from the inner walls of the pores and a structure of micro and macropores is created which is however not as well sorted by size as is the case with molecular sieves.

For chemical activation phosphoric acid or zinc chloride solutions are mixed with wood, which swells and thus its cellular structure is relaxed. With a carbonisation process at temperatures of 400 to 500°C the activated carbons are created.

Fine-pored carbons have a pore diameter of about 10 nm, coarse-pored on the other hand have a wide distribution around 1000 nm.

The table T3.1.3.3-1 shows the broad application of activated carbons. Obviously larger molecules are preferred for this adsorption. In view of the conditions of use the following rules of thumb apply, unless the manufacturing companies provide other instructions:

- Dwelling time t_{dwell} : 1 to 5 s, for Hg, for lubricating oil up to 10 s
- Linear velocity: 0.05 bis 0.4 $m \cdot s^{-1}$
- $C_{output} \leq 0.01 \cdot C_{input}$ at $C_{input} \leq 10^3$ ppm
- It makes no sense to dry the activated carbons especially. The remaining water has a relaxing effect for the predominant chemisorption.

Only in a few cases physisorption is involved, then regeneration is possible. An example is the adsorption of hydrocarbons C_3 and higher from CH_4 or C_2H_6. Here, the regeneration of the activated carbons takes place with vapour heated to 120°C. Afterwards drying with hot N_2 is necessary.

Table T3.1.3.3-1: Examples of the use of activated carbons.

Carrier gas	Impurities	Application field
synthesis gas,CO_2 , H_2 , CH_4	H_2S , CS_2 , mercaptans	Chemical industry petroleum chemistry
all crygenic	SO_2 , HCl, NO_2 , HF	chemical industry industrial gases
compressed air, N_2, O_2	lubricating oil	all industries
natural gas	Hg (vapour)	petroleum chemistry
nuclear reactor gases	radioactive iodine	nuclear plant
exhaust gas	kerosene	airports
exhaust gas	PH_3 , AsH_3	semiconductor industries (LED-production)
CH_4 , C_2H_6	C_nH_m at C_3	petroleum chemistry

3.1.4 Permeation

The word permeation is derived from the Latin “permeo”, which is translated by “perambulating” or “arriving”. In a physical – technical sense, it refers to the diffusion of gases or liquids through materials such as like plastics, ceramics or metallic alloys. Permeation has a significant meaning in daily life, e.g. blood dialysis. On the other hand, permeation of gases and vapours is only a small area of use from a huge choice. It is carried out using membranes and metallic alloys. Thus, one sometimes also uses the expression diffusion through a dividing wall.

Using Fick’s first Law according to Eq. (2.2.3-4) we have already introduced the basic reference for diffusion.

$$Q_V = -D \cdot A \frac{dC}{dx}$$

For further considerations a permeable membrane made of plastic with a special thickness is introduced, on one side of which a gas mixture flows by and on the other side one component of the gas mixture is removed. This should lead to a state of equilibrium. Using this process, we cannot assume that the diffusion will flow through pores and channels. Rather the gas being permeated on side 1 is absorbed by partial pressure p_1 in the plastic and diffuses as a product of the solubility on side 2, where it forms with the discharge from the plastic with the partial pressure p_2. Therefore, the term soluble diffusion is understandable and usual. A typical example is the separation of hydrocarbons from methane (Schulz 1996).

For small partial pressures for concentration C in the plastic similarly for solution in liquids (Eq. 2.2.3-9) Henry's Law applies.

$$C = \delta_{\mathrm{Perm}} \cdot p \qquad (3.1.4\text{-}1)$$

The concentration is proportional to the partial pressure, δ_{Perm} is the solubility coefficient for the permeation. In Fick's first Law the differential quotient of the concentration in direction x is replaced by the difference in the concentrations on sides 1 and 2, divided by the thickness s of the wall, and use C from the previous Eq.

$$-\frac{dC}{dx} = \frac{C_1 - C_2}{s} = \delta_{\mathrm{Perm}} \frac{p_1 - p_2}{s} \qquad (3.1.4\text{-}2)$$

Thus, for the volume flow the following is obtained

$$Q_V = D \cdot A \cdot \delta_{\mathrm{Perm}} \frac{p_1 - p_2}{s} = P \cdot A \frac{p_1 - p_2}{s} \qquad (3.1.4\text{-}3)$$

with the specific permeability $P = D \cdot \delta_{\mathrm{Perm}}$ in the dimension $m^2 \cdot s^{-1}$. The following table is taken from (Jessel 2001) and is intended to give an indication of specific permeability.

Table T3.1.4-1: Specific permeability P in $10^{-10}\ m^2 \cdot s^{-1} \cdot bar^{-1}$ at 25°C.

Substance	**He**	**H_2**	**N_2**	**O_2**	**CO_2**
natural rubber	0.17–0.31	0.19–0.68	0.07–0.19	0.23–0.55	1.34
polyethylene	0.06–0.09	0.11–0.59	0.001–0.01	0.01–0.05	0.13–0.17
neoprene	0.04	0.13–0.46	0.01–0.02		0.29
polyvinyl chloride			0.02–0.04	0.001–0.07	0.005–0.3
polystyrene		0.9	0.01–0.08	0.03–0.23	0.37
Perbunane (Buna N)	0.11	0.15	0.02	0.04	0.30

The principle of the diffusion cell can be seen from Illustration P3.1.4-1 on the next page. Permeation takes place through the thin-walled plastic tubes which are closed on one side by grouting, usually with synthetic resin. The other end of the tube is open, the fastening is also grouted. Integration in a flange enables an easy exchange of the tubes which are connected into one unit. In this way permeations of one or several square meters can be achieved. The units can be switched to be parallel and consecutive (cascade).

Example E3.1.4-1: calculation of the amount of gas to be permeated. Specifications: starting mixture 60% CO_2 in N_2 at p_1= 3 bar (g). Permeation area 1 m^2, polyethylene-tubes with thickness s = 0.5 mm. Output pressure p_2= 0.4 bar abs. of the permeate CO_2 through pumping.

Using Eq. (3.1.4-3) with the value $P_{CO2} = 0.15 \cdot 10^{-10}\ m^2 \cdot s^{-1} \cdot bar^{-1}$ from table T3.1.4-1. A = 1 m^2, p_1 = 2.4 bar abs. (=4 x 60%), p_2 = 0.4 bar abs., $s = 0.5 \cdot 10^{-3}$ m

$$Q_{V,CO2} = 0.15 \cdot 10^{-10} \cdot 1 \cdot \frac{2.4 - 0.4}{0.5 \cdot 10^{-3}} = 0.6 \cdot 10^{-7} \left[m^3 \cdot s^{-1}\right] = 0.216 \left[l \cdot h^{-1}\right]$$

As the specific permeability P_{N2} is not negligibly small one obtains for the volume flow of N_2

$$Q_{V,N2} = 0.005 \cdot 10^{-10} \cdot 1 \cdot \frac{1.6 - 0.4}{0.5 \cdot 10^{-3}} = 0.012 \cdot 10^{-7} \left[m^3 \cdot s^{-1} \right] = 4.32 \cdot 10^{-3} \left[l \cdot h^{-1} \right]$$

This means that the nitrogen portion of the permeate gas is about 2%.

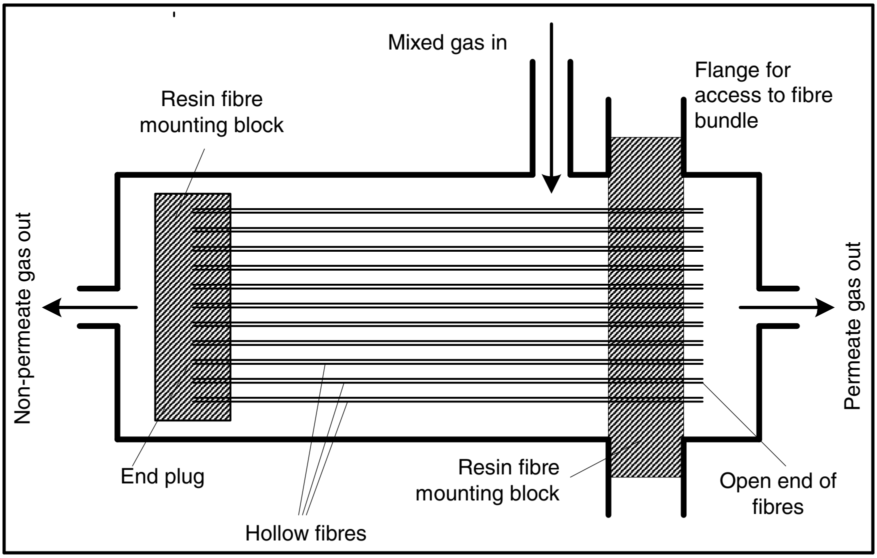


Illustration P3.1.4-1: Principle of a diffusion cell.

One can draw two important conclusions from the results:

- For viable production it is necessary to use large permeation areas. For industrial application see (Scott et Hughes 1996).
- The gas obtained by permeation using plastic is still impure due to other gases, further steps are necessary.
- At the moment the most important areas of use are the already mentioned purification of natural gas and the production of N_2 with a quality of up to 99.5%.

On the other hand diffusion of H_2 takes place using metals and alloys. This is an ultrafine form of purifying. Moreover the procedure is basically very different from that used with plastics.

Example E3.1.4-2: purifying different impurities from H_2.

The example according to Illustration P3.1.4-2 assumes a gas mixture with H_2 as the principle component and with impurities He, H_2O, CO_2 and CH_4. The palladium alloy is heated up to about 300°C.

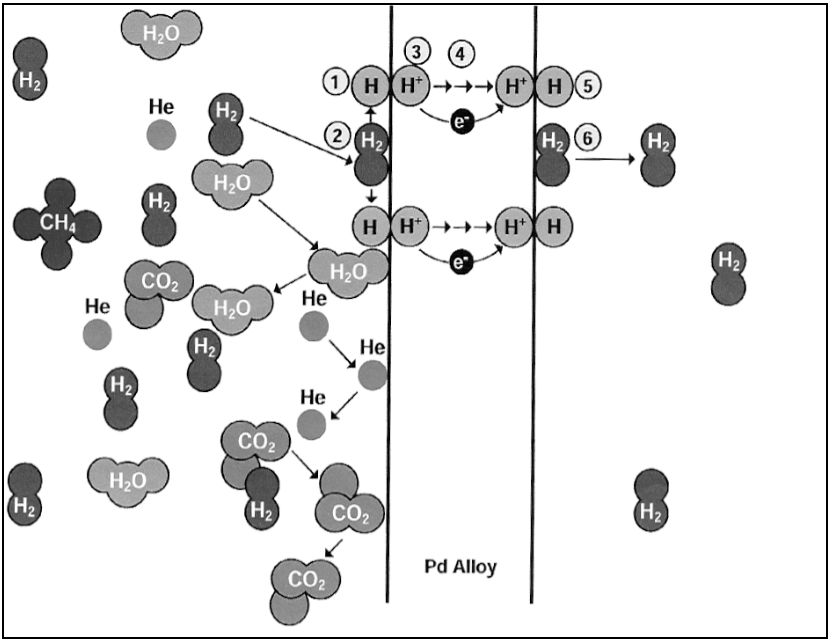


Illustration P3.1.4-2: Procedure for diffusing H_2 through a palladium alloy according to (Chu 1989)

On the surface of the first side is the mixture where adsorption (2) of the molecular H_2 takes place. This is the prerequisite for the dissociation (1) in the atomic state of the H atoms, which are mostly referred to as radicals nowadays. Then an ionisation (3) takes place. By diffusion (4) the H ions pass to the pure side. Then they bind with the electrons which have also gone through to form radicals (5). These then combine to form H_2 molecules which are desorbed from the surface (6). It is very interesting that even the atomic He cannot penetrate the wall of the palladium alloy.

For technical application usually thin-walled tubes from palladium alloys are used. The direction of flow is both outside → inside and vice versa.

Example E3.1.4-3: efficiency of palladium diffusion cells according to information provided by the firm Johnson Matthey in West Chester / USA.

- *Volume of flow: outside → inside*
- *Rate of flow 0.5 to 160* $l \cdot min^{-1}$.
- *Purity achieved* $> 7.0 = 99.99999$ % .
- *Remaining impurities* $H_2O < 1.5$ ppb, $N_2 < 1$ ppb, $CO < 1$ ppb, $CO_2 < 0.1$ ppb, $CH_4 < 0.1$ ppb.

Finally, further important developments have to be pointed out:

- Membranes for fuel cells, (Ruffmann et Rohland 2005).
- Utilisation of oxide ceramics with high oxygen transport in the form of oxide ions offers new perspectives for separation of O_2 from air, process temperatures are 800 to 900 °C, (Ullmann et al. 2004).

3.1.5 Isotope Separation

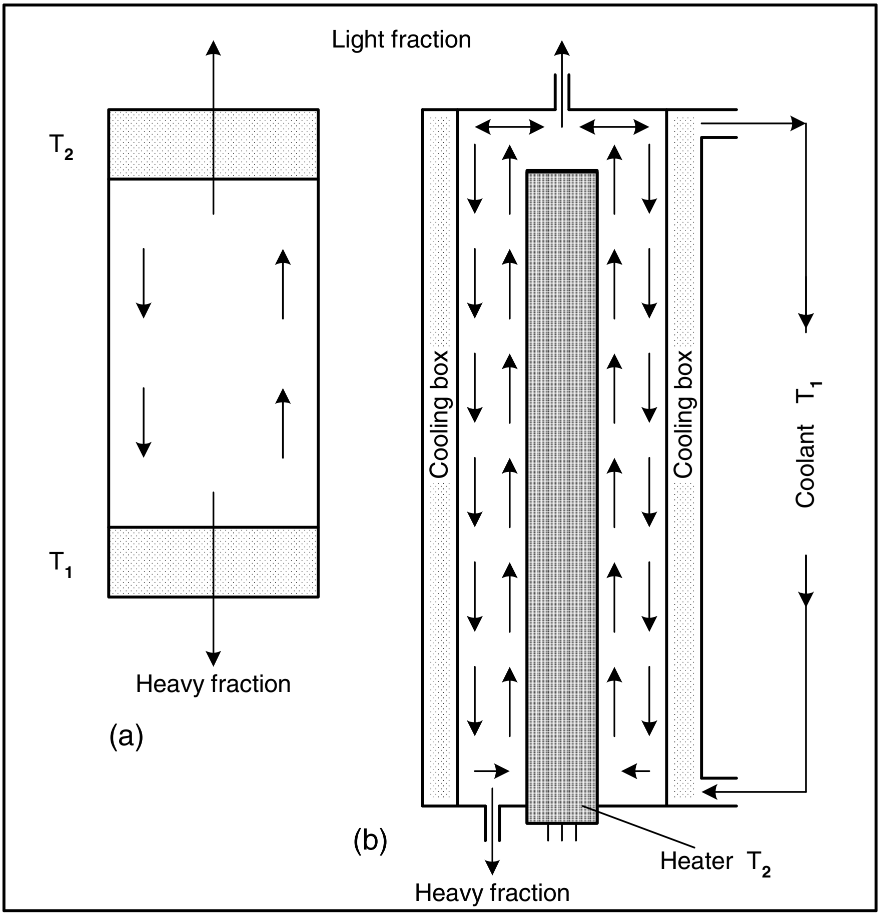


Illustration P3.1.5-1: (a) Principle of thermal diffusion. (b) Schematic representation of a separation tube.

Isotope separation in the public opinion is usually associated with the production of ${}^{235}_{92}U$ which can be used for nuclear weapons. This is how the magnetic mass separator and the ultra centrifuges have become well-known.

For isotope separation all properties which are dependent on the mass of the molecule are suitable: density, viscosity, diffusion, vapour pressure, ability to transfer heat, melting point, boiling point and other. In this way heavy water D_2O which is present in small quantities in H_2O is separated by electrolysis and enriched through distillation in the bottom of the column. The distillation of H_2 is similar, the D_2 is heavier in the bottom than in the top. Later a procedure will be dealt with in more detail, which is carried out predominantly in the gaseous state: thermal diffusion which takes place in gases and liquids.

It was predicted and examined by Enskog (1911) and Chapman (1917) on the basis of the kinetic gas theory. The simple principle is represented in Illustration I3.1.5-1 (a). In a gaschamber, using a temperature gradient $T_2 > T_1$ a diffusion flow is created in a binary gas mixture which leads to a concentration gradient. This process causes the lighter component to diffuse at a higher temperature T_2. In this case it can be extracted at the head of the container. The difference in the relative atomic concentration ΔC_{Atom} for the lighter component at the warm end is:

$$\Delta C_{\text{Atom}} = D_{\text{Thermo}} \cdot \ln \frac{T_2}{T_1} \qquad (3.1.5\text{-}1)$$

with a thermal diffusion coefficient D_{Thermo} which needs to be calculated using common approximation methods or it has to be determined empirically. For a $D_{\text{Thermo}} = 0.1$, $T_1 = 15°C$ and $T_2 = 500°C$, $\Delta C_{\text{Atom}} \cong 0.1\%$ is obtained. This shows the low degree of efficiency.

Thermal diffusion made a decisive step towards implementation by Clusius and Dickel's 1938 separation tube. In the middle of a double jacketed is found glass apparatus an electrical heating wire at temperature T_2, and the water cooling in the jacket at T_1. Illustration I3.1.5-1(b) shows a common separation tube according to the same principle. The heating element in the middle and the cooling jacket outside create a convection which supports the thermal diffusion. A further advantage is that the procedure can be carried out in several stages. Many isotopes have been separated using this principle:

$$^{3}_{1}H_2\,,\ ^{3}_{2}He\,,\ ^{13}_{6}CH_4\,,\ ^{18}_{8}O_2\,,\ ^{85}_{36}Kr\,,\ ^{86}_{36}Kr\,,\ ^{235}_{92}UF_6\,.$$

The monographs of (Grew 1952) and (Vasura et al. 1969) contain technical solutions and the calculations.

Example E3.1.5-1: Obtaining 1 liter of Kr-86

In 1961 this task was solved by the former Institute for Stable Isotopes in Leipzig. The order was given by the Federal Physical Technical Institute which needed the Kr-86 for the metrological connection of the "standard meter" to the red wavelength of this inert gas. Kr-86 is contained within normal Kr with an atomic percentage of 17.4%. To accomplish this separation an annual production of 6 m^3 *from the Leuna Factory's air separation plant had to be used. One of the author's first task in his professional career was to purify this liter of Kr-86 from all other components of air.*

The enrichment was atomic 98%, the purity was better than 99.9% volume, the price of DM 34,000 was exorbitant!

Example E3.1.5-2: carbon dioxide with a special composition and purity is to be produced:

$$^{13}_{6}C\,^{17}_{8}O_2 \;\; 6.0 \;\; SFC \;\; 99 Atom-\% \qquad (3.1.5\text{-}2)$$

SFC means "suitable for Supercritical Fluid Chromatography". This example is constructed and is intended to show that the manufacture of such a gas involves enormous effort. The carbon has 2 stable isotopes, C-13 is only present at 1.1 atomic % and O-17 only with 0.037 atomic % compared with O-16 and O-18. It would be possible to obtain the C-13 from methane, thus concentrating the $^{13}_{6}C\,^{1}_{1}H_4$. *Furthermore it is necessary to separate the O-17 which is only possible with enormous effort to achieve the desired enrichment of 99.9 atomic % due to the low occurance and the fact that this isotope lies between the two others. Then it would be necessary to carry out a synthesis to carbon dioxide. Further tasks would be to remove the usual total impurities to under 1 ppm for grade 6.0 and the CFC´s under 10 ppb so that the special condition of SFC is adhered to.*

3.2 Chemical and Electro-chemical Procedures

3.2.1 Heterogeneous Catalysis

According to Ostwald's definition 1907 a catalyst is a substance which in only a very low quantity changes the speed of a given reaction without taking part in it more than superficially. The first large-scale process using catalysts with a decisive effect was the synthesis of ammonia in 1913 using the Haber-Bosch method. The general public only became aware of the catalyst in the late 1970s through the reduction of toxic elements in car exhaust fumes.

Older published works differentiate partially between "real" and "unreal" catalysts. The former strictly correspond to Ostwald's definition, the latter are referred to as catalysing through chemical bonding of substances and they have to be regenerated. Strictly speaking these are not catalysts but should be included in the area of chemisorption. However, old terms such as Ni-catalyst are still wide spread.

One differentiates between homogeneous and heterogeneous catalysis. With homogeneous catalysis the catalyst and the reactance are in a the same state as is the case with a chemical reaction in liquids with a dissolved catalyst. With heterogeneous ones at least two phases are involved, the catalyst is often a solid substance and the reactants are liquids or gases. By a stationary catalyst bed one speaks of fixed-bed (solid) catalyst.

The speed of reaction v_{React} serves as a measure of the activity of a catalyst. It is the relationship between the amount of substance M_G used to the product of the amount of the catalyst M_{cat} and time t.

$$v_{React} = \frac{M_G}{M_{cat} \cdot t} \qquad (3.2.1\text{-}1)$$

The dimension is either mol · kg^{-1} · h^{-1} with M_G in mol or h^{-1}. With the references (φ = density)

$$M_G = Q_{M,G} \cdot t = \varphi_G \cdot Q_{V,G} \cdot t = \varphi_G \cdot C_{v,G} \cdot Q_V \cdot t$$

$$M_{cat} = \varphi_{bulk} \cdot V_{cat} = \varphi_{bulk} \cdot V_{geom}$$

one obtains the relation to the spatial velocity (GHCV) in v_V in $[h^{-1}]$ according to Eq. (3-2)

$$v_{React} = \frac{\varphi_G \cdot C_{v,G}}{\varphi_{bulk}} \frac{Q_V}{V_{geom}} = \frac{\varphi_G \cdot C_{v,G}}{\varphi_{bulk}} v_V \qquad (3.2.1\text{-}2)$$

The speed of reaction and the spatial velocity are also directly proportional to one another. v_V provides both the necessary amount of the catalyst and the required dwell time.

Using the catalyst in large-scale chemistry is intended to produce as large an amount of substance as possible. The catalyst for the fine purification of gases should still work at low partial pressures of the impurities which have to be converted. These are often different formulations for the development of the catalysts which one can obtain tailor-made today.

Fixed bed-catalysts consist of one carrier with as large a surface as possible covered with the catalytic material. Suitable carriers are highly porous materials like Al_2O_3 , SiO_2 , TiO_2 and activated carbons. For temperatures above 500°C porous glasses and quartzes are used as well as SiO_2. Active substances are metals like Pd, Pt, Fe, Cr, Cu und Ni. However, the other metals of the periodic table have already been tested for suitability and are used in special cases. The field of catalysts is still developing dynamically.

For the physico-chemical foundations and the principles of the manufacture of catalysts please refer to the well-known descriptions by (Hagen 1996) and (Ertl et al. 1997).

A paradigm is the removal of methane from air or oxygen. To implement CH_4 the partner O_2 is present in more than the necessary stoichiometric proportion.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \qquad (3.2.1\text{-}3)$$

If CH_4 is to be removed from N_2 or inert gases one must first check if there is enough O_2 as an impurity or otherwise O_2 has to be added before the catalyst. Water and carbon dioxide are two additional products created which need to be removed in an another process. Mostly one uses an adsorption with molecular sieve 13X.

Table T3.2.1-1: Platinum and palladium catalysts for supplementary purifying.

Carrier gas	**Impurities**	**$C_{v,output}$ in [ppm]**	**T in °C**	**v_V x1000**	**Active metal**
Air	H_2 , CO	0.005	130 – 220	5 – 15	Pd, Pd/Ag,
Air	CO	0.005	80 – 130	5 – 15	Pd, Pt
Air	CO,H_2,CH_4	0.1	300 – 450	4 – 8	Pd
H_2 , N_2, Ar, He	O_2	0.1	20 – 120	5 – 8	Pd
CO_2	H_2 ,HC	0.02–20	230 – 350	5 – 8	Pd, Pt, Pd/Pt
CO_2	CH_4	20	350 – 450	5 – 8	Pd, Pt, Pd/Pt

Table T3.2.1-1 shows representative examples according to information provided by the firm W.C. Heraeus GmbH in Germany. The proportion of the concentrations at the entrance and the exit is about $C_{v,output}$ = 0.001 to 0.01 $C_{v,input}$, in the most unfavourable cases the factor is only 0.1.

Example E3.2.1-1: Purification of crude CO_2 from natural sources and synthetic production using catalysts according to documents of the firm W.C. Heraeus GmbH.

Table T3.2.1-2: T*ypical impurities of raw CO_2 in ppm.*

Impurities	**Natural CO_2**	**Synthetic –CO_2**
H_2	50	
CH_4	17,000	10
C_2H_6	1,000	6
C_2H_4		7,600
C_3H_8	500	
C_4	100	
$C_5 – C_8$	500	
Benzene	500	

Methane is almost always the main problem with these purification processes because its tetrahedron structure is very stable. The ignition temperature of CH_4 in air is thus high at 595°C in contrast to to e.g. n-butane at 365°C. The ignition temperature for the catalytic transfer of methane is given at about 350°C. Here one must take into consideration the fact that at this temperature the transfirmation $CH_4 \rightarrow CO_2$ is relatively small. Transformation of around 95% can only be expected at temperatures >550°C. However, for most substances this temperature represents a technical limit. To solve this problem it is recommended to use a combination of platinum and palladium catalyst with a linear velocity of about $0.5\ m \cdot s^{-1}$.

One must still consider the case where the impurity bonds with the (unreal) catalyst. This has the advantage that it is not necessary to add the co-reactant. Typical examples are catalysts which contain Ni. In a reduced form, i.e. as finely distributed Ni, O_2 bonds to give NiO. A suitable regeneration with e.g. H_2 is necessary after the oxidation. The reverse applies when H_2 traces have to be removed by a NiO catalyst. Here a large transformation of material is not preferred but to remove the smallest possible amounts of trace impurities.

Sulphur and chlorine compounds are damaging to catalysts with Pd, Pt or Ni, they lead to irreversible changes and reduce the durability. They are referred to as catalyst poisons.

3.2.2 Electrolyses

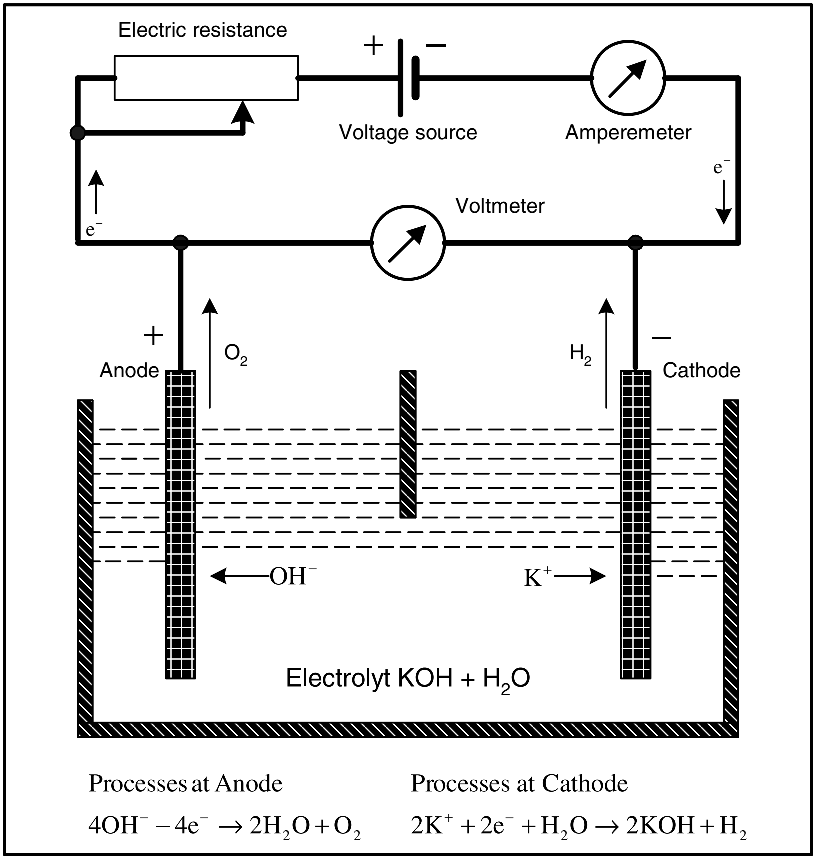
Shortly after the discovery of Volta's column (1776) Ritter's (1800) described electrolysis. Then Davy followed in 1807 with the first electrolytic separation to obtain potassium and sodium, which influenced Faraday greatly. In 1833 Faraday formulated the laws which bear his name. The path to the enormous technical significance occurred *via* the Al_2O_3 melting flow electrolysis by Heroult in 1889 and the chlorine-potassium electrolysis by Kellner and Kastner in 1892. Similarly, another milestone of this development was the production of O_2 and H_2. For a more detailed study of this matter it is recommended to refer to the work by (Drossbach 1952) as well as the work by (Bard et Faulkner 1999).

Liquids can conduct electric current when ions are present as carriers. With electrolysis two electrodes, the cathode and the anode, are immersed in the electrolytic solution. A source of voltage between the electrodes causes electricity to flow through the liquid. The cathode has a reducing and the anode an oxidising effect. At the phase boundaries between electrode and electrolyte different processes which depend on the type of electrode, the composition of the electrolytes and the voltage used take place. One differentiates between four cases.

- The material of the electrode is itself involved in the reaction.
- The material of the electrode and its oxide or the insoluble salts on the electrode are involved in the reaction.
- A gas which surrounds the electrode is involved.
- The electrode is inert and is only used to add or divert the electrons, the reduced and oxidised reactants of the redox pair are dissolved homogeneously. A typical example for this is the electrolysis of water which we will now look at in more detail.

Due to its low dissociation water alone is not suitable for electrolysis. On the contrary low electrical conductivity is a measure of the quality of pure water. Thus the water is mixed with an acid or an alkali which strongly dissociate. Common materials are sulphuric acid, sodium hydroxide solution or potassium hydroxide solution.

The principle can be seen in Illustration P3.2.2-1 on the this page. The dissociated components K^+ and OH^- of the potassium hydroxide solution move in opposite directions to the electrodes and take on or give off electrons which flow back over the electric circuit. Thus the whole electric circuit is completed *via* the electrolyte and the conductor. H_2 and O_2 are produced at the electrodes which leave the electrolysis cells.



Processes at Anode

$4OH^- - 4e^- \rightarrow 2H_2O + O_2$

Processes at Cathode

$2K^+ + 2e^- + H_2O \rightarrow 2KOH + H_2$

Illustration P3.2.2-1: Representation of alkali-water electrolysis.

The following data are well-known from the large-scale production of H_2: concentration of KOH : 25 – 30%, temperature 70 – 90 ^{0}C, energy use 4.1 – 4.9 KWh per m^3 H_2, cell voltage 1.86 – 2.04 V.

From the purity point of view it is essential to note that the products of the electrolysis are saturated with the electrolyte solution and therefore a subsequent purifying process is indispensable. Today most of the O_2 is obtained from the separation of air and most of the H_2 from natural gas by steam reforming because these processes are far less expensive. The electrolysis of water could however be a technology for the future. Prerequisites for this are cheaper solar energy and vehicles powered by H_2.

The relation between the electric current I, time t and the amount of material used (mass M) is given by Faraday's laws. The first says that the amount of material converted is proportional to the amount of electricity used. The second refers to the conversion of different substances using the same amount of electricity. The amounts converted relate to the equivalent chemical weights, i.e. like the quotients of the atomic or molecular mass and the chemical valence. Both laws can be summarised in one form:

$$M = \frac{M_{\mathrm{Mol}}}{w \cdot k_{\mathrm{Faraday}}} \int_t I \cdot dt \qquad (3.2.2\text{-}1)$$

with Faraday's constant $k_{\mathrm{Faraday}} = 96{,}487\ A \cdot s \cdot mol^{-1}$, w the chemical valence and I the electrical current which is integrated over time t and thus gives the amount of electricity (measured in Ampere sec = $A \cdot s$).

Example E3.2.2-1: Laboratory production of germanium hydride GeH_4.

According to an article in a magazine by (Devyatykh et al. 1988) *an alkaline solution of germanium dioxide is used as an electrolyte. The processes at the cathode are provided by the reaction equation:*

$$GeO_3^{-2} + 7\,H_2O + 8e^- \rightarrow GeH_4 + 10\,OH^-$$

At the nickel or tin cathode there was a mixture of 1.4 to 3.75% GeH_4 in H_2, at the anode O_2. The yield was about 0.6 ml GeH_4 per 1 cm^2 cathode area. The most favourable temperature of the cell was 105°C and the electrical current varied between 0.5 und 5 $A \cdot cm^{-2}$.

Syntheses of AsH_3 and PH_3 using electrolysis are also known from Devyatykh and his colleagues in the former USSR. In the USA and Western Europe syntheses using lithium aluminium hydroxide $LiAlH_4$ or lithium hydride LiH have been developed and used at least on a small-scale.

3.2.3 Syntheses

A typical synthesis for the exclusive production of an industrial gas is the well-known acetylene generator in which calcium carbide and water are brought together. The process is technically mature, but in the meantime acetylene has gotten a competitor from the petrochemical industry.

Of the more than 100 liquefied and compressed gases, the data sheets of which can be found in chapter 9, most have been produced by special syntheses or separations from mixtures in the chemical industry. Standard literature here is (Winnacker u. Küchler 2003-05) and (Kirk-Othmer 2001). The development of the semiconductor industry has caused a need for exclusive gases which had up to then only been synthesised in laboratories for scientific use.

Example E3.2.3-1: Manufacture of monosilane (silane).
In the 80s it was necessary to develop a suitable process and plant to obtain 100 t per year (Hiller 1987) *and* (Klockner et Eschweg 1988*).*
From a number of different processes the following have achieved different technical maturity.

- *Acidolysis of silicides in liquid ammonia.*

$$Mg_2Si_4 + 4\,NH_4Cl \rightarrow SiH_4 + 2\,MgCl_2 + 4\,NH_3 \qquad (3.2.3\text{-}1)$$

- *Dismutation of chlorsilanes*

$$4\,SiHCl_3 \rightarrow 3\,SiCl_4 + SiH_4 \qquad (3.2.3\text{-}2)$$

- *Reduction of silicon tetrachloride with metal-hydrogen-compounds in organic solutions*

$$SiCl_4 + 4\,AlR_2H \rightarrow SiH_4 + 4\,AlR_2Cl \qquad (3.2.3\text{-}3)$$

- *Reduction of silicon tetrachloride with lithium hydride in a salt solution.*

$$SiCl_4 + 4\,LiH \rightarrow SiH_4 + 4\,LiCl \qquad (3.2.3\text{-}4)$$

Each of these processes has its own specific advantages. These are independent of the raw material basis of the producer, emphasising the purity of the initial components, the utilisation or refurbishing of the by-products and the amount to be produced.

The synthesis of silane is however always only the first step and has to be followed by a series of purification processes. In the case of synthesis using LiH the firms Degussa AG and Messer Griesheim GmbH from Germany have given the following information for their plant: condensation → adsorption → cryogenic rectification → filtration. The list of impurities which have to be taken in consideration is correspondingly long.

Table T3.2.3-1: Impurities in silane according to (Klockner et Eschweg 1988).

Specification of substance	**Single gases**
Air gases	N_2, O_2, H_2, Ar, CO, CO_2, H_2O
Hydrocarbons	CH_4, C_2H_6, ether
Halogenated compounds	$SiH_XCl_{4\text{-}Y}$, HCl
Siloxanes	$H_3Si\text{-}O\text{-}SiH_3$
Higher silanes	Si_2H_6
Dopant gases	B_2H_6, PH_3, AsH_3
Dust	SiO_2, metal oxides

Example E3.2.3-1: Manufacture of arsenic hydride (arsine).

In 1981 the author was given the task of developing a process to produce AsH_3*,* PH_3 *and* SiH_4 *in electronic quality without however being able to use the normal process as in the above-mentioned example E3.2.3-1. The reason for this was the* *restrictions in obtaining LiH which is well known to play an important role in the production of nuclear weapons. Here is a short description of the patented process to produce highly pure arsine* (Schön et al. 1984).

350 g of zinc arsenide in small pieces in powder form are put into a reactor. The whole apparatus is evacuated several times and filled with protective gas. Then 400 ml of degassed bi-distilled water from a drop funnel is added to the zinc arsenide and 300 ml of hot degassed 20% sodium hydroxide solution is added to the wash-bottles. The pulp of the zinc arsenide is heated to approximately 80°C.

Then a moderate stream of HCl-gas is introduced via a check valve.

Within a short time the arsine begins to develop and is led through the wash bottle with the sodium hydroxide and liquefied at –78°C. After the hydrolysis is finished the supply of HCl is interrupted. The liquid arsine slowly evaporates and the gas is dried over molecular sieve 4.4 and condenses in a cold trap. After heating and fractionated condensation one obtains 131 g AsH_3*, which corresponds to 83%, considering the stoichiometric content of As in* Zn_2As_3 *.*

The arsine obtained was tested by producing LED´s and corresponded to the comparison product received from the firm Matheson/USA. The purity of the Zn_2As_3 *and the gaseous HCl were decisive for the high quality. Using liquid hydrochloric acid which had been additionally purified did not lead to success.*

As a result of bureaucratic decisions in the then DDR the most promising path towards a technical apparatus with an annual capacity of about 1 t was not taken. Until 1989 this amount would have been enough to cover the need of the microelectronic industry in the Eastern Block completely.

3.2.4 Gas Washing

Gas washing is based on the principle of absorption. In chemical technical terms this means bonding gases and evaporating them into liquids. A separation of the gas mixture is obtained when one or more of the components are selectively bonded. In gaseous form these are referred to as absorptives, in bonded form as absorbats. The washing liquid is often referred to as the absorbent.

One differentiates between absortives and absorbents according to the type of bonding.

Physical gas washing: the gases are dissolved in liquids depending on partial pressure. The descriptions in sections 2.2.3 and Eqs (2.2.3-8 and -9) apply. Characteristic is the low bonding energy and thus the possibility of desorption. For example in the chemical industry CO_2 is introduced into the washing liquid and in a second step removed again through heating (stripping) and other processes. For the fine purification of gases this method has virtually no importance.

Chemical gas washing: gas and liquid form a chemical bond. The best use of this procedure is to treat residual and waste gases. This also includes removing dust and aerosols.

There are very different methods of establishing the contact between gas and liquid. Accordingly one finds different types of scrubbers.

With spray absorbers the washing liquid is injected into the gas flow, a typical example is the Venturi scrubber. With film absorbers a film of liquid is created which the gas flow passes. Pot stills function by blowing the gas mixture from below into the liquid. For details and usage of these scrubbers please refer to (Kohl et Riesenfeld 1985) and (Sattler 2001).

Packed columns are especially significant for purifying gases. There is a close similarity to distillation and rectification.

Calculation of the cross section area A of a packed column is carried out according to Eq. (3.1.2-1) from the section "Rectification". As the columns work close to atmospheric pressure the Eq. can be simplified as

$$A = \frac{d^2 \cdot \pi}{4} = \frac{Q_V}{v_{lin}} \tag{3.2.4-1}$$

Mostly values between 0.5 and 2.0 m $\cdot$ s^{-1} are used for v_{lin} depending on the type of column packings, the density of the washing liquid and the one of the gas mixture which is to be purified.

Example E3.2.4-1: calculating the diameter of a column for $Q_V = 20\ m^3 \cdot h^{-1}$ *and* $v_{lin} = 1\ m \cdot s^{-1}$ *(*$=3600\ m \cdot h^{-1}$ *).*

After transposition of Eq. (3.2.4-1) to calculate the diameter d:

$$d = \sqrt{\frac{4 \cdot Q_V}{v_{lin} \cdot \pi}} = \sqrt{\frac{4 \cdot 20}{3600\pi}} = 0{,}0841[m] = 8{,}41[cm]$$

The calculation of the height of the column is more dependent on empirical data than that of the diameter. Please refer to the basic representations and mathematical treatment in (Kohl u. Riesenfeld 1985), (Sattler 2001) and (Ullmann 1990-92), Vol. 2. The empirical data for the column packing are provided by the manufacturers who usually also offer software for the above-mentioned calculation.

It must also be taken into consideration that absorption is an exothermic process; if necessary the amounts of heat are to be compensated by a cooling coil built into the bottom.

Example E3.2.4-2: Two-stage scrubber with packed columns. See also Illustration P3.2.4-1 on the following page.

Explanation: both columns are operated consecutively. The gas enters them from the bottom, with the appropriate washing liquids above the containers. These are added to the spray nozzles via the two centrifugal pumps and trickle down the packed columns, leading to an intensive interaction with the rising gas. The demister is used to keep back drops of liquid which the gas has taken on.

When the washing liquid is exhausted which can be ascertained by the pH-level it must be used or removed appropriately and replaced by with fresh one.

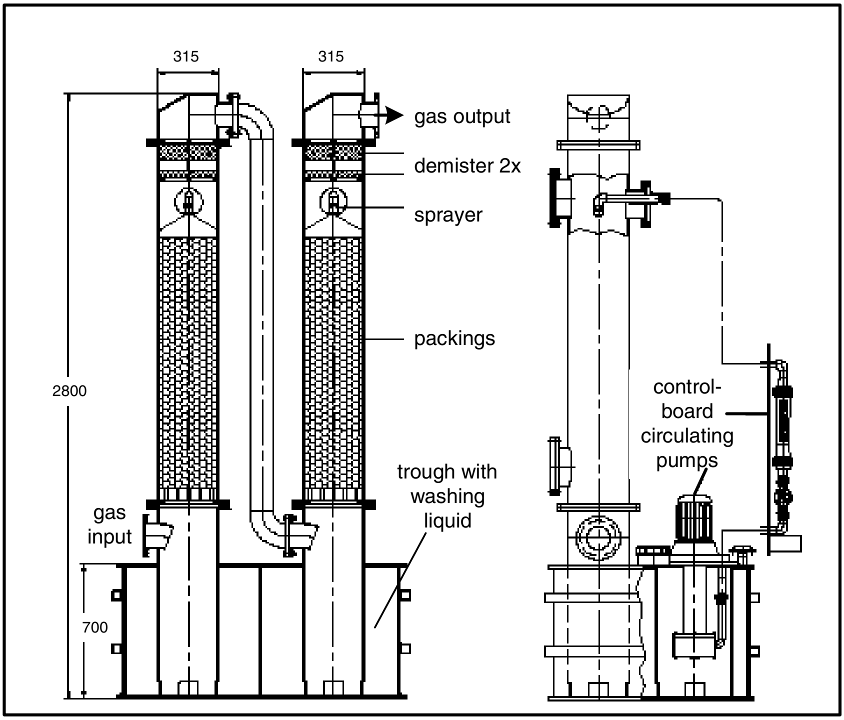


Illustration P3.2.4-1: Cross section and side view of a two-stage scrubber (factory description by the firm Jäger KG Kunststoffwerk in Braunschweig/Germany, labelling addeded).

Example E3.2.4-3: Efficiency of the laboratory scrubbers of the firm Jäger KG Kunststoffwerk with column diameters of 10 – 50 cm and heights of the packed column bed to 125 cm. If there are two columns the packed column bed is doubled.

Table T3.2.4-1: Examples of use. Maximum concentration of the absorptive ≤ 10%.

Absorptive	Absorbent	Performance in $[m^3 \cdot h^{-1}]$	Deposition in [%]	Number of columns
HCl	H_2O	10 – 500	98	1
HCl	NaOH	10 – 500	99.5	1
H_2S	NaOH	10 – 500	97	1
NH_3	H_2SO_4	10 – 500	99.8	1
HF	KOH	10 – 500	99.7	1
Cl_2	$NaOH+H_2O_2$	10 – 500	98.5	1
NO_2	$NaOH+Na_2S$	500	85	1
$NO+NO_2$	$NaClO_2+NaOH+Na_2S$	500	75	2
SO_2	NaOH	10 – 500	98.5	1
HBr	NaOH	10 – 500	98.5	1

Whereas mainly rigid packing is used with rectification columns with scrubbers the packing can be made of metal, usually stainless steel, ceramic or plastic.

(Makowiak 1990) determined the loss of pressure in ballast and packing theoretically and also compared technical data for many uses. Empirical ones are very valuable in individual cases. For example, the firm VFF offers a software solution.

Example E3.2.4-1: Ceramic packing and demisters.

The demister is used to distribute the liquid at the top end of the column and is similar in construction to the packing. The materials are metals or plastics.

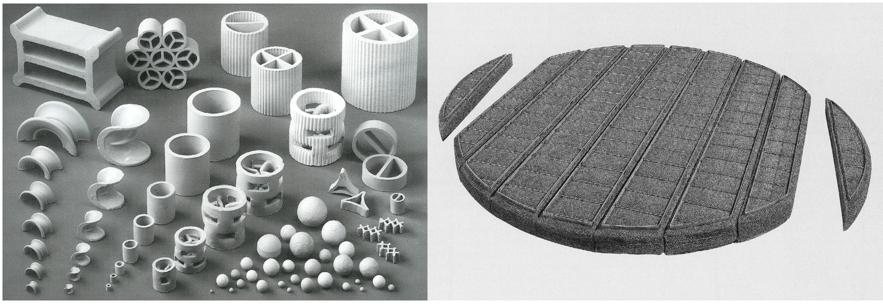


Illustration P3.2.4-2: *left: selection of ceramic packing, right: multi-part demister made of nickel. Factory photos from the firm VFF.*

3.3 Getter and Gas Purifier

The word getter is derived from “get”. In general it means the bonding of gases.

After the First World War the emergence of radio tubes led to a search for ways of producing and maintaining the necessary vacuum in them. This is done mainly by using the elements barium and zirconium. The alkali metal barium is mostly used in an alloy with aluminium. By evaporation in the vacuum a fine distribution is achieved which enables the bonding of residual gases or penetrating air gases. As zirconium has a very high melting point (1852°C) evaporation is difficult. Therefore one uses an alloy of zirconium and aluminium. Activation begins at about 900°C when the protective layers of oxides and nitrides formed in air form on the inside of the getter and below 400°C the released surfaces become receptive. Even today classical television tubes or different types of lamps are provided with getters. The physico-chemical bases are described by (Lafferty 1998) and (Juhr 1987). The processes of bonding are a combination of physisorption and chemisorption combined with catalytic effects. That is why the treatment of getters is dedicated to its own chapter.

The development has long since left the exclusive application in vacuum and tends in two directions:

- The fine purification of gases.
- The bonding of reactive components in waste gas streams.

For both types the word gas purifier is often used. In addition one must differentiate according to the size of the volume flow Q_V:

- Purifiers for the production of industrial gases and for the gas supply for large uses.
- Purification at the point of use.

Table T3.3-1: Area and house gas purification.

Carrier gas	Q_V in $[m^3 . h^{-1}]$	Removable impurities	Method
Rare gases	10 – 200	O_2 , H_2O , CO, CO_2 , CH_4 , H_2 , N_2	Getter Patent SAES
O_2	15 – 200	H_2O , CO, CO_2 , CH_4 , H_2	Catalyst + Adsorber
H_2	20 – 100	O_2 , H_2O , CO, CO_2	Getter +Adsorber
N_2	100 – 3000	O_2 , H_2O , CO, CO_2 , CH_4 , H_2	Catalyst + Adsorber

Table T3.3-1 was developed according to information provided by the firm SAES Getters in Cologne/Germany. The $C_{v,output}$ differs for all named impurities < 1 ppb, $C_{v,input}$ is different: < 2000 ppb for O_2, H_2O and N_2, < 500 ppb for H_2, < 200 ppb for CO, CO_2 and CH_4. This means that the main gas used must already be very pure.

Gas purification plants have a very long service life, at least one year. However, if adsorbers are present it is necessary to regenerate cyclically. Catalysts and getters usually work at a temperature of 500°C or above. The maximum pressure is often only 1 bar (g). For usage at high pressure special pressure containers are necessary, see section 3.6.1.

Small gas purifiers are often used directly by the consumer at the point of use, see chapter 8.4. Typical areas of use are analytic equipment, such as gas chromatographs which have special requirements on the carrier gases He, Ar, N_2 and H_2 for trace detection, or for special applications in the micro-electronic industry. The most important parameters for small gas purifiers are:

- Flow rate up to $50\,l \cdot min^{-1}$
- $V_{v,input}$ of the impurities O_2 , N_2 , H_2 , H_2O, CO, CO_2 , THC (total hydrocarbons) smaller 1 ppm
- $V_{v,output}$ smaller than 1 ppb sometimes less than 100 ppt
- Removal of particles up to 0.003 µm
- Service life of 1 year or longer
- Electro-polished equipment, VCR-connections
- Maximum pressure of about 7 bar (g).

The developments in the semiconductor industry have led to the use of many, previously not well-known, chemical substances which however have to be removed from the waste gas streams due to their toxicity. Table T3.3-2 has been created according to documents provided by the firm CS CLEAN SYSTEMS in Ismaning/Germany and gives an only short overview.

Table T3.3-2: Removal of impurities from waste gases of the semiconductor industry.

Substance	**R1**	**R2**	**R3**	**R4**	**R5**	**$C_{v,output}$ in [ppm]**
$AsCl_3$	X					0.05
AsF_5	X					0.05
$AsH_2(C_4H_9)$			X			0.05
AsH_3			X			0.05
B_2H_6	X					0.1
BBr_3				X		5
BCl_3				X		1
BF_3				X		1
BH_2NH_2	X					0.1
Br_2				X		0.1
Cl_2				X		1
ClF_3			X			0.1
CO					X	30
$COCl_2$	X					0.1
COF_2	X					2
$Cr(CO)_6$	X					30
F_2				X		1
$GeCl_4$				X		5
GeH_4					X	0.2
H_2S			X			10
H_2Se			X			0.05
HBr				X		5
HCL	X					5
HF	X					3
$In(C_2H_5)_3$			X			0.1
NH_3		X				25
$Ni(CO)_4$	X					0.05
PBr_3				X		5
PCl_3				X		5
PCl_5				X		5
$PH_2(C_4H_9)$			X			0.3
PH_3			X			0.3

Table T3.3-2: (*continued*)

Substance	R1	R2	R3	R4	R5	Cv,output in [ppm]
$POCl_3$	X					5
SbH_3			X			0.1
Si_2Cl_6			X			5
Si_2H_6	X					5
$SiCl_4$				X		5
SiF_4				X		3
$SiH_2(CH_3)_2$			X			5
SiH_2Cl_2		X				5
SiH_3CH_3			X			5
SiH_4	X					5
$SiHCl_3$				X		5
SO_2				X		2
$Te(C_2H_5)_2$			X			0.1
TeF_6	X					3
WF_6	X					3

The purifier types R1 to R5 listed in the table are not real getters. They use chemical reactions which have already been described as chemisorption in section 3.1.3. Of special interest is the fact that the reaction products are bonded as soon as they come into existence. One can talk about "chemistry in a small cavity".

Regarding the concentration of the discharge of the purifier $C_{v,output}$ it is enough to obtain the appropriate TLV (Threshold Limit Value). The cleaned waste gas is mostly mixed with waste air gas and thus extremely diluted before it reaches the atmosphere.

Example E3.3-1: fine purification of valuable inert gases.

In 1998 CS CLEAN SYSTEMS AG built a purifier to remove SF_6 from Xe with the following parameters[1]*:*

- *Source gas Xe, purity about 98%, Kr + O_2 + N_2 about 2%. Traces of CH_4 and N_2O, SF_6 max. 200 ppm*
- *$Q_V = 1$ to $1.5\ m^3 \cdot h^{-1}$, $p_{max} = 3$ bar (g)*
- *Temperature of the purifier 500 – 600°C*
- *Exit concentration of SF_6: 0.1 to 1 ppm, dependent on the size of the source concentration.*

---

[1] Used by the author in the production of inert gases for Linde AG.

3.4 Filter

Filtration of air has a long history. According to (Davis 1973) the first description was given by the Roman author Plinius the Elder in his "naturalis historia" in about 50 A.D. Up to the end of the 19th Century filtration was mainly used to hold back dust and aerosols and small drops of liquid in breath.

Nowadays filters are used to clean gases and liquids. Their use stretches from medical dialysis to fine cleaning of gases and liquid chemicals for the semiconductor industry. (Orr 1977) provides an overview.

For the filtration of gases one differentiates according to the size of the particles which need to remain behind and the relevant pore diameter, see Table T3.4-1.

At the end of the 80s the semiconductor industry reached an important point in its development with the mass production of the 1-megabit memory chip. In connection with this was the necessary particle freedom of up to 0.1 μm. In contrast to this in 2003 there was a limit of approx. 3nm.

Table T3.4-1: Allocation of filters.

Designation	**Pore size in [μm]**	**Size comparison**
Conventional filter	1 – 100	Human hair about 50 μm
Microporous filter	$10^{-2} - 1$	Virus about 0,1 μm
Ultra filter	$10^{-4} - 10^{-2}$	Glucose molecule about $5 \cdot 10^{-3}$ μm

How do particles and aerosols behave in gases at normal pressure and room temperature? For a size of 0.5 to 10 μm these particles and droplets, according to empirical observations, continue to hover at room temperature because of currents and turbulence. As soon as this state has been reached gravity causes a slow sedimentation. Below about 0.5 μm Brown's Molecular Movement of 1826 is decisive (at temperatures around 20°C). This can be understood as a trembling movement of the suspended particles which can be observed in liquids under the microscope. For a long time this mechanism was a mystery. Only in 1905 Einstein found a theoretical proof.

According to the kinetic theory of gases the molecules move at a mean speed $v_{m,G}$ according to Eq. (2.1.2-2) from which is obtained the mean energy E_m

$$E_m = \frac{M_{G,molecule}}{2} v_{m,G}^2 = \frac{3 \cdot R_{Mol} \cdot T \cdot M_{G,molecule}}{2 \cdot M_{G,Mol}} = \frac{3 \cdot R_{Mol} \cdot T}{2 \cdot k_{Avogadro}} \tag{3.4-1}$$

$$M_{Mol,G} = k_{Avogadro} \cdot M_{G,molecule} \tag{3.4-2}$$

with $k_{Avogadro} = 6.022 \cdot 10^{23}\ mol^{-1}$ as the already introduced Avogadro or Loschmidt's number and $M_{G,molecule}$ the mass of the molecule or the atom (in the case of the inert gases). They release the energy when they collide with foreign particles which then have the same E_m as the molecules. Their movement keeps the particles hovering and stops them sedimenting. One special feature of Eq. 3.4-1 must be pointed out. Whereas $v_{m,G}$ depends on the $M_{G,molecule}$ and is thus specific to the type of gas, this does not apply to the E_m. Furthermore the E_m does not depend on the pressure. It is very difficult to estimate the extent to which the real behaviour of the gases leads to differences.

Regarding their consistency filters are subdivided into fibre filters and membrane filters. The material for the former extends from cloth to metals, such as nickel and stainless steel. For membrane filters polymer plastics are used. The following forces keep the particles in the filters:

- Diffusing causes the particle to enter a channel where it is kept by Brown's Movement.
- The particle fits exactly into a pore, referred to as the sieve effect.
- The particle is sedimented by gravity.
- Electrostatic forces bond the particle.
- The particle is fixed by Van-der-Waal's forces

Which forces enable the filter effect in individual cases depends a lot on the material of the particles. Often larger particles are formed by abrasion, e.g. in pumps and compressors. Therefore pure metals and alloys come to the fore. Particle formation can however also take place by corrosion in which case complicated chemical compounds can be expected.

The areas of use for the filtration of the purest gases can be described in two extremes:

- The user usually needs smaller quantities at lower pressures, filtration is a typical operation at the point of use. The demands are high and at the moment are 3 nm (Example E3.4-1).
- The manufacturer needs to clean large quantities at high pressures, the requirements are 0.1 μm or somewhat smaller (Example E3.4-2).

Example E3.4-1: Purifying of process gases, including corrosive ones, for the semiconductor industry with a maximum flow rate 50 $l \cdot min^{-1}$, with illustration P3.4-1.

In its 4400 series the firm Pall New York offers filters with the following parameters:

- Construction: electro-polished housing made of stainless steel 316l with a fibre filter made of nickel.
- Retaining the particles: number 109 at a size of ≥ 0.003 μm.
- Maximum pressures: 207 bar at 38°C, 116 bar at 450°C.
- Maximum pressure difference at the filter: 10 bar at 20°C, 5 bar at 450°C.
- Leak rate: $\leq 10^{-9}$ $ml \cdot s^{-1}$ (measured according to the overpressure process).
- Connections: double-sided ¼“ VCR.
- Resulting purity of the process gases: H_2O, O_2 and THC < 10 ppb each.

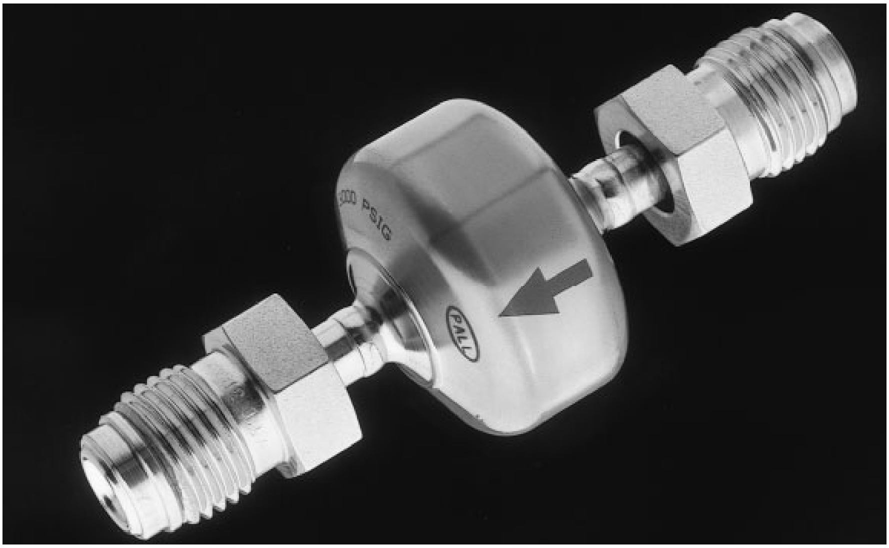


Illustration P3.4-1: Ultramet L 4400 Series Filter Assembly of firm Pall New York.

Example E3.4-2: Filter for high pressure and flow rates of 100 to 500 $m^3 \cdot h^{-1}$.

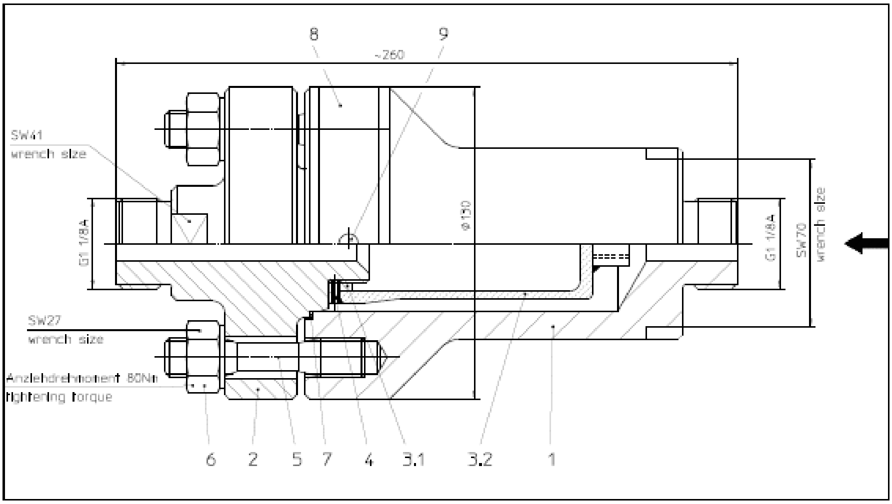


Illustration P3.4-2: Filter DN15, PN400 of firm Hofer GmbH in Mühlheim an der Ruhr in Germany, material stainless steel 1.4471, design temperature 100 ^{0}C.

Description: 1 housing, 2 cover, 3.1+.2 filter element Firm Pall 0.015 mm, 4 threaded pin M3x8, 5 stud bolt M16x90, 6 hexagon nut M16, 7 sealing ring 58x62x2, 8 name plate filter, 9 notched nail 4x8

4 Filling Manifolds

This chapter introduces the necessary basics for constructing stations to fill compressed gas cylinders with as well as appropriate technical elements. These are also required for the stations to manufacture gas mixtures which will be dealt with in chapter 5.

Metallic systems containing lines, valves, and other fittings are often described as "manifolds". In the USA the term "manifold" is predominantly used to describe filling stations for gas cylinders. Nevertheless, the same concept is also used worldwide for gas cylinder supply systems.

4.1 Filling Manifolds for Pure Gases

The difference between industrial and higher purity quality is not precisely defined with respect to compressed and liquefied gases. This difference in purity is expressed according to the quality 5.0 of the grade-point notation.

Filling stations for compressed and liquefied gases are generally well-known. The chemical sector offers a range of good versions including control engineering.

With pure gases the only special features concern special equipment and sophisticated methods to finding leaks which are necessary to achieve the purity. Moreover a continuous or at least a very frequent analytical supervision is to be accomplished.

The concept of the leak rate was introduced in chapter 2.5. In example E2.5-2 it was estimated that it is necessary to adhere to an overall leak rate of around 10^{-4} $cm^3 \cdot s^{-1}$ and individual leak rate of 10^{-5} to 10^{-6} $cm^3 \cdot s^{-1}$ in order to achieve a purity of 6.0. This means that it is indispensable to use leak check methods according to the principle of mass spectrometry. An overview of the different methods of searching for leaks is given below.

- Pressure decrease method: the station is filled with the pressure p_1. After a long interval, e.g. 24 hours, the pressure p_2 is measured. It is important that the temperatures at the time of the measurements are as equal as possible. Otherwise it is necessary to use a correction calculation, see Example E4.1-1. This determines the overall leakage.
- Immersion method: the sample under pressure is completely immersed in a water bath. The rising bubbles are observed. For an observation time of 10 seconds and a bubble diameter of 5 mm the proof limit is $6.5 \cdot 10^{-3}$ $cm^3 \cdot s^{-1}$. This procedure can only be regarded as qualitative. It is only possible to assign to a certain extent the location of the leak.

H. Schön, *Handbook of Purified Gases*,
DOI: 10.1007/978-3-540-32599-4_4

- Soap bubble method: again the pressurised gas cylinder is filled. Brushing or spraying with a soap solution achieves a proof limit of about $1 \cdot 10^{-3}\ \mathrm{cm}^3 \cdot \mathrm{s}^{-1}$. Individual leaks can be located well.
- Pressure increase method: the station is in an evacuated state and a sensitive vacuum meter is available. The pressure p_1 is determined and then the station is separated from the vacuum pump. After a time t the increase in pressure is determined as p_2. This method is very inaccurate because water can desorb from the walls. This implies a higher leak rate. On the other hand the method can be used to ascertain the presence of desorbable gases, predominantly H_2O and CO_2.
- Helium-sniffing test: the sample is flooded with He as close to operating pressure as possible. The mass spectrometer has a sniffing probe which identifies escaping He. This test is the one most often used and has a proof limit of several $10^{-8}\ \mathrm{cm}^3 \cdot \mathrm{s}^{-1}$ and identifies the individual leak.
- Helium-casing test: the sample is placed in a plastic casing into which the sniffing probe is inserted. This provides the integral or overall leak rate to be stated up to a limit of several $10^{-10}\ \mathrm{cm}^3 \cdot \mathrm{s}^{-1}$.
- Helium vacuum test: the sample can be evacuated to pressures less than 10^{-4} mbar and the leak check mass spectrometer is directly connected to the system. Helium is sprayed or flooded from outside. This method allows the leak-checking up to $10^{-12}\ \mathrm{cm}^3 \cdot \mathrm{s}^{-1}$ as well as the location of the individual leak.

Example E4.1-1: In a high-pressure station the pressure $p_1 = 245.0$ bar at $T_1 = 22°C$ is measured. After $t = 72$ h a second measurement of $p_2 = 241.5$ bar and $T_2 = 28.5°C$ takes place. The volume of the station is $V_{geom} = 1.2$ Liter.

Using Eq. (2.1-5) the pressure p_2 is corrected to the temperature T_1.

$$p_{2,T1} = \frac{T_1}{T_2} p_{2,T2} = \frac{295.15}{301.65} \cdot 241.5 = 236.3[\mathrm{bar}]$$

Without correction and using Eqs. (2.5-1 and -2) at $\Delta p=8.7$ bar one obtains $\Delta p = 3.5$ bar and $V_{geom} = 1200$ ml.

$$L_{p=245\mathrm{bar}} = \frac{\Delta p \cdot V_{geom}}{t} = \frac{8.7 \cdot 1200}{72 \cdot 60 \cdot 60} = 4.03 \cdot 10^{-2} \left[\mathrm{cm}^3 \cdot \mathrm{s}^{-1}\right]$$

The calculation can also be carried out in mbar and litres with the same result. Now one estimates the appropriate vacuum leak rate by dividing by the pressure p = 245 bar (g) :

$$L_{vac} = 1.64 \cdot 10^{-4} \left[\mathrm{mbar} \cdot \mathrm{l} \cdot \mathrm{s}^{-1}\right]$$

Example E4.1-4: Using the pressure increase method $p_1 = 2 \cdot 10^{-3}$ mbar and after t =15 min $p_2 = 1.2 \cdot 10^{-2}$ mbar are measured. $V_{geom} = 1.2$ l.

$$L_{vac} = \frac{\Delta p \cdot V_{geom}}{t} = \frac{10^{-2} \cdot 1.2}{15} = 8 \cdot 10^{-4} \left[\mathrm{mbar} \cdot \mathrm{l} \cdot \mathrm{s}^{-1}\right] \cong 8 \cdot 10^{-4} \left[\mathrm{cm}^3 \cdot \mathrm{s}^{-1}\right]$$

The Δp is $(12 - 2) \cdot 10^{-3} = 1 \cdot 10^{-2}$ mbar and Eq. (2.5-1) applies.

$$L_{vac} = \frac{\Delta p \cdot V_{geom}}{t} = \frac{10^{-2} \cdot 1.2}{15} = 8 \cdot 10^{-4} \left[\mathrm{mbar} \cdot \mathrm{l} \cdot \mathrm{s}^{-1}\right] \cong 8 \cdot 10^{-4} \left[\mathrm{cm}^3 \cdot \mathrm{s}^{-1}\right]$$

Stations which are used to fill portable compressed gas cylinders for commercial purposes are certified by a testing organisation, e.g. TÜV in Germany to be inspected. Nevertheless it is recommended to use the same technical criteria for stations used to fill cylinders for private consumption.

4.1.1 Compressed Pure Gases

Firstly, important pressure stages of the filling stations and the pressurised gas cylinders have to be introduced:

- p_{plant} = pressure of station: maximum station pressure which is secured by suitable installations, such as safety valve Si-V or bursting discs BS. Reference in the USA: MAWP (maximum allowable working pressure). EC: according to (97/23/EC 1997) PS (maximum allowable pressure).
- $p_{test,plant}$ = test pressure of plant
- p_{work} = working pressure of plant, reference in the USA: MOP (maximum operating pressure)
- $p_{service}$ = maximum filling pressure of cylinder (declaration of temperature is necessary, e.g. 0 or 15°C or 70°F)
- $p_{test,cyl}$ = test pressure of cylinder

Example E4.1.1-1: the pressure stages for N_2 in Europe (Germany) and the USA.

Table T4.1.1-1: Pressure stages on the basis of European standards (97/23/EC 1997) and USA standards (ASME B31.3 2006) and (49CFR 173 1999)

Pressure stage	**Germany**	**USA**
$p_{test,plant}$	= 1.43 x p_{plant} = 357.5 bar (g)	= 1.2 to 1.25 x p_{plant} = 3000 to 3750 psig
$p_{test,cyl}$	= 1.5 x $p_{service}$ = 300 bar (g)	= 5/3 x $p_{service}$ = 4000 psig
p_{plant} (example)	= 250 bar (g)	= 3000 psig = 206.7 bar (g)
$p_{working}$	< 0.95 x p_{plant} = 237.5 bar (g)	= 0.8 to 0.9 p_{plant} = 2440 to 2700 psig
$p_{service}$(example)	= 200 bar (g)	= 2400 psig = 165.4 bar (g)

With reference to the occurring pressures the filling of gases into compressed gas cylinders can be regarded as safe if the following relationship is adhered to

$$p_{service} < p_{plant} < p_{test,cyl} \qquad (4.1.1\text{-}1)$$

The principle of filling stations for compressed pure gases is explained in Illustration P4.1.1.-1. In each case a high pressure line is assumed which is equipped with a safety valve Si-V, adjusted to the maximum operational pressure of the manifold and with a manometer.

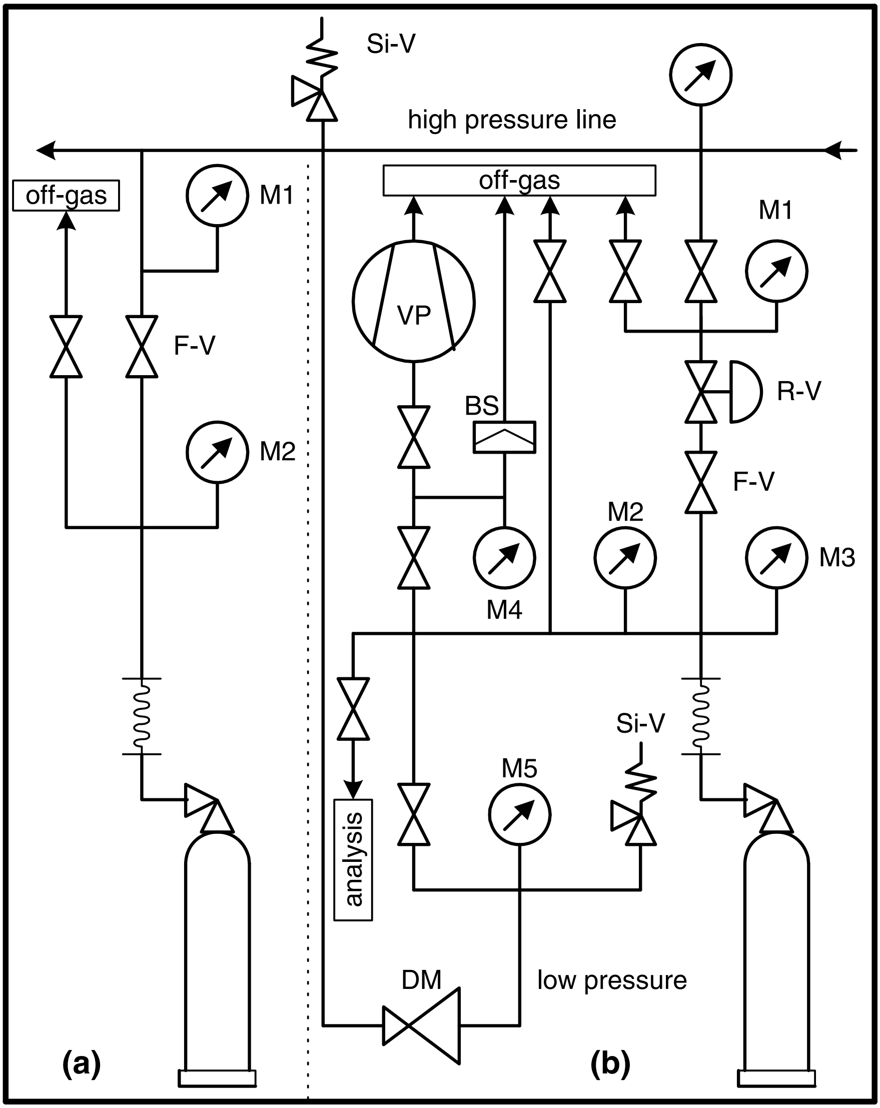


Illustration P4.1.1-1: Schematic representation of filling stations for compressed pure gases. (a) simple hand filling (b) station capable of automation with evacuation and low pressure purge.

In part (a) the gas cylinder (or several) is filled by hand. The operators are informed of the available pressure with manometer M1. As it is inevitable that the plant is open to the atmosphere when the gas cylinder is connected, it is recommended that several purges are carried out. To this effect, high-pressure gas is introduced with the cylinder valve closed and then discharged through the vent line (off-gas). The filling begins by opening the cylinder valve when the supply pressure is low. Then, the filling valve F-V is slowly opened. During the filling the gas cylinder heats up, thus it is not over until the adjusted pressure is higher than the operational one. The adjusted pressure is either ascertained experimentally or calculated using the temperature measured in the cylinder being filled.

Part (b) of the Illustration P4.1.1-1 shows the principle of a station which enables the filling to be prepared and carried out automatically. The evacuation of the station is accomplished with the vacuum pump VP and vacuum gauge M4. Thus, the pressure increase test mentioned above can be carried out. To this purpose the valve situated directly in front of VP is closed after a vacuum state has been reached and after time t the increase in pressure is measured. The bursting disc BS protects the VP from over pressurisation if operation is faulty.

Because of the presence of the VP purges the connection to the cylinder differs from the one used in (a). A low-pressure gas is provided from the high pressure (HP)-supply line *via* the pressure reducer DM. It is shown *via* M5. If the valve to the HP-part leaks the Si-V protects the station. Purging is carried out in the following stage:

- The connecting pipes are at atmospheric pressure and are evacuated to pressure p_1.
- Low-pressure gas is filled until p_2 is achieved. This pressure should be selected in a way that it is compatible with the VP. p_2=1.3bar abs. is suitable for the often used rotary-vane vacuum pump.
- Evacuating is repeated to p_1.

How large is the dilution achieved by the purge? With an impurity having partial pressure $p_{Part,1}$ at the beginning of the process, after $p_{Part,n}$, purges one obtains :

$$p_{Part,n} = p_{Part,1} \cdot \left(\frac{p_1}{p_2} \right)^n \qquad (4.1.1\text{-}2)$$

Example E3.5.1-1: in a filling station for N_2 *6.0 the connecting pipes have to be purged so often that the residual impurity of* O_2 *is less than 0.1 ppm (*$=10^{-7}$ *parts).*

The starting partial pressure for the O_2 *in the atmosphere is* $p_{Part,1} = 0.2$ *bar abs., the partial pressure to be obtained for the 200 bar filling is* $p_{Part,n} = 200 \cdot 10^{-7}$ *bar* $=2 \cdot 10^{-5}$ *mbar. We insert the exponential function into Eq. (4.1.1-2):*

$$p_{Part,n} = p_{Part,1} \cdot e^{n \cdot \ln(p_1/p_2)} \qquad (4.1.1\text{-}3)$$

This Eq. is solved using n:

$$n = \frac{\ln \frac{p_{\text{Part},n}}{p_{\text{Part},1}}}{\ln \frac{p_1}{p_2}} \tag{4.1.1-4}$$

For the low-pressure purge between 1 and 1300 mbar N_2 *6.0 one obtains n at*

$$n = \frac{\ln \frac{2 \cdot 10^{-5}}{0.2}}{\ln \frac{1}{1300}} = 1.28 \rightarrow 2$$

For pressures from 1 – 200 bar the n for the high-pressure purge is

$$n = \frac{\ln \frac{2 \cdot 10^{-5}}{0.2}}{\ln \frac{1}{200}} = 1.74 \rightarrow 2$$

The results do not differ significantly. Nevertheless the purge in the vacuum/low-pressure has distinct advantages. A prerequisite for an effective purge is the mixing of impurity and purging gas by diffusion. This however decreases as the pressure increases. If the geometry of the pipes to be purged is unfavourable ("dead legs") then the residual gases are concentrated in the ends. For a high-pressure purge to be successful, long waiting times must be utilized, in practice the theoretical number for n is doubled.

Furthermore, the calculation is idealized in sofar as the starting point is a zero concentration of O_2 in N_2 6.0. One must also take into consideration that the gas consumption for the high-pressure purge in our example is over 200 times higher than the low-pressure one.

With (b) after the described preparation of the HP-supply tube the filling into the gas cylinder is effected *via* the control valve R-V and the filling valve F-V. With automation the R-V is driven by the electric pressure transducer M3. One assumes a normal manometric filling. With a gravimetric filling the bottle stands on a set of scales and the gradient of the increase in mass is the monitored variable for the R-V.

The filling is switched off by closing the filling valve after the adjusted values for the pressure or the mass have been reached. For safety-technical reasons the filling valve plays a decisive role. When it is closed, the supply of high-pressure gas is stopped immediately. For this reason the F-V is usually controlled pneumatically. This enables the use of an emergency shut-off switch which also disables the filling process in an instant in case of danger.

4.1.2 Liquefied Gases

The Illustration P4.1.2-1 shows the filling of a gas barrel from a so-called mother cylinder. This is carried out from cylinder 1 with a dual-ported valve and a dip-tube. Cylinder 2 which is to be filled is on a scale as the filling of liquefied gases has to be effected according to mass. The amount to be filled is the result of the product of the filling factor f_{fill} in kg per liter with the cylinder volume.

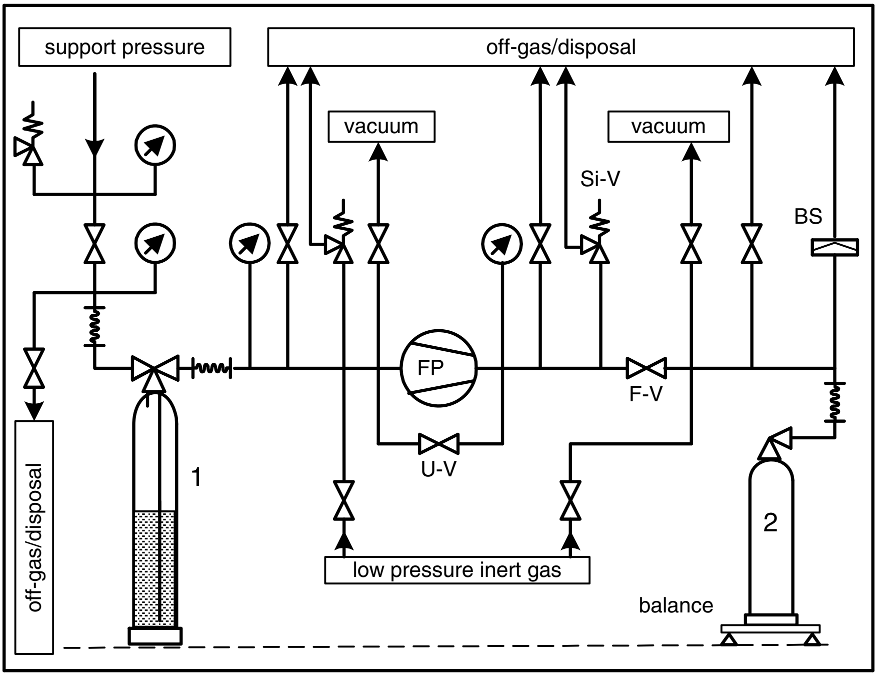


Illustration P4.1.2-1: Schematic representation of a filling station with a liquid pump.

The filling station between bottles 1 and 2 is divided into three sections: pigtail and equipment for cylinder 1 up to the liquid pump FP, the section between the FP and the filling valve F-V, the connecting part for cylinder 2. The common ground is all of them containing liquid which expands in the case of a faulty operation during the what heating, could lead to a high hydrostatic pressure. Therefore it is necessary to have automatic pressure relief like pressure relief valve Si-V or bursting discs BS in every section. The FP is located parallel to a bypass valve U-V. Each part of the station can be evacuated or filled with inert gas. This is necessary if toxic or corrosive gases are being filled.

For the mother cylinder 1 it is assumed that a support pressure is used. This is mostly He or N_2 and facilitates removal from the cylinder. Thus refilling into cylinder 2 can take place exclusively *via* the U-V, especially when bottle 2 has a very small volume. The filling valve F-V is controlled by scale and closes when the given mass for the filling has been reached. By closing the F-V the FP is also switched off.

4.2 Tips for the Construction of Stations

In different countries there is a large number of individual rules and regulations for the construction of stations for production, purification and filling of pressurised gases.

Manufacturers of such stations must acquaint themselves with this information. In the following some of these rules are reffered to. If a station is to be designed, it is advisable to put documents together. They have to contain all informations of the manufacturers, like testing certificates and records of use. Such a station is usually a one-off construction, mass production is rarely achieved. Nevertheless one is obliged to adhere to the relevant technical principles.

4.2.1 Pressure Vessels and Pressure Piping

The following descriptions mostly concern stationary pressure containers and pressure tubes as defined in the European standard (97/23/EC 1997), the gas cylinders are dealt with in chapter 6. The following terms are used.

- PS = maximum allowable pressure = p_{plant} in section 4.1.1. Containers with $p_{plant} \leq 0.5$ bar (g) are not included in this standard.
- V, here one uses V_{geom} in litres.
- Product of PS and V : $p_{plant} \times V_{geom}$
- Fluids = gases, liquids and vapours as pure phases and their mixtures.
- DN = nominal size in mm

(1) Group 1 comprises fluids defined as: explosive, extremely flammable, highly flammable, flammable (when the maximum allowable temperature is above flashpoint), very toxic, toxic.
(2) Group 2 comprises all other fluids not referred to in Group 1

(97/23/EC 1997) contains all the basic technical and organisational details such as classification, pressure layout, testing times, the operator's obligations and rules of behaviour.

Article 3 of the standard (97/23/EC 1997) contains limitations for pressurised containers and piping which are subject to the supervision of authenticated testing organisations:

- vessels for fluids in group 1 with $V_{geom} > 1$ l and a product $p_{plant} \times V_{geom} > 25$ bar · l, or with a $p_{plant} > 900$ bar
- vessels for fluids in group 2 with $V_{geom} > 1$ l and a product $p_{plant} \times V_{geom} > 50$ bar · l, or with a $p_{plant} > 1000$ bar
- piping for fluids in group 1 with a DN greater than 25

- piping for fluids in group 2 with a DN greater than 32 and a product of p_{plant} x DN > 1000 bar · mm

Example E4.2.1-1: In an analysis device there is a collection vessel for CO with a V_{geom} = 0.6 l, with a pressure of 6 bar (g). Is this vessel a pressurised container according to (97/23/EC 1997)?

Answer: no. CO is in group 2, but the product is p_{plant} x V_{geom} = 3.6 and therefore smaller than 25 bar · l. Thus this container is exclusively the responsibility of the operator but must be manufactured and used according to the technical principles of (97/23/EC 1997).

Different pressurised containers are sorted into different groups:

- Pressurised containers with frequent changes of pressures.
- Pressurised containers with built-in appliances for cooling and heating through liquids.
- Pressurised containers with built-in electrical appliances.
- Pressurised containers for work at extremely high or extremely low temperatures.
- Pressurised containers can also consist of piping systems, e.g. large heat exchangers.

Table T4.2.1-2: Frequently used stainless steels and important alloys (Key to steel 2004). EC name and number: (EN 10020 2000), USA name: ASTM (American Society for Testing and Materials) standards from ANSI (American National Standard Institution)

EC: name	EC: number	USA: name	Suitable for
X5CrNiTi 18-10	1.4301	SS-304	Food industry
G-X2CrNiN 18-9	1.4306	SS-304L	Food industry
X2CrNiN 18-10	1.4311	SS-304LN	Valves and fittings, cryogenic temperatures
X5CrNiMo 17-12-2	1.4401	SS-316	Chemical industry, breweries
X2CrNiMo 17-12-2	1.4404	SS-316L	Piping for pure gases
X2CrNiMoN 17-11-2	1.4406	SS-316LN	Valves and fittings, cryogenic temperatures
X2CrNiMo 18-14-3	1.4435	SS-316L	Piping for pure gases
X6CrNiTi 18-10	1.4541	SS-321	Valves and fittings
X6CrNiMoTi 17-12-2	1.4571	SS-316TI	Valves and fittings
X10NiCrAlTi 32-20	1.4876	Inconel 800	High temperatures
NiCu30Fe	2.4360	Monel 400	Fluorine
NiMo16CrTi	2.4610	Hastelloy C4	Valve system, very hard, against valve seat in 1.4571
NiCr15Fe	2.4816	Inconel 600	High temperatures
NiMo16Cr15W	2.4819	Hastelloy C276	Valve system, very hard, against valve seat in 1.4571

The preceding table provide information about a selection of materials which are not only used for pressurised containers but also for tubing, fittings and measuring instruments.

When selecting tubing the parameters material of construction, compressive strength, loss of pressure and surface quality have to be taken into consideration. Primarily SS-316 (1.4401) and SS-316L (1.4404 und 1.4435) with a tensile strength above 490 N · mm^{-2} are used as materials.

Table T4.2.1-3: Compressive strength in bar of metric seamless stainless steel tubing 1.4401, considering the external diameter d_a and the thickness of walls s_w, both given in mm. The permissible range of temperature is from –30 to +40°C.

s_W **d_a**	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**4.0**
3	497	1032					
6		497	774				
8		359	558				
10		280	440				
12		231	359	497			
14		195	302	416	535	654	
16		169	261	358	460	564	
18		150	230	314	403	496	
22		121	185	252	322	394	540
25		108	162	220	280	342	470
32						250	340
50						150	200

As well as highly stable tubes with small diameters d_a and wall thickness s_W for 250 bar d_a • s_W = 3 x 0.5 , 10 x 1 and 16 x 2 are used and for 400 bar 8 x 1.5, 12 x 2 and 16 x 3 are often used.

Table T4.2.1-4: Compressive strength in bar of seamless stainless steel tubing, considering the external diameter d_a in inches and the wall thickness s_W, in mm and inches. The permissible range of temperature is from –30 to +40 °C.

s_W mm **inch** **d_a**	**0.7** **0.028**	**0.9** **0.035**	**1.2** **0.049**	**1.7** **0.065**	**2.1** **0.083**	**2.4** **0.095**	**2.8** **0.109**	**3.0** **0.12**	**4.0** **0.156**
1/8"= 3.175 mm	585	750							
1/4"= 6.35 mm	275	350	515	705					
3/8"= 9.525 mm		225	330	450					
1/2"= 12.7 mm		165	240	325	425				
3/4"= 19.05 mm			165	225	290	340	400		
1" = 25.4 mm				165	215	250	290	325	
2" = 50.8 mm							140	150	200

Table T4.2.1-5: compressive strength in bar of seamless tubing in Monel-400, considering the external diameter d_a in inches and the wall thickness s_W, in mm and inches. The permissible range of temperature is from –30 to +40 °C.

s_W mm inch d_a	**0.7** **0.028**	**0.9** **0.035**	**1.2** **0.049**	**1.6** **0.065**	**2.1** **0.083**	**2.4** **0.095**	**2.8** **0.109**	**3.0** **0.12**
1/8"= 3.175 mm	545	695						
1/4"= 6.35 mm	255	330	485	655				
3/8"= 9.525 mm		215	305	420				
1/2"= 12.7 mm		160	220	305				
3/4"= 19.05 mm			150	205	275	315		
1" = 25.4 mm				150	200	235	270	300

For the calculation of the loss of pressure it is necessary to know the dimensionless Reynold's number Re

$$\mathrm{Re} = \frac{d \cdot \varphi_{p,T} \cdot v_{lin}}{\eta_{p,T}} \tag{4.2.1-1}$$

The Reynold's number is the relation of inertial force to friction force and has a central significance in hydrodynamics and aerodynamics. For gases the calculation is complicated in so far as the density φ and the dynamic viscosity η depend enormously on the pressure and temperature and have to be ascertained using approximation formulae. For the laminar flow Re ≤ 2320 applies. Then the pressure decrease can be assigned by using the Hagen-Poisselle Law introduced in Eq. 2.5-4. Re > 2300 is a turbulent flow. Examples for both types of flow including empirical formulae can be found in (Drewes 1973), (Jessel 2001) and (Hering et al 1999). All formulae use the pipe friction number τ (often referred to as λ, which we use admittedly for the thermal conductivity coefficient).

$$\tau = \frac{64}{\mathrm{Re}} \qquad \text{for Re} \le 2320 \tag{4.2.1-2}$$

$$\tau = \frac{0.3164}{\sqrt[4]{\mathrm{Re}}} \qquad \text{(Blasius)} \qquad \text{for } 2320 < \mathrm{Re} < 10^5 \tag{4.2.1-3}$$

For many practical tasks Table T4.2.1-6 is enough. This considers only a 5% loss of pressure.

The following principles apply for the selection:

- The smallest pressure at which the station is intended to work is the decisive factor.
- In a borderline situation it is necessary to choose a higher nominal width.

The smooth straight tube has the lowest resistance to flow and Table T4.2.1-6 only applies to such tubing. Every connection, bend and fitting has a higher resistance to flow, the measure for this is the drag coefficient c_W. Many manufacturers indicate the c_W for their products.

Table T4.2.1-6: Inner diameter DN in mm of tubing considering overpressure and volume flow in $m^3 \cdot h^{-1}$, roughness ≤ 1 µm

Length in [m]	**Pressure in [bar(g)]**	**10 [$m^3 \cdot h^{-1}$]**	**20 [$m^3 \cdot h^{-1}$]**	**50 [$m^3 \cdot h^{-1}$]**	**100 [$m^3 \cdot h^{-1}$]**	**200 [$m^3 \cdot h^{-1}$]**	**500 [$m^3 \cdot h^{-1}$]**
10	2.5	8	10	15	20	25	40
	10	4	5	8	10	13	15
	100	3	3	3	3	4	4
	250	2	2	2	2	3	4
	400	2	2	2	2	2	3
20	2.5	10	13	20	25	32	40
	10	5	6	8	10	13	20
	100	3	3	3	3	4	5
	250	2	2	3	3	3	4
	400	2	2	2	2	3	3
50	2.5	13	15	20	25	40	50
	10	5	8	10	13	15	25
	100	3	3	3	3	4	6
	250	2	3	3	3	4	5
	400	2	2	2	3	3	4
100	2.5	13	20	25	32	40	60
	10	6	8	13	15	20	25
	100	3	3	3	4	5	8
	250	3	3	3	3	4	6
	400	2	2	3	3	3	4
200	2.5	15	20	32	40	50	60
	10	8	10	13	20	20	32
	100	3	3	4	4	6	8
	250	3	3	3	3	5	6
	400	2	2	3	3	4	4
500	2.5	20	25	32	40	60	100
	10	8	10	15	20	25	40
	100	3	3	4	5	8	10
	250	3	3	4	4	6	8
	400	2	3	3	3	4	5

Example E4.2.1-1: for its high pressure diaphragm valve of the series "HD" the firm Swagelok Co. gives a $c_W = 0.14$ *and accordingly a pressure drop of 10 bar at 200 bar inlet pressure and a gas flow* $Q_V = 700\ l \cdot min^{-1}$*. On both sides the valve has 1/4"- VCR-connections which make the tube 6x1 close to normal size ND 4. Which length of tubing has the same pressure decrease?*

Firstly the Q_V *is calculated in* $m^3 \cdot h^{-1}$*:*

$$Q_V = 700 \ \left[1 \cdot \min^{-1}\right] = 6 \cdot 10^{-2} \cdot 700 = 42 \ \left[m^3 \cdot h^{-1}\right]$$

From the Table one uses the slightly higher values $Q_V = 50\ m^3 \cdot h^{-1}$ *and* $p =$ *250 bar (g). At ND 4 the appropriate length of tubing is 500 metres!*

The example shows that a station's dimensions are primarily determined by the fittings' resistance to flow (assuming it is not exclusively used to withdraw gas).

As well as the above-mentioned criteria for the measurement tubing it is also necessary to adhere to maximum linear velocities v_{lin} according to Eq.3-1. In general one uses $v_{lin} \leq 30\ m \cdot s^{-1}$. Above this value the noise level caused by the gas flow becomes *annoying* for the operators. For safety reasons for oxygen and acetylene smaller values are used. They vary between different countries.

Example E4.2.1-2: In Germany the following values apply for v_{lin}*:*

- *Oxygen: according to (M034 2005):* $< 8\ m \cdot s^{-1}$
- *Acetylenes: according to (TRAC 204 1990) the overpressure for acetylene tubing is limited: at DN 50 max. 1.5 bar, at DN 100 max. 0.6 bar. This restriction is primarily intended to prevent the acetylene decomposition, which means that* v_{lin} *is also limited.*

With respect to the quality of the interior surface the surface roughness depth Ra, often simply referred to as roughness, and the cleaning are decisive. Nowadays the usual levels of the irregularities remaining on the inner surface are: surface roughness depth 0.20 µm: electrolytic polishing, 0.40 µm: drawing quality, 1 µm: drawing.

The cleaning usually implies the following criteria: cleaned to a shiny surface, CFC free, dried. High-quality tubing has to be sealed with caps by the manufacturer.

Heat exchangers and vaporisers are also included in the pressurised containers and tubing. The transfer of heat applies to the pair's gas-gas and gas-liquid. In large-scale industrial manifolds the heat exchangers play a significant role with respect to economic efficiency. One differentiates between plate exchangers and coiled exchangers. Both have specific advantages and disadvantages. As an individual item the plate exchanger has proved to be relatively competitive. However, if it is necessary to use several parallel plate exchangers it been proven coiled ones are more cost-effective.

In the technical region of small Q_V the task is often to carry out cleaning at high or cryogenic temperatures. In such cases a gas-gas heat exchanger is needed, even in the high pressure range. The task can be solved easily by connecting two tubes lengthwise by soldering or welding. The connected tubes are often wound into a coil. It is recommended to subject this arrangement to a hydrostatic pressure test. Usage is affected according to the principle of counter flow.

4.2.2 Valves and Fittings

For the items dealt with in this chapter the general principles are based on the need of a small leak rate. This has to be be ascertained and guaranteed by the manufacturer. The highest leak tightness between fitting and tubing is achieved by welding which however makes the exchange of fittings exceedingly difficult and ultimately necessitates cleaning procedures at the end of the process.

4.2.2.1 Resealable Connections

Several characteristics are expected from resealable connections: high leak tightness, multiple use, simplicity, temperature reliability up to at least 400°C, usability in high pressure (250/400 bar), particle-free, well-tempered surfaces, and resistant materials (stainless steel, monel). It is advantageous if the tubing or fittings which need to be connected do not have to be welded. The most widespread connection of this kind is the Two-Ferrule-Connection of the firm Swagelok Co.

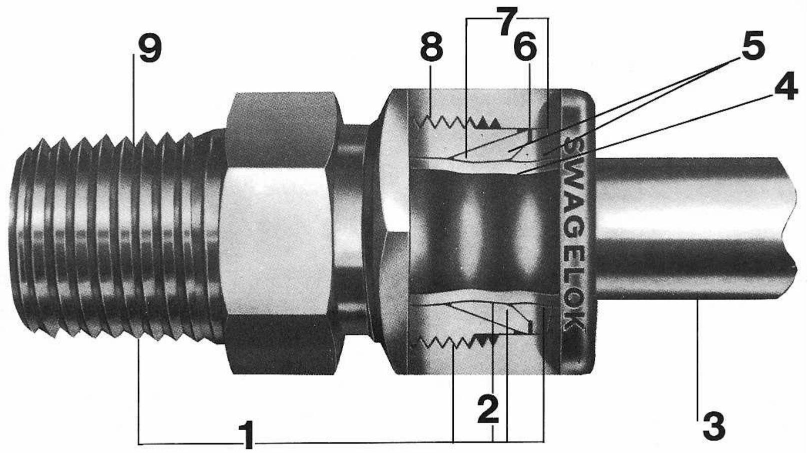


Illustration P4.2.2.1-1: Two-Ferrule-Connection (Swagelok Co. in Solon, Ohio USA).

Explanation: 1: All four parts are consisting of the same material. 2: Metal-to-metal seal. 3: Tube, in inches or metres, from 2 to 25 mm. 4: smallest diameter of the tube. 5. The two clamping rings achieve an elastic sealing which enables repeated breaking and re-making. 6: The clamping procedure is regulated and avoids stress. 7: Security against vibration. 8: Connecting nut. 9: Threaded connecting component.

This connection is a disadvantage when it is the necessary to have the flexibility to rotate the industrial gas installation tubing, fittings and measuring instruments.

This is avoided by the following way of sealing, referred to as VCR$^{(R)}$: vacuum coupling remakeable. The name indicates its origin in the ultra-high vacuum technology as well as its reusability. It is, however, necessary to weld the fittings. The VCR achieves a leak rate of $1 \cdot 10^{-10}$ mbar · l · s^{-1} and is the lowest for known resealable connections. Their development has been necessitated by the high demands for quality in the semiconductor industry; their use is standard in many other areas. The temperature ranges from –270 (liquid He) to +400 °C.

The principle of the VCR consists of a flat seal, made of stainless steel or nickel, with a partial layer of silver, copper or aluminium. This metallic seal is symmetrically pressed by semicircular, highly polished sealing torroid made of stainless steel. The thread is asymmetrical; the fittings have to be welded. The seals can be changed without axial misalignment.

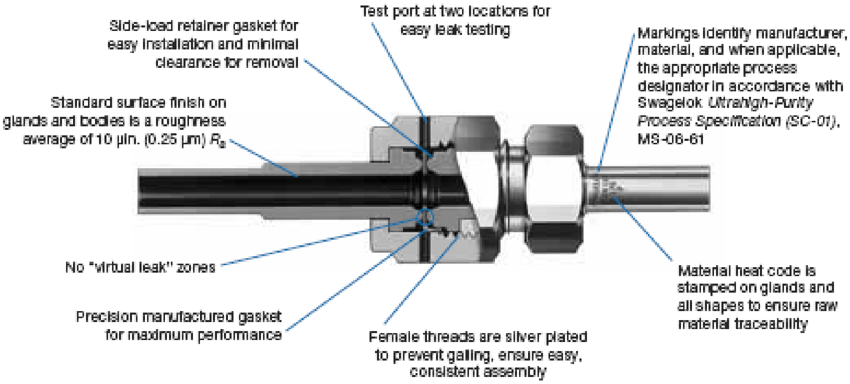


Illustration P4.2.2.1-2: VCR-fitting of Swagelok Co.

The principle of not opening or closing under pressure applies to all threaded connections because they are only for use under static forces without containg lubricant. Operating under pressure can easily lead to irreversible damage or in the worst case to a break in the connection with unforeseeable consequences.

If the connection needs to be changed frequently, the possibility of Quick release couplings exists.

Explanation: The plug (1) consists of the stainless steel X6CrMoS17 (=1.4105) or X2CrNiMo18.10 (=1.4404). The hardening bevelling (or polishing) is essential for the leak tightness and long operation. The plug is guided by two separate bearings (2). This excludes the possibility of twisting the plug before entry into the O-ring as well as other additional mechanical problems. The mechanical locking device (3) enables the connection to be unscrewed at pressures up to 15 bar with the DN 5.5 mm. The working pressure is 400 bar. The sealing between the plug and the socket (from 1.4404) is formed by one or two O-rings (4) which consist of elastomers such as Fluorocarbon (FPM), Fluorosilicon (FMQ), Nitril rubber (NBR) or PTFE.

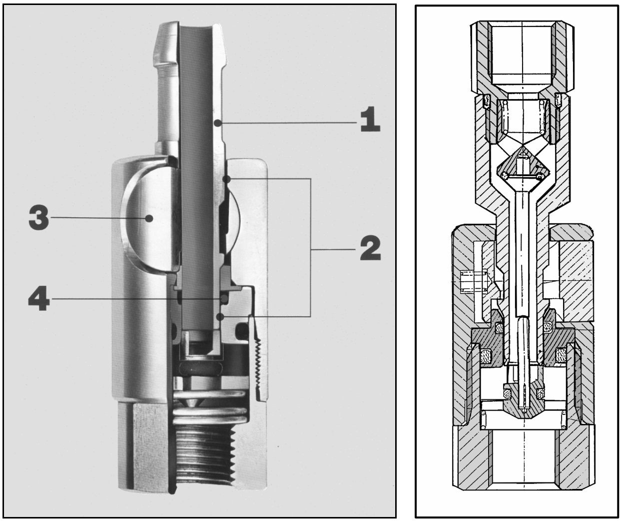


Illustration P4.2.2.1-3: Quick release coupling type RBE from the firm Stäubli Tec Systems GmbH Connectors in Bayreuth / Germany. Left: Factory photo with a tube connection, right: Cross section, with thread connections on both ends.

When the coupling is open, there are three kinds of barriers: open – isolated on one side – isolated on both sides. In the above illustration the plug is not isolatable. When it is inserted into the device it presses a valve with the O-ring sealing downwards, hence opening the gas flow. If the connection is opened the spring under the valve presses against the seal, thus closing the gas flow. This ability to isolate has the great advantage of preventing atmospheric moisture penetrating into the depressurised manifold.

4.2.2.2 Safety Devices for Protection against Excessive Pressure

The installation of safety devices for protection against excessive pressure is compulsory wherever unacceptably high pressure can occur. Typical examples are:

- The discharge of pumps and compressors.
- Containers or tubing in which pressurised liquefied gases are or can be trapped.
- Containers, manifolds and tubing which are subject to higher ambient temperatures.
- The low pressure side of pressure regulators.

We differentiate between safety valves and bursting discs. Details concerning the use of pressurised containers and filling stations are regulated by PED (97/23/EC 1997) in the EC and (DOT 2005) in the USA.

The safety valves placed on steam boilers are restricted to levers and weight. All other types are adjusted by springs. For industrial gases the threaded connection is preferred over the flange.

Safety valves should be sealed from the atmosphere at an appropriate pressure. However, it is possible that there are minuscule leaks when the manifold is evacuated in spite of the soft seals. Bursting discs achieve a smaller leak rate but in this case the entire contents of gas in the station are lost.

Example E4.2.2.2-1: Safety valve with an average performance for pure gases by the firm LESER GmbH & Co. KG in Hamburg / Germany.

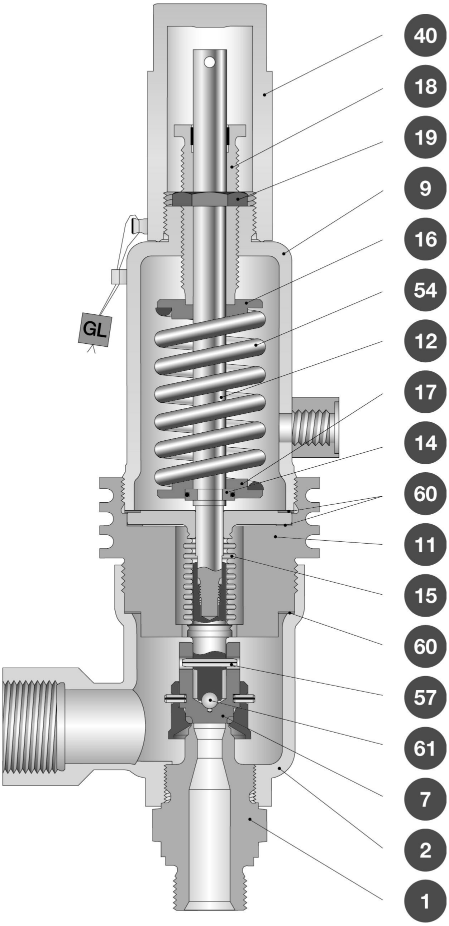


Illustration P4.2.2.2-1: Threaded safety relief valve spring loaded, balanced bellow design.

Explanation: 1: inlet body, 2: outlet body, 7: disc with soft seal, 9: bonnet, 11: bonnet spacer, 12: spindle, 14: split ring, 15: bellows, 16/17: spring plate, 18: adjusting screw with bushing, 19: lock nut, 40: cap H2, 54: spring optional, 57: pin, 60: gasket, 61: ball.

Bursting discs are safety devices which have to be thoroughly tested. They fulfil their task by bursting a certain differential pressure. However, in general bursting discs must put up with significant stress below the bursting point, e.g. changing the pressure-cycling stress, without leaking. At the bursting pressure of a ready-to-use bursting disc it can only be closed with the bursting test of the same series.

So as not to lose the amount of gas in the manifold when the bursting disc cracks the following configuration has proved effective “bursting disc – pressure indication – safety valve – vent gas tube”. Appropriate pressures should be selected in suitable stages.

Example E4.2.2.2-3: Bursting discs for low and high pressure.

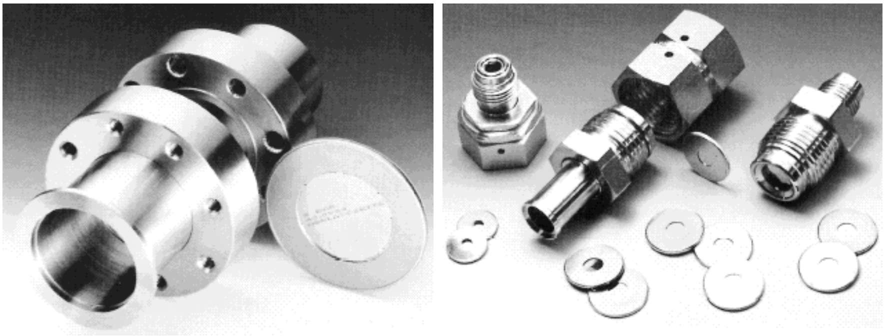


Illustration P4.2.2.2-2: Factory photos from Schlesinger GmbH in Germany.

Left: bursting disc made of stainless steel or PTFE in a flange fitting. A typical application is to protect a vacuum pump at 1.3 bar abs. Right: bursting discs in the VCR system. The combination with the VCR sealing fulfils the highest demands in the field of pure gases and semiconductor production. Nominal widths 6 – 20 mm, bursting pressures 5 – 100 bar.

The discharge of safety valves and bursting discs has to lead into the atmosphere and be unblockable. The minimal dimensions for the pipe are determined by the nominal widths of the exit of the device discharge. If there are waste removal devices, e.g. gas scrubbers, in the vent gas line then these must also be unblockable.

Check valves are not safety devices at high pressure however they are important fittings in systems with varying pressure levels.

Example E4.2.2.2-3: check valve installed with a highly efficient external sealing: CH-series of Swagelok Co.: Fixed cracking pressures from 0.03 to 1.9 bar

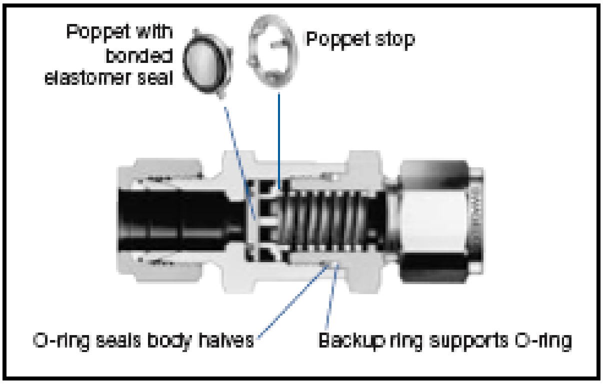


Illustration P4.2.2.2-3: Check valve with bonded elastomer seal (factory photo from Swagelok Co. Ohio/USA).

Explanation: gas flow only from left to right. Connections: double ferrule Swagelok. The strength of the springs determines the maximum back-pressure with which a flow can be achieved. If this is exceeded then the valve closes.

Other constructions, especially those suitable for oxygen, use the sealing of a metallic sphere against a conical opening. This is usually associated with less leak tightness.

Example E4.2.2.2-4: Use of a check valve in low-pressure nitrogen purging for a high-pressure hydrogen station (manifold).

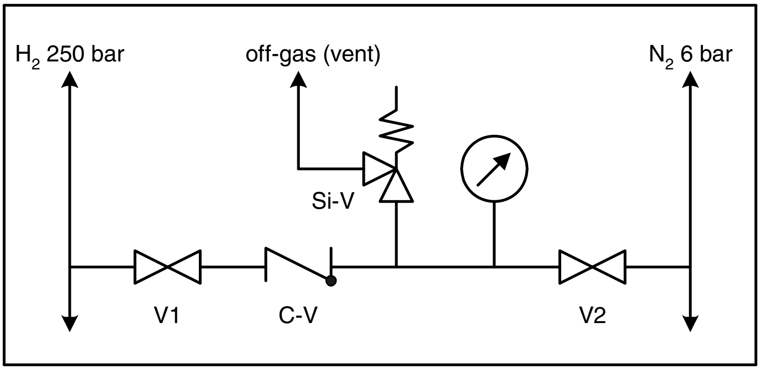


Illustration P4.2.2.2-4: Connection of tubing with varying pressure levels in a manifold.

The key point of this configuration is the serial switching of the check valve C-V (no return valve) with the safety valve Si-V. This must be adjusted to the low-pressure. The valve V1 and the C-V are to be selected in the way that they are rated for high pressure. The V2 can be a low-pressure valve.

4.2.2.3 Shut-Off Valves

In accordance with the nominal diameter DN in mm and the pressure PN in bar one can ascertain two different developmental directions with shut-off valves. After the Second World War in chemical installations and for nuclear power plants very low leakrate values with convoluted bellow sealing were developed for DN $\geq$ 10 up to 400 and they had to conform to high safety standards. The rapidly developing semiconductor industry was the reason for the acceleration with DN about 3 mm. In this case the development with small PN led to diaphragm seal and specially treated internal surfaces. Nowadays, however, diaphragm valves in DN 3 are also available for pressures up to 400 bar.

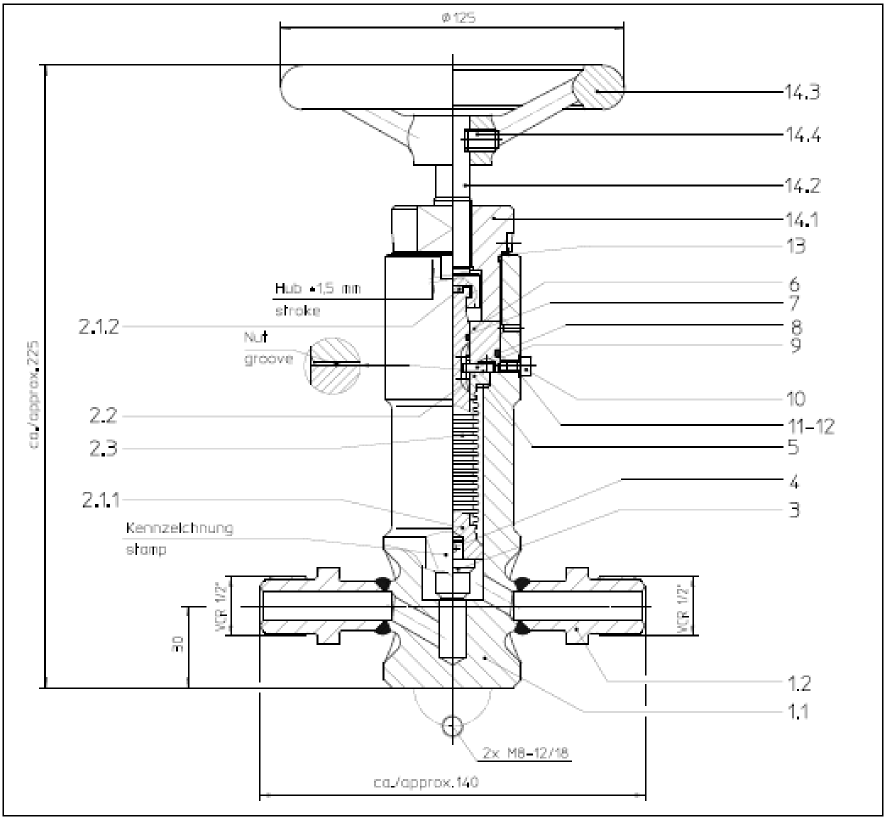


Illustration P4.2.2.3-1: Straight through valve, DN10, PN320, factory drawing of Andreas Hofer GmbH in Mülheim an der Ruhr/Germany.

Description: 1.1 valve body, 1.2 VCR port, 2.1.1 stem, 2.1.2 disc, 2.2 flange, 2.3 bellow DN10, PN320, 3 needle, hardened, 4 notched pin 3x20, 5 ring 27x23x1, 6 thrust piece, 7 O-ring ID 9x1.5, 8 O-ring ID 30x2, 9 parallel key 3x3x12, 10 cylinder screw M4x5, 11 ring 8x6x0.7, 12 O-ring ID 4x1, 13 locking plate 44x36x0.5, 14.1 thrust screw DN15, 14.2 threaded stem M16x1 DN10, 14.3 hand wheel, 14.4 threaded pin M8x12

For both types of valve the choice of seat in place is strongly dependent on the substances which have to be isolated. The very stable metal-metal sealing is disadvantageous because of the leak rate being $1 \cdot 10^{-3}$ mbar $\cdot$ l $\cdot$ s^{-1} and of the increased forces necessary to close it. While the characteristics of the substance allow, it is preferred to use a soft seat made of elastomers.

Example E4.2.2.3-1: Hand-use convoluted bellow valve DN10.
See Illustration P4.2.2.3-1 on page before.

Example E 4.2.2.3-3: Diaphragm(membrane) valve DN 4

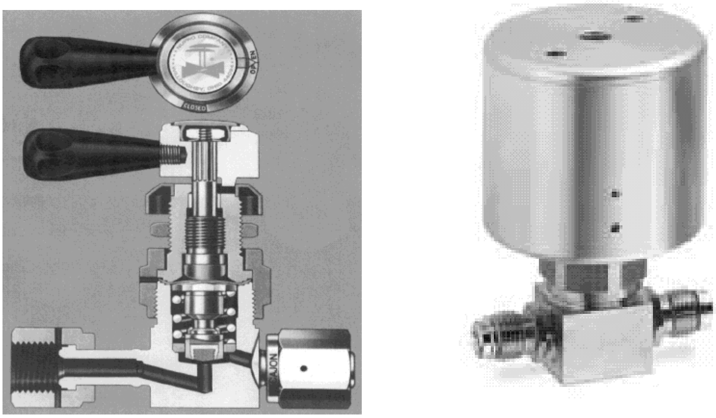


Illustration P4.2.2.3-2: Factory drawing and photo from the company Swagelok Co Ohio / USA

Left: Diaphragm valve type DS with a toggle. Under the diaphragm can be found the lower shaft with a soft seal and a spring which supports the opening process in the case of back-pressure. Operating pressure 241 bar (g) = 3500 psig, the valve opens against a maximum pressure of 103 bar (g) = 1500 psig. The wetted parts are made of stainless steel 316 L or 316 SS. The allowable temperature range is between -73 and +121 °C. Right: Actuated (pneumatic) diaphragm valve from the series DP for a pressure of 210 bar (g).

4.2.2.4 Control Valves

The regulating fitting dealt with are either used to set a certain pressure or a certain flow rate. The simplest case is when a person regulates the flow of gas by hand. This is, for example, the case when a gas cylinder is filled from a gas receiver at high pressure. The valves needed for this procedure are either blocking valves with special closing plugs or needle valves.

As the regulating valves have to fullfil diverse tasks, it makes sense to differentiate between settings which can be changed regularly and those which must remain stable for a longer period of time. Regulating valves which are continually in use are similar to needle valves.

Example E4.2.24-1: Control valves from the firm Flowserve GmbH in Essen/Germany. Ill. P4.2.2.4-1 and -2.

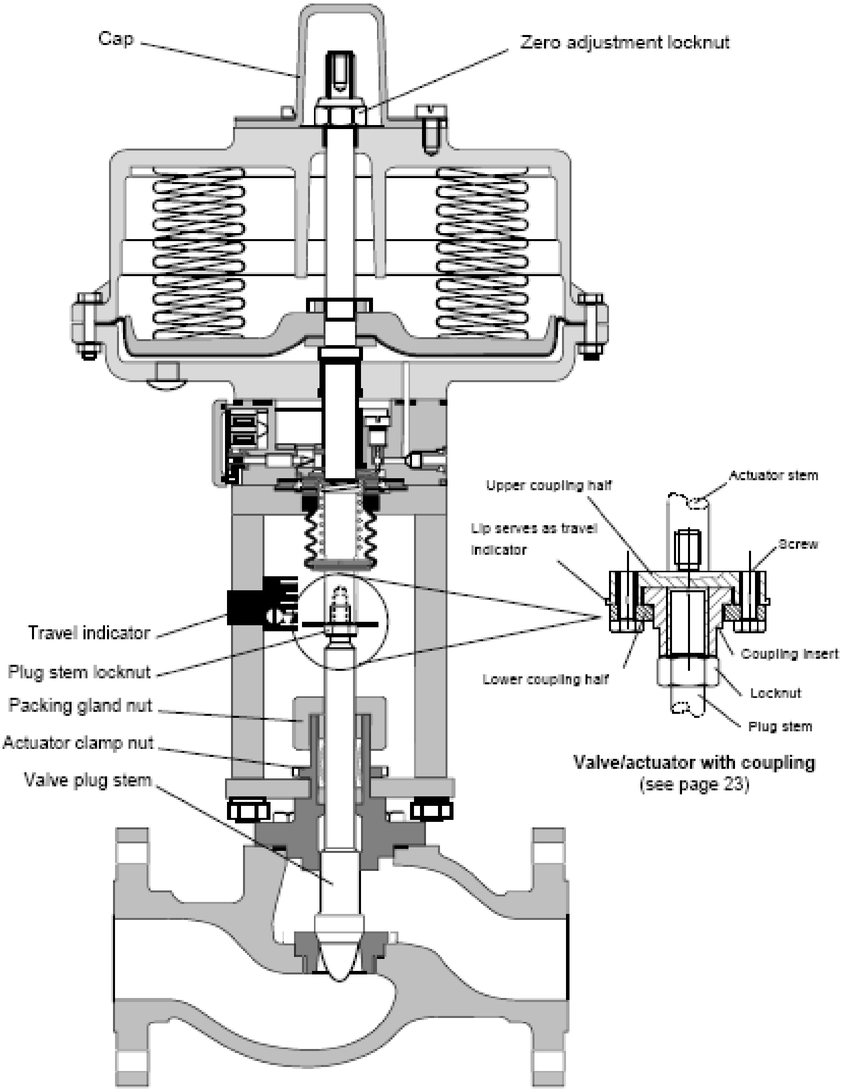


Illustration P4.2.2.4-1: Typical actuator and valve configuration.

The setting of the valve is either achieved by the pneumatic actuator or by an electric motor or by a solenoid shown here. Sealing from the atmosphere is achieved by a packing but a bellows seal is more advantageous.

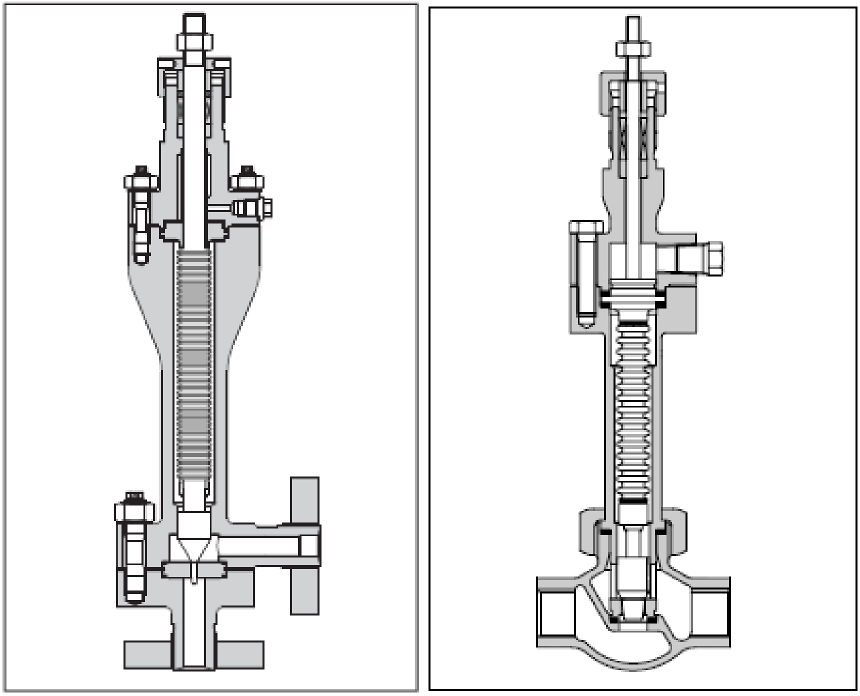


Illustration P4.2.2.4-2: Kämmer valves with bellows sealing from the firm Flowserve in Essen GmbH (factory drawings).

Left: The valve needle of the high pressure valve is made of stellite and has a very small slope. It is seated in the round base made of 1.4122 which can be found in the valve and sealed with two exchangeable opturators. Various pairings for the base/needle are possible 1.4541/1.457, tungsten carbide/Hastelloy C und nickel/monel. The nominal values are between 3 and 16 mm. Noticeable is the long bellows which is necessary to achieve a maximum range of 10 mm.
Right: Regulating valve for lower pressures. Partial use of PTFE which can be advantageous in the case of corrosive gases serve.

The following are possible methods for operating regulating valves:

- by hand which however means a fixed position,
- electric motor or solenoid,
- pneumatic pressure, especially suitable for explosion-proof rooms
- pneumatic pressure with an integrated regulator.

The amount of flow which has to be regulated in filling plants and mixing plants is mostly between 0.5 and 500 $\mathrm{l} \cdot \mathrm{min}^{-1}$ STP, the necessary volumetric flow ratio is $1{:}10^4$. However, this value can not be achieved with a single valve. The typical volumetric flow ratio of a standard valve is 1:100.

To overcome the problem of constant volume of flow in a plant a pressure regulator can be used. This sets the downstream pressure as constant as possible and also fluctuation can be compensated to a certain extend. In standard pressure regulator designs the diaphragm needs to be as elastic as possible. An adjustable spring fitted above it exerts a force on the diaphragm.

Example E4.2.2.4-2: *Pressure regulator for a capacity of 100* $m^3 \cdot h^{-1}$ *at STP.*

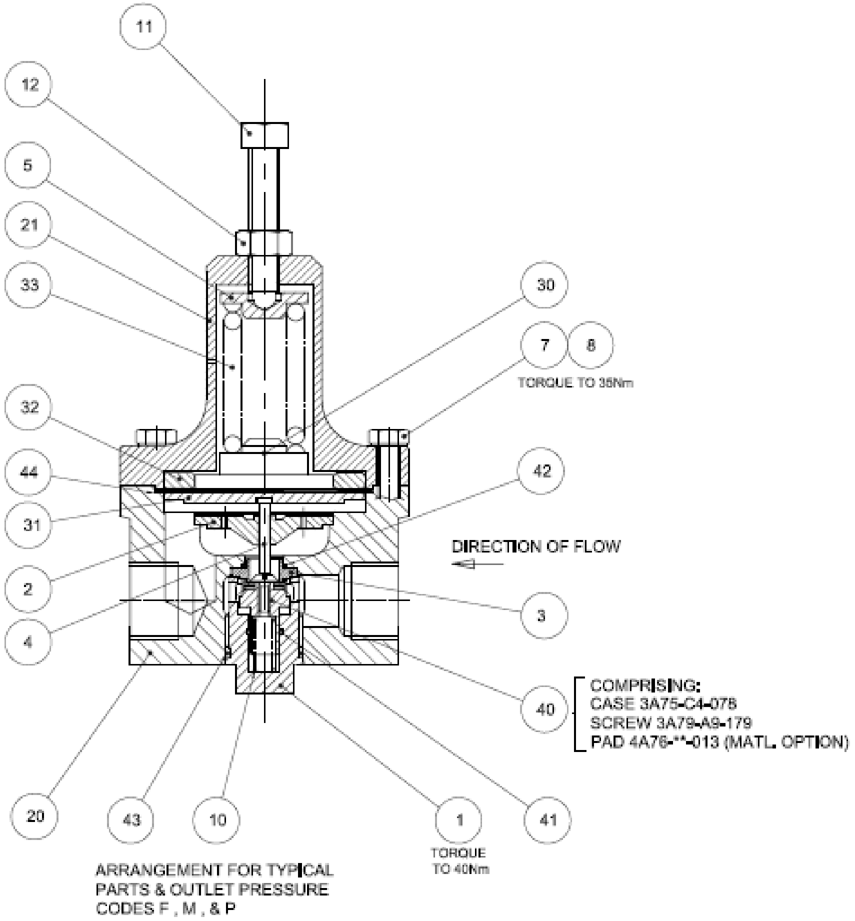


Illustration P4.2.2.4-3: Cross section of a pressure regulator. Factory drawing by the firm Hochdruck-Reduziertechnik GmbH (VATEC) in Germany**.** Designation “spring loaded regulator“, maximum inlet pressure 210 bar, outlet pressure in 5 settings (with different springs): 1 to 70 bar.

Description: 1: body plug, 2: body plate, 3: seat, 4: push rod, 5: spring plate, 7: setscrew M10x35, 8: spring washer, 10: valve spring, 11: adjusting screw, 12: locking nut, 20: body, 21: spring housing, 30: piston, 31: piston plate, 32: washer, 33: spring, 40: valve member, 41+42+43: O-rings (viton, nitrile, EPDM)

Section 8.2 deals with fittings for small flows for the withdrawal from gas cylinders.

4.2.2.5 Special Characteristics for Oxygen

The concentration of oxygen in our atmospheric air is 20.99 Vol.-% which under normal conditions corresponds to a partial pressure of 212.7 mbar. The evolutions of life as well as many developments in trade and industry are tied to 21 ± 1 Vol.-% O_2. When leaving this narrow range significant adverse effects and changes must be expected.

When dealing with large quantities of gases like N_2 and the corresponding displacement of oxygen with inadequate ventilation the danger of oxygen deficiency has to be factored. Below 17 Vol.-% O_2 the well-functioning of the human body is no longer assured.

In contrast a rise of the oxygen level above 23 Vol.-% is no distress for breathing, as it is demonstrated by using pure oxygen in medicinal therapy.

In this case however the danger is high combustibility. Many materials like clothes or oils and fats (including those from the body) burn exceedingly well over 23 Vol.-% O_2. Therefore a basic requirement for safe working conditions is that all parts in contact with the oxygen have to be free of oil and fat. Systems for the production and storage of compressed or cryogenic oxygen have to be specially cleaned. For this purpose solvents such as tensides and tri- or tetrachlorethylene are used. The purity level can be tested by chemical analyses. These demands correspond well with the quality criteria for pure gases.

Particles, e.g. from rust or metallic and non-metallic abrasion are another danger. They can catch fire under a pressurised flow of oxygen. As the purification systems are mainly made of high-quality stainless steel the particles are limited anyway. Nevertheless filters should be installed at appropriate places.

Cryogenic oxygen is particularly dangerous. Evaporation produces extremely cold gaseous oxygen which is very dense. Saturated clothes can catch fire and cause death.

Therefore suitable sensors for detection of oxygen deficiency or excess have to be installed in order to provide warning in time. Recalibration of these sensors is mandatory in many countries at least every six months.

Pressurised oxygen increases the above-mentioned problems so that there are very strict legal regulations in Europe, e.g. technical bulletin (M034 2005) in Germany. The regulations in the USA are more general (OSHA 1910.104 1996) and it is the manufacturer's responsibility to guarantee safety when dealing with oxygen. The choice of suitable materials concerns metals and especially more non-metals, such as elastomers for seals.

Example E4.2.2.5-1: Material demands for fittings and plants for oxygen systems according to (M034 2005).

The following metallic materials are suitable for casings, internal parts and seals:

- *Cu, Cu alloys with a concentration of Cu > 55%, Ni*
- *Cr-Ni-steels with a concentration of Cr+Ni >22%*
- *Cr-Ni-steels with a concentration of Cr > 22%*

Non-metallic materials for packing and as well as sealings in flanges and lids have to be checked.

Non-metallic materials for packing for seals have to be checked. For pressures over 40 bar(g) it has long been unacceptable to use a combination of stainless steel and elastomers.

In addition to the above-mentioned materials it is also possible to use lead and tin as metallic sealing materials for all pressure ranges.

According to the present state of knowledge the following metallic materials are not suitable: titanium, zirconium and their alloys.

The problem with non-metallic sealing materials, mainly elastomers, is that they could combust without being exposed to pure oxygen and therefore the organization constructing the material must decide, whether the sealing is safe and usable. The official testing office in Germany is the Bundesanstalt für Materialforschung und -prüfung (BAM) in Berlin. Moreover, the testing office of L´Air Liquide in France is very well-known in Europe.

Ni and Cu and their alloys as well as monel are very good conductors of heat which reduces the possibility of combustion of the seals. In comparison stainless steel conducts heat very effectively. Thus it was not possible for a long time to combine stainless steel – elastomer for the sealing seat. Today however better sealing materials have been developed and their construction improved. The solution of this problem is: if the sample passes the combustion test by a recognised testing office, then it is permissible. There are already diaphragm valves with soft sealing in the seat on the market which have passed the test for oxygen below 250 bar.

4.2.3 Pumps and Compressors

Industrial filling of compressed or pressurised liquefied gases makes it necessary to use compressors and pumps which must prove to be resistant against highly corrosive substances and also to have very small leak rates.

Universal, classic piston compressors are lubricated which there is a main disatvantage because of the various stages of compression. It has to be removed again from the gas after the last stage. The availability of modern elasomers which are heat-resistant, chemically stable and have a low-friction enabled the development of dry-running compressors. Thus the use of oils in the cylinder room could be prevented but there were at least two new disadvantages: lower leak-tightness and friction-caused particle production. The attempt to avoid the above-mentioned problems and the need to meet the demands for purity led to the development from piston compressors to diaphragm ones. This principle has also been used in the pumps for liquids.

4.2.3.1 Dry-Running Gas Compressors

In the 40s, Corken Inc., founded in Oklahoma USA in 1924, brought very successful pumps for compressed or liquedied gases into the liquid gas market. Corken-compressors are now offered by various firms although both types have a different construction. In the following image are only dealing with gaseous compression. With dry-running Corken-compressors the self-lubricating seals of the piston rings are crucial to the leak rate and usability.

Example E4.2.3.1-1: Corken-compressor

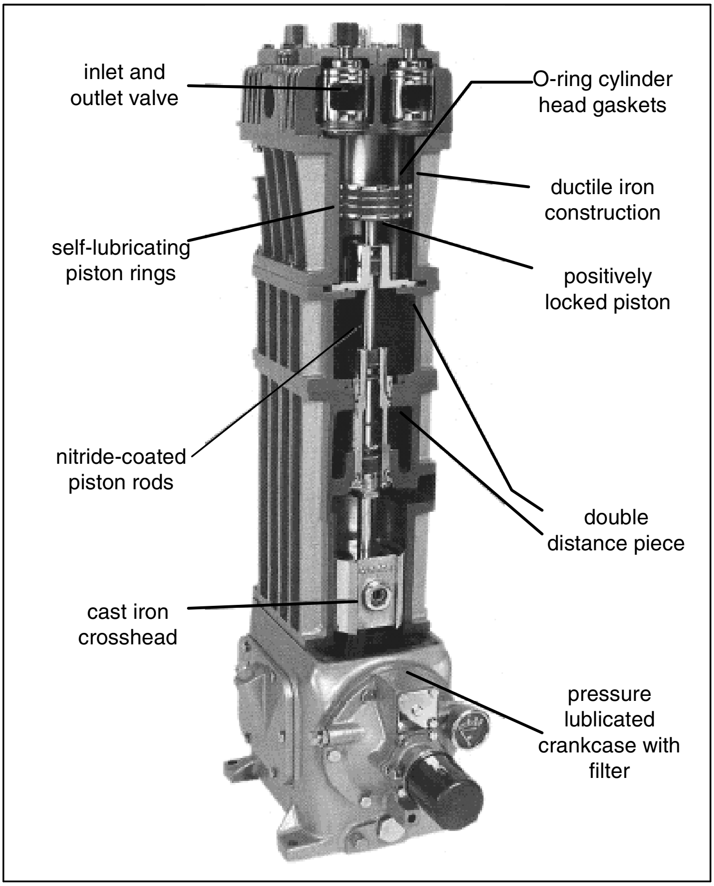


Illustration P4.2.3.1-1: Corken single stage oil-free compressors, Type D891a: max. flow rate 192 m³/h, max. working pressure 24 bar abs.

4.2.3.2 Diaphragm Compressors

The following description of the working principle including Illustration P.2.3.2-1 has been taken from a factory bulletin by the company of Andreas Hofer Hochdrucktechnik GmbH in Mülheim an der Ruhr in Germany.

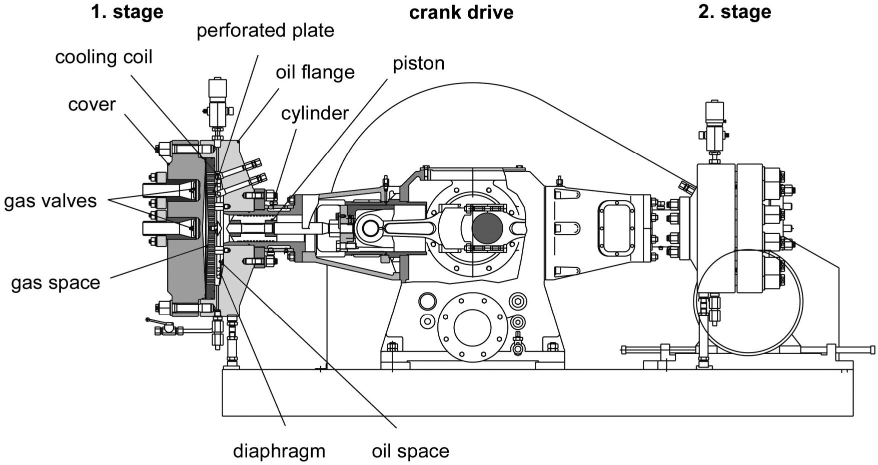


Illustration P4.2.3.2-1: Diagram of a two-stage diaphragm compressor, factory description of the firm Hofer GmbH.

The maximum compression ratio in one-stage is 1:15. This means that one stage is normally insufficient with low inlet pressure and the required high final pressure.

The required oil pressure to deflect the diaphragm is built up by a crank shaft with a piston moving to and from. The displacement of this piston corresponds approximately to the displacement of the diaphragm head. During the pressure displacement the piston pushes the oil into the diaphragm head and through the perforated plate to the reverse side of the diaphragm which is thus bent against the concave surface area of the perforated plate. The oscillation frequency of the diaphragm corresponds to the compressor speed (revolutions per minute). For small machines with a flow rate below 10 $m^3 \cdot h^{-1}$ this is 720 min^{-1} for medium-sized and large machines with a flow rate of up to 1000 $m^3 \cdot h^{-1}$ this is 400 to 600 min^{-1}.

Without much expense sealing the metallic diaphragm from the atmosphere allows a leakage rate of 10^{-4} mbar · l · s^{-1}. With special modifications it is possible to achieve 10^{-8} mbar · l · s^{-1}.

The gas only comes into contact with metallic materials. For casing the range of materials extends from normal carbon steel through stainless steel types such as 1.4541 and 1.4571 to special materials such as Hastelloy. Nevertheless an exception is provided by those diaphragms which due to the enormous mechanical demands can only be made of extremely hard materials with great resistance and elasticity. Very often Cr-Ni-steel 1.4310, Hastelloy and Inconel are used.

Example E4.2.3.2-1: Three-stage diaphragm compressor

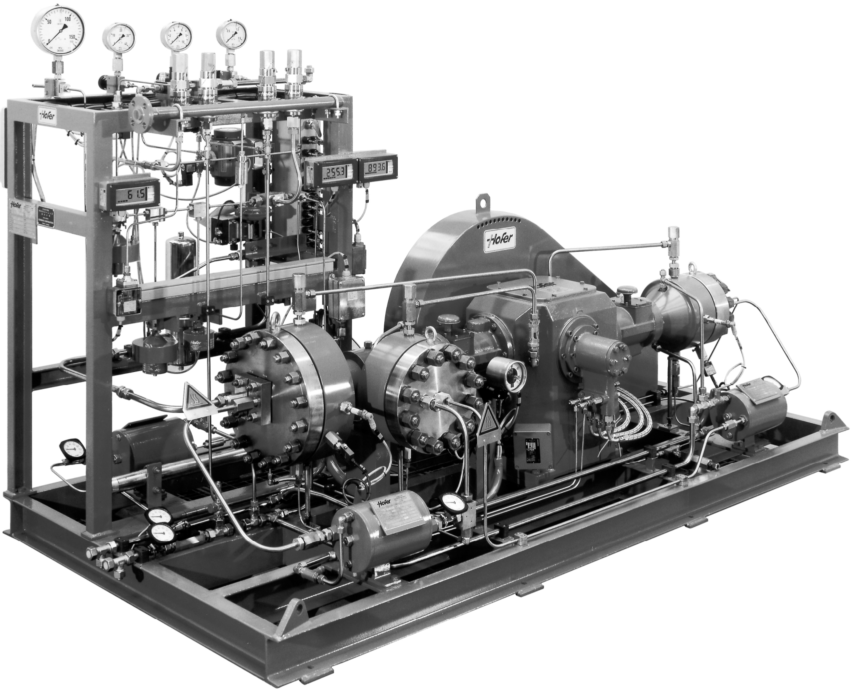


Illustration P4.2.3.2-2: Three-stage diaphragm compressor, factory photo of the firm Hofer GmbH.
Technical data: Suction pressure 8 bar abs., final pressure 800 bar abs., medium: He, output: 20 $m^3 \cdot h^{-1}$ at STP, construction: horizontal, duplex.

As far as industrial gas connections are concerned the following points have to be specifically taken into consideration:

- frequent on and off switching is to be avoided, always start without pressure.
- starting the compressor should quickly be followed against back-pressure. For this purpose back-pressure valves are used which are constructed in a similar way as pressure relief valves. They do not open until a previously fixed pressure has been reached.

One-stage compressors with low volume need not use a special procedure for starting and stopping. However it is appropriate for multi-stage machines where it is necessary to treat the diaphragms carefully and operate the compressor closed-loop without pressure for a short time (< 1 min).

Example E4.2.3.2-3: Technical gaseous connection of a two-stage compressor, see Illustration P4.2.3.2-3 .
The simple example is suitable for inert gases or oxygen where the pressurised residual can be vented to the atmosphere without any problems. Furthermore an evacuation and/or a low-pressure purging need to be used.

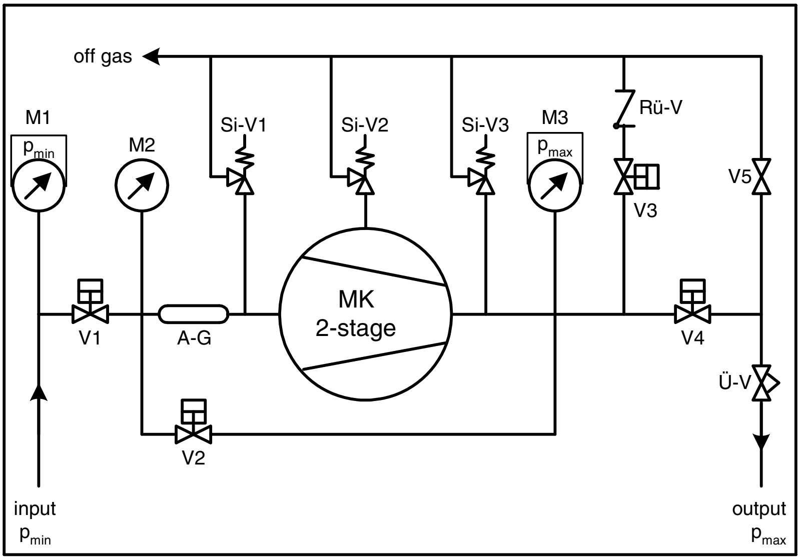


Illustration P4.2.3.2-3: Technical gaseous connection for switching, starting and stopping a two-stage or multi-stage diaphragm compressor (MK).

Explanation: the gas to be transferred is available at a p_{min}. The contact manometer M1 allows the running of the compressor motor at $p > p_{min}$. When standing idle the installation's valves are switched as follows:
V1: suction valve, normally closed, V2: bypass valve, normally closed, V3: vent valve, normally open, V4: pressure valve, normally closed.

Switching on the diaphragm compressor:

- start: cooling water valve open, V2 open
- after 2 – 5 secs.: compressormotor on, V3 closed
- after 30 – 60 secs: V1 open, V4 open
- after 2 – 5 secs: V2 closed.

Switching off the diaphragm compressor:

- start: compressor motor off, V1 closed, V3 open, V4 closed
- after 2 -5 secs: V2 open
- after 60 – 120 secs: V2 closed, compressor's cooling valve closed.

Each stage of the diaphragm compressor is protected by a safety valve Si-V1 to V3. A surge vessel container A-G (most V_{geom} = 5 to 10 l) at the suction lowers the impulses during operation. The contact manometer M3 switches the compressor off immediately when p_{max} has been reached. p_{max} has to be smaller than the set-pressure of the Si-V3 . The back-pressure valve BP-V is adjusted to a response pressure of about $0.5 \cdot p_{max}$ and prevents the compressor having to operate for against a low pressure a long time.

The following supervisory control is recommended to ensure smooth operation:

- continual indication and alarming of a break in the diaphragm
- continual oil pressure indication and automatic shut-down if the oil pressure is too low
- temperature measurement at the cylinder heads: once a year. If CO has been compressed it is necessary to have a temperate limitation below 150°C at every stage to avoid the formation of undesirable iron pentacarbonyl.

In addition to being used in industrial facilities diaphragm compressors are equally noteworthy in laboratories. They are mostly referred to as diaphragm pumps. Here, a slightly different principle without oil pressure is used. The following Illustration P4.2.3.2-4left: has been taken from monograph (Becker 1998).

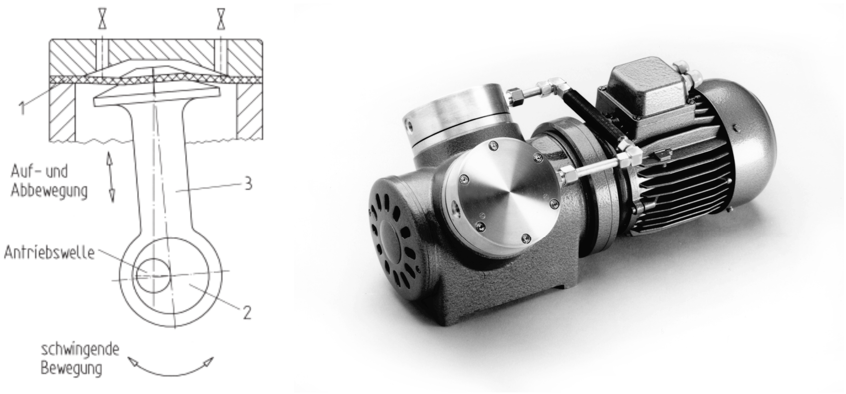


Illustration P4.2.3.2-4: Diaphragm pumps**.** Left: construction principle of a diaphragm pump. Right: two-stage diaphragm pump, factory photo from the firm KNF Neuberger GmbH in Freiburg/Germany.

An elastomer diaphragm (1) is firmly connected to the the piston rod (3). This is driven by an eccentric connecting-rod. An electric motor moves the driveshaft so that the piston rod swings. This causes the diaphragm to move up and down. The suction valve and the discharge valve are indicated with the valve symbols. Capacity: 0.2 to 300 $\mathrm{l \cdot min^{-1}}$ at STP. Auf- und Abbewegung: up and down, Antriebswelle: driving shaft, schwingende Bewegung: swing.

One-stage version: pressures up to 7 bar (g), vacuum up to 100 mbar, two-stage version: pressures up to 16 bar (g), vacuum up to < 0.5 mbar. Leakage rate: $5 \cdot 10^{-3}$ $\mathrm{mbar \cdot l \cdot s^{-1}}$, in special cases at $5 \cdot 10^{-6}$ $\mathrm{mbar \cdot l \cdot s^{-1}}$.

Example E4.2.3.2-3: Two-stage diaphragm pump and vacuum pump of type N186.3 with a performance of 25 $l \cdot min^{-1}$ *at STP from the firm KNF Neuberger GmbH, see Illustration P4.2.3.2-4 right. Casing material: stainless steel or aluminium. Diaphragm material: PTFE, Viton or Neoprene, leak rate* $6 \cdot 10^{-6}$ $mbar \cdot l \cdot s^{-1}$*, achieved vacuum 3 mbar, achievable final pressure 12 bar (g) at a suction pressure of 1 bar abs.*

4.2.3.3 Pumps for Liquefied Gases

Pumps for liquefied gases and liquids which require a very low leak rate are based on the same principles as the diaphragm compressor dealt with in the previous section. For transporting gases in laboratories pumps are mostly provided with an eccentric drive for transporting gases which we have already dealt discussed.

For more performance and high pressure again a diaphragm whose movement is supported by oil is used. The function of a pump using this principle can be seen in Illustration P4.2.3.3-1 which shows a suction stroke and a discharge stroke. In addition it shows a diaphragm control. This functions for the principle of measuring the pressure between the individual diaphragms of which at least two can be inserted in the head of the compressor. The similarity with the diaphragm compressor as shown in Illustration P4.2.3.2-1 is unmistakable.

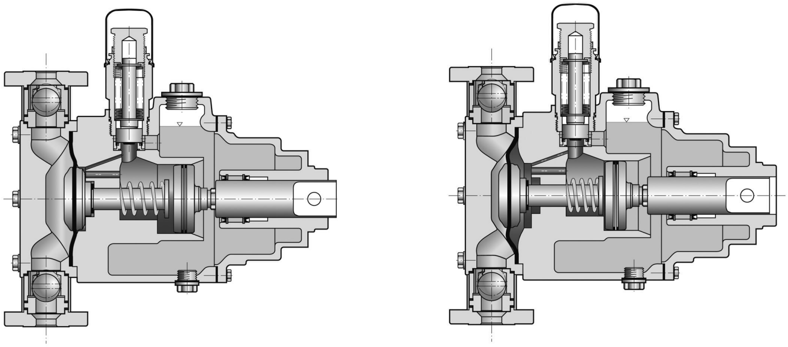


Illustration P4.2.3.3-1: Function of a diaphragm liquid pump**.** Both, suction (left) and discharge (right) stroke are shown. Works drawing of LEWA GmbH in Leonberg/Germany.

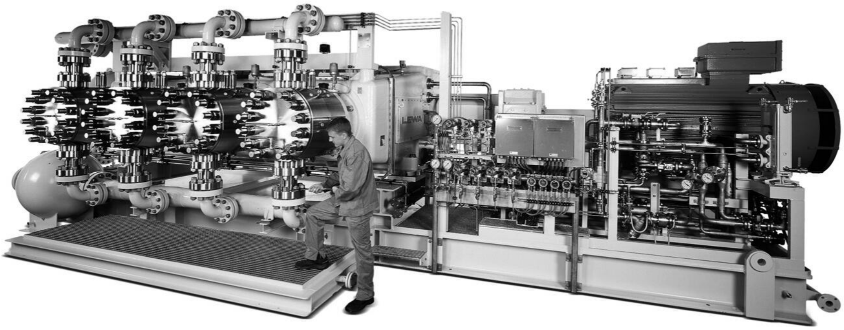


Illustration P4.2.3.3-2: LEWA diaphragm pump Type G4T (works photo) at Hammerfest/Norway.

Example E4.2.3.3-1: LEWA diaphragm metering pumps with the technical specification flow rate 0.005 $l \cdot h^{-1}$ *to 180* $m^3 \cdot h^{-1}$*, discharge pressure 20 to 1200 bar, fluid temperature –80 to +200°C. Little known is the fact that diaphragm metering pumps for liquids can also be used for conveying and circulating gases as long as the differential pressure does not exceed 1:1.25, (Jarosch and Philippin 2005).*
See Illustration P4.2.3.3-2. Type G4T: pump conveys a volume of 110 m^3 *liquid* CO_2 *per hour (approx. 91500* $kg \cdot h^{-1}$*) against 216 bar (g) at a suction pressure of 60 bar (g). In spite of the high compressibility of gaseous* CO_2 *the pump reaches a volumetric efficiency of approx. 80%. The drive power is 900 KW.*

As the requirements for leak tightness and protection when conveying toxic and corrosive liquified gases are so high, dry-running piston pumps come into consideration.

Example E4.2.3.3-3: Compressed air operated piston pump

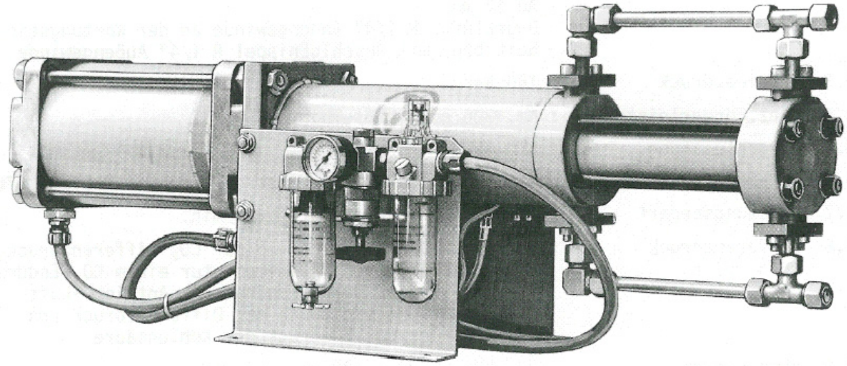


Illustration P42.3.3-2: Decanting and emptying pump Type 7900 for liquid and liquefied gas (NINNELT International GmbH in Stuttgart-Wien).

Description:

- *Universal application for both filling and emptying steel cylinders and containers*
- *Decanting is possible under unfavourable temperature conditions by adjusting the amount of air with a control valve.*
- *By controlling the air pressure it is possible to adjust the pump's delivery pressure and this pressure is automatically held constant by the pump.*
- *The pump automatically stops when the filling process has finished, i.e. the pressure supply is closed. Thus by-pass valves or tubing are unnecessary.*
- *Gaskets washers and fairlead bushings are of polytetrafluoroethylene (PTFE) compound. The pump is thus suitable for dry running and can deliver gas phase.*

4.2.3.4 Vacuum Pumps

The evacuation of tubing and pressurised containers is an ever-recurring task. The necessary vacuum levels are between 1 and 10^{-6} mbar. Here the partial pressures of sealants in the rotary vane pump have to be kept as low as possible. In addition it is often necessary to consider the presence of residual gases with corrosive and/or toxic characteristics. Types of pumps often used are summarized in Table T4.2.3.4-1.

Table T4.2.3.4-1: Vacuum pumps. *) Sorption trap is necessary (oil).

Pump	**Stages**	**Max. inlet pressure [mbar abs.]**	**Ultimate pressure [mbar abs.]**	**Pumping speed [$m^3 \cdot h^{-1}$]**
Rotary vane pump *)	1	1500	10^{-3}	0.5 to 100
Diphragm pump	1 2	1500	2 10^{-2}	0.5 to 4
Roots vacuum pump	2	1000	10^{-3}	50 to 2000
Turbomolecular pump	1	10^{-2}	10^{-6}	10 to 300

4.2.4 Measurement and Control Technology

For the operation of plants for manufacturing and filling the presence of operations personnel is the decisive factor in determining how much instrumentation and control are necessary[1]. After the Second World War it was standard practice to have permanent staffing at air separation plants and other chemical plants. Nowadays they are fully automated and are supervised from time to time by distribution centres which are several hours away by car.

The production of pure gases takes place on very different scales, see the volume of flow in Table T3-1, in each it is reasonable and necessary to have principal control up to full automation in order to reduce the supervisory personnel tasks. There are specialised companies which deal with the implementation of these at all levels which is why it is not necessary to go into further detail. Mostly programmable logic controllers (PLC) are used. They are often combined with a small PC for entering data and visualising the processes.

The systems dealt with in this book usually have one or more parameters which have to be adhered to absolutely for safety reasons. Examples are the allowable filling pressure when filling compressed gases or the upper temperature limit for catalytic purification. If the supervision of the measuring instruments takes place only in frequently, it is necessary that the techniques for alarm- and shutdown-instrumentation function perfectly.

---

[1] Pressure and temperature measurement (WIKA 1995)

Some concepts of safety technologies are dealt with below, even if we do not have to adhere to the standards of aerospace technology or nuclear technology.

"Redundancy" means extravant or superficial. In controls technology redundancy or a redundant factor means the parallel switching of two sensors or measuring systems. If in a measuring instrument the probability of breaking down between two maintenance or calibration periods can be assumed, this probability can significantly be reduced by a parallel measuring instruments. Generally the probability W_R two mutually independent procedures with probabilities W1 and W2 can be expressed as

$$W_R = W_1 \cdot W_2 \tag{4.2.4-1}$$

In our example is $W_R = 10^{-4}$ or 0.01%.

The redundant factor can be avoided if the components show a particularl certainty. For this purpose they are subject of a type approval test. Afterwards the component has a "pattern approval". Typical equipment components are: pressure regulators and switches, safety valves and flow limiting devices, very often from the operation of steam boilers. To reach higher pressure in the filling systems for pure gases the German firm LABOM Mess- und Regeltechnik GmbH in Hude offers pressure limiters in the series BP4540 with bourdon tube and inductive contact switches.

For electrical or pneumatic switches the steady flow principle which is well known in alarm systems applies. In the case of systems for production, purification and filling the following principle applies: when there is energy failure the system has to be brought into a safe condition.

For amplifiers or control systems one uses the term "fail-safe" It is very often the case that the electrical or electronic instrument has an internal switch which complies with the principle of redundancy. The test is carried out according to (IEC 61508 2000). The PLC already mentioned is available in a fail-safe version by the company Siemens AG. In the series S7 the type S7-400F/FH is very often used for complex tasks and the type S7-300F for distributed schemes.

Fail-safe control systems based on hardware like the PLC or the CPU need suitable software. The testing institutes often demand that this is based on electrically erasable programmable read only memory (EEPROM), which means that any change in the software, has to be shown to the testing institute again.

If only one parameter has to be monitored, e.g. filling pressure, there are simpler solutions.

Example E4.2.4-1: Safe mechanism pressure switch for a filling station with a prototype approved pressure limiter; see Illustration P4.2.4-1 on the following page.

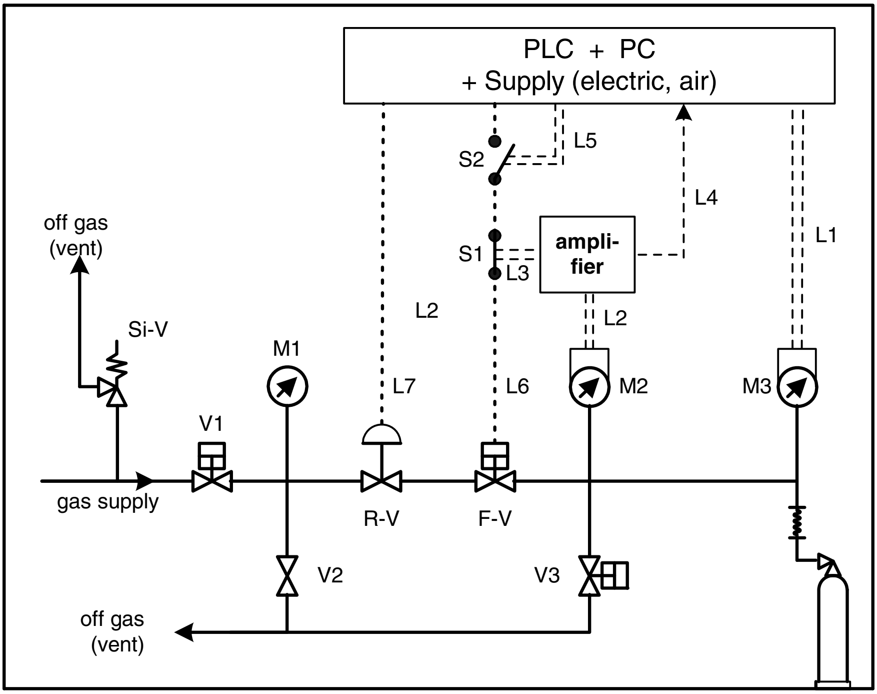


Illustration P4.2.4-1: Switching of a pressure safety chain.

The gas supply provides pressure p_1 which is maintained at the pressure p_0 via the safety valve Si-V, p_1 is indicated on M1. The cylinder is slowly filled through the regulating valve R-V and the following filling valve F-V. The pressure in the cylinder is determined by the pressure sensor M3 which is connected to the control system by the electric connection L1 which operates the R-V via the electric or pneumatic connection L7. The targeted filling pressure is p_3. When this is achieved the F-V is closed via switch S2, as shown in the illustration. L6 is designed to operate electrically or pneumatically.

M2 is an approved pressure limiter (firm Labom) which can open the switch S1 in the connection L6 via the electrical connection L2 using the fail-safe amplifier. This occurs if p_3 is exceeded and a maximum filling pressure p_2 is reached in the cylinder. Then the F-V is closed independently of the control system SPS/PC and the switching condition is relayed via the connection L4. The firm Labom recommends amplifier type WE77-Ex-SH-03 und KHAG-SH-Ex1 of the firm Pepperl und Fuchs in Germany. For these pressures $p_0 > p_1 > p_2 > p_3$ apply.

In addition to being cost-effectiveness the advantage of this type of system is the greater variability of the remaining control which is no longer affected by the switches necessary for safety.

5 Mixtures of Pure Gases

In this chapter we will deal with the production of gas mixtures in gas cylinders. Here the components should be in the gas phase and the associated pressure can be up to 300 bars. The production of cylinders with virtually no pressure for analytical calibration is briefly touched upon in point 7.1. Likewise, the methods for production for the user of mixtures with virtually no pressure are given in point 8.3.

The physics of gas mixtures was introduced in paragraph 2.3 in the main features. The production of gas mixtures occurred after the Second World War mainly based on the measurement of pressure with exact volumes. Nevertheless, it was necessary to include the real behaviour of the gases in the calculation. Since the availability of precise scales, direct relation became possible to the mass and therefore the SI basis. Because a component in a gas mixture is measured by mass regardless of pressure and temperature, no correlations are necessary by means of the real gas factor. The calculation of the ideal volume for a gas G is carried out based on the Molecular weight $M_{G,Mol}$ and the ideal volume V_{STP} as is. The certification of the composition of the gas mixture is carried out on this basis. Nevertheless, the actual pressure should be controled due to industrial safety. For the calculation based on the real gas factor, see example E2.3-1.

The following information is necessary for the characterization of a gas mixture:

- Composition in material amounts, volume fraction, or mass fraction. The composition is mostly certified based on measurement of a physico-chemical value.
- The error in %-rel. from the analytical value, see para. 7.2.
- Purity of the source components, if necessary guaranteed through the measurement of the concentration in the final components. The limitation of moisture content is frequent.
- The stability statement as the minimum time from the production date of the test gas that the measured value can be used see para. 7.2.

The user gives a target specification for the gas mixture with his order; the producer guarantees the adherence to the blending tolerance.

Example E5-1: Gas mixture Helium with 4 % O_2 and 150 ppm CH_4, specified as Mol/Mol. The producer guarantees for 4 % O_2 a blending tolerance of 5 %-rel. as well as an analytical certainty of 1 %-rel., accordingly for the 150 ppm CH_4 10 %-rel. and 3 %-rel.

H. Schön, *Handbook of Purified Gases*,
DOI: 10.1007/978-3-540-32599-4_5

The analyzed mixture is delivered with the following composition: 4.15 % O_2*, 138 ppm* CH_4*. The evaluation must result from the correlation between the blending tolerance and analytical accuracy.*

In the case of the O_2 *– content, 4.15 % ± 1 %-rel. signifies: the actual concentration value lies between 4.11 and 4.19 %* O_2 *(values rounded). The measured value and the true value lie within the guaranteed blending tolerance from 3.8 to 4.2 %* O_2 *.*

With methane, the following situation arises: 138 ppm ± 3 %-rel. for the analytical value, this corresponds to a rounded concentration range from 134 to 142 ppm. The lower value does not lie within the blending tolerance range from 135 to 165 ppm. On the other hand, the measured value is sufficiently placed. For many applications, this difference is marginal; with high demands for quality e.g. the testing of exhaust gas from automobile industry it should not be neglected.

Gas mixtures are required not only for the calibration of analytical instruments, but also for material applications. For both types, the precision required has risen steadily over the recent years. Because normally the homogenised gas mixture fabricated in a suitable procedure must be tested by means of a physical or chemical method. The target-performance comparison must also be considered. This is included in the area of the metrological (instrumentation) certainty which is taken up in para. 7.1. Gas mixtures which serve as standard are often called calibration gas mixtures. Their certification is reserved to national or nationally accredited facilities. The gas mixtures used thereby are called test or calibration gases.

In the USA the National Institute of Standards and Technology (NIST) establish certification. Standard gases sold by NIST are called Standard Reference Materials (SRM). Gas manufacturers may produce NIST Traceable Reference Materials (NRTM). Other standards may be purchased from other national agencies such as the Netherlands NMI.

5.1 Static Procedures

With the static procedures the gases are inserted successively into the cylinder or the volumes that were filled individually are combined. An additional mixing, often called homogenization, or the so-called rolling, is a necessary rule.

On the other hand with the dynamic procedures two or more gases are mixed at the correct concentrations while flowing and are immediately filled into the gas cylinder, most often by means of a compressor.

5.1.1 Gravimetric Procedure

The first pictures, which showed compressed gas cylinders on beam scales, were to be seen in the late 70's. Nevertheless, this was no gravimetric procedure but rather a gravimetric confirmation of the composition because the mixtures were produced mostly manometrically (by pressure). Before the first and after every following addition of a gas, the cylinder would be disconnected from the filling manifold and weighed. The data obtained through large balance accuracy were clearly better than the results achieved by analysis through a comparative process, e.g. dilution by means of gas blenders.

Example E5.1.1-1: Balance mechanism in 1978 in the Specialty Gas Plant of the company Messer Griesheim GmbH/Germany , (Grefer et al 1978).

Illustration P5.1.1-1: Beam balance, taken from (Grefer et al. 1978).

Data of the scales: Loading capacity 100 kg, precision ± 20 mg. The weights were put on by hand. A mix of 2% CO_2 in CO could be certified with a relative error of ± 0.2%-rel.

The weighing on beam balances always takes place against a compressed gas cylinder of the same design. Thus errors caused by the buoyancy in atmospheric air are usually avoided. The scales should be in a dust-free and air conditioned room. The compressed gas cylinders used must exhibit a flawless internal and external condition; loose paint residue can rapidly lead to additional errors.

The principles of this kind of the mass determination have remained unmodified up to now, the accuracy has further increased; see among other things (Wilde 1988). Newer data about the methodology and the analysis of errors as well as examples can be found in (ISO 6142 2001). The three most important errors are:

- The error of the weighings, which is caused primarily by the inaccuracies of the balance. It can be reduced by repeated weighings.
- The uncertainty in the purity. As already discussed in the introduction, this is usually only represented in the type "greater than 5.0". Then it is to be set for the contents

$$G_R \pm \Delta G_R = 99.999\,\% \pm 0.0005\%$$

Here the error is half the difference from the content to 100%.

- The uncertainty of the molecular weight. Given in the data sheets for arsine $M_{Mol} = 77.95\ g \cdot mol^{-1}$. Provided that no more precise information about the value is given, one uses the error ±1 in this digit place.

$$M_{Mol,AsH3} \pm \Delta M_{Mol,AsH3} = 77.95 \pm 0.01 \left[g \cdot mol^{-1} \right]$$

Experiences and possible errors related to the production of precision gas mixtures using highly accurate beam scales were reported by (Heller 1992) and (Gaier u. Heller 1998).

If one proceeds with a light steel cylinder with a volume of 50 l and a working pressure of 200 bar, one must connect an empty cylinder weighing 65 kg. This demonstrates one of the negative sides of the trade of compressed gas cylinders: the unfavourable relation of product mass to the total mass. In our case, the relation is 11.7 : 76.7 ≅ 1 : 6.6.

Example E5.1.1-2: The correlation between an initially weighed-in quantity to the resolution of the scale.

If a mixture of 1 % O_2 ($\varphi = 1.34\ kg \cdot m^{-3}$) in a 50l-cylinder with 200 bar working pressure is desired 0.1 m^3 = 0.134 kg is to be weighed-in. Because a production tolerance of 5 % (= 0.0067 kg) has to be met, the resolution of the scale should be better than 6.7 g. Thus the real gravimetric production began only with the availability of single-pan balances of sufficient resolution in the load range of 100 kg.

In comparison to this, if a mixture of 0.01% = 100 ppm is required, then the initially weighed-in quantity is only 0.00134 kg = 1.34 g and the resolution should be better than 0.067 g = 67 mg. If this is not to be achieved with available scales, a premixture (also called intermediate mixture) with the same gas type can be manufactured with the same components as the target mixture, whose concentration exhibits a favourable intermediate value. In our case a 1% premixture would be very suitable.

Example E5.1.1-3: Data from modern, single-pan electronic balances. The information in the following table was put together by Mettler-Toledo GmbH, Greifensee/Switzerland

Table 5.1.1-1: Scales for the gravimetric production.

Suitable for the cylinder size [l]	Maximum load in [kg]	Readability (resolution) in [g]	Suitable for explosion protection
10	32	0.1	yes
50	150	1	yes
12x50 *	1500	20	yes

*in the pallet: single cylinders, in bundles firmly secured.

Before the following details are to be applied to gas mixing stations and the principle of re-weighing, special attention needs to be paid to the liquid mixtures, see e.g. (Air Liquide 2005). These include mixtures at ambient temperature containing a combination of liquefied gases and liquids. The characteristics of these excluded mixtures which can be produced gravimetrically are:

- The composition of the liquid and gas phase is different and dependent on temperature.
- The composition changes with the withdrawal.
- A filling factor in kg/l of an authorized institute must be present for the liquid mixture concerned, e.g. in Germany through the Bundesanstalt für Materialprüfung (BAM).
- With the presence of a double-valve with tubing, the mixture can be withdrawn both gas-phase as well as liquid.

5.1.1.1 Principle of Gas Mixing Stations (Manifolds)

The principle of the gas mixing manifold can be seen in Illustration P5.1.1.1-1 on the next page.

For the supply, the three inert gases N_2, He, and Ar as well as O_2 were selected. Furthermore, the possibility for up to three premixtures, PM1 to 3 exists. With these connections, another gas, e.g. Kr or N_2O can be connected, of course. In the selected example, one should strictly exclude the use of a cylinder with flammable contents since O_2 is available at high pressure. This principle also applies vice versa to manifolds in which flammable gases are used. In these cases O_2 and other oxidising gases are to be excluded. The same principle applies similarly with acid and basic gases. For instance, HCl and NH_3 are to be avoided in a gas mixing manifold!

The available gases or premixes are supplied to the regulating valve R-V and the parallel valve V10. In the simplest case, the R-V is a needle valve. Since the purging process cannot take place sufficiently *via* the R-V, a parallel valve is recommended. On the way to the compressed gas containers 1 to 4, the fill valve F-V can be found. From here, the pipe lengths to the cylinders should be the same to prevent longer pressure settle-times after the addition of each component. Given the maximum allowable concentration deviation of 0.1%-rel. between the cylinders, pressure settle-times of 5 to 15 minutes are not unusual. They must be determined separately for each installation type. The parallel filling was planned for up to 4 cylinders, which can be isolated individually by valves V12 to V15.

The cylinders should be evacuated; because of time limitations the use of the vacuum pump VP at the manifold should be restricted to residual evacuation of the cylinders.

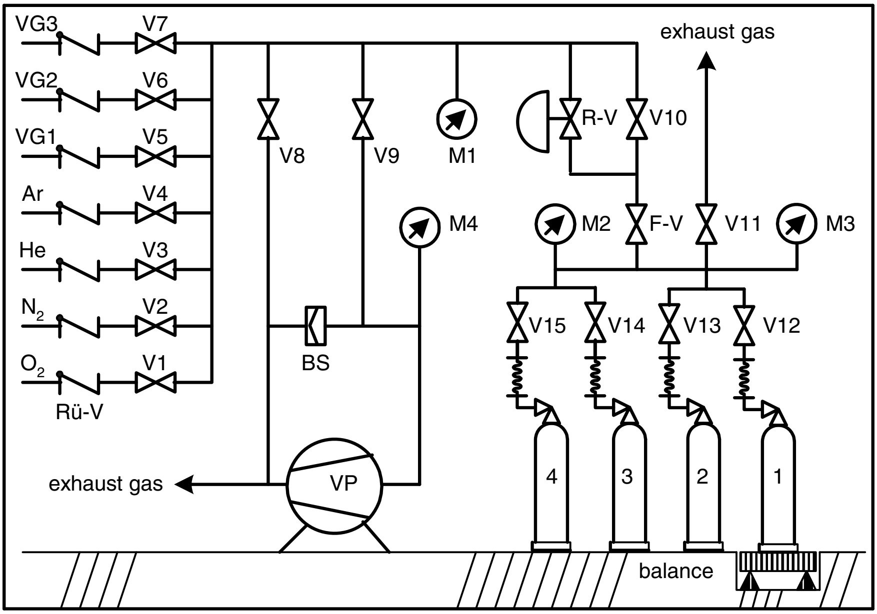


Illustration P5.1.1.1-1: Principle of a manually operated gas mixing manifold.

Cylinder 1 with isolation valve V12 is put on the scale embedded in the floor. The mass of the evacuated cylinder 1 is to be determined and creates the initial value for the following inputs according to the recipe. For the calculation of these, see the example E2.3-1.

Before changing each gas type, F-V must be closed. The pressure venting of the manifold between valves V1 to V9 and F-V is through V8. The evacuation occurs through V9. It is recommended that one conducts at least one purging with each new component followed by a pressure venting and evacuation.

The pressure gauges M1 and M2 are important to the filling process, which can only take place when M1 indicates a higher pressure than M2. Otherwise, an uncontrolled back-flow takes place most often causing the gas mixture to be rejected. M3 is intended as a positive pressure safety device. The manifold can be automated if control valves are used.

Example E5.1.1.1-1: The filling cabinet of the Linde AG Speciality Gas Plant in Unterschleißheim. Photos Mettler-Toledo GmbH, published in the magazine (Mettler-Toledo 2001).

Illustration P5.1.1.1-2: View in a filling cabinet.

Abb. Illustration P5.1.1.1-3: View of the operating side of the filling cabinet.

Illustrations P5.1.1.1-2 and -3 show the filling manifold for the production of flammable mixtures which came into operation in the year 2000.
Two Metler-scales with 32 and 150 kg maximum capacity are installed in the ground, 11 cylinders of either 10 or 50 litres can be filled in parallel. In addition, a vacuum pump on the rear wall and a metering device (Example E5.1.2-1) for liquid injections can be detected on the right hand side. The cabinet has a roll-up door that is locked when p>10 bar and has its own air inlet and exhaust. On the operations side: In the upper box are the valve controllers. With the control unit ID7 from Mettler-Toledo beneath.

5.1.1.2 Re-Weighing (Also Referred to as Back-Weighing)

When looking at filling and analytical control from a distance, an anachronism becomes apparent: The measured value determination is based on mixtures whose mass was determined very precisely by means of re-weighing. The calibration gases are produced gravimetrically, the initially weighed-in quantities adhere to the blending tolerance. A manually complex re-weighing is only accomplished if the customer or additional interests require these data. However, the resolution of modern scales would be sufficient with re-weighing for a certification based on the mass determination for many calibration gases and thus the need for physico-chemical measurements would be reduced significantly.

An easily automated, patented solution has been indicated (Schön 1996)[1] . This consists of:

- A control valve which is firmly connected to the scale and is attached to the compressed gas cylinder to be filled.
- An adjustment element which can be detached and closed. In the open position, a portion remains on the scale while the other portion belongs to the fill plant. Thus, the desired isolation of the filling line is achieved.

Fig. P5.1.1.2-1 shows a simple solution in this sense. A gas cylinder 1 is connected to valve V12 which is closely connected by support A over the scale. The name V12 was chosen because this system fits directly into the gas mixing schematic in Fig. P5.1.1.1-1. V12 is a pneumatically controlled valve with a normally state closed. Now two more lines are necessary for the remaining gas mixing arrangement: the filling line and the instrument air (working air). The heart of the manifold is two detachable connections for which the VCO seals with O-Rings from the product range of the Swagelok Company are suitable. A pneumatic piston cylinder is firmly connected by support B to the floor. The upper portion of the VCO seals is firmly attached to this as well. The lower portions are kept flexible by the filling and air line, which is indicated by coils in the drawing. The piston cylinder can only close or open both VCO seals together. Instead of a piston cylinder, one can also use double-acting pneumatic or electrically operated cylinders. The operations are:

---

[1] The European Patent is in the possession of Linde AG

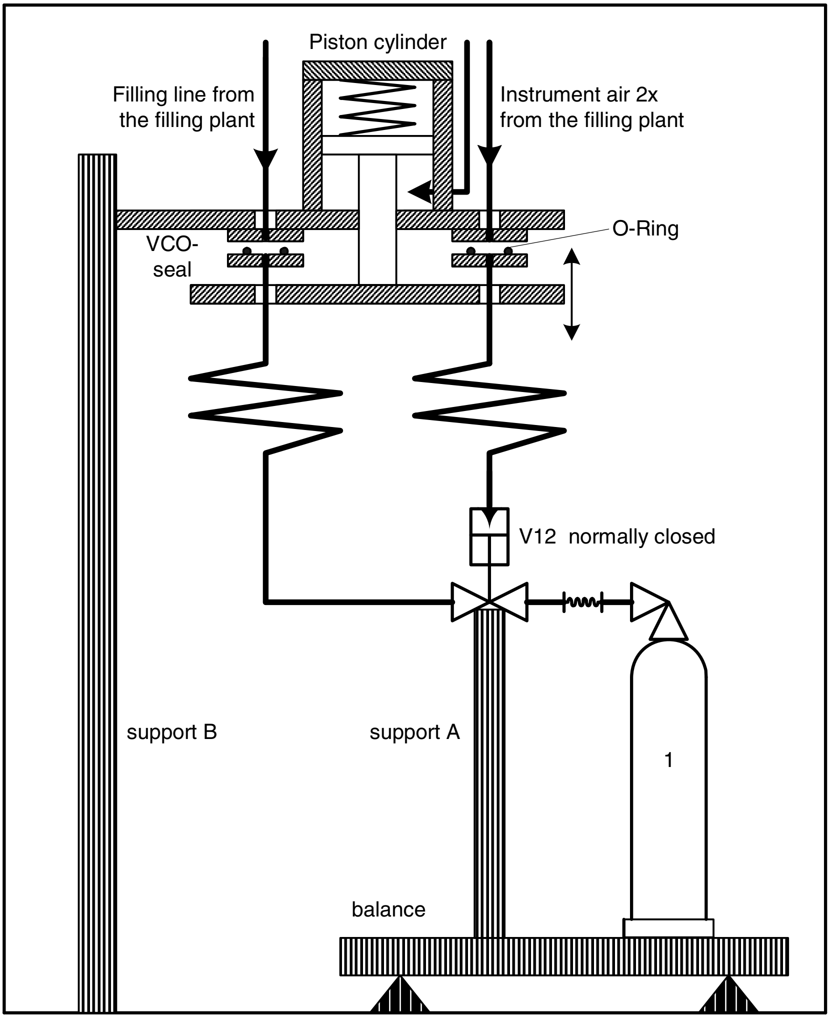


Illustration P5.1.1.2-1: Schematic representation of the re-weighing.

- A: The seals are closed, V12 is open like the cylinder valve, which is evacuated. Then V12 is closed, the filling line and the working air line are brought to atmospheric pressure. The disconnection and weighing of the cylinder follow.
- B: The VCO-seals are closed; the filling line up to V12 is evacuated. After opening V12, the first (smallest) component is introduced.
- C: V12 is closed; the filling and working air lines are relieved. The VCO-seals are opened. The weighing of the first component then takes place.
- D: The introduction of the next components and the mass measurements take place as in Step C.

- E: After the filling of the last component, the gas cylinder valve is closed and after venting the filling line from V12, the cylinder is removed from the scale.

5.1.2 Manometric and Volumetric Procedures

A significant number of manometric (by pressure) and volumetric procedures as well as combinations of both have been developed. Descriptions can be taken from the article of (Hamann et Riedel 1980) as well as the standards (ISO 6146 1979, withdrawn) and (ISO 6144 2003). As already described, their meaning has rapidly diminished.

The traditional manometric procedure can be described on the basis of Fig. P5.1.1.1-1. In the sequence of events, one imagines the scale shut-down and the Pressure Gauge M2 replaced by several very precise pressure transducers for different pressure ranges. The addition of components takes place as described up to the pre-calculated pressures. A significant warming of the gas cylinder normally only occurs with higher pressures. This often assessable temperature rise must be considered with the default pressure. Another method consists of filling the main component up to an intermediate pressure close to the expected pressure. A temperature sensor on the cylinder gives the data for recalculation and, on this basis is further filled to the final pressure.

A purely volumetric procedure occurs when two or more very precisely known volumes of different gases but at the same pressure are subsequently combined. This procedure is important for the analytical calibration.

One can obtain mixtures in the ppm-range by using volumes of different pressures. The principle is shown in the following fig.

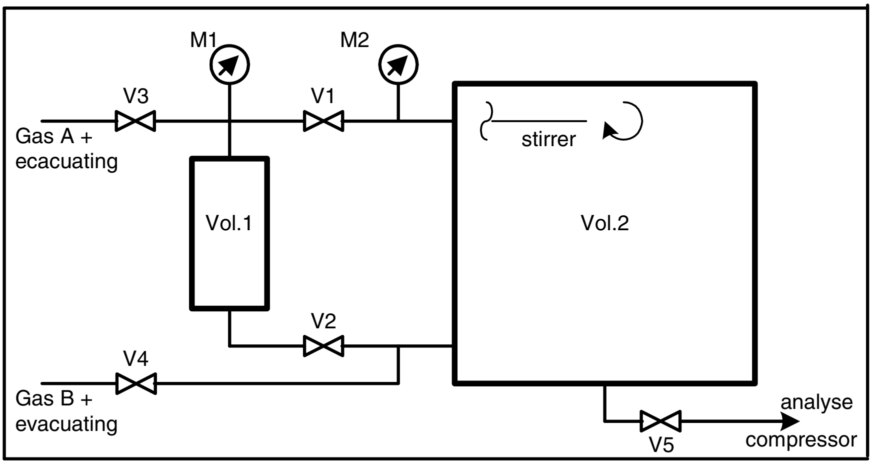


Illustration P5.1.2-1: Principle of the volumetric-manometric procedure at low pressure.

Explanation: Both volumes, Vol. 1 and 2, must be determined very precisely including the tubing and fittings. It is favourable that the structural design occurs in such a way as to permit complete filling with water. Vol. 1 and 2 are evacuated individually through valves V3 and V4 and then filled with gases A and B up to the intended pressure. With work at low pressure and small masses of gas, a thermocouple is usually not necessary. The connection between the volumes is made through valves V1 and 2 as the pressures are equalized. An agitator is necessary for sufficient mixing. Now the mixture can be used through valve V5 either for analytical purposes or to be filled through a compressor into a compressed gas container.

As early as 1970, a mixture of 10 ppm could be produced using such an arrangement in a single step with an accuracy of better than 5 %-rel. if the following parameters were selected: Vol.1 = 1 l, Vol.2 = 1000 l, volumetric precision ± 0.2 %-rel., M1 and M2 mercury manometers with a reading precision of ± 0.05 mm Hg, measurement range from 15 to 1500 mm Hg abs. Such an installation and its operation require a great deal of effort for little productivity.

For the combination of the volumetric-manometric with the gravimetric, the following examples were selected.

Example E5.1.2-1: Possible retrofit installations for a gravimetric mixing manifold, as illustrated in Fig. P5.1.2-2.

Explanation (a): The use of gas-tight syringes is well-known from gas and liquid chromatography. With valve V4 open and V1 and V2 closed, the manifold including the product cylinder to be filled is under vacuum. With the syringe, the septum of soft plastic is punctured, through which gas or evaporating liquid reaches the manifold. V4 is then closed and the next component is introduced through the path V2 – coil – V3. Thus remnants of the injected substance are rinsed into the target cylinder. The coil is externally heated (T = 50 to 150°C) if hard-to-evaporate liquids are introduced. This also includes water.

The procedure becomes entirely gravimetric if in the case of liquids the syringe is weighed before and after the input. With gases, this procedure is usually excluded due to the small mass in the syringe.

Explanation (b): Principal item is a small receiver that can hold a glass ampoule. This is filled with a gas or liquid on a separate manifold under very special conditions. Examples are radioactive isotopes Kr-85 and H-3. The small receiver can be removed from the manifold with the detachable seals B and C shown with O-Ring seals. The container also has an additional seal A through which the ampoule can be inserted. The recommended seals are VCR, thus no realignment of the lines needs be accomplished and one achieves a low leak rate. The approach is analogous to example (a). The ampoule is destroyed by means of a rotating shaft through a sealed port while the manifold is under vacuum. This can be easily constructed by the upper portion of a needle valve. With gases, it is necessary to know the volume and pressure of the ampoule or another parameter, e.g. for Kr-85 the activity is Becquerel (Bq). With liquids, there is the possibility to use preweighed quantities if the mass of the ampoule is known.

A related method is the use of a smaller receiver without seals C, but, with additional valves in the lines to seals B and C. Here, likewise, filling is possible on a separate manifold.

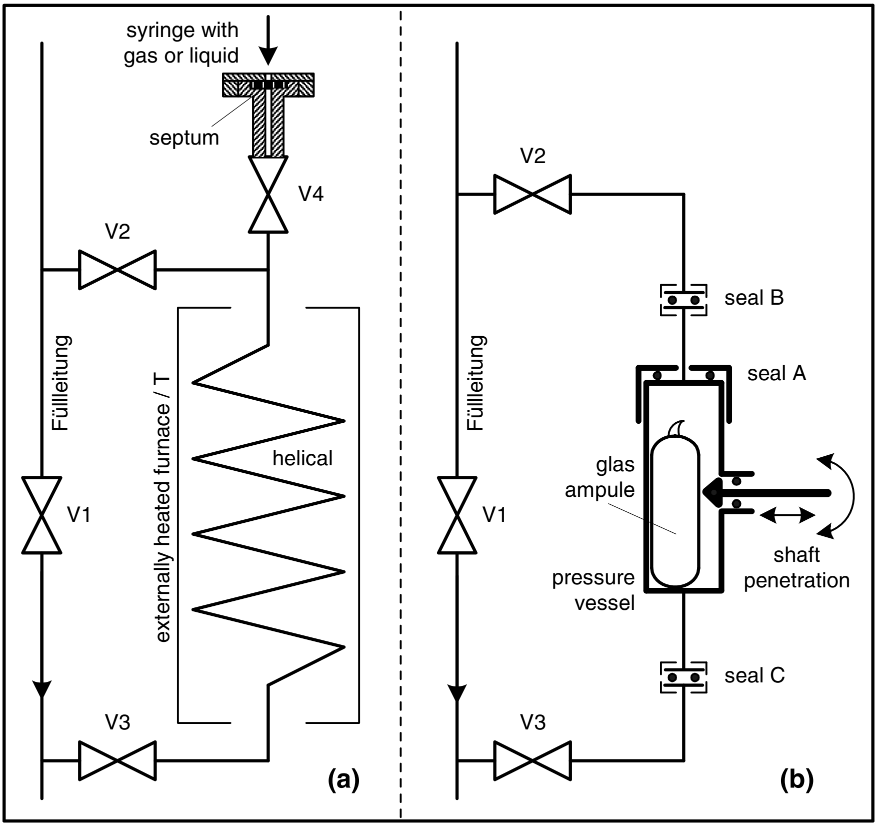


Illustration P5.1.2-2: The volumetric blending of defined masses of gas into a filling manifold for mixing.

5.1.3 Homogenization and Separation

If two or more gases are added successively into a gas pressure container, a homogenization (mixing) occurs. This is due to diffusion which has been discussed in para. 2.2.3. This homogenization can be completed in as short a time as a few minutes or taking several years. Examples of quick mixing are:

- Two or more light gases such as He and H_2 mix at 200 bar after approx. 30 minutes.
- If the lighter gas is introduced first, the heavier gas causes a rapid homogenization. It “falls” through the light and they swirl themselves together. Diffusion smoothes the local concentration gradients. A typical application: Synthetic air starting first with N_2 and then O_2.

- The homogenisation takes place faster in shorter containers with larger diameters than in taller, narrow ones.
- Using a so-called mixing-tube. This is a dip-tube screwed-into the valve (similar to those used for the withdrawal of liquefied gases), but with a closed end and containing many small, laterally drilled-holes up to the end. During gas input, a steady distribution occurs along its axis. The disadvantage is the limited ability to evacuate the cylinder, so that this principle finds little use.

If one cannot determine a specific mixture by obligatory homogenization two methods present themselves:

- By rolling the cylinder around its axis, mechanical impulses are transferred to the particles which lead to turbulence due to inertia when stopping and reversing direction, thus promoting diffusion. One to one and a half minute in one direction is an appropriate turning time. The use of the so-called “mixing strips,” metal or plastic strips that lie loosely in the cylinder, are not recommended. Because they cause abrasion on the walls, the gas cylinder “mutates” and becomes a particle generator.
- The diffusion increases with warming of the cylinder. According to Equ. (2.2.3-8) it increases with $T^{3/2}$. A water bath up to a quarter of the cylinder (“foot bath”) is very effective because of convection forming in the cylinder.

With diffusion, the Entropy of the system increases. This arises from fundamental physical laws: In the absence of external physical forces, no separation occurs!

We have however, a terrestrial force to which every process is subject: the force resulting from the acceleration of gravity with $g_{\mathrm{Earth}} = 9.81\ \mathrm{m} \cdot \mathrm{s}^{-2}$. In evaluating the influence, with a first look is taken at the average (kinetic) energy of a particle according to Eq. (3.4-1).

$$E_m = \frac{M_{\mathrm{particle}}}{2} v_m^2 = \frac{3 \cdot R_{\mathrm{Mol}} \cdot T}{2 \cdot k_{\mathrm{Avogadro}}} = \frac{3 \cdot 8.31441}{2 \cdot 6.022 \cdot 10^{23}} T = 2.07 \cdot 10^{-23} \cdot T \quad [\mathrm{J}]$$

The E_m depends only on temperature, but not upon the mass of the particle. Because of E_m, the particle moves in every direction.

The force F that acts upon the particle through the acceleration of gravity is calculated by the well-known formula “mass times acceleration.”

$$\begin{aligned} F = M_{\mathrm{particle}} \cdot g_{\mathrm{earth}} &= \frac{M_{\mathrm{Mol}} \cdot g_{\mathrm{earth}}}{k_{\mathrm{Avogadro}}} \\ &= \frac{9.81}{6.022 \cdot 10^{23}} M_{\mathrm{Mol}} = 1.63 \cdot 10^{-23} \cdot M_{\mathrm{Mol}} \ [\mathrm{N}] \end{aligned} \qquad (5.1.3\text{-}1)$$

One obtains the potential energy E_{pot} by multiplying F with the height of the particle (s in m).

$$E_{\mathrm{pot}} = F \cdot s = M_{\mathrm{particle}} \cdot g_{\mathrm{earth}} \cdot s = 1.63 \cdot 10^{-23} \cdot s \cdot M_{\mathrm{Mol}} \ [\mathrm{J}] \qquad (5.1.3\text{-}2)$$

Example E5.1.3-1: Computation of the average kinetic and potential energy of H_2 *and* CO_2 *at –20 and +20°C and a height s, which approximate the conditions in a 10-liter cylinder.*

The temperatures are $T = 253.15$ *and* $T = 293.15$ *K,* $M_{Mol,H2} = 2.016 \cdot 10^{-3}$ *kg and* $M_{Mol,CO2} = 44.01 \cdot 10^{-3}$ *kg . By using these in the above shown Eqs. one obtains*

- $-20°C$ *:* $E_m = 5.24 \cdot 10^{-21}$ *J ,* $E_{pot,H2} = 3.29 \cdot 10^{-26}$ *J ,* $E_{pot,CO2} = 7.17 \cdot 10^{-25}$ *J*
- $+20°C$ *:* $E_m = 6.07 \cdot 10^{-21}$ *J ,* E_{pot} *invariably*

The resulting values for CO_2 *indicate that the average kinetic energy at the ambient temperature dominates in contrast to the average potential energy in a proportion of over 100:1, however, a change in the mixing proportion between the upper and lower portion of the cylinder cannot be excluded in principle.*

A calculation of the concentration differences results from the use of the barometric height formula. (Jessel 2001) has shown that for the most unfavourable case regarding concentration of a 50/50 mixture of H_2/CO_2 , at a height of 1 m and 20°C as well as atmospheric pressure, the following deviation results

$$\frac{\Delta C}{C} = 85 \cdot 10^{-6} = 0.0085\ \% - \text{rel.}$$

This leads to C_{H2} = 50.00425 % and at the upper end = 49.99575 % at the lower one. If one uses a pressure of approx. 80 bar abs. for the 50/50 mixture, a small correction would be necessary due to the real behaviour of CO_2, which is however insignificant for our purposes. These resulting values cannot be verified with our current measuring technology. From this one concludes: The force of gravity has a negligible influence.

Note: If one could measure so precisely, one would thoroughly roll a test gas cylinder before sampling the gas mixture and then measure again with the cylinder in the horizontal position.

A decrease in temperature may lead to a separation in components if condensable components are present.

Example E5.1.3-2: The mixture looked-at above, $H_2:CO_2 = 50:50$ *at 80 bar abs., is placed outside overnight at a temperature of about –5°C. What must be considered and done?*

The mixture was calculated with the condition of certain use above +10 °C. With the contents of 900 l N, the partial pressure composition of the mixture amounts to approximately 40 bar abs. H_2 *and 40 bar abs.* CO_2*. From Table T10.4.8. one obtains the vapour pressure of* CO_2 *at –5°C to be approximately 30.3 bar abs. and at +10°C approximately 45.1 bar abs. That means that the mixture has about a 10 bar safety margin above the vapour pressure at +10°C. But at –5°C a portion of the* CO_2 *will condense and a higher* H_2 *concentration will result.*
The cylinder is once again homogenized after heating in a water bath at 40 to 50°C for 2 to 3 hours.

Usually, the computation limit for condensation ("Dew-point limit") is prescribed with +5°C. In the USA a limit of 0°C (+32°F) is often used. All components occurring in the mixture are to be considered at the same time. If there is the risk of the test gas cylinders exposed to much lower temperatures during transportation (winter!) compared to the ones in the lab, then the calculation limit must be decreased, e.g. to –10°C.

5.1.4 Mixtures of Flammable and Oxidizing Gases

If flammable as well as oxidizing components should both be contained in a gas mixture, then during production it has to be asked whether the explosive range is reached. The fact that the completed mixture does not lie in this range is understood. Whoever brings these mixtures into commerce, an evaluation should be carried-out by an authorized institution. In Germany this is the Federal Institute for Material Testing (Bundesanstalt für Materialprüfung – BAM), Abt II. Chemical Safety Engineering. This organization also supported the following discussions. We will look at the first three examples. The %-data are material concentration, the container is a 10 l – cylinder in each case.

Example E5.1.4-1: Gravimetric production of a mixture at a half of the Lower Explosive Limit (LEL) of H_2 in air, which is 4 %, the Upper Explosive Limit (UEL) is 77.0 %. For this mixture, there is an approval by BAM for production up to pressures of 150 bar.

Because the Hydrogen concentration is small, we proceed from a premixture PM containing 49.9% H_2 in N_2. The preweighed quantities M_G were calculated as in example E2.3-1.

Table T5.1.4-1: Preweighed quantities for the mixture 2% H_2 in air ($N_2 : O_2 = 80 : 20$).

Gas G	Concentration in [%]	Volume in [l]	M_G in [g]
H_2 from PM	2.00	56.48	37.90
O_2	19.60	276.18	394.29
N_2	78.40	1076.43	1345.37

Filling directly through the explosive range can be avoided with this mixture if one chooses the filling sequence $H_2 + N_2 \rightarrow$ homogenize $\rightarrow + O_2 \rightarrow$ homogenize. The intermediate homogenization steps are absolutely necessary in order to prevent a location within the cylinder where an explosive mixture can develop. Note that O_2 is introduced at the end of the process at high pressure. Thus conditions are expected to be the same as if pure O_2 is handled. In particular, seals should be oxygen-compatible, also see further below.

Example E5.1.4-2: Gravimetric production of a mixture of 1 % O_2 in H_2. LEL: 4.0 % H_2 in O_2, UEL: 95.2 % (thus 4.8 % O_2 as LEL, related to the filling *sequence* $O_2 \rightarrow H_2$*). A BAM approval for this mixture allows production up to 100 bar.*

Table T5.1.4-2: Preweighed quantities for the mixture 1% O_2 in H_2.

Gas G	Concentration in [%]	Volume in [l]	M_G in [g]
O_2	1.00	8.89	12.70
H_2	99.00	880.49	79.20

With this mixture, one will choose the following sequence $O_2 + H_2$ *and will fill directly through the explosive range from LEL. It will exit this range if the "dilution" of the* O_2 *with* H_2 *reaches the value of 1:21, thus 22 bar abs. Homogenization is again necessary after completion of the filling.*

Example E5.1.4-3: Gravimetric filling of 60 % CH_4 *in air mixture. LEL: 4.4 %, UEL: 17.0 % . A BAM authorization is exists for this mixture at pressures up to be this 150 bar. Because the production has already led to problems, we will calculate it only for 30 bar.*

Table T5.1.4-3: Preweighed quantities for the mixture 60% CH_4 in air ($N_2 : O_2 = 80 : 20$).

Gas G	Concentration in [%]	Volume in [l]	M_G in [g]
CH_4	60.00	180.57	129.24
O_2	8.00	24.08	34.37
N_2	32.00*	96.30	120.36

If one chooses the filling sequence $O_2 + N_2 \rightarrow$ *Homogenize* $\rightarrow CH_4 \rightarrow$ *Homogenize, then filling through the explosive range is inevitable. First 12 bar abs. is introduced, followed by the addition of the CH4, an explosive mixture will result between 12.53 and 14.04 bar, assuming an ideal mixture. We have proceeded from filling pressure of 30 bar, to 150 bar, this sequence must be avoided because the explosive range will be traversed above 60 bar. And it generally applies: the higher the pressure of an explosive mixture, the greater the effect.*

The following filling sequence is also conceivable: CH_4 *+ homogenized* O_2/N_2 *- mixture. Locally combustible mixtures may develop; the filling of air however, is less dangerous than filling* O_2 *as the last component under high pressure.*

As seen, filling through the explosive range cannot always be excluded when producing mixtures with both flammable and oxidizing components. The following prioritization applies to generally prevent explosion and gas mixing:

- Primary explosion prevention: Avoid mixtures capable of explosion.
- Secondary explosion prevention: Avoid all forms of ignition sources.

- Constructive explosion prevention: Pressure resistant building method, protective chambers.

For the evaluation of explosivity of a mixture, the pressure and material dependencies of the explosive limits must be evaluated. In tables and safety data sheets, one usually only finds the values for atmospheric conditions with air as the oxidizing agent.

Now we turn to some concepts and models of explosion prevention. In addition, further details can be read in the monographs from (Bartknecht 1993) and (Steen 2000) safety-relevant numbers are from (Brandes u. Möller 2003) and (Molnárné et al 2003). For the determination of explosive limits, see (EN 1839 2003).

The velocities at which the combustion processes spread in an explosive gas mixture lie between some cm · s^{-1} and several km · s^{-1}. Within the range of low velocities, for example with the Bunsen burner at 40 cm · s^{-1} laminar flow occurs. This can also become turbulent with larger throughput. One calls both cases deflagration, or detonation, if it involves multiples of the speed of sound. As an example, for the H_2-O_2-detonating gas explosion, flame speeds of 3 km · s^{-1} and temperatures over 3000 K can be measured. Explosion is the generic term for detonation and deflagration.

For a gas cylinder it is necessary to ask oneself what could be the ignition source for this closed system. There are two proven possibilities.

a) Particles or also remnants of polymer seals or the like can be electrostatically charged in the cylinder by the gas flow during filling or also during withdrawal. If the cylinder is grounded, as is the case with the connection of a filling line, then sparking can result.
b) If the oxygen concentration of a gas mixture is greater than 23 volume %, then many materials react differently than under atmospheric conditions, they burn more easily. Ignition can develop particularly with high pressures and pressure surges.

The author experienced two harmless cases of the formation of water from detonating gas during the production of calibration gas mixtures of the composition as in the example B5.1-4. In the first case the concentration of O_2 could not be determined; an appropriate water vapour concentration in the cylinder could however. In the second case, a co-worker at the filling manifold noticed that the cylinder had already become very warm after only approx. 20 bar which occurs actually only after filling over 100 bar. The immediate investigation came to the same conclusion as in the first case. Here it had apparently concerned a virtually quiet deflagration, as the ignition source in both cases was only the electrostatic charging.

In two other cases the author has experienced detonations of light steel cylinders at distances of approx. 30 m, in which they were totally destroyed, fortunately but no personal injury occurred.

During the homogenization of an Ar-O_2-H_2-mix in a 10l-cylinder so-called plastic mixing-strips were used. The majority were twisted strips of 200 x 20 x 2 mm. Fortunately the roller was outside a filling building on a covered dock.

With the detonation about 600 cylinders were thrown from the dock, the roofing and roller were damaged, all windows facing the dock were shattered. Only individual pieces of the cylinder remained. The cause for the ignition was a reaction of O_2 with the mixing strips, in addition these proved to be another flammable component in addition to the H_2.

During the gas input to a combustion manifold of a disposal system, an operational error resulted in the interconnection of cylinders which on the one hand contained large amounts of O_2 and on the other H_2. It occurred during the introduction of high pressure. In the course of the detonation the building was severely damaged and burned. The author arrived within a few seconds after the explosion; it reminded him of an image he had experienced in 1943 after a bomb attack on the town centre of Munich. A part of a cylinder was found approx 50 m away in the roof of a delivery van. A likely ignition source was determined to be the effect of O_2 on the seals in the cylinder with the H_2-component, which was not equipped with O_2-compatible materials.

It is asked about the energy, which is released during detonation in a gas cylinder, and the temperature rise and the increase of pressure. We use the calculation for ideal a gas as well as some highly simplified assumptions.

Example E5.1.4-4: In a 10 l-cylinder at 15°C and 100 bar abs. is a H_2-Air-Mixture, whereby H_2 and O_2 are in the stoichiometric proportions. This represents the worst case. The cylinder has a working pressure of 200 bar. One would manufacture this mixture naturally only with a suicidal intention!

The relationship in air is for instance N_2 (with 1% Ar, which is counted as N_2): O_2 = 79:21. The stoichiometric relationship reads $H_2 : O_2 = 2:1$. From this $H_2 : O_2 : N_2 = 42:21:79$ follows. From (D'Ans Lax 1983-98) *one infers the value of 242 kJ · mol^{-1} from ΔH_{H2O} for the water vapour as formation enthalpy at 20°C and 1013.25 mbar.*

The data required for the further calculation in the cylinder have been arranged in the following table.

Table T5.1.4-4: The H_2-Air-Mixture in the 10l-cylinder. ν_G is the number of moles in a molar volume of 23.96 l at 15°C und 1 bar. The specific heat $c_{V,G}$ at constant volume from the ideal kinetic gas theory. Real gases see a dependence $c_{V,G}$ on temperature.

Gas G	V_G in [m^3]	ν_G [number]	$c_{V,G}$ in [kJ . mol^{-1} . K^{-1}]
H_2	0.296	12.35	(3/2) R_{Mol} = 0.0125
O_2	0.148	6.18	0.0125
N_2	0.556	23.21	0.0125
Sum	1.000	41.75	–
H_2O	0.148	6.18	(6/2) R_{Mol} = 0.0250

With the explosion 6.18 Mol of water vapour developed and an energy of

$$E = \Delta H_{H2O} \cdot \nu_{H2O} = 242 \cdot 6.18 = 1495.6 [kJ] = 0.415 [kWh] \qquad (5.1.4\text{-}1)$$

has been released. This divides into radiation energy, which is transferred directly to the cylinder wall, and the amount of heat, which heats the gas in the cylinder and causes an increase in the pressure. There is no reliable data concerning the portions of both energy quantities.

If the detonation does not lead to a destruction of the cylinder, then all of the energy E must lead to a heating $\Delta T_{cylinder}$ *of the cylinder.*

We take the heat capacity of iron $c_{Fe}=0.465\ kJ \cdot kg^{-1} \cdot K^{-1}$ *at 25°C from a table like* (D'Ans Lax 1983-98). *We will dispense with the small correction of the value from 15°C. The mass of the cylinder of 10 kg without a valve is taken from table T6.1.1. The cylinder valve is* $M_{cylinder} = 10.3\ kg$.

$$\Delta T_{cylinder} = \frac{E}{M_{cylinder} \cdot c_{Fe}} = \frac{1495.6}{10.3 \cdot 0.465} = 312 [K] \qquad (5.1.4\text{-}2)$$

This rise in temperature alone would not be sufficient in order to bring the cylinder from a pressure of 100 bar to bursting. However structural changes could occur in the steel or aluminium. If the portion of the radiation energy is only a few percent, then its contribution to the destruction of the cylinder is negligible.

We still have 29.39 Mol of gas in the cylinder from the evolution of water vapour and the remaining N_2. *A* $c_{V,mixture}$ *is calculated on the proportional distribution basis.*

$$c_{V,mixture} = \frac{\nu_{H2O}}{\nu_{H2O} + \nu_{N2}} c_{V,H2O} + \frac{\nu_{N2}}{\nu_{H2O} + \nu_{N2}} c_{V,N2} \qquad (5.1.4\text{-}3)$$

$$= \frac{6.18}{29.39} 0.0250 + \frac{23.21}{29.39} 0.0125 = 0.0151 \left[kJ \cdot mol^{-1} \cdot K^{-1} \right]$$

Analogously with Eq. (5.1.4-2) ΔT_{Gas} *can be calculated, whereby the E undivided is used.*

$$\Delta T_{Gas} = \frac{E}{(\nu_{H2O} + \nu_{N2}) \cdot c_{V,mixture}} = \frac{1495.6}{29.39 \cdot 0.0151} = 3370 [K] \qquad (5.1.4\text{-}4)$$

We proceed from $T_1 = 288\ K$, *resulting in a* $T_2 = T_1 + \Delta T_{Gas} = 3658\ K$. *This value lies in the range of temperatures which have been measured in detonations. We calculate the pressure rise in the cylinder to* p_2 *via Equ. (2.1-7) and* $V_1 = V_2 = V_{geom}$ *as well as* $p_1 = 70.4$ *bar abs.*

$$p_2 = p_1 \frac{T_2}{T_1} = 70.4 \frac{3658}{288} = 894 [bar]$$

The calculated pressure lies within the range of the cylinder burst pressure given gas the test pressure of 300 bar. It should be considered that in the case of *detonation, the pressure develops as a wave whose amplitude can be greater than the calculated one.*

If one carries-out this calculation with a starting pressure of 20 bar in Example E5.1.4-1, one calculates a $p_2 = 179$ bar. A cylinder with a test pressure of 300 bar will withstand such a pressure shock. In this simple calculation it is neglected that at high temperature processes of dissociation (e.g. $H_2O \rightarrow H^+ + OH^-$) take place, which consume energy and therefore decrease the temperature. On the other hand, the dissociation increases the number of moles and thus the pressure.

One can derive from this a rule of thumb can be derived: the explosion pressure in the cylinder may not exceed the test pressure.

In the deflagration, the maximum explosion pressure amounts to 8- to 10-fold the beginning pressure. Thus, during the filling process, the pressure passing through the explosion region should therefore not exceed 10% of the test pressure. As is known detonations cannot be counted on with higher inert gas concentrations. With no or only a slight inert gas concentration, the danger of detonation is clearly higher. Then the factor 10 is too low. This applies also to the following exceptions:

- Acetylene with its triple bond has a very large flammable region from 2.3 to 100 Vol-% in air, a low ignition temperature of 305 °C and may possibly dissociate explosively. This similarly applies to ethane, butadiene, and other chemically unstable gases.
- Laughing gas N_2O is oxidizing gas and supports combustion such as O_2, but when its bonds break, they release additional energy and through its decay, the number of moles increases resulting in a rise of pressure. The resulting explosion is more violent than with the oxidizers air or O_2.

Should it be discovered that a combustion process has taken place in a gas cylinder; a structural change in the cylinder material cannot be excluded. The result can be a tearing-open of the cylinder at a weak point after other pressure changes. Such a cylinder is to be removed from service and certainly scrapped.

Because the filling of reactive mixtures is very complex, when in doubt, consult a responsible institution, such as BAM in Germany.

5.2 Dynamic Process

These processes are used much less often in the production of gas mixtures in compressed gas cylinders than the static methods described above.

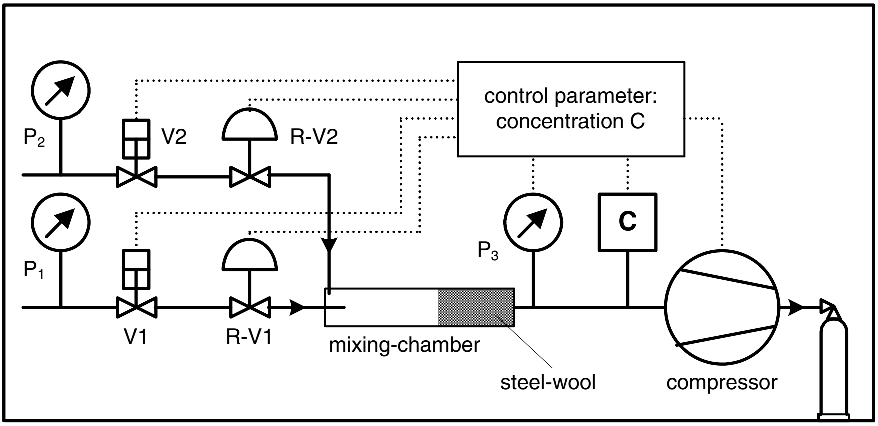


Illustration P5.2-1: Principle of a dynamic blending**.**

Explanation: Two gases 1 and 2 are supplied from lines under pressure p_1 and p_2.

The purpose is to flow the desired relative volumetric flow rates of the two through suitable automatic controllers R-V1 and R-V2 which are supervised by means of the concentration measurement C. The volume flows must be mixed. A mixing chamber serves this purpose wherein one gas enters tangentially and one axially. In addition, in the outlet side of the chamber steel wool is advantageous for homogenization. There are also a significant number of good, patented mixing methods available. A compressor transports the mixture to the cylinder.

This procedure is only logical if there are a large number of cylinders to be filled because deviations from the desired value occur during the start-up process. The procedure has mostly been limited to simple mixtures with large blending tolerances e.g. nitrogen-hydrogen (forming gas) mixtures.

The Mass Flow Controller (MFC) will be discussed in para. 8.3. In recent years the range of application has expanded to both higher pressures up to 400 bar and mass flows to some 100 $m^3 \cdot h^{-1}$. Thus the MFC had also gained interest in industrial dynamic blending mixtures.

Example E5.2-1: Dynamic Mixture with Linde in the USA. A tube trailer is to contain 22,000 ft^3 at STP (623 m^3) of the food packaging mixture, 0.4% CO/35% CO_2/N_2 at 950 psi (65.5 bar). The blending tolerance is 1% relative. Because the mixture has to be put into a tube-trailer where normal mixing techniques are not possible, this application is best suited to be blended dynamically.
As the installation of a dynamic blending system is complex and expensive, a system which can be flexible and utilised for a multitude of gases serves the best function. For this reason, the solution proposed uses components which can

support other mixtures for cylinders or tube-trailers. The automatic controllers from P5.2.1 are Mass Flow Controllers. These are well suited for the application because they measure and control the flow of each gas component to a tight tolerance. The concentration differences warrant different sized MFC's to ensure adequate control.

Table T5.2 summarises the values for the controllers and flow rates. In this case are 0–10 l/min for CO, 0–500 l/min for CO_2 *and 0–1000 l/min for* N_2*. These are commercially available and can be purchased from one of a number of suppliers.*

Table 5.2-1: Component specifications and flow rates for Example E5.2-1**.**

Gas G	Concentration C	Q_V [$l \cdot min^{-1}$]	Q_V MFC [$l \cdot min^{-1}$]
CO	0.004	5.7	0 – 10
CO_2	0.350	496	0 – 500
N_2	0.646	915	0 – 1000
Sum	1.000	1417	–

The concentration is measured through a micro-GC. This allows a rapid response to concentration changes.

A side note: Because this mixture contains CO and CO_2*, moisture must be kept at a minimum (< 0.5 ppm) to prevent the formation of iron pentacarbonyl. Additionally, the final pressure has specifically been reduced to lower the potential for the formation of this compound.*

6 Compressed Gas Cylinders

“Pressure equipment” according to (97/23/EC 1997) means vessels, piping, safety accessories and pressure accessories. “Vessels” means housing designed and built to contain fluids under pressure including its direct attachment to the coupling point connecting to other equipment. “Fluids” are gases, liquids and vapours in pure phase as well as mixtures thereof. A fluid may contain a suspension of solids. A pressure gas vessel (compressed gas container) is only spoken of when it can be used to store gas because it is provided with a suitable valve. The ones without a valve is only a metallic container for which there are no special regulations for transport. Vessels are gas cylinders, bundles, trailers and barrels.

Pressure (compressed) gas cylinders are manufactured for a specific test pressure and are at this pressure subject to an examination of consistency and leak tightness before delivery. For compressed gases the test pressure is normally 3/2 times the service pressure. In the USA, the test pressure is typically 5/3 times the service pressure. Compressed gas cylinders are to be tested periodically. In Europe and in the USA the regulations are different

- EC: (ADR 2005), Pressure Equipment Directive (97/23/EC 1997) and Transport Pressure Equipment Directive (99/36/EC 1999)
- USA: (DOT 2005)

6.1 Types and Conditions

Gas cylinders are manufactured from various materials and brought into circulation:

- Steel or stainless steel: made of seamless or welded pipes.
- Aluminium.
- Special materials like nickel or monel: special procedures by recognized testing organisations are necessary.

For pure gases and especially calibration gases the type of material, the quality of the internal surface and advanced preparation are important to achieve and maintain quality.

H. Schön, *Handbook of Purified Gases*,
DOI: 10.1007/978-3-540-32599-4_6

Example E6.1-1: Sizes and forms of high pressure cylinders made of light steel. From the gas cylinders for technical gases of the company EUROCYLINDER SYSTEMS in Apolda/Germany common sizes were selected from the product range and the most important data were compiled in Table T6.1-1. All cylinders included were specially produced from precision steel tubing by certified manufacturers, (EN 1964-1 2000 and -2 2001)*; they all have a convex base and are subject to a water pressure test. The type of steel used is C22E - 34CrMo4 (=1.1151, USA: 1023). The following applies for the quality of the inner surfaces: devoided of rust, scale and impurities,* (ISO 8501-1 1988).
Sometimes the cylinders are internally sandblasted. The surface quality can be significantly improved by electro-polishing, a procedure reserved for specialized firms.

Table T6.1-1: Common sizes of gas cylinders made of light steel.

Volume in [l]	Outside Diameter in [mm]	Test pressure in [bar]	Length L in [mm]	Mass in [kg]
5	139.7	300	445	5.5
6	139.7	450	535	9
10	139.7	300	805	10
10	139.7	450	855	15
20	204	300	810	24
20	204	450	850	35
50	229	300	1510	57
50	229	450	1560	78

The use of steel, at first normal steel, then enriched steels and stainless steels was determined by availability and technological development from around 1900. After the Second World War aluminium was introduced as a material for cylinders. This had two advantages:

- Lower mass. In comparison with a similar cylinder made of light steel the saving in weight is as much as 30%.
- Increased chemical durability. Aluminium forms its own oxide layer on its surface and is therefore much less reactive than iron. In addition, elemental iron is a catalyst for chemical reactions. The oxide layer is regarded as passivation, see section 6.4. Typical uses of aluminium cylinders are for calibration gases and CO where it is necessary to prevent the formation of iron pentacarbonyl. However this material is not suitable for every gas. F_2 , Cl_2 , HCl, HBr and others cause safety-related damage to the cylinder because of their high affinity with Al.

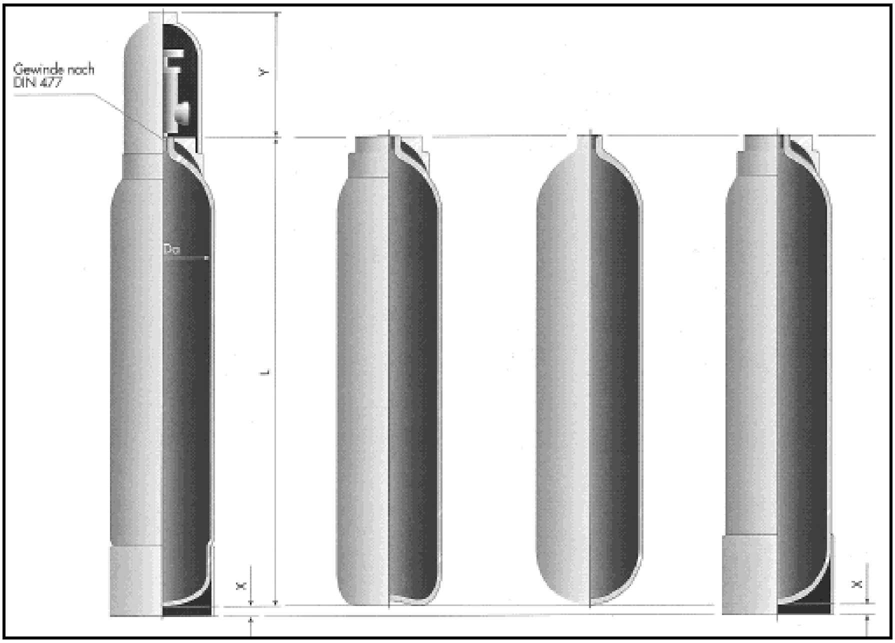


Illustration P6.1-1: Various high pressure steel cylinders. Works drawing from the company EUROCYLINDER SYSTEMS in Apolda/Germany**.**
Explanation: the bottoms are either convex (round, bent outwards) or concave (drawn-in, second from left), L is the length of the cylinder according to Table T6.1-1, X is the foot space for convex bottoms and foot-rings, Y is the height of the protective cap which is screwed onto a neck ring (Gewinde nach DIN477: thread as per German standard).

Example E6.1-2: Aluminium gas cylinders.
The following tables show common cylinder sizes compiled from the product range of the company Luxfer Gas Cylinders in Colwick/Nottingham.

Table T6.1-2: Cylinders from series 6000, material 6061 alloy (Al-Mg-Si).

Volume in [l]	Outside Diameter in [mm]	Test pressure in [bar]	Length L in [mm]	Mass in [kg]
0.5	70	300	230	0.72
1	102	300	240	1.62
2	102	300	390	2.6
5	140	300	525	6.57
10	140	300	965	11.4
20	204	300	940	23.4
40	229	300	1430	44.32
50	250	300	1500	56.02

Table T6.1-3: Cylinders, USA: old english units.

Volume in [cu in]	Outside Diameter in [in]	Service Pressure in [psi]	Length L in [in]	Mass in [lbs]
43	3.21	2216	9.0	1.9
43	3.21	2216	11.8	2.2
87	4.38	2015	9.2	3.0
244	5.25	2216	17.1	8.8
515	5.25	2216	33.1	16.0
1302	8.00	2216	36.3	40.0
2040	8.60	1800	46.3	50.6
2831	9,80	2216	51.9	87.0

The following qualities for the internal surfaces are offered: for untreated pressure gas cylinders the roughness is about 1 µm. Cylinders for pure gases are honed. Honed aluminium cylinders have a roughness which is better than 0.36 µm.

Further development in the field of pressure gas cylinders can be described in the following basic principles:

- The maximum service pressure of 300 bar is increased.
- Using stainless steel and nickel as cylinder material will lead to improved resistance to aggressive substances.
- Efforts to reduce weight will also apply to so-called multi-wall containers. The company Luxfer Gas Cylinders already offers cylinders referred to as “carbon composite cylinders“. Here the internal wall consists of an aluminium alloy which is externally reinforced by the actual pressure carrier, a material made of carbon fibres and composite resin.
- For very chemically active components special layers for the inner surface of steel cylinders are being developed. A nickel layer has very good prospects.

6.2 Accessories

As well as its actual container a pressure gas cylinder also needs its own equipment. Just like the container this has to be suitable for the temperature range from –20 to +70°C. Separate accessories are for example:

- openings for inspection or cleaning.
- the pressed-on foot of the bottle.
- the pressed-on neck ring with the thread to hold the cylinder cap.
- handles or other attachments on the cylinder.

The most important separate accessory is the isolation mechanism, the valve of the cylinder. Cylinder valves are commonly found with combinations of bursting discs, pressure transducers, liquid measurement displays and temperature measurement facilities. For cylinder valves and their additional equipment it is necessary to obtain a construction authorisation or an individual approval by an authorised testing organisation such as TÜV in Germany.

Separate accessories also include measuring devices which can be located inside the cylinder. Every component which comes into contact with the gas has to be suitable for the testing pressure and, if necessary, authorised.

Example E6.2-1: Various cylinder valves for pure gases.

Illustrations P6.2-1 and -2 and the appropriate technical data have been compiled from documents provided by Rotarex S.A. (Ceodeux) in Luxembourg. Explanation of Illustrations P6.2-1: PN 200, DN each 3.5, outboard leakage rate and through the seat each 10^{-7} *mbar · l ·* s^{-1}*. Left: type D200 with soft sealing in the seat: PCTFE, nylon or vespel. Right: type D201 with metallic sealing in the seat suitable for oxygen.*

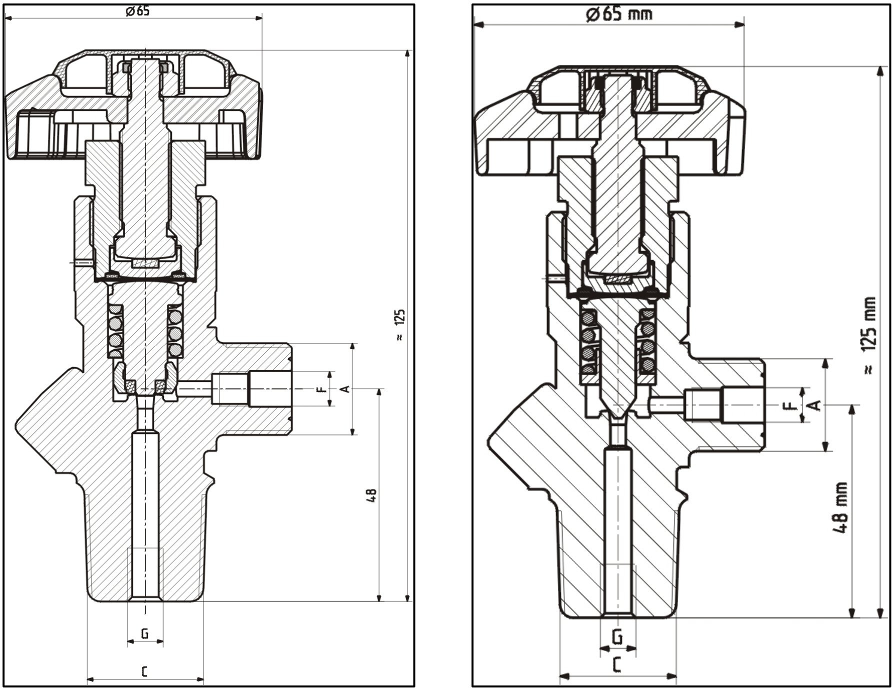


Illustration P6.2-1: Cylinder valves with diaphragm seals.

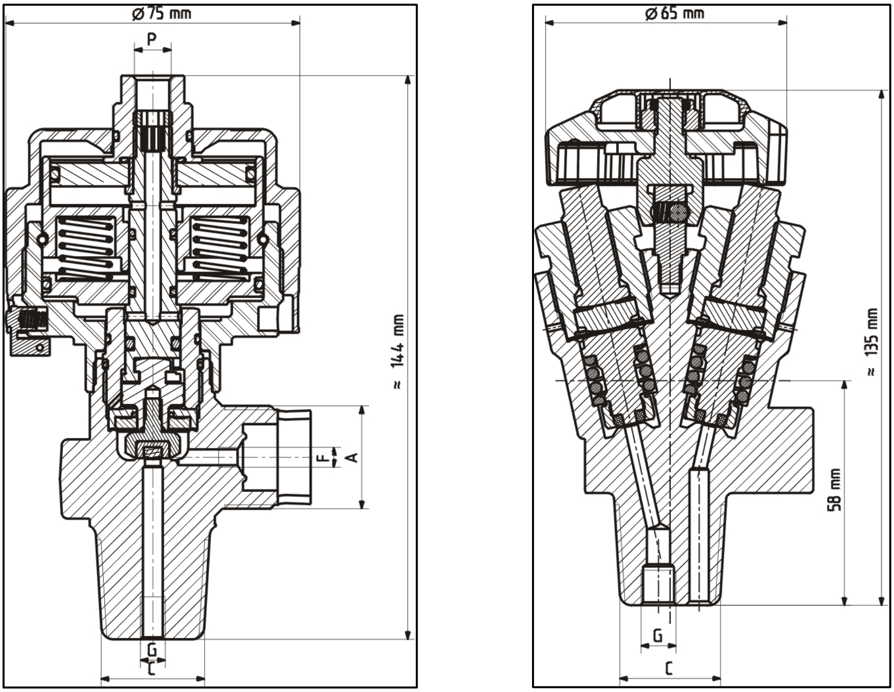


Illustration P6.2-2: Cylinder valves for ultra high purity gases (works drawings).

Explanation: PN 200, DN 4, leakage rate 10^{-8} *mbar ·* $l \cdot s^{-1}$*. Left: type D350, opening and closing via a pneumatic air cylinder. Right: dual valve type D395 for an alternative way of extracting the gas or liquid from the cylinder. The hand wheel is in transport position and for withdrawal is placed on the appropriate valve stem. The dip tube at "G" is not shown.*

Gas cylinders with additional integrated accessories make it easier for the user to put the gas into the station or equipment while maintaining the purity. This also avoids the necessity of obtaining suitable withdrawal manifolds. We will deal with two examples from recent years.

Example E6.2-2: Gas cylinder with pressure regulator of Linde AG.

All gas cylinders require a regulator to reduce the pressure of the cylinder to the normal process pressure of 3 to 4 bar. ECOCYL^{TM} *is a small, refillable cylinder equipped with a valve, a fixed regulator and a flow meter. These devices are fully integrated into the cylinder's cap. Illustration is P6.2-3.*
Technical data overall unit: diameter 9.5 cm, height 44 cm, weight (empty) 2.4 kg, filling pressure 150 bar, outlet pressure 3.8 bar, gas volume 0.15 m^3*, outlet flow 0.25 to 8.0 l/min.*

Illustration P6.2-3: ECOCYL^{TM} from Linde AG.

Example E6.2-3: Sub-atmospheric delivery system UpTime^{TM} from Praxair Inc. Illustration P6.2-4.

The system is a delivery gas package designed as an alternative to existing adsorbent-based technology used in ion implanters. It is comprised of an internal vacuum-actuated excess pressure valve in series with a special designed capillary flow restrictor. The UpTime^{TM} product family encompasses the three primary gases for ion implantation – arsine, phosphine and isotopically enriched boron-11 trifluoride.

Illustration P6.2-4: UpTime$^{\text{TM}}$ from Praxair Inc.

6.3 Marking

Marking the pressure gas cylinders takes place in three steps:

- Engraving letters and numbers on the shoulder of the cylinder. With compressed gases the admissible filling pressure is indicated. For liquid gases the tare weight and the net mass as well as the name of the gas in some jurisdiction is given. This has to agree with the filling factor (the name of the gas is not a requirement in the USA). Furthermore each cylinder has to be provided with the last date (USA) or the next date of the next recurring test (in Germany). Tare mass and net mass can be indicated on a label (metal or plastic) below the valve of the cylinder.
- Colour coding of the bottle, see section 10.10.
- By a caution mark sticker this must be provided at least with the name of the gas and the UN-number.

6.4 Preparation for Filling

The preparation of the gas cylinder is the first step on the way to filling and quality control. This is decisive because mistakes in preparation can not be adequately corrected later and mostly require a new fill with the entire procedure being repeated. For a simultaneous special gas production in the sense of filling different pure gases and gas mixtures it is noted that the staff costs for the individual steps of preparation, filling and quality control are the same. In (Schön 1998) provided Linde AG with an overview of preparation after a new building came into operation in the special gas factory in Unterschleissheim.

The pressure gas cylinder is not only packaging but first and foremost a container for as many as several 100 fills. Ignoring clear cases of using new cylinders or cylinders which have come back after being re-tested, cylinders used by the customers the following questions must be asked: pressure, type of gas, purity? In very few cases it is possible to refill the cylinder without emptying and preparing it. Very frequently residual gases have to be removed. With the so-called air gases such as N_2, O_2, Ar, etc. it is easy to vent them into the atmosphere. As far as possible one proceeds according to the basic principle “Recycling before Removing”. This also applies to rare inert gases Xe and Kr because of their high material value.

For flammable substances there may be oxidation with an open flame or by catalysts. Combustion may also produce hazardous waste.

If as is often the case with small amounts or gas mixtures with corrosive or toxic components, this is not possible then the use of gas washers (scrubber), as dealt with in chapter 3.2.4, is recommended. The advantage is that the operation is almost without overpressure so that both the gases with reduced pressure and the gases from the vacuum pump can be cleaned. In addition, the remaining gases from the filling stations can be taken into consideration.

Of course special procedures which are heavily dependent on the type of gas are well-known. Here are two examples:

Example E6.4-1: Removing highly toxic arsine.

This is a difficult procedure in so far as all the subsequent products are also toxic and therefore subject to a suitable treatment or special waste handling. AsH_3 *can easily be disposed in gas scrubbers with NaOH or KOH, the waste gases usually contain less* AsH_3 *than the concentration of the threshold limit value, but the resultant residue is also subject to the above-mentioned regulation.*

Likewise noteworthy is bonding AsH_3 *with activated carbon. If the charged charcoal is then used in the smelting process to obtain As the circle is elegantly completed.*

Example E6.4-2: Bonding fluorine (F_2)

In gas scrubbers the bonding of F_2 *is not as noteworthy as in the previous example. An alternative is the bonding with aluminium oxide. As the* F_2 *has a greater* *affinity to the Al than the* O_2 *it displaces the latter from the* Al_2O_3*. This process is very exothermic and best takes place at temperatures between 500 and 800°C. Therefore usually quartz pipes are used which have the additional advantage that the reddish burning area can be observed well. The resultant AlF has to either be disposed of in special waste facilities or re-introduced in a smelting process.*

In order to further prepare the relaxed, i.e. at atmospheric pressure, cylinder it is necessary to use vacuum processes. Here it is not just a question of removing gaseous residues but predominantly of removing moisture or other substances which have bonded with the wall of the cylinder. This bonding is mostly a mixture of adsorption and chemisorption. The amounts increase as the surface quality decreases. Removing the gases from the wall in the vacuum at normal temperature takes a long time and is therefore ineffective. It is possible to heat the gas cylinder up to 70°C without special approval. Principally the methods shown in Illustration P6.4-1 are used.

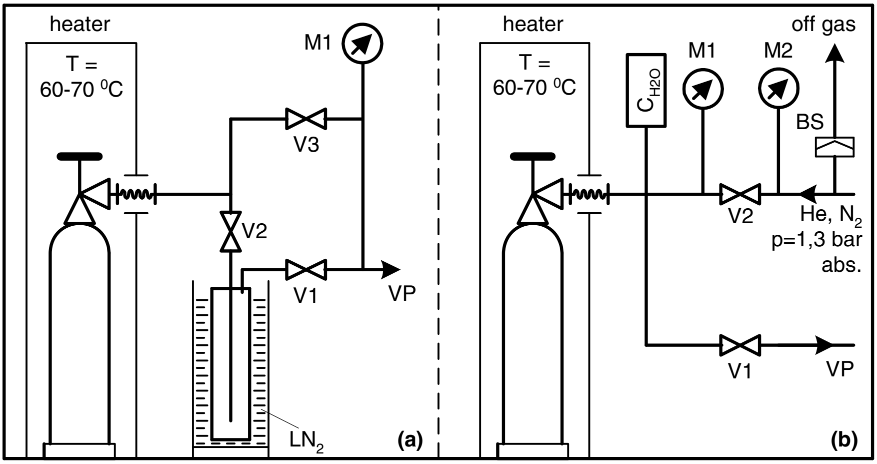


Illustration P6.4-1: Principles of removing residual gases using vacuum.

On the left-hand side (a) there is a representation of a pure evacuation using a cooling trap with liquid nitrogen (LN_2 at –196°C). The cylinder which is at atmospheric pressure is emptied *via* V3 to about 20 mbar with valves V1 and V2 closed. Measurement takes place with vacuum gauge M1. The vacuum pump usually is an oil filled rotary vane pump which however has only a little suction for water vapour or hydrocarbons. Therefore V3 is closed and the cooling trap is switched on by opening valves V1 and V2. Here the condensable components are collected. This method is in vacuum-technological terms disadvantageous because the seat opening is mostly only 3 to 3.5 mm diameter and the flow resistance is proportional to r^3. Thus the method is time-consuming and mostly used in the laboratory.

The method on the right-hand side (b) uses the concept of low-pressure washing usually with an inert gas which has already been dealt with in section 3.5.1 for filling stations for compressed gases. This is available for a possible future evacuation at a pressure of p = 1.3 bar abs. measured with the manometer M1. Firstly the remaining gas present is removed *via* V1. After a chosen pressure (20 – 50 mbar abs.) has been reached V1 is closed again and the purging gas enters *via* V2. Then a significant period of time (up to 5 minutes) has to be available so that the impurities and the purge gas can difuse into each other. Afterwards another evacuation takes place. Usually a fixed number of cycles is chosen (1 cycle = 1 x rinsing gas + 1 x evacuation) 20 to 40 cycles are often necessary. Another possibility is to measure the remaining concentration. In our case the moisture C_{H2O} is determined in the venting purge gas. Suitable measuring instruments are capacitor hygrometers or electrolytic cells (P_2O_5). Then the sequence of cycles can be ended before the maximum number has been reached, e.g. C_{H2O} = 5 or 10 ppm.

The information in section 4.2.3.4 is necessary for vacuum pumps. For high requirements one uses pumps with no oil vapour pressure, such as turbo-molecular pumps with a final vacuum of around 10^{-6} mbar. For corrosive gases like HCl it is necessary to use the so-called chemical pumps. These are usually dry-running pumps with a corrosion-proof implementation with an additional N_2 purge at places where there is a risk of leakage. These pumps can also achieve vacuums below 2 mbar.

There is a special field which is part of preparing cylinders for filling: passivation. This means saturating the wall of the cylinder with a particular substance. It can be achieved by adsorption, chemisorption, and often a combination of both.

For fluoridising (fluorinating) the bottles or the steel equipment important safety factors have to be considered. Passivation is necessary to prevent uncontrolled bonding of the F_2 with the steel. The chemical bonding is exothermic and can lead to burning through in places where the walls are thin. If, however, the surface is specially covered with iron fluoride, it provides a protective layer.

This fluorinating is usually achieved by allowing a low-concentrated mixture to soak in for a long period of time (usually half to one month).

Passivation is also very important to guarantee the stability of small concentrations of highly reactive additives like HCl, NH_3 or NO_2 in gas mixtures. Here a gas mixture is put into the well-prepared and above all dry bottle for a long period of time. If the required mixture has the partial pressure p_G the passivation mixture should have partial pressure p_{Pass} in the region of

$$0.1 \cdot p_G < p_{Pass} < 1.5 \cdot p_G \tag{6.4-1}$$

The passivating mixture has to be removed from the cylinder which should then not be heated again. Passivation involves many empirical considerations and in addition, like internal coating, it leads to a segregation of cylinders pools.

7 Analysis of Purity and Composition

The different requirements for the analysis of purity and composition have already been mentioned briefly in the introduction and are re-introduced here:

- The values for the composition of a gas mixture should have as small an error as possible which are then certified by the gas mixture standards with great precision and use statistical methods. Instead of the word "error" the designation "uncertainty of measurement" is often used.
- Trace analysis has to be able to detect ever smaller amounts. The error occurring here can be dealt with more generously as usual sufficient to the state "the concentration is below the guaranteed maximum value".

The usual terms used in gas analysis can be found in (VIM 1993) and (GUM 1993).

If it is necessary to provide detection for special requirements for a particular use then a validation is needed. This means asking whether a testing procedure, an analytical method, a measuring or testing facility as well as the use of available gas mixtures are suitable in order to fulfill a specific task. The word validation did not establish itself until the 70s, the cutting edge was provided by the pharmaceutical industry, see (Anderson 2002), Germany: (Kromidas 1999) and (Doerffel et al. 1994).This is understandable because using medicine on a patient requires careful and accountable examination for which there are strict rules, e.g. GMP (Good Manufacturing Practice) or FDA (Food and Drug Administration – USA). In 1976 the national organisation FDA issued regulations for good laboratory practice (GLP). In 1983 the US environmental organisation EPA (Environmental Protection Agency) followed suit. The OECD (Organisation of Economic Cooperation and Development) and the EC have adopted this procedure so that in many European countries there are regulations for GLP. An overview can be found in (Seiler 2000) and (Christ et al. 1998).

A special problem in gas analysis is the multiplicity of substances which need to be identified. The concentration of these substances is decisive for choosing the method or the analytical equipment. Proving 10 ppb i-C_4H_{10} in extremely pure CO_2 is a completely different task to proving 1 ppm CO_2 in i-C_4H_{10} .

If the number n of components is present with one another then, copying the mathematical concept, one refers to an n-dimensional matrix. This means that the measuring of one component in a mixture is often influenced by the other substances present. For example, if an analytical method is based on thermal conductivity then it is relatively easy to set up a calibration curve for a binary gas mixture. In a ternary mixture the proportion of both gases which have to be

H. Schön, *Handbook of Purified Gases*,
DOI: 10.1007/978-3-540-32599-4_7

mutually determined needs to be known and appropriate gas standard needs to be available.

As far as the concentrations which has to be determined and is dependent on the sample volume, is a limit for each method of measurement. Beneath this the measurement uncertainty is so large that it is no longer possible to refer to it as measuring. It is called the limit of detection (LOD). A definition can be found in section 7.2.2. The LOD can significantly be decreased if it is possible to concentrate the relevant impurity by a preconcentration from a larger sample volume. Typical methods are adsorption or reaction in a solvent.

7.1 Metrological Certainty

Metrology is the science of measurement and embraces all areas of industry, an overview can be found in (Smith 2002). For the analysis there is the aforementioned book (VIM 1993).

Each result of an analytic determination contains an error. One differentiates between systematic and random errors. Metrological certainty referres to those measures which guarantee that systematic errors can be minimised or avoided and that a predetermined analytical error can be adhered to. Therefore metrological or measurement certainty is a part of the more comprehensive validation.

Manufacturing a calibration mixture, or more generally a gas mixture can usually be achieved with the methods described in chapter 5. In few cases it is possible to attribute the components of a gas mixture directly to their physical units by so-called absolute methods, as is the case with a dewpoint mirror for the temperature or titration for the amounts of the substances.

Very often it is necessary to make a comparison with a calibration gas mixture. The measuring instrument is then used as a comparator to enable the comparison. With standard gas mixtures it must be differentiated between

- Gas mixtures which have been manufactured in gas cylinders under increased pressure and can be stored and tested until an expiration date. In this book we have often referred to the great importance of a gravimetric production of such mixtures.
- The standards of the NIST (National Institut of Standards and Technology, USA), the NMI (Neederlands Meetinstitut) and BAM (Bundesanstalt für Materialprüfung in Berlin) are extremely well-known. These mixtures are delivered with a certificate and are characterised by a tested stability. A company which deals with special gases must inevitably maintain and administer a significant range of these mixtures. It is expected that the use of these standards will continue to increase.
- Mixtures which are manufactured at atmospheric pressure or small gauge pressure immediately before or during the measurement of the calibration mixture. They are already established before the gravimetric production under high pressure and described in standards. The precision obtainable varies enormously and in some cases achieves that of gravimetric production. Even today

they are still partially regarded to classic methods. These are described in ISO 6145: Gas analysis – Preparation of calibration gas mixtures, 10 parts.

- (ISO 6145-1 2003): Methods of calibration.
- (ISO 6145-2 2001): Volumetric pumps.
- (ISO 6145-4 2004): Continuous syringe injection method.
- (ISO 6145-5 2001): Capillary calibration method.
- (ISO 6145-6 2003): Critical orifices.
- (ISO 6145-7 2001): Thermal mass-flow controllers.
- (ISO 6145-8 2005): Diffusion method.
- (ISO 6145-9 2001): Saturation method.
- (ISO 6145-10 2002) Permeation method.
- (ISO 6145-11 2005) Electrochemical method.

Sampling is a further point of metrological certainty. When sampling the following points must be observed:

- Contamination by impurities, predominantly atmospheric air, has to be avoided by appropriate purging and the guarantee of high leak tightness.
- Especially with corrosive gases moisture on the walls can lead to errors in the measurement. If necessary the equipment for withdrawal has to be kept in a drying chamber or purged with inert gas.
- If pressure decreases during the sampling it is necessary to avoid a so-called mass discrimination. This means disadvantaging gases with large masses when they flow through small diameter tubing. It is therefore necessary to choose laminar flow conditions.
- When withdrawing from the liquid phase it is necessary to make sure that a complete vaporisation is achieved. If a permanent sampling takes place from one tank then an evaporating coil must always be placed above the liquid with its axis vertical.

Metrological certainty is an important point for certification according to (ISO 9001 2000) to manufacture pure gases and gas mixtures and involves a not inconsiderable effort. For laboratories which test according to (ISO/IEC 17025 2005), the significance is considerably greater.

Here it is necessary to verify the self-manufactured secondary or dynamic procedures with standard mixtures like NIST by measuring exactly.

7.2 Error Analysis

Here is an introduction to the generally well-known concepts of the theory of errors. These concern random errors. Conclusions about systematic errors can only be drawn when random errors have been minimised with statistical certainty.

Anyone dealing with gas analysis has to concern himself with common methods of the theory of errors. Reading the already quoted works (GUM 1993) and (Kromidas 1999) is recommended, as well as (Doerffel 1990) and (Skog u. Leary 1996). As previously mentioned the word “uncertainty” is increasingly being used instead of the word “error”.

7.2.1 Mean, Error and Error Propagation

If the values X_i are present in mA, mV, mm or simply as a scale division and if their number is n then the mean is usually formed as the arithmetic term $\overline{X}$

$$\overline{X} = \frac{\sum_{i=1}^{n} X_i}{n} \qquad (7.2.1\text{-}1)$$

Coming to different kinds of errors the variance σ^2 is introduced and the experimental standard deviation σ as positive square root from the variance.

$$\sigma = \sqrt[2]{\frac{\sum_{i=1}^{n} \left(X_i - \overline{X}\right)^2}{n-1}} \qquad (7.2.1\text{-}2)$$

In addition to this experimental standard deviation based on the mean of the measurements a second standard deviation σ_B has also to be introduced by the so-called investigative method B. This is based on the fact that a value σ_B has been attributed on the basis of scientific examinations, experience and probability considerations. Also included are details about standard mixtures which have been produced gravimetrically and where the errors associated with the scales used are the most significant part of the measurement uncertainty.

The term (n–1) in the denominator is referred to as the number of degrees of freedom f_{FG}. Here one often uses relative standard deviation σ_{rel} also known as RSD.

$$\sigma_{rel} = \frac{\sigma}{\overline{X}} 100\,[\%] \qquad (7.2.1\text{-}3)$$

For further observations with a large number n of measurements a normal distribution or a Laplace-Gauss distribution can be assumed as well as the adaption. The fluctuation in the values is caused by independent or only vaguely dependent random causes. If the number n is in the normal range of up to 30 then one needs to use a slightly deviating distribution, the so-called t-function (also referred to as student’s distribution). This is shallower than the Gauss distribution and is dependent on the chosen probability W and on f_{FG}.

The simplest indication of the mean for few errors with a small n is

$$\overline{X} \pm \sigma \qquad (7.2.1\text{-}4)$$

In contrast there is the so-called confidence interval of the mean which contains a statistical component and provides correct information about the error.

$$\overline{X} \pm \Delta\overline{X} = \overline{X} \pm \frac{t(W, f_{FG})}{\sqrt[2]{n}}\,\sigma \qquad (7.2.1\text{-}5)$$

Of course σ_{rel} can be used instead of σ then one gets $\Delta\overline{X}_{rel}$. The t-distribution is a function of the chosen probability W ($0 < W < 1$) and the number of the degrees of freedom $f_{FG} = n-1$. Appendix T10.8 is a table which gives various probabilities.

Example E7.2.1-1: calculation of mean and error for peak heights in mm or area units in mm² of a gas chromatogram. The following values of quantity should be available.

$X_1 = 65.4$
$X_2 = 64.7$
$X_3 = 66.3$
$X_4 = 63.0$
$X_5 = 64.1$
$X_6 = 67.3$
$X_7 = 67.8$
$X_8 = 65.1$
$X_9 = 66.9$
$X_{10} = 66.1$
$X_{11} = 63.4$
$X_{12} = 65.9$

Using the above equations we carry on the calculation with a calculator.

$$\overline{X} = \frac{\sqrt{\sum X_i}}{n} = \frac{786}{12} = 65.5[\text{mm}]$$

and

$$\sigma = \sqrt{\frac{\sum\left(X_i - \overline{X}\right)^2}{n-1}} = 1.51[\text{mm}]$$

One chooses a probability of 95%, thus $W = 0.95$. From Table T10.8 one obtains for $f_{FG} = 11$ and the t value is 2.20.
Thus the information about the absolute and relative error is

$$\Delta\overline{X} = \frac{t\left(W = 0.95, f_{FG} = 11\right)}{\sqrt{12}}\sigma = \frac{2.20}{3.46}1.51 = 0.96[\text{mm}]$$

$$\Delta\overline{X}_{rel} = \frac{\Delta\overline{X}}{\overline{X}}100 = \frac{0.96}{65.5}100 = 1.47[\%-\text{rel.}]$$

Now the error propagation needs to be considered. Here one assumes an analysis function $f_{Analysis}$ which describes the desired concentration depending on the values X_j and the calibration standards with the concentrations $C_{k,Standard}$. j and k are running indices up to $j = p$ and $k = r$.

$$C = f_{Analysis}\left(X_1, X_2, ...X_p, C_{q,\text{Standard}}, C_{2,\text{Standard}}, ...C_{r,\text{Standard}}\right) \qquad (7.2.1\text{-}6)$$

If $f_{Analysis}$ is a random mathematical function of what can change in the brackets then the calculation of the error requires the help of the partial differential equation.

$$\Delta C = +\sqrt{\left(\sum_{j=1}^{q}\frac{\partial f_{Analysis}}{\partial X_j}\cdot\Delta\overline{X}_j\right)^2 + \left(\sum_{k=1}^{r}\frac{\partial f_{Analysis}}{\partial C_{k,\text{Standard}}}\cdot\Delta C_{k,\text{Standard}}\right)^2} \qquad (7.2.1\text{-}7)$$

For further explanation in this chapter one now simplifies twice:

- f_{Analysis} should only include the four basic mathematical calculations (i.e. not squares, roots, exponential functions or logarithms), for more complicated cases see (GUM 1993) and (Doerffel et al. 1994).
- One always accounts for the relative errors.

The relative errors are the $\Delta\overline{X}_{j,\mathrm{rel}}$ according to Eq. (7.2.1-5) using $\sigma_{j,\mathrm{rel}}$. The gas standards have the relative errors $\Delta C_{k,\mathrm{Standard}}$ omitting the relevant indices. Furthermore it is assumed that the values of the standard gas are produced before the calibration mixture or vice versa. One now differentiates between the three different types of error:

- The additive error $$\Delta C_{\mathrm{add,rel}} = \sum_{j=1}^{l} \Delta\overline{X}_{j,\mathrm{rel}} + \sum_{k=1}^{m} \Delta C_{k,\mathrm{Standard}} \qquad (7.2.1\text{-}8)$$
- The error according to the least squares method, which is obtained from Eq. (7.2.1-7). This calculation is scientifically correct.

$$\Delta C_{\mathrm{kQ,rel}} = \sqrt{\sum_{j=1}^{l}\left(\Delta\overline{X}_{j,\mathrm{rel}}\right)^2 + \sum_{k=1}^{m}\left(\Delta C_{k,\mathrm{Standard}}\right)^2} \qquad (7.2.1\text{-}9)$$

- The mixed error which is very often used.

$$\Delta C_{\mathrm{mixture,rel}} = \sqrt{\sum_{j=1}^{l}\left(\Delta\overline{X}_{j,\mathrm{rel}}\right)^2} + \sum_{k=1}^{m}\Delta C_{k,\mathrm{Standard}} \qquad (7.2.1\text{-}10)$$

- This applies for the absolute and the relative errors.

$$\Delta C_{\mathrm{add}} \geq \Delta C_{\mathrm{mixture}} > \Delta C_{\mathrm{kQ}} \qquad (7.2.1\text{-}11)$$

Example E7.2.1-2: One intends to measure a calibration mixture with approx. 10 ppm benzene in N_2 against a standard with $C_{Standard}$ = 10.8 ppm and an error of $\Delta C_{Standard}$ = ± 1 %-rel. The means of the values of the measurements are given in mm:

From Example E7.2.1-1: $C_{\mathrm{Standard}} \hat{=} \overline{X}_1 = 65.5$ *with* $\Delta\overline{X}_{1,\mathrm{rel}} = 1.47\,[\%-\mathrm{rel.}]$

Values of the sample $C \hat{=} \overline{X}_2 = 61.1$ *with* $\Delta\overline{X}_{2,\mathrm{rel}} = 1.15\,[\%-\mathrm{rel.}]$

The analytical function and thus the concentration sought then are

$$C = f_{\mathrm{Analysis}} = \frac{\overline{X}_2}{\overline{X}_1}\cdot C_{\mathrm{Standard}} = \frac{61.1}{65.5}\cdot 10.8 = 10.07\,[\mathrm{ppm}]$$

The relative errors are

$\Delta C_{\mathrm{add,rel}} = 3.62$ $\Delta C_{\mathrm{mixture,rel}} = 2.87$ $\Delta C_{\mathrm{kQ,rel}} = 2.12$ *in %-rel.*

When alternately producing the values of standard gas mixture and calibration mixture, the mean $\overline{X}_{1-2}$ and the standard deviation $\sigma_{1\text{-}2}$ are different from Eqs

(7.2.1-1) and (7.2.1-2), because the first step is to form the proportion of the respective values. Altogether n values are produced but there are only n/2 pairs.

$$\overline{X}_{1-2} = \frac{2 \cdot \sum_{i=1}^{n} \frac{X_{i,2}}{X_{i,1}}}{n} \tag{7.2.1-12}$$

$$\sigma_{1-2} = \sqrt[2]{\frac{\sum \left(\frac{X_{i,2}}{X_{i,1}} - \overline{X}_{1-2} \right)^2}{\frac{n}{2} - 1}} \tag{7.2.1-13}$$

$$C = f_{\text{Analysis}} = \overline{X}_{1-2} \cdot C_{\text{S tan dard}} \tag{7.2.1-14}$$

$$\Delta\overline{X}_{1-2} = \frac{\sqrt{2} \cdot t(W, f_{FG})}{\sqrt{n}} \sigma_{1-2} \tag{7.2.1-15}$$

7.2.2 Determining Expanded Uncertainty

Gum's 1993 work describes another means of determining uncertainties through statistical methods: using a somewhat different "variance of the mean "σ^*" the empirical variance σ can be deduced from Eq. (7.2.1-2).

$$\left(\sigma^*\right)^2 = \frac{\sigma^2}{n} \tag{7.2.2-1}$$

The combined standard uncertainty "σ_{komb}", which is the same as the positive square root from the combined variance σ^2_{komb} is determined by using the error propagation about the partial derivations of the analysis function f_{Analysis} according to the values X_i and the concentrations $C_{\text{k,Standard}}$.

$$\sigma^2_{\text{komb}} = \sum_{1}^{p} \left(\frac{\delta f_{\text{Analysis}}}{\delta X_i} \right)^2 \cdot \left(\sigma^*_{X,i}\right)^2 + \sum_{1}^{q} \left(\frac{\delta f_{\text{Analysis}}}{\delta C_{\text{k,S tan dard}}} \right)^2 \cdot \Delta C^2_{\text{k,S tan dard}} \tag{7.2.2-2}$$

The expanded uncertainty ΔC^* is obtained by multiplication with the coverage factor k_W which is dependent on the chosen probability W.

$$\Delta C^* = k_W \cdot \sigma_{\text{komb}} \tag{7.2.2-3}$$

k_W can be taken from the following table. A practical simplification of Eq. (7.2.2-2) is obtained by using the relative variance $\left(\sigma^*_{\text{rel}}\right)^2$ which then leads to the relative combined uncertainty ΔC^*_{rel}.

Table T7.2.2-1: Coverage factor.

Probability W	**Coverage factor k_W**
0.90	1.645
0.95	1.960
0.99	2.576

$$\Delta C^{*}_{rel} = k_W \cdot \sigma_{komb,rel} = k_W \sqrt{\sum_{1}^{p} \left(\sigma^{*}_{X,i,rel}\right)^2 + \sum_{1}^{q} \Delta C^2_{k,Standard,rel}} \qquad (7.2.2\text{-}4)$$

Using the figures from the example E7.2.1-3 $\sigma_{komb,rel}$ = 1.1 %-rel is obtained. One chooses W = 0.95 and takes k_W as 1.960 from the above table. This results in a ΔC^*_{rel} of approx. 2.2 %-rel., which compares well with the result $\Delta C_{kQ,rel}$ = 2.12 %-rel.

Comparing the mathematical methods in section 7.2.1 and 7.2.2 it is striking that

- The formation of the mean is the same.
- The standard uncertainties differ by the factor $1/\sqrt{n}$, which is an additional statistical evaluation for the combined standard uncertainty.
- In section 7.2.1 to obtain the mean of the individual measurement the standard uncertainty is also multiplied by $1/\sqrt{n}$ and then follows multiplication by the value from the t-distribution. This results in the error of the mean with statistical certainty. The error of the measurement result $\Delta C = \Delta f_{Analysis}$ is obtained with the formulae of the error propagation and the least squares.
- The combined uncertainty dispenses with the definition of an error of the mean with statistical certainty. The combined standard uncertainties are included in the formulae for the error propagation and the least squares. The result is multiplied by the statistical coverage factor and results in ΔC^*.

Determining the combined uncertainty uses GUM's (1993) method A, it is also permitted to determine on the basis of verbal characteristics and estimations (method B). This is often the case when the error has to be provided from standards or comparative procedures.

For the error calculations no method is prescribed. The analysts have to decide which method is suitable for the measuring procedure being used. It is, however, important that the method used is comprehensible and traceable.

7.2.3 Poisson Distribution

Now one concerns oneself with error determination when there is no Laplace-Gauss distribution. This is the case when counting impulses, such as the measurement of radioactivity which releases an optical or electrical impulse every time an atom disintegrates. Then the so-called Poisson distribution is obtained. The value Y_i is the sum of the impulses registered during the measurement time. If these measurements are repeated n times within the same timeframe then the mean $\overline{Y}$ can be formed analogous with Eq. (7.2.1-1). However, the standard deviation looks completely different from that described above.

$$\sigma = \sqrt[2]{\overline{Y}} \tag{7.2.3-1}$$

Table T7.2.3-1: Standard deviation σ for the Poisson distribution depending on the count rate**.**

Average (mean) $\overline{Y}$	σ	σ_{rel} **in %-rel.**
100	10	10
1000	31.6	3.16
10000	100	1
100000	316	0.316
1000000	1000	0.1

The t table can also be used for the Poisson distribution when the error is calculated according to Eq. (7.2.1-5).

7.2.4 Noise and Limit of Detection

The term noise in the sense of a background noise began its origin in radio technology after World War 1 and means that the radio reception was accompanied by various disturbing components. In analysis, noise means short-term fluctuations in the line of reference (zero line). The causes are as follows:

- Fluctuations in the frequency of the electricity supply (usually 50 Hz, USA: 60 Hz).
- Influence of external electrical fields.
- Thermal fluctuations of the electrical flow in resistors, condensers, galvanic elements etc.
- Fluctuations in the electron flow in transitional areas as in semi-conductors, called Schottky noise (or shot noise)
- Influence of temperature, pressure and other parameters on chemical processes.

To obtain a quantification one uses the term S for the measurement value and N for the noise, whereby predominantly is the ratio S/N which is interesting because the individual S is otherwise reserved for entropy. The measurement signal S corresponds with the $\overline{X}$ which is allocated to the standard deviation σ. If $\overline{X}$ is a direct current signal the relationship S/N can be approximated with

$$\frac{S}{N} = \frac{\overline{X}}{\sigma} = \frac{1}{\sigma_{rel}} \tag{7.2.4-1}$$

This leads to the definition that a measurement value can visually be clearly differentiated and evaluated from the background, and then one obtains

$$\frac{S}{N} \geq 3 \qquad \text{or} \qquad \overline{X} \geq 3\sigma \qquad (7.2.4\text{-}1)$$

This formula also defines the already mentioned limit of detection (LOD). In addition many analysts also use the destination limit of S/N larger than 9 or 10. This, however, means that the admissible error has to be significantly reduced in comparison with LOD. Please refer to (Doerffel et al. 1994) for more exact but mathematically more complicated definitions of limits of determination and destination limits.

Using analysis to improve the signal/noise ratio is a continual task. Here are some possibilities:

- Protection against electrical fields and stabilising the voltage and frequency of the supply.
- With low frequency or direct current signals it is advantageous to modulate the mean frequency as this allows an amplification of the signal and thus the noise can be filtered out. In order to obtain the final measurement a demodulation is necessary, i.e. the medium frequency has to be removed once again. This procedure is well-known from radio technology.
- The principle of the chopping amplifier is very often used. Here the pending signals are formed by mechanical or electronic choppers into rectangles which can then be amplified with less noise and then turned back into an analogue signal.
- The so-called lock-in-amplifier works in a similar way. Here it is possible to filter out a measurement signal from the signal/noise ratio ≤ 1. This method is often used for optical signals and should then be further explained. It uses two sources which have the same frequency and phase which is why it is referred to as a coherent amplifier. The continual light of both sources is mechanically chopped which corresponds to a modulation. The chopped light from one of the sources runs through the sample and then through a spectral disintegration and a detector which changes the light into electrical current. The light from the other source runs directly into a similar detector. Afterwards both electrical currents are compared in a demodulator, the noise is largely filtered out and then there is the measurement signal.
- Using scratch filters (resistor-capacitor units) it is possible to eliminate high frequency interference from low frequency or direct current measurements. Examples are the total hydrocarbon analyzer (THC) or the thermal conductivity detector.
- Partition into a Fourier series, which also enables a filtering, refer to section 7.3.3.1 about FTIR.

7.2.5 *Stability of a Gas Mixture*

The concentration information C ± ΔC means that the "true value C_{true} is in the interval of

$$C - \Delta C \leq C_{true} \leq C + \Delta C \qquad (7.2.5\text{-}1)$$

This corresponds to the understanding based on the probability calculation that each measurement value C_i is equally probable in this interval. Here an additional condition is $\Delta C_i \leq \Delta C$.

Information about the stability of a calibration gas mixture is orientated according to this. It says that in the given period of time the true value is in the interval as per Eq. (7.2.5-1). Reasons that can lead to a fluctuation of the true value from this interval and thus stop the stability are usually as follows:

- Sorption processes on the wall of the container. The level of moisture is the most common example.
- The formation of a liquid phase when condensable components cool. Here warming-up can help to achieve a renewed homogenisation.
- Chemical reactions between the components. An example is small amounts of O_2 in H_2.
- If there are small leaks gases with small atoms can escape faster than others. Example: calibration gases in He.
- Chemical change of a component. An example is ethylene oxide which can polymerise.

When the end of the stability period is reached and the calibration gas mixture is still needed then a new analysis can determine the value of the existing concentration. If the difference from the original value is in the range of the given error then the stability period can be prolonged.

7.3 Instrumental Analysis

In 1961 the author started work at the Industrial Gas Company[1] in East Berlin as well as the previously mentioned purification of one litre of the stable isotope Kr-86 it was his task to construct thermal conductivity cells and ionization detectors for the recently established gas chromatography. Many wet chemical methods were still being used. Instrumental analysis uses the physical characteristics of the substances to be analysed, the first developments go back to the 30s of the previous century. Meanwhile this direction has become decisive for analysis. It enabled the use of electrical and electronic innovations and has a significant future due to the miniaturisation of sensors and circuits.

Recommended reading is the monographs by (Doerffel et al 1994), (Hogan 1997), (Staab 1994), (Skoog and. Leary 1996) and (Jessel 2001).

---

[1] (VEB Technische Gase-Werke Berlin).

7.3.1 Mass Spectrometry

A mass spectrum is produced by changing the components of a sample into gaseous ions. These can then be electrically accelerated and separated and collected on the basis of their mass/charge ratio.

This principle was first realized in 1919 by F.W. Aston in his mass spectrograph. Recommended standard works are (White and Wood 1986) and (Duckworth et al. 1986). The working principle can be seen in the following illustration.

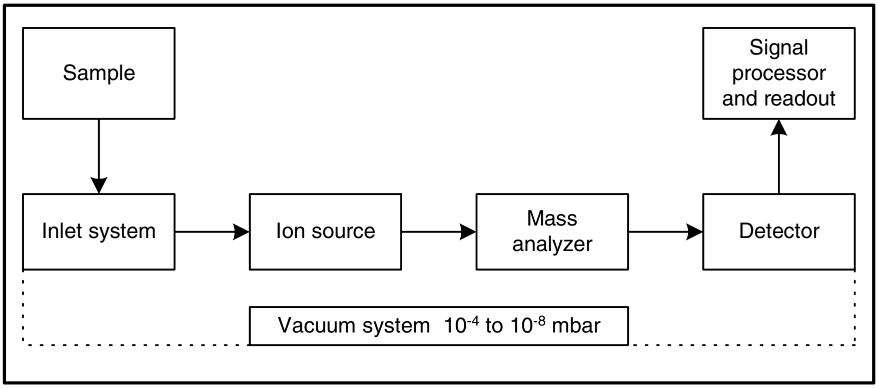


Illustration P7.3.1-1: Principle of a mass spectrometer.

In the inlet system the pressure of the gaseous or liquid sample has to be reduced to such an extent that the necessary ionisation can take place in the ion source. Considering an operating pressure of 200 bar and the pressure in the ion source of usually $\leq 10^{-4}$ mbar there is a difference in pressure of more than $1{:}10^9$. This reduction has to take place without a change in the concentration (mass discrimination).

The most important methods of ionising gases are:

- Ionisation by electron impulse, a very common method.
- Chemical ionisation.
- ICP (Inductively Coupled Plasma)
- High frequency arc discharge in a vacuum.
- Photo-ionisation.
- Ionisation at atmospheric pressure. This method gave the name to the APIMS (Atmospheric Pressure Ionization Mass Spectrometer) which will be dealt with in more detail because of its importance for trace analysis.

Separation of ionised substances takes place according to various methods, a uniform evaluation of the achieved separation is provided by the resolution R_{MS}.

$$R_{MS} = \frac{M}{\Delta M} \qquad (7.3.1\text{-}1)$$

M is the relative atomic or molecular mass; ΔM is the difference in the masses of both neighbouring signals, whereby these may show an overlap of only 10% maximum according to normal determination.

Example E7.3.1-1: How high does the R_{MS} *have to be if the mercury isotopes Hg-200 and Hg-201 still need to be separated?*

$$R_{MS} = \frac{201}{1} \cong 200$$

The resolution for the trace analysis in gases mostly has values of 500, but for the isotopic separation of heavier elements and larger molecules a R_{MS} of 500,000 is also necessary. In older publications the expression mass number is used for the M with the unit amu (atomic mass unit). Per definition one amu = 1/12 of the mass of the carbon-12-nuclide.

The most important separation methods are:

- Magnetic sector analyzers with permanent magnets or electromagnets. These lead the ion beam in a circular arc of 180^0, 90^0 or 60^0. Here it is also possible to use it twice, thus it is referred to as double-focus devices.
- Quadrupole mass filters. The ions are diverted by a high frequency voltage superimposed on a direct voltage. These devices are more robust and cheaper than the magnetic sector analyzers and have established themselves widely. They are introduced in more detail below.
- Time-of flight analyzers. The ions are periodically produced with a frequency of about 10 kHz, electrically accelerated and passed through a tube with a length of about 1 m. The light ions with the smaller mass reach their destination first and are caught by detectors which are synchronised with the ion production.
- Multi-dimensional mass spectrometry: to increase the resolution two mass spectrometers are used after one another.

The already mentioned F.W. Aston used a photographic plate to register the separated ion beams whereas nowadays the detection takes place exclusively by electronic means. For this purpose it is however necessary to bring the ion beams to the detector one after another. This takes place by varying the electrical or magnetic values in the ion source and in the analyzers. Secondary electron multipliers are more effective. In these an arriving ion first releases an electron which is then multiplied in further stages.

7.3.1.1 Quadrupole Mass Spectrometers

Nowadays these are the most widespread type of mass spectrometer. The principle is explained in the following illustration.

The beam which is produced in the ion source and accelerated, contains ions with different mass/charge proportions: M/z. z denominates the level of ionisation, e.g. z = 1 means N_2^+. The ions enter an electrical field, which has been created by the four quadrupole electrodes.

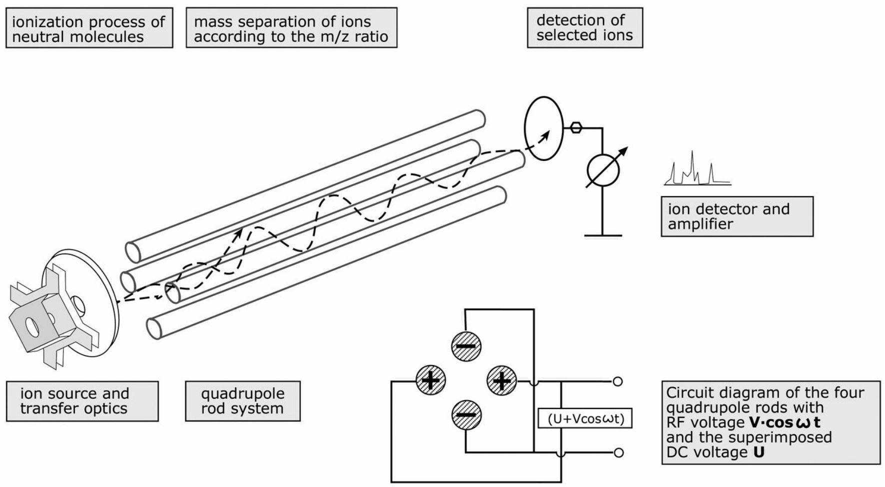


Illustration P7.3.1.1-1: Principle of the quadrupole mass spectrometer (works drawing from the InProzessInstruments (IPI) Gesellschaft für Prozeßanalytik mbH in Bremen/Germany)**.**

The electrical voltage $U_{electric}$ in the Illustration is referred to as

$$U_{electric} = U + V \cdot \cos \omega t \tag{7.3.1.1-1}$$

with ω as the angular velocity. This is a high frequency voltage $V \cdot \cos \omega t$ superimposed on a direct current voltage U. Depending on their M/z values the ions fly in different spiral paths with a maximum diameter of $2r_0$, also called trajectories. r_0 designates the radius of the imagined radius within the four rods. Only one M/z type, however, reaches the ion detector at a time.

Quadrupole mass spectrometers are characterised by robustness, compact construction and especially by low scan times (< 100 ms). This is advantageous for the scanning of chromatographic signals because they take place virtually in real time. In this way soon after the establishing of this type of mass spectrometer the combination with gas and liquid chromatography could be achieved.

Example E7.3.1.1-1: The compact device GAM 500UT from the firm IPI (illustration P7.3.3.1-2). Description:

- *Digitally controlled mass spectrometer with mass range 1 to 512. At this resolution N_2 and CO cannot be separated.*
- *Determination of main and trace components in ultra pure gases*
- *Sample pressure < 0.01 mbar to approx. 5 bar.*
- *Gastight crossbeam ion source with long uptime.*
- *Measurement dynamics from 100% to approx. 10 ppb, >10 decades.*
- *Detection limits: H_2 < 500ppb, H_2O < 300ppb, N_2+CO < 100ppb, CO_2, Ar, He, O_2 each < 10 ppb*
- *Computer controlled gas switching valve system.*

Illustration P7.3.1.1-2: Quadrupol mass spectrometer of the company IPI.

7.3.1.2 APIMS

The special production of ions at atmospheric pressure succeeded at the beginning of the 90s, it helped to develop the verification of impurities in pure gases in the ppb region. Publications from this time are (Siefering et al. 1992) and (Neu and Schmidt 1994). The principle is shown in the following Illustration.

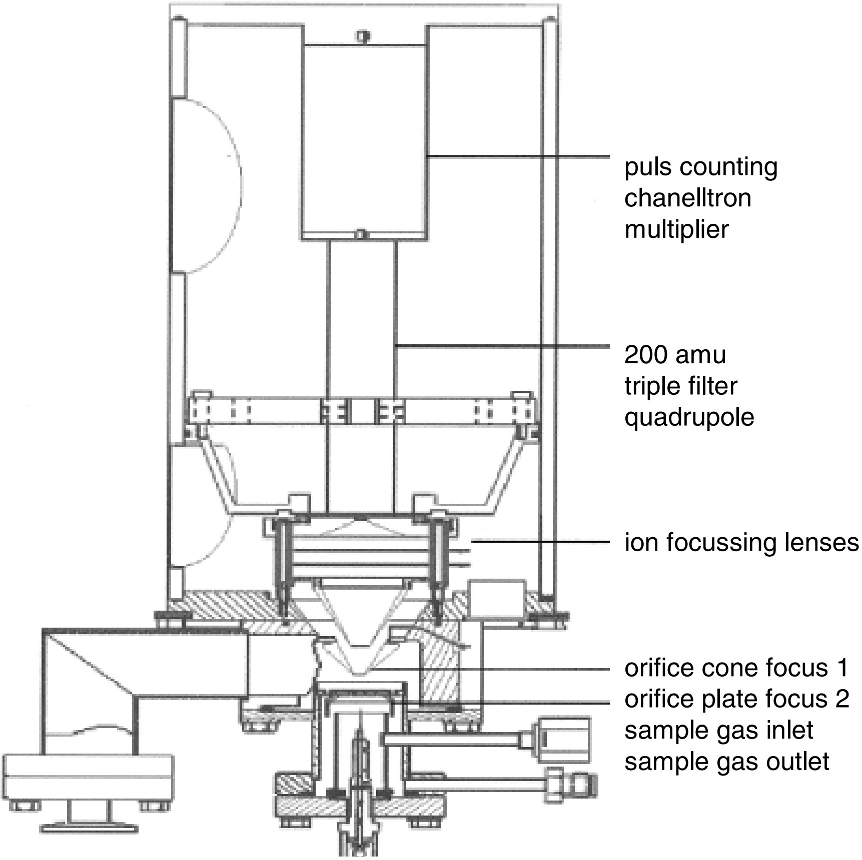


Illustration P7.3.1.2-1: Principle of the APIMS. Works drawing from the company Thermo ONIX in Winsford / UK, earlier VG Gas Analysis.

The molecules are ionised in two stages. A corona discharge is ignited at the top of a tungsten needle. This type of ignition takes place because of the large electrical density at the top of the needle and is limited to its immediate proximity. The illustration shows the needle near the sample entrance. Predominantly ions of the main gas are formed, e.g. for nitrogen N^+ and N_2^+. The second step is a charged transfer which is made possible by the gas density at atmospheric pressure.

$$N_2^+ + 2N_2 \rightarrow N_4^+ + N_2$$

The very short-lived ion N_4^+ makes sure that the impurities are ionised, e.g. for O_2 and CO_2:

$$N_4^+ + O_2 \rightarrow O_2^+ + 2N_2$$

$$N_4^+ + CO_2 \rightarrow CO_2^+ + 2N_2$$

In addition, by applying a suitable direct voltage the ions in the ion source are accelerated. These then pass through several apertures where the pressure in the mass analyzer is gradually reduced to about 10^{-8} mbar.

Usually the analyzer is the well-known quadrupole mass filter to which a multiplier is attached to detect the ions.

This type of stimulation improves the sensitivity by a factor of 1000.

Example E7.3.1.2-1: LOD´s in the ppt region.

Table T7.3.1.2-1: LOD in ppt for the device VG APIX from company Thermo ONIX.

Impurities	**in N_2**	**in Ar**	**in He**	**in H_2**
O_2	1	10	< 10	50
H_2	50	50	< 10	–
Total - C_nH_m	1	1	< 10	< 10
H_2O	< 10	< 10	< 10	< 10
CO	50	10	< 50	< 10
CO_2	1	1	< 10	< 10
N_2	---	50	< 10	< 10
Kr	< 10	< 10	< 10	< 10

7.3.1.3 Vacuum Leak Detector

Example E7.3.1.3-1: The world's smallest mass-spectrometer-based helium leak detector (2007)

Illustration P7.3.1.3-1: PICO^{TM} of firm MKS in Andover/USA. Features: Weight 17 lbs (= 7.73 kg) and truly transportable, integral turbomolecular and scroll pump, maximum inlet test pressure 200 mTorr (= 0.267 mbar), $1 \cdot 10^{-10}$ cm³/s minimum detectable leak rate, responds time < 1s, removable handheld remote display.

7.3.2 Chromatographic Methods

Many analytical methods are rarely specific to one group of materials and even more rarely specifically selective for one substance. Therefore, when carrying out an analysis, it is absolutely essential to separate the analyte from the accompanying substances to be ascertained. The material separation is relatively simple as long as the individual mixture components form their own phases. Physical methods of separation, such as distillation, sublimation, crystallisation, extraction and adsorption from a gaseous or liquid phase are based on the formation of phase equilibrium. Here the molecules of the materials to be separated continually pass the phase limit in both directions, whilst trying to maintain a stable state of material distribution. Thus the concentration of the materials involved remains constant in each phase, although the differences in concentrations in the phases can and should be considerable.

If the materials to be separated are only slightly different as regards the decisive characteristics for this method, such as vapour pressure, solubility or adsorption then there is only a small enrichment in one of the two phases.

In all chromatographic separations the sample is dissolved in a mobile phase, which may be a gas, a liquid, or a supercritical fluid. This mobile phase is then forced through an immiscible stationary phase, which is fixed in place in a column or on a solid surface. The two phases are chosen so that the components of the sample distribute themselves between the mobile and the stationary phase to varying degrees. Those components that are strongly retained by the stationary phase move only slowly with the flow of mobile phase. In contrast, components that are weakly held by the stationary phase travel rapidly. As a consequence to these differences in mobility, sample components separate into discrete bands that can be analyzed qualitatively and quantitatively. Column chromatography was invented and named by the Russian botanist Michael Tswett shortly after the turn of the 19th century[2]. He coined the word “chromatography” from the Greek “chroma” (colour) and “grafo” (writing) to describe the new technique.

(Smith 1988) and (Katz 1988) are recommended as standard reading.

The allocation of chromatographic methods usually takes place after the mobile phase.

- Gas chromatography (GC) with the stationary phases: fixed material, liquids adsorbed on fixed materials, chemically bonded substances on the surface of the fixed material.
- Liquid: liquid chromatography (LC) with stationary phases like with gas chromatography as well as the ion exchange chromatography with the stationary phase ion exchange resin.
- Supercritical liquids and liquefied gases like CO_2: supercritical fluid chromatography (SFC) with the stationary phase of organic substances which are chemically bonded on the surface with fixed materials. This method is not dealt with particularly in this book.

---

[2] Different time data: 1901 to 1906

A further differentiation must be made according to the way in which the stationary phase and the mobile phase come into contact with each other. In column chromatography the stationary phase is located in thin tubes, the mobile phase moves through the tubes by pressure, rarely also by gravity. Planar chromatography is different. The stationary phase then takes place on a disc or a flat piece of paper and the mobile phase is achieved by capillary force or gravity.

Column chromatography has the typical set up: carrier gas – sample input – column – detector. The time needed for an analyte G from the input of the sample until its registering in the detector is referred to as retention time $t_{R,G}$.

7.3.2.1 Gas Chromatography (GC)

Gas chromatography is the most frequently used method for the analysis of gases and therefore a wide variety of commercial devices exists. Relevant literature is (Willet 1987), (Grob 1985) and (Leibnitz u. Struppe 1984).

The carrier gas to be chosen is dependent on the detector which is being used for the verification. Commonly used carrier gases are He, Ar, N_2, H_2 and CO_2 which have to be available under pressure and in a very pure state. Occasionally further purification is necessary, as described in section 8.4.

When injecting the sample it is important to assure leak tightness in order that purity is maintained and that for the analysis of the gas mixture the reproducibility is good and the errors are as small as possible. Thus the original way of introducing the sample with a syringe is no longer relevant. Automatically adjustable sample volumes are used.

With gas chromatographic columns one usually differentiates between the three following types:

- Packed separating columns with a liquid phase: so-called separating fluids are introduced onto a carrier with a large surface. The separating process is achieved by setting a balance between the dissolving and the evaporating of the gaseous mobile phase.
- WCOT: Wall Coated Open Tubular: the separating process is based on the balance adsorption/desorption.
- Capillary columns: here capillaries are used with an internal diameter smaller than 1 mm and lengths of 100 – 200 m which are covered with a layer of separating fluid or WCOT.

The switching techniques of the columns have been adjusted to meet the ever-increasing demands, particularly for corrosive gases, as shown by two examples taken from publication (Warren 2000).

Example E7.3.2.1-1: Analysis of trace impurities in anhydrous HCl.

When analysing trace impurities in corrosive gases such as HCl, Cl_2 and BCl_3 the choice of the materials to be used plays a decisive role. Hastelloy C is used very *frequently. Connections, valves, samplers and dividing columns then must also be made of this material. It is also important to have a supply of He for purging purposes. The corrosive main gas, also called the matrix gas, should not reach the detector which is not corrosion-resistant. Therefore one uses a column switching system which allows a reversal of the direction of flow after the impurities have passed (back-flushed), thus retaining the carrier gas and directing the impurities into the vent. The system shown is equipped with two ten-way valves, each with a sample loop. Two parallel column systems are connected via back-flush switching with a detector (PDID, described later). One channel is equipped with a porapack column (back-flush one) for the back-flush which retains the matrix gas, and the CO_2, whereas the air gases continue to elute on the molecular sieve column (Analysis 1). The second channel contains two porapack columns. Components which elute quickly pass both columns and reach the detector unreported. The CO_2 elutes from the column back-flush 2 quicker than the matrix gas and enters the column analysis 2. The peaks from both channels are united in the chromatogram.*

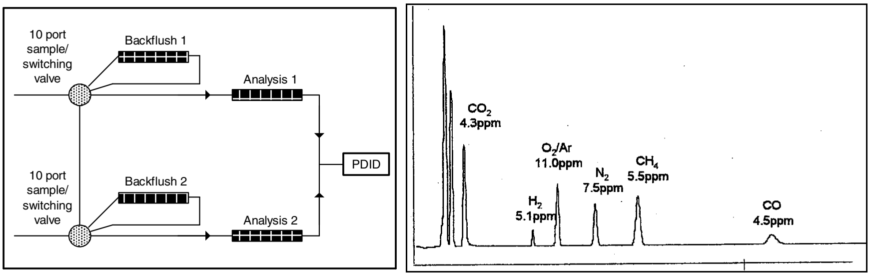


Illustration P7.3.2.1-1: Left: backflush column switching. Right: chromatogram of impurities in anhydrous HCL, (Warren 2000).

Example E7.3.2.1-2: Chromatographic separation of impurities in CF_4.

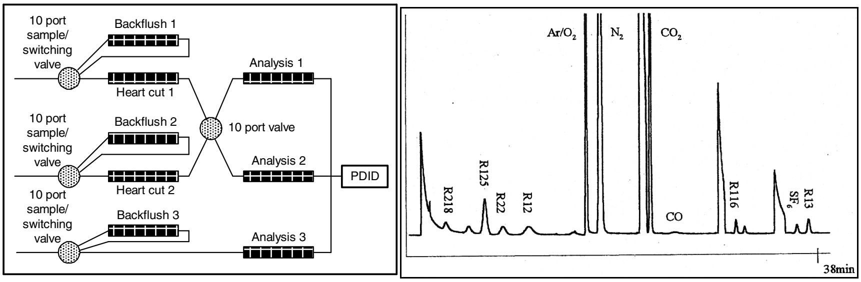


Illustration P7.3.2.1-2: Heart-cut switching and chromatogram of the trace impurities in CF_4, (Warren 2000).

Tetrafluoromethane is a well-known etching gas used in the chemical vapour deposition technology of microelectronics. Unlike HCl, CF_4 has a shorter retention time than some of the impurities. It is therefore desirable not to let the matrix gas reach the detector. This is possible with a different column switching (left), the so-called heart-cut, combined with the back-flush. Three channels are needed for *this. Channels 1 and 2 contain the columns heart-cut 1 and 2 as well as an additional 10-way valve. The chromatogram (right) shows not only the air gases Ar/*O_2*,* N_2 *, CO and* CO_2 *but also shows the Freon's R12, 13, 22, 116, 125 and 218 as well as the* SF_6*. It is interesting to notice the three unusual peaks before the* CO_2*, the R116 and the* SF_6*. They are not cut-off remains of the* CF_4*. However, without the heart-cut switching the disturbance by the matrix gas would be so high, that it would not be possible to separate the impurities completely.*

Since M.A.Jones and A.J.P.Martin separated the first complex material mixture with a gas chromatograph in 1952 (Martin also received the Nobel Prize in 1952) there has been an extraordinarily dynamic development. This affected all the functions of the GC, but especially the detectors. A good detector must be sensitive towards many substances; it must have high stability and low reaction time as well as a linear dynamic measurement region of several decimal powers. The sensitivity of a detector is shown in $g \cdot s^{-1}$ which is the mass of the analytes which are captured by the detector in 1s. The values are between 10^{-8} and 10^{-16} $g \cdot s^{-1}$. One must differentiate between a detector depending on the concentration or the mass flow rate.

It is dealt only with the most frequently used detectors, firstly the most important concentration detector: thermal conductivity detector (TCD).

This was one of the first detectors to be introduced onto the market technically ready. The principle consists of one heated element, usually a metallic filament whose temperature is dependent on the thermal conductivity of the surrounding gas. When the gas is changed the temperature changes as does the electrical resistance of the filament. At the beginning of its development a Wheatstone bridge was employed, in which two filaments are used for both the sampled gas and the reference gas. Starting in 1979 a different gas switching system was used. A micro-measuring chamber of 5 µl volume with only one filament was periodically (10 Hz) loaded with the sampled gas and the reference gas. Thus the signal is frequency modulated and can be electronically filtered as is the case with noise reduction. The TCD is a detector with a variety of uses and is not too sensitive; it is part of the standard equipment of a GC. LOD is 10^{-10} $g \cdot s^{-1}$. Linearity is 10^4, i.e. 4 decades.

There is a large variety of detectors which depend on the mass flow rate.

- Flame ionization detector (FID): This is also a detector which could be perfected in the early days of gas chromatography. The carrier gas is brought into a diffusion flame with the eluted compounds. H_2 is introduced at the discharge of the separating column; the air is introduced from the side of the flame. This flame produces ions which are introduced to the anode *via* an electrical field. The FID is a specific detector for hydrocarbons, inorganic substances are not detectable. The LOD is 10^{-12} $g \cdot s^{-1}$; the linear area is 10^3 to 10^4. Without a chromatographic column the FID can also be used to determine the total content of C_nH_m.
- With the electron capture detector (ECD) the electrons ionise carrier gas N_2 or Ar/CH_4 so that there is a basic ion flow of 10^{-8} A. If electrically negative

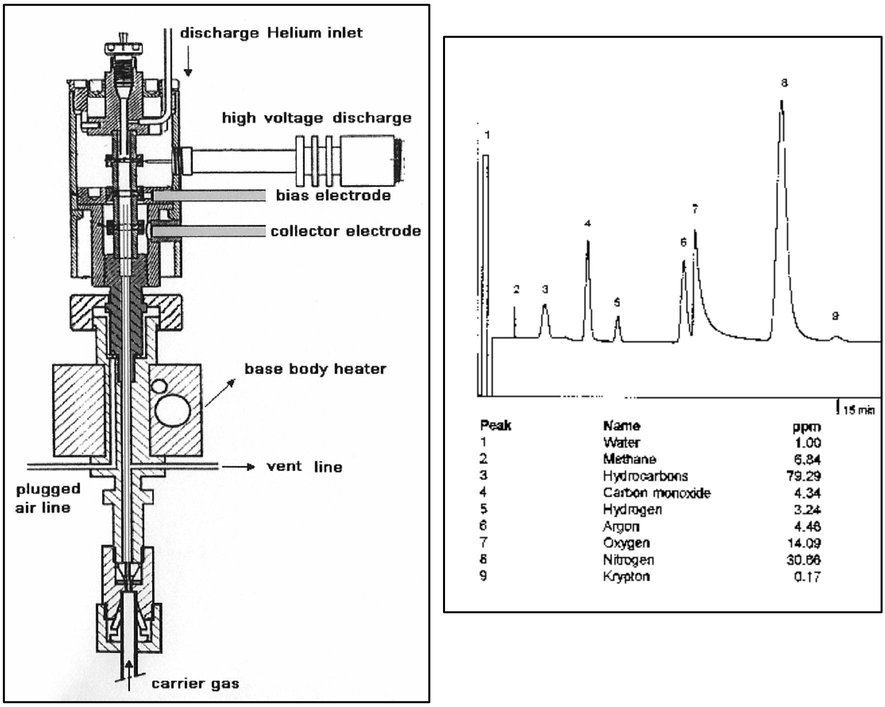
compounds reach the detector they pick up electrons by agglomeration. Thus electrons are removed by the ionization of the operating gas and the basic ion flow falls to 10^{-10} A. The linear region is up to 10^{-14} g · s^{-1}. The detector is selective for halogened hydrocarbon compounds.

- Radioactive ionization detectors: Low-energy ß emitters like H-3 and Ni-63 supply electrons which are used for the ionization. Inert gas ionization detectors (He and Ar) accelerate the available electrons from the radioactive substances through a strong electrical field and produce excited, meta-stable states in the noble gases. Those electrons which are on energetically higher paths do not return to their basic states after emission of a photon but release the absorbed energy in pulses with the impurities, whose ionization potential is smaller than or equal to the stimulating energy. LOD is below 10^{-14} g · s^{-1}, the linear area is up to 10^3. In recent years pulsed variants have been developed. This detector can be used almost universally because the meta-stable levels of He are larger than the ionization potential of all substances except Ne.
- The He-discharge detector is related to the He ionization detector although the former does not use a radioactive source.

Example E7.3.2.1-3: Pulsed discharge ionization detector (PDID).

The working principle of the PDID: The He for the pulsed high voltage discharge is fed in separately from above. The discharge supplies energy-rich photons whose path leads downwards in the detection chamber. The carrier gas enters from below, flows in a narrow tube until it is above the bias electrode. In this chamber all the processes to ionize the impurities take place where once again the excited, meta-stable levels of the carrier gas play an important role. The electrons created are collected with the collector electrode and serve as a measurement signal. The carrier gas flows through the annular passage between the inlet tube and the frame and leaves the detector at the vent line. The detector is thermostatically controlled by a base body heater. The sensitivity is 10^{-16} g · s^{-1} with linearity above 5 decimal powers.

- Chemoluminescence detector (CLD): The detector was developed to determine the presence of nitrogen oxides and sulphur compounds and can be explained best using the example of NO_2. A requirement is that the substance X, which is to be determined, can be converted to NO. This means that a suitable reactor is necessary. The NO produced is to react with ozone which creates an excited molecule $(NO_2)^*$, which returns to its basic state by emission of a photon. The LOD is in the ppb region for different nitrogen compounds, linearity about 10^3.



Peak	Name	ppm
1	Water	1.00
2	Methane	6.84
3	Hydrocarbons	79.29
4	Carbon monoxide	4.34
5	Hydrogen	3.24
6	Argon	4.46
7	Oxygen	14.09
8	Nitrogen	30.66
9	Krypton	0.17

Illustration P7.3.2.1-3: *PDID. Left: Plan, works diagram of the firm UNICAM Chromatography in Kassel, the detector is a product of the firm Vici Valco Instruments Co. in the USA. Right: A chromatogram of impurities in CO_2 produced using PDID, according to* (Warren and Heisz 1999).

7.3.2.2 Liquid Chromatography (LC)

Using a liquid as mobile phase in chromatography has achieved a significantly larger importance than the mobile gaseous phase described in the previous section. Liquids are separated and detected in many sectors, such as pharmaceutical (antibiotics, steroids), environmental protection (tensides, insecticides, PCB), forensic and clinical analysis (poisons, narcotics, blood alcohol, urine samples, medicaments).

Liquid chromatography was initially accomplished in glass columns with diameters of a few cm and lengths up to 5 m using gravity. The particle sizes of the stationary phases were in the region of up to 200 µm, the separations often lasted hours. In the 1960s packing material with particle diameters below 10 µm and high-performance pumps up to 400 bar were developed for the mobile phase. These new techniques were compiled under the concept of high-performance liquid chromatography (HPLC). The principle is shown in the next illustration without more detailed explanations.

The use of HPLC for the identification and quantification of the gas content in various groups of substances has remained limited. These are on the one hand hydrocarbons which are already liquids and no longer liquefied gases, such as aromatic compounds, aldehydes and ketones, and on the other hand the anion suppliers such as HCl, HF, NO_X and SO_2 ($\rightarrow Cl^-, F^-, NO_3^-$ und SO_4^{2-}) as well as the cation suppliers such as NH_3 ($\rightarrow NH_4^+$), whose fixed place in ion chromatography needs to be addressed briefly. More detailed explanations can be found in the monographs by (Haddad and Jackson 1990), (Gjerde and Fritz 1987) and (Jensen 2000).

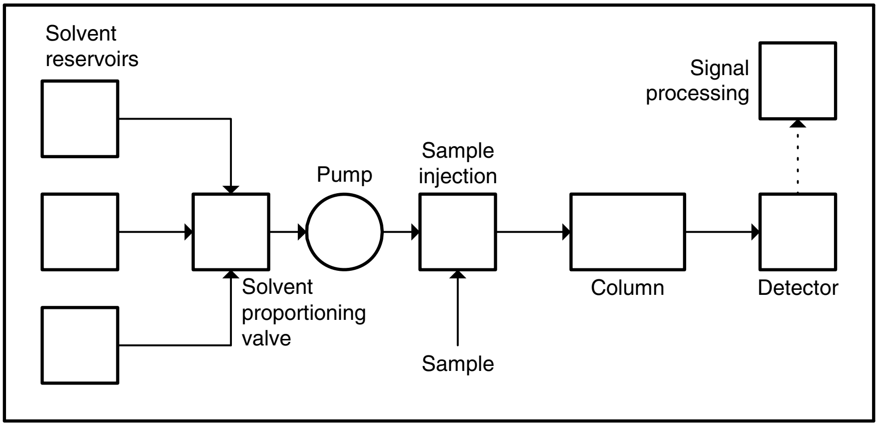


Illustration P7.3.2.2-1: Principle of the HPLC.

Ion chromatography (IC) was introduced as a new analytical method by (Small et al. 1975). The ion separation is based on exchange processes between the ions in the solution and those with the same sign (+/–) on the surfaces of high molecular weight fixed material in the column. When IC was first developed clays and zeolites were used, nowadays artificial resins are preferred. In order to determine cations one often uses exchange resins with the strong sulphurous acid groups ($-SO_3^- H^+$) or the weak carbonic acid groups ($-CO_2^- H^+$). If there is contact with a watery solution which contains a cation X_i^{n+} then in the stationary phase (fixed material) this forms a compound of $\left(M - SO_3^-\right)_n X_i^{n+}$ which sticks to the polymer molecule M. Therefore nH^+ goes into the solution (mobile phase). As there is a different level of affinity between the various types of cation X_i and the exchange resin, the movement through the column does not take place at one speed but with the desired temporal separation.

The development of a separation technique of the eluted ions after the packed column was decisive for the use of the IC. A second column (not included in our Ill. P7.3.2.2-1) is situated between the first column and the detector and here a stripping takes place. On the one hand it is the task of the so-called suppressor column to reduce chemically the high basic conductivity of the electrolytes used for the elution and on the other hand to transform the sample to be analysed in a more conductive form. Nowadays the use of constantly working membrane suppressors is preferred. At first the ions were quantified by the conductivity detector, today further kinds of detection have been introduced: mass spectrometer, electrochemical (amperometric) detector, UV-VIS absorption detector and photodiode array detector.

Using the IC for gas analysis presupposes that the substances to be sampled can be brought into a suitable solution. In most cases this takes place by introducing the sampled gas into the liquid, the non-soluble parts bubble through, the English "bubble method". According to (Hogan 1997) it is possible to undergo many difficult determinations, e.g. HCl and HF in HBr or SiH_4 with LOD´s about 100 to 300 ppb or the detection of NH_3 in N_2O. A further advantage of the IC is the use of sample solutions or also salts as a standard instead of gaseous standards ones. The relative standard uncertainty of these salt solutions is typically $\leq 0.2\%$, e.g. Merck CertiPur® ion chromatography standard solutions are traceable to NIST.

As long as the gaseous samples can be brought into a solution medium IC instruments can carry out further procedures automatically, so that for instance a large number of samples can be measured during the night.

Example E7.3.2.2-1: Automatic sampling and a chromatogram of relevant anions. The following illustrations were taken from documents about system ICS-2500 from the company Dionex Corp. in Salt Lake City / USA.

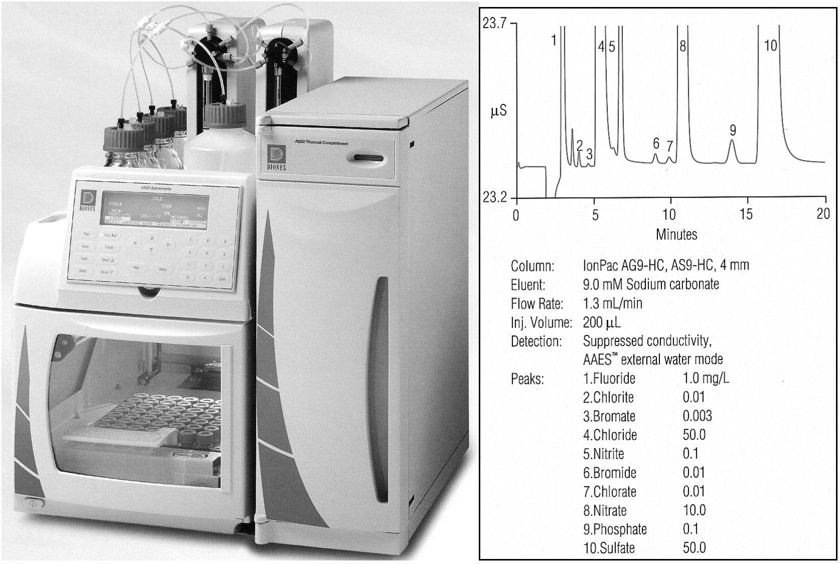


Illustration P7.3.2.2-2: *Left: AS50 automatic sampler, right: determination of 10 anions with the conductivity detector (after the suppressor).*

7.3.3 Spectroscopic Methods

In 1961 when the author began with his professional career he was responsible, among other things, for filling inert gases, N_2 and O_2 into glass ampoules with a volume of 2 and 1 litre and a pressure of 700 Torr (760 Torr = 1013.25 mbar). Quality control was affected by a high frequency discharge of the filled gases at a pressure of 20 to 100 mbar, whose visible light was disintegrated in a spectrograph and recorded on a glass photo disc. The emission lines of the impurities were photometrically evaluated against a comparative recording with a known concentration. This example shows the early use of spectroscopic methods in gas analysis.

The demonstration are restricted to the so-called optic spectroscopy, which means the electromagnetic wavelength region from infra red to ultra violet. Using even shorter wavelengths as in nuclear resonance and X-ray spectroscopy is hardly relevant for gas analysis.

When sub-dividing optical spectroscopy it is adhered to the excellent description of (Skoog u. Leary 1996).

- Absorption: The light emitted from an external beaming source penetrates the sample and is disintegrated in a wavelength separator. Detectors for the absorption of the beams and the signal processing follow. The very widespread molecular absorption spectrometry is dealt with in section 7.3.3.1, atomic absorption spectrometry is dealt with in section 7.3.3.2.
- Luminescence proceses: Fluorescence and phosphorescence are alike thereby that excitation is brought about by absorption of photons. As a consequence, the two phenomena are often referred to by the more general term photoluminescence. The third type is the chemoluminescence.
- Fluorescence differs from phosphorescence in the way that the electronic energy transitions responsible for the fluorescence do not involve a change in the electron spin. As a consequence, fluorescence is short-lived, with luminescence ceasing almost immediately (< 10 µs). In contrast, a change in electron spin accompanies phosphorescence emissions, which causes the radiation to endure for an easily detectable time after termination of irradiation – often several seconds or longer. In most instances, photoluminescence, be it fluorescence or phosphorescence, is longer in wavelength than the radiation used for its excitation.
- Chemiluminescence is based upon the emission spectrum of an excited specie that is formed in the course of a chemical reaction. In some instances, the excited particles are the products of a reaction between the analyte and a suitable reagent (usually a strong oxidant such as ozone or hydrogen peroxide); the result is a spectrum characteristic for the oxidation product of the analyte rather than the analyte itself. In other examples, the analyte is not directly involved in the chemiluminescence reaction; instead, it is inhibiting the effect of the analyte on a chemilumiscence reaction that serves as the analytical parameter.
- Emission spectrometry: based upon the more energetic atomization sources, namely the direct current plasma (DCP), the inductively coupled plasma (ICP), the electric arc and the electric spark, included the high frequency discharge. The latter two sources have been used for spectroscopic studies at the turn of

the 20th century and have found widespread application in elemental analysis beginning in the early 1930s. In contrast, plasma sources have been developed largely during the 1970s.

- Scattering: When radiation passes through a transparent medium, the species present scatter of the beam in all directions. In 1928, the Indian physicist C.V.Raman discovered that the wavelength of a small fraction of the radiation scattered by certain molecules differs from that of the incident beam and furthermore that the shifts in wavelength depend upon the chemical structure of the molecule responsible from the scattering. The use of Raman spectroscopy and the related Raleigh spectroscopy is restricted to individual cases in gas analysis only.
- Particle measurement: The optical methods also use light scattering, see section 7.5.

7.3.3.1 Molecule Absorption Spectrometry

When electromagnetic radiation hits gas molecules quantified portions are absorbed depending on the wavelength $\tilde{\lambda}$ (in mm). So they are lost or lead to a weakening of the beam after the sample. In spectroscopy it is preferred to use the wave number $\tilde{\nu}$ (in cm^{-1}) instead of the $\tilde{\lambda}$[3]

$$\tilde{\nu}\left[\mathrm{cm}^{-1}\right]=\frac{10^7}{\tilde{\lambda}\left[\mathrm{nm}\right]} \qquad (7.3.3.1\text{-}1)$$

The radiation is subdivided into the ultra violet (200 – 380 nm), the visible (380 – 780 nm) the near infra red (780 – 3000 nm) and the medium infra red region (2.5 – 25 µm).

The energy E of the light quantum is determined according to the fundamental formula with Planck's constant h and the speed c_{light} of light in vacuum. f_{Frequ} is the known frequency in Hz.

$$E = h \cdot \tilde{\nu} \cdot c_{\mathrm{light}} = h \cdot f_{\mathrm{Frequ}} \qquad (7.3.3.1\text{-}2)$$

The energy increases with the wave number, or, expressed otherwise, E is inversely proportional to the wavelength. An introduction to absorption spectrometry can be found in the works of (Skoog and Leary 1992) and (Staab 1994).

One now considers the different types of absorption spectra of molecules using the following illustrations. A molecule can absorb the largest amount of energy by radiation absorption when its valence electrons are brought to an energetically higher level. Smaller amounts of energy are absorbed in order to reinforce the oscillation and/or the rotation of the molecule. As there are various combinations of these possibilities one can fall back on a multitude of spectra. It can be seen from the illustrations that the chance for a selective, i.e. as free from cross sensitivity as possible, determination of a gas in a complicated matrix is all the larger when the the distances between lines are larger and their breadth is smaller.

---

[3] λ has been used for the thermal conductivity coefficients, ν for the amount of substance, therefore for spectroscopy one uses these symbols with the wave sign.

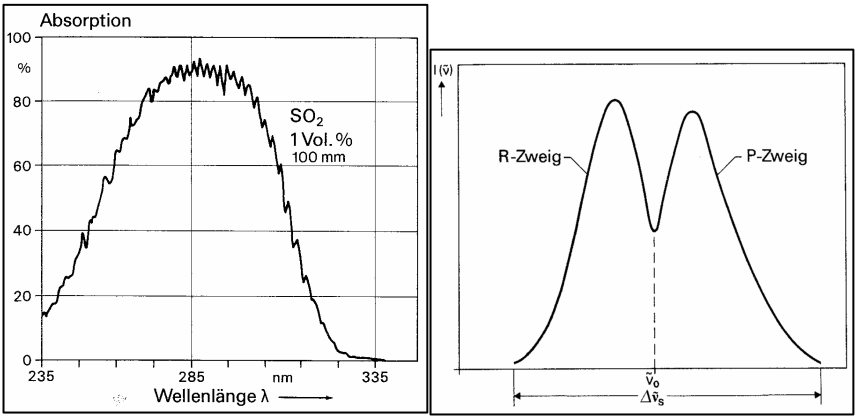


Illustration P7.3.3.1-1: left: Valence-electron-band of SO_2 molecule with an easily recognizable oscillation structure, cuvette length 100 mm, according to (Wiegleb et al. 1983).Right: Schematic representation of a non-dissolved rotation-vibration band with P and R branch, according to (Staab 1994). Wellenlänge = wave length, Zweig = branch.

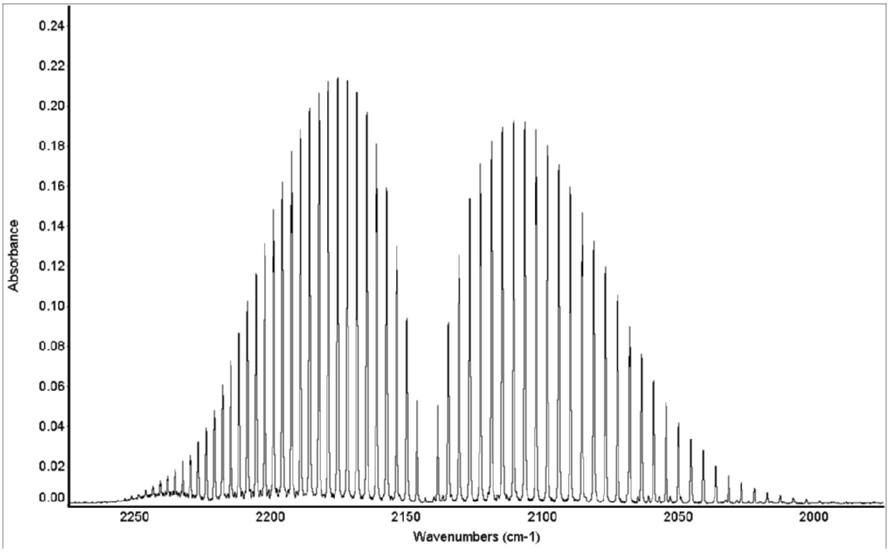


Illustration P7.3.3.1-2: Vibration rotation spectrum of CO with small traces of N_2O according to documents from the firm Thermo Electron GmbH in Dreieich / Germany.

In order to differentiate this very large area it is subdivided according to the wavelength in UV/VIS, NIR and MIR as well as analogiously to the type of spectral disintegration.

- Interference filters only allow a wavelength with a small width at half-height to pass. Thus the analytical instrument is fixed to these wavelengths of the built-in interference filter.

- Selective beamers like fluorescence ones or hollow cathode lamps do not provide a band spectrum but discreet lines so that a spectral disintegration is not necessary. Therefore one refers to non-dispersive instruments (e.g. NDIR). Typical analytes are CO, CO_2, N_2O and NH_3. These instruments are widespread.
- In this context attention also needs to be drawn to selective detectors, such as those used in the NDIR systems for CO, CO_2 etc. These systems use a broadband beaming source with a detector which is filled with the same gas as the one needed to be measured and is thus specifically used for this gas.
- The use of optic grating presupposes efficient beamers with a large spectral width. Mostly silicon carbide radiators and deuterium lamps are used, but xenon and halogen high pressure lamps are also suitable. Glass prisms can hardly be used for the spectral disintegration as these can not measure the mostly important IR area. Holographic concave gratings are often used because they reflect the split light. In order to detect this one needs a series of many small photodiodes which are linked together in so-called diode arrays with sometimes more than 500 individual receptors. These multifunctional instruments are often referred to as simultaneous spectrometers. The very short sampling times of about 10 μs per spectrum allow many components to be sampled virtually at the same time.
- A changeable spectral selection can be achieved with an acousto-optic tuneable filter crystal containing light in the wavelength area of 900 to 2400 nm from a tungsten halogen lamp. The advantage of this is the rapid changing of the passing wavelength. It is similar with an InGaAsP-laser as a selective light source for the NIR region, see section 3.5.7.2 for the moisture analysis.

One special development became possible only with the rapid calculations provided by the modern computer: the use of the Fourier analysis, which is not confined to absorption spectrometry. For an explanation a short trip into the world of mathematics is necessary. Many periodic processes such as oscillation, alternating current, astronomical and geophysical phenomena which recur regularly can be shown approximately in an equation with the trigonometric functions sin and cos. The aim is to show a function or measurement signal f(x) with a function $f_n(x)$.

$$\begin{aligned} f_n(x) = a_0 + a_1 \cos x + a_2 \cos 2x + \ldots + a_n \cos nx \\ + b_1 \sin x + b_2 \sin 2x + \ldots + b_n \sin nx \end{aligned} \qquad (7.3.3.1\text{-}3)$$

The larger the n the greater is the degree of approximation.

The x stands for $x = \omega \cdot t$ with the circular frequency (angular velocity) ω which relates to the usual frequency as $f_{\mathrm{Frequ}} = \frac{\omega}{2\pi}$

The formulae for the calculation of the coefficients a_n and b_n were derived from the mathematicians Euler (1748) and Fourier (1822) but are not a subject for discussion here.

The measured signal is introduced into a detector *via* mechanical devices which divide it into sections and small intervals. From the ensuing signal the function

$f_n(x)$ is calculated by the Fourier transformation and stored as data. This can then be compared with reference spectra. In addition it is also possible to filter the background, which is advantageous for the signal/noise ratio S/N.

This procedure was first used in astronomy in the 50s to examine the IR spectra of distant stars. Since then the so-called Fourier transformation equipment has been continuously developed so that currently it is no longer a huge analytical machine. Sometimes it can be transported (Reimann u. Brenner 1999).

The sectional production of the measurement signal requires mirror movements which are based on the principle of the Michelson interferometer. In his famous experiment of 1881 Michelson proved that there is no “light or world ether” which was supposed to combine electrical and magnetic oscillation according to the physics of the 19th century.

Example E7.3.3.1-1: Principle and function of an FTIR spectrometer.

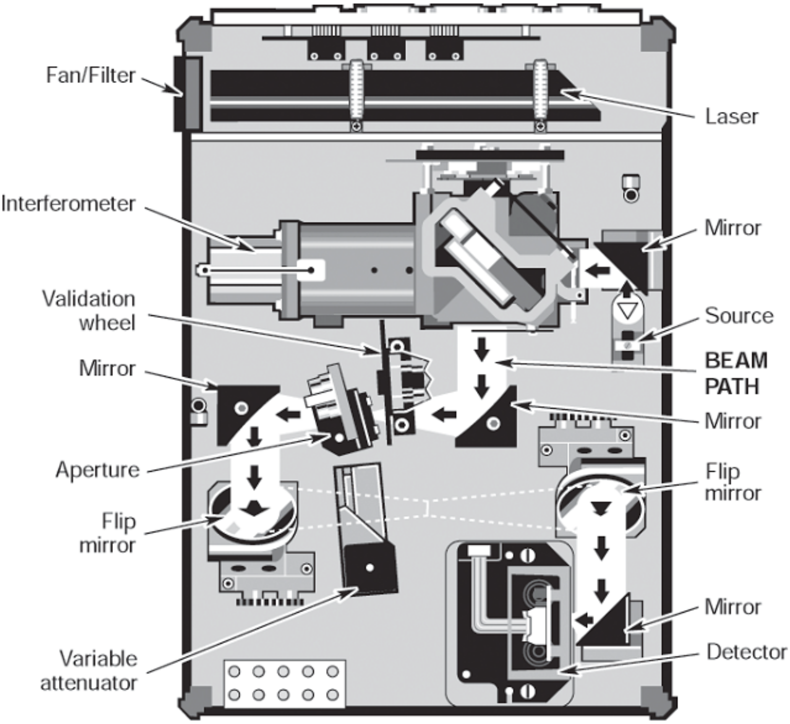


Illustration P7.3.3.1-3 Construction of an FTIR gas analyzer of type Nicolet Antaris IGS. Seen from above without gas cell. Works drawing by the firm Thermo Electron Gmbh in Dreieich/Germany.

Explanation: The light of the source is directed into the interferometer via the first collimating mirror. The modulated beam of light is focussed on one aperture, then collimated again and via the left flip mirror brought in the part of the FTIR gas analyzer situated above it to the gas cell. The path of the light in the gas cell is *indicated with dashes. After the gas cell the light is once again reflected into the bottom part and focused on the detector via the right flip mirror and a further mirror. It produces a reference beam which is used to direct the interferometer. Both flip mirrors can be used for reference measurements and diagnostic purposes and to pass the light through the bottom region and thus past the gas cell. With the variable attenuator the amount of light can be adjusted. The validation wheel contains standards for internal system testing. There are three advantages to this kind of measurement:*

- *Fast measurement of all wavelengths in one scan. The signal/noise ratio can be improved by addition and by forming the median from several scans (multiplex advantage).*
- *A powerful throughput of light with a simultaneously high spectral resolution (so-called throughput advantage).*
- *The HeNe reference laser allows a high reproduction of the wave number as well as long-term stability.*

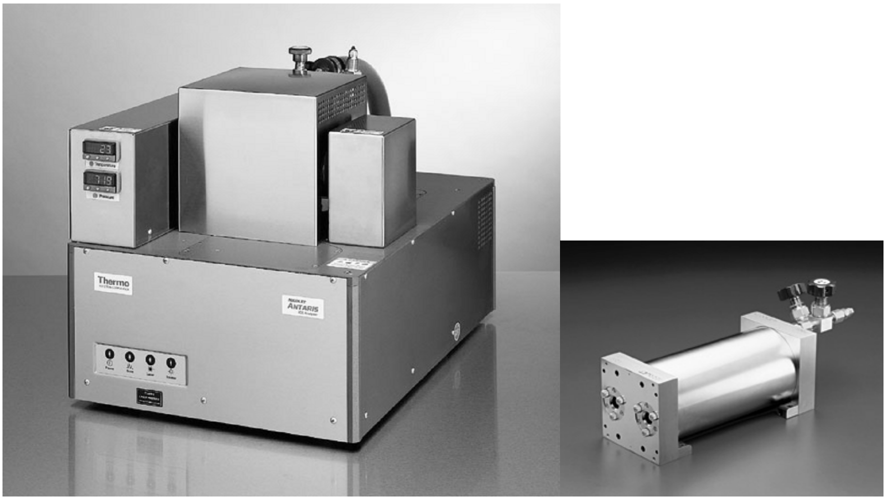


Illustration P7.3.3.1-4: Left: FTIR gas analyzer of the type Nicolet Antaris IGS. Various gas cells are available. Right: Ten metre optical gas cell without heating. Factory photos by Thermo Electron GmbH.

It is very advantageous that many components in the gas being sampled can be determined simultaneously. Therefore these instruments are very suitable for the manufacturer of calibration gas as well as for the user, as is shown by the exhaust gas measurements in the automobile industry published by (Jetter et al. 2000). (Esler et al. 2000) reported about precision trace gas analysis.

A new analytical technology is the Cavity Ring-Down Spectroscopy (CRDS). The basic operating principle was developed by (O´Keefe and Deacon 1988).CRDS is essentially a term to describe laser light that is absorbed by the contaminant of interest dircted into an optical cavity between couple mirrors and measuring the decay rate of light. The faster the light decays the more of what is being monitored is present in the sample gas. The light bounces back and forth and some actually travels as much as 10 km. Result: great measurement sensitivity, fast speed of response, great accuracy and no need for calibration gases.

Table 7.3.3.1-1: List of contaminants and their respective sensitivity (Tiger Optics /USA)

Species detected	**Sensitivity: LOD [ppb]**	**Measurement range [ppb]**
H_2O	0.2	1,000
O_2	0.1	500
CH_4	2	8,000
NH_3	1.5	15,000
PH_3	30	15,000
AsH_3	1	5,000
HCl	0.5	5,000
HF	0.1	1,000
HBr	2	10,000
HCN	1.5	15,000
H_2S	50	500,000
NO	80	500
N_2O	250	2,500,000
CO	50	1,000000
CO_2	300	1,500000
C_2H_2	1	8,000
C_2H_4	6	30,000
C_3H_6	15	20,000
H_2CO	7	100,000
H_2	0.5	5,000

7.3.3.2 Atomic Absorption Spectrometry

In the 70s developments in microelectronics suddenly created demands both in respect to much higher purity of traditional gases and regarding the need to limit impurities in the necessary special gases. Gases like AsH_3 and PH_3, used to manufacture light-emitting diodes (LED´s), were precursors of this trend, as was SiH_4, used to manufacture thin layers with a high electrical resistance. This also involved the task of looking for elements of this half of the periodic table for these gases. At that time a good possibility was provided by the already familiar atomic absorption spectrometry (AAS). Publications such as (Chakrabati et al. 1981) concerned themselves with the emerging problems. Please refer to (Robinson 1990) for general information about AAS.

The principle of the AAS consists of the evaporation of suitable liquids containing the analytes and the subsequent atomisation. A prerequisite for AAS is that the relevant impurities in a gas can be dissolved in a liquid. The number of ions from disassociation or other energy addition should be kept to a minimum. A strong source of light irradiates the mixture of atoms and ions and leads to their agitation by the absorption of photons so that the weakness in light can be measured at wavelengths specific to the element. Unlike molecular absorption spectrometry with its bands AAS provides mainly discreet lines. These are the so-called resonance lines which are a result of the transfers of the electrons from their basic state to higher levels. As these lines are very narrow there is a high selectivity specific to the substance.

Example E7.3.3.2-1: Analytical instrument Analyst 800 AAS of the firm PerkinElmer as a combined flame and graphite tube system.

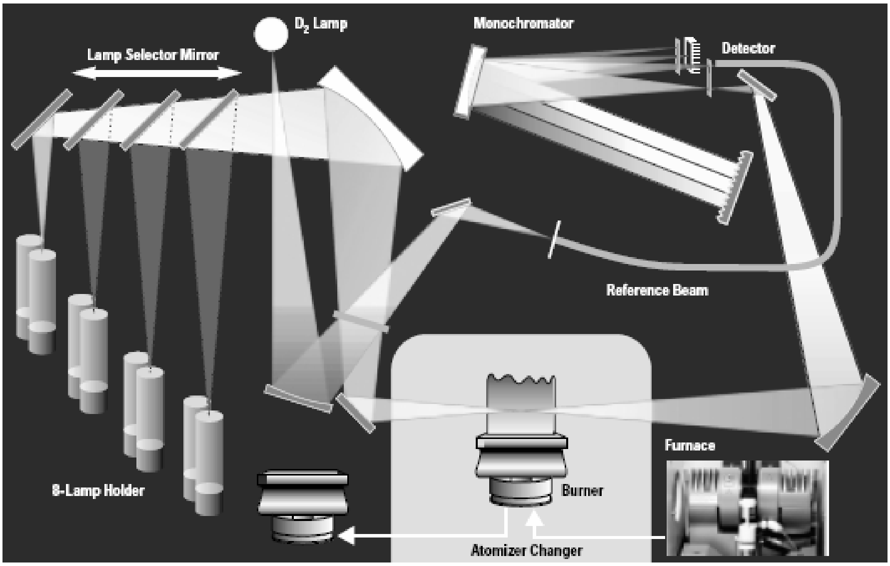


Illustration P7.3.3.2-1: Optical system for AAS Type 800 Analyst of PerkinElmer Life and Analytical Science Shelton, USA.

Explanation: The energy-rich selective spectrum was provided by several (in this case: 8) hollow cathode lamps. The light is divided by a chopper. The test beam either hits a burner, as illustrated, or a graphite tube oven (electro-thermal atomiser). Here the atomisation takes place and the liquid introduced is partially ionized. Sample beams and reference beams are then reunited by a semi-transparent mirror and enter the monochromator alternately. Usually this is a grating monochromator which is operated mechanically. In the detector, which used to be a secondary electron multiplier but is nowadays over more often a solid-state detector, the wavelengths of the sample beam and the reference beam are compared.

Illustration P7.3.3.2-2: Analyst 800 AAS of the firm PerkinElmer.

Description: Monochromator: wavelength range 190-870 nm, grating area 64 x 72 mm, reciprocal linear dispersion 1.6 nm/mm, spectral bandwidths 0.2, 0.7 and 2.0 nm.
Burner system: Alignment of flame in the light beam is fully automatic and optimized, using a motorized burner mount for vertical and horizontal burner adjustments, high-precision nebuliser and all-titanium, 10 cm wavelength, single slot burner head for air-acetylene operation.

Furnace features: temperature from ambient up to 2600°C in steps of 10°C, 0 to 99 s in steps of 1 s for ramp and hold time, 0 or 50 or 250 ml/min internal gas flow.

The electro-thermal excitation is significantly more sensitive than that in the flame. According to (Skoog and Leary 1992) it is possible to achieve extreme limits of detection, e.g. for Fe $5 \cdot 10^{-3}$ ng $\cdot$ ml^{-1} or for Mg $2 \cdot 10^{-5}$ ng $\cdot$ ml^{-1} liquid.

7.3.4 Electro-Analytical Methods

The electro-analytical methods are a subgroup of electro-chemistry, standard works are the monographs by (Bard and Faulkner 2001) and (Hamann and Vielstich 1998).

Electro-chemical cells are suitable for the analysis of some gases. These cells consist of two electrodes which are immersed in electrolyte solutions. According to definition the cathode is the electrode at which the reduction takes place. The oxidation depletes at the anode. An electrical current flows when the electrodes are connected by an external electrical conductor. The electrons enter the solution at the cathode. Electro-chemical cells have two distinct advantages.

- There is very little cross sensitivity for accompanying components and the electro-chemical measurements are substance specific.
- Faraday's Laws (around 1830) apply.
- a) The electrically deposited quantities of a substance are proportional to the amount of electricity Q_{electr}, which has flowed through the electrolytes. Q_{electr} is measured in coulomb with 1 C = 1 A. A and s are SI basic units.
- b) Using the same amount of electricity equivalent amount quantities of different substances are deposited. These behave like the quotients from the atomic weight and the chemical valence. In so far as Faraday's Laws are used the result of the measurement can be directly referred to the SI units, it is adhered to a so-called "absolute procedure", which needs no calibration. Unfortunately the electrolytic discharge can never be achieved to 100%. Therefore it is necessary to determine the degree of discharge and consider this as a correction factor.

Electrochemical cells are sub-divided into galvanic and electrolytic cells. The former cells produce electrical energy and include the rapidly developing fuel cells. Electrolytic cells use electrical energy. Now two important uses with the trace measurement of O_2 and H_2O shall be examined.

7.3.4.1 Galvanic Determination of Oxygen

In 1956 by using a galvanic cell Hersch[4] succeeded in determining O_2 in the range of 1 ppm. He also made popular both a usual wet cell with a solution of potassium hydroxide and the so-called dry cell, a sandwich construction.

Here is a short description of a simple laboratory layout of the dry cell, which the author himself has used frequently. A 1 mm thick foil made of lead or cadmium as an anode is wrapped concentrically around a glass tube. Here only very pure materials should be used as the sensitivity of the cell depends on this. Then there is a diaphragm made of filter paper or PVC fibre. A silver wire net forms the cathode. A 5-normal KOH solution, with which the diaphragm is soaked, is employed as the electrolyte. This construction is used as the internal pipe of a double-pipe layout and the gas, which is to be measured, flows through its annular space. The electrodes are connected with an external electrical resistance of 100 Ω and the electrical current is measured with an ampere meter. The measurement depends on the temperature so that a thermal regulation at e.g. 40 °C is appropriate.

In a simplified form the mechanism for the detection of oxygen is as follows.

Cathode (Ag): $$O_2 + 2H_2O + 4e^- \rightarrow 4OH^- \tag{7.3.4.1-1}$$

Anode (Cd): $$2\,Cd \rightarrow 4e^- + 2\,Cd^{2+} \tag{7.3.4.1-2}$$

---

[4] See (Hersch 1956)

Each O_2 molecule binds four electrons. According to the definition $6.24 \cdot 10^{18}$ electrons = 1 Coulomb C, $1\ A = 1\ C \cdot s^{-1}$. Considering the gas flow Q_V and the temperature T one obtains according to Faraday's Laws.

$$I[A] = 0.0784 \frac{Q_V\left[ml \cdot min^{-1}\right] \cdot C_{O2}[ppm]}{T[K]} \qquad (7.3.4.1\text{-}3)$$

At 20°C, 1013 mbar and a gas flow of 100 ml · min^{-1}, one obtains an electric current of

$$I = 26.7\ \mu A \quad \text{per} \quad 1\ ppm\, O_2 \qquad (7.3.4.2\text{-}1)$$

Example E7.3.4.1-1: Modern instrument for the determination traces of oxygen, see the illustration below.

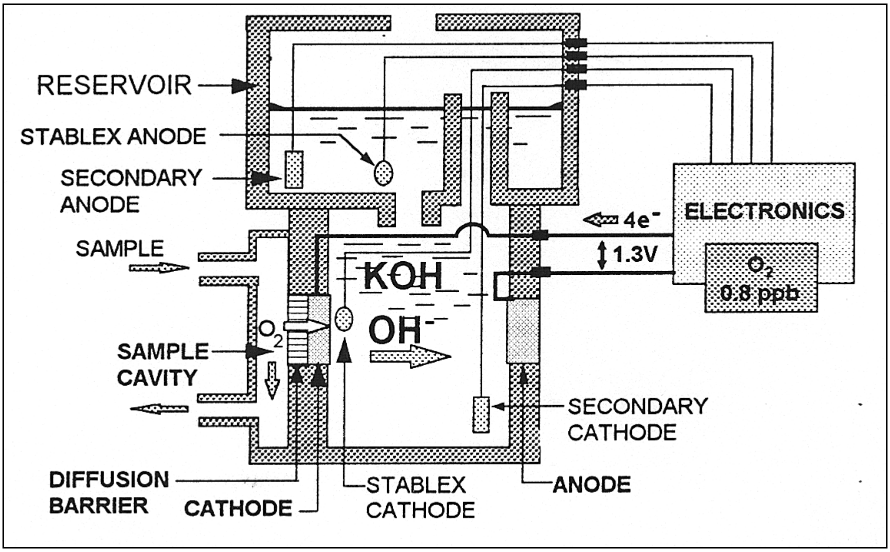


Illustration P7.3.4.1-1: Construction of the Hersch cell of type Nano Trace of the firm Delta F Corp. in Woburn/USA.

The flow to be tested does not penetrate directly into the wet cell but the O_2 molecules pass a diffusion barrier and make contact with the cathode. A system of several auxiliary anodes and cathodes serve to reduce the background flow.

The firm Delta F gives the following information about its cell NanoTrace II: Smallest range of measurement 0-2 ppb, LOD 75 ppt, response time < 2 sampled gases N_2, H_2, rare gases, low C_nH_m and CFC´s.

7.3.4.2 Electrolytic Determination of Moisture

The determination of traces of moisture in gases by a coulometric cell has been described by (Keidel 1959) and (Barendrecht 1961). The measuring cell is relatively simple, it consists of a glass tube or a plastic tube which is coated with phosphorous pentoxide and contains two separate spiral platinum coils which form the electrodes. The P_2O_5 is a well-known desiccant and is an electric conductor when it absorbs H_2O. The mechanism is similar to the electrolysis described in section 3.2.2, here too the H_2O breaks down into gaseous O_2 at the anode and H_2 at the cathode. The direct voltage used is about 50 V. For a reproducible measurement it is necessary that the electrolytic cell, also referred to as electrolytic sensor, is the right size so that all the H_2O of the flowing gas can be bonded and dissociated. Using Faraday's Laws again, the measurement of the current leads to a relation between the strength of the current and the mass of dissociated water.

$$1\ \text{mA} \mathrel{\hat{=}} 5.565 \cdot 10^{-6}\ \text{g}\ H_2O = 6.925 \cdot 10^{-6}\ \text{l}\ H_2O(\text{vapour}) \qquad (7.3.4.2\text{-}1)$$

Let the amount of dissociated water be $Q_{V,H2O}$. When once again a volume flow $Q_V = 100\ \text{ml} \cdot \text{min}^{-1}$ of the gas to be analysed is assumed then a material concentration $C_{v,H2O}$ for $I = 1$ mA is obtained by forming the quotient

$$C_{v,H2O} = \frac{Q_{V,H2O}}{Q_V} = \frac{6.925 \cdot 10^{-6}}{0.1} = 6.925 \cdot 10^{-5} = 69.25\ [\text{ppm}]$$

Example E7.3.4.2-1: Electrolysis cell for the ppb range.
The following representation was taken from documents of the firm MEECO Inc. in Warrington/USA. (Mettes et al. 1998*) reported about experiments with this cell and a comparison with the APIMS.*

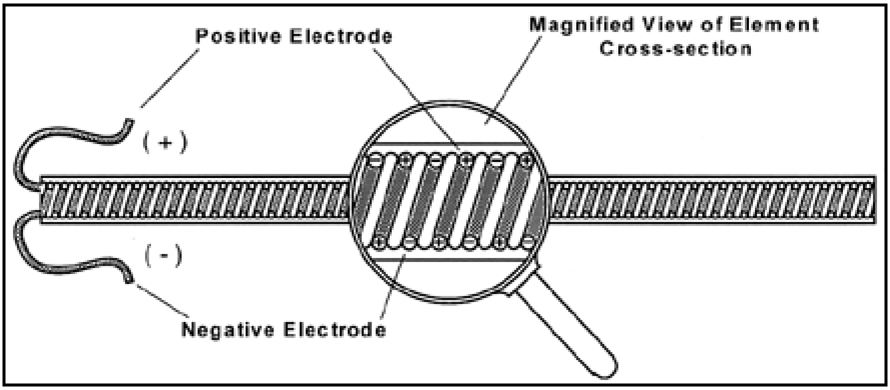


Illustration P7.3.4.2-1: *Schematic representation of the coils in the electrolysis cell.*

Description: The electrode wires extend from one end of the element and pass through to the outside of the cell body. They are connected to a pair of terminals that protrude from both sides of the cell. An electrical check on it across the electrode terminals, prior to the application of the P_2O_5 film, will show an open circuit. The complete mechanical assembly can be plumbed into a gas sampling system. In operation, the sample gas enters the cell at a known flow rate and the P_2O_5 film absorbs all the moisture molecules present in the gas flow. A voltage, applied across the electrode terminals, electrolyzes moisture in the film. Once equilibrium is reached, the rate at which moisture molecules enter the cell will exactly match the rate at which molecules are electrolyzed.

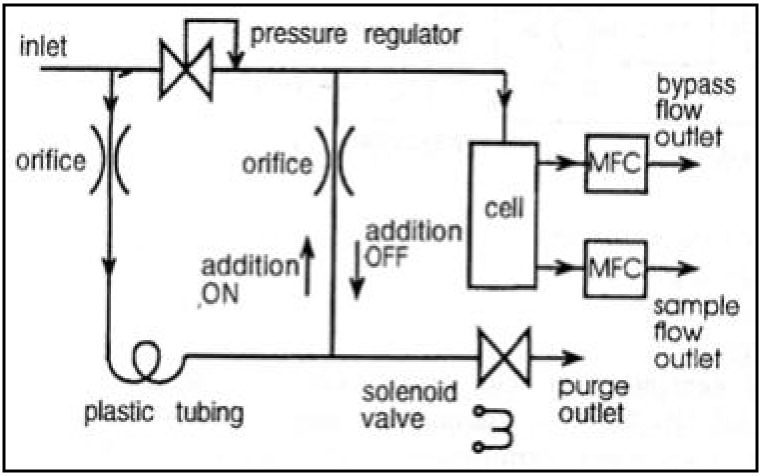


Illustration P7.3.4.2-2: Flow schematic of the hygrometer.

Before the incoming gas enters a pressure regulator, a small stream of gas is split off to flow through a piece of plastic tubing. Atmospheric moisture permeates through the wall of this tubing and is added to the gas stream, which is then either merged back into the main flow downstream of the pressure regulator (the moisture addition "on" position), or vented (the moisture addition "off" position). The direction of the flow in the tubing that connects to the main stream downstream of the regulator is opposite in the two positions, where it consists of the unwetted main stream gas that merged with the wetted stream in the moisture "off" situation. The moisture addition is controlled by opening or closing a solenoid valve that allows or blocks the venting of gas. Various flow restricting orifices and check valves control the amount of the flows and prevent moisture from reaching the cell in the absence of any, i.e. when shipping the instrument.

After moisture addition, the main stream of gas enters the housing of the electrolytic cell where part of the flow passes through the cell itself, hereafter called the sample flow. The remainder of the flow is split off at the element's entrance to form the so-called bypass flow, which is designed to create a large throughput of gas through the instrument. Both sample and bypass flow are driven by mass flow controllers, positioned downstream of the sensor housing, afterwards they exit the instrument.

The fact that moisture is blended into the gas flow to the cell by an active flow leads to short wetting times and also faster cycle times compared to previous scenarios (Ma et al. 1995). *This results in a faster speed of response as well as a better accuracy and a lower detection limit.*

MEECO Inc. provides the following specification: measured gases are air, inert gases, rare gases, N_2, H_2, O_2, CO_2, SF_6, CH_4 and other non-corrosive ones. Sensitivity one ppb, sensitivity of 5 ppb is achieved in 15 min.

7.3.5 Moisture Measurement

This book has already referred several times to the special position of water as an impurity. For this reason the various methods for moisture determination shall be explained briefly, in so far as they were not already defined in the preceding section about the analytical methods. Previous compilations have been provided by (Schön 1995), (Michell 1996), (Hogan 1997) and especially by (Wiederhold 1997). An overview of the determination of moisture including the one in the surrounding air can be found in (Weber 2002). Here the area of vapour pressure over ice is considered exclusively. Nowadays the main focus of measurements is for dew points below –70°C, which corresponds to a content of 2.55 ppm with reference to 1013.25 mbar.

If there is no absolute procedure like the determination of the dew-point temperature which enables an immediate reference to an SI unit, then it is necessary to use calibrating gas mixtures. Although, in principle it is possible to gravimetrically fill it in a high pressure cylinder, this method is extremely inaccurate because of the adsorption on the wall. Using documents provided by the PTB four basic types of generators can be distinguished:

- With two-pressure generators saturation is adjusted at increased pressure. In the NIST in the USA there is an apparatus which permits calibrations up to –100°C.
- With mixed-gas generators a partial flow with known moisture is diluted by an extremely dry gas, such a system exists at the firm Air Liquide in France.
- Permeation generators work according to the principle of diffusion through a permeable medium, such as a piece of tube. The rate of permeation is determined gravimetrically and depends on the temperature. These systems are relatively simple to construct.

- The normal PTB works according to the principle of the coulometric generator. Here an electrolytic dissociation of the water takes place. The dissociation products H_2 and O_2 as well as the carrier gas are dried intensively and then recombined to vapour catalytically. The amount of vapour is calculated according to Faraday's Law.

Here is an overview about the different methods for inert or non-reactive gases.

- Determination with the APIMS: section 7.3.1.2
- Electrolytic determination of moisture: section 7.3.4.2
- Capacitive hygrometer: section 7.3.5.1
- Laser absorption spectrometry: section 7.3.5.2
- Cooled mirror hygrometer: section 7.3.5.3
- Piezoelectric hygrometer: section 7.3.5.4

Not all of these methods are suitable for the measurement of the amount of vapour in corrosive gases. (Hogan 1997) and (Wiederhold 1997) provide tips about the problems involved and the appropriate measurement methods.

7.3.5.1 Capacitive Hygrometer

The history of capacitive measurement of moisture began in 1960 with the development of a sensitive miniaturized measuring element for meteorological research in the upper atmosphere. This sensor was the foundation for the present day widespread technique for the measurement of moisture in gases and liquids. The following representation arose with the help of documents provided by the firm Panametrics GmbH in Hofheim/Germany affiliate GE Panametrics.

The sensors consist of an aluminium strip which has been oxidised anodically in a special procedure. The oxide layer has a maximum thickness of 300 nm. A layer of gold is applied to this by evaporation.

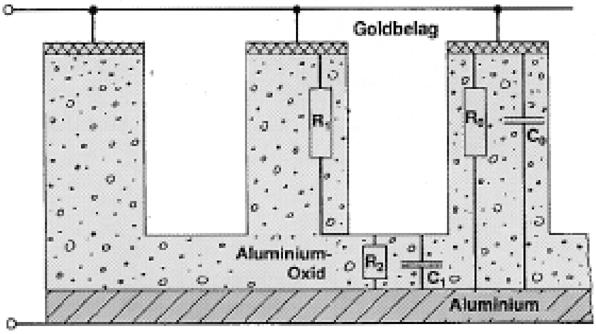


Illustration P7.3.5.1-1: Construction of the aluminium oxide sensor, works drawing by GE Panametrics. Goldbelag = gold coating.

Explanation: The Ohm resistances are R_1 for the pore layer, R_2 between the pore base and the aluminium, R_0 for the total oxide layer. Capacities are C_0 between the layer of gold and aluminium, C_1 between the pore base and aluminium.

Water vapour penetrates through the gold film and forms a layer in the pores of the oxide layer *via* adsorption. The number of these water molecules is determined by the impedance of the capacitor (condensator) and is employed to measure the moisture using the resistances and capacities provided.

Example E7.3.5.1-1: Capacitive sensor for high and low pressure.

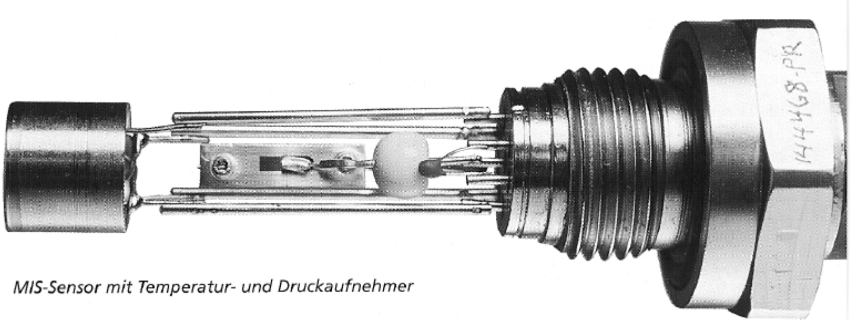


Illustration P7.3.5.1-2: Capacitative moisture sensor. Works photo from GE Panametrics GmbH/Germany.

Explanation: In addition the sensor contains a pressure transducer and a temperature sensor. An essential advantage is the large range of working pressure from 1 µbar to 350 bar. The measurement at 200 bar enables a detection limit in the low ppb region.
When measuring under high pressure it has to be assured that the ideal gas law can be used with high approximation for the partial pressure of the water vapour. For the main gas, however, corrections are necessary, as dealt with in section 2.2 for the real gas.

In addition to the temperature dependence of the capacity sensor on the basis of Al_2O_3, another problem is caused by wear and tear. After some time this leads to lower moisture values than are actually present. That is why a lot of work is being done to improve this sensor.

Example E7.3.5.1-2: Ceramic moisture sensor from Michell Instruments GmbH in Germany. Operation of the sensor depends upon the adsorption of water vapour into a porous non-conducting "sandwich" between two conductive layers built on top of base ceramic substrate. The active layer is very thin – less than 1 µm and the porous top conductor that allows transmission of water vapour into the sensor is less than 0.1 µm. Therefore the sensor responds very rapidly to changes in applied moisture, both when being dried (on process start-up) and when called upon if there is moisture ingress into a process. Technical data: Measurement range –120 to +20°C dew point, accuracy better than ± 1°C, pressure rating to 300 bar, gases: inert and aggressively acid media, warranty: 1 year.

7.3.5.2 Laser Absorption Spectrometry

A measurement of the moisture content is possible with the FTIR, which has already been dealt with. The development of adjustable lasers for the IR range led to new possibilities for the molecular absorption spectrometry, without it being necessary to carry out spectral dissociation.
The basic construction can be seen in the next illustration, which was taken from documents provided by the firm Delta F Corp. in Woburn/USA.

Example E7.3.5.2-1: Moisture determination in the ppb range. The firm Delta F Corp. provides the following specifications for the instrument DF-750: Measuring range 0 – 20 ppm, LOD 200 ppt length of the measurement 10 min., measured gases are inert gases, rare gases, other non-corrosive, or the corrosive ones NH_3.

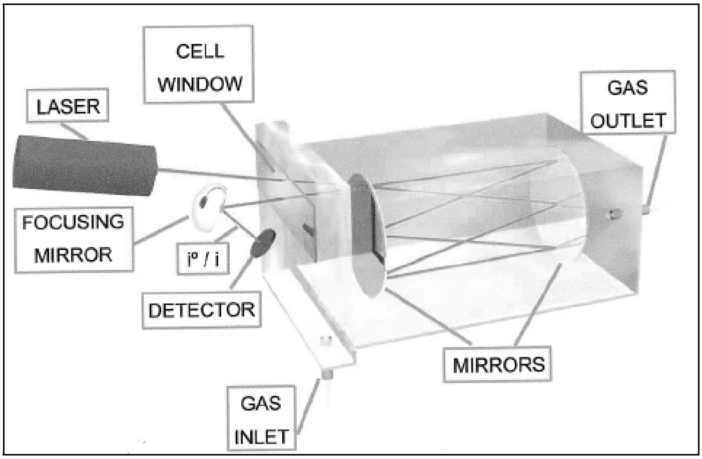


Illustration P7.3.5.2-1: Tuneable Diode Laser Absorption Spectroscopy (TDLAS) from Delta-F Corp. Nano Trace Moisture Analyzer and Nano Trace Dual Moisture and Oxygen Analyzer.

Explanation: The wavelength of the laser can be adjusted within certain limits, in addition the light is amplitude modulated. *Via* a cell window it penetrates into the cuvette through which the gas flows. Two mirrors allow a long path for the light. The water or oxygen molecules in the gas absorb photons which cause gaps in the spectrum. Then the light leaves the cuvette *via* the cell window again, is focussed by a mirror and reaches the detector.

7.3.5.3 Cooled Mirror Hygrometer

The optical condensation principle of dew point measurement has been established for centuries as the fundamental method of determining the content of moisture and other condensable vapours in gases as air, O_2, N_2, H_2 etc. The major uncertainties in this measurement are related to the instantaneous detection of the on-set of condensation and the accuracy to which the temperature of the condensing surface can be measured. Early manual dew-point hygrometers suffered inaccuracies due to their cyclical nature, being cooled by an external coolant such as carbon dioxide or by the evaporation of a solvent, and also because of the time taken to produce an observable layer of condensate, often lead to an underestimation of the moisture content. The modern, automatic cooled mirror sensor addresses these deficiencies and also provides an instrument that is rugged and reliable enough to be applied to process control measurement as well as laboratory use.

Example E.3.5.3-1: Cooled mirror sensor type S4000 TRS from Michell Instruments GmbH in Germany.

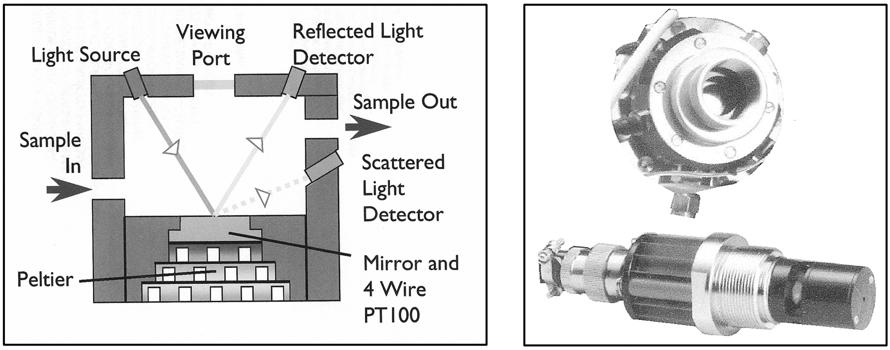


Illustration P7.3.5.3-1: *Left: principle of measurement. Right: cooled mirror on the top, bottom optical system.*

Description: In these mirror sensors, a miniature polished metal mirror is cooled by a solid state Peltier thermoelectric heat pump until it reaches the dew point of the gas being tested. When this temperature has been reached, condensation will begin to form on the mirror surface. An electro-optical loop, comprising of a visible emitting diode and a high gain photo-detector, captures that condensation is forming. A reduction in the intensity of light reflected from the mirror surface is used as a feed input into the instrument control electronics to modulate the cooling power applied to the Peltier element. The mirror surface is then controlled in an equilibrium state whereby evaporation and condensation are occurring at the same rate. In this condition the temperature of the mirror (measured by a platinum resistance thermocouple) is equal to the dew-point of the gas.

At trace moisture levels, the rate of formation of condensation (ice crystal) is slow and so Michell employs a novel dual optics system that measures both the reflected and scattered light intensities from the mirror surface. By using these two signals in a differential mode of operation, much smaller layers of condensate can be detected, allowing faster and more precise operation of the sensor. A further enhancement at these trace levels is the use of a special unique speed pipe technology, a system that concentrates condensation formation on the mirror surface to render an even faster response.

Technical specifications of S4000 TRS: Operating range –100 to +90°C dew point, accuracy ± 0.1°C, pressure rating 10 bars, mirror: rhodium plated copper.

7.3.5.4 Piezoelectric Hygrometer

It is possible to use an oscillating crystal (oscillating in the MHz region) to measure moisture when sorption processes on the hygroscopic coating of the quartz leaf lead to a shifting of its own frequency, (Wiederhold 1997) and (van Haltern 2003). Mostly resins are used for this purpose, but also well known are gelatines, calcium oxide and phosphorous oxide.

In recent years the actual measurement has been carried out mainly using the reference procedure, whereby the gas to be measured and a comparison gas which has been specially dried in a molecular sieve are introduced into the measuring cell.

Example E7.3.5.4-1: Moisture analyzer 5920 with quartz-crystal sensor from AMETEK Process Instruments in USA.

The heart of the analyzer is a quartz-crystal microbalance sensor and analysis technique developed by AMETEK specifically for highly accurate moisture measurements. The sensor consists of a pair of electrodes that support the sensor. When voltage is applied to the sensor, a very stable oscillation occurs.

The faces of the oscillator are covered with a hygroscopic polymer. As the amount of moisture sorbed onto the polymer varies, the mass of the quartz-crystal changes producing a corresponding change in the frequency of oscillation. These easily measurable changes are directly related to the moisture concentration of the sample gas.

The sensor responds quickly to both increases and decreases in moisture concentration because the analyzer employs a unique non-equilibrium measurement technique. This technique continuously exposes the sensor to wet sample gas followed by dry sample to make its analysis. With this technique the analyzer never needs to wait for the sensor to reach equilibrium to establish its accurate measurement. Importantly, this technique is based upon the defined, repeatable physical properties of moisture transport to/from the sensor's surface. This means that quartz-crystal technology never consumes gross quantities of valuable gas nor does it employ questionable prediction software as is often used to "speed-up" the apparent response times of other, more limited technologies.

Technical specifications of model 5920: Measurement range 0 to 150 ppb, trend indication to 1 ppm, accuracy ± 1 ppb, LOD 1 ppb, response time: 80% of a 25 ppb step change in either direction in less than 10 min, compatible gases: rare gases, H_2, O_2, N_2.

7.3.6 Determination of Oil

The determination of oil in pure gases has moved into the background to a certain extent due to the use of compression with dry-running machines or diaphragm compressors. In the 60s the author still experienced filling N_2 through oily compressors and also examined thin films of oil on water layers for gas cylinders when determining moisture, section 2.4, (Schön 1999).

Oil is transported in the gases as oil vapour both in the form of droplets and in a gaseous form. The oil is determined *via* paper filters, which are charged with several m³ of gas. The oil remaining in the paper used to be dissolved with CCl_4 which is no longer used today because of its carcinogenic effect. At the present time the determination takes place with a dispersive IR spectrometer. The detection limit was a few $mg \cdot m^{-3}$.

When referred to oil as an impurity nowadays one refers exclusively to vaporous components. If it is necessary to determine the type of oil then it is sensible to use mass spectrometers exclusively. However the mass numbers are already above 200. When measuring moisture per the above-mentioned experiments the author used the oil acid

$$CH_3 - (CH_2)_7 - CH = CH - (CH_2)_7 - COOH$$

which has a molecular weight of $282.47 \text{ g} \cdot \text{mol}^{-1}$ as can be seen in (Merck 2002).

Another possibility is to segregate the oil vapours in a container filled with saddle packing at a temperature of –78°C then the oil is dissolved, e.g. in pentane trichlortrifluorethene and then both the type of oil and the concentration are determined using IR spectrometry.

In so far as one does not need to determine the type of oil it is possible to determine the total HC content. There are testing tubes on the market which are suitable for a large number of carrier gases. According to (Dräger 2003) the smallest measurement range is 0.1 to 1 $mg \cdot m^{-3}$. Using the mole weight for the oil acid and V_{Norm} one obtains

$$1\left[\text{mg} \cdot \text{m}^{-3}\right] = \frac{22.41 \cdot 10^{-3}}{282.47 \cdot 10^{3}} \cong 80\,[\text{ppb}]$$

7.4 Chemical Absolute Methods

All gases can be dissolved well in liquid solutions to a greater or lesser extent. In some cases, especially with the inert gases, this is exclusively a physical solubility, as was briefly dealt with in section 2.2.3. On the other hand many of the other gases form a definite chemical bond. As early as the 19th century this characteristic led to the development of mass analytic methods and thus to the determination of the content. The then widespread visual methods to determine the endpoint such as a colour charge, were rather inaccurate and in the 20th century were almost completely replaced by electrometric methods. Here it is not important to determine the absolute potential differences or conductivities but rather the stepwise charges at the equivalent point. Event today the well-known text books by (Jander and Jahr 1986) and (Jander and Blasius 1989) are still regarded as standard literature. An overview of the special wet chemistry for gases can be found in (Müller and Gnauck 1965).

The significance of chemical absolute methods is decreasing and they are being replaced by methods of instrumental analysis. Nevertheless there are various analytical tasks, for which they are still necessary. The reasons for this are as follows:

- The analyses can usually be achieved with the standard equipment of a chemical laboratory.
- One quickly obtains an at least half-quantitative result which facilitates the choice of an instrumental method.
- No calibration gas standard is necessary. In fact it is possible to check this.

Listed below are examples of some methods of determination.

- Acid-base titrations: Determination of the contents of HCl or NH_3.
- Iodometry: Iodine is not very soluble in water. It only has a very small inclination to bond with H_2. Iodine combines immediately with a number of nonmetals and the majority of metals. Various substances displace the iodine from its compounds. The release of it from a solution of potassium iodide is used to determine the amount of oxidising material. The determination of ozone takes place according to the reaction equation

  $$2\,KI + O_3 + H_2O \rightarrow I_2 + O_2 + 2\,KOH \tag{7.4-1}$$

  After being acidified with sulphuric acid the released iodine is titrated with sodium thiosulphate $Na_2S_2O_3$. The determination of the contents of Cl_2 is analogous.

  $$\begin{aligned} 2KI + Cl_2 &\rightarrow I_2 + 2KCl \\ I_2 + 2Na_2S_2O_3 &\rightarrow Na_2S_4O_6 + 2NaI \end{aligned} \tag{7.4-2}$$

- Argentometry (from argent = silver) a typical use is the determination of H_2S. The gas containing H_2S is directed through KOH and then titrated with silver nitrate.

  $$\begin{aligned} H_2S + KOH &\rightarrow KHS + H_2O \\ KHS + KOH &\rightarrow K_2S + H_2O \\ K_2S + 2AgNO_3 &\rightarrow 2KNO_3 + Ag_2S \end{aligned} \tag{7.4-3}$$

7.5 Particle Measurement

It is undisputed that gases contain particles since they have been industrially produced. In the “pre-micro-electronic age” and when using non-rust-free steels and piston compressors one mainly thought that friction was the source of the particles. It was common to use sinter metal filters, which were mostly only effective to some µm.

With the production of electronic chips on silicon wafers it was inevitable that these would come into contact with room air during the manufacturing process as it was not possible to carry out all the steps in a vacuum or in closed gas systems.

This led to the development of clean room technology, including particle measurement, and was then also extended to the gases being used.

In section 3.4 it was shown that particles up to a diameter of 0.5 µm can be kept hovering at room temperature by Brown's molecular movement, thus they are also contained in relaxed or slowly flowing gas. Here it is not only necessary to recognise solid materials such as rust as particles but also aerosols. Why is such significance attributed to contamination by particles? For this purpose a heavy metal compound is selected as model substance: SnO_2, the oxide of 4-valenced tin, a solid substance. One takes $M_{Mol} = 150.69\ g \cdot mol^{-1}$ from (Merck 2002) and the density $\varphi = 6.95\ g \cdot cm^{-3}$ at 20 ^{0}C at. Idealising the form as a sphere one obtains the equation for the number $n_{particle}$ of the SnO_2 molecules in a particle. With a diameter d = 0.1 µm and $k_{Avogadro} = 6.022 \cdot 10^{23}$ one obtains

$$n_{particle} = \frac{\pi \cdot \left(d^3\left[\mu m^3\right]\right) \cdot \varphi\left[g \cdot cm^{-3}\right]}{6 \cdot 10^{15} \cdot M_{Mol}\left[g \cdot mol^{-1}\right]} \; k_{Avogadro}\left[mol^{-1}\right] \tag{7.5-1}$$
$$= 1.45 \cdot 10^7$$

These 14.5 million SnO_2 molecules can cause irreversible damage in a microelectronic structure. The SnO_2 has such a low vapour pressure that it cannot be considered as a gaseous impurity. Therefore one can understand that the demands for ever finer filters have continually increased. Nowadays they are in the range of 3 nm.

If it is to examine heavy metal impurities in gases it is necessary to assume that they are bonded to particles as a paste or a liquid or that they form particles themselves. It is usually not successful to prove this directly by inputting the gas to be examined in an analytical device. Therefore it is necessary to find a suitable separation of the substances to be determined from the matrix gases or gas mixtures (Koehler 1988). In practice there are only 2 ways of achieving this:

- The direct bonding of the particles in liquids, (Schram 1992).
- The use of filters and the subsequent extraction with liquids, (Faix et al. 1988) and (Laly et al. 1996).

Analytical procedures like ICP-MS or graphite furnace AAS have developed very quickly since the first experiments to determine heavy metals in the 80s so that by 2004 the sub-ppq-region ($< 1{:}10^{15}$) had been reached (Mickadeit et al. 2004).

To measure particles in extremely pure gases there are currently only 2 methods which are basically used and these differ strongly in type and the effort, (Taetz and Schmidt-Steffen 1991). Here it has to be differentiated between through examinations of the form of the procedure as well as the system components and the procedural controls to assure quality.

For basic developments the most certain method is the filtration of the pure gases to be tested by an analysis membrane with a subsequent counting under the electron microscope. It is sensitive enough and above all enables the identification/characterisation of individual particles and thus the localisation of sources of contamination. Due to the necessary measuring effort and the required temporal delay between measurement and evaluation this method is however not suitable for process control.

To measure the purity of both the room and the gases being used optical particle counting instruments have established themselves. These use the scattered light effect and/or the decrease in light intensity when passing a particle through a cell which is illuminated with white light or a narrow-band laser beam as a basis to determine size and number.

Example E7.5-1: Particle counter HPGP-101 from the firm PMT Partikel-Messtechnik AG in Heimsheim/Germany.

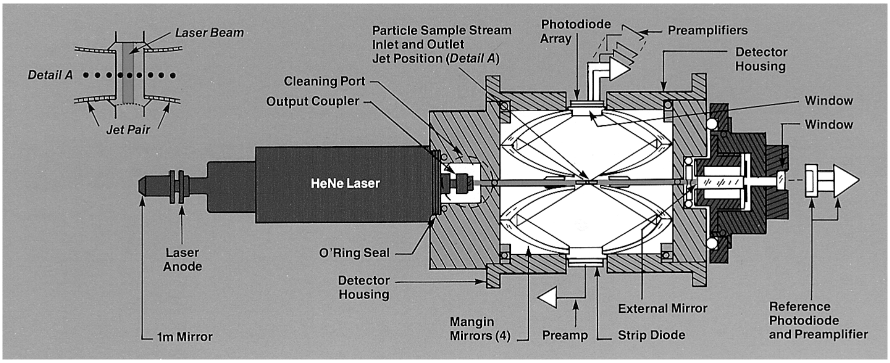


Illustration P7.5-1: *Schematic construction of the particle counter HPGP-101. Works drawing from the firm PMT.*

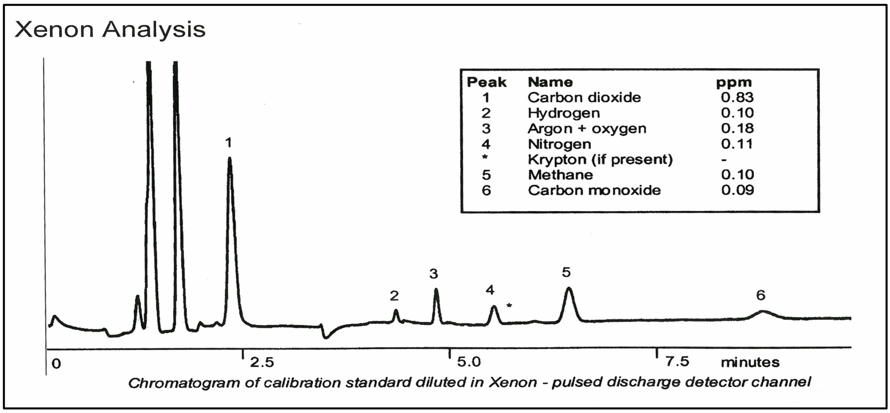
Description: The light comes from a HeNe laser with a power of 5 mW and the wavelength 633 nm. The beam has a diameter of about 1 mm and falls on the gas flowing through. The light scattered by the particles is directed through 4 specially formed mirrors with several photodiode arrays with preamplifiers behind a window and is measured. In addition, the non-reflected beam is determined at a reference photodiode. Technical data of the HPGP-101: Particle size: 0.1 to 5.0 µm, 8 channels for 0.1/0.2/0.3/0.5/1.0/2.0/3.0/5.0 µm, zero counting rate < 0.2 counting events per minute. Flow rate 2.8 $l \cdot min^{-1}$*, input pressure 2.8 to 10.5 bar.*

7.6 Automation of Complex Systems

The need for purer and purer gases has meant that the effort to analyse impurities has increased disproportionately. This concerns both the concentration of the impurities to be determined and their number.

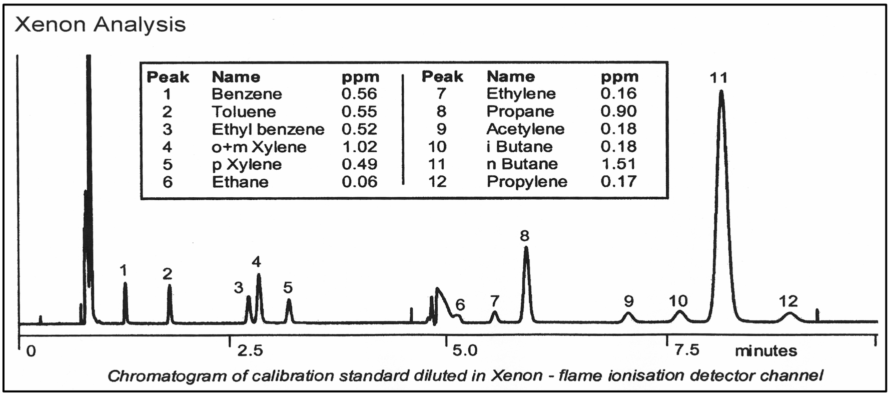
Therefore manufacturers are interested in complex analysis systems. There should be as few individual analysis instruments as possible to measure the specified impurities which can then be collected in a single electronically usable documentation system. This leads to systems which, after the cylinder has been connected and opened manually, involve a predominantly automatic purging of the gas paths, distribution of the gas flows to the individual analysis instruments, measurement taking the statistical conditions into consideration (t-table) and combining of the results in one single protocol. In some cases the number of impurities is greater than 10. Here too, the determination of moisture plays a subsidiary role for which it is always necessary to use a special device, except for measurements with mass spectrometers or FTIR devices.

Example E7.6-1: Analysis of xenon using gas chromatography



Peak	Name	ppm
1	Carbon dioxide	0.83
2	Hydrogen	0.10
3	Argon + oxygen	0.18
4	Nitrogen	0.11
*	Krypton (if present)	-
5	Methane	0.10
6	Carbon monoxide	0.09

Illustration P7.6-1: Chromatogram of air gases in Xenon (UNICAM Chromatography).



Peak	Name	ppm	Peak	Name	ppm
1	Benzene	0.56	7	Ethylene	0.16
2	Toluene	0.55	8	Propane	0.90
3	Ethyl benzene	0.52	9	Acetylene	0.18
4	o+m Xylene	1.02	10	i Butane	0.18
5	p Xylene	0.49	11	n Butane	1.51
6	Ethane	0.06	12	Propylene	0.17

Illustration P7.6-2: *Chromatogram of hydrocarbons ((*UNICAM Chromatography).

It is necessary to use two completely separate systems to analyse the impurities. The ones in air gases are detected with a discharge ionisation detector and the C_nH_m *with a FID.*

7.7 Testing Relevance to Application Technology

In 1967 the author visited the light bulb factory in the Warschauer Straße in East Berlin and examined the internal supply of pure N_2. The delivered N_2 had the quality 3.0 and was re-purified using nickel catalysts and a molecular sieve. The purity was checked with the so-called molybdenum clamp lamp. These were the well-known universal lamps into which a special filament made of a molybdenum alloy had been inserted. The blackening of the glass by the evaporation of the filament material was an indication that the N_2 being used in the factory no longer corresponded to the quality demands. A subsequent measurement with the Hersch-cell showed that this blackening occurred with an O_2 content of ≥ 1 ppm.

One needs to differentiate between two methods as regards testing relevant to application technology.

- Trying out: Here an experimental batch is manufactured with the delivered gas. This method is used especially when a new product is being developed or large batches are to be produced. Trying out is a very reliable but also very expensive test. The gas producer often uses a designation for a product introduced in this way such as "suitable for …." see the explanations in section 1.1.
- Measurement with a method which is a direct result of the application is or has been specially developed from some elements: An example of this is the measurement of the specific electrical resistance of an epitaxically deposited layer of silicon by pyrolysis of SiH_4. This ascertained that impurities decrease the resistance (in $\Omega \cdot$ cm) so that this measurement is an integral measure of the quality. (Schön 1985) reported that a monosilane with 10^2 to 10^3 $\Omega \cdot$ cm had been achieved, currently it is possible to achieve more than 10^4 $\Omega \cdot$ cm.

A more recent development goes in this direction and it has its origin in pure space technology (Dressler 2002). AMC (airborne molecular contamination) refers to the molecular pollutants in the air. Detection is possible with the well-known methods IC, GC, AAS or FTIR, including enrichment but this is very elaborate. Therefore the search was focused on online detection. The method which is most efficient at the moment takes place by using a surface effect. It consists of changing the resonance frequency of an oscillating silicon crystal by covering the surface with a foreign mass. In addition a surface acoustic wave (SAW) is used. At first this method is non-selective but can be formed in a partially selective way by using different surface materials of the vibrating crystal for various groups of substances. One uses ng $\cdot$ cm^{-3} as a unit of measurement for the separated amount of substance.

Example 7.7-1: Monitor AiM FT of the firm Partikel-Meßtechnik AG in Heimsheim/Germany. The following layers on the sensors are suitable for various detections. SiO_2: organic material, Cu: HCl, HF, HBr, Cl_2 and NO_X, Ag: SO_X, H_2S and NO_X . Measurement takes place in real time; the LOD is 0.02 ng $\cdot$ m^{-3} which corresponds to content in the lower ppb region or less. As the pressure resistance is 7 bar it is possible to incorporate it in the low pressure supply tubing with VCR connections. With 11.4 x 9.4 x 5.0 cm the dimensions are remarkably small (without electrical supply and analysis).

8 Handling

It is advisable to differentiate between storage, moving the cylinders and withdrawing the gas in the filling station. In some cases there are different legal regulations which take into consideration the very different number of cylinders. It is quite conceivable for there to be more than 100,000 cylinders in a filling station, whereas in laboratories or production facilities there are often only a few.

Anyone who professionally fills containers (cylinders, bundles, barrels and cryogenic containers) and brings them into commerce as well as anyone who transports and delivers these containers has to be aware of the international and domestic legal regulations and adhere to these. Here the most important regulation is the (ADR 2005) and the annual updates. In addition, the publications of the organisations of gas-producing firms are very helpful, especially EIGA and CGA.

This chapter deals with the regulations that concern the user and what must be considered when withdrawing the gas in order to both maintain the purity and cope with toxicity and corrosiveness.

8.1 Tips for Transport, Storage and Gas Withdrawal

Listed below are general rules compiled for the user which are based on the German regulations (BGI 671 2003), (BGI 744 1995) and (IGV 2003).

- Only experienced and trained people are allowed to handle pressurised gas containers and gases (withdrawal, piping).
- Gas cylinders may only be transported with an appropriate valve protection such as a cylinder cap or a valve guard. Exceptions are cylinder containing a very small volume. These cylinders have no neck thread.
- Suitable measures such as clamps or chains must ensure that the gas cylinders cannot tip or fall over. This applies to the storage, withdrawal and transport. In the latter case it is often better to have the cylinders lying. Nevertheless, it is necessary to avoid the cylinders rolling around.
- Only in exceptional cases should the cylinders be transported in cars. Using trailers or pick-ups is more appropriate. When using closed vehicles it is necessary to ensure adequate ventilation.
- It is necessary to ensure that the gas container is adequately marked with a hazardous material label. In most cases the manufacturing company provides a

H. Schön, *Handbook of Purified Gases*,
DOI: 10.1007/978-3-540-32599-4_8

Material Safety Data Sheet MSDS which contains the most important tips for transport and use.

- Gas cylinders must be protected from being heated by radiators. The recommended minimum distance is 0.5 m. It is permissable to use open flames to warm up the pressurised gas cylinder. If this is necessary then the right means are water baths or heat gun (industrial har dryer).
- If there are traces of damage or burning on the valve and the bottle then it is necessary to consult the gas supplier as to how to proceed.
- The user is not allowed to transfer gases from a pressurised gas bottle into another container and bring this into commerce.
- In Germany the date of the next recurring test is engraved on the cylinder, cylinders from abroad may use other markings. In the USA the requirement is only the most recent past test date. Although filling can only take place within the revision period it is possible to withdraw the gas after exploration. However, a prerequisite for this is that the cylinder is in a completely intact state.
- Before withdrawing the gas it is necessary to examine the valve. For inflammable, corrosive and toxic gases the thread connection must be provided with an outlet cap nut for safety reasons. This is also necessary for pure gases in order to maintain the purity. When this nut has been removed it is easy to ascertain whether the connection is clean and oil-free. If a cleaning is necessary this can be done with cotton swabs which have been soaked in alcohol or acetone. Then it is necessary to wait a short time before connecting the withdrawal equipment so that the remains of these substances can evaporate.
- After connecting the gas cylinder to the equipment it is necessary to examine the leak tightness by brushing with a soapy liquid or using a leak-detection spray. Any escaping gases may cause burning or poisoning.
- Even if a very small quantity of oxygen escapes the operating personnel face the danger that their clothing is soaked in O_2. Then bodily fat and hairs provide the necessary requirement for the body to catch fire. Acetylene requires particular attention because it tends to deteriorate explosively and is very flammable. Valve fires are common.
- With SiH_4 a small leak is enough to cause a flame.
- Coping with a burning cylinder (at the valve or in the use station) requires experience and personal courage. Two pieces of advice can be given: cool it down with water and, wearing gloves, try to close the valve. If it cannot be closed, then it is essential to maintain the cooling to avoid the risk of an explosion.
- In the case of toxic gases it is necessary to refer to company-specific sensors (gas warning devices) if there is a leak.

8.2 Fittings and Equipment for Gas Withdrawal

Large manufacturers of technical gases normally provide their customers with a comprehensive range of equipment to withdraw gases from pressurised gas containers, usually including:

- Manifolds for withdrawing gases flowing of 12 to 25 $m^3 \cdot h^{-1}$ for supplying through tubing or for major individual customers. Pre-pressure up to 240 or even 350 bar and outlet pressure of 10 to 15 bar.

  Example E8.2-1: Manifold for oxygen

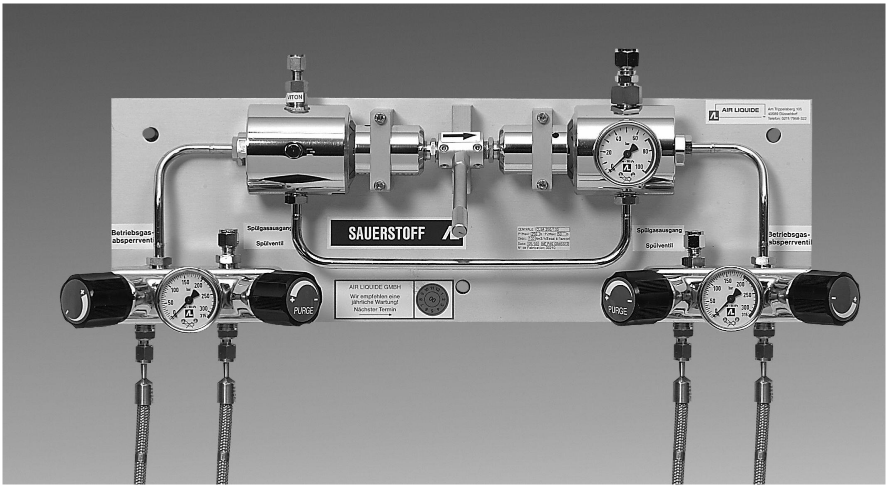


Illustration P8.2-1: *Station for selective withdrawal from two cylinders or even two bundles. Switching is simply done by moving the lever between the two pressure regulators. Works photo from AIR LIQUIDE GmbH /Germany.*

- Pressure regulator for individual cylinders. Choice of pressure regulator should adhere to the following criteria:
  a) Inlet pressure: mostly up to 240 bar for the 200 bar cylinder or 350 bar for the 300 bar cylinder. This takes temperature-related pressure increases in the cylinder into consideration.
  b) Outlet pressure: mostly 0.1 to 7 bar. If it is necessary to maintain a constant after-pressure even though the cylinder pressure is decreasing then it is best to use two-stage or multiple-stage pressure regulators.
  c) Gas flow rates: mostly smaller than 3 $m^3 \cdot h^{-1}$.
  d) Material: choice depends on the gas. Corrosive gases such as HCl or acetylene are particularly difficult to deal with.
  e) Purging: indispensable for toxic and corrosive gases.
  f) Gas purity: For pure gases it is necessary to use metal diaphragms and suitable seals (VCR). The surface quality is decisive for achieving low-particle withdrawal.

Example E8.2-2: Principle of a pressure regulator and its rinsing

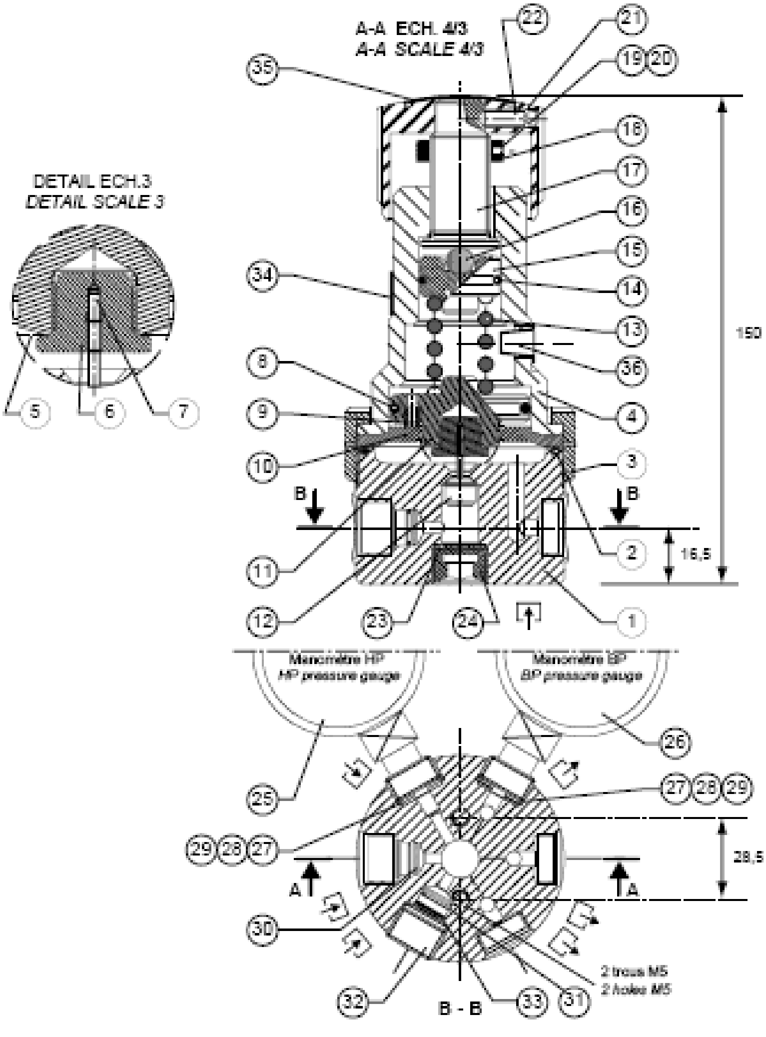


Illustration P8.2-2: Single-stage pressure regulator type DIM for all pure gases except O_2 of company Air Liquide. Maximum inlet pressure 240 bar, adjustable output pressure 0.3 to 3 bar (g), maximum flow rate 5 m^3/h.

Description: 1: body, 2: diaphragm seal, 3:cover nut, 4: cover, 5: diaphragm, 6: push rod support, 7: stop piece, 8: O-ring dia.32.92x3.53, 9: valve spring, 10: space piece, 11: diaphragm plate, 12: set pitch valve, 13: load spring, 14: O-ring 20x2, 15: spring centre, 16: ball dia.8, 17: pressure relief screw, 18: lock nut, 19: screw M4x6, 20: ball, 21: hand wheel, 22: screw M5x15, 23: leak disc, 24: plug, 25+26: pressure gauge, 27: seal washer 0.5, 28: seal washer 1, 29: seal washer 1.5, 30: filter dia.11, 31: elastic ring, 32: plug, 33: seal washer, 34: characteristic plate, 35: AL firm plate, 36: protection cover.

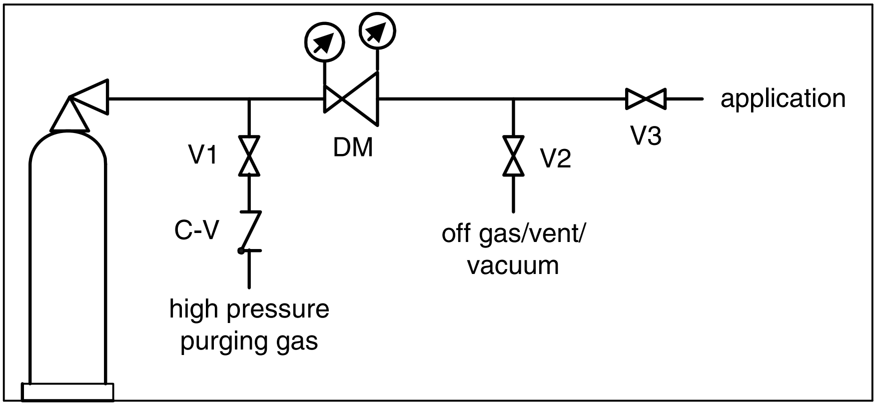


Illustration P8.2-3: Switching of a pressure regulator DM with high pressure purging. Description: V1: High pressure valve for the inlet of the purging gas. C-V: Check valve (no return valve) V2: Low pressure valve for the venting of the purging gas into the waste gas or also for connection to a vacuum pump. V3: Low pressure valve before use.

- Gas cylinder cabinets: If the gas cylinders are to be stored as near as possible to the point of use then it is really advantageous to have visibility and short piping. For toxic and/or corrosive gases the disadvantage is the immediate proximity to the personnel who face additional risks if there is a leak. For this reason gas cylinder cabinets which have their own ventilation systems and in the case of fire are resistant for at least 90 min were developed. In addition the discharge equipment and pressure safety systems provide sensors which warn if gas is escaping and because an automatic shutdown of the gas flows.

Example E8.2-4: Gas cylinder cabinets of company asecos GmbH in Gründau/Germany.

Safe storage of gas cylinders in workroom in accordance with (EN 14470-2 2006)*, complete uniform ventilation inside the cabinet (floor and ceiling) with pressure drop below 150 Pa by withdrawal of the air with a 120-times air change. Highest safety class: G 90. Illustration P8.2-3 next page.*

Illustration P82-4 : G90 Gas Cylinder Cabinet from firm Asecos GmbH / Germany.

- Other fittings are valves, pressure measuring equipment, flexible pipes, spiral connections, seals and fittings which will not be listed here because they have been at least partly dealt with in chapter 4.

8.3 Gas Mixtures at the User

If the user needs concentrations for the gas mixtures, which frequently vary then it is advisable to use a mixture device switched after the pressure regulators. For this purpose mass flow controllers (MFC) are used. These allow defined gas flows to be adjusted.

The principle is shown in Illustration P8.3-1 bellow and was taken from documents provided by the company Bronkhorst HI-TEC B.V. in the Netherlands. As can be seen in the illustration, a small portion of the flow (Q_M) runs through a parallel tube containing the sensor. This consists of a heating element R_H which is situated between the temperature measurements R_{T1} and R_{T2}. The resulting difference in temperature $\Delta T = T_1 - T_2$ is the specific heat capacity c_P at a constant pressure and is proportional (expressed as k) to the mass flow Q_M.

$$\Delta T = k \cdot c_P \cdot Q_M \tag{8.3-1}$$

The temperatures T_1 and T_2 are represented electrically as changeable resistances R_{T1} und R_{T2} which give a signal for a regulator in a Wheatstone bridge. This is compared with a standard value signal and is used to control a regulating valve.

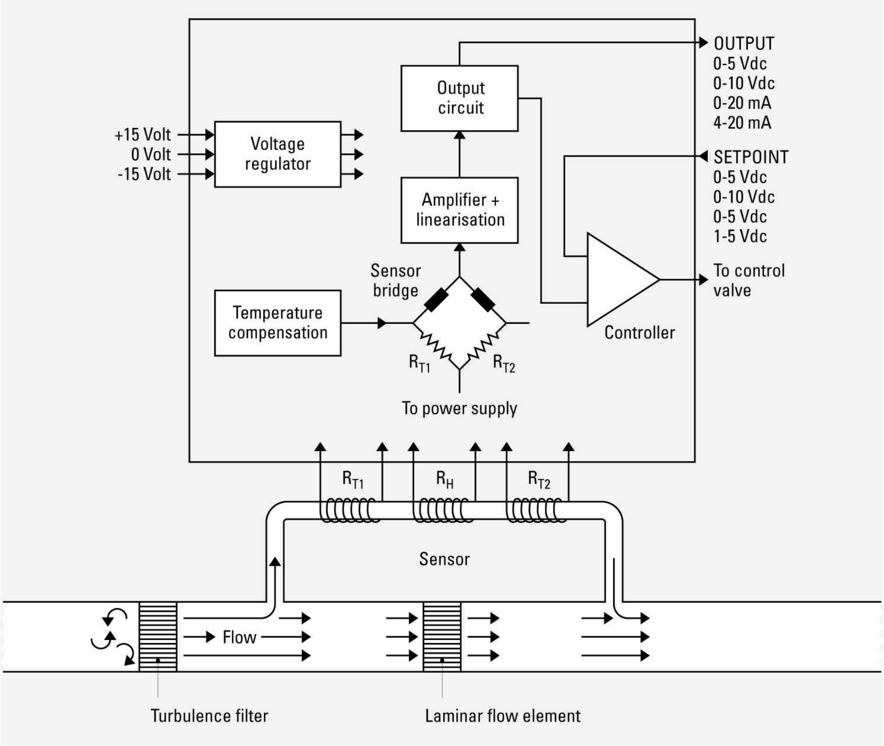


Illustration P8.3-1: *Measuring principle of an MFC. Works drawing from the firm Bronkhorst HI-TEC B.V.*

Currently a common specification for the MFC was also taken from descriptive literature of the firm Bronkhorst HI-TEC B.V.

- Mass flow: 0.06 – 3 $cm^3 \cdot min^{-1}$ up to approx. 1000 $m^3 \cdot h^{-1}$ at STP.
- Accuracy of the mass flow: 0.5% of the measured value + 0.1% of the final value.

- Reproducibility: < 0.1% of the final value.
- Regulator stability: < ± 0.1% of the final value (for 1 l · min^{-1} N_2).
- Time constant: 1 – 2 s.
- Pressure sensitivity: 0.1% per bar (for N_2), which means that small pressure fluctuations have no significant effect.
- Temperature sensitivity: 0.05% of the final value per °C.
- Operating temperature: –10 to +70 °C
- Warming-up time: max. 30 min.
- Leak-rate: $< 1 \cdot 10^{-9}$ mbar · l · s^{-1}.
- Material: Stainless steel SS-316, suitable for almost all gases and gas mixtures.
- Surface quality: Roughness Ra = 0.2 to 0.6 µm.
- The necessary regulating valve is either integrated or can be supplied as a separate component.

If producing a binary calibrated gas mixture using two MFCs then one achieves a relatively inaccurate concentration of about ± 1% is achieved. As already mentioned in section 7.1 a description and error estimation can be found in (ISO 6145-7 2001).

Example E8.3-2: Gas mixtures with MFCs

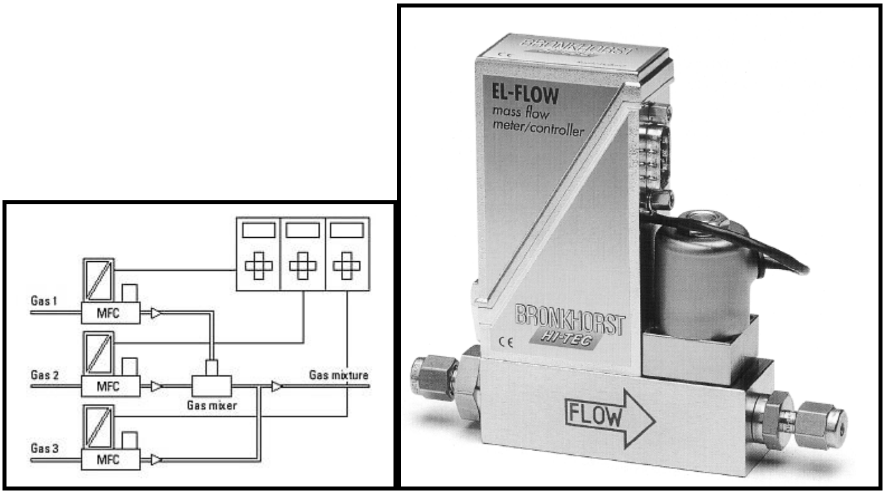


Illustration P8.3-2: Mass flow controller according to works drawings by the company *Bronkhorst*. Left: Switching for a ternary mixture, on the right at the top there are three individual controlling units including the current supply. Right: The type *F-201C/F* with an integrated control valve, measuring range minimum $0.15 - 7.5\ cm^3 \cdot min^{-1}$ and maximum $0.3 - 15\ l \cdot min^{-1}$ at a maximum pressure of 64 bar. The compact form of the regulator also allows a maximum measuring range of up to $1000\ m^3 \cdot h^{-1}$.

To manufacture very accurate mixtures with an MFC it is recommended to calibrate these individually using precision gas counters.

8.4 Purification at the "Point of Use"

There are two reasons for needing to carry out a further purification at the "point of use".

- With regard to individual accompanying components the available gas is not sufficiently pure for the purpose intended.
- There are impurities on the way from the gas cylinder to the point of use. The most important are: a) air components such as above all O_2 but also N_2 and moisture. b) moisture resulting from the walls. c) particles.

One of the first further purifications of gas was described by (Schubert u. Erdmann 1971) in Volume 1 of well-known magazine "gas aktuell" (Germany). This uses a combination of silica gel and chromium trioxide to remove O_2 and moisture from N_2 or other inert gases. The oxygen is bonded to the chromium by chemisorption. When uncharged chrome is 2-valent, when charged it is 6-valent. The moisture is bonded by adsorption.

To purify the gas at the point of use many of the methods described in chapter 3 are suitable. It is usually necessary to use a combination of several methods so that no further impurities can get into the gas flow. In addition it is necessary for the user to be able to control the temperatures necessary for these methods. This means that methods at very low temperatures cannot be used.

Example E8.4-1: Point of use purifier.
Using these purifiers it is possible to remove the above-mentioned impurities up to residual concentrations in the lower ppb region. The maximum through-flow amounts Q_V are usually $50\ l \cdot min^{-1}$ at small positive pressures.

Table T8.4-1: Purifiers of the company Air Liquide GmbH in Germany.

Gas	Impurities removed	Unsuitable for	Method	Designation ALPHAGAZ
Rare gases, N_2, CO, H_2, CO_2, saturated C_nH_m	O_2, H_2O	O_2, unsaturated C_nH_m, compressed air	Chemisorption Adsorption	O_2-free
Rare gases, N_2, CO, H_2, saturated C_nH_m, O_2, N_2O, CFC, compressed air	H_2O, CO_2		Adsorption	H_2O-free
Rare gases, N_2, CO, H_2, CO_2, compressed air	C_nH_m	O_2	Adsorption	HC-free
Rare gases, N_2, CO, H_2, CO_2, saturated C_nH_m, compressed air	H_2S, SO_2, COS, CS_2, mercaptane, NO	O_2	Chemisorption Adsorption	Sulphur-free

Table T8.4-2: Purifier from the construction series Mono Torr of SAES Pure Gas, Inc. in San Luis Obisco, USA. Each purifier has a particle filter at the gas discharge. THC = total hydro carbons.

Gas	**Impurities removed**	**Designation Product**
Rare gases	H_2O, O_2, H_2, CO, CO_2, N_2, THC	MT-R
N_2	H_2O, O_2, H_2, CO, CO_2, THC	MT-N
H_2	H_2O, O_2, CO, CO_2, N2	MT-H
SiH_4	H_2O, O_2, siloxanes	MT-SI
NH_3	H_2O, O_2, oxides	MT-NH
CF_4, C_2F_6, CHF_3	H_2O, O_2, oxides	MT-CF
SF_6	H_2O, O_2, oxides	MT-SF
CH_4	H_2O, O_2, oxides	MT-CH

9 Data Sheets

Data sheets are intended to provide an overview. They have mainly been compiled from data from the specialty gas catalogues of the firms (Air Liquide 2000), (Linde AG 1999) and (Messer Griesheim 2003) as well as from the safety data sheets of the firms (Air Liquide 2003–07), (Linde AG 2003) and (Messer Griesheim 2003) and also supplemented by the up-to-date reference works of (D´Ans-Lax 1983–98), (Gerling, Holz & Co. 1996), (L´Air Liquide 1976), (Kühn u. Birett 2003–05), (Landolt-Börnstein from 1951), (Messer Griesheim 1989), (Poling et al. 2001) and (Yaws 2001) et (DIN 1871 1999) and (TRB 610 2001)Additional information about toxic gases can also be found in (Ludewig 1999).

9.1 Classification and Limiting Values

The definition of what constitutes a gas in comparison to a liquid and the classification of gases are the same all over the world. The bracket # provides the appropriate EU classification code (division) according to ADR/RID.

- The difference from liquids is defined by the vapour pressure. At 50°C a gas must have a vapour pressure larger than 3 bar or at 20 °C a vapour pressure greater than or equal to 1.01325 bar.
- Non-liquefied compressed gas: critical temperature $T_{Cri} \leq -50$ °C (–58 °F), examples: He, Ne, Ar, Kr, H_2, N_2, O_2, CH_4, CO. {1}
- High pressure liquefied gas: –50 °C (–58 °F) $< T_{Cri} \leq +65$ °C (149 °F), examples: Xe, CO_2, SiH_4, SF_6. {2}
- Low pressure liquefied gas: $T_{Cri} > +65$ °C (149 °F), examples: NH_3, C_3H_8 , i- and n-C_4H_{10}, C_2H_4O, CCl_2F_2 (R12). {2}
- Compressed gas in solution: non-liquefied compressed gas, which is dissolved in a solvent, example: C_2H_2. {4}
- Cryogenic liquid: refrigerated liquefied gas having a boiling point $T_{bp} < -90$ °C (–130 °F), examples: LN_2, LO_2, LNG (Liquid Natural Gas). {3}
- The EU Classification Code is supplemented by a number and letters, examples:
  - Arsine: class 2, class code 2TF
  - Carbon monoxide: class 2, class code 1TOC
  - Phosgene: class 2, class code 2TC
  - Trifluoromethane : class 2, class code 2A

H. Schön, *Handbook of Purified Gases*,
DOI: 10.1007/978-3-540-32599-4_9

- Class 2: Gases:
  - Division 2.1: Flammable gases
  - Division 2.2: Non-flammable, non-toxic gases
  - Division 2.3: Toxic gases
- Class 3: Flammable liquids
- Class 5: Oxidizing Agents
  - Division 5.1: Oxidizing Agents
- Class 6: Toxic and Infectious Substances
  - Division 6.1: Toxic Substances
- Class 7: Radioactive Substances
- Class 8: Corrosive Substances

Table T9.1-1: Descriptions according to the class code.

A	Asphyxiating	TF	Toxic, flammable
O	Oxidizing	TC	Toxic, corrosive
F	Flammable	TO	Toxic, oxidizing
T	Toxic	TFC	Toxic, flammable, corrosive
		TOC	Toxic, oxidizing, corrosive

The UN-No. is a four-figure number to mark materials or objects according to the model regulation handbook of the UN. Examples: Propane 1978, Oxygen 1072.

Hazard identification number placard:

This identification system is in use for placards (ADR 2005) for road transport. The background of the placards is orange

Example: LO_2 liquid oxygen

225
1072

The upper number is indicating the danger and the lower number identifies the substance with the UN-number

Table T9.1-2: hazard identification number combinations have following meanings

20	Inert gas
22	Refrigerated gas
223	Refrigerated flammable gas
225	Refrigerated oxidizing (fire-intensifying) gas
23	Flammable gas
236	Flammable gas, toxic
239	Flammable gas, which can spontaneously lead to violent reaction
25	Oxidizing (fire-intensifying) gas
26	Toxic gas
265	Toxic gas, oxidizing (fire-intensifying)
266	Highly toxic gas
268	Toxic gas, corrosive
286	Corrosive gas, toxic

The CAS No. is an internationally common registration number for the unequivocal identification of chemical substances which has been allocated by the Chemical Society of America, a private scientific organisation.

The threshold limit value for the concentration at the workplace which has been published by the Conference of Governmental Industries Hygienists (ACGIH) is regarded as the international standard, although many countries have their own classification, see the German MAK value.

The LC_{50}/1h – value (Lethal Concentration): The lethal concentration value is determined by experiments on rats and gives the concentration in proportion to the toxic substances used on the experimental animals when more than 50% die after 14-days exposure. The LC_{50}/1h is the extrapolation relevant to human beings after an exposure time of 1 hour which leads to severe health damage or even death. Example AsH_3: 20 ppm. Literature . See also section 10.9.

The EU No: Dangerous substances on the market have been included in the European List – EINECS. These are 7-figure numbers following the pattern XXX-XXX-X, beginning with 201-010-9. Dangerous substances which have been registered in the European List ELINCS also follow the pattern XXX-XXX-X but begin with 400-010-9.

The EC classification: This classification for dangerous substances is contained in the already quoted lists EINECS and EILINCS. It is both expressed by danger characteristics and by risk and safety statements. According to the directive (67/548/EEC 1967) the important characteristics are:

Table T9.1-3: Important characteristics

Explosives	E	Toxic	T
Oxidizing agents	O	Very toxic	T+
Highly flammable	F	Corrosive substances	C
Extremely flammable	F+	Irritants	Xi
Harmful substances	Xn	Dangerous for the environment	N
Mutagens	Mut.Cat.1-3	Toxic for reproduction	Repr.Cat.1-3
Carcinogens	Carc.Cat.1-3		

The appendix to the directive (67/548/EEC 1967) contains a further number for the identification of a dangerous Substance: The EU index number. This is compiled according to the principle XXX-XXX-XX-X, examples: HCl (Gas) 017-002-00-2, Vinyl bromide 602-024-00-2, Methyl chloride 602-001-00-7.

The interested reader will share the author's opinion that the multiplicity of regulations and the differences between the countries lead to uncertainties and danger. To face this danger, and given the reality of the extensive global trade in chemicals and the need to develop national programs to ensure their safe use, transport and disposal, it was recognised that an internationally-harmonized approach to classification and labelling would provide the foundation for such programs. The new system, which was called "Globally Harmonized System of Classification and Labelling of chemicals" (GHS), addresses classification by types of hazard and proposes harmonized hazard communication elements, including labels and safety data sheets. The plan of implementation of the World Summit on Sustainable Development (WSSD), encourages countries to implement the GHS as soon as possible with a target to having the system fully operational by 2010. Many countries are continuing to implement this system.

9.2 Physical-Technical Data

In the case of physical and technical data some important data are not listed, either because the author could not ascertain them or because they will only be available in the future after new measurement results. The sizes are mostly determined by the reference values, pressure and temperature.

Substances which come into contact with gases are listed as "all common ones" (= All known):

- All metals and alloys of steel, stainless steel, monel, copper, brass and aluminium.
- As sealing substances: PE(polyethylene), PVC(polyvinylchloride), PTFE (polytetrafluoroethylene, usually referred to as Teflon), PCTFE (polyclorotrifluoroethylene,including Kel-F) and PVDF(polyvinylidene fluoride). In so far as this does not apply to a substance, then the individual materials are listed.

Determining the substances is intended to cover the case in which there are leaks in the containers or contaminations in the surrounding air. One uses simple chemical methods, simultaneously useable detectors as well as detector tubes (Dräger 2003).

If there is a fire, if possible, the most important action is to close the cylinder valve (chapter 8). Usual extinguishers are water, powder, CO_2, sand.

In order to understand individual data, the source of the numbers according to the following table has been added.

Table 9.2-1: Literature used for the physical-technical data the appropriate number [x] has been provided in the data sheets.

Number	Reference	Title
[1]	(L´Air Liquide 1976)	Encyclopedie des Gaz
[2]	(Kühn u. Birett 2005–07)	Merkblätter gefährliche Arbeitsstoffe
[3]	(Messer Griesheim 1989)	Gase-Handbuch
[4]	(Gerling, Holz & Co. 1996)	Kleine Enzyklopädie der Gase
[5]	(Poling et al. 2001)	The Properties of Gases and Liquids
[6]	(Air Liquide 2005–07)	Material Safety Data Sheets (MSDS)
[7]	(Linde AG 2005–07)	MSDS
[8]	(Messer Griesheim 2003)	MSDS
[9]	(Air Liquide 2000)	Spezial gas catalog/Germany
[10]	(Linde AG 1999)	Spezial gas catalog /Germany
[11]	(DIN 1871 1999)	Gasförmige Brennstoffe und sonstige Gase. Dichte u. andere volumetrische Größen
[12]	(TRB 610 2001)	Aufstellen von Druckbehältern
[13]	(Brandes u. Möller 2003)	Sicherheitstechnische Kenngrößen, Bd.1
[14]	(DIN 51857 1997)	Gasförmige Brennstoffe und sonstige Gase. Berechnung von Brennwerten, Heizwerten, .
[15]	(ISO 14912 2003)	Gas analysis – Conversation of gas mixture composition data.
[16]	(Calm 1995)	Refrigerants and Lubricants – Data for Screening and Application
[17]	(Matheson Trigas 2005–07)	Material Safety Data Sheets
[18]	(Gerling, Holz & Co.2005–07)	Material Safety Data Sheets
[19]	(Air Products 2005)	Material Safety Data Sheets
[20]	(Voltaix 2005-07)	Material Safety Data Sheets
[21]	(Voltaix 2004-07)	Materials for Chemical Vapour Deposition and Ion Implantation
[22]	(Hommel 2005)	Handbuch der gefährlichen Güter
[23]	(Lide 2003/04)	GRC Handbook of Chemistry and Physics
[24]	(Yaws 2001)	Matheson Gas Data Book
[25]	(Gestis 2006-07)	Stoffdatenbank des BGIA
[26]	(CGA 2003)	Handbook of Compressed Gases
[27]	(Downie 2002)	Industrial Gases
[28]	(Air Liquide 2005)	1 x 1 der Gase
[29]	(Praxair 2007)	Material Safety Data Sheets

The following notes and conversions will facilitate the use of the physical-technical data.

- $$1 \text{ bar} = 14.404 \text{ psi} \tag{9.2-1}$$
- $$b\ °\text{F} = a \cdot (9/5)\ °\text{C} + 32 \tag{9.2-2}$$
- $$1 \text{ kJ/kg} = 0.4299 \text{ BTU/lb} \tag{9.2-3}$$
- $$1 \text{ Ps} = 0.1 \cdot 10^{-6} \text{ Ns/m}^3 \tag{9.2-4}$$
- $$1 \text{ W/m} \cdot \text{K} = 10 \text{ mW/cm} \cdot \text{K} \tag{9.2-5}$$
- $$1 \text{ g/l} = 0.0624 \text{ lb/ft}^3 \tag{9.2-6}$$
- $$1\,\text{MJ}/\text{kg} = \frac{1\,\text{MJ}/\text{kmol}}{10^3 M_{\text{Mol,G}}} \tag{9.2-7}$$
- $M_{\text{Mol,G}}$ is the molecular weight of the gas G in g/mol
- ideal density $$\varphi_{\text{ideal,G}} = \frac{M_{\text{Mol,G}}}{V_{\text{Mol,ideal}}} \tag{9.2-8}$$

with $V_{\text{Mol,ideal}} = 22.4138$ [l]

9.3 Synonyms and Data Sheets

In order to facilitate the location of individual gases the following table compiles a list of synonyms.

Table T9.3-1: gas lists: Overview of the data sheets. The name under which a gas has been allocated to the data sheets has been marked with a *. The third column is the CAS No. The number in the last column is the author's internal number and has no connection with any other classification. (#): identical name for different gases.

Gas	Synonym	CAS-Nr	Nr
(E)-2-Butene	trans-2-Butene*, trans-2-Butylene, trans-But-2-ene, beta-Butylene, Low-boiling Butene-2	00624-64-6	011
(Z)-2-Butene	cis-2-Butene*, cis-2-Butylene, cis-But-2-ene, High-boiling Butene-2	00590-18-1	010
1,1,1,2- Tetrafluoroethane	Tetrafluoroethane*, R134a	00811-97-2	026
1,1,1,2,2- Pentafluoroethane*	Pentafluoroethane*, R125	00354-33-6	029
1,1,1,2,3,3,3- Heptafluoropropane	Heptafluoropropane*, Apaflurane, R227	00431-89-0	104
1,1,1-Trifluoroethane*	Trifluoroethane, R143a, R143 (IMDG-Code)	00420-46-2	093
1,1,1-Trimethylethane	2,2-Dimethylpropane*, Neopentane, Tert-Pentane	00463-82-1	030

1,1,2,2- Tetrafluoro-ethylene	Tetrafluoroethylene* inhibited, TFE, Perfluoroethylene, R1114	00116-14-3	109
1,1,2,3,4,4-Hexafluroro-1,3-Butadiene	Hexafluoro-1,3-Butadiene*, Sifren46, Perfluorobutadiene-1,3	00685-63-2	056
1,1-Difluoroethane*	Ethylene fluoride, R152a, Algofrene Type 67	00075-37-6	088
1,2-Dichloro-1,1,2,2-tetrafluoroethane	Dichlorotetrafluoroethane*, R114, Cryofluorane, Tetrafluorodichloroethane	00076-14-2	100
1,2-Epoxyethane	Ethylene oxide*, Oxirane, Oxacyclo-propane	00075-21-8	040
1,2-Propadiene	Allene*, Dimethylene methane, sym-Allylene	00463-49-0	038
1,3-Butadiene* stabilized	Bivinyl, Buta-1,3-diene, Divinyl, alpha-gamma-Butadiene, Erythrene, Pyrrolylene, Vinylethylene	00106-99-0	006
1-Butene*	1-Butylene, alpha-Butylene, But-1-ene, n-Butene	00106-98-9	009
1-Butylene	1-Butene*, alpha-Butylene, But-1-ene, n-Butene	00106-98-9	009
1-Butyne* inhibited	Ethylacetylene, Ethylethyne, But-1-yne	00107-00-6	013
1-chloro-1,1,2,2,2-pentafluoroethane	Chlorotrifluoroethane*, R115, Pentafluorochloroethane, Pentafluoroethyl chloride	00074-15-3	086
1-Chloro-1,1,2,2-tertra-fluoroethane	R124a	00354-25-6	114
1-Chloro-1,1-difluoroethane	Difluoromonochloroethane*, Chlorodifluoroethane, R142b, alpha-Cloroethylidene fluoride	00075-68-3	085
1-Chloro-2,2,2-trifluoroethane	Chlorotrifluororethane*, R133a. 2-Chloro-1,1,1-trifluoroethane	00075-88-7	098
1-Propene	Propene*, Propylene, Methyl ethylene, R1270, Methylethene	00115-07-1	037
1-Propyne	Methylacetylene*, Allylene, Propine, Propyne,	00074-99-7	106
2,2-Dimethylpropane*	Neopentane, 1,1,1-Trimethylethane, Tert-Pentane	00463-82-1	030
Tert-Pentane	2,2-Dimethylpropane*, Neopentane, 1,1,1-Trimethylethane	00463-82-1	030
2-Chloro-1,1,1,2-tertra-fluoroethane	R124	02837-89-0	115
2-Chloro-1,1,1-trifluoroethane	Chlorotrifluoroethane*, 1-Chloro-2,2,2-trifluoroethane, R133a	00075-88-7	098
2-Methyl propane	Isobutane*, i-Butane, i-Methyl ethyl methane, R600a, Trimethyl- methane	00075-28-5	008
2-Methylpropene	Isobutene*, Isobutylene, gamma-Butylene, Liquefied Petroleum Gas(#), asym. Dimethylethylene	00115-11-7	012

Acetene	Ethylene*, Olefiant gas, R1150, Bicarburretted hydrogen, Etherin, Elayl, Ethene	00074-85-1	035
Acetylene*	Ethine, Ethyne, Narcylene, Carbide gas, Dissousgas	00074-86-2	073
Aethylis chloridum	Ethyl chloride*, Chlorethane , Muriatic ether, Kelene, Narcotile, Chelen ,Ether chloratus, R160	00075-00-3	017
AHF	Hydrogen fluoride, anhydrous*, Hydrofluoric acid gas, Fluorhydric acid gas	07664-39-3	060
Air fixe	Carbon dioxide*, Carbonic acid gas, Carbonic anhydride, Dioxide of carbon,	00124-38-9	082
Algofrene Type 67	1,1-Difluoroethane*, Ethylene fluoride, R152a	00075-37-6	088
Allene*	1,2-Propadiene, Dimethyl methane, sym-Allylene	00463-49-0	038
Allylene	Methylacetylene*, Propine, Propyne, 1-Propyne	00074-99-7	106
alpha-Butylene	1-Butene*, 1-Butylene, But-1-ene, n-Butene	00106-98-9	009
alpha-Cloroethylidene fluoride	Difluoromonochloroethane*, 1-Chloro-1,1-difluoroethane, Chlorodifluoroethane, R142b	00075-68-3	085
alpha-gamma-Butadiene	1,3-Butadiene*, stabilized, Buta-1,3-diene, Vivinyl, Divinyl, Erythrene, Pyrrolylene, Vinylethylene	00106-99-0	006
Aminoethane	Ethylamine*, Ethanamine, R631	00075-04-7	039
Aminomethane	Methyamine* anhydrous, Mercurialin, Methanamine, R630	00074-89-5	031
Ammonia, anhydrous*	R717, H3N	07664-41-7	074
Antimony trihydride	Stibine*, Hydrogen antimonide	07803-52-3	094
Apaflurane	Heptafluoropropane*, 1,1,1,2,3,3,3-Heptafluoropropane, R227	00431-89-0	104
Argon,compressed*	R740	07440-37-1	068
Arsenic trihydride	Arsine*, Hydrogen arsenide	07784-42-1	001
Arsine*	Arsenic trihydride, Hydrogen arsenide	07784-42-1	001
asym. Dimethylethylene	Isobutene*, Isobutylene, 2-Methylpropene, gamma-Butylene, Liquefied Petroleum Gas(#)	00115-11-7	012
beta-Butylene	trans-2-Butene*, trans-2-Butylene, trans-But-2-ene, Low- boiling Butene-2, (E)-2-Butene	00624-64-6	011
Bicorburretted hydrogen	Ethylene*, Acetene, Olefiant gas, R1150, Etherin, Elayl, Ethene	00074-85-1	035
Bimethyl	Ethane*, Dimethyl, Ethyl hydride, R170, Methyl methane	00074-84-0	034

Bivinyl	1,3-Butadiene*, stabilized, Buta-1,3-diene, Divinyl, alpha-gamma-Butadiene, Erythrene, Pyrrolylene, Vinylethylene	00106-99-0	006
Boroethane	Diborane*, Diboron hexahydride	19287-45-7	046
Boron trichloride*	Trichloro borane	10294-34-5	002
Boron trifluoride*	Trifluoroborane	07637-07-2	003
Boron trimethyl	Trimethylboron*, trimethylborane, TMB	00593-90-8	111
Bromochlorodifluoromethane*	Monochlorodifluoromonobromomethane, R12B1, Halon 1211, Chlorodifluorobromomethane	00353-59-3	095
Bromoethene	Vinyl bromide, stabilized*, Monobromoethylene, R1140B1,	00593-60-2	096
Bromofluoroform	Bromotrifluoromethane*, R13B1, Halon 1301, Trifluoromonobromomethane	00075-63-8	004
Bromomethane	Methyl bromide*, R40B1, Halon 1001, Dowfume, Rotox, Zytox, Pestmaster, Methogas	00074-83-9	084
Bromotrifluoro-methane*	Bromofluoroform, R13B1, Halon 1301, Trifluoromonobromomethane	00075-63-8	004
But-1-ene	1-Butene*, 1-Butylene, alpha-Butylene, n-Butene	00106-98-9	009
But-1-yne	1-Butyne* inhibited, Ethylacetylene, Ethylethyne	00107-00-6	013
Buta-1,3-diene	1,3-Butadiene*, stabilized, Bivinyl, Divinyl, alpha-gamma-Butadiene*, Erythrene, Pyrrolylene, Vinylethylene	00106-99-0	006
Butane*	n-Butane, Diethyl, R600, Methylethylmethane	00106-97-8	007
Carbide gas	Acetylene*, Ethine, Ethyne, Narcylen, Dissousgas	00074-86-2	073
Carbon dioxide*	Carbonic acid gas, Carbonic anhydride, Dioxide of carbon, Air fixe	00124-38-9	082
Carbon monoxide*	Carbon oxide, Monoxide of Carbon, Exhaust gas, Flue gas	00630-08-0	078
Carbon oxide	Carbon monoxide*, Exhaust gas, Flue gas	00630-08-0	078
Carbon oxide sulfide	Carbonyl sulfide*, Oxycarbonsulfide	00463-58-1	062
Carbon oxychloride	Phosgene*, Carbonyl chloride, Chloroformyl chloride, Carbon dichloride oxide,	00075-44-5	042
Carbon tetrafluoride	Tetrafluoromethane*, R14, Perfluoromethane, Tetrafluorocarbon	00075-73-0	025
Carbonic acid gas	Carbon dioxide*, Carbonic anhydride, Dioxide of carbon, Air fixe	00124-38-9	082
Carbonic anhydride	Carbon dioxide*, Carbonic acid gas, Dioxide of carbon	00124-38-9	082

Carbon dichloride oxide	Phosgene*, Carbonyl chloride, Carbon oxychloride, Chloroformyl chloride, Diphosgene	00075-44-5	042
Carbonyl chloride	Phosgene*, Carbon oxychloride, Chloroformyl chloride, Carbon dichloride oxide, Diphosgene	00075-44-5	042
Carbonyl sulfide*	Carbon oxide sulfide, Oxycarbonsulfide	00463-58-1	062
Celphos	Phosphine*, Hydrogen phosphide, Delicia, Detia gas EX-B, Phosphorus trihydride, Phosphane	07803-51-2	043
Chelen	Ethyl chloride*, Chlorethane , Muriatic ether, Kelene, Narcotile, Aethylis chloridum, Ether chloratus, R160	00075-00-3	017
Chlorethane	Ethyl chloride*, Muriatic ether, Kelene, Narcotile, Aethylis chloridum, Chelen, Ether chloratus, R160	00075-00-3	017
Chlorethene	Vinyl chloride*, R1140, Ethylene monochloride	00075-01-4	018
Chlorine Cyanide	Cyanogen Chloride*, Chlorocyanogen	00506-77-4	097
Chlorine Trifluoride*	Chlorotrifluoride, CTF	07790-91-2	064
Chlorine*		07782-50-5	015
Chlorocyanogen	Cyanogen Chloride*	00506-77-4	097
Chlorodifluoro-bromomethane	Bromochlorodifluoromethane*, Monochlorodifluoromonobromomethane, R12B1, Halon 1211	00353-59-3	095
Chlorodifluoroethane	Difluoromonochloroethane*, 1-Chloro-1,1-difluoroethane, R142b, alpha-Cloroethylidene fluoride	00075-68-3	085
Chlorodifluoromethane*	Difluoromonochloromethane, R22	00075-45-6	016
Chlorofluorocarbon	Dichlorodifluoromethane*, Difluorodichloromethane, R12	00075-71-8	021
Chloroformyl chloride	Phosgene*, Carbonyl chloride, Carbon oxychloride, Carbon dichloride oxide, Diphosgene	00075-44-5	042
Chloromethane	Methyl chloride*, R40	00074-87-3	019
Chloropentafluoroethane*	1-Chloro-1,1,2,2,2-pentafluoroethane, R115, Pentafluorochloroethane, Pentafluoroethyl chloride	00074-15-3	086
Chloro-tetrafluroethane	1-Chloro-1,1,2,2-tertrafluoroethane (R124a)	00354-25-6	114
Chlorotrifluoride	Chlorine Trifluoride*, CTF	07790-91-2	064
Chlorotrifluoroethene	Trifluorochloroethylene*, R1113, CTFE, Trithene, 1,1,2-Trifluoro-2-chloroethylene, Trifluorovinyl chloride	00079-38-9	099
Chlorotrifluoromethane*	Trifluorochloromethane, R13	00075-72-9	020
Chlorotrifluoroethane*	1-Chloro-2,2,2-trifluoroethane, R133a, 2-Chloro-1,1,1-trifluoroethane	00075-88-7	098

cis-2-Butene*	cis-2-Butylene, cis-But-2-ene, High-boiling Butene-2, (Z)-2-Butene	00590-18-1	010
cis-2-Butylene	cis-2-Butene*, cis-But-2-ene, High-boiling Butene-2, (Z)-2-Butene	00590-18-1	010
cis-But-2-ene	cis-2-Butene*, cis-2-Butylene, High-boiling Butene-2, (Z)-2-Butene	00590-18-1	010
Cryofluorane	Dichlorotetrafluoroethane*, R114, 1,2-Dichloro-1,1,2,2-tetrafluoroethane, Tetrafluorodichloroethane	00076-14-2	100
CTF	Chlorine Trifluoride*, Chlorotrifluoride	07790-91-2	064
CTFE	Trifluorochloroethylene*, Chlorotrifluoroethene, R1113, Trithene, Trifluoro-2-chloroethylene, Trifluorovinyl chloride	00079-38-9	099
Cyanogen Chloride*	Chlorocyanogen, Chlorine Cyanide	00506-77-4	097
Cyanogen*	Dicyanogen, Ethane dinitril, Prussite, Oxalonitril	00460-19-5	083
Cyclobutane*	Tetramethylene	00287-23-0	113
Cyclooctafluorobutane	Octafluorocyclobutane*, Perfluorocyclobutane, RC318	00115-25-3	027
Cyclopropane*	Trimethylene	00075-19-4	014
Delicia	Phosphine*, Hydrogen phosphide, Celphos, Detia gas EX-B, Phosphorus trihydride, Phosphane	07803-51-2	043
Detia gas EX-B	Phosphine*, Hydrogen phosphide, Celphos, Delicia, Phosphane	07803-51-2	043
Deuterium*	Heavy Hydrogen, Diplogen, Hydrogen-D2	07782-39-0	076
Diborane*	Boroethane, Diboron hexahydride,	19287-45-7	046
Diboron hexahydride	Diborane*, Boroethane	19287-45-7	046
Dichlorodifluoromethane*	Chlorofluorocarbon, Difluorodichloromethane, R12	00075-71-8	021
Dichlorofluoromethane*	Dichloromonofluoromethane, R21, Fluorodichloromethane	00075-43-4	022
Dichloromonofluoromethane	Dichlorofluoromethane*, R21, Fluorodichloromethane	00075-43-4	022
Dichlorotetrafluoroethane*	R114, Cryofluorane, 1,2-Dichloro-1,1,2,2-tetrafluoroethane, Tetrafluorodichloroethane	00076-14-2	100
Dichlorosilane*	Silicon chloride hydride, Dichlorosilicane	04109-96-0	048
Dicyanogen	Cyanogen*, Ethane dinitril, Prussite, Oxalonitril	00460-19-5	083
Diethyl	Butane*; n-Butane, R600, Methylethylmethane	00106-97-8	007
Difluorodichloromethane	Dichlorodifluoromethane*, Chlorofluorocarbon, R12	00075-71-8	021

Difluoromonochloro-ethane*	1-Chloro-1,1-difluoroethane, Chlorodifluoroethane, R142b, alpha-Cloroethylidene fluoride	00075-68-3	085
Difluoromonochloro-methane	Chlorodifluoromethane*, R22	00075-45-6	016
Dihlorsilicane	Dichlorosilane*, Silicon chloride hydride	04109-96-0	048
Dihydrogen	Hydrogen*, Hydrogenium, Protium	07782-39-0	075
Dihydrogen monosulfide	Hydrogn sulfide*, Sulphuretted hydrogen	07783-06-4	045
Dimethyamine* anhydrous	DMA, N-Methylmethanamine	00124-40-3	032
Dimethyl	Ethane*, Bimethyl, Ethyl hydride, R170, Methyl methane	00074-84-0	034
Dimethyl ether*	Methyl ether, Methoxy methane, Wood ether, Methyl oxide, Oxybismethane	00115-10-6	066
Dimethyl methane	Propane*, Dimethyl methane, Ethyl methyl, R290, Propyl hydrid, Liquefied Petroleum Gas(#)	00074-98-6	036
Dimethyl methane	Allene*, 1,2-Propadiene, sym-Allylene	00463-49-0	038
Dimethyl silane*	Dimethyl silicane	01111-74-6	092
Dimethyl silicane	Dimethyl silane*	01111-74-6	092
Dinitrogen oxide*	Nitric oxide, Nitrogen monoxide, Nitrous oxide, Laughing gas, R744a	10024-97-2	083
Dinitrogen tetraoxide	Nitrogen dioxide, liquefied*, Nitrogen peroxide	10102-44-0	080
Dioxide of carbon	Carbon dioxide*, Carbonic acid gas, Carbonic anhydride,	00124-38-9	082
Dioxygen	Oxygen*, Oxygenium, Hyperoxia	07782-44-7	081
Diphosgene	Phosgene*, Carbonyl chloride, Carbon oxychloride, Chloroformyl chloride, Carbonic dichloride oxide	00075-44-5	042
Diplogen	Deuterium*, Heavy Hydrogen, Hydrogen-D2	07782-39-0	076
Disilane*	Disilicoethane, Disilicane, Silicon hexahydrite	01590-87-0	049
Disilicane	Disilane*, Disilicoethane, Silicon hexahydrite	01590-87-0	049
Disilicoethane	Disilane*, Disilicane, Silicon hexahydrite	01590-87-0	049
Dissousgas	Acetylene, Ethine, Ethyne, Narcylene, Carbide gas	00074-86-2	073
Divinyl	1,3-Butadiene*, stabilized, Buta-1,3-diene, Bivinyl, alpha-gamma-Butadiene, Erythrene, Pyrrolylene, Vinylethylene	00106-99-0	006
DMA	Dimethyamine* anhydrous, N-Methylmethanamine	00124-40-3	032

Dowfume	Methyl bromide*, Bromomethane, R40B1, Halon 1001, Rotox, Zytox, Pestmaster, Methogas	00074-83-9	084
Elayl	Ethylene*, Acetene, Olefiant gas, R1150, Bicarburretted hydrogen, Etherin, Ethene	00074-85-1	035
Elegas	Sulfur hexafluoride*, Sulphur hexafluoride	02551-62-4	053
Erythrene	1,3-Butadiene*, stabilized, Bivinyl, Buta-1,3-diene, Divinyl, alpha-gamma-Butadiene, Pyrrolylene, Vinylethylene	00106-99-0	006
Ethanamine	Ethylamine*, Aminoethane, R631	00075-04-7	039
Ethane dinitril	Cyanogen*, Dicyanogen, Prussite, Oxalonitril	00460-19-5	083
Ethane*	Bimethyl, Dimethyl, Ethyl hydride, R170, Methyl methane	00074-84-0	034
Ethene	Ethylene*, Acetene, Olefiant gas, R1150, Bicarburreted hydrogen, Elayl, Etherin	00074-85-1	035
Ether chloratus	Ethyl chloride*, Chlorethane , Muriatic ether, Kelene, Narcotile, Aethylis chloridum, Chelen, R160	00075-00-3	017
Etherin	Ethylene*, Acetene, Olefiant gas, R1150, Bicarburretted hydrogen, Elayl, Ethene	00074-85-1	035
Ethine	Acetylene*, Ethyne, Narcylen, Carbide gas, Dissousgas	00074-86-2	073
Ethoxymethane	Ethyl methyl ether*, Methyl ethyl ether, Methoxyethane	00540-67-0	101
Ethyl chloride*	Chlorethane, Muriatic ether, Kelene, Narcotile, Aethylis chloridum, Chelen, Ether chloratus, R160	00075-00-3	017
Ethyl fluoride	Fluoroethane*, R161	00353-36-6	102
Ethyl hydride	Ethane*, Bimethyl, Dimethyl, R170l, Methyl methane	00074-84-0	034
Ethyl methyl	Propane*, Dimethyl methane, R290, Propyl hydrid, Liquefied Petroleum Gas(#)	00074-98-6	036
Ethyl methyl ether*	Methyl ethyl ether, Methoxyethane, Ethoxymethane	00540-67-0	101
Ethylacetylene	1-Butyne* inhibited, Ethylethyne, But-1-yne	00107-00-6	013
Ethylamine*	Aminoethane, Ethanamine, R631	00075-04-7	039
Ethylene oxide*	Oxirane, 1,2-Epoxyethane, Oxacyclopropane	00075-21-8	040
Ethylene fluoride	1,1-Difluoroethane*, R152a, Algofrene Type 67	00075-37-6	088
Ethylene monochloride	Vinyl chloride*, Chlorethene, R1140	00075-01-4	018
Ethylene*	Acetene, Olefiant gas, R1150, Bicarburretted hydrogen, Etherin, Elayl, Ethene	00074-85-1	035

Ethylethyne	1-Butyne* inhibited, Ethylacetylene, But-1-yne	00107-00-6	013
Ethylhexafluoride	Hexafluoroethane*, Perfluoroethane, R116	00076-16-4	055
Ethyne	Acetylene*, Ethin, Narcylen, Carbide gas, Dissousgas	00074-86-2	073
Exhaust gas	Carbon monoxide*, Monoxide of Carbon, Carbon oxide, , Flue gas	00630-08-0	078
F3N	Nitrogen fluoride*, Perfluoroammonia, Trifluoroammonia, Trifluoroamine	07783-54-2	057
F4Si	Silicon tetrafluoride*, Tetrafluorosilane, Silicon fluoride, Perfluorosilane	07783-61-1	050
F6W	Tungsten hexafluoride*, Wolfram hexafluoride, Hexafluorotungsten,	07783-82-6	054
Fermenticide liquid	Sulfur dioxide liquefied*, Sulphurous anhydride, R764	07446-09-5	044
Flue gas	Carbon monoxide*, Monoxide of Carbon, Carbon oxide, Ehaust gas,	00630-08-0	078
Fluorhydric acid gas	Hydrogen fluoride, anhydrous*, Hydrofluoric acid gas, AHF	07664-39-3	060
Fluorine*		07782-41-4	051
Fluorodichloromethane	Dichlorofluoromethane*, Dichloromonofluoromethane, R21,	00075-43-4	022
Fluoroethane*	Ethyl fluoride, R161	00353-36-6	102
Fluoroethylene	Vinyl fluoride*, R1141	00075-02-5	103
Fluoromethane*	Methyl fluoride, R41	00593-53-3	033
Formonitril	Hydrogen cyanide*, Hydrocyanic acid, Purric Acid	0074-90-8	113
gamma-Butylene	Isobutene*, Isobutylene, 2-Methylpropene, Liquefied Petroleum Gas(#), asym. Dimethylethylene	00115-11-7	012
Germane	Germanium Tetrahydride*, Monogermane, Germanomethane	07782-65-2	059
Germanium Tetrafluoride*	Tetrafluorogermane	07783-58-6	058
Germanium Tetrahydride*	Germane, Monogermane, Germanomethane	07782-65-2	059
Germanomethane	Germanium Tetrahydride*,Monogermane	07782-65-2	059
Germanomethane	Germanium Tetrahydride*, Monogermane	07782-65-2	059
H3N	Ammonia, anhydrous*, R717	07664-41-7	074
Halon 1001	Methyl bromide*, Bromomethane, R40B1, Dowfume, Rotox, Zytox, Pestmaster, Methogas	00074-83-9	084
Halon 1211	Bromochlorodifluoromethane*, Monochlorodifluoromonobromomethane, R12B1, Chlorodifluorobromomethane	00353-59-3	095

Halon 1301	Bromotrifluoromethane*, Bromofluoroform, R13B1, Trifluoromonobromomethane	00075-63-8	004
HBR	Hydrogen bromide*, Hydro bromide acid – anhydrous	10035-10-6	005
Heavy Hydrogen	Deuterium*, Diplogen, Hydrogen-D2	07782-39-0	076
Helium, compressed*	R704, Helium-4	07440-59-7	067
Helium-4	Helium, compressed*, R704	07740-59-7	067
Heptafluoropropane*	1,1,1,2,3,3,3- Heptafluoropropane, Apaflurane, R227	00431-89-0	104
Hexafluoro-1,3-Butadiene*	1,1,2,3,4,4-Hexafluroro-1,3-Butadiene, Sifren46, Perfluorobutadiene-1,3	00685-63-2	056
Hexafluoroethane*	Perfluoroethane, Ethylhexafluoride, R116	00076-16-4	055
Hexafluorotungsten	Tungsten hexafluoride*, Wolfram hexafluoride, F6W	07783-82-6	054
High-boiling Butene-2	cis-2-Butene*, cis-2-Butylene, cis-But-2-ene, (Z)-2-Butene	00590-18-1	010
hydriodic acid	Hydrogen iodide, anhydrous*	10034-85-2	090
Hydro bromide acid – anhydrous	Hydrogen bromide*, HBR	10035-10-6	005
Hydrochloric Acid (anhydrous)	Hydrogen Chloride*, Spirits of salt, Muriatic Acid	07647-01-0	041
Hydrocyanic acid	Hydrogen cyanide*, Formonitrile, Prussic acid	0074-90-8	113
Hydrofluoric acid gas	Hydrogen fluoride, anhydrous*, Fluorhydric acid gas, AHF	07664-39-3	060
Hydrogen antimonide	Stibine*, Antimony trihydride	07803-52-3	094
Hydrogen arsenide	Arsine*, Arsenic trihydride	07784-42-1	001
Hydrogen bicarbide	Methane (compressed)*, Methyl hydride, R50	00074-82-8	072
Hydrogen bromide*	Hydro bromide acid – anhydrous, HBR	10035-10-6	005
Hydrogen Chloride*,	Hydrochloric Acid(anhydrous), Spirits of salt, Muriatic Acid	07647-01-0	041
Hydrogen cyanide*	Hydrocyanic acid, Formonitrile, Prussic acid	0074-90-8	113
Hydrogen fluoride, anhydrous*	Hydrofluoric acid gas, Fluorhydric acid gas, AHF	07664-39-3	060
Hydrogen iodide, anhydrous*	hydriodid acid	10034-85-2	090
Hydrogen phosphide	Phosphine*, Celphos, Delicia, Detia gas EX-B, Phosphorus trihydride , Phosphane	07803-51-2	043
Hydrogen selenide, anhydrous*	Selenium hydride, Hydroselenic acid, anhydrous, Selane	07783-07-5	065
Hydrogen silicide	Silane*, Monosilane, Silicane, Silicon tetrahydrite	07803-62-5	047
Hydrogen*	Hydrogenium, Dihydrogen, Protium	07782-39-0	075

Hydrogen-D2	Deuterium*, Heavy Hydrogen, Diplogen	07782-39-0	076
Hydrogenium	Hydrogen*, Dihydrogen, Protium	07782-39-0	075
Hydrogen sulfide*	Dihydrogen monosulfide, Sulphuretted hydrogen	07783-06-4	045
Hydroselenic acid, anhydrous	Hydrogen selenide, anhydrous*, Selenium hydride, Selane	07783-07-5	065
Hyperoxia	Oxygen*, Oxygenium , Dioxygen,	07782-44-7	081
i-Butane	Isobutane*, i-Methyl ethyl methane, R600a, 2-Methyl propane, Trimethyl methane	00075-28-5	008
i-Methyl ethyl methane	Isobutane*, i-Butane, R600a, 2-Methyl propane, Trimethyl methane	00075-28-5	008
Isobutane*	i-Butane, i-Methyl ethyl methane, R600a, 2-Methyl propane, Trimethyl methane	00075-28-5	008
Isobutene*	Isobutylene, 2-Methylpropene, gamma-Butylene, Liquefied Petroleum Gas(#), asym. Dimethylethylene	00115-11-7	012
Isobutylene	Isobutene*, 2-Methylpropene, gamma-Butylene, Liquefied Petroleum Gas(#), asym. Dimethylethylene	00115-11-7	012
Kelene	Ethyl chloride*, Chlorethane , Muriatic ether, Narcotile, Aethylis chloridum, Chelen , Ether chloratis, R160	00075-00-3	017
Krypton, compressed*		07439-90-9	070
Laughing gas	Dinitrogen oxide*, Nitric oxide, Nitrogen monoxide, Nitrous oxide, R744a	10024-97-2	083
Liquefied Petroleum Gas(#)	Isobutene*, Isobutylene, 2-Methylpropene, gamma-Butylene, asym. Dimethylethylene	00115-11-7	012
Liquefied Petroleum Gas(#)	Propane*, Dimethyl methane, Ethyl methyl, R290, Propyl hydrid,	00074-98-6	036
Low-boiling Butene-2	trans-2-Butene*, trans-2-Butylene, trans-But-2-ene, beta-Butylene, (E)-2-Butene	00624-64-6	011
Mercurialin	Methyamine* anhydrous, Aminomethane, Methanamine, R630	00074-89-5	031
Methanamine	Methyamine* anhydrous, Aminomethane, Mercurialin, R630	00074-89-5	031
Methane (compressed)*	Methyl hydride, Natural gas, Hydrogen bicarbide , R50	00074-82-8	072
Methanethiol	Methyl mercaptan*, Methyl sulfhydrate	00074-93-1	061
Methogas	Methyl bromide*, Bromomethane, R40B1, Halon 1001, Dowfume, Rotox, Zytox, Pestmaster	00074-83-9	084
Methoxy methane	Dimethyl ether*, Methyl ether, Wood ether, Methyl oxide, Oxybismethane	00115-10-6	066

Methoxyethane	Ethyl methyl ether*, Methyl ethyl ether, Ethoxymethane	00540-67-0	101
Methoxyethylene	Vinyl methyl ether* stabilized, Methyl vinyl ether	00107-25-5	063
Methyamine* anhydrous	Aminomethane, Mercurialin, Methanamine, R630	00074-89-5	031
Methyl bromide*	Bromomethane, R40B1, Halon 1001, Dowfume, Rotox, Zytox, Pestmaster, Methogas	00074-83-9	084
Methyl chloride*	Chloromethane, R40	00074-87-3	019
Methyl ether	Dimethyl ether*, Methoxy methane, Wood ether, Methyl oxide, Oxybismethane	00115-10-6	066
Methyl ethyl ether	Ethyl methyl ether*, Methoxyethane, Ethoxymethane	00540-67-0	101
Methyl ethylene	Propene*, Propylene, R1270, 1-Propene, Methylethene	00115-07-1	037
Methyl fluoride	Fluoromethane*, R41	00593-53-3	033
Methyl hydride	Methane (compressed)*, Natural gas, Hydrogen bicarbide, R50	00074-82-8	072
Methyl mercaptane*	Methanethiol, Methylsulfhydrate	00074-93-1	061
Methyl methane	Ethane*, Bimethyl, Dimethyl, Ethyl hydride, R170,	00074-84-0	034
Methyl oxide	Dimethyl ether*, Methyl ether, Methoxy methane, Wood ether, Oxybismethane	00115-10-6	066
Methyl silane*	Silicoethane	00992-94-9	091
Methyl vinyl ether	Vinyl methyl ether* stabilized, Methoxyethylene	00107-25-5	063
Methylacetylene*	Allylene, Propine, Propyne, 1-Propyne	00074-99-7	106
Methylethene	Propene*, Propylene, Methyl ethylene, R1270, 1-Propene	00115-07-1	037
Methylethylmethane	Butane*; n-Butane, Diethyl, R600	00106-97-8	007
Methyl sulfhydrate	Methyl mercaptan*, Methanethiol	00074-93-1	061
Monobromoethylene	Vinyl bromide, stabilized*, R1140B1, Bromoethene	00593-60-2	096
Monochlorodifluoro-mono-bromomethane	Bromochlorodifluoromethane*, R12B1, Halon 1211, Chlorodifluorobromomethane	00353-59-3	095
Monogermane	Germanium Tetrahydride*, Germanomethane	07782-65-2	059
Mononitrogen monoxide	Nitric oxide*, Nitrogen monoxide	10102-43-9	079
Monosilane	Silane*, Silicane, Silicon tetrahydrite, Hydrogen silicide	07803-62-5	047
Monoxide of Carbon	Carbon monoxide*, Carbon oxide, Exhaust gas, Flue gas	00630-08-0	078
Muriatic Acid	Hydrogen Chloride*, Spirits of salt	07647-01-0	041

Muriatic ether	Ethyl chloride*, Chlorethane, Kelene, Narcotile, Aethylis chloridum, Chelen, Ether chloratus, R160	00075-00-3	017
N,N-Dimethyl-methanamine	Trimethylamine*anhydrous, TMA	00075-50-3	111
Narcotile	Ethyl chloride*, Chlorethane, Muriatic ether, Kelene, Aethylis chloridum, Chelen, Ether chloratis, R160	00075-00-3	017
Narcylen	Acetylene*, Ethine, Ethyne, Carbide gas, Dissousgas	00074-86-2	073
Natural gas	Methane (compressed)*, Methyl hydride, Hydrogen bicarbide , R50	00074-82-8	072
n-Butane,	Butane*, Diethyl, R600, Methylethyl-methane	00106-97-8	007
n-Butene	1-Butene*, 1-Butylene, alpha-Butylene, But-1-ene	00106-98-9	009
Neon*		07440-01-9	069
Neopentane,	2,2-Dimethylpropane*, 1,1,1-Trimethyl-ethane, Tert-Pentane	00463-82-1	030
Nitric oxide	Dinitrogen oxide*, Nitrogen monoxide, Nitrous oxide, Laughing gas, R744a	10024-97-2	083
Nitric oxide*	Nitrogen monoxide, Mononitrogen monoxide	10102-43-9	079
Nitrogen dioxide, liquefied*	Dinitrogen tetraoxide, nitrogen peroxide	10102-44-0	080
Nitrogen fluoride*	Perfluoroammonia, Trifluoroammonia, Trifluoroamine, F3N	07783-54-2	057
Nitrogen gas	Nitrogen, compressed*. R728	07727-37-9	072
Nitrogen monoxide	Nitric oxide*, Mononitrogen monoxide	10202-43-9	079
Nitrogen monoxide	Dinitrogen oxide*, Nitric oxide, Nitrous oxide, Laughing gas, R744a	10024-97-2	083
Nitrogen peroxide	Nitrogen dioxide, liquefied*, Dinitrogen tetraoxide	10102-44-0	080
Nitrogen, compressed*	Nitrogen gas, Nitrogenium, R728	07727-37-9	072
Nitrous oxide	Dinitrogen oxide*, Nitric oxide, Nitrogen monoxide, Laughing gas, R744a	10024-97-2	083
N-Methylmethanamine	Dimethyamine* anhydrous, DMA	00124-40-3	032
Octafluorocyclobutane*	Perfluorocyclobutane, RC318, Cyclooctafluorobutane	00115-25-3	027
Octafluoropropane	Perfluoropropane*, R218	00076-19-7	028
Octafluorotetrahydro-furan*	Perfluorotetrahydrofuran	00773-14-8	105
Olefiant gas	Ethylene*, Acetene, R1150, Bicarburretted hydrogen, Elayl, Etherin, Ethene	00074-85-1	035
Oxacyclopropane	Ethylene oxide*, Oxirane, 1,2-Epoxy-ethane	00075-21-8	040

Oxalonitril	Cyanogen*, Dicyanogen, Ethane dinitril, Prussite,	00460-19-5	083
Oxirane	Ethylene oxide*, 1,2-Epoxyethane, Oxacyclopropane	00075-21-8	040
Oxybismethane	Dimethyl ether*, Methyl ether, Methoxy methane, Methyl oxide, Wood ether,	00115-10-6	066
Oxycarbonsulfide	Carbonyl sulfide*, Carbon oxide sulfide	00463-58-1	062
Oxygen*	Oxygenium, Dioxygen, Hyperoxia	07782-44-7	081
Oxygenium	Oxygen*, Dioxygen, Hyperoxia	07782-44-7	081
Pentafluoro-chloroethane	Chloropentafluoroethane*, 1-Chloro-1,1,2,2,2-pentafluoroethane, R115, Pentafluoroethyl chloride	00074-15-3	086
Pentafluoroethane*	1,1,1,2,2- Pentafluoroethane, R125	00354-33-6	029
Pentafluoroethyl chloride	Chloropentafluoroethane*, 1-Chloro-1,1,2,2,2-pentafluoroethane, R115, Pentafluorochloroethane	00074-15-3	086
Perfluoroammonia	Nitrogen fluoride*, Trifluoroammonia, Trifluoroamine, F3N	07783-54-2	057
Perfluorobutadiene-1,3	Hexafluoro-1,3-Butadiene*, 1,1,2,3,4,4-Hexafluroro-1,3-Butadiene, Sifren46,	00685-63-2	056
Perfluorocyclobutane	Octafluorocyclobutane*, RC318, Cyclooctafluorobutane	00115-25-3	027
Perfluoroethane	Hexafluoroethane*, Ethylhexafluoride, R116	00076-16-4	055
Perfluoroethylene	Tetrafluoroethylene* inhibited, 1,1,2,2-Tetrafluoroethylene, TFE, R1114	00116-14-3	109
Perfluoromethane	Tetrafluoromethane*, Carbon tetrafluoride, R14, Tetrafluorocarbon	00075-73-0	025
Perfluoropropane*	Octafluoropropane, R218	00076-19-7	028
Perfluorosilane	Silicon tetrafluoride*, Tetrafluorosilane, Silicon fluoride, F4Si	07783-61-1	050
Perfluorotetrahydrofuran	Octafluorotetrahydrofuran*	00773-14-8	105
Pestmaster	Methyl bromide*, Bromomethane, R40B1, Halon 1001, Dowfume, Rotox, Zytox, Methogas	00074-83-9	084
Phosgene*	Carbonyl chloride, Carbon oxychloride, Chloroformyl chloride, Carbon dichloride oxide, Diphosgene	00075-44-5	042
Phosphane	Phosphine*, Hydrogen phosphide, Delicia, Detia gas EX-B, Phosphorus trihydride	07803-51-2	043
Phosphine*	Hydrogen phosphide, Celphos, Delicia, Detia gas EX-B, Phosphorus trihydride, Phosphane	07803-51-2	043
Phosphorus trihydride	Phosphine*, Hydrogen phosphide, Celphos, Delicia, Detia gas EX-B, Phosphane	07803-51-2	043

Propane*	Dimethyl methane, Ethyl methyl, R290, Propyl hydrid, Liquefied Petroleum Gas(#)	00074-98-6	036
Propene*	Propylene, Methyl ethylene, R1270, 1-Propene, Methylethene	00115-07-1	037
Propine	Methylacetylene*, Allylene, Propyne, 1-Propyne	00074-99-7	106
Propyl hydrid	Propane*, Dimethyl methane, Ethyl methyl, R290, Liquefied Petroleum Gas(#)	00074-98-6	036
Propylene	Propene*, Methyl ethylene, R1270, 1-Propene, Methylethene	00115-07-1	037
Propyne	Methylacetylene*, Allylene, Propine, 1-Propyne	00074-99-7	106
Protium	Hydrogen*, Hydrogenium, Dihydrogen	07782-39-0	075
Prussic acid	Hydrogen cyanide*, Hydrocyanic acid, Formonitrile	0074-90-8	113
Prussite	Cyanogen*, Dicyanogen, Ethane dinitril, Oxalonitril	00460-19-5	083
Pyrrolylene	1,3-Butadiene*, stabilized, Bivinyl, Buta-1,3-diene, Divinyl, alpha-gamma-Butadiene, Erythrene, Vinylethylene	00106-99-0	006
R1113	Trifluorochloroethylene*, Chlorotrifluoroethene, CTFE, Trithene, Trifluoro-2-chloroethylene, Trifluorovinyl chloride	00079-38-9	099
R1114	Tetrafluoroethylene* inhibited, 1,1,2,2-Tetrafluoroethylene, TFE, Perfluoroethylene	00116-14-3	109
R114	Dichlorotetrafluoroethane*, Cryofluorane, 1,2-Dichloro-1,1,2,2-tetrafluoroethane, Tetrafluorodichloroethane	00076-14-2	100
R1140	Vinyl chloride*, Chlorethene, Ethylene monochloride	00075-01-4	018
R1140B1	Vinyl bromide, stabilized*, Monobromoethylene, Bromoethene	00593-60-2	096
R1141	Vinyl fluoride*, Fluoroethylene	00075-02-5	103
R115	Chloropentafluoroethane*, 1-Chloro-1,1,2,2,2-pentafluoro-ethane, Pentafluorochloroethane, Pentafluoroethyl chloride	00074-15-3	086
R1150	Ethylene*, Acetene, Olefiant gas, Bicarburretted hydrogen, Etherin, Elayl, Ethene	00074-85-1	035
R116	Hexafluoroethane*, Perfluoroethane, Ethylhexafluoride	00076-16-4	055
R12	Dichlorodifluoromethane*, Chlorofluorocarbon, Difluorodichloromethane	00075-71-8	021
R124	2-Chloro-1,1,1,2- tertrafluoroethane	02837-89-0	115

R124a	1-Chloro-1,1,2,2-tertrafluoroethane	00354-25-6	114
R125	Pentafluoroethane*, 1,1,1,2,2- Pentafluoroethane	00354-33-6	029
R1270	Propene*, Propylene, Methyl ethylene, 1-Propene, Methylethene	00115-07-1	037
R12B1	Bromochlorodifluoromethane*, Monochlorodifluoromonobromomethane, Halon 1211, Chlorodifluorobromomethane	00353-59-3	095
R13	Chlorotrifluoromethane*, Trifluorochloromethane	00075-72-9	020
R133a	Chlorotrifluoroethane*, 1-Chloro-2,2,2-trifluoroethane, 2-Chloro-1,1,1-trifluoroethane	00075-88-7	098
R134a	Tetrafluoroethane*, 1,1,1,2- Tetrafluoroethane	00811-97-2	026
R13B1	Bromotrifluoromethane*, Bromofluoroform, Halon 1301, Trifluoromonobromomethane	00075-63-8	004
R14	Tetrafluoromethane*, Carbon tetrafluoride, Perfluoromethane, Tetrafluorocarbon	00075-73-0	025
R142b	Difluoromonochloroethane*, 1-Chloro-1,1-difluoroethane, Chlorodifluoroethane, alpha-Cloroethylidene fluoride	00075-68-3	085
R143 (IMDG-Code)	1,1,1-Trifluoroethane*, Trifluoroethane, R143a,	00420-46-2	093
R143a	1,1,1-Trifluoroethane*, Trifluoroethane, R143 (IMDG-Code)	00420-46-2	093
R152a	1,1-Difluoroethane*, Ethylene fluoride, Algofrene Type 67	00075-37-6	088
R160	Ethyl chloride*, Chlorethane, Muriatic ether, Kelene, Narcotile, Aethylis chloridum, Chelen, Ether chloratus	00075-00-3	017
R161	Fluoroethane*, Ethyl fluoride	00353-36-6	102
R170	Ethane*, Bimethyl, Dimethyl, Ethyl hydride, Methyl methane	00074-84-0	034
R21	Dichlorofluoromethane*, Dichloromonofluoromethane, Fluorodichloromethane	00075-43-4	022
R218	Perfluoropropane*, Octafluoropropane	00076-19-7	028
R22	Chlorodifluoromethane*, Difluoromonochloromethane	00075-45-6	016
R227	Heptafluoropropane*, 1,1,1,2,3,3,3-Heptafluoropropane, Apaflurane	00431-89-0	104
R290	Propane*, Dimethyl methane, Ethyl methyl, Propyl hydrid, Liquefied Petroleum Gas(#)	00074-98-6	036
R40	Methyl chloride*, Chloromethane	00074-87-3	019

R40B1	Methyl bromide*, Bromomethane, Halon 1001, Dowfume, Rotox, Zytox, Pestmaster, Methogas	00074-83-9	084
R41	Fluoromethane*, Methyl fluoride	00593-53-3	033
R50	Methane (compressed)*, Methyl hydride, Hydrogen bicarbide	00074-82-8	072
R600	Butane*; n-Butane, Diethyl, Methylethyl-methane	00106-97-8	007
R600a	Isobutane*, i-Butane, i-Methyl ethyl methane, 2-Methyl propane, Trimethyl methane	00075-28-5	008
R630	Methyamine* anhydrous, Aminomethane, Mercurialin, Methanamine	00074-89-5	031
R631	Ethylamine*, Aminoethane, Ethanamine	00075-04-7	039
R704	Helium, compressed*, Helium-4	07440-59-7	067
R717	Ammonia, anhydrous*, H3N	07664-41-7	074
R728	Nitrogen, compressed*, Nitrogen gas	07727-37-9	072
R740	Argon, compressed*	07440-37-1	068
R744a	Dinitrogen oxide*, Nitric oxide, Nitrogen monoxide, Nitrous oxide, Laughing gas	10024-97-2	083
R764	Sulfur dioxide liquefied*, Sulphurous anhydride, R764, Fermenticide liquid	07446-09-5	044
RC318	Octafluorocyclobutane*, Perfluoro-cyclobutane, Cyclooctafluorobutane	00115-25-3	027
Rotox	Methyl bromide*, Bromomethane, R40B1, Halon 1001, Dowfume, Zytox, Pestmaster, Methogas	00074-83-9	084
Selane	Hydrogen selenide, anhydrous*, Selenium hydride,	07783-07-5	065
Selenium hydride	Hydrogen selenide, anhydrous*, Hydro-selenic acid, anhydrous, Selane	07783-07-5	065
Sifren46	Hexafluoro-1,3-Butadiene*, 1,1,2,3,4,4-Hexafluroro-1,3-Butadiene, Perfluoro-butadiene-1,3	00685-63-2	056
Silane*	Monosilane, Silicane, Silicon tetrahydrite, Hydrogen silicide	07803-62-5	047
Silicane	Silane*, Monosilane, Silicon tetrahydrite, Hydrogen silicide	07803-62-5	047
Silicoethane	Methyl silane*	00992-94-9	091
Silicon chloride hydride	Dichlorosilane*, Dichlorsilicane	04109-96-0	048
Silicon fluoride	Silicon tetrafluoride*, Tetrafluorosilane, Perfluorosilane, F4Si	07783-61-1	050
Silicon hexahydrite	Disilane*, Disilicoethane, Disilicane	01590-87-0	049
Silicon tetrafluoride*	Tetrafluorosilane, Silicon fluoride, Perfluorosilane, F4Si	07783-61-1	050
Silicon tetrahydrite	Silane*, Monosilane, Silicane, Hydrogen silicide	07803-62-5	047

Spirits of salt	Hydrogen Chloride*, Muriatic Acid	07647-01-0	041
Stibine*	Antimony trihydride, Hydrogen antimonide	07803-52-3	094
Sulfur dioxide liquefied*	Sulphurous anhydride, R764, Fermenticide liquid	07446-09-5	044
Sulfur hexafluoride*	Sulphur hexafluoride, Elegas	02551-62-4	053
Sulfur tetrafluoride*	Tetrafluorosulfurane, Sulphur tetrafluoride	07783-60-0	107
Sulfuryl fluoride*	Sulfuric oxyfluoride, Sulphuryl difluoride, Vikane fumigant	02699-79-8	108
Sulphur hexafluoride	Sulfur hexafluoride*, Elegas	02551-62-4	053
Sulphur tetrafluoride	Sulfur tetrafluoride*, Tetrafluorosulfurane	07783-60-0	107
Sulphuretted hydrogen	Hydrogen sulfide*, Dihydrogen monosulfide	07783-06-4	045
Sulfuric oxyfluoride	Sulfuryl fluoride*, Sulphuryl difluoride, Vikane fumigant	02699-79-8	108
Sulphurous anhydrite	Sulfur dioxide liquefied*, R764, Fermenticide liquid	07446-09-5	044
Sulfuryl difluoride	Sulfuryl fluoride*, Sulfuric oxyfluoride, Vikane fumigant	02699-79-8	108
sym-Allylene	Allene*, 1,2-Propadiene, Dimethylene methane, Methyl methane	00463-49-0	038
Tetrafluorocarbon	Tetrafluoromethane*, Carbon tetrafluoride, R14, Perfluoromethane,	00075-73-0	025
Tetrafluorodichloroethane	Dichlorotetrafluoroethane*, R114, Cryofluorane, 1,2-Dichloro-1,1,2,2-tetrafluoroethane	00076-14-2	100
Tetrafluoroethane*	1,1,1,2- Tetrafluoroethane, R134a	00811-97-2	026
Tetrafluoroethylene* inhibited	1,1,2,2- Tetrafluoroethylene, TFE, Perfluoroethylene, R1114	00116-14-3	109
Tetrafluorogermane	Germanium Tetrafluoride*	07783-58-6	058
Tetrafluoromethane*	Carbon tetrafluoride, R14, Perfluoromethane, Tetrafluorocarbon	00075-73-0	025
Tetrafluorosilane	Silicon tetrafluoride*, Silicon fluoride, Perfluorosilane, F4Si	07783-61-1	050
Tetrafluorosulfurane	Sulfur tetrafluoride*, Sulphur tetrafluoride	07783-60-0	107
Tetramethylene	Cyclobutane*	00287-23-0	113
TFE	Tetrafluoroethylene* inhibited, 1,1,2,2-Tetrafluoroethylene, Perfluoroethylene, R1114	00116-14-3	109
TMA	Trimethylamine*anhydrous, N,N-Dimethylmethanamine	00075-50-3	110
TMB	Trimethylboron*, Boron trimethyl, trimethylborane	00593-90-8	111

trans-2-Butylene*	trans-2-Butylene, trans-But-2-ene, beta-Butylene, Low boiling Butene-2, (E)-2-Butene	00624-64-6	011
trans-2-Butylene	trans-2-Butene*, trans-But-2-ene, beta-Butylene, Low-boiling Butene-2, (E)-2-Butene	00624-64-6	011
trans-But-2-ene	trans-2-Butene*, trans-2-Butylene, beta-Butylene, Low- boiling Butene-2, (E)-2-Butene	00624-64-6	011
Trichloro borane	Boron trichloride*	10294-34-5	002
Trifluorochloroethylene*	Chlorotrifluoroethene, R1113, CTFE, Trithene, Trifluoro-2-chloroethylene, Trifluorovinyl chloride	00079-38-9	099
Trifluoro-2-chloroethylene	Trifluorochloroethylene*, Chlorotrifluoroethene, R1113, CTFE, Trithene, Trifluorovinyl chloride	00079-38-9	099
Trifluoroammonia	Nitrogen fluoride*, Perfluoroammonia, Trifluoroamine, F3N	07783-54-2	057
Trifluoroborane	Boron trifluoride*	07637-07-2	003
Trifluorochloromethane	Chlorotrifluoromethane*, R13	00075-72-9	020
Trifluoroethane	1,1,1-Trifluoroethane*, R143a, R143 (IMDG-Code)	00420-46-2	093
Trifluoromonobromomethane	Bromotrifluoromethane*, Bromofluoroform, R13B1, Halon 1301,	00075-63-8	004
Trifluorovinyl chloride	Trifluorochloroethylene*, Chlorotrifluoroethene, R1113, CTFE, Trithene, Trifluoro-2-chloroethylene	00079-38-9	099
Trifluoroamine	Nitrogen fluoride*, Perfluoroammonia, Trifluoroammonia, F3N	07783-54-2	057
Trimethyl methane	Isobutane*, i-Butane, i-Methyl ethyl methane, R600a, 2-Methyl propane,	00075-28-5	008
Trimethylamine*, anhydrous	N,N-Dimethylmethanamine, TMA	00075-50-3	110
trimethylborane	Trimethylboron*, Boron trimethyl, TMB	00593-90-8	111
Trimethylboron*	Boron trimethyl, trimethylborane, TMB	00593-90-8	111
Trimethylene	Cyclopropane*	00075-19-4	014
Trimethylsilane*		00993-07-7	052
Trithene	Trifluorochloroethylene*, Chlorotrifluoroethene, R1113, CTFE, Trifluoro-2-chloroethylene, Trifluorovinyl chloride	00079-38-9	099
Tungsten hexafluoride*	Wolfram hexafluoride, Hexafluorotungsten, F6W	07783-82-6	054
Vikane fumigant	Sulfuryl fluoride*, Sulfuric oxyfluoride, Sulphuryl difluoride	02699-79-8	108

Vinyl bromide, stabilized*	Monobromoethylene, R1140B1, Bromoethene	00593-60-2	096
Vinyl chloride*	Chlorethene, R1140, Ethylene monochloride	00075-01-4	018
Vinyl fluoride*	Fluoroethylene, R1141	00075-02-5	103
Vinyl methyl ether* stabilized	Methyl vinyl ether, Methoxyethylene	00107-25-5	063
Vinylethylene	1,3-Butadiene*, stabilized, Bivinyl, Buta-1,3-diene, Divinyl, alpha-gamma-Butadiene, Erythrene, Pyrrolylene	00106-99-0	006
Wolfram hexafluoride	Tungsten hexafluoride*, Hexafluorotungsten, F6W	07783-82-6	054
Wood ether	Dimethyl ether*, Methyl ether, Methoxy methane, Methyl oxide, Oxybismethane	00115-10-6	066
Xenon*	Xenon, compressed	07440-63-3	071
Xenon, compressed	Xenon*	07440-63-3	071
Zytox	Methyl bromide*, Bromomethane, R40B1, Halon 1001, Dowfume, Rotox, Pestmaster, Methogas	00074-83-9	084

H.Schön: Handbook of Purified Gases

Data Sheet DS088.0 **Date: 07-02-16**

Name: 1,1-Difluoroethane Chemical Formula: $C_2H_4F_2$

Synonyms: Ethylene fluoride, R152a, Algofrene Type 67 **$HF_2C\text{-}CH_3$**

Properties:
Low pressure liquefied gas, flammable, colorless, relatively non-toxic, ether-like odor.Thermal decomposition may produced CO, COF_2 and HF.

Production and Purification:
Intermediate in chemical synthesis. Rectification.
Widespread Applications:
Refrigerant. Aerosol propellant gas.
Important Impurities:
Other HC´s and CFC´s.
Disposal:
Combustion: burner with flash back arrestor. Toxic and corrosive Gases formed during combustion should be scrubbed before discharge to air.
Detection of 1,1-Difluorethane:
Gas test tube. Halogen leak detector.

Suitable Materials:		All known metals - ABS, PA
Valve Thread:	*Europe:*	Not standardized. Germany: No.1, W21,8x1/14" LH.
	USA:	CGA connection 510, 0.855"-1/14 LH INT.
Filling Density(Factor):		0.79 kg/l at test pressure 18 bar.

Toxicological Information:
No known acute toxicological effects from this product.
Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of coordination. In high concentration may cause asphyxiation.
First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.
Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH):1000 ppm, LC50 / 1h : --- ppm

1,1-Difluoroethane $C_2H_4F_2$ DS088.0

Physical Data:

Molar Mass, [11] 66.051 g/mol

Melting Point T_{mp} at 1.013 bar, [10]
-117 ^{0}C (= -178.6 ^{0}F)

Enthalpy of Fusion at T_{mp}]
kJ/kg (= BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [11]
-25.8 ^{0}C (= -14.44 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [10]
326.6 kJ/kg (= 140.41 BTU/lb)

Critical Point, [14]:
-Temperature 113.50 ^{0}C (= 236.30 ^{0}F)
- Pressure 44,90 bar (= 651.23 psia)
- Density Liquid 0.365 kg/l

Density Gas:
- ideal 2.9469 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1 bar, [24]
2.735 g/l (= 0.1708 lb/ft^3)
- at 15 ^{0}C, 1 bar, [10] 2.808 g/l
- at 0 ^{0}C, 1.013 bar, [15] 2.828 g/l

Density Liquid
- at T_{bp} and 1.013 bar, [10] 1.011 kg/l
- at 25 ^{0}C, [24] 0.898 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [14]

-10	0	10	20	^{0}C
1.9	2.7	3.7	5.1	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -30.6 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -20.0 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.139 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar, [10] 1.03 kJ/(kg K)

Solubility in Water at 20^{0}C, 1.013 bar, [10] 0.706 l gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C,1 bar, [24] 11.81 x 10^{-6} Ns/m^2

Explosion Limits in Air,
[13] 4-18.5 Vol.-%
[14] 4.9-20.2 Vol.-%

Autoignition Temperature, [13]
455 ^{0}C (= 851 ^{0}F)

Heating Value, [24] 11.484 MJ/kg

Suitable Extinguishing Media:
All known.

Identification and Classification:

CAS Number:	00075-37-6
EU Number:	200-866-1
EU Classification:	F+
EU Symbols:	F+
Index Number:	

UN Number:	1030
	1,1-DIFLUOROETHANE
Class/Div:	2.1
ADR/RID: Class 2, Number	2F
ADR/RID Hazard Number:	23
Labeling ADR/DOT:	2.1

EU Classification:

Risk Phrases:

R12: Extremely flammable.

Safety Phrases:

S9: Keep container in a well ventilated places.

S16: Keep away from ignition source - No smoking.

S33: Take precautionary measures against static discharges.

H.Schön: Handbook of Purified Gases

Data Sheet DS089.0 **Date: 07-02-19**

Name: 1,1-Difluoroethylene Chemical Formula: $C_2H_2F_2$

Synonyms: Vinylidene fluoride, R1132a **$F_2C{=}CH_2$**

Properties:
High pressure liquefied gas, flammable, colorless, relatively non-toxic, ether-like odour.Thermal decomposition yields CO, COF_2 and HF. Tending to polymerisize.

Production and Purification: Three main processes:
Elimination of HF from 1,1,1-trifluoroethane (143a). Pyrolysis of 1-chloro-1,1-difluoroethan. Dechlorinating of 1,2-dichloro-1,1-difluoroethane.

Widespread Applications:
Important monomer for polymer manufacture.

Important Impurities: HC´s (C_2H_2) and other CHC´s.

Disposal:
Combustion: burner with flash back arrestor. Toxic and corrosive Gases formed during combustion should be scrubbed before discharge to air.

Detection of 1,1-Difluoroethylene:
Detector for flammable gases.

Suitable Materials: Steel, stainless steel, PE, PTFE, EPDM.

Valve Thread: *Europe:* Not standardized.
Germany: No.1, W21.8x1/14" LH.
USA: CGA connection 350, 0.825"-1/14 LH EXT.

Filling Density(Factor): 0.77 kg/l at test pressure 250 bar.

Toxicological Information:
No known acute toxicological effects from this product.

Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of coordination. In high concentration may cause asphyxiation.

First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.

Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH):--- ppm, LC50 / 1h : --- ppm

1,1-Difluoroethylene $C_2H_2F_2$ DS089.0

Physical Data:

Molar Mass, [5] 64.035 g/mol

Melting Point T_{mp} at 1.013 bar, [5]
-144 ^{0}C (= -227.2 ^{0}F)

Enthalpy of Fusion at T_{mp}
kJ/kg (= BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-85.65 ^{0}C (= -122.17 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [24]
238.15 kJ/kg (= 102.4 BTU/lb)

Critical Point:
-Temperature, [5]
30.05 ^{0}C (= 86.09 ^{0}F)
- Pressure, [5] 44.6 bar (= 646.9 psia)
- Density Liquid, [14] 0.414 kg/l

Density Gas:
- ideal 2.8569 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1 bar, [24]
2.652 g/l (= 0.1656 lb/ft^3)
- at 15 ^{0}C, 1 bar, [28] 2.6961 g/l
- at 0 ^{0}C,1.013 bar, [11] 2.8858 g/l

Density Liquid
- at T_{bp}, 1.013 bar, [2] 1.12 kg/l
- at 25 ^{0}C, [24] 0.594 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [14]

-10	0	10	20	^{0}C
17.3	22.5	28.6	36.1	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -10,4 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -7,4 x 10^{-3} bar^{-1}

Thermal Conductivity at 15^{0}C and 1.013 bar, [24]: 0.1545 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar, [24] 0.934 kJ/(kg K)

Solubility in Water at 20^{0}C, 1.013 bar, [2] 0.063 l Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C, 1 bar, [24] 13.055 x 10^{-6} Ns/m^2

Explosion Limits in Air,
[13] 4.7-25.1 Vol.-%
[24] 5.5-21.3 Vol.-%

Autoignition Temperature,
[13] 390 ^{0}C (= 734 ^{0}F)
[24] 640 ^{0}C (= 1184 ^{0}F)

Heating Value, [24] 10.807 MJ/kg

Suitable Extinguishing Media:
All known.

Identification and Classification:

CAS Number: 00075-38-7
EU Number: 200-867-7
EU Classification: F+
EU Symbols: F+
Index Number:

UN Number: 1959
1,1-DIFLUOROETHYLENE
Class/Div: 2.1
ADR/RID: Class 2, Number 2F
ADR/RID Hazard Number: 239
Labeling ADR/DOT: 2.1

EU Classification:
Risk Phrases:
R12: Extremely flammable.

Safety Phrases:
S9: Keep container in a well ventilated places.
S16: Keep away from ignition source - No smoking.
S33: Take precautionary measures against static discharges.

H.Schön: Handbook of Purified Gases

Data Sheet DS030.0 **Date: 06-07-22**

Name: 2,2-Dimethylpropane **Chemical Formula: C_5H_{12}**

Synonyms: Neopentane, 1,1,1-Trimethylethane, Tetramethylmethane **$C(CH_3)_4$**

Properties:
Low pressure liquefied gas, flammable, colorless, odorless, relatively non-toxic.

Production and Purification:
Present in low levels in petroleum and natural gas.
Widespread Applications:
Raw material in the production of isobutylene. Used in halogination reactions.

Important Impurities:	Other HCs.
Disposal:	Combustion .
Detection of Neopentane:	Detector for flammable gases.
Suitable Materials:	All known.
Valve Thread: *Europe:*	Not standardized. Germany: No.1, W21,8x1/14" LH.
USA:	CGA connection 510, 0.885"-1/14 LH INT.
Filling Density(Factor):	0.53 kg/l at test pressure 10 bar.

Toxicological Information:
No known acute toxicological effects from this product.
Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of coordination. In high concentration may cause asphyxiation.
First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH): 600 ppm , LC50 / 1h : ---

2,2-Dimethylpropane C_5H_{12} DS030.0

Physical Data:

Molar Mass, [5] 72.150 g/mol

Melting Point T_{mp} at 1.013 bar, [5, 10] -16.67 ^{0}C (= 1.99 ^{0}F)

Enthalpy of Fusion at T_{mp}, [10] 45.78 kJ/kg (= 20.14 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5] 9.50 ^{0}C (=49.10^{0}F)

Enthalpy of Vaporisation at T_{bp}, [10] 315.56 kJ/kg (= 135.66 BTU/lb)

Critical Point:

-Temperature, [5] 160.60 ^{0}C (= 321.08 ^{0}F)

- Pressure, [5] 31.99 bar (= 463.98 psia)
- Density Liquid, [10] 0.238 kg/l

Density Gas:

- ideal 3.2191 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1.013 bar, [24] 2.988 g/l (= 0.1866 lb/ft^3)
- at 15 ^{0}C, 1 bar, [10] 3.194 g/l
- at 0 ^{0}C and 1.013 bar --- g/l

Density Liquid, [10]

- at T_{bp} and 1.013 bar 0.603 kg/l
- at 20 ^{0}C 0.591 kg/l

Vapor Pressure (about), [14]

-10	0	10	20	^{0}C
0.48	0.72	1.05	1.45	bar

2.Pressure Virial Coefficient, [11]

- at 0 ^{0}C: -53.1×10^{-3} bar^{-1}
- at 30 ^{0}C: -35.4×10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.156 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar, [10] 1.687 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [7] 0.052g Gas / kg H_2O

Dynamic Viscosity at 27 ^{0}C, 1 bar, [24] 7.359×10^{-6} Ns/m^2

Explosion Limits in Air, [13] 1.4-7.5 Vol.-%

Autoignition Temperature,[13] 450 ^{0}C (= 842 ^{0}F)

Heating Value, [24] 45.051 MJ/kg

Suitable Extinguishing Media: All known.

1 bar = 14.504 psi ,
1g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number: 00463-82-1
EU Number: 207-343-7
EU Classification: F+
EU Symbols: F+
Index-Number: 601-005-00-6

UN Number: 2044 2,2-Dimethylpropane
Class/Div: 2.1
ADR/RID: Class 2, Number 2F
ADR/RID Hazard Number: 23
Labeling ADR/DOT: 2.1

EU Classification:

Risk Phrases:

R12: Extremely flammable.

Safety Phrases:

S9: Keep container in a well ventilated places.

S16: Keep away from sources of ignition - No smoking.

S33: Take precautionary measures against static discharges.

H.Schön: Handbook of Purified Gases

Data Sheet DS006.0 **Date: 06-02-06**

Name: 1,3-Butadiene, stabilized Chemical Formula: C_4H_6

Synonyms: Bivinyl , Buta-1,3-diene, Divinyl, alpha-gamma-Butadiene, Erythrene, Pyrrolylene, Vinylethylene **$H_2C=CH-CH=CH_2$**

Properties: Low pressure liquefied gas, flammable, colorless, aromatic odor, readily soluble in organic solvents, polymerisable, inhibitor (usually 4-tert-butylcatechol) is added for storage and shipping.

Production and Purification: Formerly the Reppe synthesis: acetylene via acetaldehyde. Today Butadiene is an important byproduct in petroleum cracking. Purification by Rectification.

Widespread Applications: Raw material for synthetic rubber, styrene, chloroprene and polyamide (Nylon, Perlon).

Important Impurities: Other HC´s.

Disposal: Combustion.

Detection of 1,3-Butadiene: Detector for flammable gases. Gas test tube.

Suitable Materials: All known.

Valve Thread: *Europe:* Not standardized.
Germany: No.1, W21,8x1/14" LH.
USA: CGA connection 510, 0.885"-1/14 LH INT.

Filling Density(Factor): 0.55 kg/l at test pressure 10 bar.

Toxicological Information:
May have carcinogenic effect. May cause heritable genetic damage.

Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of coordination. In high concentration may cause asphyxiation.

First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH): 10 ppm, LC_{50} / 1h : ---

1,3-Butadiene, stabilized C_4H_6 DS006.0

Physical Data:

Molar Mass, [15] 54.092 g/mol

Triple Point at 0.69 mbar, [3], -108.91 ^{0}C (= -164.04 ^{0}F)

Enthalpy of Fusion, [24] 147.62 kJ/kg (= 63.48 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5] - 4.51 ^{0}C (= 23.88 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [10] 417.8 kJ/kg (= 179.65 BTU/lb)

Critical Point, [12]:
-Temperature 152.00 ^{0}C (= 305.6 ^{0}F)
- Pressure 43.23 bar (= 627.01psia)
- Density Liquid 0.245 kg/l

Density Gas: ideal 2.4134 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1.013 bar, [24] 2.240 g/l (= 0.1399 lb/ft^3)
- at 15 ^{0}C and 1 bar, [10] 2.33 g/l
- at 0 ^{0}C and 1.013 bar, [3] 2.497 g/l

Density Liquid, [10]
- at T_{bp} and 1.013 bar 0.650 kg/l
- at 20 ^{0}C 0.620 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
0.77	1.18	1.70	2.45	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -34 $\times 10^{-3}$ bar^{-1}
- at 30 ^{0}C: -24 $\times 10^{-3}$ bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.169 mW/(cm K)

Heat Capacity at 25 ^{0}C and 1.013 bar, [10] 1.47 kJ/(kg K)

Solubility in Water at 20 ^{0}C and 1.013 bar, [10] 0.202 l Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar, [24] 8.66 $\times 10^{-6}$ Ns/m^2

Explosion Limits in Air, [13] 1.4-16.3 Vol.-%

Autoignition Temperature, [13] 415 ^{0}C (= 779 ^{0}F)

Heating Value, [14] 2,408.72 MJ/kmol

Suitable Extinguishing Media: All known.

Identification and Classification:

CAS Number: 00106-99-0
EU Number: 203-450-8
EU Classification: F+ Carc.Cat. 1, Mut. Cat. 2
EU Symbols: F+, T

UN Number: 1010 BUTA-1,3-DIENE, stabilized
Class/Div: 2.1
ADR/RID: Class 2, Number 2F
ADR/RID Hazard Number: 239
Labeling ADR/DOT: 2.1

EU Classification:
Risk Phrases:
R12: Extremely flammable.
R45: May cause cancer.
R46: May cause heritable genetic damage.

Safety Phrases:
S45: In case of accident or if you feel unwell, seek medical advice immediatly, show the lable where possible.
S53: Avoid exposure - obtain special instructions before use.

H.Schön: Handbook of Purified Gases

Data Sheet DS009.0 **Date: 06-02-08**

Name: 1-Butene **Chemical Formula: C_4H_8**

Synonyms: 1-Buthylene, alpha-Buthylene, But-1-ene, n-Butene **$H_2C{=}CH{-}CH_2{-}CH_3$**

Properties: Low pressure liquefied gas, flammable, colorless, with an aromatic odor, unsaturated hydrocarbon. It is very soluble in alcohol and ether. One of four isomers of the butenes.

Production and Purification:
The butenes are obtained from the cracking gases of the petroleum industry or by the catalytic dehydrogenetion of butanes. Rectification.
Widespread Applications:
Butenes are used to manufacture of a variety of organic compounds. Polmerisation to high-octane gasolines, plastics and synthetic rubber.

Important Impurities:		Other HCs.
Disposal:		Combustion.
Detection of 1-Butene:		Detector for flammable gases. Gas test tube.
Suitable Materials:		All known .
Valve Thread:	*Europe:*	Not standardized. Germany: No.1, W21,8x1/14" LH.
	USA:	CGA connection 510, 0.885"-1/14 LH INT.
Filling Density(Factor):		0.53 kg/l at test pressure 10 bar.

Toxicological Information:
No known acute toxicological effects from this product.
Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of coordination. In high concentration may cause asphyxiation.
First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH): ---, LC50 / 1h : ---

1-Butene **C_4H_8** **DS009.0**

Physical Data:

Molar Mass, [5] 56.108 g/mol

Melting Point at 1.013 bar, [10]
-185.35 ^{0}C (= -218.02 ^{0}F)

Enthalpy of Fusion, [10]
68.6 kJ/kg (= 29.49 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-6.23 ^{0}C (= 20.75 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [10]
390.6 kJ/kg (= 167.93 BTU/lb)

Critical Point:
-Temperature, [5]
146.35 ^{0}C (= 295.43 ^{0}F)
- Pressure, [5]
40.20 bar (= 583.06 psia)
- Density Liquid, [10] 0.233 kg/l

Density Gas:
- ideal 2.5033 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1.013 bar, [24] 2.324 g/l (= 0.1451 lb/ft^3)
- at 15 ^{0}C and 1 bar, [10] 2.417 g/l
- at 0 ^{0}C, 1.013 bar, [10] 2.599 g/l

Density Liquid, [10]
- at T_{bp} and 1.013 bar 0.630 kg/l
- at 20 ^{0}C 0.605 kg/l

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
1.0	1.28	1.82	2.54	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -35 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -25 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.148 mW/(cm K)

Heat Capacity at 25 ^{0}C and 1.013 bar, [10] 1.53 kJ/(kg K)

Solubility in Water at 20 ^{0}C and 1.013 bar, [6] 0.2 l Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar, [3] 7.76 x 10^{-6} Ns/m^2

Explosion Limits in Air, [13]
1.2-10.6 Vol.-%

Autoignition Temperature, [13]
360 ^{0}C (= 680 ^{0}F)

Heating Value, [14]
2,540.76 MJ/kmol

Suitable Extinguishing Media:
All known .

1 bar = 14.504 psi ,
1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number: 00106-98-9
EU Number: 203-449-2
EU Classification: F+
EU Symbols: F+

UN Number: 1012
BUT-1-ENE
Class/Div: 2.1
ADR/RID: Class 2, Number 2F
ADR/RID Hazard Number: 23
Labeling ADR/DOT: 2.1

EU Classification:
Risk Phrases:
R12: Extremely flammable.

Safety Phrases:
S9: Keep container in a well ventilated places.
S16*:* Keep away from sources of ignition - No smoking.
S33: Take precautionary measures against static discharges.

H.Schön: Handbook of Purified Gases

Data Sheet DS013.00 **Date: 07-02-04**

Name: 1-Butyne, inhibited Chemical Formula: C_4H_6

Synonyms: Ethylacetylene, Ethylethyne, But-1-yne $HC \equiv C - CH_2 - CH_3$

Properties:

Low pressure liquefied gas, flammable, colorless, garlic odor, tends to polymerisize spontaneously. React vigorously with halogens.

Production and Purification:

Manufactured from sodium acetylide and diethyl sulfate.

Widespread Applications:

Carrier of ethyl- or ethinyl-groups in syntheses.

Important Impurities: Other HC´s.

Disposal: Combustion.

Detection of 1-Butyne:

Detector for flammable gases. IR-spectrometry. Gas test tube.

Suitable Materials: Steel, stainless steel, PTFE, PCTFE

Valve Thread: Europe: Not standardized.

Germany: No.1, W21,8x1/14" LH.

USA: CGA connection 510, 0.855"-1/14 LH INT.

Filling Density(Factor): 0.57 kg/l at test pressure 10 bar.

Toxicological Information:

No known acute toxicological effects from this product.

Symptoms of Poisoning:

In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of coordination. In high concentration may cause asphyxiation.

First Aid:

Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.

Environmental Information:

No known ecological damage caused by this product.

Exposure Limits:

TLV(ACGIH): --- ppm, LC50 / 1h : --- ppm

1-Butyne, inhibited C_4H_6 DS013.0

Physical Data:

Molar Mass, [5]	54.092 g/mol
Melting Point T_{mp} at 1.013 bar, [5]	-125.86 ^{0}C (= -194.55 ^{0}F)
Enthalpy of Fusion at T_{mp}, [24]	111.46 kJ/kg (= 47.93 BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [5]	8.06 ^{0}C (= 46.51 ^{0}F)
Enthalpy of Vaporisation at T_{bp}, [28]	454 kJ/kg (= 195.17 BTU/lb)
Critical Point:	
-Temperature, [5]	166.85 ^{0}C (= 332.33 ^{0}F)
- Pressure, [24]	49.5 bar (= 717.94 psia)
- Density Liquid, [24]	0.2437 kg/l
Density Gas:	
- ideal	2.4133 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1 bar, [24]	2.240 g/l (= 0.1399 lb/ft^3)
- at 15 ^{0}C, 1 bar, [28]	2.342 g/l
- at 0 ^{0}C and 1.013 bar	--- g/l
Density Liquid	
- at T_{bp} , 1.013 bar, [28]	0.6690 kg/l
- at 25 ^{0}C, [24]	0.648 kg/l

Vapor Pressure (about), [1, 4]

-10	0	10	20	^{0}C
0.46	0.83	1.10	1.65	bar

2.Pressure Virial Coefficient, [11]	
- at 0 ^{0}C:	-43.6 $\times 10^{-3}$ bar^{-1}
- at 30 ^{0}C:	-29.9 $\times 10^{-3}$ bar^{-1}
Thermal Conductivity at 25^{0}C, [24]	0.1443 mW/(cm K)
Heat Capacity at 25 ^{0}C, 1.013 bar [28]	1.505 kJ/(kg K)
Solubility in Water at 20 ^{0}C and 1.013 bar, [6]	4.4g Gas / kg H_2O
Dynamic Viscosity at 25 ^{0}C and 1 bar,	$\times 10^{-6}$ Ns/m^2
Explosion Limits in Air,	
[4]	3.2-16.5 Vol.-%
[24]	2 - 32.9 Vol.-%
Autoignition Temperature, [4]	410 ^{0}C (= 770 ^{0}F)
Heating Value, [24]	45.565 MJ/kmol
Suitable Extinguishing Media:	All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number:	00107-00-6
EU Number:	203-451-3
EU Classification*:	F+
EU Symbols:	F+
Index-No.:	

UN Number:	2452
ETHYLACETYLENE, stabilized	
Class/Div:	2.1
ADR/RID: Class 2, Number	2F
ADR/RID Hazard Number:	239
Labeling ADR/DOT:	2.1

EU Classification:*
Risk Phrases:
R12: Extremley flammable.

* Not included in Annex1
Proposed by the industry.

Safety Phrases:
S9: Keep container in a well ventilated places.
S16: Keep away from ignition source - No smoking.
S33: Take precautionary measures against static discharges.

H.Schön: Handbook of Purified Gases

Data Sheet DS073.0 **Date: 06-01-06**

Name: Acetylene Chemical Formula: C_2H_2 $H-C\equiv C-H$

Synonyms: Ethine, Ethyne, Narcylene, Carbid gas, Dissousgas

Properties: Compressed gas in solution. Solvent: acetone, dimethylformamide. Porous materials: kieselguhr, wood charcoal. Combustible, colorless, pure acetylene is odourless, garlic-like odour is caused by impurity phosphine. Because of its triple bond, acetylene is chemical metastable and very endothermic.

Production and Purification: Convential: decomposition of calcium carbide and water. Chemical bulk production: steam cracking processes, pyrolysis of methane. Purification: gas-washing, adsorption.

Widespread Applications: Fuel gas, purified for flame-AES. It was formerly used in numerous organic syntheses, still important for methyl vinyl ether and vinylacetylene production.

Important Impurities: N_2 , PH_3 , H_2S, AsH_3 , NH_3, HC.

Disposal: Combustion. Use suitable burner with flash back arrestor.

Detection of acetylene: Gas test tube .

Suitable Materials: Steel, SS, Monel, Brass (Copper less than 65%), PVC , PTFE, PCTFE .

Valve Thread: *Europe:* Not standardized . Germany: No.3, tension arm .
USA: CGA connection 510, 0.885"-1/14 LH INT.

Filling Density(Factor): acetylene dissolved: dependent on porous material (example): 1,5 kg/l at test pressure 60 bar.
solvent-free acetylene (example): 0,03 kg/l at test pressure 60 bar.

Toxicological Information:
No known toxicological effects from this product.

Symptoms of Poisoning:
In high concentration may cause asphyxiation, in low concentration narcotic effects. Symptoms may include dizziness, headache, nausea and loss of coordination.

First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH): --- LC_{50} / 1h : ---

Acetylene C_2H_2 **DS073.0**

Physical Data:

Molar Mass, [11] 26.038 g/mol

Triple Point at 1,282 bar, [10] -80.8 ^{0}C (= -113.44 ^{0}F)

Enthalpy of Fusion, [24] 144.63 kJ/kg (= 62.19 BTU/lb)

Sublimation Point T_{Subl} at 1.013 bar, [10] -84.03 ^{0}C (=-119.25^{0}F)

Enthalpy of Vaporisation at T_{Subl}, [10] 801.9 kJ/kg (= 344.8 BTU/lb)

Critical Point, [10]:

-Temperature 35.2 ^{0}C (= 95.36 ^{0}F)

- Pressure 61.91 bar (= 897.9 psia)
- Density Liquid 0.2308 kg/l

Density Gas: ideal 1.1617 g/l

- at 70 ^{0}F (= 21.1 ^{0}C) and 1.013 bar, [24] 1.078 g/l (= 0.06734 lb/ft^3)
- at 15 ^{0}C and 1 bar, [10] 1.095 g/l
- at 0 ^{0}C and 1.013 bar, [5] 1.1715 g/l

Density Liquid at 25 ^{0}C, [24] 0.377 kg/l

1 bar = 14.504 psi, 1 g/l = 0.0624 lb/ft^3

Vapor Pressure (about),

- liquid, [4], [10]

-10	0	10	20	^{0}C
18.6	26.7	32	43.15	bar

- dissolved about 19 bar at 15 ^{0}C

2.Pressure Virial Coefficient, [11]

- at 0 ^{0}C: -8.4 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -5.8 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0,201 mW/(cm K)

Heat Capacity at 25 ^{0}C and 1.013 bar, [10] 1.685 kJ/(kg K)

Solubility in Water at 20 ^{0}C and 1.013 bar, [10] 1.047 l Gas/kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar, [3] 10.46 x 10^{-6} Ns/m^2

Explosion Limits in Air, [13] 2.3-100 Vol.-%

Autoignition Temperature, [13] 305 ^{0}C (= 581 ^{0}F)

Heating Value, [14] 1,256 MJ/kmol

Suitable Extinguishing Media: All known .

Identification and Classification:

CAS Number: 00074-86-2

EU Number: 200-816-9

EU Classification: F+

EU Symbols: F+

UN Number: 1001 ACETYLENE (dissolved)

Class/Div: 2.1

ADR/RID: Class 2, Number 4F

ADR/RID Hazard Number: 239

Labeling ADR/DOT: 2.1

EU Classification:

Risk Phrases:

R5: Heating may cause an explosion.

R6: Explosive with or without contact with air.

R12: Extremely flammable.

Safety Phrases:

S7: Keep container tighly closed.

S9: Keep container in a well ventilated places.

S16: Keep away from sources of ignition - No smoking.

S33: Take precautionary measures against static discharges .

H.Schön: Handbook of Purified Gases

Data Sheet DS038.0 **Date: 06-03-03**

Name: Allene Chemical Formula: C_3H_4

Synonyms: 1,2-Propadiene (inhibited), **$H_2C=C=CH_2$**
Dimethyl methane, sym-Allylene

Properties:
Low pressure liquefied gas, flammable, colorless, nontoxic, with a sweetish smell. May polymerisize, inhibitor usually added (propen).

Production and Purification:
Byproduct of petroleum refining in cracking processes.

Widespread Applications:
Is used mainly together with methyl acetylene as a fuel gas (MAPP gas) to generate high temperatures.

Important Impurities:		Other HCs.
Disposal:		Combustion .
Detection of Allene:		Detector for flammable gases. Gas test tube.
Suitable Materials:		All known .
Valve Thread:	*Europe:*	Not standardized . Germany: No.1, W21,8x1/14" LH.
	USA:	CGA connection 510, 0.885"-1/14 LH INT.
Filling Density(Factor):		0,50 kg/l at test pressure 220 bar .

Toxicological Information:
No known acute toxicological effects from this product.
Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of coordination. In high concentration may cause asphyxiation.
First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH): --- , LC50 / 1h : ---

Allene C_3H_4 DS038.0

Physical Data:

Molar Mass, [5] 40.065 g/mol

Melting Point T_{mp} at 1.013 bar, [24]
-136.28 ^{0}C (= -213.3 ^{0}F)

Enthalpy of Fusion at T_{mp}
kJ/kg (= BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [[5]
-34.38 ^{0}C (= -29.88 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [24]
514.16 kJ/kg (= 221.09 BTU/lb)

Critical Point:
-Temperature, [5]
120.85 ^{0}C (= 249.53 ^{0}F)
- Pressure, [24]
54.7 bar (= 793.36 psia)
- Density Liquid, [12] 0.247 kg/l

Density Gas:
- ideal 1.7875 g/l
- at 70 ^{0}F (= 21.1 ^{0}C),1.013 bar, [24]
1.659 g/l (= 0.1036 lb/ft^3)
- at 15 ^{0}C and 1 bar, [3] 1.701 g/l
- at 0 ^{0}C and 1.013 bar, [11] 1.824 g/l

Density Liquid
- at T_{bp} and 1.013 bar, [3] 0.6620 kg/l
- at 25 ^{0}C, [24] 0.579 kg/l

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
2.87	3.86	5.30	7.59	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -20.4 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -14.6 x 10^{-3} bar^{-1}

Thermal Conductivity at 50 ^{0}C,
[24] 0.1822 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar,
[3] 1.472 kJ/(kg K)

Solubility in Water at 20 ^{0}C and
1.013 bar l Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C, 1 bar
[24] 8.304 x 10^{-6} Ns/m^2

Explosion Limits in Air, [13]
1.1-17 Vol.-%

Autoignition Temperature
^{0}C (= ^{0}F)

Heating Value, [14]
1,855.08 MJ/kmol

Suitable Extinguishing Media:
All known .

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number: 00463-49-0
EU Number: 207-335-3
EU Classification: F+
EU Symbols: F+

UN Number: 1060 METHYL-ACETYLENE and PROPADIENE MIXTURE, stabilized
Class/Div: 2.1
ADR/RID: Class 2, Number 2 F
ADR/RID Hazard Number: 239
Labeling ADR/DOT: 2.1

EU Classification:
Risk Phrases:
R12: Extremely flammable.

Safety Phrases:
S9: Keep container in a well ventilated places.
S16: Keep away from sources of ignition - No smoking.
S33: Take precautionary measures against static discharges.

H.Schön: Handbook of Purified Gases

Data Sheet DS074.0 **Date: 07-09-10**

Name: Ammonia, anhydrous **Chemical Formula: NH_3**

Synonyms: R717, H3N

Properties: Low pressure liquefied gas, non flammable, toxic, colorless, pungent odour, corrosive, dissolves readily in water. Thermal decomposition mays produce NO and NO_2.

Production and Purification:
Industrially by the Haber-Bosch-process from the elements at elevated temperature, high pressure and by use of an iron-catalyst.

Widespread Applications:
Starting material for the chemical industry. Used as refrigerant in large plants.

Important Impurities:
Air, C_nH_m.

Disposal:
Pass in water or dilute acids.

Detection of Ammonia: Gas test tube.

Suitable Materials:		Steel, stainless steel, no copper and its compounds. PE , PTFE, PCTFE, PA.
Valve Thread:	*Europe:*	Not standardized. Germany: No.6, W21.8x1/14" RH.
	USA:	CGA connection 705, 1.125"-1/14 RH EXT.
Filling Density(Factor):		0.53 kg/l at test pressure 33 bar.

Toxicological Information:
May cause inflammation of the respiratory tract. Inhalation of large amounts leads to bronchospasm, laryngeal oedema and pseudomembrane.

Symptoms of Poisoning:
Dry cough, skin and eye burns, shortness of breath.

First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.
Obtain medical asistance.

Environmental Information:
May cause pH changes in aqueous ecological systems.

E*xposure Limits:*
TLV(ACGIH): 25 ppm, LC_{50} / 1h : 4000 ppm .

Ammonia NH_3 DS074.0

Physical Data:

Molar Mass 17.031 g/mol

Triple Point at 60.7 mbar, [5]
-77.74 ^{0}C (= -107.93 ^{0}F)

Enthalpy of Fusion at T_{mp} , [24]
332.16 kJ/kg (= 142.83 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-33.33 ^{0}C (= -27.99 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [24]
1336.97 kJ/kg (= 574.9 BTU/lb)

Critical Point:

-Temperature, [5]
132.25 ^{0}C (= 270.05 ^{0}F)

- Pressure, [5]
113.53 bar (= 1646.3 psia)

- Density Liquid, [28] 0.234 kg/l

Density Gas: - ideal 0.7598 g/l

- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
0.705 g/l (= 0.0440 lb/ft^3)

- at 15 ^{0}C, 1 bar, [28] 0.71979 g/l

- at 0 ^{0}C, 1.013 bar, [28] 0.7714 g/l

Density Liquid, [10]

- at T_{bp} and 1.013 bar 0.682 kg/l

- at 20 ^{0}C 0.610 kg/l

Vapor Pressure (about), [

-10	0	10	20	^{0}C
2.9	4.3	6.2	8.5	bar

2.Pressure Virial Coefficient

- at 0 ^{0}C: -14.9 x 10^{-3} bar^{-1}

- at 30 ^{0}C: -9.7 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.247 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar [10] 2.16 kJ/(kg K)

Solubility in Water at 20^{0}C, 1.013 bar, [10] 685.7 l Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C, 1 bar, [28] 10.02 x 10^{-6} Ns/m^2

Explosion Limits in Air, [13]
15.4-33.6 Vol.-%

Autoignition Temperature, [13]
630 ^{0}C (= 1,166 ^{0}F)

Heating Value, [14]
383.51 MJ/kmol

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi

1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number: 07664-41-7

EU Number: 231-635-3

EU Classification: T, C, N

EU Symbols: T, N

Index Number: 007-001-00-5

UN Number: 1005
AMMONIA, anhydrous

Class/Div: 2.3

ADR/RID: Class 2, Number 2TC

ADR/RID Hazard Number: 268

Labeling ADR/DOT: 2.3 + 8

EU Classification:
Risk Phrases:
R10: Flammable.
R23: Toxic by inhalation.
R34: Causes burns.
R50: Very toxic to aquatic organisms.
Safety Phrases:S9: Keep container in a well-ventilated place. S16: Keep away from sources of ignition - No smoking.
S26: In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.
S36/37/39: Wear suitable protective clothing, gloves and eye/face protection.
S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).
S61: Avoid release to the environment. Refer to special instructions/Safety data sheets.

H.Schön: Handbook of Purified Gases

Data Sheet DS068.0 **Date: 08-03-19**

Name:Argon, compressed Chemical Formula: Ar

Synonyms: R740

Properties: Compressed, non liquefied gas, non flammable, non-toxic, colourless, odourless, extremely chemically inert (noble Gas). Air contains 0.93% of Ar. The radioactive isotop ^{41}Ar is used in the investigation of gas flows.

Production and Purification:
Manufactured by fractional destillation of liquid air.

Widespread Applications:
shielding gas in the extraction and machining of metals, in the electrical welding.

Important Impurities:
Air, moisture

Disposal:
Pass in the atmosphere.

Detection of Argon: Mass spectrometry.

Suitable Materials: All known.

Valve Thread: *Europe:* for 300 bar: No 54, W30x2 RH.
Germany: for 200 bar: No. 6, W21.8x1/14" RH.
USA: CGA connection 677, 1.030"x1/14" RH EXT.

Test pressue/service pressure =1.5

Toxicological Information:
No known toxicological effects from this product.

Symptoms of Poisoning:
In high concentrations may cause asphyxiation. Symptoms may include loss of mobility/consciouness. Victim may not be aware the asphyxiation.

First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.

Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH):-- ppm, LC_{50} / 1h :--- ppm .

Argon, compressed Ar DS068.0

Physical Data:

Molar Mass, [5] 39.948 g/mol

Triple Point at 0.689 bar, [28]
-189.37 ^{0}C (=-308.87 ^{0}F)

Enthalpy of Fusion at T_{mp} , [24]
29.59 kJ/kg (= 12.72 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [24]
-189.35 ^{0}C (= -308.83 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [24]
161.21 kJ/kg (= 69.32 BTU/lb)

Critical Point, [24]:
-Temperature -122.29 ^{0}C (= -188.12^{0}F)
- Pressure 48.98 bar (=710.4 psia)
- Density Liquid 0.598 kg/l

Density Gas: ideal 1.7823 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
1.654 g/l (= 0.1033 lb/ft^3)
- at 15 ^{0}C and 1 bar, [10] 1.669 g/l
- at 0 ^{0}C, 1.013 bar, 28] 1.784 g/l

Density Liquid
- at T_{bp} and 1.013 bar, [10] 1.394 kg/l
- at -140 oC, (28) 1.028 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [4]

-186	-163	-143	-122	^{0}C
1	6.7	20	49	bar

2.Pressure Virial Coefficient, 11]
- at 0 ^{0}C: -0.96 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -0.61 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.161 mW/(cm K)

Heat Capacity at 25 ^{0}C,1.013 bar, [10] 0.519 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 0.034 l Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C, 1 bar, [3] 22.8 x 10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

Identification and Classification:

CAS Number: 07740-37-1
EU Number: 231-147-0
EU Classification: ---
EU Symbols: --
Index Number:

UN Number: 1006
ARGON, compressed
Class/Div: 2.2
ADR/RID: Class 2, Number 1A
ADR/RID Hazard Number: 20
Labeling ADR/DOT: 2.2

EU Classification:
Risk Phrases:
RAs: Asphyxiant in high concentrations.

Safety Phrases:
S9: Keep container in a well ventilated places.
S23: Do not breathe the gas.

H.Schön: Handbook of Purified Gases

Data Sheet DS001.0 **Date: 07-09-12**

Name: Arsine **Chemical Formula: AsH_3**

Synonyms: Arsenic trihydride, Hydrogen arsenide

Properties:
Low pressure liquefied gas, flammable, colorless, garlic-like odour, very toxic. Decompose on heating above than 230 ^{0}C into the elements.

Production and Purification:
Formed by the reaction of dilute acids on arsenides by hydrolytic cleavage. Other synthesis use $LiAlH_4$. Purification by destillation and adsorption.

Widespread Applications:
Used in the doping gas mixtures for the manufaction of semiconductor materials, important for production of LED´s.

Important Impurities:
Air, P- and Cl-compounds.

Disposal:
Pass in dilute alcaline solutions. Adsorption on activated carbon.

Detection of Arsine: Gas test tube, Marsh test.

Suitable Materials: All known.
Valve Thread: *Europe:* Not standardized.
Germany: No.1, W21,8x1/14" LH.
USA: CGA connection 350, 0.825"-1/14 LH EXT.
Filling Density(Factor): 1.1 kg/l at test pressure 42 bar.

Toxicological Information:
Damage to red blood cells (haemolytic poison). Damage to central nervous system. Fatal intoxication possible with low concentration.

Symptoms of Poisoning:
Toxic by inhalation. Headache, nausea, shortness of breath, stomach pain, coma, after a few hours urine has a red colour.

First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information:
Very toxic to water organisms.

E*xposure Limits:*
TLV(ACGIH): 0.05 ppm, LC_{50} / 1h : 20 ppm

Arsine AsH_3 DS001.0

Physical Data:
Molar Mass, [24] 77.945 g/mol
Triple Point at 29,84 mbar, [28]
-116.95 ^{0}C (= -178.51 ^{0}F)
Enthalpy of Fusion at T_{mp} , [10]
15.38 kJ/kg (= 6.61 BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [10]
-62.48 ^{0}C (= -80.46 ^{0}F)
Enthalpy of Vaporisation at T_{bp} , [10]
214.3 kJ/kg (= 92.13 BTU/lb)
Critical Point, [24]
-Temperature 99.85 ^{0}C (= 211.73 ^{0}F)
- Pressure 64.13 bar (= 930.13 psia)
- Density Liquid 0.5883 kg/l
Density Gas: -ideal 3.4775 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
3.228 g/l (= 0.2015 lb/ft^3)
- at 15 ^{0}C, 1 bar, [10] 3.253 g/l
- at 0 ^{0}C, 1.013 bar, [28] 3.5198 g/l
Density Liquid
- at T_{bp} and 1.013 bar, [10] 1.63 kg/l
- at 25 ^{0}C, [24] 1.321 kg/l

Vapor Pressure (about), [4, 10]

-20	0	20	^{0}C
5.20	9.10	15	bar

2.Pressure Virial Coefficient, [28]
- at 0 ^{0}C: -12 $\times 10^{-3}$ bar^{-1}
- at 30 ^{0}C: -9 $\times 10^{-3}$ bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.156 mW/(cm K)
Heat Capacity at 25 ^{0}C, 1.013 bar [10] 0.494 kJ/(kg K)
Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 0.23 l Gas / kg H_2O
Dynamic Viscosity at 25 ^{0}C, 1 bar [28] 16.04 $\times 10^{-6}$ Ns/m^2
Explosion Limits in Air, [13]
3.9-77.8 Vol.-%
Autoignition Temperature, [13]
285 ^{0}C (= 545 ^{0}F)
Heating Value MJ/kmol
Suitable Extinguishing Media:
All known.

Identification and Classification:

CAS Number:	07784-42-1
EU Number:	232-066-3
EU Classification:	F+, T+, Xn, N
EU Symbols:	F+, T+, N
Index Number:	033-006-00-7

UN Number:	2188 ARSINE
Class/Div:	2.3
ADR/RID: Class 2, Number	2TF
ADR/RID Hazard Number:	263
Labeling ADR/DOT:	2.1+2.3

EU Classification:
Risk Phrases:
R12: Extremely flammable.
R26: Very toxic by inhalation.
R48/20: Harmful: danger of serious damage to health by prolonged exposure through inhalation.
R50/53: Very toxic to aquatic organisms, may cause log-term adverse effects in the aquatic anvironment.
Safety Phrases: S9: Keep container in a well-ventilated place.
S16: Keep away from sources of ignition - No smoking.
S28: After contact with skin, wash immediately with water.
S33: Take precautionary measures against static discharges.
S36/37: Wear suitable protective clothing and gloves.
S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).
S60: This material and its container must be disposed of as hazardous waste.
S61: Avoid release to the environment. Refer to special instructions / MSDS.

H.Schön: Handbook of Purified Gases

Data Sheet DS002.0 **Date: 07-06-27**

Name: Boron trichloride **Chemical Formula: BCl_3**

Synonyms: Trichloro borane

Properties:
Low pressure liquefied gas, non flammable, colorless, pungent odour, very toxic, corrosiv. Forms white fumes with moist air or ammonia vapour. Decomposed in water to give hydrochloric acid and boric acid.

Production and Purification:
Produced by reduction of borax or boron trioxide with carbon or bitumen, followed by reaction with Cl_2.

Widespread Applications:
Used in the field of high energy fuels and rocket propellents, in the semiconductor industry and in the manufacture of electrical resistors.

Important Impurities:
$COCl_2$, CCl_4, HCl, Cl_2, CO, CO_2

Disposal: Pass in dilute NaOH- or KOH-solution.

Detection of Boron trichloride: Gas test tube.

Suitable Materials: Steel,stainless steel, monel, no brass, copper or aluminium . PTFE, PCTFE, PVDF, EPDM .

Valve Thread: *Europe:* Not standardized.
Germany: No.1, 21,8x1/14"LH
USA: CGA connection 660, 1.030"-1/14 RH EXT.

Filling Density(Factor): 1.19 kg/l at test pressure 10 bar.

Toxicological Information:
In high concentration severe corrosion to skin, eyes and respiratory tract. Delayed fatal pulmonary edema possible.

Symptoms of Poisoning:
Very toxic by inhalation.
May cause severe chemical burns to skin and cornea.

First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information:
May cause pH changes in aqueous ecological systems.

E*xposure Limits:*
TLV(ACGIH): ppm, LC_{50} / 1h : 2541 ppm .

Boron trichloride BCl_3 DS002.0

Physical Data:
Molar Mass, [11] 117.169 g/mol
Triple Point at 37.3 mbar,[28]
-107 ^{0}C (= -160.6 ^{0}F)
Enthalpy of Fusion at T_{mp}, [10]
17.9 kJ/kg (= 7.70 BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [11]
12.5 ^{0}C (= 54.5 ^{0}F)
Enthalpy of Vaporisation at T_{bp}, [10]
203.5 kJ/kg (= 87.48 BTU/lb)
Critical Point:
-Temperature, [12, 24]
178.8 ^{0}C (= 353.84 ^{0}F)
- Pressure, [12, 24]
38.71 bar (= 561.44 psia)
- Density Liquid, [12] 0.79 kg/l
[24] 0.4405 kg/l
Density Gas:
- ideal 5.2275 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
4.852 g/l (= 0.3030 lb/ft^3)
- at 15 ^{0}C, 1 bar, [15] 5.06 g/l
- at 0 ^{0}C and 1.013 bar --- g/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Density Liquid
- at 0 ^{0}C, [12] 1.43 kg/l
- at T_{bp}, 1.013 bar, [10] 1.346 kg/l

Vapor Pressure (about), [12]

-10	0	10	20	^{0}C
0.4	0.6	0.9	1.3	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -39 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -29 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.080 mW/(cm K)
Heat Capacity at 25 ^{0}C, 1.013 bar [10] 0.532 kJ/(kg K)
Solubility in Water at 20 ^{0}C, 1.013 bar hydrolysed
Dynamic Viscosity at 25 ^{0}C, 1 bar [24] 11.86 x 10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

Identification and Classification:
CAS Number: 10294-34-5
EU Number: 233-658-4
EU Classification: T+, C
EU Symbols: T+
Index Number: 005-002-00-5

UN Number: 1741
BORON TRICHLORIDE
Class/Div: 2.3
ADR/RID: Class 2, Number 2TC
ADR/RID Hazard Number: 268
Labeling ADR/DOT: 2.3, 8

EU Classification:
Risk Phrases:
R14: Reacts violently with water.
R26/28: Very toxic by inhalation and if swallowed. R34: Causes burns.
Safety Phrases:
S9: Keep container in a well-ventilated place.
S26: In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.
S28: After contact with skin, wash immediately with plenty of water.
S36/37/39: Wear suitable protective clothing, gloves and eye/face protection.
S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible)

H.Schön: Handbook of Purified Gases

Data Sheet DS003.0 **Date: 07-06-28**

Name: Boron trifluoride Chemical Formula: BF_3

Synonyms: Trifluoroborane

Properties:

High pressure liquefied gas, non flammable, colorless, pungent odour, very toxic, corrosiv. Forms white fumes with moist air or ammonia vapour. Reacts rapidly with water, forming boric acid and various fluoroboric acids.

Production and Purification:

Manufactured by reacting hydrofluoric acid with boric acid. The reaction is carried out in concentrated sulphuric acid to bind the water that is formed.

Widespread Applications:

Etching gas in the seminconductor industry. Used as catalyst in condensations, polymerizations and cracking processes. Raw material for borane syntheses.

Important Impurities: SiF_4, HF, S-compounds , O_2 .

Disposal: Pass in dilute NaOH- or KOH-solvent.

Detection of Boron trifluoride: Gas test tube.

Suitable Materials: Steel,stainless steel, monel, no brass, copper or aluminium . PTFE, PCTFE, PVDF, EPDM .

Valve Thread: *Europe:* Not standardized.
Germany: No.8, 1" RH.
USA: CGA connection 330, 10.825"-1/14 LH EXT.

Filling Density(Factor): 0.86 kg/l at test pressure 300 bar.

Toxicological Information:

In high concentration severe corrosion to skin, eyes and respiratory tract. Delayed fatal pulmonary edema possible. Absorption of excessive fluorine: can result in acute fluorosis with hypocalmenia, interfenrence with various metabolic functions and organ damage (heart, liver, kidneys).

Symptoms of Poisoning:

May cause severe chemical burns to skin and cornea.

First Aid:

Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.

Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information:

May cause pH changes in aqueous ecological systems.

E*xposure Limits:*

TLV(ACGIH): 1 ppm, LC_{50} / 1h : 387 ppm .

Boron trifluoride BF_3 DS003.0

Physical Data:

Molar Mass, [11] 67.806 g/mol

Melting Point T_{mp} at 1.013 bar, [24]
-127.1 ^{0}C (= -196.78 ^{0}F)

Enthalpy of Fusion at T_{mp}, [10]
62.112 kJ/kg (= 26.70 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [11, 24]
-99.8 ^{0}C (= -147.64 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [10]
278.8 kJ/kg (= 119.86 BTU/lb)

Critical Point: [10]
-Temperature -12.2 ^{0}C (= + 10.04 ^{0}F)
- Pressure 49.9 bar (= 723.75 psia)
- Density Liquid 0.591 kg/l

Density Gas:
- ideal 3.0249 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
2.808 g/l (= 01753 lb/ft^3)
- at 15 ^{0}C, 1 bar, [10] 2.867 g/l
- at 0 ^{0}C, 1.013 bar, [28] 3.0435 g/l

Density Liquid
- at T_{bp}, 1.013 bar, [10] 1.59 kg/l
- at -70 ^{0}C, [24] 1.433 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [14]

-100	-30	-20	-12.2	^{0}C
1	28	41	49.9	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -6×10^{-3} bar^{-1}
- at 30 ^{0}C: -4×10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.183 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar [10] 0.745 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 1.06 l Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C,1 bar [3] 17×10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

Identification and Classification:

CAS Number: 07637-07-2
EU Number: 231-569-5
EU Classification: T+, C
EU Symbols: T+, C
Index Number: 005-001-00-X

UN Number: 1008
BORON TRIFLUORIDE
Class/Div: 2.1
ADR/RID: Class 2, Number 2TC
ADR/RID Hazard Number: 268
Labeling ADR/DOT: 2.3, 8

EU Classification:
Risk Phrases:
R14: Reacts violently with water.
R26: Very toxic by inhalation.
R35: Causes severe burns.
*Safety Phrases:*S9: Keep container in a well-ventilated place.
S26: In case of contact with eyes, rinse immediatediately with plenty of water and seek medical advice.
S28: After contact with skin, wash immediately with plenty of water.
S36/37/39: Wear suitable protective clothing, gloves and eye/face protection.
S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible)

H.Schön: Handbook of Purified Gases

Data Sheet DS095.0 **Date: 07-06-16**

Name:Bromochlorodifluoromethane **Chemical Formula:**

Synonyms: Monochlorodifluoromonobromomethane **$CBrClF_2$**

R12B1, Halon 1211, Chlorodifluorobromomethane

Properties: Low pressure liquefied gas, non flammable, colorless, ethereal odour, relatively non-toxic. Thermically and chemically stable. Thermal decomposition mays produce CO, $COCl_2$, COF_2, $COBr_2$, HBr, HF and HCl.

Production and Purification:
Manufactured by fluorination of Br-Cl-CH-compounds. Rectification.

Widespread Applications:
Subject to restrictions by EC Regulations 3093/94 and 2037/00, no longer importance as a refrigerant and fire extinguishant.

Important Impurities: Other HC´s and Cl-Br-F-CH-compunds.

Disposal:
Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.

Detection of R12B1: Halogen leak detector, gas test tube, IR-spectrometry .

Suitable Materials: All known.

Valve Thread: *Europe:* Not standardized.
Germany: No.6, W21,8x1/14" RH.
USA: CGA connection 660, 1.030"-1/14 RH EXT.

Filling Density(Factor): 1.61 kg/l at test pressure 10 bar.

Toxicological Information:
May produce irregular heart beat and nervous symptoms.

Symptoms of Poisoning:
In high concentration may cause asphyxiation. Symptoms may include loss of mobility/consiousness. Victim may not aware of asphyxiation.
In low concentration may cause narcotic effects . Symptoms may include dizziness, headache, nausea and loss of co-ordination.

First Aid: Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information: May have damaging effect on ozone layer. Covered by the "Montreal Protocol".

Exposure Limits:
TLV(ACGIH): --- ppm, LC50 / 1h : ppm .

Bromochlorodifluoromethane CBrClF$_2$ DS095.0

Physical Data:

Molar Mass, [5] 165.365 g/mol

Melting Point T$_{mp}$ at 1.013 bar, [5]
-159,50 ^{0}C (= -255,10 ^{0}F)

Enthalpy of Fusion at T$_{mp}$
kJ/kg (= BTU/lb)

Boiling Point T$_{bp}$ at 1.013 bar, [5]
-3.95 ^{0}C (= +24.89 ^{0}F)

Enthalpy of Vaporisation at T$_{bp}$, [3]
133,20 kJ/kg (= 57.26 BTU/lb)

Critical Point:

-Temperature, [5]
153,90 ^{0}C (= 309.02 ^{0}F)

- Pressure,[5] 42,6 bar (= 617.87 psia)
- Density Liquid, [12] 0.673 kg/l

Density Gas:

- ideal 7.3778 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1,013 bar
g/l (= lb/ft^3)
- at 15 ^{0}C, 1 bar, [3] 7.1362 g/l
- at 0 ^{0}C, 1.013 bar, [11] 7.634 g/l

Density Liquid at T$_{bp}$, 1.013 bar, [3]
1.899 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [12]

-10	0	10	20	^{0}C
0.9	1.3	1.9	2.5	bar

2.Pressure Virial Coefficient, [11]

- at 0 ^{0}C: -34 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -24 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [1] 0.0736 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar [3] 0.4509 kJ/(kg K)

Solubility in Water at 20 ^{0}C and 1.013 bar l Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C, 1 bar [3] 13.03 x 10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

Identification and Classification:

CAS Number: 00353-59-3
EU Number: 200-537-9
EU Classification: N
EU Symbols: N
Index Number:

UN Number: 197 BROMOCHLORO DIFLUOROMETHANE
Class/Div: 2.2
ADR/RID: Class 2, Number 2A
ADR/RID Hazard Number: 20
Labeling ADR/DOT: 2.2

EU Classification:
Risk Phrases:

R59: Dangerous for the ozone layer.

Safety Phrases:

S59: Refer to manufacturer / supplier for information on recovery / recycling.

H.Schön: Handbook of Purified Gases

Data Sheet DS004.0 **Date: 07-06-19**

Name: Bromotrifluoromethane Chemical Formula: $CBrF_3$

Synonyms: R13B1, Halon 1301, Trifluoromonobromomethane
Bromofluoroform

Properties: Low pressure liquefied gas, non flammable, colorless, ethereal or sweet odour, relatively non-toxic. Thermal decomposition mays produce CO, $COCl_2$, COF_2, $COBr_2$, HBr and HF .

Production and Purification:
Manufactured by fluorination of Br-C_nH_m-compounds. Rectification.
Widespread Applications:
Subject to restrictions by EC Regulations 3093/94 and 2037/00, no longer important as a refrigerant and fire extinguishant.
Important Impurities: Other HC´s and Cl-Br-F-CH-compunds.
Disposal:
Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.
Detection of R13B1: Halogen leak detector, gas test tube, IR-spectrometry .

Suitable Materials: All known.
Valve Thread: *Europe:* Not standardized.
Germany: No.6, W21,8x1/14" RH.
USA: CGA connection 660, 1.030"-1/14 RH EXT.
Filling Density(Factor): 1.60 kg/l at test pressure 250 bar.

Toxicological Information:
May produce irregular heart beat and nervous symptoms.
Symptoms of Poisoning:
In high concentration may cause asphyxiation. Symptoms may include loss of mobility/consiousness. Victim may not aware of asphyxiation.
In low concentration may cause narcotic effects . Symptoms may include dizziness, headache, nausea and loss of co-ordination.
First Aid: Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information: May have damaging effect on ozone layer. Covered by the "Montreal Protocol".
Exposure Limits:
TLV(ACGIH): --- ppm, LC50 / 1h : ppm .

Bromotrifluoromethane $CHBrF_3$ DS004.0

Physical Data:
Molar Mass, [5] 148.910 g/mol
Melting Point T_{mp} at 1.013 bar, [5]
-168 ^{0}C (= -270.4 ^{0}F)
Enthalpy of Fusion at T_{mp}
kJ/kg (= BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [5]
-57.74 ^{0}C (= -71.93 ^{0}F)
Enthalpy of Vaporisation at T_{bp}, [10]
121.42 kJ/kg (=52.20 BTU/lb)
Critical Point:
-Temperature, [5] 67 ^{0}C (= 152.6 ^{0}F)
- Pressure, [24]
39.72 bar (= 576.09 psia)
- Density Liquid, [10] 0.745 kg/l
Density Gas:
- ideal 6.6437 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
6.167 g/l (= 0.3850 lb/ft^3)
- at 15 ^{0}C, 1 bar, [10] 6.3 g/l
- at 0 ^{0}C,1.013 bar, [11] 6.765 g/l
Density Liquid, [10]
- at T_{bp} and 1.013 bar 1.992 kg/l
- at 20 ^{0}C 1.570 kg/l

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
6.3	8.45	11.1	14.3	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -17 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -13 x 10^{-3} bar^{-1}
Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.08 mW/(cm K)
Heat Capacity at 25 ^{0}C, 1.013 bar [10] 0.469 kJ/(kg K)
Solubility in Water at 20^{0}C, 1.013 bar, [10] 0.044 l Gas / kg H_2O
Dynamic Viscosity at 25 ^{0}C, 1 bar [3] 14.4 x 10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:
CAS Number: 00075-63-8
EU Number: 200-887-6
EU Classification: N
EU Symbols: N
Index Number:

UN Number: 1009
BROMOTRIFLUOROMETHANE
Class/Div: 2.2
ADR/RID: Class 2, Number 2A
ADR/RID Hazard Number: 20
Labeling ADR/DOT: 2.2

EU Classification:
Risk Phrases:
R59: Dangerous for the ozone layer.

Safety Phrases:
S59: Refer to manufacturer / supplier for information on recovery / recycling.

H.Schön: Handbook of Purified Gases

Data Sheet DS007.0 **Date: 06-02-07**

Name: Butane **Chemical Formula: C_4H_{10}**

Synonyms: n-Butane, Diethyl, R600, Methylethylmethane **$H_3C\text{-}CH_2\text{-}CH_2\text{-}CH_3$**

Properties:
Low pressure liquefied gas, flammable, colorless, relativ nontoxic, with a characteristic gas odor.

Production and Purification:
From natural gas by pressure destillation and from the C4-fraction, in cracking process or coal hydrogenation. Rectification.
Widespread Applications:
Fuel gas, propellant gas. Industially important in the manufacture of gasoline and many organic chemicals.

Important Impurities:		Other HCs.
Disposal:		Combustion .
Detection of n-Butane:		Detector for flammable gases. Gas test tube.
Suitable Materials:		All known.
Valve Thread:	*Europe:*	Not standardized.
		Germany: No.1, W21,8x1/14" LH.
	USA:	CGA connection 510, 0.885"-1/14 LH INT.
Filling Density(Factor):		0.51 kg/l at test pressure 10 bar.

Toxicological Information:
No known acute toxicological effects from this product.
Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of coordination. In high concentration may cause asphyxiation.
First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

Environmental Information:
No known ecological damage caused by this product.

E*xposure Limits:*
TLV(ACGIH): 800 ppm, LC_{50} / 1h : ---

Butane C_4H_{10} DS007.0

Physical Data:

Molar Mass, [5] 58,123 g/mol

Triple Point at 0.004 mbar, [5], [10]
-138.36 ^{0}C (= -217.05 ^{0}F)

Enthalpy of Fusion, [10]
80.22 kJ/kg (= 34.49 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-0.49 ^{0}C (= 31.12 ^{0}F)

Enthalpy of Vaporisation at $T_{bp,}$ [10]
385.6 kJ/kg (= 165.81 BTU/lb)

Critical Point:
-Temperature, [5]
151.57 ^{0}C (= 304.83 ^{0}F)
- Pressure, [5]
37.96 bar (= 550.57 psia)
- Density Liquid, [10] 0.228 kg/l

Density Gas:
- ideal 2.5933 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1.013 bar, [24] 2.407 g/l (= 0.1503 lb/ft^3)
- at 15 ^{0}C, 1 bar, [10] 2.522 g/l
- at 0 ^{0}C, 1.013 bar,[11] 2.709 g/l

Density Liquid, [10]
- at T_{bp} and 1.013 bar 0.6014 kg/l
- at 20 ^{0}C 0.580 kg/l

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
0.78	1.03	1.48	2.08	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -40.2 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -29.9 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.149 mW/(cm K)

Heat Capacity at 25 ^{0}C and 1.013 bar, [10] 1.66 kJ/(kg K)

Solubility in Water at 20 ^{0}C and 1.013 bar, [10]
0.034 l Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar, [3] 7.51 x 10^{-6} Ns/m^2

Explosion Limits in Air, [13]
1.4-9.4 Vol.-%

Autoignition Temperature, [13]
365 ^{0}C (= 689 ^{0}F)

Heating Value, [14]
2,657.32 MJ/kmol

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi ,
1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number: 00106-97-8
EU Number: 203-448-7
EU Classification: F+
EU Symbols: F+

UN Number: 1011
BUTAN
Class/Div: 2.1
ADR/RID: Class 2, Number 2F
ADR/RID Hazard Number: 23
Labeling ADR/DOT: 2.1

EU Classification:
Risk Phrases:
R12: Extremely flammable.

Safety Phrases:
S9: Keep container in a well ventilated places.
S16: Keep away from sources of ignition - No smoking.

H.Schön: Handbook of Purified Gases

Data Sheet DS082.0 **Date: 08-04-05**

Name: Carbon dioxide Chemical Formula: CO_2 O=C=O

Synonyms: Carbonic acid gas, Carbonic anhydride, Dioxide of carbon, Air fixe

*Properties:*High pressure liquefied gas, non-combustible, non-toxic, colourless, odourless, thermally very stable. The liquid phase does not exist at normal pressure, i.e. carbon dioxide sublimes, the solid phase is called dry ice. Is formed in the fermentation of organic materials.

Production and Purification: Obtained industrially from the combustion flue gases from generator gas, scrubber and rectification.
Widespread Applications: Used as an inerting agent in fire extinguishers and canned food products to prevent oxidation, for carbonating beverages. Liquid CO_2 is used as a refrigerant
Important Impurities: Air, HC´s, CO, H_2 .
Disposal: Pass low quantities in the atmosphere.
Contact supplier if guidance is required.
Detection of Carbon dioxide: Gas test tube.
Suitable Materials: All known.
Valve Thread: *Europe:* not standardized .
Germany: for 200 bar(test pressure): No. 6, W21.8x1/14" RH.
USA: CGA connection 320, .825"x 1/14" RH EXT.
Filling Density(Factor): 0,75 kg/l at test pressure250 bar.

Toxicological Information:
Low concentrations cause increased respiration and headache, in high concentrations cause rapid circulatory insuffiency.
Symptoms of Poisoning:
In high concentrations may cause asphyxiation. Symptoms may include loss of mobility/consciouness. Victim may not be aware the asphyxiation.
First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information:
When discharged in large quantities may contribute to the greenhouse effect.
E*xposure Limits:*
TLV(ACGIH): 5000 ppm, LC_{50} / 1h : ppm.

Carbon dioxide CO_2 DS082.0

Physical Data:

Molar Mass, [5] 44.010 g/mol

Triple Point at 5.185 bar, [24]:
-56.57 ^{0}C (= -69.83 ^{0}F)

Enthalpy of Fusion at T_{mp} , [24]
204.93 kJ/kg (= 88.12 BTU/lb)

Sublimation Point T_{subl} at 1.013 bar
-78.5 ^{0}C (= -109.3 ^{0}F)

Enthalpy of Sublimation at T_{subl} , [10]
573.02 kJ/kg (= 246.4 BTU/lb)

Critical Point, [24]:
-Temperature 31.04 ^{0}C (=87.87^{0}F)
- Pressure 73.82 bar (=1070.67 psia)
- Density Liquid 0.4682 kg/l

Density Gas: ideal 1.9635 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
1.823 g/l (= 0.1138 lb/ft^3)
- at 15 ^{0}C and 1 bar, [10] 1.848 g/l
- at 0 ^{0}C, 1.013 bar, [12] 1.977 g/l

Density Liquid
- at T_{bp} and 1.013 bar, [10] 1.178 kg/l
- at 20 ^{o}C, [12] 0.775 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [1]

-10	0	10	20	^{0}C
26.5	34.8	45.0	57.3	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -6.64×10^{-3} bar^{-1}
- at 30 ^{0}C: -4.78×10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.157 mW/(cm K)

Heat Capacity at 25 ^{0}C,1.013 bar, [10] 0.85 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 0.87 l Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar, [3] 14.83×10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

Identification and Classification:

CAS Number:	00124-38-9
EU Number:	204-696-9
EU Classification:	---
EU Symbols:	---
Index Number:	

UN Number: 1013
CARBON DIOXIDE

Class/Div:	2.2
ADR/RID: Class 2,Number	2A
ADR/RID Hazard Number:	20
Labeling ADR/DOT:	2.2

EU Classification:
Risk Phrases:
RAs: Asphyxiant in high concentrations.

Safety Phrases:
S9: Keep container in a well ventilated places.
S23: Do not breathe the gas

H.Schön: Handbook of Purified Gases

Data Sheet DS078.0 **Date: 08-04-03**

Name: Carbon monoxide Chemical Formula: CO

Synonyms: Carbon oxide, Monoxide of carbon, Exhaust gas, Flue gas

*Properties:*Non-liquefied, compressed gas flammable, colorless, odorless, toxic, forms with air or O_2 a detonating gas, readily soluble in some organic solvents, but poorly in water. Large amounts from the incomplete combustion of fossil fuels, from vulcano and motor vehicle enter the atmosphere, where are oxidised to CO_2 within few months.Forms with iron the corrosive and toxic iron carbonyl.

Production and Purification: Obtained industrially from fossil fuels in various processes (generator gas, blast-furnace gas, towns gas, synthesis gas).
*Widespread Applications:*Used in fuel gas mixtures with H_2 and other gases for heating and the reduction of ores.

Important Impurities:	Air, Ar, HC´s .
Disposal:	combustion .

Detection of Carbon monoxide: Detector for flammable gases, gas test tube.

Suitable Materials:		Steel, copper, nickel, aluminium, PTFE, PCTFE.
Valve Thread:	*Europe:*	for 300 bar: No 57, W30x2 LH.
	Germany:	for 200 bar: No. 5, 1" LH.
	USA:	CGA connection 350, 0.825"x1/14" LH EXT.

Test pressure/service pressure = 1.5

Toxicological Information:
Damage to red blood cells (haemolytic poison)
Symptoms of Poisoning: Toxic by inhalation
Symptoms may include dizziness, headache, nausea and loss of coordination
First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Do not discharge into areas when is a risk of forming an explosive mixture with air.
Environmental Information:
No known ecological damage caused by this product.

E*xposure Limits:*
TLV(ACGIH):25 ppm, LC_{50} / 1h : 3760 ppm .

Carbon monoxide CO DS078.0

Physical Data:

Molar Mass, [5] 28.010 g/mol
Triple Point at 0.1535 bar, [5]
-205.01 ^{0}C (= -337 ^{0}F)
Enthalpy of Fusion at T_{mp} , [24]
30.02 kJ/kg (=12.91 BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [5]
-191.53 ^{0}C (= -312.8 ^{0}F)
Enthalpy of Vaporisation at T_{bp} , [24]
211 kJ/kg (= 90.73 BTU/lb)
Critical Point, [24]:
-Temperature -140.23 ^{0}C (= -220.41 ^{0}F)
- Pressure 34.53 bar (=507.49 psia)
- Density Liquid 0.3009 kg/l
Density Gas: ideal 1.2497 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
1.160 g/l (=0.0724 lb/ft^3)
- at 15 ^{0}C and 1 bar, [10] 1.17 g/l
- at 0 ^{0}C, 1.013 bar, [11] 1.2505 g/l
Density Liquid
-at T_{bp} and 1.013 bar, [10] 0.789 kg/l
- at -160 ^{o}C, [24] 0.967 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [4, 5]

-205	-180	-160	-140	^{0}C
1	3.28	12.2	35	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -0.66×10^{-3} bar^{-1}
- at 30 ^{0}C: -0.31×10^{-3} bar^{-1}
Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.241 mW/(cm K)
Heat Capacity at 25 ^{0}C,1.013 bar, [10] 1.04 kJ/(kg K)
Solubility in Water at 20 ^{0}C,1.013 bar, [10] 227 ml Gas / kg H_2O
Dynamic Viscosity at 25 ^{0}C and 1 bar, [3] 17.7×10^{-6} Ns/m^2
Explosion Limits in Air, [13]
10.9-76 Vol.-%
Autoignition Temperature, [13]
605 ^{0}C (= 1121 ^{0}F)
Heating Value, [24]
10.104 MJ/kg
Suitable Extinguishing Media:
All known.

Identification and Classification:

CAS Number: 00630-08-0
EU Number: 211-128-3
EU Classification: F+, T, Repr.Cat.1
EU Symbols: F+, T
Index Number: 006-001-00-2

UN Number: 1016 CARBON MONOXIDE, compressed
Class/Div: 2.3
ADR/RID: Class 2, Number 1TF
ADR/RID Hazard Number: 263
Labeling ADR/DOT: 2.1, 2.3

EU Classification:
Risk Phrases:

R12: Extremely flammable.
R23: Toxic by inhalation
R48/23: Toxic: danger of serious damage to health by prolonged exposure through inhalation.

Safety Phrases:

S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).
S53: Avoid exposure, obtain special instructions before use.

H.Schön: Handbook of Purified Gases

Data Sheet DS062.0 **Date: 08-06-27**

Name: Carbonyl sulfide Chemical Formula: COS

Synonyms: Carbon oxide sulfide, Oxycarbonsulfide **S=C=O**

Properties: Low pressure liquefied gas, flammable, colourless, toxic, smelling of rotten eggs, undergoes thermal decomposition to CO and SO_2, hydrolysis to H_2S and CO_2 .

Production and Purification:
Partial oxidation of S-content fuels. Condensation and destillation.
Widespread Applications: Useful in the synthesis of thioacids, trisubstituted carbinols, substituted thioazoles and thiocarbamic acids.
Important Impurities: HC´s, S-Compounds.
Disposal: Toxic and corrosive gases formed during combustion should be scrubbed before discharge to atmosphere. Contact supplier is required.

Detection of Carbonyl sulfide: Detector for flammable gases, gas test tube.

Suitable Materials: Steel, stainless steel, PTFE, PCTFE, PE.
Valve Thread: *Europe:* Not standardized.
Germany: No.5, 1" LH.
USA: *CGA connection 330, 0.825"-1/14 LH EXT.*
Filling Density(Factor): 0.84 kg/l at test pressure 16 bar.

Toxicological Information: May cause irritazion to the respiratory tract. Damage to central nervous system.
Symptoms of Poisoning:
Toxic by inhalation.
First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information:
Toxic to aquatic organism. Endangering to drinking water.

E*xposure Limits:*
TLV(ACGIH): ppm, LC_{50} / 1h :1700 ppm

Carbonyl sulfide COS DS062.0

Physical Data:

Molar Mass, [11] 60.076 g/mol

Melting Point T_{mp} at 1.013 bar, [6, 24]
-138.8 ^{0}C (= -217.84 ^{0}F)

Enthalpy of Fusion at T_{mp} , 24]
78.7 kJ/kg (= 33.84 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [24]
-50.15 ^{0}C (= -58.27 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [24]
309.77 kJ/kg (= 133.2 BTU/lb)

Critical Point, [24]:
-Temperature 105.65 ^{0}C (= 222.17 ^{0}F)
- Pressure 63.49 bar (= 920.85 psia)
- Density Liquid 0.4447 kg/l

Density Gas: ideal 2.6803 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1,013 bar, [24]
2.488 g/l (= 0.1553lb/ft^3)
- at 15 ^{0}C and 1 bar, [15] 2.540 g/l
- at 0 ^{0}C, 1.013 bar, [3] 2.721 g/l

Density Liquid at T_{bp} and 1.013 bar, [3]
1.178 kg/l

Vapor Pressure (about), [1, 4]

-10	0	10	20	^{0}C
4.5	6.18	8.5	11.6	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -14.9 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -10.8 x 10^{-3} bar^{-1}

Thermal Conductivity at 25 ^{0}C, [24]
0.1394 mW/(cm K)

Heat Capacity at 25 ^{0}C,1.013 bar, [3] 0.693 kJ/(kg K)

Solubility in Water at 20 ^{0}C and 1.013 bar Hydrolysis

Dynamic Viscosity at 25 ^{0}C, 1 bar, [3] 12.42 x 10^{-6} Ns/m^2

Explosion Limits in Air
[13] 6.5 - 29 Vol.-%
[24] 12-29 Vol.-%

Autoignition Temperature, [6]
greater 250 ^{0}C

Heating Value, [24] 91.26 MJ/kg

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi ,1g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number: 463-58-1
EU Number: 207-340-0
EU Classification: F+, T
EU Symbols: F+, T
Index Number:

UN Number: 2204
CARBONYL SULFIDE
Class/Div: 2.3
ADR/RID: Class 2, Number 2TF
ADR/RID Hazard Number: 263
Labeling ADR/DOT: 2.1, 2.3

EU Classification:

Risk Phrases:

R12: Extremely flammable.
R23: Toxic by inhalation.

Safety Phrases:

S9: Keep container in a well ventilated place.
S16: Keep away from sources of ignition- No smoking
S33: Take precautionary measures against static dischargs.
S36: Wear suitable protective clothing
S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible)

H.Schön: Handbook of Purified Gases

Data Sheet DS015.0 **Date: 07-09-14**

Name: Chlorine Chemical Formula: Cl_2

Synonyms:

Properties:

Low pressure liquefied gas, non flammable, greenish-yellow colour, pungent odour, toxic, corrosive, irritant.
May react violently with combustible materials.

Production and Purification:

Obtained industrially by using the chlor-alcali-electrolysis process.
Destillation.

Widespread Applications:

Basic material for the chemical industry. Used to manufacture vinyl chloride, PVC, chloroform, refrigerants and bleaching agents. Etching agent for the semiconductor and glass fiber industry.

Important Impurities:

Air, H_2O, CO_2, alcaline compounds.

Disposal: Pass in dilute alcaline solution..

Detection of Chlorine: Gas test tube .

Suitable Materials: steel, stainless steel, no aluminium, stannous, tin, no oil , grease.

Valve Thread: *Europe:* Not standardized.
Germany : No.8, 1" RH.
USA: CGA connection 660, 1.030"-1/14 RH EXT.

Filling Density(Factor): 1.25 kg/l at test pressure 22 bar.

Toxicological Information:

Toxic by inhalation. May cause inflammation to the respiratory sytem and skin.

Symptoms of Poisoning:

Cough, burns, vomitting, difficulty breathing, haedache, dizzines, lung congestion.

First Aid:

Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information:

Toxic to water organisms. May cause pH changes in aqueous ecological systems.

Exposure Limits:

TLV(ACGIH): 0.5 ppm, LC_{50} / 1h : 293 ppm .

Chlorine Cl_2 **DS015.0**

Physical Data:

Molar Mass, [5] 70.906 g/mol

Triple Point at 13.87 mbar, (28)
-100.98 ^{0}C (= -149.76 ^{0}F)

Enthalpy of Fusion at T_{mp} , [10]
90.44 kJ/kg (= 38.88 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-34.03 ^{0}C (= -29.25 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [10]
288.05 kJ/kg (= 123.83 BTU/lb)

Critical Point:
-Temperature, [5]
143.35 ^{0}C (= 290.03 ^{0}F)
- Pressure, [5] 77 bar (= 1,116.08 psia)
- Density Liquid, [10] 0.573 kg/l

Density Gas:
- ideal 3.1635 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
2.936 g/l (= 0.1833 lb/ft^3)
- at 15 ^{0}C, 1 bar, [10] 3.007 g/l
- at 0 ^{0}C, 1.013 bar, [28] 3.2149 g/l

Density Liquid
- at T_{bp} and 1.013 bar, [10] 1.563 kg/l
- at 25 ^{0}C, [24] 1.398 kg/l

Vapor Pressure (about), [4, 28]

-10	0	10	20	^{0}C
2.75	3.59	4.85	6.776	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -15.8 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -11.8 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [28] 0.088 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar [10] 0.473 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 2.26 l Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C, 1 bar, [28] 13.55 x 10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number:	07782-50-5
EU Number:	231-959-5
EU Classification:	T, Xi, N
EU Symbols:	T, N
Index Number:	017-001-00-7

UN Number:	1017 CHLORINE
Class/Div:	2.3
ADR/RID: Class 2, Number	2TC
ADR/RID Hazard Number:	268
Labeling ADR/DOT:	2.3+8

EU Classification:
Risk Phrases:

R23: Toxic by inhalation.
R36/37/38: Irritating to eyes, respiratory sytem and skin.
R50: Very toxic to aquatic organisms.

Safety Phrases:

S9: Keep container in a well-ventilated places.
S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).
S61: Avoid release to the environment. Refer to special instructions / MSDS.

H.Schön: Handbook of Purified Gases

Data Sheet DS064.0 **Date: 08-01-30**

Name: Chlorine Trifluoride Chemical Formula: ClF_3

Synonyms: Chlorotrifluoride, CTF

Properties: Low pressure liquefied gas, non flammable, corrosive, very toxic, colorless, pungent odour, reacts extremely violently with water or organic compounds, is the most reactive interhalogene compound.

Production and Purification:
Manufactured from the elements at about 227 - 327 ^{0}C, purified by reaction with KF.
Widespread Applications:
Propellant for rockets and missiles, used for fluorinating and/or oxidising.
Important Impurities: Cl- and S-compounds .
Disposal: Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.

Detection of XChlorine Trifluoride: IR-Spectrometry.
Suitable Materials: monel, PTFE, PCTFE, PVDF.
Valve Thread: *Europe:* Not standardized.
Germany : No.8, 1" RH.
USA: CGA connection 67, 1.030"-1/14 LH EXT.
Filling Density(Factor): 1.13 kg/l at test pressure1 19 bar.

Toxicological Information: Delayed fatal pulmonary oedema possible. Severe corrosion to skin, eyes and respiratory tract at high concentrations. May cause inflammation of the respiratory system and skin.
Symptoms of Poisoning: Very toxic by inhalation. Burns, tearing, nausea, difficulty breathing, headache, dizziness, loss of coorination.
First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.
Environmental Information:
May cause pH changes in aqueous ecological systems.
Exposure Limits:
TLV(ACGIH): 0.1 ppm, LC50 / 1h : 299 ppm .

Chlorine Trifluoride **ClF$_3$** **DS064.0**

Physical Data:

Molar Mass, [11] 92.448 g/mol

Melting Point T$_{mp}$ at 1.013 bar, [24]
-83 ^{0}C (= -117.4 ^{0}F)

Enthalpy of Fusion at T$_{mp}$,

Boiling Point T$_{bp}$ at 1.013 bar, [11]
11.75 ^{0}C (= 53.15 ^{0}F)

Enthalpy of Vaporisation at T$_{bp}$, [24]
300.93 kJ/kg (= 129.4 BTU/lb)

Critical Point,: -Temperature,
[11] 153.7 ^{0}C (= 308.66 ^{0}F)
[24] 186.24 ^{0}C (= 367.23 ^{0}F)

- Pressure,
[11] 58.00 bar (= 841.23 psia)
[24] 77.79 bar (=1128.25 psia)

- Density Liquid, [11] 0.548 kg/l
[24] 0.6872 kg/l

Density Gas: ideal 4.1246 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1,013 bar,
[24] 3.829 g/l (= 0.2390 lb/ft^3)
- at 15 ^{0}C and 1 bar, [3] 3.97 g/l
- at 0 ^{0}C and 1.013 bar --- g/l

Density Liquid
- at T$_{bp}$ and 1.013 bar, [3] 1.8502 kg/l
- at 20 ^{0}C, [12] 1.825 kg/l

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
0.22	0.61	0.96	1.43	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -34 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -24 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C,1.013 bar, [24] 0.1386 mW/(cm K)

Heat Capacity at 25 ^{0}C and 1.013 bar, [3] 0.7037 kJ/(kg K)

Solubility in Water at 20 ^{0}C and 1.013 bar Hydrolysis

Dynamic Viscosity at 25 ^{0}C and 1 bar, [3] 22.3 x 10^{-6} Ns/m^2

Heating Value MJ/kmol

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi ,
1 g/l = 0.0624 lb/ft3

Identification and Classification:

CAS Number: 07790-91-2
EU Number: 232-230-4
EU Classification: O, T, C
EU Symbols: O, T, C
Index Number: ---

UN Number: 1749
CHLORINE TRIFLUORIDE
Class/Div: 2.3
ADR/RID: Class 2, Number 2 TOC
ADR/RID Hazard Number: 265
Labeling ADR/DOT: 2.3, 5.1, 8

EU Classification:

Risk Phrases:

R8: Contact with combustible mateial may cause fire.
R23: Toxic by inhalation.
R34: Causes burns.

Safety Phrases:

S9: Keep container in a well-ventilated place.
S17: Keep away from combustible material

Safety Phrases:

S26: In case of contact with eyes, rinse immediatediately with plenty of water and seek medical advice.
S36/37/39: Wear suitable protective clothing, gloves and eye/face protection.
S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible)

H.Schön: Handbook of Purified Gases

Data Sheet DS016.0 **Date: 07-06-13**

Name:Chlorodifluoromethane Chemical Formula: $CHClF_2$

Synonyms: Difluoromonochloromethane, R22

Properties:
Low pressure liquefied gas, non flammable, colorless, ether-like odour, non-toxic, thermically and chemically very stable. Thermal decomposition mays produce CO, $COCl_2$, COF_2, HF and HCl.

Production and Purification:
Manufactured by reacting trichloromethane with HF in the presence of a catalyst, byproducts R21 and R23. Rectification.

Widespread Applications:
Production of PTFE (Teflon). Subject to restrictions by EC Regulations 3093/94 and 2037/20000, no longer important as a refrigerant.

Important Impurities: Other HC´s and CFC´s.

Disposal:
Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.

Detection of R22: Halogen leak detector, gas test tube, IR-spectrometry.

Suitable Materials: All known.

Valve Thread: *Europe:* Not standardized.
Germany: No.6, W21,8x1/14" RH.
USA: CGA connection 660, 1.030"-1/14 RH EXT.

Filling Density(Factor): 1.03 kg/l at test pressure 29 bar.

Toxicological Information:
May produce irregular heart beat and nervous symptoms.

Symptoms of Poisoning:
In high concentration may cause asphyxiation. Symptoms may include loss of mobility/consiousness. Victim may not aware of asphyxiation.
In low concentration may cause narcotic effects . Symptoms may include dizziness, headache, nausea and loss of co-ordination.

First Aid: Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.

Environmental Information: May have damaging effect on ozone layer. Covered by the "Montreal Protocol".

E*xposure Limits:*
TLV(ACGIH): --- ppm, LC_{50} / 1h : ppm .

Chlorodifluoromethane $CHClF_2$ DS016.0

Physical Data:

Molar Mass, [5] 86.468 g/mol

Melting Point T_{mp} at 1.013 bar, [5]
-157.42 ^{0}C (= -251.36 ^{0}F)

Enthalpy of Fusion at T_{mp}, [24]
47.68 kJ/kg (= 20.5 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
- 41.01 ^{0}C (= - 41.82 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [10]
234.32 kJ/kg (= 100.74 BTU/lb)

Critical Point:

-Temperature, [5]
96.13 ^{0}C (= 205.03 ^{0}F)

- Pressure,[5]
49.86 bar (= 723.17 psia)

- Density Liquid, [10] 0.525 kg/l

Density Gas:

- ideal 3.8578 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
3.581 g/l (= 0.2236 lb/ft^3)
- at 15 ^{0}C, 1 bar, [10] 3.67 g/l
- at 0 ^{0}C, 1.013 bar, [3] 3.9358 g/l

Density Liquid, [10]

- at T_{bp} and 1.013 bar 1.413 kg/l
- at 20 ^{0}C 1.211 kg/l

Vapor Pressure (about), [4, 10]

-10	0	10	20	^{0}C
3.80	4.99	6.85	9.22	bar

2.Pressure Virial Coefficient, [11]

- at 0 ^{0}C: -19.1 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -13.7 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.104 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar [10] 0.657 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 0.775 l Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar, [3] 12.82 x 10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number: 00075-45-6
EU Number: 200-871-9
EU Classification: N
EU Symbols: N
Index Number:

UN Number: 1018
CHLORODIFLUOROMETHANE
Class/Div: 2.2
ADR/RID: Class 2, Number 2A
ADR/RID Hazard Number: 20
Labeling ADR/DOT: 2.2

EU Classification:

Risk Phrases:

R59: Dangerous for the ozon layer.

Safety Phrases:

S59: Refer to manufacturer / supplier for information on recovery / recycling.

H.Schön: Handbook of Purified Gases

Data Sheet DS086.0 **Date: 07-06-08**

Name:Chloropentafluoroethane Chemical Formula: C_2ClF_5

Synonyms: 1-Chloro-1,1,2,2,2-pentafluoroethane, R115, **$ClF_2C\text{-}CF_3$**
Pentafluorochlorethane, Pentafluoroethyl chloride

Properties: Low pressure liquefied gas, non flammable, colorless, ether-like odour, chemically very stable. Thermal decomposition mays produce CO, $COCl_2$, COF_2, HF and HCl.

Production and Purification:
Manufactured by fluorination of chloroethane. Rectification.
Widespread Applications:
Aerosol propellant gas, low-temperature refrigerant, but is not subject to stringent limitations by the CFC-prohibition regulation.
Important Impurities: Other HC´s and CFC´s.
Disposal:
Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.
Detection of R115: IR-spectrometry, halogen leak detector.

Suitable Materials: All known.
Valve Thread: *Europe:* Not standardized.
Germany: No.6, W21,8x1/14" RH.
USA: CGA connection 660, 1.030"-1/14 RH EXT.
Filling Density(Factor): 1.06 kg/l at test pressure 25 bar.

Toxicological Information:
May produce irregular heart beat and nervous symptoms.
Symptoms of Poisoning:
In high concentration may cause asphyxiation. Symptoms may include loss of mobility/consiousness. Victim may not aware of asphyxiation.
In low concentration may cause narcotic effects . Symptoms may include dizziness, headache, nausea and loss of co-ordination.
First Aid: Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.
Environmental Information:
May have damaging effect on ozone layer. Covered by the "Montreal Protocol".
Exposure Limits:
TLV(ACGIH): 1000 ppm, LC_{50} / 1h : ppm .

Chloropentafluoroethane C_2ClF_5 DS086.0

Physical Data:

Molar Mass, [5] 154.467 g/mol

Melting Point T_{mp} at 1.013 bar, [5]
-99.42 ^{0}C (= -146.96 ^{0}F)

Enthalpy of Fusion at T_{mp}, [24]
12.16 kJ/kg (= 5.23 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-39.07 ^{0}C (= -38.33 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [24]
125.14 kJ/kg (= 53.81 BTU/lb)

Critical Point:
-Temperature, [5]
79.95 ^{0}C (= 175.91 ^{0}F)
- Pressure, [5]
31.29 bar (= 453.83 psia)
- Density Liquid, [14] 0.596 kg/l

Density Gas:
- ideal 6.8916 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
6.397 g/l (= 0.3994 lb/ft^3)
- at 15 ^{0}C, 1 bar, [10] 6.598 g/l
- at 0 ^{0}C, 1.013 bar, [11] 7.0523 g/l

Density Liquid
- at T_{bp} and 1.013 bar, [10] 1.544 kg/l
- at 25 ^{0}C, [24] 1.287 kg/l

Vapor Pressure (about), [14]

-10	0	10	20	^{0}C
3.1	4.4	6.0	7.8	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -22.1 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -15.58 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.118 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar, [10] 0.71 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 0.0087 l Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C,1 bar, [28] 12.76 x 10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number:	00076-15-3
EU Number:	200-938-2
EU Classification:	N
EU Symbols:	N
Index Number:	

UN Number: 1020 CHLORO-PENTAFLUOROETHANE

Class/Div:	2
ADR/RID: Class 2, Number	2A
ADR/RID Hazard Number:	20
Labeling ADR/DOT:	2.2

EU Classification:
Risk Phrases:

Safety Phrases:
S59: Refer to manufacturer / supplier for information on recovery / recycling.

H.Schön: Handbook of Purified Gases

Data Sheet DS114.0 **Date: 08-06-07**

Name: 1-Chloro-1,1,2,2-tetrafluoroethane Chem. Formula C_2HClF_4

Synonym: R124a, Tetrafluoroethane,

Isomer: 2-Chloro-1,1,1,2-tetrafluoroethane (R124)

*Properties:*Low pressure liquefied gas, non flammable, colorless, ether-like odour, nontoxic, thermically and chemically very stable. Thermal decomposition mays produce CO, COCl2, COF2, HF and HCl.

Production and Purification:
Fluorination and following chlorination of HC´s

Widespread Applications:
Used in refrigerant mixtures and as aeroaol propellant gas.

Important Impurities:
Air, HC´s, FHC´s

Disposal:
Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.

Detection of R124a: Halogen leak detector, gas test tube, IR-spectrometry.

Suitable Materials: All known.

Valve Thread: *Europe:* Not standardized.
Germany (DIN 477): No.6, W21,8x1/14" RH.
USA: CGA connection 660, 1.030"-1/14 RH EXT.

Filling Density(Factor): 1.20 kg/l at test pressure 12 bar

Toxicological Information:
No known toxicological effects fom this product.

Symptoms of Poisoning:
In high concentration may cause asphyxiation. Symptoms may include loss of mobility/consiousness. Victim may not aware of asphyxiation.
In low concentration may cause narcotic effects . Symptoms may include dizziness, headache, nausea and loss of coordination.

First Aid: Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.

Environmental Information: May have damaging effect on ozone layer. Covered by the "Montreal Protocol".

Exposure Limits:
TLV(ACGIH): ppm, LC_{50} / 1h : ppm

1-Chloro-1,1,2,2-tetrafluoroethane(R124a) C_2HClF_4 DS114.0

Physical Data:

Molar Mass, [5] 136.476 g/mol

Melting Point T_{mp} at 1.013 bar, [5]
-117 ^{0}C (=-178.6 ^{0}F)

Enthalpy of Fusion at T_{mp}
kJ/kg (= BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-11.77 ^{0}C (= -10.81 ^{0}F)

Enthalpy of Vaporisation at T_{bp}
kJ/kg (= BTU/lb)

Critical Point:

-Temperature, [5]
126.85^{0}C (= 260.33 ^{0}F)

- Pressure, [5]
37.6 bar (= 545.35 psia)

- Density Liquid kg/l

Density Gas: ideal 6.08893 g/l

- at 70 ^{0}F (= 21.1 ^{0}C) and 1,013 bar
g/l (= lb/ft^3)

- at 15 ^{0}C and 1 bar, [28] 5.877 g/l

- at 0 ^{0}C and 1.013 bar g/l

Density Liquid at 30 ^{o}C, [4 1.38 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about)

-10	0	10	20	^{0}C
				bar

2.Pressure Virial Coefficient, [28]

- at 0 ^{0}C: -3.65 x 10^{-2} bar^{-1}
- at 30 ^{0}C: -2.53 x 10^{-2} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar mW/(cm K)

Heat Capacity at 25 ^{0}C,1.013 bar, [28] 0.7658 kJ/(kg K)

Solubility in Water at 20 ^{0}C and 1.013 bar, [25] 1.49ggas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar x 10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number:	2837-89-0
EU Number:	220-629-6
EU Classification:	N
EU Symbols:	N
Index Number:	

UN Number: 1021
1-CHLORO-1,1,2,2-TETRAFLUORETHANE
(REFRIGERANTGAS R124a)

Class/Div:	2.2
ADR/RID:	Class 2, Number 2A
ADR/RID Hazard Number:	
Labeling ADR/DOT:	2.2

EU Classification:

Risk Phrases:

R59: Dangerous for the ozone layer.

Safety Phrases:

S59: Refer to manufacture/supplier for information on recovery/ recycling.

H.Schön: Handbook of Purified Gases

Data Sheet DS115.0 **Date: 08-02-11**

Name: 2-Chloro-1,1,1,2-tetrafluoroethane Chem. Formula:

Synonyms: R124, Chlorotetrafluoroethane **C_2HClF_4**

Isomer :1-Chloro-1,1,2,2-tetrafluoroethane (R124a)

*Properties:*Low pressure liquefied gas, non flammable, colorless, ether-like odour, non- toxic, thermically and chemically very stable. Thermal decomposition mays produce CO, $COCl_2$, COF_2, HF and HCl.

Production and Purification:
Fluorination and following chlorination of HC´s
Widespread Applications:
Used in refrigerant mixtures and as aeroaol propellant gas.
Important Impurities: Air, HC´s, FHC´s
Disposal: Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.
Detection of R124: Halogen leak detector, gas test tube, IR-spectrometry.

Suitable Materials: All known.
Valve Thread: *Europe:* Not standardized.
Germany (DIN 477): No.6, W21,8x1/14" RH.
USA: CGA connection 660, 1.030"-1/14 RH EXT.
Filling Density(Factor): 1,20 kg/l at test pressure 12 bar

Toxicological Information:
No known toxicological effects fom this product.
Symptoms of Poisoning:
In high concentration may cause asphyxiation. Symptoms may include loss of mobility/consiousness. Victim may not aware of asphyxiation.
In low concentration may cause narcotic effects . Symptoms may include dizziness, headache, nausea and loss of co-ordination.
First Aid: Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.
Environmental Information: May have damaging effect on ozone layer. Covered by the "Montreal Protocol".
Exposure Limits:
TLV(ACGIH): ppm, LC50 / 1h : ppm

2-Chloro-1,1,1,2,2-tetrafluoroethane(R124) C_2HClF_4 DS115.0

Physical Data:

Molar Mass, [5] 136.476 g/mol

Melting Point T_{mp} at 1.013 bar, [5]
-117 ^{0}C (= -178.6 ^{0}F)

Enthalpy of Fusion at T_{mp}
kJ/kg (= BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-11.96^{0}C (= + 10.47 ^{0}F)

Enthalpy of Vaporisation at T_{bp}
kJ/kg (= BTU/lb)

Critical Point:

-Temperature, [5]
122.45^{0}C (= 252.41 ^{0}F)

- Pressure, [5]
36.24 bar (=527.08 psia)

- Density Liquid kg/l

Density Gas: ideal 6.08893 g/l

- at 70 ^{0}F (= 21.1 ^{0}C) and 1,013 bar
g/l (= lb/ft^3)

- at 15 ^{0}C and 1 bar g/l

- at 0 ^{0}C and 1.013 bar,[28] 5,335 g/l

Density Liquid at 30 ^{o}C,[4] 1.35 kg/l

Vapor Pressure (about)

-10	0	10	20	^{0}C
				bar

2.Pressure Virial Coefficient

- at 0 ^{0}C: x 10^{-3} bar^{-1}

- at 30 ^{0}C: x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar mW/(cm K)

Heat Capacity at 25 ^{0}C and 1.013 bar kJ/(kg K)

Solubility in Water at 20 ^{0}C and 1.013 bar,[25] 1.49g gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar x 10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi ,
1g/l = 0.0624 lb/ft3

Identification and Classification:

CAS Number: 2837-89-0
EU Number: 220-629-6
EU Classification: N
EU Symbols: N
Index Number:

UN Number: 1021
2-CHLORO-1,1,1,2-TETRAFLUOROETHANE
(REFRIDERAND GAS R124)
Class/Div: 2.2
ADR/RID: Class 2, Number 2A
ADR/RID Hazard Number:
Labeling ADR/DOT: 2..2

EU Classification:
Risk Phrases:
R59: Dangerous for the ozone layer.

Safety Phrases:
S59: Refer to manufacture/supplier for information on recovery/ recycling.

H.Schön: Handbook of Purified Gases

Data Sheet DS098.0 **Date: 07-06-09**

Name: Chlorotrifluoroethane Chemical Formula: $C_2H_2ClF_3$

Synonyms: 1-Chloro-2,2,2-trifluoroethane, R133a, **$H_2ClC\text{-}CF_3$**
2-Chloro-1,1,1-trifluoroethane

Properties: Low pressure liquefied gas, non flammable, colorless, ether-like odour, chemically very stable. Thermal decomposition mays produce CO, $COCl_2$, COF_2, HF and HCl.

Production and Purification:
Pilot plant manufacture only.

Widespread Applications:
Subject to restrictions by EC Regulation 3093/94, no longer importance as a refrigerant.

Important Impurities: Other HC´s and CFC´s.

Disposal:
Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.

Detection of R133a: Halogen leak detector, gas test tube.

Suitable Materials: All known.
Valve Thread: *Europe:* Not standardized.
Germany: No.6, W21,8x1/14" RH.
USA: CGA connection 660, 1.030"-1/14 RH EXT.
Filling Density(Factor): 1.18 kg/l at test pressure 10 bar.

Toxicological Information:
No known toxicological effects from this product.

Symptoms of Poisoning:
In high concentration may cause asphyxiation. Symptoms may include loss of mobility/consiousness. Victim may not aware of asphyxiation.
In low concentration may cause narcotic effects . Symptoms may include dizziness, headache, nausea and loss of coordination.

First Aid: Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.

Environmental Information: May have damaging effect on ozone layer. Covered by the "Montreal Protocol".

Exposure Limits:
TLV(ACGIH): --- ppm, LC_{50} / 1h : ppm .

Chlorotrifluoroethane $C_2H_2ClF_3$ DS098.0

Physical Data:

Molar Mass, [12] 118.48 g/mol
Melting Point T_{mp} at 1.013 bar, [3]
-105.45 ^{0}C (= -157.81 ^{0}F)
Enthalpy of Fusion at T_{mp}
kJ/kg (= BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [12]
6.93 ^{0}C (= 44.47 ^{0}F)
Enthalpy of Vaporisation at T_{bp} , [3]
206 kJ/kg (= 88.56 BTU/lb)
Critical Point:
-Temperature, [6] 150 ^{0}C (= 302 ^{0}F)
- Pressure bar (= psia)
- Density Liquid kg/l
Density Gas:
- ideal 5.2863 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1,013 bar
g/l (= lb/ft^3)
- at 15 ^{0}C and 1 bar g/l
- at 0 ^{0}C and 1.013 bar --- g/l
Density Liquid at T_{bp} ,1.013 bar, [2]
1.39 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [12, 25]

-10	0	10	20	^{0}C
0.6	0.9	1.3	1.559	bar

2.Pressure Virial Coefficient
- at 0 ^{0}C: $\times 10^{-3}$ bar^{-1}
- at 30 ^{0}C: $\times 10^{-3}$ bar^{-1}
Thermal Conductivity at 15 ^{0}C and 1.013 bar, [3] 0.9 mW/(cm K)
Heat Capacity at 25 ^{0}C, 1.013 bar [3] 0.7528 kJ/(kg K)
Solubility in Water at 20 ^{0}C and 1.013 bar l Gas / kg H_2O
Dynamic Viscosity at 25 ^{0}C and 1 bar $\times 10^{-6}$ Ns/m^2

Suitable Extinguishing Media:
All known.

Identification and Classification:

CAS Number:	00075-88-7
EU Number:	200-912-0
EU Classification:	N
EU Symbols:	N
Index Number:	

UN Number: 1983 1-CHLORO-2,2,2- TRIFLUOROETHANE

Class/Div:	2.2
ADR/RID: Class 2, Number	2A
ADR/RID Hazard Number:	20
Labeling ADR/DOT:	2.2

EU Classification:

Risk Phrases:

R59: Dangerous for the environment.

Safety Phrases:

S59: Refer to manufacturer / supplier for information on recovery / recycling.

H.Schön: Handbook of Purified Gases

Data Sheet DS020.0 **Date: 07-06-14**

Name:Chlorotrifluoromethane Chemical Formula: $CClF_3$

Synonyms: Trifluorochloromethane, R13

Properties:
High pressure liquefied gas, non flammable, colorless, ether-like odour, thermically and chemically very stable. Thermal decomposition mays produce CO, $COCl_2$, COF_2, HF and HCl.

Production and Purification:
Manufactured by catalytic fluorination of Trichlorosilane with HF, Destillation.

Widespread Applications:
Low temperature refrigerant. Subject to restrictions by EC Regulation 3093/94, no longer importance as a refrigerant.

Important Impurities: Other HC´s and CFC´s.

Disposal:
Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.

Detection of R13: Halogen leak detector, gas test tube, IR-spectrometry.

Suitable Materials: All known.

Valve Thread: *Europe:* Not standardized.
Germany: No.6, W21,8x1/14" RH.
USA: CGA connection 660, 1.030"-1/14 RH EXT.

Filling Density(Factor): 1.10 kg/l at test pressure 250 bar.

Toxicological Information:
No known toxicological effects from this product.

Symptoms of Poisoning:
In high concentration may cause asphyxiation. Symptoms may include loss of mobility/consiousness. Victim may not aware of asphyxiation.
In low concentration may cause narcotic effects . Symptoms may include dizziness, headache, nausea and loss of coordination.

First Aid: Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.

Environmental Information: May have damaging effect on ozone layer. Covered by the "Montreal Protocol".

Exposure Limits:
TLV(ACGIH): --- ppm, LC50 / 1h : ppm .

Chlorotrifluoromethane $CClF_3$ DS020.0

Physical Data:

Molar Mass, [5] 104.459 g/mol
Melting Point T_{mp} at 1.013 bar, [5]
-181.15 ^{0}C (= -294.07 ^{0}F)
Enthalpy of Fusion at T_{mp}
kJ/kg (= BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [5]
-81.44 ^{0}C (= -11459 ^{0}F)
Enthalpy of Vaporisation at T_{bp}, [10]
150.1 kJ/kg (= 64.53 BTU/lb)
Critical Point:
-Temperature, [5]
28.69 ^{0}C (= 83.64 ^{0}F)
- Pressure,[5] 38.73 bar (= 561.93 psia)
- Density Liquid, [10] 0.581 kg/l
Density Gas:
- ideal 4.6605 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
4.326 g/l (= 0.2701 lb/ft^3)
- at 15 ^{0}C, 1 bar, [10] 4.414 g/l
- at 0 ^{0}C, 1.013 bar, [3] 4.718 g/l
Density Liquid, [10]
- at T_{bp} and 1.013 bar 1.526 kg/l
- at 20 ^{0}C 0.929 kg/l

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
15.5	19.7	25.2	32.4	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -12.1 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -8.6 x 10^{-3} bar^{-1}
Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.123 mW/(cm K)
Heat Capacity at 25 ^{0}C, 1.013 bar [10] 0.641 kJ/(kg K)
Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 0.02 1 Gas / kg H_2O
Dynamic Viscosity at 25 ^{0}C and 1 bar, [3] 14.45 x 10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number: 00075-72-9
EU Number: 200-894-4
EU Classification: N
EU Symbols: N
Index Number:

UN Number: 1022
CHLOROTRIFLUOROMETHANE
Class/Div: 2.2
ADR/RID: Class 2, Number 2A
ADR/RID Hazard Number: 20
Labeling ADR/DOT: 2.2

EU Classification:
Risk Phrases:
R59: Dangerous for the ozon layer.

Safety Phrases:
S59: Refer to manufacturer / supplier for information on recovery / recycling.

H.Schön: Handbook of Purified Gases

Data Sheet DS010.0 **Date: 06-02-10**

Name: cis-2-Butene **Chemical Formula: C_4H_8**

Synonyms: cis-2-Buthylene, cis-But-2-ene, **H_3C-CH=CH-CH_3**
High-boiling Butene-2, (Z)-2-Butene

*Properties:*Low pressure liquefied gas, flammable, colorless, with an aromatic odor, unsaturated hydrocarbon. It is very soluble in alcohol and ether. One of the four isomers of the butenes.

Production and Purification:
The butenes are obtained from the cracking gases of the petroleum industry or by the catalytic dehydrogenetion of butanes. Rectification.
Widespread Applications:
Butenes are used to manufacture of a variety of organic compounds. Polmerisation to high-octane gasolines, plastics and synthetic rubber.

Important Impurities:		Other HCs.
Disposal:		Combustion.
Detection of cis-2Butene:		Detector for flammable gases. Gas test tube.
Suitable Materials:		All known .
Valve Thread:	*Europe:*	Not standardized. Germany : No.1, W21,8x1/14" LH.
	USA:	CGA connection 510, .885"-1/14 LH INT.
Filling Density(Factor):		0.55 kg/l at test pressure 10 bar.

Toxicological Information:
No known acute toxicological effects from this product.
Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of coordination. In high concentration may cause asphyxiation.
First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH): ---, LC50 / 1h : ---

cis-2-Butene C_4H_8 DS010.0

Physical Data:
Molar Mass, [5] 56.108 g/mol
Triple Point at 0.0011 mbar, [10]
-138.90 ^{0}C (= -218.02 ^{0}F)
Enthalpy of Fusion, [10]
130.3 kJ/kg (= 56.02 BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [10]
3.72 ^{0}C (= 38.7 ^{0}F)
Enthalpy of Vaporisation at $T_{bp,}$ [10]
416.4 kJ/kg (= 179.02 BTU/lb)
Critical Point:
-Temperature, [5]
162.37 ^{0}C (= 324.27 ^{0}F)
- Pressure, [5]]
42.10 bar (= 610.62 psia)
- Density Liquid, [10] 0.239 kg/l
Density Gas:
- ideal 2.5033 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1.013 bar ,
[24] 2.324 g/l (=0.1451 lb/ft^3)
- at 15 ^{0}C and 1 bar, [10] 2.424 g/l
- at 0 ^{0}C and 1.013 bar --- g/l
Density Liquid, [10]
- at T_{bp} and 1.013 bar 0.641 kg/l
- at 20 ^{0}C 0.620 kg/l

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
0.65	0.88	1.27	1.81	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -36×10^{-3} bar^{-1}
- at 30 ^{0}C: -25×10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and
1.013 bar, [10] 0.140 mW/(cm K)
Heat Capacity at 25 ^{0}C and
1.013 bar, [10] 1.58 kJ/(kg K)
Solubility in Water at 20 ^{0}C and
1.013 bar, [10]
0.158 l Gas / kg H_2O
Dynamic Viscosity at 25 ^{0}C and 1
bar, [24] 7.822×10^{-6} Ns/m^2
Explosion Limits in Air, [13]
1.6-10 Vol.-%
Autoignition Temperature, [13]
325 ^{0}C (= 617 ^{0}F)
Heating Value, [14]
2,533.9 MJ/kmol
Suitable Extinguishing Media:
All known .
1 bar = 14.504 psi,
1 g/l = 0.0624 lb/ft^3

Identification and Classification:
CAS Number: 00590-18-1
EU Number: 203-452-9
EU Classification: F+
EU Symbols: F+

UN Number: 1012
cis-BUT-2-ENE
Class/Div: 2.1
ADR/RID: Class 2, Number 2F
ADR/RID Hazard Number: 23
Labeling ADR/DOT: 2.1

EU Classification:
Risk Phrases:
R12: Extremely flammable.

Safety Phrases:
S9: Keep container in a well ventilated places.
S16: Keep away from sources of ignition - No smoking.
S33: Take precautionary measures against static discharges.

H.Schön: Handbook of Purified Gases

Data Sheet DS087.0 **Date: 07-02-15**

Name: Cyanogen **Chemical Formula:$(CN)_2$**

Synonyms: Dicyanogen, Ethane dinitrile, Prussite, Oxalnitrile **$(NC\text{-}CN)_2$**

Properties:
Low pressure liquefied gas, flammable, colorless, toxic, almond-like odor. In water it is slowly hydrolysed to ammonia, oxalic acid, hydrogen cyanide and urea. Soluble in alcohol and ether, polymerisises on heating.

Production and Purification:
Manufactured by dehydrating ammonium oxalate with phophorus pentoxide. Rectification.

Widespread Applications:
Rocket fuel. Used for welding and cutting heat-resistant metals. Used in organic syntheses in addition reactions.

Important Impurities:	HC´s.
Disposal:	Combustion.
Detection of Cyanogen:	IR-Spectrometry.

Suitable Materials:
Steel, stainless steel, monel, inconel,PTFE, PCTFE, PVDF.

Valve Thread:	*Europe:*	Not standardized.
		Germany : No.5, 1" LH.
	USA:	CGA connection 669, 1.030"-1/14 RH EXT.
Filling Density(Factor):		1.23 kg/l at test pressure 10 bar.

Toxicological Information:
May cause irritation to the respiratory tract, damaging to central nervous system, metabolism and gastrointestinal tract.

Symptoms of Poisoning:
Irritation, nausea, vomitting, headache, drowsiness, dizziness, shortness of breath.

First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested, call a doctor. Apply artificial respiration if breathing stopped.

Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.

Environmental Information:
Toxic to water organism. Endangering to drinking water.

E*xposure Limits:*
TLV(ACGIH): 10 ppm, LC_{50} / 1h : 350 ppm

Cyanogen $(CN)_2$ DS087.0

Physical Data:

Molar Mass, [15] 52.035 g/mol

Triple Point at 0.737 bar, [28]
-27.83 ^{0}C (= -18.09 ^{0}F)

Enthalpy of Fusion at T_{mp}, [24]
155.83 kJ/kg (= 67.01 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [12]
-21.12 ^{0}C (= -6.02 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [28]
448 kJ/kg (= 192.60 BTU/lb)

Critical Point:
-Temperature, [14]
126,60 ^{0}C (= 259.88 ^{0}F)
- Pressure, [28]
59.78 bar (= 867.04 psia)
- Density Liquid, [28] 0.2669 kg/l

Density Gas: ideal 2.3216 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1 bar, [28]
2.155 g/l (= 0.1345 lb/ft^3)
- at 15 ^{0}C,1 bar, [15] 2.215 g/l
- at 0 ^{0}C, 1.013 bar, [11] 2.3786 g/l

Density Liquid
- at T_{bp} , 1.013 bar, [28] 0.953 kg/l
- at 25 ^{0}C, [24] 0.866 kg/l

Vapor Pressure (about), [4,14,28]

-10	0	10	20	^{0}C
1.60	2.35	3.45	4.88	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -24 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -15 x 10^{-3} bar^{-1}

Thermal Conductivity at 25 ^{0}C, [24]
0.1282 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar, [28] 1.0935 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [2] 4.5 l Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C, 1 bar, [28] 10.144 x 10^{-6} Ns/m^2

Explosion Limits in Air, [14]
3.9-36.6 Vol.-%

Autoignition Temperature, [2]
850 ^{0}C (= 1562 ^{0}F)

Heating Value, [28] 21.064 MJ/kg

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number: 00460-19-5
EU Number: 207-306-5
EU Classification: F, T, N
EU Symbols: F, T, N
Index-Number: 608-011-00-8

UN Number: 1026
CYANOGEN
Class/Div: 2.3
ADR/RID: Class 2, Number 2TF
ADR/RID Hazard Number: 263
Labeling ADR/DOT: 2.3 + 2.1

EU Classification:

*Risk Phrases:*R11: Highly flammable.
R23: Toxic by inhalation.
R50-53: Very toxic to aquatic organisms, mays cause long-term adverse effect in the aquatic environment.

Safety Phrases:
S23: Do not breathe the gas..
S45: In case of accident or if you feel unwell, seek medical advice immediately.
S60: This material and its container must be disposed as hazardous waste.
S61: Avoid release to the environment. Refer to special instructions / Safety data sheets.

H.Schön: Handbook of Purified Gases

Data Sheet DS097.0 **Date: 07-09-16**

Name: Cyanogen chloride, inhibited **Chem. Formula: CClN**

Synonyms: Chlorocyanogen, Chlorine Cyanide **N ≡C-Cl**

Properties: Low pressure liquefied gas, non flammable, colorless,pungent odour, very toxic. The gas is stable, but in presence of water or catalysts it polymerisize to cyanuric chloride $(CClN)_3$, stabilizer: e.g. sodium pyrophosphate.Thermal decomposition mays produce $COCl_2$ and HCl.

Production and Purification:
Manufactured from hydrogen cyanide and chlorine in an organic solvent or in the gas phase over a catalyst.
Widespread Applications:
Used as an intermediate in chemical syntheses: guanides, nitriles, thiocyanates.
Important Impurities: Air, HC´s.
Disposal:
Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.
Detection of Cyanogen chloride: Gas test tube.

Suitable Materials: Steel, stainless steel, monel, PTFE, PCTFE, PVDF.
Valve Thread: *Europe:* Not standardized.
Germany: No.8, 1" RH.
USA: CGA connection 660, 1.030"-1/14 RH EXT.
Filling Density(Factor): 1.03 kg/l at test pressure 20 bar.

Toxicological Information:
Severe corrosion to skin, eyes and respiratory tract. Damage to red blood cells (haemolytic poison). Damage to central nervous system.
Symptoms of Poisoning:
Very toxic by inhalation. Burns, tearing, nausea, difficulty breathing, headache, dizziness, lung congestion.
First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information:
May cause pH changes in aqueous ecological systems.
Exposure Limits:
TLV(ACGIH): 0.3 ppm, LC_{50} / 1h : 80 ppm .

Cyanogen chloride $CClN$ DS097.0

Physical Data:

Molar Mass,[28] 27,0256 g/mol
, Triple Point at 0.187 bar, [28]
13.25 ^{0}C (= 55.85 ^{0}F)
Enthalpy of Fusion at T_{mp} [24]
311.03 kJ/kg (= 133.74 BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [12]
25.70 ^{0}C (= 78.26 ^{0}F)
Enthalpy of Vaporisation at T_{bp} , [24]
1016.8 kJ/kg (= 437.22 BTU/lb)
Critical Point: [12]
-Temperature 183.50 ^{0}C (= 362.3 ^{0}F)
- Pressure 53.90 bar (= 781.77 psia)
- Density Liquid 0.195 kg/l
Density Gas: ideal g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1,013 bar
g/l (= lb/ft^3)
- at 15 ^{0}C and 1 bar g/l
- at 0 ^{0}C and 1.013 bar g/l
Density Liquid at T_{bp} and 1.013 bar
kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
0.3	0.6	0.9	1.37	bar

2.Pressure Virial Coefficient, [28]
- at 0 ^{0}C: $- 3.5 \times 10^{-3}$ bar^{-1}
- at 30 ^{0}C: -2.3×10^{-3} bar^{-1}
Thermal Conductivity at 15 ^{0}C and 1.013 bar, [24] 0.07mW/(cm K)
Heat Capacity at 25 ^{0}C and 1.013 bar, [24] 0.728 kJ/(kg K)
Solubility in Water at 20 ^{0}C and 1.013 bar, 1 Gas / kg H_2O
Dynamic Viscosity at 25 ^{0}C and 1 bar, [24] 1.65×10^{-6} Ns/m^2
Explosion Limits in Air, [24]
Upper limit 23.5 Vol.-%
Autoignition Temperature
^{0}C (= ^{0}F)
Heating Value, [24] 8.638 MJ/kmol
Suitable Extinguishing Media:
All known.

Identification and Classification:

CAS Number: 00506-77-4
EU Number: 208-052-8
EU Classification: T+, C
EU Symbols: T+, C
Index Number:

UN Number: 1589
CYANOGEN CHLORIDE, stabilized Class/Div: 2.3
ADR/RID: Class 2, Number 2TC
ADR/RID Hazard Number:
Labeling ADR/DOT: 2.3+8

EU Classification:
Risk Phrases:
R26: Very toxic by inhalation.
R35: Cause severe burns
Safety Phrases:
S1: Keep locked up.
S9: Keep container in a well-ventilated place.
S26: In case of contact with eyes, rinse immediatetely with plenty of water and seek medical advice.
S36/37/39: Wear suitable protective clothing, gloves and eye/face protection.
S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible)

H.Schön: Handbook of Purified Gases

Data Sheet DS113.0 **Date: 06-07-25**

Name: Cyclobutane Chemical Formula: C_4H_8

Synonyms: Tetramethylene **$(CH_2)_4$**

Properties:
Low pressure liquefied gas, flammable, colorless, sweetish odor, non-toxic,

Production and Purification:
Manufactored by hydrogenating Cyclobutene over a nickel catalyst.
Widespread Applications:
Used as a solvent and occurs as an intermediate in chemical synthesis.
Physicochemical studies of the four-membered ring.

Important Impurities:		Other HCs.
Disposal:		Combustion .
Detection of Cyclopropane:		Detector for flammable gases, Gas test tube.
Suitable Materials:		All known.
Valve Thread:	*Europe:*	Not standardized. Germany: No.1, W21,8x1/14" LH.
	USA:	CGA connection 510, 0.885"-1/14 LH INT.
Filling Density(Factor):		0.63 kg/l at test pressure 10 bar.

Toxicological Information:
No known acute toxicological effects from this product.
Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of coordination. In high concentration may cause asphyxiation.
First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH): --- ppm , LC50 / 1h : ---

Cyclobutane C_4H_8 DS113.0

Physical Data:

Molar Mass, [5] 56.108 g/mol

Melting Point T_{mp} at 1.013 bar, [5]
-90.73 ^{0}C (= -131.31 ^{0}F)

Enthalpy of Fusion at T_{mp}, [24]
19.39 kJ/kg (= 8.34 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
12.49 ^{0}C (= 54.48 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [28]
431.31 kJ/kg (= 185.42 BTU/lb)

Critical Point:

-Temperature, [5]
186.85 ^{0}C (= 368.33 ^{0}F)

- Pressure, [5]
49.90 bar (= 723.75 psia)

- Density Liquid, [12] 0.267 kg/l

Density Gas:

- ideal 2.5033 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1.013 bar,
[24] 2.324 g/l (= 0.1451 lb/ft^{3})
- at 15 ^{0}C and 1 bar g/l
- at 0 ^{0}C and 1.013 bar g/l

Density Liquid at 25 ^{0}C, [24]
0.689 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^{3}

Vapor Pressure (about), [25]

-10	0	10	20	^{0}C
			1.3	bar

2.Pressure Virial Coefficient, [15]
- at 0 ^{0}C: -36.2 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -25.9 x 10^{-3} bar^{-1}

Thermal Conductivity at 25 ^{0}C and 1 bar, [24] 0.144 mW/(cm K)

Heat Capacity at 25 ^{0}C and 1.013 bar, [28] 1.2872 kJ/(kg K)

Solubility in Water at 20 ^{0}C and 1.013 bar 1 Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar, [24] 8.531 x 10^{-6} Ns/m^{2}

Explosion Limits in Air,
[24] 1.8-11.1 Vol.-%
[22] 1.8 - 10 Vol.-%

Autoignition Temperature, [24]
426.7 ^{0}C (= 800 ^{0}F)

Heating Value, [24]
47.766 MJ/kmol

Suitable Extinguishing Media:
All known.

Identification and Classification:

CAS Number: 00287-23-0
EU Number: 206-014-5
EU Classification: F+
EU Symbols: F+

UN Number: 2601
CYCLOBUTANE
Class/Div: 2.1
ADR/RID: Class 2, Number 2F
ADR/RID Hazard Number: 23
Labeling ADR/DOT: 2.1

EU Classification:
Risk Phrases:
R12: Extremely flammable.

Safety Phrases:
S9: Keep container in a well ventilated place.
S16: Keep away from sources of ignition - No smoking.
S33: Take precautionary measures against static discharges.

H.Schön: Handbook of Purified Gases

Data Sheet DS014.0 **Date: 06-07-24**

Name: Cyclopropane Chemical Formula: C_3H_6

Synonyms: Trimethylene **$(CH_2)_3$**

Properties:
Low pressure liquefied gas, flammable, colorless, characteristic odor resembling petroleum ether. Soluble in water and in organic solvents.

Production and Purification:
Manufactered by cyclising 1,3-dihalopropanes with metals.

Widespread Applications:
Anesthetic gas. Its derivates used as pharmaceuticals and herbicides.

Important Impurities: Other HCs.
Disposal: Combustion .
Detection of Cyclopropane: Detector for flammable gases, Gas test tube.

Suitable Materials: All known.
Valve Thread: *Europe:* Not standardized.
Germany: No.1, W21,8x1/14" LH.
USA: CGA connection 510, 0.885"-1/14 LH INT.

Filling Density(Factor): 0.53 kg/l at test pressure 10 bar.

Toxicological Information:
No known acute toxicological effects from this product.
Symptoms of Poisoning:
In low concentration may cause narcotic effects (inhalation anestheticum). In high concentration may cause asphyxiation.
First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH): --- ppm , LC50 / 1h : ---

Cyclopropane C_3H_6 DS014.0

Physical Data:

Molar Mass, [5] 42.081 g/mol

Melting Point T_{mp} at 1.013 bar, [5,10]
-127.42 ^{0}C (= -197.36 ^{0}F)

Enthalpy of Fusion at T_{mp}, [10]
129.4 kJ/kg (= 55.63 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-32.81 ^{0}C (= -27.06 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [10]
477.3 kJ/kg (= 205.19 BTU/lb)

Critical Point:

-Temperature, [5]
125.15 ^{0}C (= 257.27 ^{0}F)

- Pressure, [5]
55.75 bar (= 808.60 psia)

- Density Liquid, [12] 0.259 kg/l

Density Gas:

- ideal 1.8775 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1.013 bar, [24]
1.743 g/l (= 01068 lb/ft^3)
- at 15 ^{0}C,1 bar, [10] 1.785 g/l
- at 0 ^{0}C,1.013 bar, [11] 1.919 g/l

Density Liquid

- at T_{bp} , 1.013 bar, [10] 0.680 kg/l
- at 20 ^{0}C, [12] 0.610 kg/l

Vapor Pressure (about), [12]

-10	0	10	20	^{0}C
2.5	3.5	4.7	6.4	bar

2.Pressure Virial Coefficient, [11]

- at 0 ^{0}C: -21.1 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -15 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1 bar, [10] 0.139 mW/(cm K)

Heat Capacity at 25 ^{0}C and 1.013 bar, [10] 1.33 kJ/(kg K)

Solubility in Water at 20 ^{0}C and 1.013 bar, [10]
0.999 l Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar, [24] 8.923 x 10^{-6} Ns/m^2

Explosion Limits in Air, [13]
2.4-10.4 Vol.-%

Autoignition Temperature, [13]
495 ^{0}C (= 923 ^{0}F)

Heating Value, [24]
46.56 MJ/kg

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi,
1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number:	00075-19-4
EU Number:	200-847-8
EU Classification:	F+
EU Symbols:	F+
UN Number:	1027 CYCLOPROPANE
Class/Div:	2.1
ADR/RID: Class 2, Number	2F
ADR/RID Hazard Number:	23
Labeling ADR/DOT:	2.1

EU Classification:

Risk Phrases:

R12: Extremely flammable.

Safety Phrases:

S9: Keep container in a well ventilated place.

S16: Keep away from sources of ignition - No smoking.

S33: Take precautionary measures against static discharges.

H.Schön: Handbook of Purified Gases

Data Sheet DS076.0 **Date: 08-02-07**

Name: Deuterium **Chemical Formula: D_2**

Synonyms: Heavy hydrogen, Diplogen, Hydrogen-D2 ${}^{2}_{1}H_2$

*Properties:*Non-liquefied, compressed gas, The second stable hydrogen isotop is present to the xtend of 0.15% in ordinary hydrogen.has different physical properties because the mass is about twice of normal H_2 , chemical poperties ae largely identical: flammable, colorless, odorles, non-toxic, with air or O_2 forms the detonating gas.

Production and Purification:
Obtained from heavy water (D_2O) , electrolxsis, rectification
Widespread Applications:
Used in UV-lamps and as raw material (fuel) in nuclear fusion. Fully deuterated compounds used as solvent in NMR spectroscopy.
Important Impurities:
Air, H2, HD, HC´s .
Disposal: Combustion .
Detection of Deuterium: Detector for flammable gases, gas test tube.
Suitable Materials: All known.
Valve Thread: *Europe:* *for 300 bar: No 57, W30x2 LH.*
Germany : for 200 bar: No 1 W21.8x1/14" LH.
USA : CGQ connection 350, 0.825"x1/14" LH EXT.

Test pressue/service pressure =1.5

Toxicological Information:
No known toxicological effects from this peoduct.
Symptoms of Poisoning:
In high concentrations may cause asphyxiation, may include loss of mobility/ consciousness. Victim may not be aware of asphyxiation.
First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Do not discharge into areas there is a risk of forming an explosive mixture with air.
Environmental Information: No known ecological damage caused by this product.
Exposure Limits:
TLV(ACGIH): --- ppm, LC_{50} / 1h : --- ppm

Deuterium **D_2** **DS076.0**

Physical Data:

Molar Mass, [5] 4.028 g/mol

Melting Point T_{mp} at 1.013 bar, Triple Point at 0.171 bar, [10, 24]
-254.42 ^{0}C (= -425.96 ^{0}F)

Enthalpy of Fusion at T_{mp} , [24]
49.36 kJ/kg (=21.22 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5, 24]
-249.5 ^{0}C (= -417.1 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [24]
292.66 kJ/kg (= 125.84 BTU/lb)

Critical Point, [24]:
-Temperature -234.8 ^{0}C (= -390.64 ^{0}F)
- Pressure 16.42 bar (= 241.34 psia)
- Density Liquid 0.06699 kg/l

Density Gas: ideal 0.179.71 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1,013 bar,[24]
0.167 g/l (=0.0104 lb/ft^3)
- at 15 ^{0}C and 1 bar, [10] 0.1667 g/l
- at 0 ^{0}C and 1.013 bar, [3] 0.1796 g/l

Density Liquid at T_{bp} and 1.013 bar, [10] 0.1624 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [4]

-250	-242	-238	-235	^{0}C
1	5.34	10.4	16.7	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: +0.58 $\times 10^{-3}$ bar^{-1}
- at 30 ^{0}C: + 0.56 $\times 10^{-3}$ bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar,[10] 1.360 mW/(cm K)

Heat Capacity at 25 ^{0}C and 1.013 bar,[10] 5.187 kJ/(kg K)

Solubility in Water at 20 ^{0}C and 1.013 bar, [1] 3.6 mg gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar, [24] 12.59 $\times 10^{-6}$ Ns/m^2

Explosion Limits in Air , [1]
4.9 - 80 Vol.-%

Autoignition Temperature, [24]
400 ^{0}C (=752 ^{0}F)

Heating Value, [24]
61.073 MJ/kmol

Suitable Extinguishing Media:
All known.

Identification and Classification:

CAS Number: 07782-39-0
EU Number: 231-952-7
EU Classification: F+
EU Symbols: F+
Index Number: 001-001-00-9

UN Number: 1957
DEUTERIUM, compressed
Class/Div: 2.1
ADR/RID: Class 2, Number 1F
ADR/RID Hazard Number: 23
Labeling ADR/DOT: 2.1

EU Classification:
Risk Phrases:
R12: Extremely flammable.

Safety Phrases:
S9: Keep container in a well ventilated places.
S16: Keep away from sources of ignition - No smoking.
S33: Take precautionary measures against static discharges.

H.Schön: Handbook of Purified Gases

Data Sheet DS046.0 **Date: 08-01-15**

Name: Diborane Chemical Formula: B_2H_6

Synonyms: Boroethane, Diboron hexahydride, **$H_2BH_2BH_2$**

*Properties:*Compresed gas, below 16,65 ^{0}C high pressure liquefied gas, flammable,tends to explode, toxic, unpleasant sweetish odor, colorless, above temperature 500 ^{0}C decomposes very slowly to give hydrogen and higher boranes. Marketed mostly diluted with H_2 or Ar.

*Production and Purification:*Manufactured from boron trichloride and a metal hydride in an inert solvent such as diethyl ether.

Widespread Applications:
Used as a reducing agent, polymerisation catalyt (as a Lewis acid), for doping semiconductors and in hydroborations.

Important Impurities: Air gases, BCl_3, HC´s .

Disposal:
Pass in dilute alcaline solution.

Detection of Diborane: Gas test tube.

Suitable Materials: Steel, stainles steel, monel, PTFE, PCTFE .

Valve Thread: Europe: Not standardized.
Germany : No.1, W21,8x1/14" LH.
USA: CGA connection 350, 0.825"-1/14 LH EXT.

Filling Density(Factor): 0.072 kg/l at test pressure of 250 bar.

Toxicological Information:
Irritation to eyes,skin and respiratory tract. Damage to kidneys and liver. Delayed fatal pulmonary oedema possible

Symptoms of Poisoning:
Very toxic by inhalation. Burns, tearing, nausea, difficulty breathing, headache, dizziness, lung congestion, unconsciousness.

First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Do not discharge into areas there is a risk of forming an explosive mixture with air.

Environmental Information:

Exposure Limits:
TLV(ACGIH): 0.1 ppm, LC_{50} / 1h : 80 ppm

Diborane B_2H_6 DS046.0

Physical Data:
Molar Mass, [11] 27.67 g/mol
Triple Point at 0.61 mbar, [10]
-165 ^{0}C (= -265.9 ^{0}F)
Enthalpy of Fusion at T_{mp} , [10, 24]
161.6 kJ/kg (= 69.51 BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [10, 24]
-92.5 ^{0}C (= -134.5 ^{0}F)
Enthalpy of Vaporisation at T_{bp} , [10, 24] 516.81 kJ/kg (=222.23 BTU/lb)
Critical Point, [10, 24]:
-Temperature 16.65 ^{0}C (=61.97 ^{0}F)
- Pressure 40.53 bar (= 587.84 psia)
- Density Liquid 0.1598 kg/l
Density Gas: ideal 1.2345 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
1.146 g/l (= 0.0715 lb/ft^3)
- at 15 ^{0}C, 1 bar, [28] 1.165 g/l
- at 0 ^{0}C, 1.013 bar, [3] 1.247 g/l
Density Liquid at T_{bp}, 1.013 bar, [10]
0 .421 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [4]

-10	0	10	16.6	^{0}C
22	28	34	40.4	bar

2.Pressure Virial Coefficientm, [11]
- at 0 ^{0}C: -10 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -7 x 10^{-3} bar^{-1}
Thermal Conductivity at 15 ^{0}C,1.013 bar, [10]
0.106 mW/(cm K)
Heat Capacity at 25 ^{0}C, constant pressure, [24] 2.351 kJ/(kg K)
Solubility in Water at 20 ^{0}C and 1.013 bar ----
Dynamic Viscosity at 25 ^{0}C and 1 bar, [24] 7.94 x 10^{-6} Ns/m^2
Explosion Limits in Air, [13]
0.8-98 Vol.-%
Autoignition Temperature, [1]
38 ^{0}C (= 100.4 ^{0}F)
Heating Value, [24]
72.28 MJ/kmol
Suitable Extinguishing Media:
All known.

Identification and Classification:
CAS Number: 19287-45-7
EU Number: 242-940-6
EU Classification: F+, T+
EU Symbols: F+, T+
Index Number:

UN Number: 1911
DIBORANE, compressed
Class/Div: 2.3
ADR/RID: Class 2, Number 2TF
ADR/RID Hazard Number: 263
Labeling ADR/DOT: 2.1 + 2.3

EU Classification:
Risk Phrases:
R12: Extremely flammable.
R26: Very toxic by inhalation.

Safety Phrases:
S9: Keep container in a well ventilated places..
S16: Keep away from sources of ignition - No smoking.
S33: Take precautionary measures against static discharges.
S36: Wear suitable protective clothing

H.Schön: Handbook of Purified Gases

Data Sheet DS021.0 **Date: 07-06-14**

Name:Dichlorodifluoromethane Chem. Formula: CCl_2F_2

Synonyms: Chlorofluorocarbon, R12, Difluorodichloromethane

Properties:
Low pressure liquefied gas, non flammable, colorless, mild or ether-like odour, relatively non-toxic. Thermal decomposition mays produce CO, $COCl_2$, COF_2, HF and HCl.

Production and Purification:
R12 and R11 are synthetised in a single process from tetrachloromethane and HF with an antimony-catalyst, byproducts are HCl and R13.

Widespread Applications:
For a long time the most used refrigerant and propellant aerosol gas. Subject to restrictions by EC Regulations 3093/94 and 2037/00, no longer importance as a refrigerant.

Important Impurities: Other HC´s and CFC´s.

Disposal:
Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.

Detection of R12: Halogen leak detector, gas test tube, IR-spectrometry

Suitable Materials: All known.

Valve Thread: *Europe:* Not standardized.
Germany: No.6, W21,8x1/14" RH.
USA: CGA connection 660, 1.030"-1/14 RH EXT.

Filling Density(Factor): 1.15 kg/l at test pressure18 bar.

Toxicological Information:
May produce irregular heart beat and nervous symptoms.

Symptoms of Poisoning:
In high concentration may cause asphyxiation. Symptoms may include loss of mobility/consiousness. Victim may not aware of asphyxiation.
In low concentration may cause narcotic effects . Symptoms may include dizziness, headache, nausea and loss of co-ordination.

First Aid: Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information: May have damaging effect on ozone layer. Covered by the "Montreal Protocol".

Exposure Limits:
TLV(ACGIH): --- ppm, LC50 / 1h :-- ppm .

Dichlorodifluoromethane CCl_2F_2 DS021.0

Physical Data:

Molar Mass, [5] 120.913 g/mol

Melting Point T_{mp} at 1.013 bar, [5]
-157.96 ^{0}C (= -252.33 ^{0}F)

Enthalpy of Fusion at T_{mp}, [10]
34.33 kJ/kg (= 14.76 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-29.70 ^{0}C (= -21.46 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [10]
167.22 kJ/kg (= 71.89 BTU/lb)

Critical Point:
-Temperature, [5]
111.95 ^{0}C (= 233.51 ^{0}F)
- Pressure,[5] 41.3 bar (= 599.02 psia)
- Density Liquid, [10] 0.577 kg/l

Density Gas:
- ideal 5.3946 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
5.008 g/l (= 0.3126 lb/ft^3)
- at 15 ^{0}C, 1 bar, [3] 5.1589 g/l
- at 0 ^{0}C, 1.013 bar, [3] 5.5389 g/l

Density Liquid, [10]
- at T_{bp} and 1.013 bar 1.486 kg/
- at 20 ^{0}C 1.330 kg/l

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
2.20	3.08	4.23	5.66	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -27.5 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -18.3 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.095 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar [10] 0.582 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 0.052 1 gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C, 1 bar [3] 12.7 x 10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number:	00075-71-8
EU Number:	200-893-9
EU Classification:	N
EU Symbols:	N
Index Number:	

UN Number: 1028 DIFLUORO-DICHLOROMETHANE

Class/Div:	2.2
ADR/RID: Class 2, Number	2A
ADR/RID Hazard Number:	20
Labeling ADR/DOT:	2.2

EU Classification:
Risk Phrases:
RAs: Asphyxiant in high concentrations.
R59: Dangerous for the ozon layer.

Safety Phrases:
S9: Keep container in a well ventilated place.
S23: Do not breathe the gas.
S59: Refer to manufacturer / supplier for information on recovery / recycling.

H.Schön: Handbook of Purified Gases

Data Sheet DS022.0 **Date: 07-06-15**

Name:Dichlorofluoromethane* Chem. Formula: $CHCl_2F$

Synonyms: Dichloromonofluoromethane, R21, Fluorodichloromethane

Properties:
Low pressure liquefied gas, non flammable, colorless, weak odour, toxic. Thermal decomposition mays produce CO, $COCl_2$, COF_2, HF and HCl.

Production and Purification:
Synthetised from CCl_4 und HF. Rectification.
Widespread Applications:
Used as a refrigerant and solvent. Subject to restrictions by EC Regulations 3093/94 and 2037/00, no longer importance as a refrigerant.
Important Impurities: Other HC´s and CFC´s.
Disposal:
Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.
Detection of R21: Halogen leak detector, gas test tube, IR-spectrometry .

Suitable Materials: All known.
Valve Thread: *Europe:* Not standardized.
Germany: No.6, W21,8x1/14" RH.
USA: CGA connection 660, 1.030"-1/14 RH EXT.
Filling Density(Factor): 1.23 kg/l at test pressure 10 bar.

Toxicological Information:
Repeated exposure may cause liver damage or failure.
Symptoms of Poisoning:
In high concentration may cause asphyxiation. Symptoms may include loss of mobility/consiousness. Victim may not aware of asphyxiation.
In low concentration may cause narcotic effects . Symptoms may include dizziness, headache, nausea and loss of co-ordination.
First Aid: Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.
Environmental Information: May have damaging effect on ozone layer. Covered by the "Montreal Protocol".

Exposure Limits:
TLV(ACGIH): --- ppm, LC50 / 1h : ppm .

Dichlorofluoromethane CHCl$_2$F DS022.0

Physical Data:

Molar Mass, [5] 102.923 g/mol

Melting Point T_{mp} at 1.013 bar, [5]
-134.95 ^{0}C (= -210.91 ^{0}F)

Enthalpy of Fusion at T_{mp}
kJ/kg (= BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
8.82 ^{0}C (= 47.88 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [10]
239,4 kJ/kg (= 102.94 BTU/lb)

Critical Point:

-Temperature, [5]
178.35 ^{0}C (= 353.03 ^{0}F)

- Pressure, [5]
51.87 bar (= 752.32 psia)

- Density Liquid, [10] 0.522 kg/l

Density Gas:

- ideal 4.5919 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
4.263 g/l (= 0.2661 lb/ft^3)
- at 15 ^{0}C, 1 bar, [10] 4.436 g/l
- at 0 ^{0}C and 1.013 bar --- g/l

Density Liquid, [10]

- at T_{bp} and 1.013 bar 1.3975 kg/l
- at 20 ^{0}C 1.380 kg/l

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
0.47	0.71	1.06	1.53	bar

2.Pressure Virial Coefficient, [11]

- at 0 ^{0}C: -31.1 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -21.1 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.0808 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar [10] 0.586 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 2.066 l Gas / kg H$_2$O

Dynamic Viscosity at 25 ^{0}C and 1 bar, [3] 11.43 x 10^{-6} Ns/m^2

Heating Value, [24]
2.246 MJ/kmol
(= 965,9 BTU/lb)

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number: 00075-43-4
EU Number: 200-869-8
EU Classification: N
EU Symbols: N
Index Number:

UN Number: 1029
DICHLOROFLUOROMETHANE
Class/Div: 2.2
ADR/RID: Class 2, Number 2A
ADR/RID Hazard Number: 20
Labeling ADR/DOT: 2.2

EU Classification:
Risk Phrases:

R59: Dangerous for the ozon layer.

Safety Phrases:

S9: Keep container in a well ventilated places.

S23: Do not breathe the gas.

S59: Refer to manufacturer / supplier for information on recovery / recycling.

H.Schön: Handbook of Purified Gases

Data Sheet DS085.0 **Date: 07-06-12**

Name: Difluoromonochloroethane Chemical Formula:

Synonyms: 1-chloro-1,1-difluoroethane, R142b, **$C_2H_3ClF_2$**
Chlorodifluoroethane, alpha-Chloroethylidne fluoride **$H_3C\text{-}CCLF_2$**

Properties: Low pressure liquefied gas, flammable, colorless, ether-like odour, relatively nontoxic. Thermal decomposition mays produce CO, $COCl_2$, COF_2, HF and HCl.

Production and Purification:
Intermediate product in different organic syntheses. Rectification.
Widespread Applications:
Refrigrant, aerosol propellant gas.
Important Impurities: Other HC´s and CFC´s.
Disposal:
Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.
Detection of R142b:
IR-spectrometry, halogen leak detector, gas test tube.

Suitable Materials: All known, without rubber and viton.
Valve Thread: *Europe:* Not standardized.
Germany: No.1, W21,8x1/14" LH.
USA: CGA connection 510, 0.885"-1/14 LH INT.
Filling Density(Factor): 0.99 kg/l at test pressure 10 bar.

Toxicological Information:
May cause irritation to the respiratory tract.
Symptoms of Poisoning:
In high concentration may cause asphyxiation. Symptoms may include loss of mobility/consiousness. Victim may not aware of asphyxiation.
In low concentration may cause narcotic effects . Symptoms may include dizziness, headache, nausea and loss of co-ordination.
First Aid: Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.
Environmental Information:
May have damaging effect on ozone layer. Covered by the "Montreal Protocol".
Exposure Limits:
TLV(ACGIH):--- ppm, LC_{50} / 1h : ppm .

Difluoromonochloroethane $C_2H_3ClF_2$ DS085.0

Physical Data:
Molar Mass, [5] 100.495 g/mol
Melting Point T_{mp} at 1.013 bar, [5]
-130.8 ^{0}C (= -203.44 ^{0}F)
Enthalpy of Fusion at T_{mp}, [10]
26.75 kJ/kg (= 11.50 BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [24]
-10.01 ^{0}C (= 13.98 ^{0}F)
Enthalpy of Vaporisation at T_{bp}, [10]
222.95 kJ/kg (= 95.85 BTU/lb)
Critical Point:
-Temperature, [5]
135.15 ^{0}C (= 278.87 ^{0}F)
- Pressure, [5]
40.48 bar (= 587.12 psia)
- Density Liquid, [14] 0.435 kg/l
Density Gas:
- ideal 4.4836 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
4.162 g/l (= 0.2598 lb/ft^3)
- at 15 ^{0}C, 1 bar, [15)] 4.3707 g/l
- at 0 ^{0}C, 1.013 bar, [11] 4.7210 g/l
Density Liquid
- at T_{bp} and 1.013 bar, [10] 1.1928 kg/l
- 25 ^{0}C, [24] 1.107 kg/l

Vapor Pressure (about), [14]

-10	0	10	20	^{0}C
1.0	1.5	2.1	2.9	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -49.6×10^{-3} bar^{-1}
- at 30 ^{0}C: -31.0×10^{-3} bar^{-1}
Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.118 mW/(cm K)
Heat Capacity at 25 ^{0}C, 1.013 bar [10] 0.848 kJ/(kg K)
Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 0.415 l Gas / kg H_2O
Dynamic Viscosity at 25 ^{0}C, 1 bar [24] 11.439×10^{-6} Ns/m^2
Explosion Limits in Air, [13]
6.27-17.4 Vol.-%
Autoignition Temperature, [24]
631.7 ^{0}C (= 1169 ^{0}F)
Heating Value, [24] 6,597 MJ/kg
Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:
CAS Number: 00075-68-3
EU Number: 200-891-8
EU Classification: F+
EU Symbols: F+
Index Number:

UN Number: 2517
1-Chloro-1,1-DIFLUOROETHANE
Class/Div: 2.1
ADR/RID: Class 2, Number 2F
ADR/RID Hazard Number: 23
Labeling ADR/DOT: 2.1

EU Classification:
Risk Phrases:
R12: Extremely flammable.
R59: Dangerous for the ozone layer.

Safety Phrases:
S9: Keep container in a well-ventilated places.
S16: Keep away from sources of ignition - No smoking.
S33: Take precautionary measures against static discharges.
S59: Refer to manufacturer / supplier for information on recovery / recycling.
S61: May cause harm to the unborn child

H.Schön: Handbook of Purified Gases

Data Sheet DS100.0 **Date: 07-06-16**

Name: Dichlorotetrafluoroethane **Chem. Formula:**

Synonyms: 1,2-Dichloro-1,1,2,2-tetrafluoroethane, R114, Cryoflurane, Tetrafluorodichloroethane **CCl_2F_4** **$F_2ClC\text{-}CClF_2$**

Properties: Low pressure liquefied gas, non flammable, colorless, sweet odour, relatively non-toxic. Thermically and chemically stable. Thermal decomposition mays produce CO, $COCl_2$, COF_2, HF and HCl.

Production and Purification:
Fluorination of hydrocarrbons.
Widespread Applications:
Used as a refrigerant and solvent. Subject to restrictions by EC Regulation 3093/94 and 2037/00, no longer importance as a refrigerant.
Important Impurities: Other HC´s and CFC´s.
Disposal:
Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.
Detection of R114: Halogen leak detector, gas test tube, IR-spectrometry .

Suitable Materials: All known.
Valve Thread: *Europe:* Not standardized.
Germany: No.6, W21,8x1/14" RH.
USA: CGA connection 660, 1.030"-1/14 RH EXT.
Filling Density(Factor): 1.30 kg/l at test pressure 10 bar.

Toxicological Information:
May produce irregular heart beat and nervous symptoms.
Symptoms of Poisoning:
In high concentration may cause asphyxiation. Symptoms may include loss of mobility/consiousness. Victim may not aware of asphyxiation.
In low concentration may cause narcotic effects . Symptoms may include dizziness, headache, nausea and loss of coordination.
First Aid: Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information: May have damaging effect on ozone layer. Covered by the "Montreal Protocol".
Exposure Limits:
TLV(ACGIH): 1000 ppm, LC50 / 1h : ppm .

Dichlorotetrafluoroethane CCl_2F_2 DS100.0

Physical Data:

Molar Mass, [5] 170.921 g/mol
Melting Point T_{mp} at 1.013 bar, [5]
-92.6 ^{0}C (= -134.68 ^{0}F)
Enthalpy of Fusion at T_{mp}
kJ/kg (= BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [11, 24]
3.77 ^{0}C (= 38.79 ^{0}F)
Enthalpy of Vaporisation at T_{bp} , [10]
136.9 kJ/kg (= 58.85 BTU/lb)
Critical Point:
-Temperature, [5]
145.55 ^{0}C (= 293.99 ^{0}F)
- Pressure, [12, 24]
32.63 bar (= 473.26 psia)
- Density Liquid, [10] 0.582 kg/l
Density Gas:
- ideal 7.6257 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
7.079 g/l (= 0.4419 lb/ft^3)
- at 15 ^{0}C, 1 bar, [10] 7.337 g/l
- at 0 ^{0}C and 1.013 bar --- g/l
Density Liquid
- at T_{bp} and 1.013 bar, [10] 1.522 kg/l
- at 25 ^{0}C, [24] 1.455 kg/l

Vapor Pressure (about), [12]

-10	0	10	20	^{0}C
0.6	0.9	1.3	1.9	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -39.9 $\times 10^{-3}$ bar^{-1}
- at 30 ^{0}C: -27.5 $\times 10^{-3}$ bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.105 mW/(cm K)
Heat Capacity at 25 ^{0}C, 1.013 bar [10] 0.712 kJ/(kg K)
Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 0.017 l Gas / kg H_2O
Dynamic Viscosity at 25 ^{0}C and 1 bar, [3] 12.76 $\times 10^{-6}$ Ns/m^2

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number: 00076-14-2
EU Number: 200-937-7
EU Classification: N
EU Symbols: N
Index Number:

UN Number: 1958
1,2-DICHLORO-
1,1,2,2-TETRAFLUOROETHANE
Class/Div: 2.2
ADR/RID: Class 2, Number 2A
ADR/RID Hazard Number: 20
Labeling ADR/DOT: 2.2

EU Classification:
Risk Phrases:
RAs: Asphyxiant in high concentrations.
R59: Dangerous for the ozone-layer.
Safety Phrases:
S9: Keep container in a well ventilated places
S23: Do not breathe the gas.
S59: Refer to manufacturer / supplier for information on recovery / recycling.
S61: Avoid release to the environment. Refer to special instructions / Safety date sheets.

H.Schön: Handbook of Purified Gases

Data Sheet 048.0 **Date: 08-01-22**

Name: Dichlorosilane **Chemical Formula: SiH_2Cl_2**

Synonyms: Silicon chloride hydride, Dichlorsilicane **H_2-Si-Cl_2**
Silyl dichloride

Properties: Low pressure liquefied gas, flammable, corrosive, colorless, pungent odour, very toxic, hydrolyses immidiately to HCl, H_2 and various polymeric siloxanes. Autoignition can occur with readily combustible substances.

Production and Purification:
Manufactured by clorinating silane in the presence of aluminium trichloride.
Widespread Applications:
Used chiefly for the deposition of epitaxial silicon, to manufacture silylamines and silicon-organic ompounds.
Important Impurities: Air gases, HCl, CHC´s .
Disposal: Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.
Detection of Dichlorsilane: Gives off white fumes in most air.
Suitable Materials: Steel, stainless steel, monel, PTFE, PCTFE, PVDF.
Valve Thread: *Europe:* Not standardized.
Germany: No.5, 1" LH.
USA: CGA connection 678, 1.030"-1/14 LH EXT.
Filling Density(Factor): 0.90 kg/l at test pressure 10 bar.

Toxicological Information:
Severe corrosion to skin, eyes and respiratory tract. Damage to red blood cells (haemolytic poison). Damage to central nervous system.
Symptoms of Poisoning:
Very toxic by inhalation. Burns, tearing, nausea, difficulty breathing, headache, dizziness, lung congestion.
First Aid: Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.
Environmental Information:
May cause pH changes in aqueous ecological systems.
Exposure Limits:
TLV(ACGIH): 5 ppm, LC_{50} / 1h : 314 ppm .

Dichlorosilane SiH_2Cl_2 DS048.0

Physical Data:

Molar Mass, [11] 101.007 g/mol

Melting Point T_{mp} at 1.013 bar, [10]
-122^{0}C (= -187.6 ^{0}F)

Enthalpy of Fusion at T_{mp} , [10, 24]
249.49 kJ/kg (=107.28 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [10]
8.4^{0}C (= 47.12 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [10, 24] 249.49 kJ/kg (=107.28 BTU/lb)

Critical Point, [10, 24]:
-Temperature 175.85 ^{0}C (= 348.53 ^{0}F)
- Pressure 44.3 bar (= 642.52 psia)
- Density Liquid 0.443 kg/l

Density Gas: ideal 4.5065 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
4.183 g/l (= 0.2612 lb/ft^3)
- at 15 ^{0}C, 1 bar, [x] 4.344 g/l
- at 0 ^{0}C and 1.013 bar --- g/l

Density Liquid
- at T_{bp} and 1.013 bar, [10] 1.261 kg/l
- at 25 0C, [24] 1.167 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [4, 10]

-10	0	10	20	^{0}C
0.48	0.74	1.2	1.6	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -34.x 10^{-3} bar^{-1}
- at 30 ^{0}C: -25 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C, 1.013 bar, [24] 0.1009 mW/(cm K)

Heat Capacity at 25 ^{0}C,1.013 bar, [10] 0.611 kJ/(kg K)

Solubility in Water at 20 ^{0}C and 1.013 bar Hydrolyse

Dynamic Viscosity at 25 ^{0}C and 1 bar, [24] 1.12 x 10^{-6} Ns/m^2

Explosion Limits in Air,
[13] 2.5-80 Vol.-%
[24] 4-96 Vol.-%

Autoignition Temperature,
[13] 185 ^{0}C (= 365 ^{0}F)
[24] 57.8 ^{0}C (= 136 ^{0} F)

Heating Value, [24]
82.25 MJ/kmol

Suitable Extinguishing Media:
All known, not water.

Identification and Classification:

CAS Number: 04109-96-0
EU Number: 223-888-3
EU Classification: F+, T, C
EU Symbols: F+, T, C
Index Number:

UN Number: 2189
DICHLOROSILANE
Class/Div: 2.3
ADR/RID: Class 2, Number 2TFC
ADR/RID Hazard Number: 263
Labeling ADR/DOT: 2.1, 2.3, 8

EU Classification:

Risk Phrases:

R12: Extremely flmmable.
R23: Toxic by inhalation.
R34: Causes burns.

Safety Phrases:

S9: Keep container in a well-ventilated places.
S16: Keep away from sources of ignition - no smoking
S26: In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.
S33: Take precautionary measures against static discharges.
S36/37/39: Wear suitable protective clothing, gloves and eye/face protection.
S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible)

H.Schön: Handbook of Purified Gases

Data Sheet DS085.0 **Date: 07-06-12**

Name: Difluoromonochloroethane* Chemical Formula:

Synonyms: 1-chloro-1,1-difluoroethane, R142b, **$C_2H_3ClF_2$**
Chlorodifluoroethane, alpha-Chloroethylidne fluoride **$H_3C\text{-}CCLF_2$**

Properties: Low pressure liquefied gas, flammable, colorless, ether-like odour, relatively nontoxic. Thermal decomposition mays produce CO, $COCl_2$, COF_2, HF and HCl.

Production and Purification:
Intermediate product in different organic syntheses. Rectification.
Widespread Applications:
Refrigrant, aerosol propellant gas. Subject to restrictions by EC Regulation 3093/94 and2037/00, no longer importance as a refrigerant.
Important Impurities: Other HC´s and CFHC´s.
Disposal:
Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.
Detection of R142b:
IR-spectrometry, halogen leak detector, gas test tube.
Suitable Materials: All known, without rubber and viton.
Valve Thread: *Europe:* Not standardized.
Germany: No.1, W21,8x1/14" LH.
USA: CGA connection 510, 0.885"-1/14 LH INT.
Filling Density(Factor): 0.99 kg/l at test pressure 10 bar.

Toxicological Information:
May cause irritation to the respiratory tract.
Symptoms of Poisoning:
In high concentration may cause asphyxiation. Symptoms may include loss of mobility/consiousness. Victim may not aware of asphyxiation.
In low concentration may cause narcotic effects . Symptoms may include dizziness, headache, nausea and loss of coordination.
First Aid: Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.
Environmental Information:
May have damaging effect on ozone layer. Covered by the "Montreal Protocol".
Exposure Limits:
TLV(ACGIH):--- ppm, LC_{50} / 1h : ppm .

Difluoromonochloroethane $C_2H_3ClF_2$ DS085.0

Physical Data:

Molar Mass, [5] 100.495 g/mol

Melting Point T_{mp} at 1.013 bar, [5]
-130.8 ^{0}C (= -203.44 ^{0}F)

Enthalpy of Fusion at T_{mp}, [10]
26.75 kJ/kg (= 11.50 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [24]
-10.01 ^{0}C (= 13.98 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [10]
222.95 kJ/kg (= 95.85 BTU/lb)

Critical Point:
-Temperature, [5]
135.15 ^{0}C (= 278.87 ^{0}F)
- Pressure, [5]
40.48 bar (= 587.12 psia)
- Density Liquid, [14] 0.435 kg/l

Density Gas:
- ideal 4.4836 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
4.162 g/l (= 0.2598 lb/ft^3)
- at 15 ^{0}C, 1 bar, [15)] 4.3707 g/l
- at 0 ^{0}C, 1.013 bar, [11] 4.7210 g/l

Density Liquid
- at T_{bp} and 1.013 bar, [10] 1.1928 kg/l
- 25 ^{0}C, [24] 1.107 kg/l

Vapor Pressure (about), [14]

-10	0	10	20	^{0}C
1.0	1.5	2.1	2.9	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -49.6 $\times$ 10^{-3} bar^{-1}
- at 30 ^{0}C: -31.0 $\times$ 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.118 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar [10] 0.848 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 0.415 l Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C, 1 bar [24] 11.439 $\times$ 10^{-6} Ns/m^2

Explosion Limits in Air, [13]
6.27-17.4 Vol.-%

Autoignition Temperature, [24]
631.7 ^{0}C (= 1169 ^{0}F)

Heating Value, [24] 6,597 MJ/kg

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number: 00075-68-3
EU Number: 200-891-8
EU Classification: F+
EU Symbols: F+
Index Number:

UN Number: 2517 1-CHLORO-1,1-DIFLUOROETHANE
Class/Div: 2.1
ADR/RID: Class 2, Number 2F
ADR/RID Hazard Number: 23
Labeling ADR/DOT: 2.1

EU Classification:

Risk Phrases:

R12: Extremely flammable.
R59: Dangerous for the ozone layer.

Safety Phrases:

S9: Keep container in a well-ventilated places.
S16: Keep away from sources of ignition - No smoking.
S33: Take precautionary measures against static discharges.
S59: Refer to manufacturer / supplier for information on recovery / recycling.
S61: May cause harm to the unborn child

H.Schön: Handbook of Purified Gases

Data Sheet DS032.0 **Date: 07-02-03**

Name: Dimethylamine, anhydrous Chem. Formula: C_2H_7N

Synonyms: DMA, N-Methylmethanamine $(H_3C)_2NH$

Properties:
Low pressure liquefied gas, flammable, colorless, corrosive, toxic, irritant, unpleasant fishy smell, in high concentration ammonia odor. Readily soluble in water and organic solvents. Thermal decomposition yields NO, NO_2 and CO.

Production and Purification:
Manufactored from methanol and ammonia over an aluminium oxide catalyst with elimination of water, rectification.
Widespread Applications:
Intermediate for dyes, fungicides, herbicides, pharmaceuticals, vulcanisation accelerators, detergents and dimethylformamide.
Important Impurities:
HC´s.
Disposal:
Pass in water or dilute acids.
Detection of Dimethylamine:
Gas test tube, litmus-paper, detector for flammable gases ,IR-spectrometry.
Suitable Materials: Steel, stainless steel, PE, PTFE, EPDM.
Valve Thread: *Europe:* Not standardized.
Germany: No.1, W21.8x1/14" LH.
USA: CGA connection 705, 1.125"-1/14 RH EXT.
Filling Density(Factor): 0.59 kg/l at test pressure 10 bar.

Toxicological Information:
Irritation to lungs and upper respriratory tract shown as rhinitis, pharyn and pneumonia. May cause dermatitis, corneal edema and chemical burns.
Symptoms of Poisoning:
Harmful by inhalation. Respiratory tract, skin and eye burns. Difficulty in breathing.
First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested, call a doctor. Apply artificial respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.
Environmental Information:
May cause pH changes in aqueous ecological systems.
Exposure Limits:
TLV(ACGIH): 10 ppm, LC_{50} / 1h : 11,000 ppm

Dimethylamine, anhydrous C_2H_7N **DS032.0**

Physical Data:

Molar Mass, [5] 45.084 g/mol

Triple Point at 1 mbar, [10]
-92.19 ^{0}C (= -133.94 ^{0}F)

Enthalpy of Fusion at $T_{mp,}$ [10]
131.78 kJ/kg (= 56.65 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [10]
6.85 ^{0}C (= 44.33^{0}F)

Enthalpy of Vaporisation at T_{bp}, [10]
587.8 kJ/kg (= 252.70 BTU/lb)

Critical Point:
-Temperature, [5]
164.05 ^{0}C (= 327.29 ^{0}F)
- Pressure,[5] 53.40 bar (= 774.51psia)
- Density Liquid, [10] 0.256 kg/l

Density Gas:
- ideal 2,0115 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1 bar, [24]
1.867 g/l (= 0.1166 lb/ft^3)
- at 15 ^{0}C, 1 bar, [10] 1.944 g/l
- at 0 ^{0}C and 1.013 bar --- g/l

Density Liquid, [10]
- at T_{bp} and 1.013 bar 0.6708 kg/l
- at 20 ^{0}C 0.655 kg/l

Vapor Pressure (about), [4, 28]

-10	0	10	20	^{0}C
0.46	0.74	1.18	1.88	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -38.3 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -25.8 x 10^{-3} bar^{-1}

Thermal Conductivity at 15^{0}C and 1.013 bar, [10] 1.59 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar, [10] 1.532 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 118 l Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C, 1 bar, [24] 7.694 x 10^{-6} Ns/m^2

Explosion Limits in Air, [24]
2.8-14.4 Vol.-%

Autoignition Temperature, [24]
400 ^{0}C (=752 ^{0}F)

Heating Value, [24] 35.813MJ/kg

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number: 00124-40-3
EU Number: 204-697-4
EU Classification: F+, Xi, Xn
EU Symbols: F+, Xn
Index-Number: 612-001-00-9

UN Number: 1032
DIMETHYLAMINE, anhydrous
Class/Div: 2.1
ADR/RID: Class 2, Number 2F
ADR/RID Hazard Number: 23
Labeling ADR/DOT: 2.1

EU Classification:
Risk Phrases:

R12: Extremely flammable.
R20: Harmful by inhalation.
R37/38: Irritating to respiratory system and skin.
R41: Wear eye/face protection.

Safety Phrases:

S16: Keep away from ignitation source - No smoking.
S26: In case of contact with eyes, rinse immidiately with plenty of water and seek medical advice.
S39: Wear eye/face protection

H.Schön: Handbook of Purified Gases

Data Sheet DS066.0 **Date: 06-03-04**

Name: Dimethyl ether Chemical Formula: C_2H_6O

Synonyms: Methyl ether, Methoxy methane, Wood ether, Methyl oxide, Oxybismethane **$H_3C\text{-}O\text{-}CH_3$**

Properties:
Low pressure liquefied gas, extremly flammable, colorless, odor ethereal. Readily soluble in many polar and non-polar solvents.

Production and Purification:
Byproduct in methanol synthesis from synthesis gas. Rectification.
Widespread Applications:
Propellant gas. Used in chemical industry to manufacture chlormethane, dimethyl sulphate and acetic acid, and for methylations.

Important Impurities: HCs.
Disposal: Combustion .
Detection of Dimethyl ether: Detector for flammable gases. IR-spectrometry.
Suitable Materials: All known .
Valve Thread: *Europe:* Not standardized.
Germany: No.1, W21,8x1/14" LH.
USA: CGA connection 510, 0.885"-1/14 LH INT.

Filling Density(Factor): 0.58kg/l at test pressure 18 bar.

Toxicological Information:
No known acute toxicological effects from this product.
Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of coordination. In high concentration may cause asphyxiation.
First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH): --- , LC50 / 1h : ---

Dimethyl ether C_2H_6O DS066.0

Physical Data:
Molar Mass, [5] 46.069 g/mol
Melting Point T_{mp} at 1.013 bar, [24]
-141.49 ^{0}C (= -222.68 ^{0}F)
Enthalpy of Fusion at T_{mp}, [10]
111.41 kJ/kg (= 47.90 BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [10]
-24.82 ^{0}C (= -12.68 ^{0}F)
Enthalpy of Vaporisation at $T_{bp,}$ [10]
467.2 kJ/kg (= 200.86 BTU/lb)
Critical Point:
-Temperature, [5]
126.95 ^{0}C (= 260.51 ^{0}F)
- Pressure, [24]
53.7 bar (= 778.85 psia)
- Density Liquid, [10] 0.2741 kg/l
Density Gas:
- ideal 2.0554 g/l
- at 70 ^{0}F (= 21.1 ^{0}C, 1.013 bar , [24]
1.908 g/l (= 0.1191 lb/ft^3)
- at 15 ^{0}C and 1 bar, [10] 1.964 g/l
- at 0 ^{0}C and 1.013 bar, [3] 2.113 g/l
Density Liquid, [10]
- at T_{bp} and 1.013 bar 0.7347 kg/l
- at 25 ^{0}C 0.661 kg/l

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
1.76	2.55	3.72	5.10	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -27 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -19 x 10^{-3} bar^{-1}
Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.154 mW/(cm K)
Heat Capacity at 25 ^{0}C and 1.013 bar, [10] 1.438 kJ/(kg K)
Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 35 l gas / kg H_2O
Dynamic Viscosity at 25 ^{0}C and 1 bar, [3] 9.29 x 10^{-6} Ns/m^2
Explosion Limits in Air,
[13] 2.7-32 Vol.-%
[24] 3.4-18 Vol.-%
Autoignition Temperature, [13]
240 ^{0}C (= 464 ^{0}F)
Heating Value, [10]
31.702 MJ/kg
Suitable Extinguishing Media:
All known .
1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:
CAS Number: 00115-10-6
EU Number: 204-065-8
EU Classification: F+
EU Symbols: F+
Index-Number: 603-019-00-8

UN Number: 1033
DIMETHYL ETHER
Class/Div: 2.1
ADR/RID: Class 2, Number 2 F
ADR/RID Hazard Number: 23
Labeling ADR/DOT: 2.1

EU Classification:
Risk Phrases:
R12: Extremely flammable.

Safety Phrases:
S9: Keep container in a well ventilated places.
S16: Keep away from sources of ignition - No smoking.
S33: Take precautionary measures against static discharges.

H.Schön: Handbook of Purified Gases

Data Sheet DS092.0 **Date: 07-07-20**

Name: Dimethyl silane Chemical Formula: C_2H_8Si

Synonyms: Dimethyl silicane **$(CH_3)_2SiH_2$**

Properties: Low pressure liquefied gas, flammable, colorless, nasty sweet odor, toxic. Violent exothermic reaction with O_2, ethylene oxide and halogen hydrocarbons. Reaction with water may relaise H_2 , thermal decomposition mays produce CO, SiO_2, H_2.

Production and Purification:
Manufactured in a Grignard reaction from dichlorosilan and methylmagnesium bromide.

Widespread Applications:
Used as a deposition gas in the semiconductur industry.

Important Impurities:
Air, Cl-Si-Compounds.

Disposal:
Combustion, formed gases should be washed with water to remove silica .

Detection of Methyl silane:
Detector for flammable gases, mass spectrometry.

Suitable Materials:		All known.
Valve Thread:	*Europe:*	Not standardized.
		Germany: No.1, W21,8x1/14" LH.
	USA:	CGA connection 350, 0.825"-1/14 LH EXT.
Filling Density(Factor):		0.36 kg/l at test pressure 225 bar.

Toxicological Information:
May cause nausea, hedache and irritation of the respiratory tract. Hydrolysis of silanes in the body forms silicic acid or hydrated silica.

Symptoms of Poisoning: In high concentration may cause asphyxiation. Symptoms may include loss of mobility/consiousness. Victim may not aware of asphyxiation. In low concentration may cause narcotic effects.

First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.

Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH): ppm, LC_{50} / 1h : ppm

Dimethyl silane C_2H_8Si DS092.0

Physical Data:

Molar Mass, [28] 60.171 g/mol
Melting Point T_{mp} at 1.013 bar, [2]
-150.22 ^{0}C (= -238.40 ^{0}F)
Enthalpy of Fusion at T_{mp}
kJ/kg (= BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [14]
-19.6 ^{0}C (= -3.28 ^{0}F)
Enthalpy of Vaporisation at T_{bp}, [28]
354 kJ/kg (= 152.18 BTU/lb)
Critical Point:
-Temperature, [2] 125 ^{0}C (= 257 ^{0}F)
- Pressure, [2] 3.65 bar (= 52.94 psia)
- Density Liquid kg/l
Density Gas:
- ideal 2.6846 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1,013 bar
g/l (= lb/ft^3)
- at 15 ^{0}C, 1 bar, g/l
- at 0 ^{0}C, 1.013 bar, [28] 2.73 g/l
Density Liquid at T_{bp}, 1.013 bar
[2] 0.6377 kg/l
[25, 28] 0.611 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [14]

-10	0	10	20	^{0}C
1.5	2.0	2.8	3.8	bar

2.Pressure Virial Coefficient
- at 0 ^{0}C: x 10^{-3} bar^{-1}
- at 30 ^{0}C: x 10^{-3} bar^{-1}
Thermal Conductivity at 15 ^{0}C and 1.013 bar mW/(cm K)
Heat Capacity at 25 ^{0}C and 1.013 bar kJ/(kg K)
Solubility in Water at 20 ^{0}C and 1.013 bar l Gas / kg H_2O
Dynamic Viscosity at 25 ^{0}C and 1 bar x 10^{-6} Ns/m^2

Explosion Limits in Air, [2]
1.2 - 74 Vol.-%
Autoignition Temperature
[2] 205 ^{0}C (= 401 ^{0}F)
[21] 230 ^{0}C (= 446 ^{0}F)
Heating Value MJ/kmol

Suitable Extinguishing Media:
All known, but not Halons.

Identification and Classification:

CAS Number: 01111-74-6
EU Number: 214-184-7
EU Classification: F+
EU Symbols: F+
Index Number:

UN Number: 3161
LIQUEFIED GAS, FLAMMABLE, N.O.S. (Dimethylsilane)
Class/Div: 2.1
ADR/RID: Class 2, Number 2F
ADR/RID Hazard Number: 23
Labeling ADR/DOT: 2.1

EU Classification:
Risk Phrases:
R12: Extremely flammable.

Safety Phrases:
S9: Keep container in a well ventilated places.
S16: Keep away from sources of ignition - No smoking.
S33: Take precautionary measures against static discharges.

H.Schön: Handbook of Purified Gases

Data Sheet DS083.0 **Date: 08-04-17**

Name: Dinitrogen oxide Chemical Formula: N_2O

Synonyms: Nitric oxide, Nitrogen monoxide, Notrous oxide,
Laughing gas, R744a

Properties: High pressure liquefied gas, non-combustible, non-toxic with an anaesthetic reaction, colourless, sweetish odour. Because of its oxidising action it supports combustion and can form explosive mixtures with combustible substances like H_2, CO or H_2S. It plays a significant role in the greenhouse effect

Production and Purification:
Manufactured by thermal decomposition of NH_4NO_3 or as a byproduct of nitrification and denitrification in the soil.

Widespread Applications:
Used as an inhalation anesthetic (diluted with Oxygen).

Important Impurities: Air, NO_X, HC´s, H_2, CO, CO_2 .

Disposal: Pass low quantities in the atmosphere.
Contact supplier if guidance is required.

Detection of Dinitrogen oxide: IR-spectrometry.

Suitable Materials: All known, use no oil or grease.

Valve Thread: Europe: not standardized .
Germany : No.12, G 3/4" INT.

USA: CGA connection 660, 1.030"x 1/14" RH EXT.

Filling Density(Factor): 0.75 kg/l at test pressure 250 bar.

Toxicological Information:
No known toxicological effects from this product

Symptoms of Poisoning:
In high concentrations may cause asphyxiation, may include loss of mobility/ consciousness. Victim may not be aware of asphyxiation. In low concentrations may cause narcotic effects. Symptoms may include dizziness, headach, nausea and loss of co-ordination.

First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.

Environmental Information:
Significant role in the greenhouse effect,

Exposure Limits:
TLV(ACGIH): 50 ppm, LC_{50} / 1h : --- ppm .

Dinitrogen oxide N_2O DS083.0

Physical Data:

Molar Mass, [5] 44.013 g/mol

Triple Point at 0.878 bar,[10]
-90.82 ^{0}C (= -131.48 ^{0}F)

Enthalpy of Fusion at T_{mp} , [24]
148.59 kJ/kg (= 63,89 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-88.48 ^{0}C (= -127.26 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [24]
404.88 kJ/kg (= 174.1 BTU/lb)

Critical Point, [28]:
-Temperature +36.41 ^{0}C (= +97.54 ^{0}F)
- Pressure 72.4 bar (= 1,414.69 psia)
- Density Liquid 0.452 kg/l

Density Gas: ideal 1.9637 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
1.243 g/l (= 0.0776 lb/ft^{3})
- at 15 ^{0}C, 1 bar, [10] 1.853 g/l
- at 0 ^{0}C, 1.013 bar, [28] 1.078 g/l

Density Liquid, [10]
- at T_{bp} and 1.013 bar, 1.223 kg/l
- at -20 ^{o}C 0.788 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^{3}

Vapor Pressure (about), [44 12]

-10	0	10	20	^{0}C
24.3	31.2	40.2	50.8	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -7.18×10^{-3} bar^{-1}
- at 30 ^{0}C: -5.08×10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.156 mW/(cm K)

Heat Capacity at 25 ^{0}C,1.013 bar, [10] 0.879 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 0.665 l gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar, [3] 14.98×10^{-6} Ns/m^{2}

Suitable Extinguishing Media:
All known.

Identification and Classification:

CAS Number: 10024-97-2
EU Number: 233-032-0
EU Classification: O
EU Symbols: O
Index Number:

UN Number: 1070
NITROUS OXIDE
Class/Div: 2.2
ADR/RID: Class 2, Number 2O
ADR/RID Hazard Number: 25
Labeling ADR/DOT: 2.2,5.1

EU Classification:
Risk Phrases:
R8: Contact with combustible material may cause fire

Safety Phrases:
S7: Keep container tightly closed
S9: Keep container in a well ventilated places.
S17: Keep away from combustible material.

H.Schön: Handbook of Purified Gases

Data Sheet DS049.0 **Date: 07-07-22**

Name: Disilane Chemical Formula: Si_2H_6

Synonyms: Disilicoethane, Disilicane, Silicon hexahydride **$H_3Si-SiH_3$**

Properties:

Low pressure liquefied gas, flammable, autoigniting in air, colorless, irritating odour, toxic. Decomposes slowly at room temperature and explosively on heating, forming SiH_4 and H_2. Hydrolyses to SiO_2 , silicic acid and H_2.

Production and Purification:

Manufactured from magnesium silicide and HCl.

Widespread Applications:

Used as a deposition gas in the semiconductur industry.

Important Impurities:

Air, Cl-Si-Compounds.

Disposal:

Combustion, formed gases should be washed with water to remove silica .

Detection of Dilsilane:

IR-spectrometry, mass spectrometry.

Suitable Materials:		All known.
Valve Thread:	*Europe:*	Not standardized.
		Germany: No.1, W21,8x1/14" LH.
	USA:	CGA connection 350, 0.825"-1/14 LH EXT.
Filling Density(Factor):		0.74 kg/l at test pressure 15 bar.

Toxicological Information:

May cause nausea, hedache and irritation of the respiratory tract. Hydrolysis of silanes in the body forms silicic acid or hydrated silica.

Symptoms of Poisoning:

In high concentration may cause asphyxiation. Symptoms may include loss of mobility/consiousness. Victim may not aware of asphyxiation.

First Aid:

Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.

Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information:

No known ecological damage caused by this product.

Exposure Limits:

TLV(ACGIH): ppm, *LC50 / 1h : ppm*

Disilane Si_2H_6 **DS049.0**

Physical Data:

Molar Mass, [11] 62.219 g/mol

Melting Point T_{mp} at 1.013 bar, [2, 6]
-132.5 ^{0}C (= -206.5 ^{0}F)

Enthalpy of Fusion at T_{mp}
kJ/kg (= BTU/lb)

Boiling Point T_{bp} at 1.013 bar, , [11]
-14.5 ^{0}C (= +5.9 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [24]
341.21 kJ/kg (= 146.72 BTU/lb)

Critical Point:

-Temperature

[6, 28] 151 ^{0}C (= 303.8 ^{0}F)

[24] 158.85 ^{0}C (= 317.93 ^{0}F)

- Pressure

[6] 51.5 bar (= 746.96 psia)

[28] 35.8 bar (= 519.24 psia)

- Density Liquid, [24] 0.3142 kg/l

Density Gas: ideal 2.776 g/l

- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
2.577 g/l (= 016.09 lb/ft^3)

- at 15 ^{0}C,1 bar, [6] 2.66 g/l

- at 0 ^{0}C, 1.013 bar, [28] 2.85 g/l

Density Liquid: - at 0 ^{0}C, [4] 0.88 kg/l

- at 25 ^{0}C 0.782 kg/l

Vapor Pressure (about), [6]

-10	0	10	20	^{0}C
1.19			3.30	bar

2.Pressure Virial Coefficient, [28]

- at 0 ^{0}C: -2.6 x 10^{-3} bar^{-1}

- at 30 ^{0}C: -1.9 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1 bar, [24] 0.1634 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1 bar,

[24] 1.264 kJ/(kg K)

[28] 1.1608 kJ/(kg K)

Solubility in Water at 20 ^{0}C and 1.013 bar hydrolyses

Dynamic Viscosity at 25 ^{0}C,1 bar

[24] 9.58 x 10^{-6} Ns/m^2

Explosion Limits in Air, [2]
1-100 Vol.-%

Autoignition Temperature

[10] less than 85 ^{0}C (= 185 ^{0}F)

[21] less than 54 ^{0}C (= 130 ^{0}F)

Heating Value, [24] 42,109 MJ/kg

Suitable Extinguishing Media:
Dry chemicals, no CO_2 and halons.
Cool the cylinder with water.

1 bar=14.504 psi, 1g/l=0.0624 lb/ft^3

Identification and Classification:

CAS Number: 01590-87-0

EU Number: 216-466-5

EU Classification: F+

EU Symbols: F+

Index Number:

UN Number: 3161

LIQUEFIED GAS, FLAMMABLE, N.O.S. (Disilane)

Class/Div: 2.1

ADR/RID: Class 2, Number 2F

ADR/RID Hazard Number: 23

Labeling ADR/DOT: 2.1

EU Classification:

Risk Phrases:

R12: Extremely flammable.

R17: Spontaneously flammable in air.

R20: Harmful by inhalation

Safety Phrases:

S9: Keep container in a well ventilated places.

S16: Keep away from sources of ignition - No smoking.

S33: Take precautionary measures against static discharges.

S36: Wear suitable protective clothing.

H.Schön: Handbook of Purified Gases

Data Sheet DS034.0 **Date: 09-03-06**

Name: Ethane Chemical Formula: C_2H_6

Synonyms: Bimethyl, Dimethyl, Ethyl hydride, R170, Methylmethane **$H_3C\text{-}CH_3$**

Properties:
High pressure liquefied gas, flammable, colorless, odorless, nontoxic. It is one of the alkanes and as such it is relatively unreactive.

Production and Purification:
Constituent of natural gas and of petroleum cracking gases. Rectification..

Widespread Applications:
Production of chlorethane and vinyl chloride. Cryogenic Refrigerant.

Important Impurities:		Other HCs.
Disposal:		Combustion .
Detection of Ethane:		Detector for flammable gases.
Suitable Materials:		All known.
Valve Thread:	*Europe:*	Not standardized. Germany: No.1, W21,8x1/14" LH.
	USA:	CGA connection 350, 0.825"-1/14 LH EXT.
Filling Density(Factor):		0.39 kg/l at test pressure 300 bar.

Toxicological Information:
No known acute toxicological effects from this product.
Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of coordination. In high concentration may cause asphyxiation.
First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH): --- ppm , LC50 / 1h : ---

Ethane C_2H_6 DS034.0

Physical Data:

Molar Mass, [5] 30,070 g/mol

Triple Point at 0.011 mbar, [5,10]
-182.8 ^{0}C (= -297.04 ^{0}F)

Enthalpy of Fusion at T_{mp}, [10]
95.04 kJ/kg (= 40.86 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-88.6 ^{0}C (=-127.48 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [10]
488.76 kJ/kg (= 210.13 BTU/lb)

Critical Point:
-Temperature, [5]
32.17 ^{0}C (= 89.91 ^{0}F)
- Pressure, [5]
48.72 bar (= 706.63 psia)
- Density Liquid, [10] 0.2056 kg/l

Density Gas:
- ideal 1.3416 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1.013 bar, [24]
1.245 g/l (= 0.0778 lb/ft^3)
- at 15 ^{0}C and 1 bar, [10] 1.265 g/l
- at 0 ^{0}C, 1.013 bar, [3] 1.3550 g/l

Density Liquid
- at T_{bp} and 1.013 bar, [10] 0.6523 kg/l
- at 25 ^{0}C, [24] 0.315 kg/l

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
18.5	23.9	30.2	37.8	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -9.88 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -7.18 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [24] 0.2145 mW/(cm K)

Heat Capacity at 25 ^{0}C and 1.013 bar, [10] 1.768 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 0.049 l gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C, 1 bar, [3] 9.43 x 10^{-6} Ns/m^2

Explosion Limits in Air, [13]
2.4-14.7 Vol.-%

Autoignition Temperature, [13]
515 ^{0}C (= 959 ^{0}F)

Heating Value, [14]
1,428.64 MJ/kmol

Suitable Extinguishing Media:
All known .

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number: 00074-84-0
EU Number: 200-814-8
EU Classification: F+
EU Symbols: F+
Index-Number: 601-002-09-X

UN Number: 1035 ETHANE

Class/Div: 2.1
ADR/RID: Class 2, Number 2F
ADR/RID Hazard Number: 23
Labeling ADR/DOT: 2.1

EU Classification:
Risk Phrases:
R12: Extremely flammable.

Safety Phrases:
S9: Keep container in a well ventilated places.
S16: Keep away from sources of ignition - No smoking.
S33: Take precautionary measures against static discharges.

H.Schön: Handbook of Purified Gases

Data Sheet DS017.0 **Date: 07-05-30**

Name: Ethyl chloride Chemical Formula: C_2H_5Cl

Synonyms: Chloroethane, Muriatic ether, Kelene, **$H_3C\text{-}CH_2Cl$**
Narcotile, Aethylis chloridum, Chelen, Ether chloratis, R160

Properties: Low pressure liquefied gas, flammable, colorless. Anesthetic gas with an ethereal odor, it is suspected of being carcinogen. Poorly soluble in water, thermal decomposition produces CO, $COCl_2$, HCl.

Production and Purification:
Manufactured by adding reaction of HCl to Ethene or by uses Ethane and Cl_2 as raw materials.Rectification.
Widespread Applications:
Refrigerant, intermediate in organic syntheses (tetraethyl lead), solvent for phosphorus, sulfur, resins, fats, waxes and oils, local anesthetic.
Important Impurities: Other HC´s and CFC´s.
Disposal: Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.
Detection of Ethlyl chloride: Detector for flammable gases. Gas test tube.

Suitable Materials: All known for dry gas.
Valve Thread: *Europe:* Not standardized.
Germany : No.1, W21,8x1/14" LH.
USA: CGA connection 300, 0.825"-1/14 RH EXT.
Filling Density(Factor): 0.80 kg/l at test pressure 10 bar.

Toxicological Information: Overexposure may cause stomach cramps, vomitting and cough and may also kidney and liver damage.
Symptoms of Poisoning: In high concentration may cause asphyxiation. Symptoms may include loss of mobility/consiousness. Victim may not aware of asphyxiation.
In low concentration may cause narcotic effects . Symptoms may include dizziness, headache, nausea and loss of coordination.
First Aid: Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.
Environmental Information:
Not covered by the "Montreal Protocol".
Exposure Limits:
TLV(ACGIH):1000 ppm, LC_{50} / 1h : ppm .

Ethyl chloride C_2H_5Cl DS017.0

Physical Data:

Molar Mass, [5] 64.514 g/mol

Melting Point T_{mp} at 1.013 bar, [5, 10]
-138.33 ^{0}C (= -217.00 ^{0}F)

Enthalpy of Fusion at T_{mp} [10]
69.04 kJ/kg (= 29.68 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
12.27 ^{0}C (= 54.09 ^{0}F)

Enthalpy of Vaporisation at T_{bp} [10]
382.2 kJ/kg (= 164.31 BTU/lb)

Critical Point:

-Temperature, [5]
187.15 ^{0}C (= 368.87 ^{0}F)

- Press.,[24] 52.69 bar (= 764.21psia)
- Density Liquid, [10] 0.331 kg/l

Density Gas:
- ideal 2.8783 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1 bar, [24]
2.672 g/l (= 0.1668 lb/ft^3)
- at 15 ^{0}C, 1 bar, [10] 2.758 g/l
- at 0 ^{0}C and 1.013 bar --- g/l

Density Liquid, [10]
- at T_{bp} and 1.013 bar 0.877 kg/l
- at 20 ^{0}C 0.894 kg/l

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
0.37	0.58	0.85	1.33	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -43 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -29 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.126 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar [10] 0.971 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 0.199 l gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C,1 bar [24] 9.722 x 10^{-6} Ns/m^2

Explosion Limits in Air, [13]
3.6-14.8 Vol.-%

Autoignition Temperature, [13]
510 ^{0}C (= 950 ^{0}F)

Heating Value, [24]
19,917 MJ/kg

Suitable Extinguishing Media:
all known.

1 bar = 14.504 psi
1g/l = 0.0624 lb/ft3

Identification and Classification:

CAS Number: 00075-00-3
EU Number: 200-830-5
EU Classification: Carc.Cat.3, F+
EU Symbols: F+, Xn
Index Number: 602-009-00-0

UN Number: 1037
ETHYLCHLORIDE
Class/Div: 2.1
ADR/RID: Class 2, Number 2F
ADR/RID Hazard Number: 23
Labeling ADR/DOT: 2.1

EU Classification:

Risk Phrases:

R12: Extremely flammable.
R40: Limited evidence of a carcinogenic effect.
R52/53: Harmful to aquatic organisms, may cause long-term adverse effects in the aquatic environment.

Safety Phrases:

S9: Keep container in a well-ventilated places.
S16: Keep away from sources of ignition - No smoking.
S33: Take precautionary measures against static discharges.
S36/37: Wear suitable protective clothing and gloves.
S61: Avoid release to the environment. Refer to special instructions/ Safety data sheets.

H.Schön: Handbook of Purified Gases

Data Sheet DS101.0 **Date: 06-03-20**

Name: Ethyl methyl ether Chemical Formula: C_3H_8O

Synonyms: Methyl ethyl ether, Methoxyethane, Ethoxymethane **$H_3C\text{-}O\text{-}CH_2\text{-}CH_3$**

Properties: Low pressure liquefied gas, flammable, colorless, with ethereal odor, nontoxic. Tending to form peroxides under excitation of light. In mixture with air danger of explosion,

Production and Purification:
Can be obtained by Williamson synthesis from Chloromethane and Sodium ethanolate. Rectification.

Widespread Applications:
Used in organic synthesis and as solvent.

Important Impurities: Other HCs.
Disposal: Combustion .
Detection of Etyl methyl ether: Detector for flammable gases, IR-Spectrometry.
Suitable Materials: All known.
Valve Thread: *Europe:* Not standardized.
Germany: No.1, W21,8x1/14" LH.
USA: CGA connection 510, 0.885"-1/14 LH INT.

Filling Density(Factor): 0.64 kg/l at test pressure 10 bar.

Toxicological Information:
No known acute toxicological effects from this product.

Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of coordination. In high concentration may cause asphyxiation.

First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH): --- ppm , LC50 / 1h : ---

Ethyl methyl ether C_3H_8O DS101.0

Physical Data:

Molar Mass, [5] 60.096 g/mol

Melting Point T_{mp} at 1.013 bar

[5, 24] -113.5 ^{0}C (= -171.67 ^{0}F)

[6, 13] -139 ^{0}C (= -218.2 ^{0}C)

Enthalpy of Fusion at T_{mp}, [24]

132.79 kJ/kg (= 57.1 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [12]

7.40 ^{0}C (= 45.32 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [24]

443.29 kJ/kg (= 190.61 BTU/lb)

Critical Point, [12]:

-Temperature 164.70 ^{0}C (= 328.46 ^{0}F)

- Pressure 43,90 bar (= 636.73 psia)

- Density Liquid 0.272 kg/l

Density Gas:

- ideal 2.6812 g/l

- at 70 ^{0}F (= 21.1 ^{0}C), 1.013 bar, [24]

2.489 g/l (= 0.1554 lb/ft^3)

- at 15 ^{0}C and 1 bar, [15] 2.537 g/l

- at 0 ^{0}C and 1.013 bar --- g/l

Density Liquid

- at T_{bp} and 1.013 bar, [4] 0.725 kg/l

- at 25 ^{0}C, [24] 0.692 kg/l

Vapor Pressure (about), [12]

-10	0	10	20	^{0}C
0.4	0.7	1.1	1.6	bar

2.Pressure Virial Coefficient, [11]

- at 0 ^{0}C: -33.7 x 10^{-3} bar^{-1}

- at 30 ^{0}C: -22.8 x 10^{-3} bar^{-1}

Thermal Conductivity at 25 ^{0}C, [24]

0.1546 mW/(cm K)

Heat Capacity at 25 ^{0}C and 1.013 bar, [24] 1.532 kJ/(kg K)

Solubility in Water at 20 ^{0}C and 1.013 bar l gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar, [24] 8.609 x 10^{-6} Ns/m^2

Explosion Limits in Air, [13]

2.0-10.1 Vol.-%

Autoignition Temperature, [13]

190 ^{0}C (= 374 ^{0}F)

Heating Value, [24]

32,138.6 MJ/kg

Suitable Extinguishing Media:

All known .

1 bar = 14.504 psi

1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number: 00540-67-0

EU Number:

EU Classification: F+

EU Symbols: F+

Index-Number: 603-020-00-3

UN Number: 1039

ETHYL METHYL ETHER

Class/Div: 2.1

ADR/RID: Class 2, Number 2F

ADR/RID Hazard Number: 23

Labeling ADR/DOT: 2.1

EU Classification:

Risk Phrases:

R12: Extremely flammable.

Safety Phrases:

S9: Keep container in a well ventilated places.

S16: Keep away from sources of ignition - No smoking.

S33: Take precautionary measures against static discharges.

H.Schön: Handbook of Purified Gases

Data Sheet DS039.9 **Date: 07-02-03**

Name: Ethylamine Chemical Formula: C2H7N

Synonyms: Aminoethane, Ethanamine, R631, Monoethylamine **H3C-CH2-NH2**

Properties: Low pressure liquefied gas, flammable, colorless, toxic, irritant, corrosive, ammonia odor. It is miscible in all proportions with water and many organic solvents. Thermal decomposition yields NO, NO_2 and CO.

Production and Purification:
Manufacturing from ethanol or bromethane and ammonia in a condensation reaction, rectification.

Widespread Applications:
Synthesis of herbicides, pharmaceuticals and dyes.

Important Impurities:
Other HC´s, ether, HCl.

Disposal:
Pass in water or dilute acids.

Detection of Ethylamine:
Gas test tube, litmus-paper, detector for flammable gases (IR-spectrometry).

Suitable Materials: Steel, stainless steel, PE, PTFE, EPDM.

Valve Thread: *Europe:* Not standardized.
Germany : No.1, W21.8x1/14" LH..
USA: CGA connection 705, 1.125"-1/14 RH EXT.

Filling Density(Factor): 0.61 kg/l at test pressure 10 bar.

Toxicological Information:
Irritation to lungs and upper respriratory tract shown as rhinitis, pharyn and pneumonia. May cause dermatitis, corneal edema and chemical burns.

Symptoms of Poisoning:
Harmful by inhalation. Respiratory tract, skin and eye burns.

First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested, call a doctor. Apply artificial respiration if breathing stopped.

Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.

Environmental Information:
May cause pH changes in aqueous ecological systems.

Exposure Limits:
TLV(ACGIH): 10 ppm, LC_{50} / 1h : 5540 ppm

Ethylamine C_2H_7N **DS039.0**

Physical Data:

Molar Mass, [5] 45.084 g/mol

Triple Point at 1.5 mbar, [5]
-81.00 ^{0}C (= -113.8 ^{0}F)

Enthalpy of Fusion at T_{mp}, [24]
207.39 kJ/kg (= 89.18 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
16.6 ^{0}C (= 61.88 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [24]
606.65 kJ/kg (= 260.86 BTU/lb)

Critical Point:
-Temperature, [5]
183.25 ^{0}C (= 361.85 ^{0}F)
- Pressure, [5] 56.30 bar (=816.58 psia)
- Density Liquid, [10] 0.2483 kg/l

Density Gas:
- ideal 2.0114 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1.013 bar, [24]
1.867 g/l (= 0.1166 lb/ft^3)
- at 15 ^{0}C and 1 bar, --- g/l
- at 0 ^{0}C and 1.013 bar --- g/l

Density Liquid
- at T_{bp} and 1.013 bar, [10] 0.6874 kg/l
- at 25 ^{0}C, [24] 0.677 kg/l

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
0.27	0.49	0.77	1.17	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -45.1×10^{-3} bar^{-1}
- at 30 ^{0}C: -29.9×10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.201 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar, [10] 1.612 kJ/(kg K)

Solubility in Water at 20^{0}C, 1.013 bar, Hydrolysis

Dynamic Viscosity at 25 ^{0}C and 1 bar, [24] 8.051×10^{-6} Ns/m^2

Explosion Limits in Air, [13]
3.5-14 Vol.-%

Autoignition Temperature, [2]
384 ^{0}C (= 723 ^{0}F)

Heating Value, [24] 35.10 MJ/kg

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi ,
1g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number: 00075-04-7
EU Number: 200-834-7
EU Classification: F+, Xi
EU Symbols: F+, Xi
Index Number 612-002-00-4

UN Number: 1036
ETHYLAMINE
Class/Div: 2 .1
ADR/RID: Class 2, Number 2F
ADR/RID Hazard Number: 23
Labeling ADR/DOT: 2.1

EU Classification:
Risk Phrases:

R12: Extremely flammable.
R36/37: Irritating to eyes and respiratory system.

Safety Phrases:

S16: Keep away from ignitation source - No smoking.
S26: In case of contact with eyes, rinse immediately with plent of water and seek medical advice.
S29: Do not empty in the drain.

H.Schön: Handbook of Purified Gases

Data Sheet DS035.0 **Date: 06-03-18**

Name: Ethylene **Chemical Formula: C_2H_4**

Synonyms: Ethene, Acetene, Olefiant gas, R1150, Bicarburreted hydrogen, Etherin, Elalyl **$H_2C=CH_2$**

Properties:
High pressure liquefied gas, flammable, colorless, nontoxic, with a slight sweetish odor. Polymerisation reactions at high temperature and pressure.

Production and Purification:
Cracking processes of natural gas and petroleum. Rectification.

Widespread Applications:
Synthesis of polyethylene. Gasifying warehouses and refrigerated stores to control fruit pinening processes.

Important Impurities: Other HCs.
Disposal: Combustion .
Detection of Ethylene: Detector for flammable gases, Gas test tube.
Suitable Materials: All known metals, PTFE, PCTFE, PVDF.
Valve Thread: *Europe:* Not standardized.
Germany: No.1, W21,8x1/14" LH.
USA: CGA connection 350, 0.825"-1/14 LH EXT.

Filling Density(Factor): 0.37 kg/l at test pressure 300 bar.

Toxicological Information:
No known acute toxicological effects from this product.

Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of coordination. In high concentration may cause asphyxiation.

First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH): --- ppm , LC50 / 1h : ---

Ethylene C_2H_4 **DS035.0**

Physical Data:

Molar Mass, [5] 28.054 g/mol

Triple Point at 1.2 mbar, [5,10]
-169.16 ^{0}C (= -272.49 ^{0}F)

Enthalpy of Fusion at T_{mp}, [10]
119.45 kJ/kg (= 535.80 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-103,73 ^{0}C (= -154.71 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [10]
482.86 kJ/kg (= 207.59 BTU/lb)

Critical Point:
-Temperature, [5]
9.19 ^{0}C (= 48.54 ^{0}F)
- Pressure, [5]
50.41 bar (= 731.15 psia)
- Density Liquid, [10] 0.218 kg/l

Density Gas:
- ideal 1.2516 g/l
- at 70 ^{0}F (= 21.1 ^{0}C),1.013 bar, [24]
1.162 g/l (= 0.0725 lb/ft^{3})
- at 15 ^{0}C and 1 bar, [10] 1.178 g/l
- at 0 ^{0}C, 1.013 bar,[3] 1.2611 g/l

Density Liquid
- at T_{bp}, 1.013 bar, [10] 0.5679 kg/l
- at -10 ^{0}C, [24] 0.386 kg/l

Vapor Pressure (about), [4, 5]

-10	0	10	^{0}C
32.39	40.77	50.41	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -7.43 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -5.39 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.188 mW/(cm K)

Heat Capacity at 25 ^{0}C and 1.013 bar, [10] 1.54 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 0.122 l gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar, [3] 10.4 x 10^{-6} Ns/m^{2}

Explosion Limits in Air, [13]
2.4-32.6 Vol.-%

Autoignition Temperature, [13]
440 ^{0}C (= 824 ^{0}F)

Heating Value, [14]
1,323.15 MJ/kmol

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^{3}

Identification and Classification:

CAS Number: 00074-85-1
EU Number: 200-815-3
EU Classification: F+
EU Symbols: F+
Index-Number: 601-010-00-3

UN Number: 1962
ETHYLENE,
Class/Div: 2.1
ADR/RID: Class 2, Number 2 F
ADR/RID Hazard Number: 23
Labeling ADR/DOT: 2.1

EU Classification:

Risk Phrases:

R12: Extremely flammable.
R67: Vapours may cause drowsiness and dizziness.

Safety Phrases:

S9: Keep container in a well ventilated places.
S16: Keep away from sources of ignition - No smoking.
S33: Take precautionary measures against static discharges.
S46: If swallowed, seek medical advice immediately and show this container or label.

H.Schön: Handbook of Purified Gases

Data Sheet DS040.0 **Date: 08-04-14**

Name: Ethylene oxide Chemical Formula: C_2H_4O

Synonyms: Oxirane, 1,2-Epoxyethane, Oxacyclopropane, $(CH_2)_2O$

Properties:
Low pressure liquefied gas, highly flammable, colourless, sweet odor and taste, miscible in all proportions with water, methanol and diethyl ether, has a tendency to spontaneous polymerisatuion, which is catalysed by acids and alkalis with a large exotherm. It should therefore be stored cool and under N_2.

*Production and Purification:*Obtained industrially by the oxidation of ethene with atmospheric oxygen over a silver catalyst.

Widespread Applications:
Used in the manufacture of ethylene glycol and higher alcohols, as a fumigant, fungicide and sterilizing agent (mixture with CO_2).

Important Impurities: Air, HC´s.
Disposal: combustion.

Detection of Ethylene oxide: gas test tube.

Suitable Materials: Steel, stainless steel, PTFE, PCTFE.
Valve Thread: *Europe:* not standardized.
Germany: for 200 bar: No 1 W21.8x1/14" LH.
USA: CGA connection 510, 0.825"x1/14" LH INT.

Filling Density(Factor): 0.78 kg/l at test pressure 200 bar.

Toxicological Information: May cause irritation to the respiratory tract. Damage to red blood cells (haemolytic poison). May cause cancer.

Symptoms of Poisoning:
Toxic by inhalation. In high concentrations may cause asphyxiation, may include loss of mobility/consciousness. Victim may not be aware of asphyxiation. In low concentrations may cause narcotic effects.Symptoms may include dizziness, hedachr, nausea and loss of coordination.

First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Do not discharge into areas there is a risk of forming an explosive mixture with air.

Environmental Information: May cause ecological damage by this product. May cause pH changes in aqueous ecological systems.

Exposure Limits:
TLV(ACGIH): 1 ppm, LC_{50} / 1h : 2900 ppm .

Ethylene oxide C_2H_4O DS040.0

Physical Data:
Molar Mass, [11] 44.053 g/mol
Melting Point T_{mp} at 1.013 bar, [10]
-112.55^{0}C (= -170.59 ^{0}F)
Enthalpy of Fusion at T_{mp} , [24]
117.38 kJ/kg (= 50.47 BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [10]
10.45 ^{0}C (= 50.81 ^{0}F)
Enthalpy of Vaporisation at T_{bp} , [24]
583.39 kJ/kg (= 250.86 BTU/lb)
Critical Point, [24]:
-Temperature 196 ^{0}C (= 384.8 ^{0}F)
- Pressure 71.94 bar (= 1043.4 psia)
- Density Liquid 0.314 kg/l
Density Gas: ideal 1.9654 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
1.824 g/l (= 0.1139 lb/ft^3)
- at 15 ^{0}C, 1 bar, [10] 1.899 g/l
- at 0 ^{0}C and 1.013 bar --- g/l
Density Liquid
- at T_{bp} and 1.013 bar, [10] 0.887 kg/l
- at 25 ^{o}C, [24] 0.862 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
0.42	0.72	0.96	1.52	bar

2.Pressure Virial Coefficient, [28]
- at 0 ^{0}C: -3.2×10^{-3} bar^{-1}
- at 30 ^{0}C: -2.28×10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.121 mW/(cm K)
Heat Capacity at 25 ^{0}C,1.013 bar, [24] 1.121 kJ/(kg K)
Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 1.89 l gas / kg H_2O
Dynamic Viscosity at 25 ^{0}C and 1 bar, [24] 9.324 x 10^{-6} Ns/m^2
Explosion Limits in Air, [13]
2.6-100 Vol.-%
Autoignition Temperature,[13]
435 ^{0}C (= 815 ^{0}F)
Heating Value, [24]
27.65 MJ/kg
Suitable Extinguishing Media:
All known.

Identification and Classification:
CAS Number: 00075-21-8
EU Number: 200-849-9
EU Classification:
F+, Carc. Cat.2, Mut.Cat.2, T, X_i
EU Symbols: T, F+
Index Number: 603-023-00-X

UN Number: 1040
ETHYLENE OXIDE
Class/Div: 2.3
ADR/RID: Class 2, Number 2TF
ADR/RID Hazard Number: 236
Labeling ADR/DOT: 2.1, 2.3

EU Classification:
Risk Phrases:
R12: Extremely flammable.
R23: Toxic by inhalation
R36/37/38: Irritating to eyes, respiratory system and skin.
R45: May cause cancer
R46: May cause heritable genetic damage

Safety Phrases:
S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible*)*
S53: Avoid exposure, obtain special instructions before use.

H.Schön: Handbook of Purified Gases

Data Sheet DS051.0 **Date: 08-02-22**

Name: Fluorine Chemical Formula: F_2

Synonyms:

*Properties:*Non-liquefied, compressed gas, very toxic, non flammable, but supports combustion strongly, corrosive, It is one of halogens and the most reactive of all the elements. It reacts with most inorganic and almost all organic compounds, sometimes very violently and with ignition or explosion. Forms compounds with the noble gases Kr and Xe.

Production and Purification:
Obtained by electrolysing liquid hydrogen fluoride, potassium fluoride is added to improve the electrical conductivity.

Widespread Applications:
Used as an oxidiser in rocket fuels and for the complete fluorination of inorganic compunds (ClF3, BF3, SF6)

Important Impurities: HF, Air.

Disposal: pass in dilute $Ca(OH)_2$ solution.

Detection of Fluorine: Gas test tube .

Suitable Materials: Steel, stainless steel, copper, monel, nickel: necessary is the surface fluorination, PTFE.

Valve Thread: *Europe:* Not standardized .
Germany_: Nr.8, 1" .
USA: CGA connection 679, 1.030"x1/14" LH EXT.

Filling pressue: 28 bar Test pressue: 200 bar.

Toxicological Information:
Absorption of excessive F- can result in acute systemic fluorosis with hypocalmenia, intwerference with various metabolic functions and organ damage (heart, liver, kidneys)

Symptoms of Poisoning:
Very toxic by inhalation. Burns, tearing, nausea, difficulty breathing, headache, dizziness, lung congestion.

First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Immediately call a doctor. Apply artifical respiration if breathing stopped.

Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information:
May cause pH changes in aqueous ecological systems.

Exposure Limits:
TLV(ACGIH): 1 ppm, LC_{50} / 1h : 185 ppm .

Fluorine F_2 DS051.0

Physical Data:

Molar Mass, [5] 37.997 g/mol

Triple Point at 2.52 mbar, [5, 10]
-219.67 ^{0}C (= -363.41 ^{0}F)

Enthalpy of Fusion at T_{mp} , [24]
13.42 kJ/kg (=5.77 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5, 24]
-188.2 ^{0}C (= -199.91 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [24]
171.07 kJ/kg (= 73.56 BTU/lb)

Critical Point, [5, 24]:
-Temperature,
-188.2 ^{0}C (= -306.76 ^{0}F)
- Pressure, 52.15 bar (= 756.37 psia)
- Density Liquid, [24] 0.574 kg/l

Density Gas: ideal 1.6953 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
1.574 g/l (=0.0982lb/ft^3)
- at 15 ^{0}C and 1 bar, [10] 1.587g/l
- at 0 ^{0}C, 1.013 bar, [3] 1.6965 g/l

Density Liquid
- at -160 oC, [24] 1.276 kg/l
- at T_{bp} , 1.013 bar, [10] 1.505 kg/l

1 bar = 14.504 psia , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [4, 5]

-189	-160	-140	-129	^{0}C
1	10.5	31	52.2	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -0,66 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -0.37 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [3] 0.264 mW/(cm K)

Heat Capacity at 25 ^{0}C,1.013 bar, [10] 0.825 kJ/(kg K)

Solubility in Water at 20 ^{0}C and 1.013 bar forms HF(acid)

Dynamic Viscosity at 25 ^{0}C and 1 bar, [28] 22.83 x 10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known. If posssible stop flow of product.
Move away from the container and cool with water from a protected position.
1 bar = 14.504 psia ,
1 g/l = 0.0624 lb/ft3

Identification and Classification:

CAS Number: 07782-41-4
EU Number: 231-954-8
EU Classification: T+, C
EU Symbols: T+, C
Index Number: 009-001-00-0

UN Number: 1045
FLUORINE, compressed
Class/Div: 2.3
ADR/RID: Class 2, Numb. 1TOC
ADR/RID Hazard Number: 265
Labeling ADR/DOT: 0.5, 6.1, 8

EU Classification:

Risk Phrases:
R7: May cause fire.
R26: Very toxic by inhalation.
R35: Causes severe burns

Safety Phrases:
S9: Keep container in a well-ventilated places.
S26: In case of contact with eyes, rinse immediatediately with plenty of water and seek medical advice.
S36/37/39: Wear suitable protective clothing, gloves and eye/face protection.
S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible)

H.Schön: Handbook of Purified Gases

Data Sheet DS102.0 **Date: 07-02-21**

Name: Fluoroethane **Chemical Formula: C_2H_5F**

Synonyms: Ethyl fluoride, R161 **H_3C-CH_2F**

Properties:
Low pressure liquefied gas, flammable, colorless, ether-like odor, anaestethic and elevated concentrations, irritant to the eyes and mucous membranes. Thermal decomposition yields CO, COF_2 and HF.

Production and Purification:
Manufactored by reacton of HF with ethene.
Widespread Applications:
Intermediate in organic syntheses.
Important Impurities: Other HC´s and CFC´s.
Disposal:
Combustion: burner with flash back arrestor. Toxic and corrosive gases formed during combustion should be scrubbed before discharge to air.
Detection of Fluorethane:
Gas test tube. Halogen leak detector.
Suitable Materials: Steel, stainless steel, brass, no copper, PA, PTFE.
Valve Thread: *Europe:* Not standardized.
Germany: No.1, W21,8x1/14" LH.
USA: CGA connection 660, 1.030"-1/14 RH INT.
Filling Density(Factor): 0.57 kg/l at test pressure 30 bar.

Toxicological Information:
No known acute toxicological effects from this product.
Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of coordination. In high concentration may cause asphyxiation.
First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.
Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH):--- ppm, LC50 / 1h : --- ppm

Fluoroethane C_2H_5F DS102.0

Physical Data:

Molar Mass, [5] 48.060 g/mol

Melting Point T_{mp} at 1.013 bar, [5]
-143.2 ^{0}C (= -225.76 ^{0}F)

Enthalpy of Fusion at T_{mp}
kJ/kg (= BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-37.72 ^{0}C (= -35.90 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [28]
425.3 kJ/kg (= 182.84 BTU/lb)

Critical Point:

-Temperature, [5]
102.13 ^{0}C (= 215.83 ^{0}F)

- Pressure, [5]
50.27 bar (= 728.97 psia)

- Density Liquid, [28] 0.8176 kg/l

Density Gas:

- ideal 2.1442 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1 bar
g/l (= lb/ft^3)
- at 15 ^{0}C, 1 bar, [15] 2.039 g/l
- at 0 ^{0}C, 1.013 bar, [11] 2.1879 g/l

Density Liquid at T_{bp} and 1.013 bar,
[28] 0.818 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [12]

-10	0	10	20	^{0}C
3.1	4.3	5.9	8.0	bar

2.Pressure Virial Coefficient

- at 0 ^{0}C: -19 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -14 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and
1.013 bar mW/(cm K)

Heat Capacity at 25 ^{0}C, 1 bar, [28]
1.2193 kJ/(kg K)

Solubility in Water at 20 ^{0}C and
1.013 bar l Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1
bar x 10^{-6} Ns/m^2

Explosion Limits in Air, [28]
3.5-15.4 Vol.-%

Autoignition Temperature
^{0}C (= ^{0}F)

Heating Value MJ/kmol

Suitable Extinguishing Media:
All known.

Identification and Classification:

CAS Number:	00353-36-6
EU Number:	206-531-6
EU Classification:	F+
EU Symbols:	F+
Index Number:	

UN Number:	2453 ETHYL FLUORIDE
Class/Div:	2.1
ADR/RID: Class 2, Number	2F
ADR/RID Hazard Number:	23
Labeling ADR/DOT:	2.1

EU Classification:

Risk Phrases:

R12: Extremely flammable.

Safety Phrases:

S9: Keep container in a well ventilated places.

S16: Keep away from ignition source - No smoking.

S33: Take precautionary measures against static discharges.

H.Schön: Handbook of Purified Gases

Data Sheet DS033.0 **Date: 07-02-23**

Name: Fluoromethane Chemical Formula: CH_3F

Synonyms: Methyl fluoride, R41

Properties:
High pressure liquefied gas, flammable, colorless, sweet odor, anaesthetic protection at elevated concentrations. Irritant to the eyes and mucous membranes. Thermal decomposition yields CO, COF_2 and HF.

Production and Purification:
Fluorination of CH_4.
Widespread Applications:
Propellant gas.
Important Impurities:
HC´s and CFC´s.
Disposal:
Combustion: burner with flash back arrestor. Toxic and corrosive Gases formed during combustion should be scrubbed before discharge to air.
Detection of Fluoromethane:
Detector for flammable gases. IR-Spectrometry.
Suitable Materials: All known metals, no copper- PTFE, PCTFE.
Valve Thread: *Europe:* Not standardized.
Germany: No.1, W21,8x1/14" LH.
USA: CGA connection 350, 0.825"-1/14 LH EXT.
Filling Density(Factor): 0.36 kg/l at test pressure 300 bar.

Toxicological Information:
No known acute toxicological effects from this product.
Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of coordination. In high concentration may cause asphyxiation.
First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.
Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH):--- ppm, LC50 / 1h : --- ppm

Fluoromethane CH_3F **DS033.0**

Physical Data:

Molar Mass, [5] 34.033 g/mol

Melting Point T_{mp} at 1.013 bar, [5]
-141.8 ^{0}C (= -223.24 ^{0}F)

Enthalpy of Fusion at T_{mp}
kJ/kg (= BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-78.27 ^{0}C (= -108.89 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [10]
516 kJ/kg (= 221.83 BTU/lb)

Critical Point:

-Temperature,
[5] 41.85 ^{0}C (= 107.33 ^{0}F)
[24,28] 44.55 ^{0}C (= 112.19 ^{0}F)

- Pressure
[5] 55.48 bar (= 804.68 psia)
[28] 64,85 bar (= 940.58 psia)

- Density Liquid, [10] 0.30 kg/l

Density Gas: ideal 1.5184 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1 bar, [24]
1.409 g/l (= 0.0880 lb/ft^3)
- at 15 ^{0}C, 1 bar, [28] 1.434 g/l
- at 0 ^{0}C, 1.013 bar, [28] 1.5367 g/l

Density Liquid
- at T_{bp} ,1.013 bar, [10] 0.808 kg/l
- at 20 ^{0}C, [12] 0.592 kg/l

Vapor Pressure (about), [44]

-20	0	20	40	^{0}C
1.7	3.8	7.4	13.0	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -11.3 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -7.97 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1 bar, [24] 0.1438 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar, [10] 1.745 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [7] 2.295 g gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C, 1 bar, [24] 12.918 x 10^{-6} Ns/m^2

Explosion Limits in Air
Vol.-%

Autoignition Temperature
^{0}C (= ^{0}F)

Heating Value, [24] 15.335 MJ/kg

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number: 00593-53-3
EU Number: 209-796-6
EU Classification: F+
EU Symbols: F+
Index Number:

UN Number: 2454
FLUOROMETHANE
Class/Div: 2.1
ADR/RID: Class 2, Number 2F
ADR/RID Hazard Number: 23
Labeling ADR/DOT: 2.1

EU Classification:

Risk Phrases:

R12: Extremely flammable.

Safety Phrases:

S9: Keep container in a well ventilated places.

S16: Keep away from ignition source - No smoking.

S33: Take precautionary measures against static discharges.

H.Schön: Handbook of Purified Gases

Data Sheet DS058.0 **Date: 08-03-05**

Name: Germanium Tetrafluoride Chem. Formula: GeF_4

Synonyms: Tetrafluorogermane

Properties: Low pressure liquefied gas, non flammable, colorless, pungent garlic-like odour, very toxic. It hydrolyses in water to form germanium dioxide and H_2GeF_6 .The resulting solution is highly corrosive and even attacks glass.The liquid phase does not exist at atmospheric pressure, i.e. GeF_4 sublimes at -37 °C.

Production and Purification: Manufactured by reacting Germanium tetrachloride or Ge with F_2 , destillation.

Widespread Applications: Used in inplanting in the semiconductor industry.

Important Impurities: Cl- and F-Compounds, Air.

*Disposal:*Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.

Detection of Germanium tetrafluoride: Halogen detector.

Suitable Materials: Steel, stainless steel, copper, monel, nickel: necessary is the surface fluorination, PTFE.

Valve Thread: Europe: Not standardized .
Germany_: Nr.8, 1" .
USA: CGA connection 679, 1.030"x1/14" LH EXT.

Filling Density(Factor): ADR:´2.0 kg/l at test pressure 200 bar .
DOT : 1.91 kg/l at test pressure 420 psi .

Toxicological Information:
May cause chemical burns to skin and cornea (with temporary disturbance to vision)

Symptoms of Poisoning:
Fatal intoxication possible with low concentatios, Irritation to eyes, skin and respiratory tract. Symptoms are headache, nausea and vomitting, which may lead to unconsciousness.

First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information:
Toxic to water organisms. Endangering to drinking water

E*xposure Limits:*
MAK(Germany): 3 ppm, LC_{50} / 1h : ppm .

Germanium Tetrafluoride GeF_4 DS058.0

Physical Data:

Molar Mass, [6] 148.59 g/mol

Melting Point T_{mp} at 4.0 bar, [2]
-15 ^{0}C (=+5 ^{0}F)

Enthalpy of Fusion at T_{mp}
kJ/kg (= BTU/lb)

Sublimation Point T_{subl} at 1.013 bar, [4]
-37 ^{0}C (= -34.6 ^{0}F)

Enthalpy of Sublimation at T_{subl}
kJ/kg (= BTU/lb)

Critical Point, [24]:
-Temperature 93.66 ^{0}C (= 200.58 ^{0}F)
- Pressure 54.82 bar (=795.1 psia)
- Density Liquid 0.9716 kg/l

Density Gas: ideal 6.629 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
6.154 g/l (= 0.3842 lb/ft^3)
- at 17 ^{0}C 6.65 g/l
- at 0 ^{0}C and 1.013 bar --- g/l

Density Liquid
at T_{bp} and 1.013 bar, [2] 2.46 kg/l
- at 25 ^{o}C, [24] 2.162 kg/l

Vapor Pressure (about), [2, 6]

-15	0	10	20	^{0}C
4.0				bar

2.Pressure Virial Coefficient
- at 0 ^{0}C: $\times 10^{-3}$ bar^{-1}
- at 30 ^{0}C: $\times 10^{-3}$ bar^{-1}

Thermal Conductivity at 25 ^{0}C,1.013 bar, [24]
0.1164 mW/(cm K)

Heat Capacity at 25 ^{0}C and 1.013 bar, [24] 0.551 kJ/(kg K)

Solubility in Water at 20 ^{0}C and 1.013 bar hydrolysis

Dynamic Viscosity at 25 ^{0}C and 1 bar, [24] 1.723×10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known. If posssible stop flow of product.
Move away from the container and cool with water from a protected position.

1 bar = 14.504 psi ,
1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number:	07783-58-6
EU Number:	232-011-3
EU Classification:	T+, C
EU Symbols:	T+, C
Index Number:	

UN Number: 3308 Compressed or Liquefied gas, toxic, corosive n.o.s.
GEMANIUM TETRAFLURIDE
Class/Div: 2.3
ADR/RID: Class 2, Number 2TC
ADR/RID Hazard Number: 268
Labeling ADR/DOT: 2.3, 8

EU Classification:
Risk Phrases:
R26: Very toxic by inhalation.
R35: Causes severe burns
Safety Phrases:
S9: Keep container in a well-ventilated places.
S26: In case of contact with eyes, rinse immediattely with plenty of water and seek medical advice.
S28: After contact wwith skin, wash immidiately with plenty of water.
S36: Wear suitable protective clothing.
S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).

H.Schön: Handbook of Purified Gases

Data Sheet DS059.0 **Date: 09-03-29**

Name: Germanium Tetrahydride Chemical Form.: GeH_4

Synonyms: **Germane, Monogermane, Germanomethane**

Properties:
High pressure liquefied gas, flammable, colorless, pungent garlic-like odour, very toxic. Decomposes on heating above than 623 ^{0}C into the elements. It is rapidly oxidised in the air and may auto-ignite in some circumstances.

Production and Purification:
Manufactured by reacting germanium xide with sodium borohydride in acidic solution, byproducts are Digermane and Trigermane. Fractional destillation.
Widespread Applications:
Production of high purity germanium, doping agent in the semiconductor industry.
Important Impurities: Air, Ge-compounds.
Disposal: Combustion. Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.
Detection of Gemanium Tetrahydride: IR-spectrometry.

Suitable Materials:		All known.
Valve Thread:	*Europe:*	Not standardized. Germany: No.1, W21,8x1/14" LH.
	USA:	CGA connection 350, 0.825"-1/14 LH EXT.
Filling Density(Factor):		1.02 kg/l at test pressure 250 bar.

Toxicological Information:
Damage to red blood cells (haemolytic poison). Damage to kidneys and liver.
Symptoms of Poisoning:
Very toxic by inhalation. Delayed adverse effects possible.
First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.
Environmental Information:
Toxic to water organism.

Exposure Limits:
TLV(ACGIH): 0.2 ppm, LC_{50} / 1h : 20 ppm

Germanium Tetrahydride GeH_4 DS059.0

Physical Data:

Molar Mass, [11] 76.642 g/mol

Melting Point T_{mp} at 1.013 bar, [2]
-165.98 ^{0}C (=-266.76 ^{0}F)

Enthalpy of Fusion at T_{mp} , [24]
10.91 kJ/kg (= 4.69 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [24]
-88.15 ^{0}C (= -126.67 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [24]
188.54 kJ/kg (= 81.07 BTU/lb)

Critical Point, [24]:
-Temperature 34.85 ^{0}C (= 94.73 ^{0}F)
- Pressure 55.5 bar (= 904.96 psia)
- Density Liquid 0.5474 kg/l

Density Gas: ideal 3.419 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
3.174 g/l (= 0.1982 lb/ft^3)
- at 15 ^{0}C, 1 bar, [15] 3.224 g/l
- at 0 ^{0}C,1.013 bar, [11] 3.451 g/l

Density Liquid
- at T_{bp} and 1.013 bar, [2] 1.360 kg/l
- at 25 oC, [24] 0.859 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [4]

-10	0	20	^{0}C
14.8	26.5	40.1	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -9.1×10^{-3} bar^{-1}
- at 30 ^{0}C: -6.6×10^{-3} bar^{-1}

Thermal Conductivity at 25 ^{0}C, 1.013 bar, [24] 0.1345 mW/(cm K)

Heat Capacity at 25 ^{0}C and 1.013 bar. [3] 0.5781 kJ/(kg K)

Solubility in Water at 20 ^{0}C and 1.013 bar l gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar, [24] 15.89×10^{-6} Ns/m^2

Explosion Limits in Air, [4]
1-100 Vol.-%

Autoignition Temperature, [4]
350 ^{0}C (= 796 ^{0}F)

Heating Value MJ/kmol

Suitable Extinguishing Media:All known. If posssible stop flow of product. Move away from the container and cool with water from a protected position.

Identification and Classification:

CAS Number: 07782-65-2
EU Number: 231-961-6
EU Classification: F+, T+
EU Symbols: F+, T+
Index Number:

UN Number: 2192
GERMANE
Class/Div: 2.3
ADR/RID: Class 2, Number 2TF
ADR/RID Hazard Number: 236
Labeling ADR/DOT: 2.1, 2.3

EU Classification:

Risk Phrases:

R12: Extremely flammable.
R17: Spontaneously flammable in air.
R26: Very toxic by inhalation.

Safety Phrases:

S1: Keep container locked up.
S9: Keep container in a well ventilated places.
S16: Keep away from sources of ignition - No smoking.
S33: Take precautionary measures against static discharges.
S36: Wear suitable protective clothing. S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible)

H.Schön: Handbook of Purified Gases

Data Sheet DS067.0 **Date: 08-03-21**

Name: Helium, compressed **Chemical Formula: He_2**

Synonyms: R704, He-4 $^{4}_{2}He_2$

Properties: Compressed gas, non flammable, non-toxic, colourless, odourless, extremely chenically inert (noble Gas). Air contains about 0.5 vpm of He, 2 Isotopes: ^{4}He and ^{3}He. Liquefied ^{4}He occurs in 2 distinct states: below at Lambda-point (2.177 K) He passes from normal liquid state He-I to a superfluid state (He-II), in which there are no frictional forces.

Production and Purification: Separation from natural gases, permeation, rectification.
Widespread Applications: Inert shielding gas for welding, carrier gas for gas chromatography, ballon gas, leak detector gas.
Important Impurities:
Air, Ne, Ar, HC´s, Moisture.
Disposal:
Pass in the atmosphere.
Detection of Helium: Mass spectrometry.
Suitable Materials: All known.
Valve Thread: Europe: for 300 bar: No 54, W30x2 RH.
Germany: for 200 bar: No6 W21.8x1/14" RH.
USA: CGA connection 580 ,0.965"x1/14" RH EXT.
Test pressure/service pressure =1.5

Toxicological Information:
No known toxicological effects from this product.
Symptoms of Poisoning:
In high concentrations may cause asphyxiation. Symptoms may include loss of mobility/consciouness. Victim may not be aware the asphyxiation.
First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH):-- ppm, LC50 / 1h :--- ppm .

Helium He$_2$ DS067.0

Physical Data:	He-4	He-3	unit
Molar Mass, [5]	4.003	3.017	g/mol
Triple Point, [10]	---	2	mK
Lambda point, [10]	2.177	---	K
Enthalpy of Fusion at T_{mp}, [24]	12.49		kJ/kg (=5.37 BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [5]	4.30	3.33	K
Enthalpy of Vaporisation at Tbp, [10]	20.3	8.48	kJ/kg
Critical Point:			
-Temperature, [5]	5.19	3.31	K
- Pressure, [5]	2.27	1.14	bar
- Density Liquid, [10]	0.0694	0.0413	kg/l
Density Gas: ideal	0.17858	0.13456	g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1,013 bar, [24]	0.166		g/l (=0.0104 lb/ft3)
- at 15 ^{0}C and 1 bar, [10]	0.167	0.128	g/l
- at 0 ^{0}C and 1.013 bar, [3]	0.175	0.1345	g/l
Density Liquid at Tbp and 1.013 bar, [10]	0.125	0.059	kg/l
2.pressure virial coefficient,[11]			
- at 0 ^{o}C	+0.53 . 10^{-3}		1/bar
- at 30 ^{o}C	+0.47 . 10^{-3}		1/bar

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft3

Identification and Classification:	
CAS Number:	07440-59-7
EU Number:	231-168-5
EU Classification:	---
EU Symbols:	---
Index Number:	

UN Number: 1046	
	HELIUM, compressed
Class/Div:	2.2
ADR/RID: Class 2, Number	1A
ADR/RID Hazard Number:	20
Labeling ADR/DOT:	2.2

EU Classification:
Risk Phrases:
RAs: Asphyxiant in high concentrations.

Safety Phrases:
S3: Keep locked up
S7: Keep container tightly closed
S9: Keep container in a well ventilated places.
S23: Do not breathe gas.

H.Schön: Handbook of Purified Gases

Data Sheet DS104.0 **Date: 07-02-25**

Name: Heptafluoropropane Chemical Formula: C_3HF_7

Synonyms: 1,1,1,2,3,3,3-Heptafluoropropane, R227
Apaflurane **F_3C-CHF-CF_3**

Properties:
Low pressure liquefied gas, non flammable, non-toxic, colorless, ether-like odor. Thermal decomposition yields CO, COF_2 and HF.

Production and Purification:
Manufactured by dimerising tetrafluoropropane.
Widespread Applications:
Propelelnt gas, replacement for R12 and R114.
Important Impurities: Other HC´s and CFC´s.
Disposal:
Combustion: burner with flash back arrestor. Toxic and corrosive Gases formed during combustion should be scrubbed before discharge to air.
Detection of Heptafluoropropane:
Halogen leak detector. IR-spectrometry.

Suitable Materials: All known.
Valve Thread: *Europe:* Not standardized.
Germany: No. 6, W21,8x1/14" RH.
USA: CGA connection 350, 0.855"x1/14" LH
Filling Density(Factor): 1.20 kg/l at test pressure 15 bar.

Toxicological Information:
No known acute toxicological effects from this product.
Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of coordination. In high concentration may cause asphyxiation.
First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.
Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH):--- ppm, LC50 / 1h : --- ppm

Heptafluoropropane C_3HF_7 DS104.0

Physical Data:
Molar Mass, [5] 170,03 g/mol
Melting Point T_{mp} at 1.013 bar, [18]
-131 ^{0}C (= -203.8 ^{0}F)
Enthalpy of Fusion at T_{mp}
kJ/kg (= BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [16]
-17.30 ^{0}C (= +0.86 ^{0}F)
Enthalpy of Vaporisation at T_{bp}, [28]
131.37 kJ/kg (= 59.055 BTU/lb)
Critical Point:
-Temperature, [5]
102.85 ^{0}C (= 217.30 ^{0}F)
- Pressure, [16]
28.7 bar (= 416.26 psia)
- Density Liquid, (12) 0.59 kg/l
Density Gas:
- ideal 7.5860 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1 bar
g/l (= lb/ft^3)
- at 15 ^{0}C, 1 bar, [15] 7.3581 g/l
- at 0 ^{0}C, 1.013 bar, [11] 7.9184 g/l
Density Liquid at T_{bp} and 1.013 bar, [28] 1.538 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [4,28]

-10	0	10	20	^{0}C
1.38	2.02	3.99	7.99	bar

2.Pressure Virial Coefficient, [28]
- at 0 ^{0}C: - 4.2 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -2.9 x 10^{-3} bar^{-1}
Thermal Conductivity at 15 ^{0}C and 1.013 bar mW/(cm K)
Heat Capacity at 30 ^{0}C, 1 bar, [28] 0.8075 kJ/(kg K)
Solubility in Water at 20 ^{0}C, 1.013 bar, [18] 0.3-0.6 g Gas / kg H_2O
Dynamic Viscosity at 25 ^{0}C and 1 bar, [18] 27 x 10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

Identification and Classification:
CAS Number: 00431-89-0
EU Number: 207-079-2
EU Classification:
EU Symbols:
Index Number:

UN Number: 3296
HEPTAFLUOROPROPANE
Class/Div: 2.2
ADR/RID: Class 2, Number 2A
ADR/RID Hazard Number: 20
Labeling ADR/DOT: 2.2

EU Classification:
Risk Phrases:
Not classified

Safety Phrases:
Not classified

H.Schön: Handbook of Purified Gases

Data Sheet DS056.0 **Date: 07-03-01**

Name:Hexafluoro-1,3-Butadiene Chemical Formula: C_4F_6

Synonyms: 1,1,2,3,4,4-Hexafluoro-1,3-Butadiene, Sifren46,
Perfluorobutadiene-1,3 **$F_2C=CF-FC=CF_2$**

Properties:
Low pressure liquefied gas, flammable, toxic, colorless, odorless. Thermal decomposition yields CO, COF_2 and HF.

Production and Purification:
Fluorination of 1,3-butadiene.
Widespread Applications:
High performance etch gas.
Important Impurities: Other HC´s and CFC´s.
Disposal:
Combustion: burner with flash back arrestor. Toxic and corrosive Gases formed during combustion should be scrubbed before discharge to air. Contact pupplier if guidance is required.
Detection of Sifren46:
Halogen leak detector. IR-spectrometry.
Suitable Materials: Stainless steel, brass, monel, PTFE, PCTFE.
Valve Thread: *Europe:* Not standardized.
Germany: No.1, W21,8x1/14" LH.
USA: CGA connection 350, 0.855"-1/14 LH EXT.
Filling Density(Factor): 1.25 kg/l at test pressure 300 bar.

Toxicological Information:
Irritation of respiratory tract. May produce irregular heart beat and nervous symptoms.
Symptoms of Poisoning: In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of co-ordination. In high concentration may cause asphyxiation.
First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested, call a doctor. Apply artificial respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.
Environmental Information:
No known ecological damage caused by this product.
E*xposure Limits:* Proposal of manufacturer [*].
TLV(ACGIH): 0.5 ppm, LC_{50} / 1h : 1300 ppm .

Hexafluoro-1,3-Butadiene C_4F_6 DS056.0

Physical Data:

Molar Mass, [17,*] 162.03 g/mol

Melting Point T_{mp} at 1.013 bar, [*]
-130 ^{0}C (= -202 ^{0}F)

Enthalpy of Fusion at T_{mp}
kJ/kg (= BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [*]
5.5 ^{0}C (= 42 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [*]
161.8 kJ/kg (= 69.56 BTU/lb)

Critical Point:
-Temperature, [*]
139.6 ^{0}C (= 283.28 ^{0}F)
- Pressure,[*] 31.9 bar (= 462.68 psia)
- Density Liquid kg/l

Density Gas:
- ideal 7.229 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1 bar
g/l (= lb/ft^3)
- at 15 ^{0}C, 1 bar, [*] 6.8 g/l
- at 0 ^{0}C and 1.013 bar --- g/l

Density Liquid at 15 ^{0}C and 1 bar, [*]
1.44 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [*]

-10	0	10	20	^{0}C
	0.81	1.22	1.77	bar

2.Pressure Virial Coefficient
- at 0 ^{0}C: x 10^{-3} bar^{-1}
- at 30 ^{0}C: x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar mW/(cm K)

Heat Capacity at 25 ^{0}C and 1 bar, [*] 0.8437 kJ/(kg K)

Solubility in Water at 20 ^{0}C and 1.013 bar, [*] insoluble

Dynamic Viscosity at 25 ^{0}C and 1 bar x 10^{-6} Ns/m^2

Explosion Limits in Air, [*]
7-73 Vol.-%

Autoignition Temperature
^{0}C (= ^{0}F)

Heating Value MJ/kmol

Suitable Extinguishing Media:
All known.

[*] Solvay Fluor GmbH Hannover/ Germany,
Sifren46: product description 2007

Identification and Classification:

CAS Number: 00685-63-2
EU Number: 211-681-0
EU Classification: F, Xn
EU Symbols: F, Xn
Index-No:--
UN Number: 3160

Liquefied gas,toxic,flammable, n.o.s.
HEXAFLUORO-1,3-BUTADIENE
Class/Div: 2.3, 2.1
ADR/RID: Class 2, Number 2TF
ADR/RID Hazard Number: 263
Labeling ADR/DOT: 2.3, 2.1

EU Classification:
Risk Phrases:

R11: Highly flammable.
R20: Harmful by inhalation.

Safety Phrases:

S9: Keep container in a well-ventilated places.
S16: Keep away from source of ignition - No smoking.
S23: Do not breeathe gas,
S41: In case of fire and / or explo sion, do not breathe fumes.

H.Schön: Handbook of Purified Gases

Data Sheet DS055.0 **Date: 07-02-26**

Name: Hexafluoroethane Chemical Formula: C_2F_6

Synonyms: Perfluoroethane, Ethylhexafluoride, R116 **F_3C-CF_3**

Properties:
High pressure liquefied gas, non flammable, non toxic, colorless, odorless. Chemically and thermally very stable.

Production and Purification:
Manufactured by the indirect fluorination of ethane with cobalt trifluoride or silver difluoride. Rectification.

Widespread Applications: Used as a dielectric, aerosol propellant gas.
Important Impurities: Other HC´s and CFC´s (CF_4, HF).
Disposal:
Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.
Detection of Hexafluoroethane:
Halogen leak detector. IR-spectrometry.

Suitable Materials: All known.
Valve Thread: *Europe:* Not standardized.
Germany: No.6, W21,8 x 1/14" RH.
USA: CGA connection 320, 0.825"-1/14 RH EXT.
Filling Density(Factor): 1.10 kg/l at test pressure 200 bar.

Toxicological Information:
No known acute toxicological effects from this product.
Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of coordination. In high concentration may cause asphyxiation.
First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.
Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH):--- ppm, LC50 / *1h : --- ppm*

Hexafluoroethane C_2F_6 DS055.0

Physical Data:

Molar Mass, [5] 138.012 g/mol

Triple Point at 0.265 bar, [5]
-100.10 ^{0}C (= -148.18 ^{0}F)

Enthalpy of Fusion at T_{mp} , [24]
19.46 kJ/kg (= 8.37 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-77.94 ^{0}C (= -108.29 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [10]
116.7 kJ/kg (= 50.17 BTU/lb)

Critical Point:

-Temperature, [5]
19.89 ^{0}C (= 67.80 ^{0}F)

- Pressure, [5]
30.39 bar (= 440.78 psia)

- Density Liquid, [28 0.622 kg/l

Density Gas:

- ideal 6.1575 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1 bar, [24]
5.716 g/l (= 0.3569 lb/ft^{3})
- at 15 ^{0}C, 1 bar, [10] 5.829 g/l
- at 0 ^{0}C, 1.013 bar, [28] 6.2474 g/l

Density Liquid

- at T_{bp} , 1.013 bar, [10] 1.608 kg/l
- at 0^{0}C 1.112 kg/l

Vapor Pressure (about), [4,5]

-10	0	10	20	^{0}C
14	18.5	23.8	30.4	bar

2.Pressure Virial Coefficient, [11]

- at 0 ^{0}C: -14.2 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -9.94 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.1613 mW/(cm K)

Heat Capacity at 25 ^{0}C and 1 bar, [28] 0.3557 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [28] 7.9 ppm-wt

Dynamic Viscosity at 25 ^{0}C and 1 bar, [28] 14.77 x 10^{-6} Ns/m^{2}

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^{3}

Identification and Classification:

CAS Number:	00076-16-4
EU Number:	200-939-8
EU Classification:	
EU Symbols:	
Index Number:	

UN Number:	2193 HEXAFLUOROETHANE
Class/Div:	2.2
ADR/RID: Class 2, Number	2A
ADR/RID Hazard Number:	20
Labeling ADR/DOT:	2.2

EU Classification:
Risk Phrases:

RAs: Asphyxiant in high concentrations.

Safety Phrases:

S9: Keep container in a well ventilated places.

S23: Do not breathe gas,,

H.Schön: Handbook of Purified Gases

Data Sheet DS116.0 **Date: 07-02-27**

Name: Hexafluoropropylene **Chemical Formula: C_3F_6**

Synonyms: 1,1,2,3,3,3-Hexafluoro-1-propene, Perfluoropropene, HFP, R1216 **$F_2C{=}CF{-}CF_3$**

Properties:
Low pressure liquefied gas, non flammable, relatively non-toxic, colorless, odorless. Thermal decomposition yields CO, COF_2 and HF.

Production and Purification:
Byproduct in the pyrolysis of R22.

Widespread Applications:
Used in the formation of copolymers. Intermediate in organic syntheses.

Important Impurities: Other HC´s and CFC´s.

Disposal:
Combustion: burner with flash back arrestor. Toxic and corrosive Gases formed during combustion should be scrubbed before discharge to air.

Detection of Hexafluoropropylene:
Halogen leak detector, IR-spectrometry.

Suitable Materials: All known.

Valve Thread: *Europe:* Not standardized.
Germany: No.6, W21,8x1/14" RH.
USA: CGA connection 660 , 1.030"-1/14 RH EXT.

Filling Density(Factor): 1.11 kg/l at test pressure 22 bar.

Toxicological Information: May have damaging effect on respiratory system, central nervous system and liver.

Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of coordination. In high concentration may cause asphyxiation.

First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.

Environmental Information:
May cause pH changes in aquaeous ecological systems.

Exposure Limits:
TLV(ACGIH): --- ppm, LC_{50} / 1h : 5600 ppm

Hexafluoropropylene C_3F_6 DS116.0

Physical Data:

Molar Mass, [11] 150.023 g/mol
Melting Point T_{mp} at 1.013 bar, [24]
-156.5 ^{0}C (= -249.7 ^{0}F)
Enthalpy of Fusion at T_{mp}
kJ/kg (= BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [12]
-29.6 ^{0}C (= -21.28 ^{0}F)
Enthalpy of Vaporisation at T_{bp}, [24]
129.31 kJ/kg (= 55.6 BTU/lb)
Critical Point:
-Temperature
[12] 86.20 ^{0}C (= 187.16 ^{0}F)
[24] 94.85 ^{0}C (= 202.73 ^{0}F)
[28] 124.65 ^{0}C (= 256.37 ^{0}F)
- Pressure
[12] 30.0 bar (= 435,12 psia)
[28] 54.95 bar (= 796.99 psia)
- Density Liquid, [12] 0.56 kg/l
Density Gas:
- ideal 6.6933 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1 bar, [24]
6.213 g/l (=0.3879 lb/ft^3)
- at 15 ^{0}C, 1 bar, [28] 6.438 g/l
- at 0 ^{0}C, 1.013 bar, [11] 6.9145 g/l
Density Liquid
- at T_{bp} and 1.013 bar , [12] 1.44 kg/l
- at 25 ^{0}C, 1 bar, [24] 1.304 kg/l

Vapor Pressure (about), [12,28]

-10	0	10	20	^{0}C
2.4	3.4	4.8	6.7	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -31 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -23 x 10^{-3} bar^{-1}
Thermal Conductivity at 15 ^{0}C and 1 bar, [24] 0.1019 mW/(cm K)
Heat Capacity at 25 ^{0}C, 1.013 bar, [24] 0.775 kJ/(kg K)
Solubility in Water at 20 ^{0}C and 1.013 bar l Gas / kg H_2O
Dynamic Viscosity at 25 ^{0}C, 1 bar, [24] 12.831 x 10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number:	00116-15-4
EU Number:	204-127-4
EU Classification:	Xn, Xi
EU Symbols:	Xn
Index Number:	602-061-00-4

UN Number:	1858
	HEXAFLUOROPROPYLENE
Class/Div:	2.2
ADR/RID: Class 2, Number	2A
ADR/RID Hazard Number:	20
Labeling ADR/DOT:	2.2

EU Classification:
Risk Phrases:
R20: Harmful by inhalation
R37: Irritating to respiratory system.

Safety Phrases:
S41: In case of fire or explosion, do not breathe fumes.

H.Schön: Handbook of Purified Gases

Data Sheet 075.0 **Date: 08-02-17**

Name: Hydrogen **Chemical Formula: H_2**

Synonyms: Hydrogenium, Dihydrogen, Protium $^{1}_{1}H_2$

*Properties:*Non-liquefied, compressed gas, the first stable hydrogen isotop is the most abundant element in the Universe, very light gas, flammable, colorless, odourles, non-toxic, with air or O_2 forms the detonating gas. Hydrogen molecules can exist as ortho-H_2 (with parallel spins of protons) and para-H2 (with antiparallel spins), and above -73° C a mixture of 75% ortho- und 25% para-H_2 is present as normal H_2 .

Production and Purification: Majority is manufactured from petrochemical raw materials by cracking and reforming. Other processes electrolysis of water, oxidation of base metals (zinc, iron) by acids.
*Widespread Applications:*Widely used for hydrogenetion of vegetable and animals oils and fat, used in metallurgy of its ability to reduce metal oxides.
Important Impurities:
Air, D_2, HD, HC´s
Disposal: combustion .

Detection of hydrogen: Detector for flammable gases, gas test tube.
Suitable Materials: All known.
Valve Thread: *Europe:* for 300 bar: No 57, W30x2 LH.
Germany: for 200 bar: No 1 W21.8x1/14" LH.
USA: CGA connection 350, 0.825"x1/14" LH EXT.
Test pressure/service pressure =1.5

Toxicological Information:
No known toxicological effects from this product.
Symptoms of Poisoning:
In high concentrations may cause asphyxiation, may include loss of mobility/ consciousness. Victim may not be aware of asphyxiation.
First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Do not discharge into areas there is a risk of forming an explosive mixture *with air.*
Environmental Information: No known ecological damage caused by this product.
Exposure Limits:
TLV(ACGIH): --- ppm, *LC50 / 1h : --- ppm*

Hydrogen **H_2** **DS075.0**

Physical Data:

Molar Mass, [3] 2.0158 g/mol

Triple Point, [3]

ortho	para
13.957 K	13.800 K
at 0.0720 bar	0.0704 bar

Enthalpy of Fusion at T_{mp} ,[24]
58.04 kJ/kg (= 24.96 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [3]
ortho 20.39 K (= -252.76 ^{0}C)
para 20.28 K (= -252.87 ^{o}C)

Enthalpy of Vaporisation at T_{bp} , [24]
228.17 kJ/kg (= 98.11 BTU/lb)

Critical Point, [3]:
-Temperature
ortho 33.90 K (= -239.25 ^{0}C)
para 32.938 K (= -240.21 ^{o}C)
- Pressure ortho 13.15 bar
para 2.838 bar
- Density Liquid ortho 0.03012 kg/l
para 0.03136 kg/l

Density Gas: ideal 0.089945 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
0.083 g/l (=0.0052 lb/ft^3)
- at 15 ^{0}C and 1 bar, [3] 0.08409 g/l
- at 0 ^{0}C and 1.013 bar, [3] 0.08988 g/l

Density Liquid at T_{bp} and 1.013 bar, [10] 0.0708 kg/l

Vapor Pressure (about), [4]

-253	-249	-245	-243	^{0}C
1	2.6	5.7	8.2	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: +0.6 x 10^{-3} bar^{-1}
- at 30 ^{0}C: +0.58 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 1.769 mW/(cm K)

Heat Capacity at 25 ^{0}C,1.013 bar, [10] 14.27 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 0.0178 l gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C, 1 bar, [3] 8.92 x 10^{-6} Ns/m^2

Explosion Limits in Air, [13]
4-77 Vol.-%

Autoignition Temperature,
[13] 560 ^{0}C (= 1040 ^{0}F)
[24] 400 ^{o}C (= 752 ^{o}F)

Heating Value, [24]
11.99 MJ/kmol

Suitable Extinguishing Media:
all known.

Identification and Classification:

CAS Number: 1333-74-0
EU Number: 215-605-7
EU Classification: F+
EU Symbols: F+
Index Number: 001-001-00-9

UN Number: 1049
HYDROGEN, compressed
Class/Div: 2.1
ADR/RID: Class 2, Number 1F
ADR/RID Hazard Number: 23
Labeling ADR/DOT: 2.1

EU Classification:

Risk Phrases:

R12: Extremely flammable.

Safety Phrases:

S2: Keep out of the reach of children.

S9: Keep container in a well ventilated places.

S16: Keep away from sources of ignition - No smoking.

S33: Take precautionary measures against static discharges.

H.Schön: Handbook of Purified Gases

Data Sheet DS005.0 **Date: 07-06-26**

Name: Hydrogen bromide Chemical Formula: HBr

Synonyms: Hydro bromide acid-anhydrous, HBR

Properties:
Low pressure liquefied gas, non flammable, colorless, pungent odour, toxic, corrosive. Forms white fumes with moist air.

Production and Purification:
Usually manufactured from H_2 and Br_2 in gaseous state in the presence of a noble metal catalysts. Destillation.

Widespread Applications:
Used as a reagent and catalyst in organic and inorganic synthesis. Filling gas for halogen bulbs, etching gas in the semiconductor industry.

Important Impurities:
Air, H_2O, HCl, S-Compunds, Fe.

Disposal: Pass in dilute NaOH- or KOH-solution.

Detection of HBr: Gas test tube.

Suitable Materials: Stainless steel, monel, no brass, copper or magnesium .
PTFE, PCTFE, PVDF, EPDM .

Valve Thread: *Europe:* Not standardized.
Germany: No.6, 21.8x 1/14" RH.
USA: CGA connection 330, 0.825"-1/14 LH EXT.

Filling Density(Factor): 1.54 kg/l at test pressure 60 bar.

Toxicological Information:
In high concentration severe corrosion to skin, eyes and respiratory tract. Delayed fatal pulmonary edema possible.

Symptoms of Poisoning:
Toxic by inhalation.
May cause severe chemical burns to skin and cornea.

First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information:
May cause pH changes in aqueous ecological systems.

Exposure Limits:
TLV(ACGIH): 3 ppm, LC_{50} / 1h : 2860 ppm .

Hydrogen bromide **HBr** **DS005.0**

Physical Data:

Molar Mass, [5] 80.912 g/mol

Triple Point at 0.299 bar, [10, 28]
-86.81 ^{0}C (= -124.26 ^{0}F)

Enthalpy of Fusion at T_{mp}, [10]
35.4 kJ/kg (= 15.22 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-66.69 ^{0}C (= 152.04 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [10]
217.7 kJ/kg (= 93.59 BTU/lb)

Critical Point:
-Temperature, [5]
90.05 ^{0}C (= 194.09 ^{0}F)
- Pressure, [5]
85.10 bar (= 1,234.29 psia)
- Density Liquid, [10] 0.807 kg/l

Density Gas:
- ideal 3.6099 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
3.351 g/l (= 0.2092 lb/ft^{3})
- at 15 ^{0}C, 1 bar, [10] 3.409 g/l
- at 0 ^{0}C, 1.013 bar, [11] 3.645 g/l

Density Liquid, [10]
- at T_{bp} and 1.013 bar 2.203 kg/l
- at 20 ^{0}C 1.790 kg/l

Vapor Pressure (about), [12]

-10	0	10	20	^{0}C
9.4	12.5	16.2	20.9	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -9.6 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -7.0 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.094 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar [10] 0.36 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar highly soluble

Dynamic Viscosity at 25 ^{0}C, 1 bar [28] 18.75 x 10^{-6} Ns/m^{2}

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^{3}

Identification and Classification:

CAS Number:	10035-10-6
EU Number:	233-113-0
EU Classification:	C, Xi
EU Symbols:	C
Index Number:	035-002-00-0

UN Number: 1048	HYDROGEN BROMIDE, anhydrous
Class/Div:	2.3
ADR/RID:	Class 2, Number 2TC
ADR/RID Hazard Number:	268
Labeling ADR/DOT:	2.3, 8

EU Classification:
Risk Phrases:
R35: Cause severe burns.
R37: Irritating to respiratory system.

Safety Phrases:
S1/2: Keep locked up and out of the reach of children
S7/9: Keep container tigtly closed and in a well ventilated place.
S26: In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.
S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible)

H.Schön: Handbook of Purified Gases

Data Sheet DS041.0 **Date: 08-01-02**

Name: Hydrogen chloride anhydrous Chem. Formula: HCl

Synonyms: Hydrochloric Acid gas, Spirits of salt, Muriatic Acid

Properties:

High pressure liquefied gas, non flammable, colourless, pungent odour, toxic, corrosive, irritant. Reacts with basic substances exotherm to form salts, corrodes base metals as iron, zinc and magnesium

Production and Purification:

Manufactured by concentrated sulphuric acid acts on sodium chloride. Other methods include burning chlorine detonating gas or the decomposition of phosphorus trichloride with water.

Widespread Applications: Used in the production of organic chlorides, as catalyst and chemical intermediate. Etching gas in the semiconductor industry.

Important Impurities: Air gases, Moisture, HC´s

Disposal: Pass in water or dilute alcaline solution.

Detection of Hydrogen Chloride: Gas test tube.

Suitable Materials: All known, no aluminium, stannous, tin, copper, zinc.

Valve Thread: *Europe:* Not standardized.
Germany: No.8, 1" RH.
USA: CGA connection 330, 0.825"-1/14 LH EXT.

Filling Density(Factor): 0,74 kg/l at test pressure 200 bar.

Toxicological Information: Delayed fatal pulmonary oedema possible Severe corrosion to skin, eyes and respiratory tract at high concentrations.

Symptoms of Poisoning:

Respiratory tract, skin, eyes and mucous membrane burns.

First Aid:

Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.

Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information: Toxic to water organisms. May cause pH changes in aqueous ecological *systems.*

Exposure Limits:

TLV(ACGIH): 5 ppm, LC50 / 1h : 2810 ppm .

Hydrogen chloride anhydrous HCl DS041.0

Physical Data:

Molar Mass, [5] 36.461 g/mol

Triple Point at 0.138 bar, [5, 10]
-114.18 ^{0}C (= -173.52 ^{0}F)

Enthalpy of Fusion at T_{mp}, [24]
54.8 kJ/kg (=0.0943 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-85 ^{0}C (= -121 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [24]
478.05 kJ/kg (= 205.56 BTU/lb)

Critical Point:
-Temperature, [5]
51.54 ^{0}C (= 124.77 ^{0}F)
- Pressure, [24]
83.09 bar (= 1205.12 psia)
- Density Liquid, [24] 0.45 kg/l

Density Gas: ideal 1.6267 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
1.510 g/l (=0.0943 lb/ft^3)
- at 15 ^{0}C and 1 bar, [10] 1.536 g/l
- at 0 ^{0}C, 1.013 bar, [5] 1.6422 g/l

Density Liquid, [10]
- at T_{bp} at 1.013 bar 1.191kg/l
- at 20 ^{0}C 0.836 kg/l

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
19.7	25.8	33.2	42.2	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -9.3×10^{-3} bar^{-1}
- at 30 ^{0}C: -6.4×10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C, 1.013 bar, [10] 0.169 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar, [24] 0.798 kJ/(kg K)

Solubility in Water at 20 ^{0}C and 1.013 bar Hydrolyses

Dynamic Viscosity at 25 ^{0}C and 1 bar, [3] 14.60×10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi ,
1g/l = 0.0624 lb/ft3

Identification and Classification:

CAS Number: 07647-01-0
EU Number: 231-595-7
EU Classification: C, Xi
EU Symbols: C, Xi
Index Number: 017-002-01-X

UN Number: 1050 HYDROGEN CHLORIDE, anhydrous
Class/Div: 2.3
ADR/RID: Class 2, Number 2TC
ADR/RID Hazard Number: 268
Labeling ADR/DOT: 2.3, 8

EU Classification:

Risk Phrases:

R23: Toxic by inhalation.
R35: Causes severe burns

Safety Phrases:

S1/2:Keep locked up and out of the reach of children.
S9: Keep container in a well-ventilated places.
S26: In case of contact with eyes, rinse immdiately with pleenty of water and seek medical advice
S36/37/39: Wear suitable protective clothing, gloves and eye/face protection.
S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).

H.Schön: Handbook of Purified Gases

Data Sheet DS112.0 **Date: 08-01-08**

Name: Hydrogen cyanide, stabilized Chem. Formula: HCN

Synonyms: Hydrovyanic acid(anhydrous), Formonitrile,
Prussic acid (anhydrous) **H-C$\equiv$N**

Properties:
Low pressure liquefied gas, flammable, very toxic, colourless, almond odour, in present of moisture corrosive to many metals. Under temperature polymerisation, stabilisator: inorganic acids or sulphur dioxide.
HCN is mixable with water and ethanol.

Production and Purification: Manufactured by Andrussow process from CH_4, NH_3 and air at about 1000 ^{0}C over a catalyst (Pt/Rh), rectification.
Widespread Applications: Used in the manufacture of acrylonitrile, methyl metacrylate, adiponitrile for nylon, pharmaceuticals.
Important Impurities Air, Moisture, HC´s.
Disposal: Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.
Detection of Hydrogen cyanide: Gas test tube.
Suitable Materials: Steel, stainless steel, monel, PTFE, PCTFE, PVDF.
Valve Thread: Europe: Not standardized.
Germany: No.5, 1" LH.
USA: CGA connection 660, 1.030"-1/14 RH EXT.
Filling Density(Factor): 0.55 kg/l at test pressure100 bar.

Toxicological Information: The half-life for the conversion of cyanide to thiocyanide from a non-lethal dose in man is between 20 and 60 minutes.
Symptoms of Poisoning: Low-level exposure: cyanosis, headache, dizziness, unsteadiness of gait, a feeling of suffocation and nausea.High-level exposure: rapidly leads to paralysis, unconsciouness, convulsions, pespiratry arrest and death.
First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.
Environmental Information:
HCN is very unstable and sensitive to heat, light and moisture. All work practices should be aimed at eleminating environmental contamination.
Exposure Limits:
TLV(ACGIH): 0.3 ppm, LC_{50} / 1h : 50 ppm .

Hydrogen cyanide, stabilized HCN DS112.0

Physical Data:
Molar Mass, [28] 27.0256 g/mol
, Triple Point at 0.187 bar, [24]
-13.24 ^{0}C (=+8.17 ^{0}F)
Enthalpy of Fusion at T_{mp} , [24]
311.03 kJ/kg (= 133.74 BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [12]
25.70 ^{0}C (= 78.26 ^{0}F)
Enthalpy of Vaporisation at T_{bp} , [24]
1016.8 kJ/kg (= 437.22 BTU/lb)
Critical Point: [12]
-Temperature 183.50 ^{0}C (=362.3 ^{0}F)
- Pressure 53.90 bar (= 781.9 psia)
- Density Liquid 0.195 kg/l
Density Gas: ideal 1.2058 g/l
- at 70 ^{0}F (= 21.1 ^{0}C),1,013 bar, [24]
1.119 g/l (= 0.0699 lb/ft^3)
- at 15 ^{0}C and 1 bar --- g/l
- at 0 ^{0}C and 1.013 bar --- g/l
Density Liquid
- at 25 ^{0}C, [24] 0.68 kg/l
- at T_{bp} and 1.013 bar, [28] 0.667 kg/l
1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
0.15	0.29	0.49	0.78	bar

2.Pressure Virial Coefficient, [28]
- at 0 ^{0}C: -111 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -64 x 10^{-3} bar^{-1}
Thermal Conductivity at 15 ^{0}C and 1.013 bar, [28] 12.2 mW/(cm K)
Heat Capacity at 25 ^{0}C and 1.013 bar, [24] 1.329 kJ/(kg K)
Solubility in Water at 20 ^{0}C and 1.013 bar total
Dynamic Viscosity at 25 ^{0}C and 1 bar x 10^{-6} Ns/m^2
Explosion Limits in Air
[5.4-40.6 Vol.-%
[24] 6-41 Vol.-%
Autoignition Temperature, [24]
537.8 ^{0}C (= 1000 ^{0}F)
Heating Value, [24]
2.306 MJ/kmol
Suitable Extinguishing Media:
All known.

Identification and Classification:
CAS Number: 0074-90-8
EU Number: 200-821-6
EU Classification: F+, T+, N
EU Symbols: T+, N
Index Number: 006-006-00-X

UN Number:1051 Hydrogen cyanide, stabilized
Class/Div: 6.1
ADR/RID: Class 2, Number TF1
ADR/RID Hazard Number: 663
Labeling ADR/DOT: 3, 6.1

EU Classification:
*Risk Phrases:*R12: Extremely flammable.R26: Very toxic by inhalation. R50/53:Very toxic to aquqtic organism,may cause long-time adverse effect in the aquatic environment.
Safety Phrases:
S7/9: Keep vontainer tightly closed and in a well ventilated places.
S16: Keep away from sources of ignition- No smoking
S36/37: Wear suitable protective clothing and eye/face protection.
S38 : In case of insufficient ventilation, wear suitable respiratory equipment.
S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible)

H.Schön: Handbook of Purified Gases

Data Sheet DS060.0 **Date: 08-02-29**

Name: Hydrogen fluoride, anhydrous **Chemical Formula:**

Synonyms: Hydrofluoric acid gas, Fluorhydric acid gas, AHF **HF**

*Properties:*Low pressure liquefied gas, non flammable, colorless, pungent odour, very toxic, corrosive. It is one of the most important fluorine compounds. In water hydrolysis.

Production and Purification:
Obtained from fluorspar (calcium fluoride) and sulphuric acid, calcium sulphat is formed as a byproduct.
Widespread Applications:
Used as solvent and for fluorination, etching gas in glass and metal industry.
Important Impurities:
S-compounds, Air
Disposal: Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.
Detection of Hydrogen fluoride: Gas test tube.

Suitable Materials: Steel, stainless steel, monel, PTFE, PCTFE, PVDF.
Valve Thread: *Europe:* Not standardized.
Germany: No.8, 1" RH.
USA: CGA connection 660, 1.030"-1/14 RH EXT.
Filling Density(Factor): 0.84 kg/l at test pressure 10 bar.

Toxicological Information:
Absorption of excessive F- can result in acute systemic fluorosis with hypocalmenia, interference with various metabolic functions and organ damage (heart, liver, kidneys)
Symptoms of Poisoning:
Very toxic by inhalation. Burns, tearing, nausea, difficulty breathing, headache, dizziness, lung congestion.
First Aid: Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.
Environmental Information:
May cause pH changes in aqueous ecological systems.
Exposure Limits:
TLV(ACGIH): 3 ppm, LC_{50} / 1h : 1276 ppm.

Hydrogen fluoride, anhydrous **HF** **DS060.0**

Physical Data:

Molar Mass, [5] 20.006 g/mol
Melting Point T_{mp} at 1.013 bar, [24]
-83.36 ^{0}C (= -118.05 ^{0}F)
Enthalpy of Fusion at T_{mp} , [24]
228.93 kJ/kg (=98.44 BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [5]
19.53 ^{0}C (= 67.13 ^{0}F)
Enthalpy of Vaporisation at T_{bp} , [24]
1420.57 kJ/kg (= 610.85 BTU/lb)
Critical Point, [24]:
-Temperature 188 ^{0}C (=370.4 ^{0}F)
- Pressure 64.85 bar (= 940.57 psia)
- Density Liquid 0.2899 kg/l
Density Gas: ideal 0.8926 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
0.829 g/l (=0.0517 lb/ft^3)
- at 15 ^{0}C and 1 bar --- g/l
- at 0 ^{0}C and 1.013 bar --- g/l
Density Liquid
- at 0 oC, [4] 1.002 kg/l
- at T_{bp} and 1.013 bar, [3] 0.968 kg/l
1 bar = 14.504 psi

Vapor Pressure (about), [1, 4]

-10	0	10	20	50	^{0}C
0.315	0.48	0.72	1.08	2.74	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -35.6×10^{-3} bar^{-1}
- at 30 ^{0}C: -24.1×10^{-3} bar^{-1}
Thermal Conductivity at 15 ^{0}C and 1.013 bar, [3] 5.89 mW/(cm K)
Heat Capacity at 25 ^{0}C and 1.013 bar, [3] 1.457 kJ/(kg K)
Solubility in Water at 20 ^{0}C and 1.013 bar Hydrolysis
Dynamic Viscosity at 25 ^{0}C and 1 bar, [24] 11.566×10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known. If posssible stop flow of product.
Move away from the container and cool with water from a protected position.

1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number: 07664-39-3
EU Number: 231-634-8
EU Classification: T+, C
EU Symbols: T+, C
Index Number: 009-002-00-6

UN Number: 1052 HYDROGEN FLUORIDE, anhydrous
Class/Div: 8
ADR/RID: Class 8, Number CT1
ADR/RID Hazard Number: 886
Labeling ADR/DOT: 6.1, 8

EU Classification:
Risk Phrases:

R26/27/28: Very toxic by inhalation, in contact with skin and if swallowed.
R35: Causes severe burns.

Safety Phrases:
S1/2: Keep locked up and out of the reach of children
S7(9: Keep container tightly closed and in a well ventilated places.
S26: In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.
S36/37/39: Wear suitable protective clothing, gloves and eye/face protection.
S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible)

H.Schön: Handbook of Purified Gases

Data Sheet DS090.0 **Date: 08-04-07**

Name:Hydrogen iodide, anhydrous Chemical Formula: HI

Synonyms: hydriodic acid anhydrous,

Properties:
High pressure liquefied gas, non flammable, colourless, pungent odour, toxic, corrosive, irritant, on heating or illumination slowly decomposition into I_2 and H_2, with moist air is slowly oxidation to iodine and water.

Production and Purification:
Manufactured from hydrogen and iodine in the presence of a platinium cacalyst

Widespread Applications: Used primarily in the preparation of organic and inorganic iodides

Important Impurities: Air, HC´s, H_2 .

Disposal: Pass in water or dilute alcaline solvent.

Detection of Hydrogen iodide: Moist litmus-paper.

Suitable Materials: steel, stainless steel, monel, hastelloy, PTFE, PCTFE.

Valve Thread: *Europe:* Not standardized.
Germany: No.6, W 21.8x 1/14" RH.
USA: CGA connection 330, 0.825"-1/14 LH EXT.

Filling Density(Factor): 2.25 kg/l at test pressure 23 bar.

Toxicological Information: Delayed fatal pulmonary oedema possible
Severe corrosion to skin, eyes and respiratory tract at high concentrations.

Symptoms of Poisoning:
Respiratory tract, skin, eyes and mucous membrane burns.

First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information:
May cause pH changes in aqueous ecological systems.

Exposure Limits:
TLV(ACGIH): ppm, LC_{50} / 1h : 2860 ppm.

Hydrogen iodide, anhydrous **HI** **DS090.0**

Physical Data:
Molar Mass, [5] 127.912 g/mol
Melting Point T_{mp} at 1.013 bar, [5]
-50.77 ^{0}C (= -59.39 ^{0}F)
Enthalpy of Fusion at T_{mp} , [24]
22.45 kJ/kg (=9.65 BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [5]
-35.58 ^{0}C (= -32.08 ^{0}F)
Enthalpy of Vaporisation at T_{bp} , [24]
181.06 kJ/kg (= 77.86 BTU/lb)
Critical Point, [24]:
-Temperature 150.7 ^{0}C (= 303.26 ^{0}F)
- Pressure 83.1 bar (= 1205.27 psia)
- Density Liquid 1.049 kg/l
Density Gas: ideal 5.7068 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
5.297 g/l (= 0.3307 lb/ft^3)
- at 15 ^{0}C and 1 bar, [15] 5.4098 g/l
- at 0 ^{0}C, 1.013 bar, [11] 5.7954 g/l
Density Liquid at T_{bp} and 1.013 bar, [3]
2.797 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
2.77	3.82	5.39	7.25	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -15.1 $\times$ 10^{-3} bar^{-1}
- at 30 ^{0}C: -11.1 $\times$ 10^{-3} bar^{-1}
Thermal Conductivity at 15 ^{0}C and 1.013 bar, [1] 56.94 mW/(cm K)
Heat Capacity at 25 ^{0}C,1.013 bar, [3] 0.2277 kJ/(kg K)
Solubility in Water at 20 ^{0}C, 1.013 bar, [2] 425 l gas / kg H_2O
Dynamic Viscosity at 25 ^{0}C and 1 bar, [3] 18.82 $\times$ 10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

Identification and Classification:
CAS Number: 10034-85-2
EU Number: 233-109-9
EU Classification: C
EU Symbols: C
Index Number: 053-002-00-9

UN Number: 2197
HYDROGEN IODIDE, anhydrous
Class/Div: 2.3
ADR/RID: Class 2,number 2TC
ADR/RID Hazard Number: 268
Labeling ADR/DOT: 2.3, 8

EU Classification:
Risk Phrases:
R35: Causes severe burns.

Safety Phrases:
S1/2: Keep locked up and out of the reach of children
S7/9: Keep container tightly closed and in a well-ventilated places.
S26: In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.
S36/37/39: Wear suitable protective clothing, gloves and eye/face protection.
S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible)

H.Schön: Handbook of Purified Gases

Data Sheet DS065.0 **Date: 08-07-16**

Name: Hydrogen selenide, anhydrous **Chemical Formula:**

Synonyms: Selenium hydride, Hydroselenic acid, anhydrous **H_2Se**
Selane, Dihyrogen selenide

Properties: Low pressure liquefied gas, flammable, very toxic, colourless, unpleasent putric odour, produced by thermal decomposition: Selenium and its toxic oxides.

Production and Purification:
Manufactured by the action of acids on metal selenides such as Al_2Se_3 .
Widespread Applications:
Used almost exclusively in the electronics and semiconductor industry
Important Impurities: Air, HC´s, H_2S
Disposal: Pass in dilute alcaline solvents.

Detection of Hdrogen selenide: IR-spectrometry.

Suitable Materials: Steel, stainless steel, monel, PTFE, PCTFE, PVDF.
Valve Thread: *Europe:* Not standardized.
Germany: No.1,W21.8x1/14" LH
USA: CGA connection 350, 0.825"-1/14 LH EXT.
Filling Density(Factor): 1.60 kg/l at test pressure 31 bar.

Toxicological Information:
Irritating to eyes, respiratory system and skin. Damage to kidneys and liver. Delayed fatal pulmonary oedema possible
Symptoms of Poisoning:
Very toxic by inhalation. Delayed adverse effects posssible.
First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.
Environmental Information:
Toxic to aquatic organism.

Exposure Limits:
TLV(ACGIH): 0.05 ppm, LC_{50} / 1h : 51 ppm.

Hydrogen selenide H_2Se DS065.0

Physical Data:

Molar Mass, [5] 80.976 g/mol

Triple Point at 0.2738 bar, [3]
-65.73 ^{0}C (= -86.31 ^{0}F)

Enthalpy of Fusion at T_{mp} ,
kJ/kg (= BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [24]
-41.1 ^{0}C (= -41.98 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [24]
242.79 kJ/kg (= 104.4 BTU/lb)

Critical Point, [24]:
-Temperature 137.95 ^{0}C (= 280.31 ^{0}F)
- Pressure 83.44 bar (= 1210.2 psia)
- Density Liquid 0.7215 kg/l

Density Gas: ideal 3.6128 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
3.354 g/l (= 0.2094 lb/ft^{3})
- at 15 ^{0}C and 1 bar, [15] 3.418 g/l
- at 0 ^{0}C, 1.013 bar, [25] 3.6607 g/l

Density Liquid at T_{bp} and 1.013 bar, [25]
1.974 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^{3}

Vapor Pressure (about), [1, 4]

-10	0	10	20	^{0}C
4.2	5.05	6.9	9.57	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -12.9×10^{-3} bar^{-1}
- at 30 ^{0}C: -9.5×10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar mW/(cm K)

Heat Capacity at 25 ^{0}C,1.013 bar, [3] 0.2681 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [6] 7.48 g Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar, [3] 15.3×10^{-6} Ns/m^{2}

Explosion Limits in Air
Vol.-%

Autoignition Temperature
^{0}C (= ^{0}F)

Heating Value

Suitable Extinguishing Media:
All known.

Identification and Classification:

CAS Number: 07783-07-5
EU Number: 231-978-9
EU Classification: F+, T+
EU Symbols: F+, T+
Index Number: 034-002-00-8

UN Number: 2202 HYDROGEN SELENIDE, ANHYDROUS
Class/Div: 2.3
ADR/RID: Class 2, Number 2TF
ADR/RID Hazard Number: 263
Labeling ADR/DOT: 2.1, 2.3

EU Classification:

Risk Phrases:

R12: Extremely flammable.
R26: Very toxic by inhalation.

Safety Phrases:

S1/ 2: Keep locked up and out of the reach of children.
S9: Keep container in a well-ventilated places.
S16: Keep away from sources of ignition - No smoking
S28: After contact with skin, wash immadiatelywith plents of… (to be specificated by manufacturer).
S33: Take precautionary measures against static dischargs.
S36: Wear suitable protective clothing.
S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible)

H.Schön: Handbook of Purified Gases

Data Sheet DS045.0 **Date: 08-07-11**

Name: Hydrogen sulphide **Chemical Formula:** H_2S

Synonyms: Dihydrogen monosulphide, Sulphuretted hydrogen $H_2\text{-}S$

Properties:

Low pressure liquefied gas, flammable, toxic, colourless, strong smell of rotten eggs, poor warning properties at high concentrations, in present of moisture corrosive to many metals.

Production and Purification:

Some natural gases contain high concentration arises as a byproduct in the manufacture of carbon disulfide, prepared in laboratory from metal sulfides and acids.

Widespread Applications:

Used in metallurgy for the preparation of metallic sulfides.

Important Impurities: Air, HC´s.

Disposal: Pass in dilute alcaline solvents.

Detection of Hydrogen sulfide: gas test tube.

Suitable Materials: Steel, stainless steel, monel, PTFE, PCTFE, PVDF.

Valve Thread: Europe: Not standardized.

Germany: No.5, 1" LH.

USA: CGA connection 330, 0.825"-1/14 LH EXT.

Filling Density(Factor): 0.67 kg/l at test pressure55 bar.

Toxicological Information: Damage to central nervous system

Symptoms of Poisoning:

Very toxic by inhalation, poor warning properties at high concentration (above 150 ppm). May cause damaging effects to central nervous system, metabolism and gastrointestinal tract.

First Aid:

Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.

Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information:

May cause pH changes in aqueous ecological systems.

Exposure Limits:

TLV(ACGIH): 10 ppm, LC_{50} / 1h : 712 ppm.

Hydrogen sulphide H_2S DS045.0

Physical Data:
Molar Mass, [5,9] 34.082 g/mol
Triple Point at 0.227 bar, [5, 10]
-85.53 ^{0}C (= -121.95 ^{0}F)
Enthalpy of Fusion at T_{mp} , [24]
69.74 kJ/kg (= 29.99 BTU/lb)
Boiling Point T_{bp} at 1.013 bar , [5]
-60.31 ^{0}C (= -76.56 ^{0}F)
Enthalpy of Vaporisation at T_{bp} , [24]
517.87 kJ/kg (= 222.68 BTU/lb)
Critical Point, [24]:
-Temperature 100.38^{0}C (= 212.68 ^{0}F)
- Pressure 89.63 bar (= 1299.98 psia)
- Density Liquid 0.346 kg/l
Density Gas: ideal 1.5206 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
1.411 g/l (=0.0881 lb/ft^3)
- at 15 ^{0}C, 1 bar, [10] 1.434 g/l
- at 0 ^{0}C, 1.013 bar, [11] 1.5355 g/l
Density Liquid
- at T_{bp} and 1.013 bar, [10] 0.9149 kg/l
- at 20 ^{o}C, [12] 0.796 kg/l
1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
7.59	10.3	13.5	17.9	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -10×10^{-3} bar^{-1}
- at 30 ^{0}C: -7×10^{-3} bar^{-1}
Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.139 mW/(cm K)
Heat Capacity at 25 ^{0}C,1.013 bar, [10] 1.001 kJ/(kg K)
Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 2.58 l Gas / kg H_2O
Dynamic Viscosity at 25 ^{0}C, 1 bar, {24] 12.6×10^{-6} Ns/m^2
Explosion Limits in Air, [13]
3.9-44.5 vol.-%
Autoignition Temperature, [13]
270 ^{0}C (=518 ^{0}F)
Heating Value, {24]
18.1 MJ/kg (=7784.5 BTU/lb)
Suitable Extinguishing Media:
All known.

Identification and Classification:
CAS Number: 07783-06-4
EU Number: 231-977-3
EU Classification: F+, T+, N
EU Symbols: F+, T+, N
Index Number: 016-001-00-4

UN Number: 1053
HYDROGEN SULPHIDE
Class/Div: 2. 3
ADR/RID: Class 2, Number 2TF
ADR/RID Hazard Number: 263
Labeling ADR/DOT: 2.1, 2.3

EU Classification:
Risk Phrases:
R12: Extremely flammable.
R26: Very toxic by inhalation.
R50: Very toxic for aquatic organism.
Safety Phrases: S1/2: Keep locked up and out of reach of children.
S9: Keep container in a well-ventilated places
S16: Keep awy from sources of ignition – No smoking.
S36: Wear suitable protective clothing. S38: In case of insufficient ventilation, wear suitable respiratory equipment
S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible)
S61: Avoid release to the environment. Refe to special instuctions / Safety data sheets.

H.Schön: Handbook of Purified Gases

Data Sheet DS008.0 **Date: 06-02-20**

Name: Isobutane **Chemical Formula: C_4H_{10}**

Synonyms: i-Butane, i-Methyl ethyl methane, R600a, **$(CH_3)_3CH$**
2-Methyl propane, Trimethyl methane. Isomer: n-Butane (R600)

Properties:
Low pressure liquefied gas, flammable, colorless, odorless.

Production and Purification:
From natural gas by pressure destillation and from the C4-fraction in cracking process or coal hydrogenation. Rectification.
Widespread Applications:
Fuel gas, propellant gas. Industially important in the manufacture of aviation fuel and many organic chemicals.

Important Impurities:		Other HCs.
Disposal:		Combustion .
Detection of Isobutane:		Detector for flammable gases. Gas test tube.
Suitable Materials:		All known.
Valve Thread:	*Europe:*	Not standardized. Germany: No.1, W21,8x1/14" LH.
	USA:	CGA connection 510, 0.885"-1/14 LH INT.
Filling Density(Factor):		0.49 kg/l at test pressure 10 bar.

Toxicological Information:
No known acute toxicological effects from this product.
Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of coordination. In high concentration may cause asphyxiation.
First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH): --- , LC50 / 1h : ---

Isobutane C_4H_{10} DS008.0

Physical Data:

Molar Mass, [5] 58.123 g/mol

Triple Point at 0.05 mbar, [5, 10]
-159.61 ^{0}C (= 255.3 ^{0}F)

Enthalpy of Fusion , [10]
78.17 kJ/kg (= 33.61 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-11.81 ^{0}C (= +10.74 ^{0}F)

Enthalpy of Vaporisation at T_{bp},[10]
366.8 kJ/kg (= 157.70 BTU/lb)

Critical Point:
-Temperature, [5]
134.70 ^{0}C (= 274.46 ^{0}F)
- Pressure, [5]
36.40 bar (= 527.95 psia)
- Density Liquid, [10] 0.221 kg/l

Density Gas:
- ideal 2.5933 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1.013 bar, [24]
2.407 g/l (= 0.1503 lb/ft^3)
- at 15 ^{0}C and 1 bar, [10] 2.514 g/l
- at 0 ^{0}C and 1.013 bar, [3] 2.697 g/l

Density Liquid
- at T_{bp} and 1.013 bar 0.5934 kg/l
- at 20 ^{0}C 0.5571 kg/l

Vapor Pressure (about), [1, 4]

-10	0	10	20	^{0}C
1.08	1.57	2.25	3.07	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -37.9 $\times 10^{-3}$ bar^{-1}
- at 30 ^{0}C: -27.1 $\times 10^{-3}$ bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.152 mW/(cm K)

Heat Capacity at 25 ^{0}C and 1.013 bar, [10] 1.67 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 0.0325 l gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar, [3] 7.52 $\times 10^{-6}$ Ns/m^2

Explosion Limits in Air, [13]
1.5-9.4 Vol.-%

Autoignition Temperature, [13]
460 ^{0}C (= 860 ^{0}F)

Heating Value, [24]
45.576 MJ/kmol

Suitable Extinguishing Media:
All known .

1 bar = 14.504 psi,
1 g/l = 0.0624 lb/ft3

Identification and Classification:

CAS Number: 00075-28-5
EU Number: 200-857-2
EU Classification: F+
EU Symbols: F+
Index-Number: 601-004-00-0

UN Number: 1969
ISOBUTANE
Class/Div: 2.1
ADR/RID: Class 2, Number 2F
ADR/RID Hazard Number: 23
Labeling ADR/DOT: 2.1

EU Classification:

Risk Phrases:

R12: Extremely flammable.

Safety Phrases:

S2: Keep out of the reach of childen.
S9: Keep container in a well ventilated places.
S16: Keep away from sources of ignition - No smoking.

H.Schön: Handbook of Purified Gases

Data Sheet DS012.0 **Date: 06-02-12**

Name: Isobutene Chemical Formula: C_4H_8

Synonyms: Isobuthylene, 2-Methylpropene, **$H_2C{=}C{-}(CH_3)_2$**
gamma-Buthylen, Liquefied Petroleum Gas, asym. Dimethylethylene

Properties: Low pressure liquefied gas, flammable, colorless, with an petroleum odor, unsaturated hydrocarbon. It is very soluble in alcohol and ether. One of four isomers of the butenes.

Production and Purification:
The butenes are obtained from the cracking gases of the petroleum industry or by the catalytic dehydrogenetion of butanes. Rectification.
Widespread Applications:
Butenes are used to manufacture of a variety of organic compounds. Polmerisation to high-octane gasolines, plastics and synthetic rubber.

Important Impurities:		Other HCs.
Disposal:		Combustion.
Detection of Isobutene:		Detector for flammable gases. Gas test tube.
Suitable Materials:		All known .
Valve Thread:	*Europe:*	Not standardized. Germany: No.1, W21,8x1/14" LH.
	USA:	CGA connection 510, 0.885"-1/14 LH INT.
Filling Density(Factor):		0.55 kg/l at test pressure 10 bar.

Toxicological Information:
No known acute toxicological effects from this product.
Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of coordination. In high concentration may cause asphyxiation.
First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH): ---, LC50 / 1h : ---

Isobutene C_4H_8 **DS012.0**

Physical Data:

Molar Mass, [5] 56.108 g/mol

Melting Point T_{mp} at 1.013 bar, [5]
-140.34 ^{0}C (= -220.61 ^{0}F)

Enthalpy of Fusion at T_{mp}, [24]
105.71 kJ/kg (= 45.46 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-6.91 ^{0}C (= -19.56 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [24]
395.85 kJ/kg (= 170.22 BTU/lb)

Critical Point:
-Temperature, [5]
144.75 ^{0}C (= 292.55 ^{0}F)
- Pressure, [24]
39.99 bar (= 580.01 psia)
- Density Liquid, [24] 0.2349 kg/l

Density Gas:
- ideal 2.5033 g/l
- at 70 ^{0}F (= 21.1 ^{0}C, 1.013 bar, [24]
2.324 g/l (= 0.1451 lb/ft^3)
- at 15 ^{0}C and 1 bar, [10] 2.418 g/l
- at 0 ^{0}C, 1.013 bar, [5] 2.599 g/l

Density Liquid, [10]
- at T_{bp} and 1.013 bar 0.6262 kg/l
- at 20 ^{0}C 0.5986 kg/l

Vapor Pressure (about), [1,2, 4]

-10	0	10	20	^{0}C
0.91	1.31	1.87	2.50	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -36 $\times$ 10^{-3} bar^{-1}
- at 30 ^{0}C: -25 $\times$ 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.153 mW/(cm K)

Heat Capacity at 25 ^{0}C and 1.013 bar, [10] 1.59 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [6] 0.390 1 Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar, [24] 8.162 $\times$ 10^{-6} Ns/m^2

Explosion Limits in Air, [13]
1.6-10 Vol.-%

Autoignition Temperature, [13]
465 ^{0}C (= 869 ^{0}F)

Heating Value, [44]
44,986 MJ/kmol

Suitable Extinguishing Media:
All known .

1 bar = 14.504 psi,
1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number: 00115-11-7
EU Number: 204-066-3
EU Classification: F+
EU Symbols: F+
Index-Number: 601-012-00-4

UN Number: 1055
ISOBUTYLENE
Class/Div 2.1
ADR/RID: Class 2, Number 2F
ADR/RID Hazard Number: 23
Labeling ADR/DOT: 2.1

EU Classification:
Risk Phrases:
R12: Extremely flammable.

Safety Phrases:
S2: Keep out of the reach of children
S9: Keep container in a well ventilated places.
S16: Keep away from sources of ignition - No smoking.
S33: Take precautionary measures against static discharges.

H.Schön: Handbook of Purified Gases

Data Sheet DS070.0 **Date: 08-03-28**

Name: Krypton, compressed **Chemical Formula: Kr**

Synonyms:

Properties: Compressed gas, non flammable, non-toxic, colourless, odourless, extremely chemically inert (noble Gas), but in contrast to the lighter noble gases it forms genuine chemical compounds e.g. KrF_2. Isotopes: stable Kr-78, -80, -82,-83,-84,-86, radioactive Kr-85, which is especially interesting, since its concentration in the air provides information about the consumption of nuclear fuels.

Production and Purification: Air contains about 0.1 ppm Kr.
Obtained as a byproduct in the fractional distillation of liquid air.
Widespread Applications:
Used in the lighting and electronic industry.
Important Impurities: Air, Xe, HC´s, CFC´s.

Disposal: Pass in the atmosphere.
Detection of Krypton: Mass spectrometry.

Suitable Materials: All known.
Valve Thread: *Europe:* for 300 bar: No 54, W30x2 RH.
Germany: for 200 bar: No6 W21.8x1/14" RH.
USA: CGA connection580 0.965"x1/14" RH INT.

Test pressure/service pressure =1.5

Toxicological Information:
No known toxicological effects from this product.
Symptoms of Poisoning:
In high concentrations may cause asphyxiation. Symptoms may include loss of mobility/consciouness. Victim may not be aware the asphyxiation.

First Aid: Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.

Environmental Information:
No known ecological damage caused by this product.
Exposure Limits:
*T*LV(ACGIH):-- ppm, LC50 / 1h :--- ppm .

Krypton, compressed **Kr** **DS070.0**

Physical Data:

Molar Mass, [5] 83.800 g/mol

Triple Point at 0.731 bar, [5, 10]
-157.2 ^{0}C (=-250.96 ^{0}F)

Enthalpy of Fusion at T_{mp}, [24]
19.57 kJ/kg (=8.42 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-153.41 ^{0}C (= -244.14 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [24]
108.47 kJ/kg (= 46.64 BTU/lb)

Critical Point, [24]:
-Temperature -63.8 ^{0}C (= -82.84 ^{0}F)
- Pressure 55.02 bar (= 798 psia)
- Density Liquid 0.9189 kg/l

Density Gas: ideal 3.7388 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, {24]
3.471 g/l (= 0.2167 lb/ft^3)
- at 15 ^{0}C and 1 bar,[10] 3.507g/l
- at 0 ^{0}C, 1.013 bar, [11] 3.749 g/l

Density Liquid at T_{bp} and 1.013 bar,
[10] 2.413 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [4]

-153	-120	-90	-70	^{0}C
1	7.5	25	47	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -2.74×10^{-3} bar^{-1}
- at 30 ^{0}C: -1.95×10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C, 1.013 bar, .[10] 0.096 mW/(cm K)

Heat Capacity at 25 ^{0}C,1.013 bar, [10] 0.247 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] .23 g Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar, [3] 25.5×10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

Identification and Classification:

CAS Number:	07439-90-0
EU Number:	231-098-5
EU Classification:	---
EU Symbols:	---
Index Number:	

UN Number: 1056
KRYPTON, compressed

Class/Div:	2.2
ADR/RID: Class 2, Number	1A
ADR/RID Hazard Number:	20
Labeling ADR/DOT:	2.2

EU Classification:
Risk Phrases:
RAs: Asphyxiant in high oncentrations.

Safety Phrases:
S9: Keep container in well ventilated places.
S23: Do not breathe gas.

H.Schön: Handbook of Purified Gases

Data Sheet DS077.0 **Date: 08-03-31**

Name: Methane, compressed Chemical Formula: CH_4

Synonyms: Methyl hydride, Natural gas, Hydrogen bicarbide, R50,

*Properties:*Non-liquefied, compressed gas,flammable, colorless, odourles, non-toxic, with air or O_2 forms the detonating gas. It is the simplest an chemical most stable alkane, major component of many natural gases. Large amount of CH4 are formed by anaerobic bacterial decay of biological materials : biogas, sewage gas, landfill gas, sludge gas, fermentation gas.

Production and Purification:
industrially manufactured by coal gasification, in the laboratory by the hydrolysis of carbides.

Widespread Applications:
Fuel gas, raw material in the chemical industry.

Important Impurities: *Air, HC´s.*
Disposal: combustion .

Detection of Methane: Detector for flammable gases, gas test tube.

Suitable Materials: All known.
Valve Thread: *Europe:* for 300 bar: No 57, W30x2 LH.
Germany: for 200 bar: No 1 W21.8x1/14" LH.
USA: CGA connection 350, 0.825"x1/14" LH EXT.

Test pressure/service pressure = 1.5

Toxicological Information:
No known toxicological effects from this peoduct.

Symptoms of Poisoning: In high concentrations may cause asphyxiation, may include loss of mobility/consciousness. Victim may not be aware of asphyxiation. In low concentrations may cause narcotic effects.

First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Do not discharge into areas there is a risk of forming an explosive mixture with air.

Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH): --- ppm, LC50 / 1h : --- ppm

Methane,compressed CH_4 DS077.0

Physical Data:

Molar Mass, [5] 16.043 g/mol

Triple Point at 0.117 bar, [3]
-182.47 ^{0}C (= -296.45 ^{0}F)

Enthalpy of Fusion at T_{mp} , [24]
58.65 kJ/kg (= 25.22 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-161.52 ^{0}C (= -254.78 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [24]
508.63 kJ/kg (= 218.71 BTU/lb)

Critical Point, [24]:
-Temperature -82.57 ^{0}C (= -116.63 ^{0}F)
- Pressure 46.04 bar (=667.75 psia)
- Density Liquid 0.1616 kg/l

Density Gas: ideal 0.7158 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
0.664 g/l (= 0.0415 lb/ft^3)
- at 15 ^{0}C and 1 bar, [10] 0.671g/l
- at 0 ^{0}C, 1.013 bar, [3] 0.7175g/l

Density Liquid at T_{bp} and 1.013 bar,
[10] 0.423 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [4]

-161	-140	-110	-83	^{0}C
1	4.4	18	46	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -2.37 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -1.63 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.321 mW/(cm K)

Heat Capacity at 25 ^{0}C,1.013 bar, [10] 2.22 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 35 ml gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C, 1 bar, [3] 11.2 x 10^{-6} Ns/m^2

Explosion Limits in Air, [13]
4.4-17 Vol.-%

Autoignition Temperature, [13]
595 ^{0}C (=1103 ^{0}F)

Heating Value, [24]
50,009 MJ/kmol

Suitable Extinguishing Media:
All known.

Identification and Classification:

CAS Number:	00074-82-8
EU Number:	200-812-7
EU Classification:	F+
EU Symbols:	F+
Index Number:	601-001-00-4

UN Number:	1971
	METHANE, compressed
Class/Div:	2.1
ADR/RID: Class 2, Number	1F
ADR/RID Hazard Number:	23
Labeling ADR/DOT:	2.1

EU Classification:

Risk Phrases:

R12: Extremely flammable.

Safety Phrases:

S2: Kep out of the reach of children.

S9: Keep container in a well ventilated places.

S16: Keep away from sources of ignition - No smoking.

S33: Take precautionary measures against static discharges.

H.Schön: Handbook of Purified Gases

Data Sheet DS106.0 **Date: 06-03-02**

Name: Methylacetylene **Chemical Formula: C_3H_4**

Synonyms: Allylene, Propine, Propyne, 1-Propyne **$H_3C-C \equiv CH$**

Properties:

Low pressure liquefied gas, flammable, colorless, relativ nontoxic, unpleasent odor garlike as a result of impurities. May polymerisize, inhibitor usually added.

Production and Purification:

Byproduct of petroleum refining in cracking processes.

Widespread Applications:

Is used mainly together with propadiene as a fuel gas (MAPP gas) to generate high temperatures.

Important Impurities:		Other HCs.
Disposal:		Combustion .
Detection of Propine:		Detector for flammable gases. Gas test tube.
Suitable Materials:		Steel, SS, Monel, Brass (Copper less than 65%), PVC, PTFE, PCTFE .
Valve Thread:	*Europe:*	Not standardized . Germany: No.1, W21,8x1/14" INT.
	USA:	CGA connection 510, .885"-1/14 LH INT.
Filling Density(Factor):		mixtures 1 - 4 % in propadiene 0,50 kg/l at test pressure 22 bar.

Toxicological Information:

No known acute toxicological effects from this product.

Symptoms of Poisoning:

In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of coordination. In high concentration may cause asphyxiation.

First Aid:

Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

Environmental Information:

No known ecological damage caused by this product.

Exposure Limits:

TLV(ACGIH): 1000 ppm , LC50 / 1h : ---

Methylacetylene C_3H_4 DS106.0

Physical Data:

Molar Mass, [5] 40.065 g/mol

Melting Point T_{mp} at 1.013 bar, [5]
-102.65 ^{0}C (= -152.77 ^{0}F)

Enthalpy of Fusion at T_{mp}
kJ/kg (= BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-23.03 ^{0}C (= -9.45 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [24]
555.35 kJ/kg (= 238.8 BTU/lb)

Critical Point:

-Temperature, [5]
129.25 ^{0}C (= 264.65 ^{0}F)

- Pressure, [24]
56.28 bar (= 816.27 psia)

- Density Liquid, [12] 0.244 kg/l

Density Gas:

- ideal 1.7875 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1.013 bar, [24]
1.659 g/l (= 0.1036 lb/ft^3)
- at 15 ^{0}C and 1 bar, [3] 1.707 g/l
- at 0 ^{0}C, 1.013 bar, [12] 1.8301 g/l

Density Liquid

- at T_{bp} and 1.013 bar, [3] 0.6942 kg/l
- at 25 ^{0}C, [24] 0.607 kg/l

Vapor Pressure (about), [4,12]

-10	0	10	20	^{0}C
2.01	2.34	3.27	4.55/5.12	bar

2.Pressure Virial Coefficient, [11]

- at 0 ^{0}C: -23 $\times$ 10^{-3} bar^{-1}
- at 30 ^{0}C: -15.9 $\times$ 10^{-3} bar^{-1}

Thermal Conductivity at 25 ^{0}C, [24]
0.1603 mW/(cm K)

Heat Capacity at 25 ^{0}C and 1.013 bar, [3] 1.514 kJ/(kg K)

Solubility in Water at 25 ^{0}C, [24]
3640 ppm (weight)

Dynamic Viscosity at 25 ^{0}C and 1 bar 8.63 $\times$ 10^{-6} Ns/m^2

Explosion Limits in Air, (13)
1.8-16.8 Vol.-%

Autoignition Temperature
^{0}C (= ^{0}F)

Heating Value, [24]
46.165 MJ/kg

Suitable Extinguishing Media:
All known .

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number: 00074-99-7
EU Number: 200-828-4
EU Classification: F+
EU Symbols: F+

UN Number: 1060 METHYLACETYLENE and PROPADIENE MIXTURE, stabilized
Class/Div: 2.1
ADR/RID: Class 2, Number 2 F
ADR/RID Hazard Number: 239
Labeling ADR/DOT: 2.1

EU Classification:
Risk Phrases:
R12: Extremely flammable.

Safety Phrases:
S9: Keep container in a well ventilated places.
S16: Keep away from sources of ignition - No smoking.
S33: Take precautionary measures against static discharges.

H.Schön: Handbook of Purified Gases

Data Sheet DS031.01 **Date: 07-02-03**

Name:Methylamine anhydrous Chemical Formula: CH_5N

Synonyms: Aminomethane, Mercuralin, Methanamine, R630 H_3C- NH_2
Monomethlylamine

Properties: Low pressure liquefied gas, flammable, colorless, corrosive, toxic, irritant, fishy odor, in high concentration ammonia odor. Readily soluble in water and ethanol. Thermal decomposition yields NO, NO_2 and CO.

Production and Purification:
Manufactored from ammonia and methanol over silica or metal oxide catalysts, byproducts are H_2, Dimethyl- and Trimethylamine.
Widespread Applications:
Intermediate for dyes, fungicides, insecticides, pharmaceuticals, rocket propellants, explosives and solvents.
Important Impurities: Other HC´s.
Disposal: Pass in water or dilute acids.
Detection of Methylamine:
Gas test tube, litmus-paper, detector for flammable gases (IR-spectrometry).
Suitable Materials: Steel, stainless steel, PE, PTFE, EPDM.
Valve Thread: *Europe:* Not standardized.
Germany: No.1, W21.8x1/14" LH.
USA: CGA connection 705, 1.125"-1/14 RH EXT.

Filling Density(Factor): 0.58 kg/l at test pressure 13 bar.

Toxicological Information:
Irritation to lungs and upper respriratory tract shown as rhinitis, pharyn and pneumonia. May cause dermatitis, corneal edema and chemical burns.
Symptoms of Poisoning:
Harmful by inhalation. Respiratory tract, skin and eye burns.
First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested, call a doctor. Apply artificial respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.
Environmental Information:
May cause pH changes in aqueous ecological systems.

Exposure Limits:
TLV(ACGIH): 10 ppm, LC_{50} / 1h : 7000 ppm

Methylamine anhydrous CH_5N DS031.0

Physical Data:

Molar Mass, [5] 31.057 g/mol

Melting Point T_{mp} at 1.013 bar*, [5]
-93.46 ^{0}C (= -136.23 ^{0}F)

Enthalpy of Fusion at T_{mp}, [10]
197.6 kJ/kg (= 84.95 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-6.33 ^{0}C (= 20.61 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [10]
831.5 kJ/kg (= 357.46 BTU/lb)

Critical Point:
-Temperature, [5]
156.85 ^{0}C (= 314.33 ^{0}F)
- Pressure, (5)
74,20 bar (= 1,076.20psia)
- Density Liquid, [11] 0.216 kg/l

Density Gas:
- ideal 1.3857 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1 bar, [24]
1.286 g/l (= 0.0803 lb/ft^{3})
- at 15 ^{0}C, 1 bar, [10] 1.329 g/l
- at 0 ^{0}C, 1.013 bar, [11] 1.430 g/l

Density Liquid
- at T_{bp} , 1.013 bar, [28] 0.6942 kg/l
- at 25 ^{0}C, [24] 0.655 kg/l

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
0.87	1.37	2.06	3.00	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -30.7 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -19.8 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.183 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar [10] 1.612kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 757 l gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C,1 bar [24] 8.997 x 10^{-6} Ns/m^{2}

Explosion Limits in Air, [13]
4.9-20.7 Vol.-%

Autoignition Temperature, [24]
430 ^{0}C (= 806 ^{0}F)

Heating Value, [24] 31.397 MJ/kg

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi ,
1g/l = 0.0624 lb/ft^{3}

Identification and Classification:

CAS Number: 00074-89-5
EU Number: 200-820-0
EU Classification: F+, Xn, Xi
EU Symbols: F+, Xn
Index-Number 612-001-00-9

UN Number: 1061
METHYLAMINE, anhydrous
Class/Div: 2.1
ADR/RID: Class 2, Number 2F
ADR/RID Hazard Number: 23
Labeling ADR/DOT: 2.1

EU Classification:
Risk Phrases:
R12: Extremely flammable.
R20: Harmful by inhalation
R37/38: Irritating to eyes and skin
R41: Risk of serious-damage to eyes

Safety phrases:
S1/ 2: Keep locked and out of the reach of children S16: Keep away from ignitation source - No smoking. S26: In case of contact with eyes, rinse immatiately with plenty of water and seek medical advice. S39: Wear eye/face protection

H.Schön: Handbook of Purified Gases
Data Sheet DS084.0 **Date: 07-06-24**

Name: Methyl bromide Chemical Formula: CH_3Br
Synonyms: Bromomethane, R40B1, Halon 1001, Dowfume,
Methogas, Rotox, Zytox, Pestmaster

Properties: Low pressure liquefied gas, flammable, colorless, in high concentration chloroform-like odour, very toxic, reacts with magnesium to form the Grignard reagent .Thermal decomposition mays produce CO, $COBr_2$ and HBr.

Production and Purification:
Manufactured from methanol and HBr in the presence of a catalyst.
Widespread Applications:
Low-boiling solvent, refrigerant and pesticide. Used in organic synthesis.
Important Impurities: Other HC´s, other Br-C-H-compounds.
Disposal:
Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.
Detection of R40B1: Halogen leak detector, gas test tube .

Suitable Materials: Steel, stainless steel, monel, no magnesium .
PTFE, PCTFE, PVDF.
Valve Thread: *Europe:* Not standardized.
Germany: No.8 1" .
USA: CGA connection 320, .825"-1/14RH EXT.
Filling Density(Factor): 1.51 kg/l at test pressure 10 bar.

Toxicological Information:
Damage to central nervous system, kidneys and liver. Delayed fatal pulmonary edema possible. May cause inflammation of respiratory system and skin.
Symptoms of Poisoning:
Toxic by inhalation. In low concentration may cause narcotic effects .
Symptoms may include dizziness, headache, nausea and loss of co-ordination.
May cause stomach cramps, vomitting and irritation to the respiratory tract.
First Aid: Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.
Environmental Information:
May cause pH changes in aqueous ecological systems. Endangering to drinking water. May have damaging effect on ozone layer.
Exposure Limits:
TLV(ACGIH): 5 ppm, LC_{50} / 1h : 850 ppm .

Methyl bromide CH_3Br DS084.0

Physical Data:

Molar Mass, [11] 94.939 g/mol

Triple Point at 0.2 mbar, [28]
-93.7 ^{0}C (= -136.66 ^{0}F)

Enthalpy of Fusion at T_{mp} , [10]
62.74 kJ/kg (= 26.97 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [13, 24]
3.56 ^{0}C (= 38.41 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [10]
252.05 kJ/kg (=108.36 BTU/lb)

Critical Point: [24]
-Temperature 193.85 ^{0}C (= 380.93 ^{0}F)
- Pressure 80 bar (= 1160.3 psia)
- Density Liquid 0.6086 kg/l

Density Gas: - ideal 4.2357 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
3.932 g/l (= 0.2455 lb/ft^3)
- at 15 ^{0}C, 1 bar, [10] 4.069 g/l
- at 0 ^{0}C and 1.013 bar --- g/l

Density Liquid
- at T_{bp} and 1.013 bar, [10] 1.721 kg/l
- at 25 ^{0}C, [24] 1.662 kg/l

Vapor Pressure (about), [14]

-10	0	10	20	^{0}C
0.8	0.9	1.3	1.9	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -31.1 $\times$ 10^{-3} bar^{-1}
- at 30 ^{0}C: -20.5 $\times$ 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.0795 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar [10] 0.446 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 3.75 l gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C, 1 bar [3] 13.52 $\times$ 10^{-6} Ns/m^2

Explosion Limits in Air
[13] 8.6-20 Vol.-%
[24] 10-16 Vol.-%

Autoignition Temperature, [24]
537.2 ^{0}C (= 999 ^{0}F)

Heating Value, [24] 7,43 MJ/kg

Suitable Extinguishing Media:
All known.

Identification and Classification:

CAS Number: 00074-83-9
EU Number: 200-813-2
EU Classific.: Mut.Cat.3, T, Xn, Xi, N
EU Symbols: T, N
Index Number: 602- 002-00-2

UN Number: 1062
METHYL BROMIDE
Class/Div: 2.3
ADR/RID: Class 2, Number 2T
ADR/RID Hazard Number: 26
Labeling ADR/DOT: 2.3

EU Classification: *Risk Phrases:*
R23/25: Toxic by inhalation and if swallowed. R36/37/38: Irritating to eyes, respiratory system and skin. R48/20: Harmful: Danger of serious damage to health by prolonged exposure through inhalation.
R50: Very toxic to aquatic organism.
R59: Dangerous for the ozone layer.
R68: Possible risks of irreversible effects.
Safety Phrases: S1/2: Keep loked up and out of the reach of children S15: Keep away from heat. S27: Take off immediately all contaminated clothing.

S36/39: Wear suitable gloves and eye/ face protection.
S38: In case of insufficient ventilation, wear suitable respiratory equipment.
S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible)
S59: Refer to manufacturer/supplier for information on recovery/recycling.
S61: Avoid release to the environment. Refer to special instructions/MSDS.

H.Schön: Handbook of Purified Gases

Data Sheet DS019.0 **Date: 07-06-03**

Name: Methyl chloride Chemical Formula: CH_3Cl

Synonyms: Chloromethane, R40

Properties:
Low pressure liquefied gas, flammable, colorless, faint sweet odor. Limited evidence of a carcinogenic effect. Thermal decomposition produces CO, $COCl_2$, HCl.

Production and Purification:
Obtained industially by chlorinating of methane. Destillation.
Widespread Applications:
Used as a refrigerant, catalyst solvent in butyl rubber production, reagent in silicone production, methylating agent in organic syntheses.
Important Impurities: Other HC´s and CFC´s.
Disposal: Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.
Detection of Methyl chloride: Detector for flammable gases. Gas test tube.

Suitable Materials: All known.
Valve Thread: *Europe:* Not standardized.
Germany: No.1, W21,8x1/14" LH.
USA: CGA connection 510, .885"-1/14 LH INT.

Filling Density(Factor): 0.81 kg/l at test pressure 17 bar.

Toxicological Information:
May cause carcinogenic, mutagenic and teratogenic effects.
Symptoms of Poisoning:
In high concentration may cause asphyxiation. Symptoms may include loss of mobility/consiousness. Victim may not aware of asphyxiation.
May cause damaging effects to central nervous system, metabolism and gastrointestinal tract.
First Aid: Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.
Environmental Information:
May cause pH changes in aqueous ecological systems.
Exposure Limits:
TLV(ACGIH): 50 ppm, LC_{50} / 1h : 8300 ppm .

Methyl chloride CH_3Cl DS019.0

Physical Data:
Molar Mass, [5] 50.488 g/mol
Triple Point at 8.7 mbar, [5]
-97.71 ^{0}C (= -143.88 ^{0}F)
Enthalpy of Fusion at T_{mp}, [10]
127.45 kJ/kg (= 54.79 BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [24]
-24.22 ^{0}C (= -11.6 ^{0}F)
Enthalpy of Vaporisation at T_{bp}, [10]
428.31 kJ/kg (= 184.30 BTU/lb)
Critical Point:
-Temperature, [5]
143.1 ^{0}C (= 289.58 ^{0}F)
- Pressure,[5] 66.79 bar (= 968.71psia)
- Density Liquid, [24] 0.3032 kg/l
Density Gas:
- ideal 2.2525 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
2.091 g/l (= 0.1305 lb/ft^3)
- at 15 ^{0}C, 1 bar, [10] 2.137 g/l
- at 0 ^{0}C, 1.013 bar, [3] 2.3075 g/l
Density Liquid, [10]
- at T_{bp} and 1.013 bar 1.0029 kg/l
- at 20 ^{0}C 0.934 kg/l

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
2.21	2.56	3.58	4.89	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -23.1 $\times 10^{-3}$ bar^{-1}
- at 30 ^{0}C: -15.8 $\times 10^{-3}$ bar^{-1}
Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.105 mW/(cm K)
Heat Capacity at 25 ^{0}C and 1.013 bar, [10] 0.808 kJ/(kg K)
Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 0.317 l gas / kg H_2O
Dynamic Viscosity at 25 ^{0}C and 1 bar $\times 10^{-6}$ Ns/m^2
Explosion Limits in Air
[13] 7.6-19 Vol.-%
[24] 10.7-17.4 Vol.-%
Autoignition Temperature, [24]
632.2 ^{0}C (= 1170 ^{0}F)
Heating Value,[24] 13,377 MJ/kg
Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:
CAS Number: 00074-87-3
EU Number: 200-817-4
EU Classification: Carc .Cat.3, F+, Xn
EU Symbols: F+, Xn
Index Number: 602-001-00-7

UN Number: 1063
METHYL CHLORIDE
Class/Div: 2.1
ADR/RID: Class 2, Number 2F
ADR/RID Hazard Number: 23
Labeling ADR/DOT: 2.1

EU Classification:
Risk Phrases:
R12: Extremely flammable.
R40: Limited evidence of a carcinogenic effect.
R48/20: Harmful: danger of serious damage to health by prolonged exposure through inhalation.

Safety Phrases:
S2: Keep out of the reach of children.
S9: Keep container in a well-ventilated places.
S16: Keep away from sources of ignition - No smoking.
S33: Take precautionary measures against static discharges.

H.Schön: Handbook of Purified Gases

Data Sheet DS061.0 **Date: 07-02-04**

Name: Methyl mercaptane **Chemical Formula: CH_4S**

Synonyms: Methanethiol, Methylsulhydrate **H_3C-SH**

Properties:
Low pressure liquefied gas, flammable, colorless, toxic, disagreeable odor (threshold 0.02 ppm). Insoluble in water but readily solvent in organic solvents. Thermal decomposition generates CO and SO_2.

Production and Purification: Obtained from natural gas and is formed in the bacterial decomposition of proteins. Obtained by reacting methanol with hydrogen sulphide. Unwanted byproduct in coal-tar asphalt processing.
Widespread Applications:
Used in many organic syntheses, intermediate for jet fuel additives, fungicides, and methionine.
Important Impurities: Other HC´s.
Disposal: Combustion, following scrubber for decomposition products.
Detection of Methyl mercaptan: Gas test tube, lead acetat paper.
Suitable Materials:
Stainless steel, steel alloys (copper free), PE, PTFE, PCTFE, EPDM.
Valve Thread: *Europe:* Not standardized.
Germany: No.5, 1" LH.
USA: CGA connection 330, .825"-1/14 LH EXT.

Filling Density(Factor): 0.78 kg/l at test pressure 10 bar.

Toxicological Information:
May cause dermatitis by skin contact.
Symptoms of Poisoning:
Harmful by inhalation. Respiratory tract, skin and eye burns.
First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested, call a doctor. Apply artificial respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.
Environmental Information:
Toxic to water organism. Endangering to drinking water.

Exposure Limits:
TLV(ACGIH): 0.5 ppm, LC_{50} / 1h : 1350 ppm

Methyl mercaptan CH_4S DS061.0

Physical Data:
Molar Mass, [5] 48.109 g/mol
Melting Point T_{mp} at 1.013 bar, [5]
-122.97 ^{0}C (= -189.35 ^{0}F)
Enthalpy of Fusion at T_{mp}, [10]
122.8 kJ/kg (= 52.79 BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [5]
5.96 ^{0}C (= 42.73 ^{0}F)
Enthalpy of Vaporisation at T_{bp}, [10]
511.04 kJ/kg (= 219.70 BTU/lb)
Critical Point:
-Temperature, [5]
196.85 ^{0}C (= 386.33 ^{0}F)
- Pressure, [5]
72.30 bar (= 1048.64 psia)
- Density Liquid, [10] 0.332 kg/l
Density Gas:
- ideal 2.1464 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1 bar, [24]
1.992 g/l (= 0.1244 lb/ft^3)
- at 15 ^{0}C,1 bar, [10] 2.046 g/l
- at 0 ^{0}C and 1.013 bar --- g/l
Density Liquid, [10]
- at T_{bp} and 1.013 bar 0.886 kg/l
- at 20 ^{0}C 0.866 kg/l

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
0.50	0.79	1.18	1.66	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -27.4 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -19.3 x 10^{-3} bar^{-1}
Thermal Conductivity at 15^{0}C and 1.013 bar, [10] 0.130 mW/(cm K)
Heat Capacity at 25 ^{0}C, 1.013 bar [10] 1.05 kJ/(kg K)
Solubility in Water at 20^{0}C and 1 bar, [6] 0.023 l gas / kg H_2O
Dynamic Viscosity at 25 ^{0}C, 1 bar [24] 0.1261 x 10^{-6} Ns/m^2
Explosion Limits in Air,
[13] 4.1-21 Vol.-%
[24] 3.9-21.8 Vol.-%
Autoignition Temperature,
[13] 420 ^{0}C (= 788 ^{0}F)
[28] 360 ^{0}C (= 680 ^{0}F)
Heating Value, [24] 23.939 MJ/kg
Suitable Extinguishing Media:
All known.
1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:
CAS Number: 00074-93-1
EU Number: 200-822-1
EU Classification: F+, T, N
EU Symbols: F+, T, N
Index-Number.: 016-021-00-3

UN Number: 1064
METHYLMERCAPTAN
Class/Div: 2.3
ADR/RID: Class 2, Number 2TF
ADR/RID Hazard Number: 263
Labeling ADR/DOT: 2.3+2.1

EU Classification:
Risk Phrases:
R12: Extremely flammable.
R23: Toxic by inhalation.
R50/53: Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.
Safety Phrases:
S2: Keep out of the reach of children
S16: Keep away from sources of ignition – No smoking
S25: Avoid contact with eyes.
S60: This material and its container must be disposed of as hazardous waste.
S61: Avoid release to the environment. Refer to special instructions / Safety data sheets.

H.Schön: Handbook of Purified Gases

Data Sheet DS091.0 **Date: 07-07-17**

Name: Methyl silane Chemical Formula: CH_6Si

Synonyms: Silicoethane **$H_3C\text{-}SiH_3$**

Properties: Low pressure liquefied gas, flammable, colorless, irritating odor, toxic. Violent exothermic reaction with HCl, ethylene oxide and halogen hydrocarbons. Reaction with water may release H_2 and CH_4, thermal decomposition mays produce CO, SiO_2, H_2.

Production and Purification:

Widespread Applications:
Used as a deposition gas in the semiconductur industry.
Important Impurities:
Air, Cl-Si-Compounds.
Disposal:
Combustion, formed gases should be washed with water to remove silica .
Detection of Methyl silane:
Detector for flammable gases, Mass spectrometry.

Suitable Materials:		All known.
Valve Thread:	*Europe:*	Not standardized.
		Germany: No.1, W21,8x1/14" LH.
	USA:	CGA connection 350 .825"-1/14 LH EXT.
Filling Density(Factor):		0.39 kg/l at test pressure 225 bar.

Toxicological Information:
May cause nausea, hedache and irritation of the respiratory tract. Hydrolysis of silanes in the body forms silicic acid or hydrated silica.
Symptoms of Poisoning: In high concentration may cause asphyxiation. Symptoms may include loss of mobility/consiousness. Victim may not aware of asphyxiation. In low concentration may cause narcotic effects.
First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information:
No known ecological damage caused by this product.
Exposure Limits:
TLV(ACGIH): ppm, LC50 / 1h : ppm

Methyl silane CH_6Si DS091.0

Physical Data:

Molar Mass, [21] 46.145 g/mol

Melting Point T_{mp} at 1.013 bar, [21]
-156.4 ^{0}C (= -249.52 ^{0}F)

Enthalpy of Fusion at T_{mp}
kJ/kg (= BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [14]
-57.5 ^{0}C (= -71.5 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [14]
398 kJ/kg (= 171.10 BTU/lb)

Critical Point, [14]:
-Temperature 79.3 ^{0}C (= 174.74 ^{0}F)
- Pressure 43.7 bar (= 633.82 psia)
- Density Liquid 0.236 kg/l

Density Gas:
- ideal 2.0588 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1,013 bar
g/l (= lb/ft^3)
- at 15 ^{0}C and 1 bar g/l
- at 0 ^{0}C, 1.013 bar, [3] 2.076 g/l

Density Liquid at T_{bp} ,1.013 bar, [3]
0.628 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [14]

-10	0	10	20	^{0}C
5.8	7.7	10.2	13.0	bar

2.Pressure Virial Coefficient
- at 0 ^{0}C: x 10^{-3} bar^{-1}
- at 30 ^{0}C: x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar mW/(cm K)

Heat Capacity at 25 ^{0}C and 1.013 bar kJ/(kg K)

Solubility in Water at 20 ^{0}C and 1.013 bar l Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar x 10^{-6} Ns/m^2

Explosion Limits in Air, [14]
1.3-88.9 Vol.-%

Autoignition Temperature, [2]
160 ^{0}C (= 320 ^{0}F)

Heating Value MJ/kmol

Suitable Extinguishing Media:
CO_2, dry chemicals

Identification and Classification:

CAS Number: 00992-94-9
EU Number: 213-598-5
EU Classification: F+
EU Symbols: F+
Index Number:

UN Number: 3161
LIQUEFIED GAS, FLAMMABLE, N.O.S. (Methylsilane)
Class/Div: 2.1
ADR/RID: Class 2, Number 2F
ADR/RID Hazard Number: 23
Labeling ADR/DOT: 2.1

EU Classification:

Risk Phrases:

R12: Extremely flammable.

Safety Phrases:

S9: Keep container in a well ventilated places.

S16: Keep away from sources of ignition - No smoking.

S33: Take precautionary measures against static discharges.

H.Schön: Handbook of Purified Gases

Data Sheet DS069.0 **Date: 08-03-25**

Name: Neon, compressed **Chemical Formula:** **Ne**

Synonyms:

Properties: Compressed gas, non flammable, non-toxic, colourless, odourless, extremely chemically inert (noble Gas). Air contains 2 ppm of Ne Stable Isotopes: Ne-20, -21 and -22

Production and Purification:
Air separation. Cryogenic rectification.

Widespread Applications: Filling gas for fluorescent tubes, counter tubes, bubble chambers and gas lasers.
Important Impurities: Air, He, Ar, H2, HC´s

Disposal: Pass in the atmosphere.
Detection of Neon: Mass spectrometry.

Suitable Materials: All known.
Valve Thread: *Europe:* for 300 bar: No 54, W30x2 RH.
Germany: for 200 bar: No6 W21.8x1/14" RH.
USA: *CGA* connection 580, .965"x1/14" *RH INT.*

Test pressue/service pressure =1.5

Toxicological Information:
No known toxicological effects from this product.
Symptoms of Poisoning:
In high concentrations may cause asphyxiation. Symptoms may include loss of mobility/consciouness. Victim may not be aware the asphyxiation.
First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH):-- ppm, LC50 / 1h :--- ppm .

Neon, compressed Ne DS069.0

Physical Data:

Molar Mass, [5] 20.180 g/mol

Triple Point at 0.433 bar, [5]
-248.59 ^{0}C (= -415.46 ^{0}F)

Enthalpy of Fusion at T_{mp} , [24]
16.25 kJ/kg (= 6.99 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-246.08^{0}C (= -410.94 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [24]
86.22 kJ/kg (= 37.07 BTU/lb)

Critical Point, [24]:
-Temperature -228.75^{0}C (=-379.75 ^{0}F)
- Pressure 26.53 bar (=384.79 psia)
- Density Liquid 0.4839 kg/l

Density Gas: ideal 0.9003 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
0.836 g/l (= 0.0522 lb/ft^3)
- at 15 ^{0}C and 1 bar, [10] 0.842 g/l
- at 0 ^{0}C, 1.013 bar, [12] 0.8999 g/l

Density Liquid at T_{bp} and 1.013 bar, [10] 1.206 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [4, 5]

-245	-239	-233	-229	^{0}C
1.4	6.1	16	27	bar

2.Pressure Virial Coefficient, [1]
- at 0 ^{0}C: +0.47 x 10^{-3} bar^{-1}
- at 30 ^{0}C: +0.46 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.476 mW/(cm K)

Heat Capacity at 25 ^{0}C,1.013 bar, [10] 1.03 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 0.01 l gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar, [3] 31.6 x 10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

Identification and Classification:

CAS Number:	07440-01-9
EU Number:	231-110-9
EU Classification:	---
EU Symbols:	---
Index Number:	

UN Number: 1065
NEON, compresssed

Class/Div:	2.2
ADR/RID: Class 2, Number	1A
ADR/RID Hazard Number:	20
Labeling ADR/DOT:	2.2

EU Classification:
Risk Phrases:
RAs: Asphyxiant in high concentrations.

Safety Phrases:
S9: Keep container in a well ventilated places.
S23: Do not breathe gas.

H.Schön: Handbook of Purified Gases

Data Sheet DS079.0 **Date: 08-07-29**

Name:Nitric oxide **Chemical Formula: NO**

Synonyms: Nitrogen monoxide, Mononitrogen monoxide

Properties:
Low pressure liquefied gas, non flammable, supports combustion, toxic, colourless. It is rapidly oxidised by the oxygen of the air to form NO_2.

Production and Purification:
formed in the oxidation of ammonia with atmospheric oxygen over platinium/ rhodium catalystes (Ostwald process).

Widespread Applications:
Used as an important intermediate in the production of nitric acid, in the preparation of metal carbonyls and related compounds.

Important Impurities: Air, N_2O, NO_2.

Disposal: Oxidation to NO2 and pass in dilute alcaline solvents.

Detection of Nitric oxide: gas test tube.

Suitable Materials: All known, but not copper and brass; PTFE .

Valve Thread: *Europe:* Not standardized.
Germany: No.8, 1" RH.
USA: CGA connection 660, 1.030"-1/14 RH EXT.

Test pressure/service pressure =1.5

Toxicological Information: Delayed fatal pulmonary oedema possible. Severe corosion to skin, eyes and respiratory tract.

Symptoms of Poisoning:
Very toxic by inhalation. Irritation to eyes, skin and respiratory tract. Prolonged exposure to small concentrations may result pulmonary oedema.

First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.

Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information:
May cause pH changes in aqueous ecological systems.

Exposure Limits:
TLV(ACGIH): 25 ppm, LC_{50} / 1h : 115 ppm.

Nitric oxide NO DS079.0

Physical Data:

Molar Mass, [5] 30.006 g/mol

Triple Point at 0.219 bar, [5, 10]
-163.64 ^{0}C (= -262.55 ^{0}F)

Enthalpy of Fusion at T_{mp} , [24]
76.68 kJ/kg (= 0.0776 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-151.77 ^{0}C (= -241.19 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [24]
454.58 kJ/kg (= 195.47 BTU/lb)

Critical Point, [24]:
-Temperature -93^{0}C (=-135.4 ^{0}F)
- Pressure 64.85 bar (= 940.57 psia)
- Density Liquid 0.52 kg/l

Density Gas: ideal 1.3387 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
1.243 g/l (= 0.0776 lb/ft^3)
- at 15 ^{0}C, 1 bar, [15] 1.254 g/l
- at 0 ^{0}C, 1.013 bar, [11] 1.3402 g/l

Density Liquid at T_{bp} and 1.013 bar, [28] 1.188 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [4]

-152	-140	-110	-93	^{0}C
1	3.5	29	65	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -1.12×10^{-3} bar^{-1}
- at 30 ^{0}C: -0.75×10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.248 mW/(cm K)

Heat Capacity at 25 ^{0}C,1.013 bar, [10] 0.996 kJ/(kg K)

Solubility in Water at 20 ^{0}C,1.013 bar, [10] 47 ml Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar, [3] 19.03×10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

Identification and Classification:

CAS Number: 10102-43-9
EU Number: 233-271-0
EU Classification: O, T+, C
EU Symbols: O, T+, C
Index Number: 007-002-00-0

UN Number: 1660
NITRIC OXIDE, compresssed
Class/Div: 2.3
ADR/RID: Class2,Number 1TOC
ADR/RID Hazard Number: 265
Labeling ADR/DOT: 2.3, 5.1, 8

EU Classification:
Risk Phrases:

R8: Contact witcombustible material cause fire.

R26/27: Very toxic by inhalation and in contact with skin.

Safety Phrases: S1: Keep locked up.

S9: Keep container in a well ventilated place.

S17: Kep away from combustible material.

S26: In case of contact with eyes, rinse immediatediately with plenty of water and seek medical advice.

S36/37/39: Wear suitable protective clothing, gloves and eye/face protection.

S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible)

H.Schön: Handbook of Purified Gases

Data Sheet DS072.0 **Date: 08-07-20**

Name:Nitrogen, compressed **Chemical Formula:** N_2

Synonyms: Nitrogen gas, Nitrogenium, R728

*Properties:*Non-liquefied, compressed gas, non flammable, non toxic, colourless, odourless, chemically extremely unreactive, makes up 78.1 vol-% in the air.

Production and Purification:
Manufactured by air separation.
Widespread Applications:
Primarily used to produce ammonia, major usage as an inert gas.
Important Impurities:
O_2, H_2O, CO, CO_2, HC´s
Disposal: pass in the atmosphere.

Detection of Nitrogen: mass spectrometry.

Suitable Materials: All known,
Valve Thread: Europe: 300 bar: No. 54, W 30x2, 17,3/18,7.
Germany 200 bar: No.10, W24x1/14" RH.
USA: CGA connection 580, .965"x1/14" RH INT.

Test pressue/service pressure =1.5

Toxicological Information:
No known toxicological effects from this product.
Symptoms of Poisoning:
In high concentrations may cause asphyxiation. Sympoms are include loss of mobility/conscioness. Victim may not be aware of asphyxiation.
First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Environmental Information:
No ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH): ppm, LC_{50} / 1h : ppm

Nitrogen, compressed N_2 DS072.0

Physical Data:

Molar Mass, [5] 28.014 g/mol

Triple Point at 0.1253 bar, [5, 10]
-210.00 ^{0}C (=-346 ^{0}F)

Enthalpy of Fusion at T_{mp}, [24]
25.7 kJ/kg (= 11.05 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-195.80 ^{0}C (= -320.44 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [24]
202.76 kJ/m^3 (=87.19 BTU/lb)

Critical Point, [24]:
-Temperature
-147.05 ^{0}C (= -232.69^{0}F)
- Pressure 33.94 bar (= 492.26 psia)
- Density Liquid 0.3109 kg/l

Density Gas: ideal 1.24986 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
1.160 g/l (= 0.0724 lb/ft^3)
- at 15 ^{0}C, 1 bar, [10] 1.170 g/l
- at 0 ^{0}C, 1.013 bar, [11] 1.2504 g/l

Density Liquid at T_{bp} and 1.013 bar,
[10] 0.8085 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [4, 5]

-196	-163	-147	^{0}C
1	14.7	34	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -0.47×10^{-3} bar^{-1}
- at 30 ^{0}C: -0.17×10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.250 mW/(cm K)

Heat Capacity at 25 ^{0}C,1.013 bar, [10] 1.041 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 0.0156 l Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar, [3] 17.9×10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

Identification and Classification:

CAS Number: 07727-37-9
EU Number: 231-783-9
EU Classification: ---
EU Symbols: ---
Index Number:

UN Number: 1066
NITROGEN, COMPRESSED
Class/Div: 2.2
ADR/RID: Class 2, Number 1A
ADR/RID Hazard Number: 20
Labeling ADR/DOT: 2.2

EU Classification:
Risk Phrases:
RAs: Asphyxiant in high concentrations.

Safety Phrases:
S23: Do not breathe gas.

H.Schön: Handbook of Purified Gases

Data Sheet DS080.0 **Date: 08-07-25**

Name: Nitrogen dioxide, liquified Chemical Formula:

Synonyms: Dinitrogen tetraoxide, nitrogen peroxide **NO_2 (N_2O_4)**

Properties: Low pressure liquefied gas, non flammable, supports combustion, very toxic, red-brown colour, paramagnetic gas. NO_2 and its dimer N_2O_4 are in a temperature and pressure-dependent equilibrium, about 150 °C only NO_2 remains.

Production and Purification:
Obtained by the Ostwald propcess by the catalytic oxidation of ammonia with athmospheric Oxygen. Rectification.

Widespread Applications:
Used as acatalyst in certain oxydation reactions, inhibitor to prevent polymerization of acrylates during distillation, nitrating agent for organic compounds.

Important Impurities: Air, HNO_3, N_2O, NO

Disposal: Pass the gas in dilute alcaline solvents.

Detection of Nitrogen dioxide: gas test tube.

Suitable Materials: All known, but not copper and brass; PTFE .

Valve Thread: *Europe:* Not standardized.

Germany: No.8 , 1" RH.

USA: CGA connection 660, 1.030"-1/14 RH EXT.

Filling Density(Factor): 1.30 kg/l at test pressure10 bar.

Toxicological Information:
Delayed fatal pulmonary oedema possible

Symptoms of Poisoning:
Very toxic by inhalation. Irritation to eyes, skin and respiratory tract,

First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.

Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information:
May cause pH changes in aqueous ecological systems.

Exposure Limits:
TLV(ACGIH): 5 ppm, LC_{50} / 1h :115 ppm

Nitrogen dioxide, liqufied NO_2 DS080.0

Physical Data:

Molar Mass,[5, 1]
46.006 (92.011) g/mol
Triple Point at 0.186 bar, [5, 10]
-11.20 ^{0}C (= + 11.84 ^{0}F)
Enthalpy of Fusion at T_{mp} ,
kJ/kg (= BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [24]
20.85^{0}C (= 69.53 ^{0}F)
Enthalpy of Vaporisation at T_{bp} , [24]
536.23 kJ/kg (= 0.1190 BTU/lb)
Critical Point, [24]:
-Temperature 158.2 ^{0}C (= 316.76 ^{0}F)
- Pressure 101.33 bar (= 1469.67 psia)
- Density Liquid 0.5577 kg/l
Density Gas: ideal 2.0526 g/l
- at 70 ^{0}F (= 21.1 ^{0}C),1,013 bar, [24]
1.905 g/l (= 0.1190 lb/ft^3)
- at 15 ^{0}C and 1 bar --- g/l
- at 0 ^{0}C and 1.013 bar --- g/l
Density Liquid
- at T_{bp} and 1.013 bar, [10] 1.439 kg/l
- at 25 OC, [24] 1.442 kg/l

Vapor Pressure (about), [4]

-10	0	10	20	50	0C
0.21	0.34	0.61	0.96	3.48	bar

2.Pressure Virial Coefficient, [11]
- at 0 0C: -26.4 x 10-3 bar-1
- at 30 0C: -17.0 x 10-3 bar-1
Thermal Conductivity at 15 0C and 1.013 bar, [10] 0.132 mW/(cm K)
Heat Capacity at 25 0C,1.013 bar, [10] 1.327 kJ/(kg K)
Solubility in Water at 20 0C, 1.013 bar, [10] Hydrolysis
Dynamic Viscosity at 25 ^{0}C, 1 bar, [24] 1.74×10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number: 10102 -44-0
EU Number: 233-272-6
EU Classification: T+, O
EU Symbols: T+, O
Index Number: 007-002-00-0

UN Number: 1067
DINITROGEN TETRAOXIDE (NITROGEN DIOXIDE)
Class/Div: 2.3
ADR/RID: Class 2, Number 2TOC
ADR/RID Hazard Number: 265
Labeling ADR/DOT: 2.3, 5.1

EU Classification:
Risk Phrases:
R8: Contact with combustible material may caus fire
R26: Very toxic by inhalation.
R34: Causes burns
Safety Phrases:
S7/9: Keep container tightly closed and in a well ventilated places.
S26: In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.
S28: After contact with skin, wash immediately with water.
S36/37/39: Wear suitable protective clothing, gloves and eye/face protection.
S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible)

H.Schön: Handbook of Purified Gases

Data Sheet DS057.0 **Date: 07-07-14**

Name: Nitrogen trifluoride Chemical Formula: NF_3

Synonyms: Perfluoroammonia, Trifluoroammonia, Trifluoroamine, F3N

Properties:
High pressure liquefied gas, colorless, moldy odour, toxic, chemically stable. Strong oxidising agent, readily inflames with greases and oils. Thermal decomposition mays produce fluorinated compounds and NO.

Production and Purification:
Prepared by electrolysing ammonium fluoride in anhydrous HF.
Widespread Applications:
Rocket propellant (with H_2). Used in the preparation of tetrafluorohydrazine and fluorination of fluorocarbon olefins.
Important Impurities: Air, N_2O, SF_6 .
Disposal:
Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.
Detection of Nitrigen fluoride: IR-spectrometry .

Suitable Materials: Steel, stainless steel, monel.
PTFE, PCTFE, PVDF.
Valve Thread: *Europe:* Not standardized.
Germany: No.8, 1" RH.
USA: CGA connection 670, 1.030"-1/14 RH EXT.
Filling Density(Factor): 0.75 kg/l at test pressure 300 bar.

Toxicological Information:
Damage to red blood (haemolytic poison).
Symptoms of Poisoning:
Cause severe burnes (eyes, respiratory sytem, skin). Delayed fatal pulmonary edema possible.
First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information:
No known ecological damage caused by this product.
Exposure Limits:
TLV(ACGIH): 10 ppm, LC_{50} / 1h : 6700 ppm .

Nitrogen trifluoride **NF_3** **DS057.0**

Physical Data:

Molar Mass, [5] 71.002 g/mol

Triple Point at 1.85 mbar, [28]
-207.14 ^{0}C (= -340.85 ^{0}F)

Enthalpy of Fusion at T_{mp}, [24]
5.61 kJ/kg (= 2.41 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-129.04 ^{0}C (= -200.27 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [10]
163.1 kJ/kg (= 70.12 BTU/lb)

Critical Point:
-Temperature, [5]
-39.5 ^{0}C (= -39.1 ^{0}F)
- Pressure, [5]
45.3 bar (= 657.03 psia)
- Density Liquid, [10] 0.522 g/l

Density Gas:
- ideal 3.1678 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
2.941 g/l (= 01836 lb/ft^3)
- at 15 ^{0}C, 1 bar, [3] 2.976 g/l
- at 0 ^{0}C, 1.013 bar, [11] 3.183 g/l

Density Liquid
- at T_{bp} , 1.013 bar, [10] 1.540 kg/l
- at -70 ^{0}C, [24] 1.204 kg/l

Vapor Pressure (about), [4, 5]

-129	-100	-70	-39.15	^{0}C
1	5.5	17.8	45.3	bar

2.Pressure Virial Coefficient, [1]
- at 0 ^{0}C: -5 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -3 x 10^{-3} bar^{-1}

Thermal Conductivity at 25 ^{0}C and 1 bar, [24] 0.2198 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar [3] 0.755 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [6] 0.061 l gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C, 1 bar [24] 19.18 x 10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number: 07783-54-2
EU Number: 232-007-1
EU Classification: O, Xn
EU Symbols: O, Xn
Index Number:

UN Number: 2451
NITROGEN TRIFLUORIDE
Class/Div: 2.2
ADR/RID: Class 2, Number 2O
ADR/RID Hazard Number: 25
Labeling ADR/DOT: 2.2, 5.1

EU Classification:

Risk Phrases:

R8: Contact with combustible material may cause fire.
R20: Harmful by inhalation.

Safety Phrases:

S9: Keep container in well ventilated places..
S17: Keep away from combustible material.
S23: Do not breathe the gas, fumes, vapours, spray.

H.Schön: Handbook of Purified Gases

Data Sheet DS027.0 **Date: 07-03-03**

Name: Octafluorocyclobutane* Chemical Formula: C_4F_8

Synonyms: Perfluorocyclobutane, RC318, Cyclooctafluorobutane $(CF_2)_4$

Properties:

Low pressure liquefied gas, non flammable, non toxic, colorless, odorless. Chemically and thermally very stable. Thermal decomposition yields CO, COF_2 and HF.

Production and Purification:

Manufactured by dimerising tetrafluoroethene at 300-500 ^{0}C. Rectification.

Widespread Applications:

Used as propellant gas, dielectric and refrigerant.

Important Impurities: Other HC´s and CFC´s.

Disposal:

Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.

Detection of Octafluorocyclobutane:

Halogen leak detector. IR-spectrometry.

Suitable Materials: All known, but not Mg.

Valve Thread: *Europe:* Not standardized.

Germany: No.6, W21,8 x 1/14" RH.

USA: CGA connection 660, 1.030"-1/14 RH EXT.

Filling Density(Factor): 1.34 kg/l at test pressure 11 bar.

Toxicological Information:

No known acute toxicological effects from this product.

Symptoms of Poisoning:

In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of co-ordination. In high concentration may cause asphyxiation.

First Aid:

Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.

Environmental Information:

No known ecological damage caused by this product.

Exposure Limits:

TLV(ACGIH):--- ppm, LC50 / 1h : --- ppm .

Octafluorocyclobutane C_4F_8 DS027.0

Physical Data:

Molar Mass, [5] 200.031 g/mol

Triple Point at 0.191 bar, [5]
- 40.19 ^{0}C (= - 40.34 ^{0}F)

Enthalpy of Fusion at T_{mp} , [24]
13.85 kJ/kg (= 5.96 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-5.98 ^{0}C (= +21.24 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [24]
116.08 kJ/kg (= 49.91 BTU/lb)

Critical Point:

-Temperature, [5]
115.22 ^{0}C (= 239.4 ^{0}F)

- Pressure, [5]
27.78 bar (= 402.92 psia)

- Density Liquid, [10] 0.616 kg/l

Density Gas:

- ideal 8.925 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1 bar, [24]
8.284 g/l (= 0.5172 lb/ft^3)
- at 15 ^{0}C, 1 bar, [28] 8.771 g/l
- at 0 ^{0}C, 1.013 bar, [11] 9.338 g/l

Density Liquid, [10]

- at T_{bp} and 1.013 bar 1.637 kg/l
- 20 ^{0}C 1.541 kg/l

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
0.88	1.31	1.90	2.69	bar

2.Pressure Virial Coefficient, [11]

- at 0 ^{0}C: -43.7 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -29.8 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.067 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar, [10] 0.816 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar,[6] 0.14 g gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C, 1 bar [24] 11.74 x 10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number: 00115-25-3
EU Number: 204-075-2
EU Classification:
EU Symbols:
Index Number:

UN Number: 1976
OCTAFLUOROCYCLOBUTANE
Class/Div: 2.2
ADR/RID: Class 2, Number 2A
ADR/RID Hazard Number: 20
Labeling ADR/DOT: 2.2

EU Classification:

Risk Phrases:

RAs: Asphyxiant in high concentrations.

Safety Phrases:

S9: Keep container in a well ventilated places.
S23: Do not breathe gas.

H.Schön: Handbook of Purified Gases

Data Sheet DS105.0 **Date: 07-03-06**

Name: Octafluorotetrahydrofuran Chem. Formula: C_4F_8O

Synonyms: Perfluorotetrahydrofuran F_3C-CF_2-CF_2-COF

Properties:

Low pressure liquefied gas, non flammable, colorless, odorless. Thermal decomposition yields CO, COF_2 and HF.

Production and Purification:

Widespread Applications:

Purification of CVD chambers.

Important Impurities: Other HC´s and CFC´s, HF, F_2 .

Disposal:

Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.

Detection of Perfluorotetrahydrofuran:

Halogen leak detector. IR-spectrometry.

Suitable Materials: All known.

Valve Thread: *Europe:* Not standardized.

Germany: No.6, W21,8 x 1/14" RH.

USA: CGA connection

Filling Density(Factor): 1.00 kg/l, [*], at test pressure 11 bar.

Toxicological Information:

Symptoms of Poisoning:

In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of co-ordination. In high concentration may cause asphyxiation.

First Aid:

Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.

Environmental Information:

Exposure Limits:

TLV(ACGIH): --- ppm, LC_{50} / 1h : --- ppm

Octafluorotetrahydrofuran C_4F_8O DS105.0

Physical Data:

Molar Mass, [17] 216.03 g/mol

Melting Point T_{mp} at 1.013 bar*, Triple Point ^{0}C (= ^{0}F)

Enthalpy of Fusion at T_{mp} kJ/kg (= BTU/lb)

Boiling Point T_{bp} at 1.013 bar

[17] -0.8 ^{0}C (= 30.6 ^{0}F)

[9,*] +0.8 ^{0}C (= 33.4 ^{0}F)

Enthalpy of Vaporisation at T_{bp} kJ/kg (= BTU/lb)

Critical Point:

-Temperature, [9] 127 ^{0}C (= 260.6 ^{0}F)

- Pressure bar (= psia)
- Density Liquid kg/l

Density Gas:

- ideal 9.6383 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1 bar g/l (= lb/ft^3)
- at 15 ^{0}C, 1 bar, [9] 8.660 g/l
- at 0 ^{0}C and 1.013 bar 9.338 g/l

Density Liquid at T_{bp} and 1.013 bar

[*] 1.628 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [9]

-10	0	10	20	^{0}C
			2.12	bar

2.Pressure Virial Coefficient

- at 0 ^{0}C: x 10^{-3} bar^{-1}
- at 30 ^{0}C: x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar mW/(cm K)

Heat Capacity at 25 ^{0}C and 1.013 bar kJ/(kg K)

Solubility in Water at 20 ^{0}C and 1.013 bar l Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C, 1 bar

[17] 20 x 10^{-6} Ns/m^2

Suitable Extinguishing Media: All known.

[*] Product Data Sheet: Linde AG 2005

Identification and Classification:

CAS Number: 00773-14-8

EU Number: 204-05-2

EU Classification:

EU Symbols:

Index Number:

UN Number: 3163

Liquefied gas, n.o.s. OCTA-FLUORTETRAHYDROFURAN

Class/Div: 2.2

ADR/RID: Class 2, Number 2A

ADR/RID Hazard Number: 20

Labeling ADR/DOT: 2.2

EU Classification:

Risk Phrases:

RQAs: Asphyxiant in high concentrations.

Safety Phrases:

S9: Keep container in a well ventilated places.

S23: Do mot breathe gas, fumes, vapours, spray.

H.Schön: Handbook of Purified Gases

Data Sheet DS081.0 **Date: 08-06-29**

Name: Oxygen* Chemical Formula: O_2

Synonyms: Oxygenium, Dioxygen, Hyperoxia

*Properties:*Non-liquefied, compressed gas, non flammable, colourless, odourless, with an oxidising action or promoting combustion. Air contains about 21 % vol./vol. of O_2 . Ozon (O_3) is a further modification of oxygen.

Production and Purification:
Obtained industrially by air separation, liquefication and rectification. For small consumer O_2 can separated by membran process.
Widespread Applications:
The largest consumers are the iron and steel industry.
Important Impurities: N_2, rare gases, moisture, HC´s.

Disposal: pass in the atmosphere.

Detection of Oxygen: gas test tube.

Suitable Materials: All known, special tests required,no use oil or grease.

Valve Thread: Europe: 300 bar: No. 59, W 30x2, 17,3/18,7.
Germany 200 bar: No.9, G 3/4".
USA: CGA connection 540, 0.903"x1/14" RH EXT.
Test pressure/service pressure =1.5

Toxicological Information:
No known toxicological effets from this product.
Symptoms of Poisoning:
A human being can tolerate oxygen levels of 8-9 vol.-% without injury, lower concentrations lead to unconscioness and may be fatal. Concentration above 60 vol-% cause cell damage as a result of radical formation.
First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Environmental Information:
No ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH): ppm, LC_{50} / 1h : ppm

Oxygen O_2 DS081.0

Physical Data:

Molar Mass, [5] 31.999 g/mol

, Triple Point at 1.52 mbar, [5, 10]
-218.79 ^{0}C (= -361.82 ^{0}F)

Enthalpy of Fusion at T_{mp} , [24]
13.88 kJ/kg (= 5.97 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-182.98 ^{0}C (= -297.36 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [24]
210.63 kJ/kg (= 90.57 BTU/lb)

Critical Point, [24]:
-Temperature -118,57 ^{0}C (=-181.43 ^{0}F)
- Pressure 50.43 bar (= 731.43 psia)
- Density Liquid 0.436 kg/l

Density Gas: ideal 1.4276 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar,[24]
1.325 g/l (= 0.0827 lb/ft^3)
- at 15 ^{0}C and 1 ba, [10] 1.337 g/l
- at 0 ^{0}C, 1.013 bar, [11] 1.429 g/l

Density Liquid at T_{bp} and 1.013 bar,
[10] 1.141 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [4, 5]

-183	-163	-143	-123	^{0}C
1	5.43	17.5	50.4	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -0.97 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -0.60 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C,
1.013 bar, [10] 0.254 mW/(cm K)

Heat Capacity at 25 ^{0}C,1.013 bar,
[10] 0.919 kJ/(kg K)

Solubility in Water at 20 ^{0}C,1 bar,
[6] 39 mg gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C, 1 bar,
[3] 20.5 x 10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

Identification and Classification:

CAS Number:	07782-44-7
EU Number:	231-956-9
EU Classification:	O
EU Symbols:	O
Index Number:	008-001-00-8

UN Number:	1072 OXYGEN, compresssed
Class/Div:	2.2
ADR/RID: Class 2, Number	1O
ADR/RID Hazard Number:	25
Labeling ADR/DOT:	2.2, 5.1

EU Classification:
Risk Phrases:
R8: Contact with combustible material may cause fire

Safety Phrases:
S2: Keep out of the reach of children
S17: Keep away from combustible material

H.Schön: Handbook of Purified Gases

Data Sheet DS029.0 **Date: 07-03-08**

Name: Pentafluoroethane Chemical Formula: C_2HF_5

Synonyms: 1,1,1,2,2-Pentafluoroethane, R125 **$HF_2C\text{-}CF_3$**

Properties:
Low pressure liquefied gas, non flammable, colorless, etheral odor. Thermal decomposition yields CO, COF_2 and HF.

Production and Purification:
Fluorination of hydrocarbons. Rectification.
Widespread Applications:
Refrigerant in the low-temperature range. Etching agent for oxides.
Important Impurities: Other HC´s and CFC´s.
Disposal:
Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.
Detection of Pentafluoroethane:
Halogen leak detector. IR-spectrometry.

Suitable Materials: All known.
Valve Thread: *Europe:* Not standardized.
Germany: No.6, W21,8 x 1/14" RH.
USA: CGA connection 660, 1.030"-1/14 RH EXT.
Filling Density(Factor): 0.95 kg/l at test pressure 49 bar
or 0.72 kg/l at test pressure 36 bar.

Toxicological Information:
May produce irregular heart beat and nervous symptoms.
Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of co-ordination. In high concentration may cause asphyxiation.
First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.
Environmental Information:
No known ecological damage caused by this product.
Exposure Limits:
TLV(ACGIH): 1000 ppm, LC_{50} / 1h :--- ppm

Pentafluoroethane C_2HF_5 DS029.0

Physical Data:

Molar Mass, [5] 120.022 g/mol

Melting Point T_{mp} at 1.013 bar, [5]
-103 ^{0}C (= -153.4 ^{0}F)

Enthalpy of Fusion at T_{mp}
kJ/kg (= BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-48.09 ^{0}C (= -54.56 ^{0}F)

Enthalpy of Vaporisation at T_{bp},, [24]
159.55 kJ/kg (= 68.61 BTU/lb)

Critical Point:

-Temperature
[5] 66.02 ^{0}C (= 143.64 ^{0}F)
[24] 68.85 ^{0}C (= 155.93 ^{0}F)

- Pressure
[5] 36.15 bar (= 524.32 psia)
[24] 34.4 bar (= 498.93 psia)

- Density Liquid, [24] 0.556 kg/l

Density Gas:

- ideal 5.3548 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1 bar, [24]
4.971 g/l (= 0.3103 lb/ft^3)
- at 15 ^{0}C, 1 bar, [6] 6.76 g/l
- at 0 ^{0}C and 1.013 bar g/l

Density Liquid at T_{bp} and 1.013 bar

- at 20 ^{0}C, [7] 1.26 kg/l
- at 25 ^{0}C, [24] 1.174 kg/l

Vapor Pressure (about), []7]

-10	0	10	20	^{0}C
			12.1	bar

2.Pressure Virial Coefficient

- at 0 ^{0}C: $\times 10^{-3}$ bar^{-1}
- at 30 ^{0}C: $\times 10^{-3}$ bar^{-1}

Thermal Conductivity at 25 ^{0}C and 1 bar, [24] 0.1984 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1 bar, [24]
0.806 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1 bar [6] 0.9 g gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar, [24] 14.06 $\times 10^{-6}$ Ns/m^2

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number: 00354-33-6
EU Number: 206-557-8
EU Classification:
EU Symbols:
Index Number:

UN Number: 3220
PENTAFLUOROETHANE
Class/Div: 2
ADR/RID: Class 2, Number 2A
ADR/RID Hazard Number: 20
Labeling ADR/DOT: 2.2

EU Classification:

Risk Phrases:

RAs: Asphyxiant in high concentrations.

Safety Phrases:

S9: Keep container in a well ventilated places.
S23: Do not breathe gas.

H.Schön: Handbook of Purified Gases

Data Sheet DS028.0 **Date: 07-03-05**

Name: Perfluoropropane Chemical Formula: C_3F_8

Synonyms: Octafluoropropane, R218 **$F_3C\text{-}CF_2\text{-}CF_3$**

Properties:
Low pressure liquefied gas, non flammable, non toxic, colorless, odorless. Chemically and thermally very stable. Thermal decomposition yields CO, COF_2 and HF.

Production and Purification:
Fluorination of hydrocarbons. Rectification.
Widespread Applications:
Used as dielectric and refrigerant.
Important Impurities: Other HC´s and CFC´s.
Disposal:
Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.
Detection of Perfluoropropane:
Halogen leak detector. IR-spectrometry.

Suitable Materials: All known.
Valve Thread: *Europe:* Not standardized.
Germany: No.6, W21,8 x 1/14" RH.
USA: CGA connection 660, 1.030"-1/14 RH EXT.
Filling Density(Factor): 1.09 kg/l at test pressure 25 bar.

Toxicological Information:
No known acute toxicological effects from this product.
Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of co-ordination. In high concentration may cause asphyxiation.
First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.
Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH):--- ppm, LC50 / 1h : --- ppm .

Perfluoropropane C_3F_8 **DS028.0**

Physical Data:
Molar Mass, [5] 188.020 g/mol
Melting Point T_{mp} at 1.013 bar, [10,22]
-183 ^{0}C (= -297.4 ^{0}F)
Triple point at ? bar , [28]
-148.3 ^{0}C (= -234.94 ^{0}F)
Enthalpy of Fusion at T_{mp}, [24]
2.54 kJ/kg (= 1.09 BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [5]
-37.15 ^{0}C (= -34.87 ^{0}F)
Enthalpy of Vaporisation at T_{bp} , [10]
104 kJ/kg (= 44.71 BTU/lb)
Critical Point:
-Temperature, [5]
71.95 ^{0}C (= 161.51 ^{0}F)
- Pressure, [5] 26.8 bar (= 388.7 psia)
- Density Liquid, [10] 0.628 kg/l
Density Gas:
- ideal 8.3887 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1 bar, [24]
7.787 g/l (= 0.4862 lb/ft^3)
- at 15 ^{0}C, 1 bar, [15] 7.99 g/l
- at 0 ^{0}C, 1.013 bar, [11] 8.652 g/l
Density Liquid, [10]
- at T_{bp} and 1.013 bar 1.601 kg/l
- at 20 ^{0}C 1.345 kg/l

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
2.96	4.16	5.72	7.67	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -30.1 $\times 10^{-3}$ bar^{-1}
- at 30 ^{0}C: -20.6 $\times 10^{-3}$ bar^{-1}
Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.138 mW/(cm K)
Heat Capacity at 25 ^{0}C, 1.013 bar
[10] 0.5999 kJ/(kg K)
[24] 0.786 kJ/kg K)
Solubility in Water at 15 ^{0}C and 1 bar, [24] 5.85 ppm-w
Dynamic Viscosity at 25 ^{0}C, 1 bar
[24] 13.336 $\times 10^{-6}$ Ns/m^2

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:
CAS Number: 00076-19-7
EU Number: 200-941-9
EU Classification:
EU Symbols:
Index Number:

UN Number: 2424
OCTAFLUOROPROPANE
Class/Div: 2.2
ADR/RID: Class 2, Number 2A
ADR/RID Hazard Number: 20
Labeling ADR/DOT: 2.2

EU Classification:
Risk Phrases:
RAs: Asphyxiant in high concentrations.

Safety Phrases:
S9: Keep container in a well ventilated places.
S23: Do not breathe gas, fumes, vapours, spray.

H.Schön: Handbook of Purified Gases

Data Sheet DS042.0 **Date: 08-04-08**

Name: Phosgene **Chemical Formula: $COCl_2$**

Synonyms: Carbonyl chloride, Carbon oxychloride, Chloroformyl chloride, Carbonic dichloride oxide, Diphosgene $O{=}CCl_2$

Properties: Low pressure liquefied gas, non flammable, colourless, smelling of moudy hay, decomposes in water to form CO_2 and HCl. Readily soluble in chloroform, benzene and acetic acid. Is formed when chlorine-containing plastics are burned.

Production and Purification:
Manufactured industrially from CO and Cl2 in present of an active carbon catalyst,
Widespread Applications: Used in the manufacture of dyes, pharmaceuticals, herbicides, insecticides, resins and polymers.

Important Impurities:	Air, HC´s .
Disposal:	Pass in dilute alkaline solvents.
Detection of phosgene:	Gas test tube .
Suitable Materials:	Steel, stainless steel, PTFE, PCTFE, no rubber.
Valve Thread: *Europe:*	Not standardized. Germany: No.8, 1" RH.
USA:	CGA connection 660, 1.030"-1/14 RH EXT.
Filling Density(Factor):	1.23 kg/l at test pressure 20 bar.

Toxicological Information: Irritation to eyes, skin and respiratora tract. Pulmonary pathology after acute exposures showed bronchoconstriction, hyaline membrane formation, pulmonary oedema and emphysema.
Symptoms of Poisoning: Very toxic by inhalation, prolonged exposure to small concentrations may result in pulmonary oedema. Delayed adverse effects possible.
First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information:
May cause pH changes in aqueous ecological systems.
Exposure Limits:
TLV(ACGIH): 0.3 ppm, LC_{50} / 1h : 5 ppm .

Phosgene **$COCl_2$** **DS042.0**

Physical Data:

Molar Mass, [11] 98.916 g/mol

Melting Point T_{mp} at 1.013 bar, [24]
-127.78 ^{0}C (= -198 ^{0}F)

Enthalpy of Fusion at T_{mp} , 24]
58.01 kJ/kg (= 24.94 BTU/lb)

Boiling Point T_{bp} at 1.013 bar,
[12 7.44 ^{0}C (= 45.4 ^{0}F)
{24] 7.56 ^{o}C (= 45.61 ^{o}F)

Enthalpy of Vaporisation at T_{bp} , {24]
250.52 kJ/kg (= 107.72 BTU/lb)

Critical Point, [24]:
-Temperature 181.85 ^{0}C (= 359.33 ^{0}F)
- Pressure 56.74 bar (= 822.95 psia)
- Density Liquid 0.52 kg/l

Density Gas: ideal 4.4132 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
4.097 g/l (= 0.2558 lb/ft^3)
- at 15 ^{0}C and 1 bar, [15] 4.234 g/l
- at 0 ^{0}C, 1.013 bar, --- g/l

Density Liquid
- at T_{bp} and 1.013 bar, [12] 1.372 kg/l
- at 25 ^{o}C, [24] 1.363 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [12]

-10	0	10	20	^{0}C
0.5	0.8	1.1	1.6	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -32 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -22 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.091 mW/(cm K)

Heat Capacity at 25 ^{0}C,1.013 bar, [10] 0.582 kJ/(kg K)

Solubility in Water at 20 ^{0}C and 1.013 bar Hydrolyse

Dynamic Viscosity at 25 ^{0}C and 1 bar, [24] 11.62 x 10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

Identification and Classification:

CAS Number: 00075-44-5
EU Number: 200-870-3
EU Classification: T+, C
EU Symbols: T+
Index Number: 006-002-00-8

UN Number: 1076
PHOSGENE
Class/Div: 2.3
ADR/RID: Class 2, Number 2TC
ADR/RID Hazard Number: 268
Labeling ADR/DOT: 2.3, 8

EU Classification:

Risk Phrases:

R26: Very toxic by inhalation.
R34: Causes burns

Safety Phrases:

S9: Keep container in a well ventilated places.
S26: In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.
S36/37/39: Wear suitable protective clothing, gloves and eye/face protection.
S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible)

H.Schön: Handbook of Purified Gases

Data Sheet DS043.0 **Date: 08-04-10**

Name: Phosphine **Chemical Formula:** PH_3

Synonyms: hydrogen phosphide, Celphos, Delicia, Detia gas EX-B,
Phosphorus trihydride, Phosphane

Properties: Low pressure liquefied gas, flammable, colourless, smelling of rotten fish, diphosphine contamination can cause spontaneous ignition.The organic derivates of phosphin (PH2R, PHR2, PR3) are called phosphines and form co-ordination compounds, some of which are very stable

Production and Purification: Pure phospine is obtained from phosphonium iodid or white phosphorus with alkalic solutions.

Widespread Applications:

Used as doping agent for n-type semiconductors, initiator for polymerization, condensation catalyst.

Important Impurities: Diphosphine, Air, HC´s, H_2S .

Disposal: Pass in dilute alkaline solvent.

Detection of phosphine: Gas test tube.

Suitable Materials: Steel, stainless steel, PTFE, PCTFE .

Valve Thread: *Europe:* Not standardized.
Germany: No.1, W21,8x1/14" LH.
USA: CGA connection 350, .825"-1/14 LH EXT.

Filling Density(Factor): 0.51 kg/l at test pressure 250 bar.

Toxicological Information: Damage to central nervoeus system. Delayed fatal pulmonary oedema oossible.

Symptoms of Poisoning: Very toxic by inhalation, symptoms may include dizziness, headache, nausea and loss of coordination. Delayed adverse effects possible

First Aid: Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.

Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information:

May cause pH changes in aqueous ecological systems.

Exposure Limits:

TLV(ACGIH): 0.1 ppm, LC_{50} / 1h : 20 ppm .

Phosphine **PH_3** **DS043.0**

Physical Data:

Molar Mass, [5] 33.998 g/mol

Triple Point at 3.6 mbar, [10]
-133.78 ^{0}C (= -208.8 ^{0}F)

Enthalpy of Fusion at T_{mp} , [24]
33.24 kJ/kg (= 14.29 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-87.73 ^{0}C (= -125.93 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [24]
412.08 kJ/kg (= 177.19 BTU/lb)

Critical Point, [24]:
-Temperature 51.6 ^{0}C (= 124.88 ^{0}F)
- Pressure 65.36 bar (= 947.97 psia)
- Density Liquid 0.3 kg/l

Density Gas: ideal 1.5168 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
1.408 g/l (= 0.0879 lb/ft^3)
- at 15 ^{0}C, 1 bar, [10] 1.432 g/l
- at 0 ^{0}C, 1.013 bar, [12] 1.512 g/l

Density Liquid
- at T_{bp} and 1.013 bar, [10] 0.740 kg/l
- at 25 oC, [24] 0.491 kg/l

Vapor Pressure (about), [12]

-10	0	10	20	^{0}C
17.1	21.9	27.8	34.6	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -9.2 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -6.7 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.163 mW/(cm K)

Heat Capacity at 25 ^{0}C,1.013 bar, [10] 1.091 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 0.23 l Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C, 1 bar, [24] 12.06 x 10^{-6} Ns/m^2

Explosion Limits in Air, [2]
1.6 -100 Vol.-%

Autoignition Temperature, [2]
100 ^{0}C (=212 ^{0}F)

Heating Value, [24] 37.06 MJ/kmol

Suitable Extinguishing Media:
All known.

Identification and Classification:

CAS Number:	07803-51-2
EU Number:	232-260-8
EU Classification:	F+, T+, N
EU Symbols:	F+, T+, N
Index Number:	015-181-00-1

UN Number:	2199 PHOSPHINE
Class/Div:	2.3
ADR/RID: Class 2, Number	2TF
ADR/RID Hazard Number:	263
Labeling ADR/DOT:	2.1, 2.3

Risk Phrases: R12: Extremely flammable. R17: spontaneously flammable in air. R26: Very toxic by inhalation. R34: Causes burns.

Safety Phrases:

S1/2: Keep locked up and out of the reach of children.

S9: Keep container in a well ventilated places.

S28: After contact with skin, wash immediately with plenty of …(to be specified by the manufacturer).

S36/37: Wear suitable protective clothing and gloves.

S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible)

S61: Avoid release to the environment. Refer to special instructions/Safety data sheets.

S63: In case of accident by inhalation: remove casualty to fresh air and keep at rest.

H.Schön: Handbook of Purified Gases

Data Sheet DS036.0 **Date: 06-02-21**

Name: Propane **Chemical Formula: C_3H_8**

Synonyms: Dimethyl methane, Ethyl methyl, R290, **$H_3C\text{-}CH_2\text{-}CH_3$**
Propyl hydride, Liquefied Petroleum Gas(#)
(#) Synonym also for Isobutene

Properties:
Low pressure liquefied gas, flammable, colorless, relativ nontoxic, with a characteristic gas odor.

Production and Purification:
Constituent of natural gas and of petroleum cracking gases. Rectification.

Widespread Applications:
Fuel gas, propellant gas. Refrigerant.

Important Impurities: Other HCs.
Disposal: Combustion .
Detection of Propane: Detector for flammable gases. Gas test tube.
Suitable Materials: All known.
Valve Thread: Europe: Not standardized.
Germany: No.1, W21,8x1/14" LH.
USA: CGA connection 510, .885"-1/14 LH INT.

Filling Density(Factor): 0.42 kg/l at test pressure 25 bar.

Toxicological Information:
No known acute toxicological effects from this product.
Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of coordination. In high concentration may cause asphyxiation.
First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH): 2500 ppm , L*C50 / 1h :* ---

Propane C_3H_8 DS036.0

Physical Data:

Molar Mass, [5] 44.097 g/mol

Triple Point at 3 x 10^{-6} mbar, [5, 10]
-187.68 ^{0}C (= -305.82 ^{0}F)

Enthalpy of Fusion , [10]
95.04 kJ/kg (= 40.86 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-42.13 ^{0}C (= -43.83 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [10]
426 kJ/kg (= 183.14 BTU/lb)

Critical Point:
-Temperature, [12]
96.68 ^{0}C (= 206.02 ^{0}F)
- Pressure, [5]
42.48 bar (= 616.13psia)
- Density Liquid, [12] 0.266 kg/l

Density Gas:
- ideal 1.9674 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1.013 bar, [24] 1.826 g/l (= 0.114 lb/ft^3)
- at 15 ^{0}C and 1 bar, [10] 1.871 g/l
- at 0 ^{0}C, 1.013 bar, [12] 2.0098 g/l

Density Liquid, [10]
- at T_{bp} and 1.013 bar 0.582 kg/l
- at 20 ^{0}C 0.500 kg/l

Vapor Pressure (about), [12]

-10	0	10	20	^{0}C
3.4	4.7	6.4	8.3	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -20.87 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -14.79 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.167 mW/(cm K)

Heat Capacity at 25 ^{0}C and 1.013 bar, [10] 1.662 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 39 ml gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar, [3] 8.3 x 10^{-6} Ns/m^2

Explosion Limits in Air, [13]
1.7-10.8 Vol.-%

Autoignition Temperature, [13]
470 ^{0}C (= 878 ^{0}F)

Heating Value, [14]
2,043.11 MJ/kmol

Suitable Extinguishing Media:
All known .

1 bar = 14.504 psi,
1 g/l = 0.0624 lb/ft3

Identification and Classification:

CAS Number:	00074-98-6
EU Number:	200-827-9
EU Classification:	F+
EU Symbols:	F+
Index-number:	601-003-00-5

UN Number:	1978 PROPANE
Class/Div:	2.1
ADR/RID: Class 2, Number	2F
ADR/RID Hazard Number:	23
Labeling ADR/DOT:	2.1

EU Classification:

Risk Phrases:

R12: Extremely flammable.

Safety Phrases:

S2: Keep out of the reach of children.

S9: Keep container in a well ventilated places.

S16: Keep away from sources of ignition - No smoking.

H.Schön: Handbook of Purified Gases

Data Sheet DS037.0 **Date: 06-03-02**

Name: Propene Chemical Formula: C_3H_6

Synonyms: Propylene, Methyl ethylene, R1270 **$H_2C{=}CH{-}CH_3$**
1-Propene, Methylethene

Properties:
Low pressure liquefied gas, flammable, colorless, odorless, nontoxic. Readily soluble in many organic solvents.

Production and Purification:
From the cracking gases formed in petroleum refining. Rectification.
Widespread Applications:
Important raw material for the production of acetone, isopropyl alcohol, 1,2-epoxy-propane. Polymerisation to polypropylene.

Important Impurities:		Other HCs.
Disposal:		Combustion .
Detection of Propene:		Detector for flammable gases.
Suitable Materials:		All known.
Valve Thread:	*Europe:*	Not standardized. Germany: No.1, W21,8x1/14" LH.
	USA:	CGA connection 510, .885"-1/14 LH INT.
Filling Density(Factor):		0.43 kg/l at test pressure 300bar.

Toxicological Information:
No known acute toxicological effects from this product.
Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of coordination. In high concentration may cause asphyxiation.
First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH): --- , LC50 / 1h : ---

Propene C_3H_6 DS037.0

Physical Data:

Molar Mass, [5] 42,081 g/mol

Triple Point at 4 x 10^{-6} mbar, [5,10]
-185.26 ^{0}C (= 301.47 ^{0}F)

Enthalpy of Fusion, [10]
71.38 kJ/kg (= 30.69 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
- 47.69 ^{0}C (= -53.84 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [10]
437.94 kJ/kg (= 128.28 BTU/lb)

Critical Point:
-Temperature, [5]
91.95 ^{0}C (= 197.51 ^{0}F)
- Pressure, [24]
46.13 bar (= 669.06 psia)
- Density Liquid, [12] 0.232 kg/l

Density Gas:
- ideal 1.8775 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1.013 bar, [24]
1.743 g/l (= 0.1088 lb/ft^3)
- at 15 ^{0}C and 1 bar, [10] 1.785 g/l
- at 0 ^{0}C, 1.013 bar, [11] 1.9138 g/l

Density Liquid
- at T_{bp} and 1.013 bar, [10] 0.6139 kg/l
- at 20 ^{0}C, [12] 0.515 kg/l

Vapor Pressure (about), [12, 28]

-10	0	10	20	^{0}C
4.3	5.9	7.7	10.2	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -18.7 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -13.4 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 1.549 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar, [10] 0.156 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 0.23 l gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar, [3] 8.6 x 10^{-6} Ns/m^2

Explosion Limits in Air, [13]
1.8-9.4 Vol.-%

Autoignition Temperature, [13]
485 ^{0}C (= 905 ^{0}F)

Heating Value, [14]
1,925.97 MJ/kmol

Suitable Extinguishing Media:
All known .

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft3

Identification and Classification:

CAS Number: 00115-07-1
EU Number: 204-062-1
EU Classification: F+
EU Symbols: F+
Index-Number: 601-011-00-9

UN Number: 1077
PROPYLENE
Class/Div: 2.1
ADR/RID: Class 2, Number 2 F
ADR/RID Hazard Number: 23
Labeling ADR/DOT: 2.1

EU Classification:
Risk Phrases:
R12: Extremely flammable.

Safety Phrases:
S2: Keep out of the reach of children.

S9: Keep container in a well ventilated places.
S16: Keep away from sources of ignition - No smoking.
S33: Take precautionary measures against static discharges.

H.Schön: Handbook of Purified Gases

Data Sheet DS047.0 **Date: 07-07-24**

Name: Silane Chemical Formula: SiH_4

Synonyms: Monosilane, Silicane, Silicon tetrahydrite, Hydrogen silicide

Properties: High pressure liquefied gas, flammable, autoigniting in air, colorless, repulsive odour, toxic, stable at room temperature. Hydrolyses to SiO_2 , silicic acid and H_2.

Production and Purification:
Manufactured hy heating SiO_2 with lithium aluminium hydride or by decomposing magnesium silicide with hypochloric acid.

Widespread Applications:
Used mainly in the semiconductor industry to manufacture epitaxial silicon layers and as dotant for gallium arsenide semiconductors.

Important Impurities:
Air, HC´s, Cl-Si-Compounds.

Disposal:
Combustion, formed gases should be washed with water to remove silica .

Detection of Silane:
IR-spectrometry.

Suitable Materials: All known.

Valve Thread: *Europe:* Not standardized.
Germany: No.1, W21,8x1/14" LH.
USA: CGA connection 350, .825"-1/14 LH EXT.

Filling Density(Factor): 0.41 kg/l at test pressure 250 bar.

Toxicological Information:
May cause nausea, hedache and irritation of the respiratory tract. Hydrolysis of silanes in the body forms silicic acid or hydrated silica.

Symptoms of Poisoning:
In high concentration may cause asphyxiation. Symptoms may include loss of mobility/consiousness. Victim may not aware of asphyxiation.

First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH): 0.5 ppm, LC50 / 1h : 20,000 ppm
.

Silane SiH_4 DS047.0

Physical Data:

Molar Mass, [11] 32.117 g/mol

Triple Point at less than 1 mbar, [10] -186.4 ^{0}C (= -303.52 ^{0}F)

Enthalpy of Fusion at T_{mp} , [10] 24.62 kJ/kg (= 10.58 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [24] -112.15 ^{0}C (= -169.87 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [10] 361.2 kJ/kg (= 155.28 BTU/lb)

Critical Point, [24]:

-Temperatur -3.45 ^{0}C (= +25.79 ^{0}F)

- Pressure 48.43 bar (= 702.42 psia)

- Density Liquid 0.428 kg/l

Density Gas:

- ideal 1.4329 g/l

- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24] 1.33 g/l (= 0.083 lb/ft^{3})

- at 15 ^{0}C,1 bar, [10] 1.35 g/l

- at 0 ^{0}C, 1.013 bar, [11] 1.430 g/l

Density Liquid

- at T_{bp} , 1.013 bar, [28] 0.5828 kg/l

- at -40 ^{0}C, [24] 0.428 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^{3}

Vapor Pressure (about), [4, 12]

-111	-80	-20	-3.5	^{0}C
1	4.9	32	48.4	bar

2.Pressure Virial Coefficient, [11]

- at 0 ^{0}C: -7 x 10^{-3} bar^{-1}

- at 30 ^{0}C: -5 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.178 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar [28] 1.33 kJ/(kg K)

Solubility in Water at 20 ^{0}C and 1.013 bar hydrolyses

Dynamic Viscosity at 25 ^{0}C, 1 bar [28] 9.93 x 10^{-6} Ns/m^{2}

Explosion Limits in Air, [2] 1-100 Vol.-%

Autoignition Temperature, [7] less than 85 ^{0}C (= 185 ^{0}F)

Heating Value, [24] 44,431 MJ/kg

Suitable Extinguishing Media:
Dry chemicals, no CO_2 and halons.
Cool the cylinder with water.

Identification and Classification:

CAS Number:	07803-62-5
EU Number:	232-263-4
EU Classification:	F+
EU Symbols:	F+
Index Number:	
UN Number:	2203 SILANE
Class/Div:	2.1
ADR/RID: Class 2, Number	2F
ADR/RID Hazard Number:	23
Labeling ADR/DOT:	2.1

EU Classification:

Risk Phrases:

R12: Extremely flammable.

R17: Spontaneously flammable in air.

R20: Harmful by inhalation

Safety Phrases:

S9: Keep container in a well ventilated places..

S16: Keep away from sources of ignition - No smoking.

S33: Take precautionary measures against static discharges.

S36/37/39: Irritating to eyes, respiratorysystem and skin.

H.Schön: Handbook of Purified Gases

Data Sheet MS050.0 **Date: 07-07-14**

Name: Silicon tetrafluoride Chemical Formula: SiF_4

Synonyms: Tetrafluorosilane, Silicon fluoride, Perfluorosilane, F4Si

Properties:
High pressure liquefied gas, non flammable, colorless, pungent odour, toxic. Moist gas is severely corrosiv, because its hydrolysis to form HF and hexafluorosilicid acid. Thermal decomposition mays produce HF.

Production and Purification:
Manufactured by allowing concentrated sulphuric acid to react with a mixture of calcium fluoride and silicon dioxide.

Widespread Applications:
Used to prepare microfine silicon dioxide in the semicondutor industry, to produce cryolite and aluminium fluoride. Agent to enhance the quality of precast concrete components.

Important Impurities:	Air, HC´s, SO_2.
Disposal:	Pass in dilute NaOH- or KOH-solvent.
Detection of Silicon tetrafluoride:	IR-spectometry.

Suitable Materials:		All known, but corrosive in presence of moisture.
Valve Thread:	*Europe:*	Not standardized. Germany: No.8, 1" RH.
	USA:	CGA connection 330, .825"-1/14 LH EXT.
Filling Density(Factor):		1.1 kg/l at test pressure 300 bar.

Toxicological Information: May cause nausea and irritation of the respiratory tract. Hydrolysis of silan in the body forms silicic acid or hydrated silica. Absorption of excessive F- can result in acute systemic fluorosis, interference with various metabolic functions and organ damage (heart, liver, kidneys).

Symptoms of Poisoning: Very Toxic by inhalation.
May cause severe chemical burns to skin and cornea.

First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information:
May cause pH changes in aqueous ecological systems.

Exposure Limits:
TLV(ACGIH): ppm, LC_{50} / 1h : 450 ppm .

Silicon tetrafluoride SiF_4 DS050.0

Physical Data:
Molar Mass, [11] 104.079 g/mol
Triple Point at 2.24 bar, [3, 6]
-86.6 ^{0}C (= -124.24 ^{0}F)
Enthalpy of Fusion at T_{mp}, [24]
90.13 kJ/kg (= 38.76 BTU/lb)
Sublimation Point T_{subl} at 1.013 bar, [12] -95.20 ^{0}C (= -139.36 ^{0}F)
Enthalpy of Sublimation at T_{subl}, {28]
143 kJ/kg (= 61.48 BTU/lb)
Critical Point:
-Temperature, [12]
-14.1 ^{0}C (= +6.62 ^{0}F)
- Pressure, [3] 37.2 bar (= 539.55 psia)
- Density Liquid, [24] 0.6308 kg/l
Density Gas:
- ideal 4.6436 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
4.310 g/l (= 0.2691 lb/ft^3)
- at 15 ^{0}C, 1 bar, [3] 4.372 g/l
- at 0 ^{0}C, 1.013 bar, [11] 4.681 g/l
Density Liquid
- at T_{subl}, 1.013 bar, [28] 1.66 kg/l
- at -70 ^{0}C, [24] 1.517 kg/l

Vapor Pressure (about), [3, 12]

-86.6	-40	-14.1	^{0}C
2.2		37.2	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -8 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -5 x 10^{-3} bar^{-1}
Thermal Conductivity at 15 ^{0}C and 1.013 bar, [3] 0.195 mW/(cm K)
Heat Capacity at 25 ^{0}C, 1.013 bar [3] 0.7059 kJ/(kg K)
Solubility in Water at 20 ^{0}C, 1.013 bar Hydrolysis
Dynamic Viscosity at 25 ^{0}C, 1 bar [3] 14.96 x 10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:
CAS Number: 07783-61-1
EU Number: 232-015-5
EU Classification: T, C
EU Symbols: T, C
Index Number:

UN Number: 1859
SILICON TETRAFLUORIDE
Class/Div: 2.3
ADR/RID: Class 2, Number 2TC
ADR/RID Hazard Number: 268
Labeling ADR/DOT: 2.3, 8

EU Classification:
Risk Phrases:
R23:Toxic by inhalation.
R35: Cause severe burns.

Safety Phrases:
S9: Keep container in a well ventilated places.
S26: In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.
S36/37/39: Wear suitable protective clothing, gloves and eye/face protection.
S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible)

H.Schön: Handbook of Purified Gases

Data Sheet DS044.0 **Date: 07-07-09**

Name:Sulfur dioxide, liquefied Chemical Formula: SO_2

Synonyms: Sulphurous anhydride, Fermenticide liquid, R764

Properties:
Low pressure liquefied gas, non flammable, colorless, pungent odour, toxic, highly irritating. Dissolves in water forming sulfurous acid.
Moist SO_2 is highly corrosive.

Production and Purification: Natural emission sources are volcanoes. Anthropogenic emissions are caused by combustion of fossil fuels. Manufactured by burning elemental sulfur in air followed by partial condensation or purification by the Schröder-Grillo process.
Widespread Applications: Converted into sulfuric acid in the double contact or lead chamber methods. Refrigerant, bleaching agent, used in the foodstuffs industry for disinfection and preservation.
Important Impurities: Air, H_2SO_4.
Disposal: Pass in water or dilute alkaline solvent.
Detection of Sulfur dioxide: Gas test tube.

Suitable Materials: steel, Hastelloy, Tantal, no Nickel; PTFE, PCTFE.
Valve Thread: *Europe:* Not standardized.
Germany: No.7, 5/8" RH.
USA: CGA connection 660, 1.030"-1/14 RH EXT.
Filling Density(Factor): 1.23 kg/l at test pressure 14 bar.

Toxicological Information:
In high concentration severe corrosion to skin, eyes and respiratory tract. Delayed fatal pulmonary edema possible.
Symptoms of Poisoning:
Toxic by inhalation. Symptoms may include sneezing, coughing, burning sensation of throat with constricting sensation of the larynx and difficulty in breathing. Prolonged esposure to small concentration may result in pulmonary edema.
First Aid: Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.
Environmental Information:
May cause pH changes in aqueous ecological systems.

Exposure Limits:
TLV(ACGIH): 2 ppm, LC_{50} / 1h : 2520 ppm .

Sulfur dioxide, liquefied SO_2 DS044.0

Physical Data:

Molar Mass, [5] 64.065 g/mol

Triple Point at 16.8 mbar, [28]
-75.48 ^{0}C (= -104.44 ^{0}F)

Enthalpy of Fusion at T_{mp}, [10]
115.56 kJ/kg (= 49.68 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-10.02 ^{0}C (= +13.96 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [10]
389.37 kJ/kg (= 167.39 BTU/lb)

Critical Point:

-Temperature, [5]
157.65 ^{0}C (= 333.77 ^{0}F)

- Pressure, [5]
78.84 bar (= 1143.48 psia)

- Density Liquid, [12] 0.525 kg/l

Density Gas: - ideal 2.8582 g/l

- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
2.653 g/l (= 0.1656 lb/ft^{3})

- at 15 ^{0}C, 1 bar, [10] 2.725 g/l

- at 0 ^{0}C, 1.013 bar, [11] 2.9285 g/l

Density Liquid, [10]

- at T_{bp} and 1.013 bar 1.458 kg/l

- 20 ^{0}C 1.443 kg/l

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
1.06	1.55	2.27	3.25	bar

2.Pressure Virial Coefficient, [11]

- at 0 ^{0}C: -24 x 10^{-3} bar^{-1}

- at 30 ^{0}C: -17 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.091 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar, [10] 0.624 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 39.4 l Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C,1 bar [3] 12.74 x 10^{-6} Ns/m^{2}

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^{3}

Identification and Classification:

CAS Number:	07446-09-5
EU Number:	231-195-2
EU Classification:	T, C
EU Symbols:	T
Index Number:	016-011-00-9
UN Number:	1079 SULPHUR DIOXIDE
Class/Div:	2.3
ADR/RID:	Class 2, Number 2TC
ADR/RID Hazard Number:	268
Labeling ADR/DOT:	2.3, 8

EU Classification:
Risk Phrases:
R23: Toxic by inhalation.
R34: Causes burns

Safety Phrases:
S1/2: Keep locked up and out of the reach of children.
S9: Keep container in a well-ventilated places.
S26: In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.
S36/37/39: Wear suitable protective clothing, gloves and eye/face protection.
S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible)

H.Schön: Handbook of Purified Gases

Data Sheet DS053.0 **Date: 07-07-10**

Name: Sulfur hexafluoride Chemical Formula: SF_6

Synonyms: Sulphur hexafluoride, Elegas

Properties:
High pressure liquefied gas, non flammable, colorless, odorless, non- toxic, chemically very stable. Thermal decomposition mays produce HF.

Production and Purification:
Manufactured by reacting sulfur with fluorine. Rectification.

Widespread Applications:
Used in the semicondutor industry. Thermal insulated medium for glass windows, good dielectric in tranformers and other electric equipments.

Important Impurities: Air, CF_4, HF.

Disposal:
Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.

Detection of Sulfur hexafluoride: Halogen leak detector.

Suitable Materials: All known.

Valve Thread: *Europe:* Not standardized.
Germany: No.6, W21,8x1/14" RH.
USA: CGA connection 590, .965"-1/14 LH INT.

Filling Density(Factor): 1.37 kg/l at test pressure 160 bar.

Toxicological Information:
No known toxicological effects from this product.

Symptoms of Poisoning:
In high concentration may cause asphyxiation. Symptoms may include loss of mobility/consiousness. Victim may not aware of asphyxiation.
In low concentration may cause narcotic effects. Symptoms may include dizziness, headache, nausea and loss of co-ordination.

First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.

Environmental Information:
No known ecological effects from this product.

Exposure Limits:
TLV(ACGIH): ppm, LC_{50} / 1h : ppm

Sulfur hexafluoride SF_6 DS053.0

Physical Data:

Molar Mass, [5] 146.056 g/mol

Triple Point at 2.24 bar, [5, 10]
-50,7 ^{0}C (= -59.62 ^{0}F)

Enthalpy of Fusion at T_{mp}, [10]
34.4 kJ/kg (= 14.79 BTU/lb)

Sublimation Point T_{Subl} at 1.013 bar, [10] -63.9 ^{0}C (= -83.02 ^{0}F)

Enthalpy of Vaporisation at T_{Subl}, [10]
153.20 kJ/kg (= 65.86 BTU/lb)

Critical Point:
-Temperature, [5]
45.47 ^{0}C (= 113.85 ^{0}F)
- Pressure, [5] 37.6 bar (= 545.35 psia)
- Density Liquid, [24] 0.736 kg/l

Density Gas:
- ideal 6.1563 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
6.049 g/l (= 03776 lb/ft^3)
- at 15 ^{0}C, 1 bar, [10] 6.176 g/l
- at 0 ^{0}C, 1.013 bar, [11] 6.626 g/l

Density Liquid
- at -50.8 ^{0}C, [10] 1.910 kg/l
- at 20 ^{0}C, [12] 1.390 kg/l

Vapor Pressure (about), [12]

-10	0	10	20	^{0}C
9.3	12.5	16.3	21.0	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -15.2 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -10.8 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.1315 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar [10] 0.606 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 5.6 ml gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C,1 bar [3] 15.66 x 10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number: 02551-62-4
EU Number: 219-854-2
EU Classification:
EU Symbols:
Index Number:

UN Number: 1080
SULPHUR HEXAFLUORIDE
Class/Div: 2.2
ADR/RID: Class 2, Number 2A
ADR/RID Hazard Number: 20
Labeling ADR/DOT: 2.2

EU Classification:
Risk Phrases:
RAs: Asphyxiant in high concentrations.

Safety Phrases:
S9: Keep container in a well ventilated places.
S23: Do not breathe gas.

H.Schön: Handbook of Purified Gases

Data Sheet DS107.0 **Date: 07-07-11**

Name: Sulfur tetrafluoride Chemical Formula: SF_4

Synonyms: Tetrafluorosulfurane, Sulphur tetrafluoride

Properties:
Low pressure liquefied gas, non flammable, colorless, pungent odour, very toxic. Moist gas is severely corrosiv, because its hydrolysis to form HF.

Production and Purification:
Manufactured by luorination of sulfur chlorides.
Widespread Applications:
Used in large quantities for the selective fluorination of ketones, aldehydes and carboxylic acids.
Important Impurities:
Air, Cl-compounds.
Disposal:
Pass in dilute NaOH- or KOH-solvent.
Detection of Sulfur tetrafluoride:
Halogen leak detector.

Suitable Materials:		All known, but corrosive in presence of moisture.
Valve Thread:	*Europe:*	Not standardized. Germany: No.8, 1" RH.
	USA:	CGA connection 330, .825"-1/14 LH EXT.
Filling Density(Factor):		0.91 kg/l at test pressure 30 bar.

Toxicological Information:
In high concentration severe corrosion to skin, eyes and respiratory tract. Delayed fatal pulmonary edema possible.
Symptoms of Poisoning:
Very Toxic by inhalation.
May cause severe chemical burns to skin and cornea.
First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.
Environmental Information:
May cause pH changes in aqueous ecological systems.
Exposure Limits:
TLV(ACGIH): 0.1 ppm, LC_{50} / 1h : 40 ppm .

Sulfur tetrafluoride SF$_4$ DS107.0

Physical Data:

Molar Mass, [5] 108.060 g/mol

Melting Point T$_{mp}$ at 1.013 bar, [5] -125 ^{0}C (= -193 ^{0}F)

Enthalpy of Fusion at T$_{mp}$ kJ/kg (= BTU/lb)

Boiling Point T$_{bp}$ at 1.013 bar, [24] - 40 ^{0}C (= - 40 ^{0}F)

Enthalpy of Vaporisation at T$_{bp}$, [24] 199.15 kJ/kg (= 85.63 BTU/lb)

Critical Point:

-Temperature, [5] 90.85 ^{0}C (= 195.53 ^{0}F)

- Pressure [5] 43,3 bar (= 628.03 psia)
  [24] 51.54 bar (= 757.39 psia)
- Density Liquid, [24] 0.6806 kg/l

Density Gas: - ideal 4.8211 g/l

- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24] 4.475 g/l (= 0.2794 lb/ft^3)
- at 15 ^{0}C, 1 bar, [4] 4.8 g/l
- at 0 ^{0}C and 1.013 bar g/l

Density Liquid

- at -40 ^{0}C, [4] 1.82 kg/l
- at 25 ^{0}C, [24] 1.526 kg/l

Vapor Pressure (about), [4,25]

-40	0	10	20	^{0}C
1.01			10	bar

2.Pressure Virial Coefficient

- at 0 ^{0}C: x 10^{-3} bar^{-1}
- at 30 ^{0}C: x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [24] 01537 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar [24] 0.708 kJ/(kg K)

Solubility in Water at 20 ^{0}C and 1.013 bar hydrolysis

Dynamic Viscosity at 25 ^{0}C, 1 bar [24] 15.977 x 10^{-6} Ns/m^2

Suitable Extinguishing Media: All known.

1 bar = 14.504 psi

1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number: 07783-60-0

EU Number: 232-013-4

EU Classification: T+, C

EU Symbols: T+, C

Index Number:

UN Number: 2418

SULPUR TETRACHLORIDE

Class/Div: 2.3

ADR/RID: Class 2, Number 2TC

ADR/RID Hazard Number: 263

Labeling ADR/DOT: 2.3, 8

EU Classification:

Risk Phrases:

R26: Very toxic by inhalation.

R35: Cause severe burns.

Safety Phrases:

S1: Keep locked up.

S9: Keep container in a well ventilated places.

S26: In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.

S36/37/39: Wear suitable protective clothing, gloves and eye/face protection.

S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible)

H.Schön: Handbook of Purified Gases

Data Sheet DS108.0 **Date: 07-07-15**

Name: Sulfuryl fluoride Chemical Formula: SO_2F_2

Synonyms: Sulphuric oxyfluoride, Sulphuryl difluoride, Vikane fumigant

Properties:
Low pressure liquefied gas, non flammable, colorless, odorless, toxic, chemically inert. Thermal decomposition mays produce SO_2 and HF.

Production and Purification:
Manufactured by fluorination of SO_2 or SO_2Cl_2.
Widespread Applications:
Used as an insecticidal fumigant and for synthesing other F-compounds.
Important Impurities:
Air, SO_2, F_2 .
Disposal:
Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.
Detection of Sulfuryl difluoride: Mass spectrometry.

Suitable Materials: Stainless steel, PTFE, PCTFE, FKM

Valve Thread: *Europe:* Not standardized.
Germany: No.1, W21,8x1/14" LH.
USA: CGA connection 660, 1.030"-1/14 RH EXT.
Filling Density(Factor): 1.10 kg/l at test pressure 50 bar.

Toxicological Information:
Damage to red blood (haemolytic poison).
Symptoms of Poisoning:
May cause headache, nausea and irritation of respiratory tract. Delayed fatal pulmonary edema possible.
First Aid:
May cause stomach cramps and vomitting.
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information:
No known ecological damage caused by this product.
Exposure Limits:
TLV(ACGIH): 5 ppm, LC_{50} / 1h : 3020 ppm .

Sulfuryl fluoride **SO_2F_2** **DS108.0**

Physical Data:

Molar Mass, [11] 102.062 g/mol

Melting Point T_{mp} at 1.013 bar, [24]
-137.33 ^{0}C (= -212.48 ^{0}F)

Enthalpy of Fusion at T_{mp}, [24]
44.03 kJ/kg (= 18.93 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [11]
-55.4 ^{0}C (= 67.72 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [24]
169.94 kJ/kg (= 73.07 BTU/lb)

Critical Point, [24]
-Temperature 91.85 ^{0}C (= 197.33 ^{0}F)
- Pressure 51.17 bar (= 742.16 psia)
- Density Liquid 0.611 kg/l

Density Gas:
- ideal 4.5535 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
4.227 g/l (= 0.2639 lb/ft^3)
- at 15 ^{0}C, 1 bar, [28] 4.317 g/l
- at 0 ^{0}C,1.013 bar, [28] 4.6261 g/l

Density Liquid
- at 0 ^{0}C, [4] 1.49 kg/l
- at 25 0C, [24] 1.386 kg/l

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
	8.7	12.2	15.5	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -15.5 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -11.4 x 10^{-3} bar^{-1}

Thermal Conductivity at 25 ^{0}C and 1 bar, [24] 0.1182 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar
[28] 0.7847 kJ/(kg K)
[24] 0.669 kJ/(kg K)

Solubility in Water at 20 ^{0}C,1.013 bar, [6] 1670 mg gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C, 1 bar
[24] 14.72 x 10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number:	02699-79-8
EU Number:	220-281-5
EU Classification:	T , N
EU Symbols:	T, N
Index Number:	009-015-00-7

UN Number:	2191 SULPHURYL FLUORIDE
Class/Div:	2.3
ADR/RID: Class 2, Number	2T
ADR/RID Hazard Number:	26
Labeling ADR/DOT:	2.3

EU Classification:
Risk Phrases:

R23: Toxic by inhalation.
R48/20: Harmful: danger of serious damage to health by prolonged exposure through inhalation.
R50: Very toxic to aquatic organism.

Safety Phrases:

S1/2: Keep locked up and out of the reach of children.
S23: Do not breathe gas, fumes, vapours, spray.
S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).
S60: This material and ist container must be isposed as hazardous waste.
S61: Avoid release to the environment. Refer to special in Structions/Safety data sheets.
S63: In case of accident by inhalation: remove casualty to fresh air and keep at rest.

H.Schön: Handbook of Purified Gases

Data Sheet DS094.0 **Date: 07-09-11**

Name: Stibine Chemical Formula: SbH_3

Synonyms: Antimony trihydride, Hydrogen antimonide

Properties:
Low pressure liquefied gas, flammable, colorless, pungent odour, very toxic. Can decomposes on heating into antimony and hydrogen below the boiling point. Violent oxidation.

Production and Purification:
Prepared from magnesium antimonide Mg_3Sb_2 and hydrochloric acid.
Widespread Applications:
Special cases.
Important Impurities:
Mg- and Cl- compounds.
Disposal:
Pass in dilute alcaline solution.
Detection of Stibine:
Gas test tube, Marsh test.

Suitable Materials:		Steel, stainless steel, PTFE, PCTFE, PVDF.
Valve Thread:	*Europe:*	Not standardized. Germany: No.1, W21,8x1/14" LH.
	USA:	CGA connection 350, .825"-1/14 LH EXT.
Filling Density(Factor):		1.2 kg/l at test pressure 20 bar.

Toxicological Information:
Damage to red blood cells (haemolytic poison).
Fatal intoxication possible with low concentration.
Symptoms of Poisoning:
Toxic by inhalation. Headache, nausea, urge to pass water, after a few hours urine has a red colour.
First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information: Toxic to water organisms.
Exposure Limits:
TLV(ACGIH): 0.1 ppm, LC_{50} / 1h : 20 ppm .

Stibine SbH_3 DS094.0

Physical Data:

Molar Mass, [28] 124,774 g/mol

Melting Point T_{mp} at 1.013 bar, [28]
-88.45 ^{0}C (= -127.21 ^{0}F)

Enthalpy of Fusion at T_{mp}
kJ/kg (= BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [28]
-17.2 ^{0}C (= +1.04 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [28]
170 kJ/kg (= 73.08 BTU/lb)

Critical Point:
-Temperature, [25] 173^{0}C (= 343.4^{0}F)
- Pressure bar (= psia)
- Density Liquid kg/l

Density Gas:
- ideal 5.5667 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1,013 bar
g/l (= lb/ft^3)
- at 15 ^{0}C, 1 bar, [28] 5.28 g/l
- at 0 ^{0}C, 1.013 bar, [2] 5.3 g/l

Density Liquid
- at -35 0C, [4] 2.26 kg/l
- at T_{bp}, 1.013 bar, [28] 2.158 kg/l

Vapor Pressure (about), [3]

-10	0	10	20	^{0}C
			6	bar

2.Pressure Virial Coefficient
- at 0 ^{0}C: $\times 10^{-3}$ bar^{-1}
- at 30 ^{0}C: $\times 10^{-3}$ bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar mW/(cm K)

Heat Capacity at 25 ^{0}C and 1.013 bar kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [2] 0.2 l gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar $\times 10^{-6}$ Ns/m^2

Explosion Limits in Air
LEL, [23] 1 Vol.-%

Autoignition Temperature
^{0}C (= ^{0}F)

Heating Value MJ/kmol

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number:	07803-52-3
EU Number:	
EU Classification:	T+. F+
EU Symbols:	T+, F+
Index Number:	051-003-00-9
UN Number:	2676 STIBINE
Class/Div:	2.3
ADR/RID: Class 2, Number	2TF
ADR/RID Hazard Number:	263
Labeling ADR/DOT:	2.3+2.1

EU Classification:

Risk Phrases:

R12: Extremely flammable.
R26: Very toxic by inhalation.

Safety Phrases:

S1: Keep locked up.
S9: Keep container in a well-ventilated place.
S16: Keep away from sources of ignition - No smoking.
S33: Take precautionary measures against static discharges.
S36: Wear suitable protective clothing.
S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible)

H.Schön: Handbook of Purified Gases

Data Sheet DS026.0 **Date: 07-03-09**

Name: Tetrafluoroethane **Chemical Formula:** $C_2H_2F_4$

Synonyms: 1,1,1,2-Tetrafluoroethane, R134a $H_2FC\text{-}CF_3$

Properties:

Low pressure liquefied gas, non flammable, colorless, etheral odor. Thermal decomposition yields CO, COF_2 and HF.

Production and Purification:

Fluorination of hydrocarbons. Rectification.

Widespread Applications:

Replacement product for R12. Refrigerant mixtures as R404A, R407A-C and R502 contain R134a.

Important Impurities: Other HC´s and CFC´s.

Disposal:

Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.

Detection of Tetrafluoroethane:

Halogen leak detector. IR-spectrometry.

Suitable Materials:		All known, but not Mg.
Valve Thread:	*Europe:*	Not standardized. Germany: No.6, W21,8 x 1/14" RH.
	USA:	CGA connection 167, .500"-1/16 RH EXT.
Filling Density(Factor):		1.04 kg/l at test pressure 22 bar

Toxicological Information:

No known toxicological effects from this product.

Symptoms of Poisoning:

In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of co-ordination. In high concentration may cause asphyxiation.

First Aid:

Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.

Environmental Information:

No known ecological damage caused by this product.

Exposure Limits:

TLV(ACGIH): 1000 ppm, LC50 / 1h :--- ppm

Tetrafluoroethane $C_2H_2F_4$ DS026.0

Physical Data:

Molar Mass, [5] 105.032 g/mol

Melting Point T_{mp} at 1.013 bar, [5]
-101 ^{0}C (= -149.8 ^{0}F)

Enthalpy of Fusion at T_{mp}
kJ/kg (= BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-26.11 ^{0}C (= -15.00 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [1]
215.9 kJ/kg (= 92.82 BTU/lb)

Critical Point:
-Temperature, [5]
101.11 ^{0}C (= 214.00 ^{0}F)
- Pressure, [5]
40.59 bar (= 588.72 psia)
- Density Liquid, [1] 0.512 kg/l

Density Gas:
- ideal 4.553 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1 bar
g/l (= lb/ft^3)
- at 15 ^{0}C, 1.013 bar, [1] 4.4 g/l
- at 0 ^{0}C and 1.013 bar g/l

Density Liquid at T_{bp}
- at 0 0C, 1 bar, [4] 1.30 kg/l
- at 25 ^{0}C, 1.013 bar, [1] 1.206 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
2.01	2.93	4.15	5.72	bar

2.Pressure Virial Coefficient
- at 0 ^{0}C: x 10^{-3} bar^{-1}
- at 30 ^{0}C: x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar [1] 0.087 kJ/(mol K)

Solubility in Water at 20 ^{0}C and 1.013 bar,[6] 0.9 g gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar x 10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

Identification and Classification:

CAS Number: 00811-97-2
EU Number: 212-377-0
EU Classification:
EU Symbols:
Index Number:

UN Number: 3159 1,1,1,2-TETRAFLUOROETHANE
Class/Div 2.2
ADR/RID: Class 2, Number 2A
ADR/RID Hazard Number: 20
Labeling ADR/DOT: 2.2

EU Classification:
Risk Phrases:
RAs: Asphyxiant in high concentrations.

Safety Phrases:
S9: Keep container in a well ventilated places.
S23: Do not breathe gas.

H.Schön: Handbook of Purified Gases

Data Sheet DS109.0 **Date: 07-03-11**

Name: Tetrafluoroethylene, inhibited Chem. Formula: C_2F_4

Synonyms: 1,1,2,2-Tetrafluoroethylene, TFE, Perfluoroethene, R1114 **$F_2C=CF_2$**

Properties:
High pressure liquefied gas, flammable, colorless, sweet odor. Tending to polymerisize. Thermal decomposition yields CO, COF_2 and HF.

Production and Purification:
Manufactured by pyrolysing chlorodifluoromethane.
Widespread Applications:
Used for the syntheses of polymers and copolymers (PTFE).
Important Impurities: Other HC´s and CFC´s.
Disposal:
Combustion: burner with flash back arrestor. Toxic and corrosive Gases formed during combustion should be scrubbed before discharge to air.
Detection of Tetrafluoroethylene:
Detector for flammable gases. IR-Spectrometry.

Suitable Materials: All known.
Valve Thread: *Europe:* Not standardized.
Germany: No.1, W21,8x1/14" LH.
USA: CGA connection 350, .825"-1/14 LH EXT.
Filling Pressure (polymerisation!): 5 bar at test pressure 200 bar.

Toxicological Information:
No known acute toxicological effects from this product.
Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of co-ordination. In high concentration may cause asphyxiation.
First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.
Environmental Information:
May cause pH changes in aqueous ecological systems.

Exposure Limits:
TLV(ACGIH):--- ppm, LC50 / 1h : --- ppm

Tetrafluoroethylene inhibited C_2F_4 DS109.0

Physical Data:
Molar Mass, [5] 100.016 g/mol
Melting Point T_{mp} at 1.013 bar, *
[24] -131.15 ^{0}C (= -104.15 ^{0}F)
Triple Point at 0.01168 bar
[28] -132.25 ^{0}C (= -104.25 ^{0}F)
Enthalpy of Fusion at T_{mp}, [24]
77.14 kJ/kg (= 33.17 BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [5]
-75.64 ^{0}C (= -104.15 ^{0}F)
Enthalpy of Vaporisation at T_{bp} , [24]
168.57 kJ/kg (= 72.49 BTU/lb)
Critical Point:
-Temperature,[5] 33.25 ^{0}C (=91.85 ^{0}F)
- Pressure, [5]
39.44 bar (= 572.03 psia)
- Density Liquid, [24] 0.5815 kg/l
Density Gas:
- ideal 4.462 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1 bar, [24]
4.142 g/l (= 0.2586 lb/ft^3)
- at 15 ^{0}C, 1 bar, [28] 4.216 g/l
- at 0 ^{0}C, 1.013 bar, [11] 4.5150 g/l
Density Liquid
- at T_{bp} and 1.013 bar, [3] 1.525 kg/l
- at 25 ^{0}C, [24] 0.92 kg/l

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
13.4	17.9	23.4	30.0	bar

2.Pressure Virial Coefficient, [11]
- at 0 0C: -11.5 x 10-3 bar^{-1}
- at 30 0C: -8.2 x 10-3 bar^{-1}
Thermal Conductivity at 25 0C and 1 bar, [24] 0.1541 mW/(cm K)
Heat Capacity at 25 0C and 1 bar
[24] 0.802 kJ/(kg K)
Solubility in Water at 20 ^{0}C, 1.013 bar, [6] 179 mg gas / kg H_2O
Dynamic Viscosity at 25 ^{0}C, 1 bar
[28] 14.93 x 10-6 Ns/m2
Explosion Limits in Air, [13]
10.5-59 Vol.-%
Autoignition Temperature
[13] 180 ^{0}C (= 356 ^{0}F)
[24] 200 ^{0}C (= 392 ^{0}F)
Heating Value 1.279 MJ/kg
Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft3
*

Identification and Classification:
CAS Number: 00116-14-3
EU Number: 204-126-9
EU Classification: F+
EU Symbols: F+
Index Number:

UN Number: 1081 TETRAFLUOROETHYLENE, inhibited
Class/Div: 2.1
ADR/RID: Class 2, Number 2F
ADR/RID Hazard Number: 23
Labeling ADR/DOT: 2.1

EU Classification:
Risk Phrases:
R12: Extremely flammable.

Safety Phrases:
S9: Keep container in a well ventilated places.
S16: Keep away from ignition source - No smoking.
S33: Take precautionary measures against static discharges.

H.Schön: Handbook of Purified Gases

Data Sheet DS025.0 **Date: 07-03-13**

Name: Tetrafluoromethane* Chemical Formula: CF_4

Synonyms: Carbon tetrafluoride, R14, Perfluoromethane, Tetrafluorocarbon

Properties:
High pressure liquefied gas, non flammable, non toxic, colorless, in high concentration etheral odor. Thermal decomposition yields CO, COF_2 and HF.

Production and Purification:
Manufactured from R12 or R11 and HF in the gas phase.. Rectification.
Widespread Applications:
Inertgas, gaseous insulator, low temperature refrigerant.
Important Impurities: Other HC´s and CFC´s, CO.
Disposal:
Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.
Detection of Tetrafluoromethane:
Halogen leak detector. IR-spectrometry.

Suitable Materials: All known.
Valve Thread: *Europe:* Not standardized.
Germany: No.6, W21,8 x 1/14" RH.
USA: CGA connection 320, .825"-1/14 RH EXT.
Filling Density(Factor): 0.94 kg/l at test pressure 300 bar.

Toxicological Information:
No known toxicological effects from this product.
Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of coordination. In high concentration may cause asphyxiation.
First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.
Environmental Information:
No known ecological damage caused by this product.
Exposure Limits:
TLV(ACGIH): --- ppm, LC50 / 1h :--- ppm

Tetrafluoromethane CF_4 DS025.0

Physical Data:

Molar Mass, [5] 88.005 g/mol

Melting Point T_{mp} at 1.013 bar, [5]
-183.60 ^{0}C (= -298.48 ^{0}F)

Enthalpy of Fusion at T_{mp} , [10]
79.5 kJ/kg (= 34.18 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
-128.04 ^{0}C (= -198.47 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [10]
135.7 kJ/kg (= 58.34 BTU/lb)

Critical Point:

-Temperature, [5]
-45.64 ^{0}C (= -50.15 ^{0}F)

- Pressure, [5]
37.45 bar (= 543.17 psia)

- Density Liquid, [10] 0.633 kg/l

Density Gas:

- ideal 3.9264 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1 bar, [24]
3.645 g/l (= 0.2275 lb/ft^3)
- at 15 ^{0}C, 1 bar, [10] 3.692 g/l
- at 0 ^{0}C, 1.013 bar, [12] 3.946 g/l

Density Liquid

- at 80 ^{0}C, [24] 1.302 kg/l
- at T_{bp} , 1.013 bar, [24] 1.609 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [4,5]

-80	-60	-45.64	^{0}C
10.2	24.3	37.45	bar

2.Pressure Virial Coefficient, [11]

- at 0 ^{0}C: -4.9 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -3.4 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.162 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar [10] 0.71 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 3.8 ml gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C, 1 bar [28] 17.41 x 10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

Identification and Classification:

CAS Number: 00075-73-0
EU Number: 200-896-5
EU Classification:
EU Symbols:
Index Number:

UN Number: 1982
TETRAFLUOROMETHANE
Class/Div: 2.2
ADR/RID: Class 2, Number 2A
ADR/RID Hazard Number: 20
Labeling ADR/DOT: 2.2

EU Classification:
Risk Phrases:
RAs: Asphyxiant in high concentrations.

Safety Phrases:
S3: Keep in a cool place.
S7: Keep container tightly closed.

H.Schön: Handbook of Purified Gases

Data Sheet DS011.0 **Date: 06-02-11**

Name: trans-2-Butene Chemical Formula: C_4H_8

Synonyms: trans-2-Buthylen, trans-But-2-ene, **$H_3C\text{-}CH{=}CH\text{-}CH_3$**
beta-Buthylene, Low boiling Buten-2, (E)-2-Butene

*Properties:*Low pressure liquefied gas, flammable, colorless, with an aromatic odor, unsaturated hydrocarbon. It is very soluble in alcohol and ether. One of four isomers of the butenes.

Production and Purification:
The butenes are obtained from the cracking gases of the petroleum industry or by the catalytic dehydrogenetion of butanes. Rectification.
Widespread Applications:
Butenes are used to manufacture of a variety of organic compounds. Polmerisation to high-octane gasolines, plasics and synthetic rubber.

Important Impurities: Other HCs.
Disposal: Combustion.
Detection of trans-2-Butene: Detector for flammable gases. Gas test tube.
Suitable Materials: All known .
Valve Thread: *Europe:* Not standardized.
Germany: No.1, W21,8x1/14" LH.
USA: CGA connection 510, .885"-1/14 LH INT.

Filling Density(Factor): 0.54 kg/l at test pressure 10 bar.

Toxicological Information:
No known acute toxicological effects from this product.
Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of coordination. In high concentration may cause asphyxiation.
First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH): ---, LC50 / 1h : ---

trans-2-Butene C_4H_8 DS011.0

Physical Data:

Molar Mass, [5] 56.108 g/mol

Triple Point at 0.54 mbar, [10]
-105.57 ^{0}C (= -158.03 ^{0}F)

Enthalpy of Fusion, [24]
173.92 kJ/kg (= 74.79 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [5]
0.88 ^{0}C (= 33.58 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [24]
408.33 kJ/kg (= 175.58 BTU/lb)

Critical Point:
-Temperature, [5]
155.45 ^{0}C (= 311.81 ^{0}F)
- Pressure, [5]
41.00 bar (= 594.66 psia)
- Density Liquid, [24] 0.236 kg/l

Density Gas:
- ideal 2.5033 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1.013 bar, [24] 2.324 g/l (= 0.1451 lb/ft^{3})
- at 15 ^{0}C and 1 bar, [10] 2.426 g/l
- at 0 ^{0}C and 1.013 bar --- g/l

Density Liquid, [10]
- at T_{bp} and 1.013 bar 0.626 kg/l
- at 20 ^{0}C 0.604 kg/l

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
0.7	1.0	1.42	2.00	bar

2.Pressure Virial Coefficient, [28]
- at 0 ^{0}C: $- 39 \times 10^{-3}$ bar^{-1}
- at 30 ^{0}C: $- 27 \times 10^{-3}$ bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.141 mW/(cm K)

Heat Capacity at 25 ^{0}C and 1.013 bar, [10] 1.57 kJ/(kg K)

Solubility in Water at 20^{0}C, 1.013 bar, [24] 0.235 l Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar, [24] 7.822×10^{-6} Ns/m^{2}

Explosion Limits in Air, [13]
1.6-10 Vol.-%

Autoignition Temperature, [24]
323.9 ^{0}C (= 615 ^{0}F)

Heating Value, [14]
2,503.3 MJ/kmol

Suitable Extinguishing Media:
All known .

1 bar = 14.504 psi,
1 g/l = 0.0624 lb/ft^{3}

Identification and Classification:

CAS Number: 00624-64-6
EU Number: 210-855-3
EU Classification: F+
EU Symbols: F+
Index-Number: 601-012-00-4

UN Number: 1012
trans-BUT-2-ENE
Class/Div: 2.1
ADR/RID: Class 2, Number 2F
ADR/RID Hazard Number: 23
Labeling ADR/DOT: 2.1

EU Classification:

Risk Phrases:

R12: Extremely flammable.

Safety Phrases:

S2: Keep out of the reach of children.

S9: Keep container in a well ventilated places.

S16: Keep away from sources of ignition - No smoking.

S33: Take precautionary measures against static discharges.

H.Schön: Handbook of Purified Gases

Data Sheet DS099.0 **Date: 07-06-10**

Name: Trifluorochloroethylene, inhibited **Chem. Formula:**

Synonyms: Chlorotrifluoroethene, R1113, CTFE, Trithene C_2ClF_3

1,1,2-Trifluoro-2-chloroethylene, Trifluorovinyl chloride $ClFC{=}CF_2$

Properties: Low pressure liquefied gas, flammable, colorless, ether-like odor. Chemically very reactive, polymerization, often stabilized with tributylamine. Thermal decomposition mays produce CO, $COCl_2$, COF_2, HF and HCl.

Production and Purification:

Widespread Applications:
Used in polymerization for production of PCTFE, Kel-F.

Important Impurities: Other HC´s and CFC´s.

Disposal:
Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.

Detection of R1113: Halogen leak detector, IR-spectrometry.

Suitable Materials: All known.

Valve Thread: *Europe:* Not standardized.
Germany: No.1, W21,8x1/14" LH.
USA: GA connection 510, .885"-1/14 LH INT.

Filling Density(Factor): 1.13 kg/l at test pressure 19 bar.

Toxicological Information:
May produce irregular heart beat and nervous symptoms. Repeated exposure may cause liver damage or failure. May cause inflammation of the respiratory system and skin. Delayed fatal pulmonary oedema possible.

Symptoms of Poisoning: Toxic by inhalation. In low concentrations may cause narcotic effects. Symptoms may include dizziness, headache, nausea and loss of co-ordination. May cause stomach cramps, vomitting, irritation of the respiratory tract, sneezing, coughing, burning sensation of throat with constricting sensation of the larynx and difficulty in breathing.

First Aid: Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped. Skin/eye contact: Remove contaminated clothing, use lukewarm water.

Environmental Information:
May cause pH changes in aqueous ecological systems.

Exposure Limits:
TLV(ACGIH): --- ppm, LC_{50} / 1h : 2000 ppm .

Trifluorochloroethylene,inhibited C_2ClF_3 DS099.0

Physical Data:

Molar Mass, [11] 116.47 g/mol

Melting Point T_{mp} at 1.013 bar, [10]
-158.10 ^{0}C (= -252.58 ^{0}F)

Enthalpy of Fusion at T_{mp}
[10] 27.72 kJ/kg (= 11.92 BTU/lb)
[24] 47.68 kJ/kg (= 20.5 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [10]
-28.36 ^{0}C (= -19.05 ^{0}F)

Enthalpy of Vaporisation at T_{bp}
[10] 178.36 kJ/kg (= 76.68 BTU/lb)
[24] 134.8 kJ/kg (= 57.96 BTU/lb)

Critical Point, [12]
-Temperature 105.8 ^{0}C (= 222.44 ^{0}F)
- Pressure 40.60 bar (= 588.87 psia)
- Density Liquid 0.550 kg/l

Density Gas:
- ideal 5.1964 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
4.824 g/l (= 0.3012 lb/ft^3)
- at 15 ^{0}C and 1 bar, [11] 4.963 g/l
- at 0 ^{0}C, 1.013 bar, [28] 5.335 g/l

Density Liquid
- at T_{bp} and 1.013 bar, [10] 1.464 kg/l
- at 25 ^{0}C, [24] 1.275 kg/l

Vapor Pressure (about), [12, 28]

-10	0	10	20	^{0}C
2.1	2.9	4.1	5.66	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -26 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -18 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [24] 0.0786 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar
[10] 0.723 kJ/(kg K)

Solubility in Water at 20 ^{0}C and 1.013 bar reaction

Dynamic Viscosity at 25 ^{0}C, 1 bar
[24] 12.10 x 10^{-6} Ns/m^2

Explosion Limits in Air
[12] 4.6-64.3 Vol.-%
[4, 24] 8.4-38.7 Vol.-%

Autoignition Temperature, [6, 7]
540 ^{0}C (= 1,004 ^{0}F)

Heating Value, [24] 1,837 MJ/kg

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number:	00079-38-9
EU Number:	201-201-8
EU Classification:	F+, T
EU Symbols:	F+, T
Index Number:	

UN Number: 1082 TRIFLUORO-CHLOROETHYLENE, inhibited

Class/Div:	2.3
ADR/RID:	Class 2, Number 2TF
ADR/RID Hazard Number:	263
Labeling ADR/DOT:	2.3+2.1

EU Classification:

Risk Phrases:

R12: Extremely flammable.
R23: Toxic by inhalation.

Safety Phrases:

S9: Keep container in a well-ventilated places.
S16: Keep away from sources of ignition - No smoking.
S33: Take precautionary measures against static discharges.
S36: Wear suitable protective clothing.
S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label when possible).

H.Schön: Handbook of Purified Gases

Data Sheet DS110.0 **Date: 07-02-04**

Name:Trimethylamine anhydrous Chem. Formula: C_3H_9N

Synonyms: N,N-Dimethylmethanamine, TMA $N(CH)_3$

*Properties:*Low pressure liquefied gas, flammable, colorless, corrosive, toxic, irritant, fishy-ammonia odor. Readily soluble in water and other polar solvents. A 50% aqueous solution is combustible!
Thermal decomposition yields NO, NO_2 and CO.

Production and Purification:
Synthesis from NH_3 and Methanol over a metal oxide catalysts at 250-500^{0}C.
Widespread Applications:
Manufacturing of disinfectants, choline chloride, herbicides, insecticides. Used as a corrosion inhibitor.
Important Impurities:
Other HC´s.
Disposal:
Pass in water or dilute acids.
Detection of Triemethylamine:
Gas test tube, litmus-paper, detector for flammable gases (IR-spectrometry).
Suitable Materials: Steel, stainless steel, PE, PTFE, EPDM.
Valve Thread: *Europe:* Not standardized.
Germany: No.1, W21.8x1/14" LH.
USA: CGA connection 705, 1.125"-1/14 RH EXT.
Filling Density(Factor): 0.56 kg/l at test pressure 10 bar.

Toxicological Information:
Irritation to lungs and upper respriratory tract shown as rhinitis, pharyn and pneumonia. May cause dermatitis, corneal edema and chemical burns.
Symptoms of Poisoning:
Harmful by inhalation. Respiratory tract, skin and eye burns. Difficulty in breating.
First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested, call a doctor. Apply artificial respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.
Environmental Information:
May cause pH changes in aqueous ecological systems.

Exposure Limits:
TLV(ACGIH): 10 ppm, LC_{50} / 1h : 7000 ppm

Trimethylamine anhydrous C_3H_9N DS110.0

Physical Data:

Molar Mass, [5] 59.111 g/mol

Melting Point T_{mp} at 1.013 bar, [5]
-117,30 ^{0}C (= -179.14 ^{0}F)

Enthalpy of Fusion at T_{mp} [10]
110.71 kJ/kg (= 45.59 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [24]
2.87 ^{0}C (= 37.17 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [3]
388 kJ/kg (= 166.80 BTU/lb)

Critical Point:

-Temperature, [5]
160.15 ^{0}C (= 320.37 ^{0}F)

- Pressure, [5]
40.75 bar (= 591.04 psia)

- Density Liquid, [10] 0.233 kg/l

Density Gas: - ideal 2.6373 g/l

- at 70 ^{0}F (= 21.1 ^{0}C), 1 bar, [24]
2.448g/l (= 0.1528 lb/ft^3)

- at 15 ^{0}C, 1 bar, [28] 2.5535 g/l

- at 0 ^{0}C and 1.013 bar --- g/l

Density Liquid

- at T_{bp} , 1.013 bar, [28] 0.6534 kg/l

- at 25 ^{0}C, [24] 0.629 kg/l

Vapor Pressure (about), [12]

-10	0	10	20	^{0}C
0.6	0.9	1.4	1.9	bar

2.Pressure Virial Coefficient, [11]

- at 0 ^{0}C: -40.4×10^{-3} bar^{-1}

- at 30 ^{0}C: -28.3×10^{-3} bar^{-1}

Thermal Conductivity at 15^{0}C, 1.013 bar, [10] 0.154 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar [3] 1.552 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 180 l gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C, 1 bar, [24] 7.813×10^{-6} Ns/m^2

Explosion Limits in Air, [13]
2-11.6 Vol.-%

Autoignition Temperature, [13]
190 ^{0}C (= 374 ^{0}F)

Heating Value, [24] 37.978 MJ/kg

Suitable Extinguishing Media:
All known, but water for cooling of cylinders only.

1 bar = 14.504 psi

1g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number:	00075-50-3
EU Number:	200-875-0
EU Classification:	F+, Xn, C
EU Symbols:	F+, C
Index-No.	612-001-00-9
UN Number:	1083
TRIMETHYLAMINE, anhydrous	
Class/Div:	2.1
ADR/RID: Class 2, Number	2F
ADR/RID Hazard Number:	23
Labeling ADR/DOT:	2.1

EU Classification:Risk Phrases: R12: Extremely flammable. R20: Harmful by inhalation and if swallowed. R37/38: Irritating to respiratory system and skin. R41: Wear eye/face protection. *Safety Phrases:* S1/2: Keep loked up and out of the reach of children. S3: Keep in a cool place. S16: Keep away from ignitation source - No smoking.

S26: In case of contact with eyes, rinse immatiately with plenty of water and seek medical advice. S36/37/39: Wear suitable protective clothing, gloves and eye/face protection. S45: In case of accident or if you feel unwell,seek medical advice immediately (show the label where possible).

H.Schön: Handbook of Purified Gases

Data Sheet DS111.0 **Date: 08-07-29**

Name: Trimethylboron Chem. Formula: BC_3H_9

Synonyms: **Boron trimethyl, Trimethylborane, TMB** **$B(CH_3)_3$**

Properties:

Low pressure liquefied gas, pyrophoric, burning in air with a green flame, toxic, colourless, with repulsive, suffocating odor, violently reactive with water, oxidizers and halogens. Thermal decomposition yields methane and Boron-compounds.

Production and Purification: Prepared at Trichloride in a Grignard reaction.
Widespread Applications: Used in semionductor industry.
Important Impurities: Air, HC´s.
Disposal:
Treat process and other exhaust streams appropriately before release to the atmosphere. Contact supplier if guidance is required.
Detection of Trimethylboron: IR-spectrometry.

Suitable Materials: steel, stainless steel, Kel-F .
Valve Thread: *Europe:* Not standardized.
Germany: DIN 477 No 1, W21.8x1/14" *LH.*
USA: CGA connection 350, .825"-1/14 LH EXT.
Filling Density(Factor): [Voltaix] 0.39 kg/l at test pressure 2015 psi

Toxicological Information:
May cause chemical burns to skin and cornea(with temporary disturbance to vision)
Symptoms of Poisoning:
Irritating to eyes, respiratory system and skin.
First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.
Environmental Information:
No known ecological damage caused by this product.
Exposure Limits:
TLV(ACGIH): ppm, LC_{50} / 1h : ppm

Trimethylboron BCl_3H_9 DS111.0

Physical Data:

Molar Mass, [21] 55.916 g/mol

Melting Point T_{mp} at 1.013 bar, [*]
-161.5 ^{0}C (= -258.7 ^{0}F)

Enthalpy of Fusion at T_{mp}

Boiling Point T_{bp} at 1.013 bar, [*]
-20.2 ^{0}C (= -4.36 ^{0}F)

Enthalpy of Vaporisation at T_{bp}
kJ/kg (= BTU/lb)

Critical Point [9]:
-Temperature 160.05 ^{0}C (=320.09 ^{0}F)
- Pressure 40.7 bar (=590.31 psia)
- Density Liquid kg/l

Density Gas: ideal 2.494 g/l
- at 70 ^{0}F (= 21.1 ^{0}C) and 1,013 bar
g/l (= lb/ft^3)
- at 15 ^{0}C and 1 bar, [21] 2.318 g/l
- at 0 ^{0}C, 1.013 bar, [4] 2.52 g/l

Density Liquid
- at -100 ^{o}C , [20] 1.6 kg/l
- at 18 ^{o}C, [4] 0.52 kg/l

[*] = Sigma-Aldrich

Vapor Pressure (about), [4, 21]

-10	0	10	20	^{0}C
1.0	2.5		4.1	bar

2.Pressure Virial Coefficient
- at 0 ^{0}C: x 10^{-3} bar^{-1}
- at 30 ^{0}C: x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar mW/(cm K)

Heat Capacity at 25 ^{0}C and 1.013 bar kJ/(kg K)

Solubility in Water at 20 ^{0}C and 1.013 bar l Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar x 10^{-6} Ns/m^2

Explosion Limits in Air
Vol.-%

Autoignition Temperature
^{0}C (= ^{0}F)

Heating Value MJ/kmol

Suitable Extinguishing Media: All known, but water for cooling only.

1 bar = 14.504 psi, 1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number:	00593-90-8
EU Number:	209-816-3
EU Classification:	F, C
EU Symbols:	F, C
Index Number:	005-004-00-6

UN Number: 3160

Liquefied gas, Toxic, Flammable, n.o.s. (Trimethylboron)

Class/Div:	2.3
ADR/RID: class 2, Number	2TF
ADR/RID hazard number:	263
Labeling ADR/DOT:	2.1, 2.3

EU Classification:

Risk Phrases:

R17: Spontaneously flammable in air

R34: Causes burns (to eyes, respiratory system and skin)

Safety Phrases:

S9: Keep container in a well ventilated places.

S16: Keep away from sources of ignition - No smoking

S23: Do not breathe gas.

S26: In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.

S36/37/39: Wear suitabe protective clothing, gloves and eye/face protection. S43: In case of fire use…. (manu-facturer), but water for cooling only. S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).

H.Schön: Handbook of Purified Gases

Data Sheet DS052.0 **Date: 07-07-16**

Name: Trimethylsilane Chemical Formula: SiC_3H_{10}

Synonyms: **$HSi(CH_3)_3$**

Properties:
Low pressure liquefied gas, flammable, colorless, nasty sweet odour, toxic. Thermal decomposition mays produce CO and SiO_2.

Production and Purification:
Manufactured by reducing trimethlchlorosilane with lithium aluminium hydride.

Widespread Applications:
Used as a deposition gas in the semiconductur industry.

Important Impurities:
Air, Cl-Si-Compounds.

Disposal:
Combustion, formed gases should be washed with water to remove sil ica .

Detection of Trimethylsilane:
Detector for flammable gases, Mass spectrometry.

Suitable Materials: All known.
Valve Thread: *Europe:* Not standardized.
Germany: No.1, W21,8x1/14" LH.
USA: CGA connection 350, .825"-1/14 LH EXT.
Filling Density(Factor): 0.39 kg/l at test pressure 225 bar.

Toxicological Information:
May cause nausea, hedache and irritation of the respiratory tract. Hydrolysis of silanes in the body forms silicic acid or hydrated silica.

Symptoms of Poisoning:
In high concentration may cause asphyxiation. Symptoms may include loss of mobility/consiousness. Victim may not aware of asphyxiation.

First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information:
May cause pH changes in aqueous ecological systems.

Exposure Limits:
TLV(ACGIH): ppm, LC_{50} / 1h : ppm

Trimethylsilane SiC_3H_{10} DS052.0

Physical Data:

Molar Mass, [28] 74.198 g/mol

Melting Point T_{mp} at 1.013 bar, [24]
-135.89 ^{0}C (= -212.6 ^{0}F)

Enthalpy of Fusion at T_{mp}
kJ/kg (= BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [12]
6.7 ^{0}C (= 44.06 ^{0}F)

Enthalpy of Vaporisation at T_{bp} , [24]
297.31 kJ/kg (= 127.84 BTU/lb)

Critical Point, [24]
-Temperature 158.85 ^{0}C (= 317.93 ^{0}F)
- Pressure 31.9 bar (= 462.67 psia)
- Density Liquid 0.2386 kg/l

Density Gas:
- ideal 3.3104 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
3.073 g/l (= 01918 lb/ft^3)
- at 15 ^{0}C, 1 bar, [6] 3.4 g/l
- at 0 ^{0}C and 1.013 bar --- g/l

Density Liquid, [12]
- at 0 ^{0}C 0.643 kg/l
- at 20 ^{0}C 0.616 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [12]

-10	0	10	20	^{0}C
0.3	0.8	1.2	1.6	bar

2.Pressure Virial Coefficient
- at 0 ^{0}C: x 10^{-3} bar^{-1}
- at 30 ^{0}C: x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [24] 0.1457 mW/(cm K)

Heat Capacity at 25 ^{0}C and 1 bar
[24] 1.571 kJ/(kg K)

Solubility in Water at 20 ^{0}C and
1.013 bar Hydrolysis

Dynamic Viscosity at 25 ^{0}C, 1 bar
[24] 7.802 x 10^{-6} Ns/m^2

Explosion Limits in Air
[12] 1.3-44 Vol.-%
[24] 2-100 Vol.-%

Autoignition Temperature
[2] 235 ^{0}C (= 455 ^{0}F)
[24] 320 ^{0}C (= 608 ^{0}F)

Heating Value, [24]
42,353 MJ/kg

Suitable Extinguishing Media:
All known, but not Halons.

Identification and Classification:

CAS Number: 00993-07-7
EU Number: 213-603-0
EU Classification: F+
EU Symbols: F+
Index Number:

UN Number: 3161
LIQUEFIED GAS, FLAMMABLE, N.O.S. (Trimethylsilane)
Class/Div: 2.1
ADR/RID: Class 2, Number 2F
ADR/RID Hazard Number: 23
Labeling ADR/DOT: 2.1

EU Classification:
Risk Phrases:
R12: Extremely flammable.

Safety Phrases:
S9: Keep container in a well ventilated places.
S16: Keep away from sources of ignition - No smoking.
S33: Take precautionary measures against static discharges.

H.Schön: Handbook of Purified Gases

Data Sheet DS054.0 **Date: 07-07-13**

Name: Tungsten hexafluoride Chem. Formula: WF_6

Synonyms: Wolfram hexafluoride, F6W, Hexafluorotungsten

Properties: Low pressure liquefied gas, non flammable, colorless or yellow, pungent odour, very toxic. Violently oxidises organic material. Moist gas is severely corrosiv, because its hydrolysis to form HF and tungsten acid. Thermal decomposition mays produce HF and tungsten oxides.

Production and Purification:
Manufactured by burning tungsten powder in a stream of F_2. Rectification.
Widespread Applications:
Used for vapor phase deposition of tungsten. Powerful fluorinating agent in chemical syntheses.
Important Impurities: Air, CF_4, SiF_4, $SiCl_4$, HF.
Disposal: Pass in dilute $Ca(OH)_2$-solvent.
Detection of Tungsten hexafluoride: IR-spectometry.

Suitable Materials: Steel, stainless steel, monel, no aluminium.
PTFE, PCTFE, PVDF, EPDM.
Valve Thread: *Europe:* Not standardized.
Germany: No.8, 1" RH.
USA: CGA connection 670, 1.030"-1/14 LH EXT.
Filling Density(Factor): 2.70 kg/l at test pressure 10 bar.

Toxicological Information: In high concentration severe corrosion to skin, eyes and respiratory tract. Delayed fatal pulmonary edema possible. Absorption of excessive F- can result in acute systemic fluorosis, interference with various metabolic functions and organ damage (heart, liver, kidneys).
Symptoms of Poisoning:
Very Toxic by inhalation.
May cause severe chemical burns to skin and cornea.
First Aid:
Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.
Environmental Information:
May cause pH changes in aqueous ecological systems. Endangering to drinking water.
Exposure Limits:
TLV(ACGIH): 3 ppm, LC50 / 1h :160 ppm .

Tungsten hexafluoride WF_6 DS054.0

Physical Data:
Molar Mass, [11] 297.830 g/mol
Melting Point T_{mp} at 1.013 bar, [24]
-0.5 ^{0}C (= +31.1 ^{0}F)
Enthalpy of Fusion at T_{mp}, [24]
13.77 kJ/kg (= 5.92 BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [12]
17.06 ^{0}C (= 62.71 ^{0}F)
Enthalpy of Vaporisation at T_{bp}, [24]
80.85 kJ/kg (= 34.77 BTU/lb)
Critical Point:
-Temperature
[12] 169.8 ^{0}C (= 337.64 ^{0}F)
[24] 195.41 ^{0}C (= 383.74 ^{0}F)
- Pressure
[12] 42,7 bar (= 619.32 psia)
[24] 46.75 bar (= 678.05 psia)
- Density Liquid, [24] 1.3044 kg/l
Density Gas:
- ideal 13.2878 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
12.334 g/l (= 0.7701 lb/ft^3)
- at 15 ^{0}C, 1 bar, [6] 11.1 g/l
- at 0 ^{0}C and 1.013 bar --- g/l

Density Liquid
- at T_{bp}, 1.013 bar, [3] 3.43 kg/l
- at 25 ^{0}C, [24] 3.387 kg/l

Vapor Pressure (about), [1, 4, 6]

-10	0	10	20	^{0}C
0.47	0.55	0.76	1.13	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -46×10^{-3} bar^{-1}
- at 30 ^{0}C: -32×10^{-3} bar^{-1}
Thermal Conductivity at 25 ^{0}C, [24]
0.098 mW/(cm K)
Heat Capacity at 25 ^{0}C, 1.013 bar
[24] 0.4 kJ/(kg K)
Solubility in Water at 20 ^{0}C, 1.013 bar, [24] hydrolyse
Dynamic Viscosity at 25 ^{0}C and 1 bar 18.21×10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:
CAS Number: 07783-82-6
EU Number: 232-029-1
EU Classification: T+, C
EU Symbols: T+, C
Index Number:

UN Number: 2196
TUNGSTEN HEXAFLUORIDE
Class/Div: 2.3
ADR/RID: Class 2, Number 2TC
ADR/RID Hazard Number: 268
Labeling ADR/DOT: 2.3, 8

EU Classification:
Risk Phrases:
R26: Very toxic by inhalation.
R35: Cause severe burns.

Safety Phrases:
S1: Keep locked up.
S9: Keep container in a well ventilated places.
S26: In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.
S36/37/39: Wear suitable protective clothing, gloves and eye/face protection.
S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible)

H.Schön: Handbook of Purified Gases

Data Sheet DS096.0 **Date: 07-06-20**

Name:Vinyl bromide, stabilized Chem. Formula: C_2H_3Br

Synonyms: Bromoethene, R1140B1, Monobromoethylene **$H_2C=CHBr$**

Properties: Low pressure liquefied gas, flammable, colorless, ethereal odour, moderately toxic, polymerisises under the action of light. 0.1% phenol is suggested to stabilise. Thermal decomposition mays produce CO, $COBr_2$ and HBr.

Production and Purification:
Manufactured from 1,2-Dibromoethane by dehydrobromation with caustic soda solution.

Widespread Applications:
Used as an intermediate in organic synthesis.

Important Impurities: Other HC´s, priority C_2H_2, other Br-C-H-compounds.

Disposal:
Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.

Detection of Vinyl bromide: Halogen leak detector, gas test tube .

Suitable Materials: Steel, stainless steel, monel, no copper or magnesium, PTFE, PCTFE, PVDF.

Valve Thread: *Europe:* Not standardized.
Germany: No.1, W21,8x1/14" LH.
USA: CGA connection 290, .745"-1/14 LH EXT.

Filling Density(Factor): 1.37 kg/l at test pressure 10 bar.

Toxicological Information:
May cause carcinogenic, mutagenic and teratogenic effects.

Symptoms of Poisoning:
In high concentration may cause asphyxiation. Symptoms may include loss of mobility/consiousness. Victim may not aware of asphyxiation.
In low concentration may cause narcotic effects . Symptoms may include dizziness, headache, nausea and loss of coordination.

First Aid: Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.

Environmental Information:
Toxic to water organism. Endangering to drinking water.

Exposure Limits:
TLV(ACGIH): 0.5 ppm, LC50 / 1h : ppm .

Vinyl bromide, stabilized C_2H_3Br DS096.0

Physical Data:

Molar Mass, [10] 106.955 g/mol

Melting Point T_{mp} at 1.013 bar, [24]
-137.8 ^{0}C (= -216.04 ^{0}F)

Enthalpy of Fusion at T_{mp}, [24]
51.46 kJ/kg (= 22.13 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [10]
15.8 ^{0}C (= 60.44 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [24]
231.14 kJ/kg (= 99.39 BTU/lb)

Critical Point: [24]
-Temperature 199.85 ^{0}C (= 391.73 ^{0}F)
- Pressure 71.8 bar (= 1041.37 psia)
- Density Liquid 0.5348 kg/l

Density Gas:
- ideal 4.7718 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
4.429 g/l (= 0.2765 lb/ft^3)
- at 15 ^{0}C, 1 bar, [15] 4.6044 g/l
- at 0 ^{0}C and 1.013 bar --- g/l

Density Liquid
- at T_{bp} , 1.013 bar, [10] 1.527 kg/l
- 25 ^{0}C , [24] 1.499 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [12, 3]

-10	0	10	20	^{0}C
0.3	0.5	0.8	1.2	bar

2.Pressure Virial Coefficient, [15]
- at 0 ^{0}C: -35 x 10^{-3} bar^{-1}
- at 30 ^{0}C: - 26 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [10] 0.0834 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar [10] 0.5159 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, 1 Gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C, 1 bar [24] 12 x 10^{-6} Ns/m^2

Explosion Limits in Air
[28] 5.6-13.5 Vol.-%
[24] 9-15 Vol.-%

Autoignition Temperature
[28] 500 ^{0}C (= 932 ^{0}F)

Heating Value, [24] 11,339 MJ/kg

Suitable Extinguishing Media:
All known.

Identification and Classification:

CAS Number: 00593-60-2
EU Number: 209-800-6
EU Classification: F+, CarcCat.2
EU Symbols: F+, T
Index Number: 602-024-00-2

UN Number: 1085
VINYL BROMIDE, stabilized
Class/Div: 2.1
ADR/RID: Class 2, Number 2F
ADR/RID Hazard Number: 239
Labeling ADR/DOT: 2.1

EU Classification:
Risk Phrases:
R12: Extremely flammable.
R45: May cause cancer.

Safety Phrases:
S45: In case of accident or if you feel unwell, seek medical immediately (show the label where possible)
S53: Avoid exposure - obtain special instructions before use.

H.Schön: Handbook of Purified Gases

Data Sheet DS018.0 **Date: 07-06-01**

Name: Vinyl chloride, stabilized **Chem. Formula: C_2H_3Cl**

Synonyms: Chloroethene, R1140, Ethylene monochloride **$H_2C=CHCl$**

Properties: Low pressure liquefied gas, toxic, flammable, colorless, sweet odor. May cause cancer. As an unsaturated compound, it takes part in addition and polymerisation reactions. Thermal decomposition produces CO, $COCl_2$, HCl.

Production and Purification:
Produced by the thermal dehydrochlorination of 1,2-dichlorethane. Destillation.

Widespread Applications:
Used for the preparation of plastics by polymerization and copolymerization, intermediate in organic synthesis.

Important Impurities: Other HC´s and CFC´s.

Disposal: Special disposal in accordance with all applicable regulations. Contact supplier if guidance is required.

Detection of Vinyl chloride: Gas test tube.

Suitable Materials: Steel, stainless steel, PTFE, PCTFE, PVDF.

Valve Thread: *Europe:* Not standardized.
Germany: No.1, W21,8x1/14" LH.
USA: CGA connection 290, .745"-1/14 LH EXT.

Filling Density(Factor): 0.81 kg/l at test pressure 12 bar.

Toxicological Information:
May cause carcinogenic, mutagenic and teratogenic effects.

Symptoms of Poisoning:
In high concentration may cause asphyxiation. Symptoms may include loss of mobility/consiousness. Victim may not aware of asphyxiation.
In low concentration may cause narcotic effects . Symptoms may include dizziness, headache, nausea and loss of coordination.

First Aid: Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.

Environmental Information:
Toxic to water organism. Endangering to drinking water.

Exposure Limits:
TLV(ACGIH): 5 ppm, LC_{50} / 1h : ppm .

Vinyl chloride, stabilized C_2H_3Cl **DS018.0**

Physical Data:

Molar Mass, [10] 62.499 g/mol

Melting Point T_{mp} at 1.013 bar, [10]
-153.10 ^{0}C (= -243.58 ^{0}F)

Enthalpy of Fusion at T_{mp}, [10]
75.9 kJ/kg (= 32.63 BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [24]
-13.37 ^{0}C (= 7.93 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [24]
365.13 kJ/kg (= 157.01 BTU/lb)

Critical Point:
-Temperature, [24]
158.85 ^{0}C (= 317.93 ^{0}F)
- Pressure, [24]
56.7 bar (= 822.37 psia)
- Density Liquid, [10] 0.370 kg/l

Density Gas:
- ideal 2.7884 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
2.588 g/l (= 0.1616 lb/ft^3)
- at 15 ^{0}C and 1 bar, [10] 2.659 g/l
- at 0 ^{0}C, 1.013 bar, [3] 2.86 g/l

Density Liquid, [10]
- at T_{bp} and 1.013 bar 0.9707 kg/l
- at 20 ^{0}C 0.9202 0.9202 kg/l

Vapor Pressure (about), [4]

-10	0	10	20	^{0}C
0.96	1.72	2.54	3.43	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -22 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -16 x 10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar, [28] 0.115 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar, [10] 0.858 kJ/(kg K)

Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 1.07 l gas / kg H_2O

Dynamic Viscosity at 25 ^{0}C and 1 bar, [28] 10.9 x 10^{-6} Ns/m^2

Explosion Limits in Air
[14] 3.6-31 Vol.-%
[24] 3.6-33 Vol.-%

Autoignition Temperature
[14] 435 ^{0}C (=815 ^{0}F)
[24] 472.2 ^{0}C (= 882 ^{0}F)

Heating Value, [24] 18,528 MJ/kg

Suitable Extinguishing Media:
All known.

1 bar = 14.504 psi
1 g/l = 0.0624 lb/ft^3

Identification and Classification:

CAS Number: 00075-01-4
EU Number: 200-831-0
EU Classification: F+, T, Carc.Cat.1
EU Symbols: F+, T
Index Number: 602-023-00-7

UN Number: 1086
VINYL CHLORIDE, stabilized
Class/Div: 2.1
ADR/RID: Class 2, Number 2F
ADR/RID Hazard Number: 239
Labeling ADR/DOT: 2.1

EU Classification:
Risk Phrases:

R12: Extremely flammable.
R45: May cause cancer.

Safety Phrases:

S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).
S53: Avoid exposure, obtain special instructions before use.

H.Schön: Handbook of Purified Gases

Data Sheet DS103.0 **Date: 07-02-22**

Name: Vinyl fluoride, stabilized Chem. Formula: C_2H_3F

Synonyms: Fluoroethylene, R1141 **$H_2C{=}CHF$**

Properties:
High pressure liquefied gas, flammable, relatively non-toxic, colorless, sweetish odor. Thermal decomposition above 200^0C yields CO, COF_2 and HF. Tending to polymerisize. Readily soluble in ether and ethanol.

Production and Purification:
Manufactored by addition HF to ethine using mercury catalyst, decomposes above 200 ^0C forming HF.

Widespread Applications:
Intermediate in organic syntheses, used for the preparation of plastics.

Important Impurities: Other HC´s (C_2H_2) and CFC´s.

Disposal:
Combustion: burner with flash back arrestor. Toxic and corrosive Gases formed during combustion should be scrubbed before discharge to air.

Detection of Vinyl fluoride:
Halogen leak detector. Detector for flammable gases. IR-Spectrometry.

Suitable Materials: Steel, stainless steel, PTFE, PCTFE.

Valve Thread: *Europe:* Not standardized.
Germany: No.1, W21,8x1/14" LH.
USA: CGA connection 350 , .825"-1/14 LH EXT.

Filling Density(Factor): 0.64 kg/l at test pressure 250 bar.

Toxicological Information:
No known acute toxicological effects from this product.

Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of coordination. In high concentration may cause asphyxiation.

First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.

Environmental Information:
Toxic to water organism. Endangering to drinking water.

Exposure Limits:
TLV(ACGIH):5 ppm, LC50 / 1h : --- ppm

Vinyl fluoride, stabilized C_2H_3F DS103.0

Physical Data:

Molar Mass, [24] 46.044 g/mol

Melting Point T_{mp} at 1.013 bar, [13]
-160.5 ^{0}C (= -256.9 ^{0}F)

Enthalpy of Fusion at T_{mp}
kJ/kg (= BTU/lb)

Boiling Point T_{bp} at 1.013 bar, [13]
-72.2 ^{0}C (= -97.96 ^{0}F)

Enthalpy of Vaporisation at T_{bp}, [24]
397.88 kJ/kg (= 171.09 BTU/lb)

Critical Point: [24]
-Temperature 54.65 ^{0}C (= 130.37 ^{0}F)
- Pressure 52.39 bar (= 759.85 psia)
- Density Liquid 0.3198 kg/l

Density Gas:
- ideal 2.0543 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1 bar, [24]
1.907 g/l (= 0.1191 lb/ft^3)
- at 15 ^{0}C, 1 bar, [15] 1.9462 g/l
- at 0 ^{0}C, 1.013 bar, [28] 2.085 g/l

Density Liquid
- at T_{bp}, 1.013 bar, [2] 0.907 kg/l
- 25 0C, [24] 0.62 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [4,12]

-10	0	10	20	^{0}C
11	14.5	19	24	bar

2.Pressure Virial Coefficient, [15]
- at 0 ^{0}C: -15 x 10^{-3} bar^{-1}
- at 30 ^{0}C: -10 x 10^{-3} bar^{-1}

Thermal Conductivity at 25 ^{0}C and 1 bar, [24] 0.1447 mW/(cm K)

Heat Capacity at 25 ^{0}C, 1.013 bar, (24) 1.118 kJ/(kg K)

Solubility in Water at 20 ^{0}C and 1.013 bar, [4] insoluble

Dynamic Viscosity at 25 ^{0}C and 1 bar, [24] 11.52 x 10^{-6} Ns/m^2

Explosion Limits in Air,
[13] 2.9-28.9 Vol.-%
[24] 2.6-21.7 Vol.-%

Autoignition Temperature
[2] 375 ^{0}C (= 707 ^{0}F)
[24] 385 ^{0}C (= 725 ^{0}F)

Heating Value, [24] 21.973 MJ/kg

Suitable Extinguishing Media:
All known.

Identification and Classification:

CAS Number: 00075-02-5
EU Number: 200-832-6
EU Classification: F+
EU Symbols: F+
Index Number:

UN Number: 1860
VINYL FLUORIDE, stabilized
Class/Div: 2.1
ADR/RID: Class 2, Number 2F
ADR/RID Hazard Number: 239
Labeling ADR/DOT: 2.1

EU Classification:

Risk Phrases:
R12: Extremely flammable.

Safety Phrases:

S9: Keep container in a well ventilated places.
S16: Keep away from ignition source - No smoking.
S33: Take precautionary measures against static discharges.

H.Schön: Handbook of Purified Gases

Data Sheet DS063.0 **Date: 07-02-04**

Name: Vinyl methyl ether, stabilized **Chem. Formula: C_3H_6O**

Synonyms: Methyl vinyl ether, Methoxyethylene **$H_3C\text{-}O\text{-}CH{=}CH_2$**

Properties:
Low pressure liquefied gas, flammable, colorless, sweet odor, tends to polymerisize spontaneously.

Production and Purification:
Manufactured from ethine and methanol at 20-22 bar with sodium methanolate as catalyst.
Widespread Applications:
Intermediate in organic synthesis of polymers, copolymers and plasticizer for nitrocellulose.

Important Impurities: Other HC´s, most C_2H_2 .
Disposal: Combustion.
Detection of Vinyl methyl ether: Detector for flammable gases, Gas test tube.
Suitable Materials: Steel, stainless steel, PTFE, PCTFE
.
Valve Thread: *Europe:* Not standardized.
Germany: No.1, W21,8x1/14" LH.
USA: CGA connection 290, .745"-1/14 LH EXT.
Filling Density(Factor): 0.67 kg/l at test pressure 10 bar.

Toxicological Information:
No known acute toxicological effects from this product.
Symptoms of Poisoning:
In low concentration may cause narcotic effects. Symptoms: dizziness, headache, nausea and loss of coordination. In high concentration may cause asphyxiation.
First Aid:
Remove victims to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes.
Environmental Information:
No known ecological damage caused by this product.

Exposure Limits:
TLV(ACGIH): --- ppm, LC_{50} / 1h : --- ppm

Vinyl methyl ether, stabilized C_3H_6O DS063.0

Physical Data:
Molar Mass, [11] 58.080 g/mol
Melting Point T_{mp} at 1.013 bar, [10] -122 ^{0}C (= -187.6 ^{0}F)
Enthalpy of Fusion at T_{mp}, [10] 117.5 kJ/kg (= 50.51 BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [24] 5.5 ^{0}C (= 41.9 ^{0}F)
Enthalpy of Vaporisation at T_{bp} , [12] 422 kJ/kg (= 181.42 BTU/lb)
Critical Point:
-Temperature, [12] 171.60 ^{0}C
[24] 163.85 (=326.93 ^{0}F)
- Pressure, [12] 31.90 bar
[24] 46.7 bar (= 677.33 psia)
- Density Liquid, [3] 0.283 kg/l
Density Gas:
- ideal 2.5913 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1 bar, [24] 2.405 g/l (=0.1502 lb/ft^3)
- at 15 ^{0}C, 1 bar, [10] 2.435 g/l
- at 0 ^{0}C and 1.013 bar --- g/l
Density Liquid
- at T_{bp} , 1.013 bar,[10] 0.7684 kg/l
- at 20 ^{0}C, [12] 0.747 kg/l

Vapor Pressure (about), [12]

-10	0	10	20	^{0}C
0.5	0.8	1.2	1.7	bar

2.Pressure Virial Coefficient, [11]
- at 0 ^{0}C: -34 $\times$ 10^{-3} bar^{-1}
- at 30 ^{0}C: -24 $\times$ 10^{-3} bar^{-1}
Thermal Conductivity at 15 ^{0}C and 1.013 bar. [10] 0.147 mW/(cm K)
Heat Capacity at 25 ^{0}C, 1.013 bar [10] 1.326 kJ/(kg K)
Solubility in Water at 20 ^{0}C, 1.013 bar, [10] 3.86 l gas / kg H_2O
Dynamic Viscosity at 25 ^{0}C, 1 bar [24] 8.913 $\times$ 10^{-6} Ns/m^2
Explosion Limits in Air
[13] 2.2-28.2 Vol.-%
[24] 2.6-39 Vol.-%
Autoignition Temperature
[13] 220 ^{0}C
[24] 287.2 ^{0}C (= 549 ^{0}F)
Heating Value,[24] 30.549 MJ/kg
Suitable Extinguishing Media: All known.
1 bar = 14.504 psi
1g/l = 0.0624 lb/ft^3

Identification and Classification:
CAS Number: 00107-25-5
EU Number: 203-475-4
EU Classification: F+
EU Symbols: F+
Index-No.: 603-021-00-9

UN Number: 1087 VINYL-METHYLETHER, stabilized
Class/Div: 2.1
ADR/RID: Class 2, Number 2F
ADR/RID Hazard Number: 239
Labeling ADR/DOT: 2.1

EU Classification:
Risk Phrases:
R12: Extremely flammable.

Safety Phrases:
S2: Keep out of the reach of children.
S9: Keep container in a well ventilated places.
S16: Keep away from ignition source - No smoking.
S33: Take precautionary measures against static discharges.

H.Schön: Handbook of Purified Gases

Data Sheet DS071.0 **Date: 08-02-29**

Name: Xenon, Chemical Formula: Xe

Synonyms: Xenon, compressed

*Properties:*High pressure liquefied gas, but above 17 °C compressed only. Non-toxic, colourless, odourless, extremely chemically inert (noble Gas) , several xenon fluorides, XeF_2, XeF_4 and XeF_6 have been isolated by reaction of Xe and F_2 . Some radioactive and some stable xenon isotopes are formed in the operation of nuclear reactors.

Production and Purification:
Obtained as a byproduct in the fractional distillation of liquid air.

Widespread Applications:
Used as filling gas for various types of lamps, improved yield of white light.

Important Impurities:	Air, Kr, HC´s, CFC´s.
Disposal:	Pass in the atmosphere .
Detection of Xenon:	Mass spectrometry.

Suitable Materials:		All known.
Valve Thread:	*Europe:*	for 300 bar: No 54, W30x2 RH.
		Germany: for 200 bar: No 6 W21.8x1/14" RH.
	USA:	CGA connection580, .965"x1/14" RH INT.

Filling Density(Factor): 1.24 kg/l at test pressure 130 bar.

Toxicological Information:
No known toxicological effects from this product.
Symptoms of Poisoning:
In high concentrations may cause asphyxiation. Symptoms may include loss of mobility/consciouness. Victim may not be aware the asphyxiation.

First Aid: Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artifical respiration if breathing stopped.
Skin/eye contact: Remove contaminated clothing. Drench affected area with water for at least 15 minutes. Do not use hot water.
Environmental Information:
No known ecological damage caused by this product.
Exposure Limits:
TLV(ACGIH):-- ppm, LC50 / 1h :--- ppm .

Xenon **Xe** **DS071.0**

Physical Data:
Molar Mass, [5] 131.290 g/mol
Triple Point at 0.816 bar, [5]
-11.90 ^{0}C (=-169.42 ^{0}F)
Enthalpy of Fusion at T_{mp} , [24]
17.48 kJ/kg (= 7.52 BTU/lb)
Boiling Point T_{bp} at 1.013 bar, [5]
-108.12 ^{0}C (= -162.62 ^{0}F)
Enthalpy of Vaporisation at T_{bp} , [24]
99.66 kJ/kg (= 41.56 BTU/lb)
Critical Point, [24]:
-Temperature 16.59 ^{0}C (= 61.86 ^{0}F)
- Pressure 58.4 bar (=847.02 psi)
- Density Liquid 1.1126 kg/l
Density Gas: ideal 5.8576 g/l
- at 70 ^{0}F (= 21.1 ^{0}C), 1,013 bar, [24]
5.437 g/l (= 0.3395 lb/ft^3)
- at 15 ^{0}C, 1 bar, [15] 5.512 g/l
- at 0 ^{0}C,1.013 bar, [11] 5.898 g/l
Density Liquid
- at T_{bp},1.013 bar,10] 2.945 kg/l
- at 0 oC, [12] 1.95 kg/l

1 bar = 14.504 psi , 1g/l = 0.0624 lb/ft^3

Vapor Pressure (about), [4]

-10	0	10	16.6	^{0}C
34	42	50	58.4	bar

2.Pressure Virial Coefficient, [28]
- at 0 ^{0}C: -6.8×10^{-3} bar^{-1}
- at 30 ^{0}C: -5.8×10^{-3} bar^{-1}

Thermal Conductivity at 15 ^{0}C and 1.013 bar 0.0557 mW/(cm K)
Heat Capacity at 25 ^{0}C and 1.013 bar, [10] 0.159 kJ/(kg K)
Solubility in Water at 20 ^{0}C,1.013 bar, [10] 0.108 l Gas / kg H_2O
Dynamic Viscosity at 25 ^{0}C and 1 bar, [3] 18.3×10^{-6} Ns/m^2

Suitable Extinguishing Media:
All known.

Identification and Classification:
CAS Number: 07740-63-3
EU Number: 231-172-7
EU Classification: ---
EU Symbols: ---
Index Number:

UN Number: 2036
XENON
Class/Div: 2.2
ADR/RID: Class 2, Number 2A
ADR/RID Hazard Number: 20
Labeling ADR/DOT: 2.2

EU Classification:
Risk Phrases:
RAs: Asphyxiant in high concentrations.

Safety Phrases:
S9: Keep container in a well ventilated places.
S23: Do not breathe gas.

10 Appendix

10.1 Important Physical Constants

Table T10.1-1: Constants

Designation	**Symbol (in this book)**	**Numerical value**	**Unit**
Avogadro constant	$k_{Avogadro}$	$6.022137 \cdot 10^{23}$	$parts \cdot mol^{-1}$
Boltzmann constant	$k_{Boltzmann}$	$1.38066 \cdot 10^{-23}$	$J \cdot K^{-1}$
Unit charge (electron)		$-1.602177 \cdot 10^{-19}$	C (Coulomb)
Faraday constant	$k_{Faraday}$	96485.31	$C \cdot mol^{-1}$
Gas constant	R_{Mol}	8.31441	$J \cdot K^{-1} \cdot mol^{-1}$
Velocity of light (in vacuum)	C_{light}	$2.99792 \cdot 10^{8}$	$m \cdot s^{-1}$
Molar volume under standard condition *	V_{Norm}	22.4138	$l \cdot mol^{-1}$
Planck-Constant	h	$6.62608 \cdot 10^{-34}$	$J \cdot s$

* $T = 273.15$ K. $p = 1.01325$ bar

10.2 International Units (SI)

Table T10.2-1: International base units.

Quantity	**Base unit**	**Symbol**
length	meter	m
mass	kilogramm	kg
time	second	s
amperage	ampere	A
Amount of substances	mol	mol
Luminous intensity	candela	cd

Table T10.2-2: Decimal multiples and submultiples of SI units

Decimal multiple	Prefix	Symbol	Decimal multiple	Prefix	Symbol
10	deca	da	10^{-1}	deci	d
10^2	hecto	h	10^{-2}	centi	c
10^3	kilo	k	10^{-3}	milli	m
10^6	mega	M	10^{-6}	micro	μ
10^9	giga	G	10^{-9}	nano	n
10^{12}	tera	T	10^{-12}	pico	p
10^{15}	peta	P	10^{-15}	femto	f
10^{18}	exa	E	10^{-18}	atto	a

Note: The decimal multiples are not used in the concentration information. ppm (10^{-6}). ppb (10^{-9}) and ppt (10^{-12}) are derived from million, billion and trillion as used in the Anglo-Saxon financial system.

Table T10.2-3: Derived SI units with their own names and their relation to the other SI units.

Size	Name	Sign	Relation to SI-unit
Work or energy	Joule	J	$1\ J = 1\ N \cdot m = 1\ W \cdot s$
Pressure or Tensile strength	Pascal Bar	Pa bar	$1\ Pa = 1\ N \cdot m^{-2} = 1\ kg \cdot m^{-1} \cdot s^{-2}$ $1\ bar = 10^5\ Pa$
Electrical capacity	Farad	F	$1\ F = 1\ C \cdot V^{-1}$
voltage	Volt	V	$1\ V = 1\ W \cdot A^{-1}$
Electrical resistance	Ohm	Ω	$1\ \Omega = 1\ V \cdot A^{-1}$
Electric charge	Coulomb	C	$1\ C = 1\ A \cdot s$
frequency	Hertz	Hz	$1\ Hz = 1\ s^{-1}$
force	Newton	N	$1\ N = 1\ kg \cdot m \cdot s^{-2}$
power	Watt	W	$1\ W = 1\ J \cdot s^{-1}$
Magnetic lux density	Tesla	T	$1\ T = 1\ Wb \cdot m^{-2}$
Magnetic flux	Weber	Wb	$1\ Wb = 1\ V \cdot s$
radioactivity	Becquerel	Bq	$1\ Bq = 1 decay \cdot s^{-1}$

Table T10.2-4: SI unfamiliar units and their relation to the SI units

Quantity	Name	Sign	Relation to SI-unit
Energy. quantity of heat	calorie erg electron volt	cal erg eV	$1\ cal = 1\ 4.1868\ J$ $1\ erg = 10^{-7}\ J$ $1\ eV = 0.160219 \cdot 10^{-18}\ J$
force	dyne	dyn	$1\ dyn = 10^{-5}\ N$
length	Angström		$1\ AE = 10^{-10}\ m = 0.1\ \mu m$
Dynamic viscosity	Poise	P	$1\ P = 0.1\ Pa \cdot s$
Kinematic viscosity	Stokes	St	$1\ St = 10^{-4}\ m^2 \cdot s^{-1}$

10.3 Pressure Units

Table T10.3-1: Conversion of pressure units common in Anglo-Saxon countries.

	Pa	**bar**	**psi**	**inch Hg**	**inch H_2O**	**pdl · in^{-2}**	**tonf · in^{-2}**
Pa	1	10^{-5}	$1.4504 \cdot 10^{-4}$	$2.9528 \cdot 10^{-4}$	$4.0146 \cdot 10^{-3}$	$4.6666 \cdot 10^{-3}$	$6.4750 \cdot 10^{-8}$
bar	10^{-5}	1	14.504	29.528	$4.0146 \cdot 10^{2}$	$4.6666 \cdot 10^{2}$	$6.4750 \cdot 10^{-3}$
psi	$6.8948 \cdot 10^{3}$	$6.8948 \cdot 10^{-2}$	1	2.0359	27.680	32.175	$4.4645 \cdot 10^{-4}$
inch Hg	$3.3866 \cdot 10^{3}$	$3.3866 \cdot 10^{-2}$	0.49118	1	0.13596	0.15804	$2.1928 \cdot 10^{-4}$
inch H_2O	$2.4909 \cdot 10^{2}$	$2.4909 \cdot 10^{-3}$	$3.6127 \cdot 10^{-2}$	$7.3551 \cdot 10^{-2}$	1	1.1662	$1.6129 \cdot 10^{-5}$
pdl · in^{-2}	$2.1429 \cdot 10^{-2}$	$2.1429 \cdot 10^{-3}$	$3.1080 \cdot 10^{-2}$	$6.3267 \cdot 10^{-2}$	0.86029	1	$1.3875 \cdot 10^{-5}$
tonf · in^{-2}	$1.5444 \cdot 10^{7}$	$1.5444 \cdot 10^{2}$	$2.2399 \cdot 10^{3}$	$4.5603 \cdot 10^{3}$	$6.202 \cdot 10^{4}$	$7.2071 \cdot 10^{4}$	1

Table T10.3-2: Conversion of pressure units common in Germany

	Pa	**bar**	**mm Hg**	**at**	**atm**	**dyn · cm^{-2}**	**mm WS**
Pa	1	10^{-5}	$7.5006 \cdot 10^{-5}$	$1.0197 \cdot 10^{-5}$	$9.8692 \cdot 10^{-6}$	10	0.10197
bar	10^{5}	1	750.064	1.0197	0.98692	10^{6}	$1.0197 \cdot 10^{4}$
mm Hg*	133.32	$1.3332 \cdot 10^{-3}$	1	$1.3595 \cdot 10^{-3}$	$1.3158 \cdot 10^{-3}$	$1.3332 \cdot 10^{3}$	13.595
at	$9.8067 \cdot 10^{4}$	0.98067	735.561	1	0.96784	$9.8067 \cdot 10^{5}$	10^{4}
atm	$1.01325 \cdot 10^{5}$	1.01325	760	1.03323	1	$1.01325 \cdot 10^{6}$	$1.0332 \cdot 10^{4}$
dyn · cm^{-2}	0.1	10^{-6}	$7.5006 \cdot 10^{-4}$	$1.0197 \cdot 10^{-6}$	$9.8692 \cdot 10^{-2}$	1	$1.0197 \cdot 10^{-2}$
mmWS	9.8067	$9.8067 \cdot 10^{-5}$	$7.3546 \cdot 10^{-2}$	10^{-4}	$9.6784 \cdot 10^{-5}$	0.98067	1

* 1 mm Hg = 1 Torr = 0.03936 inch Hg; 1 mm WS (water column) = 0.039369 inch H_2O

10.4 Material Data on the Vapour-Pressure Curve

The data were taken from the Handbook of Gases by (Messer Griesheim 1989). If interim values are needed then a linear interpolation is only suitable for approximations, as according to Eq. (2.2.2-5) the decadal logarithm of the vapour pressure p_D is a function of the temperature T. However, a more exact interpolation can be obtained by using Eq. (2.2.2-5) a simplified form of the vapour pressure equation with only two constants A and B.

$$\lg p_D = A + \frac{B}{T} \tag{10.4-1}$$

The vapour pressure p_D lies between the values p_1 and p_2. Then $\lg p_1$ und $\lg p_2$ can be formed, analogous to Eq. (10.4-1).Now we carry out a linear interpolation with the logarithms of the vapour pressures. With some transpositions one easily obtains an equation without the constants A and B.

$$\frac{\lg p_D - \lg p_1}{\lg p_2 - \lg p_1} = \frac{\lg \dfrac{p_D}{p_1}}{\lg \dfrac{p_2}{p_1}} = \frac{\dfrac{1}{T} - \dfrac{1}{T_1}}{\dfrac{1}{T_2} - \dfrac{1}{T_1}} = \frac{T_2 (T - T_1)}{T (T_2 - T_1)} \tag{10.4-2}$$

For the vapour pressure at the prevailing T one obtains

$$\lg p_D = \lg p_1 + \frac{T_2 (T - T_1)}{T (T_2 - T_1)} (\lg p_2 - \lg p_1) \tag{10.4-3}$$

and for T at the given p_D

$$\frac{1}{T} = \frac{1}{T_1} - \frac{T_2 - T_1}{T_1 \cdot T_2} \left(\frac{\lg p_D - \lg p_1}{\lg p_2 - \lg p_1} \right) \tag{10.4-4}$$

Table T10.4-1: Argon

T in [K]	p_D in [bar]	φ_{fl} in [kg · l^{-1}]	φ_{gasf} in [kg · m^{-3}]	ΔH_{vap} [J · g^{-1}]
83.80	0.6891	1.414	4.112	163.9
84.00	0.7052	1.414	4.144	163.8
86.00	0.8826	1.402	5.090	162.3
87.28	1.01325	1.394	5.777	161.3
88.00	1.093	1.390	6.191	160.8
90.00	1.339	1.377	7.461	159.2
92.00	1.626	1.364	8.917	157.6
94.00	1.956	1.352	10.58	156.0
96.00	2.335	1.339	12.45	154.2
98.00	2.765	1.325	14.57	152.4
100.00	3.252	1.312	16.94	150.6
102.00	3.799	1.298	19.59	148.6
104.00	4.411	1.284	22.54	146.6

Table T10.4-1: (*continued*)

106.00	5.092	1.270	25.81	144.5
108.00	5.846	1.255	29.42	142.3
110.00	6.678	1.240	33.42	140.0
112.00	7.591	1.255	37.82	137.6
114.00	8.592	1.210	42.66	135.1
116.00	9.683	1.194	47.99	132.5
118.00	10.87	1.177	53.84	129.7
120.00	12.16	1.160	60.27	126.8
122.00	13.55	1.143	67.33	123.7
124.00	15.05	1.125	75.10	120.5
126.00	16.67	1.106	83.66	117.1
128.00	18.41	1.087	93.11	113.4
130.00	20.27	1.066	103.6	109.5
132.00	22.27	1.045	115.2	105.4
134.00	24.41	1.022	128.2	100.9
136.00	26.68	0.9976	142.9	96.02
138.00	29.11	0.9714	159.6	90.71
140.00	31.70	0.9430	178.8	84.83
142.00	34.46	0.9115	201.3	78.21
144.00	37.40	0.8757	228.6	70.59
146.00	40.53	0.8335	263.1	61.46
148.00	43.86	0.7796	310.9	49.62
150.00	47.43	0.6927	395.0	30.64
150.86	49.058	0.5357	535.7	0

Table T10.4-2: n-butane

T in [K]	**p_D in [bar]**	**φ_{fl} in [$kg \cdot l^{-1}$]**	**φ_{gasf} in [$kg \cdot m^{-3}$]**	**ΔH_{vap} [$J \cdot g^{-1}$]**
134.86	$6.736 \cdot 10^{-6}$	0.7353	$3.491 \cdot 10^{-5}$	494.7
140.00	$1.720 \cdot 10^{-5}$	0.7304	$8.592 \cdot 10^{-5}$	490.7
145.00	$3.990 \cdot 10^{-5}$	0.7257	$1.924 \cdot 10^{-4}$	486.5
150.00	$8.693 \cdot 10^{-5}$	0.7210	$4.051 \cdot 10^{-4}$	482.3
155.00	$1.789 \cdot 10^{-4}$	0.7163	$8.072 \cdot 10^{-4}$	478.1
160.00	$3.501 \cdot 10^{-4}$	0.7116	$1.530 \cdot 10^{-3}$	474.0
165.00	$6.541 \cdot 10^{-4}$	0.7069	$2.772 \cdot 10^{-3}$	469.9
170.00	$1.172 \cdot 10^{-3}$	0.7022	$4.821 \cdot 10^{-3}$	465.9
175.00	$2.022 \cdot 10^{-3}$	0.6975	$8.081 \cdot 10^{-3}$	461.9
180.00	$3.370 \cdot 10^{-3}$	0.6928	$1.309 \cdot 10^{-2}$	458.1
185.00	$5.441 \cdot 10^{-3}$	0.6881	$2.058 \cdot 10^{-2}$	454.3
190.00	$8.536 \cdot 10^{-3}$	0.6834	$3.144 \cdot 10^{-2}$	450.5
195.00	$1.304 \cdot 10^{-2}$	0.6786	$4.682 \cdot 10^{-2}$	446.8
200.00	$1.944 \cdot 10^{-2}$	0.6738	$6.810 \cdot 10^{-2}$	443.1
205.00	$2.834 \cdot 10^{-2}$	0.6691	$9.694 \cdot 10^{-2}$	439.4
210.00	$4.047 \cdot 10^{-2}$	0.6643	0.1353	435.7

Table T10.4-3: Ethane

T in [K]	**p_D in [bar]**	**φ_{fl} in [$kg \cdot l^{-1}$]**	**φ_{gasf} in [$kg \cdot m^{-3}$]**	**ΔH_{vap} [$J \cdot g^{-1}$]**
90.348	$1.131 \cdot 10^{-5}$	0.6519	$4.556 \cdot 10^{-5}$	595.6
95.00	$3.622 \cdot 10^{-5}$	0.6466	$1.379 \cdot 10^{-4}$	590.5
100.00	$1.109 \cdot 10^{-4}$	0.6411	$4.014 \cdot 10^{-4}$	584.9
105.00	$3.026 \cdot 10^{-4}$	0.6357	$1.042 \cdot 10^{-3}$	579.3
110.00	$7.466 \cdot 10^{-4}$	0.6302	$2.455 \cdot 10^{-3}$	573.8
115.00	$1.689 \cdot 10^{-3}$	0.6248	$5.314 \cdot 10^{-3}$	568.2
120.00	$3.544 \cdot 10^{-3}$	0.6193	$1.068 \cdot 10^{-2}$	562.7
125.00	$6.964 \cdot 10^{-3}$	0.6138	$2.016 \cdot 10^{-2}$	557.2
130.00	$1.291 \cdot 10^{-2}$	0.6082	$3.597 \cdot 10^{-2}$	551.7
135.00	$2.275 \cdot 10^{-2}$	0.6026	$6.108 \cdot 10^{-2}$	546.2
140.00	$3.831 \cdot 10^{-2}$	0.5970	$9.928 \cdot 10^{-2}$	540.8
145.00	$6.198 \cdot 10^{-2}$	0.5913	0.1553	535.3
150.00	$9.672 \cdot 10^{-2}$	0.5856	0.2346	529.7
155.00	0.1462	0.5798	0.3439	524.1
160.00	0.2146	0.5739	0.4905	518.4
165.00	0.3070	0.5680	0.6827	512.6
170.00	0.4289	0.5620	0.0297	506.7
175.00	0.5868	0.5559	1.241	500.6
180.00	0.7874	05498	1.628	494.3
184.55	1.01325	0.5441	2.056	488.5
185.00	1.038	0.5436	2.103	487.9
190.00	1.347	0.5372	2.676	481.2
195.00	1.723	0.5308	3.363	474.3
200.00	2.174	0.5242	4.176	467.1
205.00	2.710	0.5175	5.131	459.6
210.00	3.340	0.5106	6.246	451.8
215.00	4.074	0.5036	7.538	443.6
220.00	4.923	0.4964	9.028	435.0
225.00	5.896	0.4890	10.74	425.9
230.00	7.004	0.4814	12.69	416.4
235.00	8.259	0.4735	14.92	406.3
240.00	9.670	0.4654	17.46	395.5
245.00	11.25	0.4569	20.35	384.1
250.00	13.01	0.4480	23.63	372.0
255.00	14.96	0.4387	27.37	358.9
260.00	17.12	0.4290	31.64	344.9
265.00	19.49	0.4186	36.54	329.7
270.00	22.10	0.4075	42.18	313.2
275.00	24.95	0.3955	48.75	295.0
280.00	28.06	0.3823	56.49	274.7
285.00	31.46	0.3677	65.79	251.9
290.00	35.15	0.3509	77.30	225.3
295.00	39.17	0.3307	92.33	193.0
300.00	43.55	0.3034	114.4	149.4
305.00	48.35	0.2369	170.4	50.51
305.33	48.714	0.2067	206.7	0

Table T10.4-4: Ethene

T in [K]	**p_D in [bar]**	**φ_{fl} in [kg · l^{-1}]**	**φ_{gasf} in [kg·m^{-3}]**	**ΔH_{vap} [J · g^{-1}]**
103.986	$1.213 \cdot 10^{-3}$	0.6549	$3.999 \cdot 10^{-5}$	568.0
105.00	$1.449 \cdot 10^{-3}$	0.6544	$4.658 \cdot 10^{-3}$	566.6
110.00	$3.304 \cdot 10^{-3}$	0.6473	$1.014 \cdot 10^{-2}$	557.7
115.00	$6.953 \cdot 10^{-3}$	0.6398	$2.042 \cdot 10^{-2}$	553.4
120.00	$1.364 \cdot 10^{-2}$	0.6322	$3.843 \cdot 10^{-2}$	547.1
125.00	$2.520 \cdot 10^{-2}$	0.6269	$6.821 \cdot 10^{-2}$	540.9
130.00	$4.414 \cdot 10^{-2}$	0.6206	0.1150	534.7
135.00	$7.375 \cdot 10^{-2}$	0.6143	0.1853	528.5
140.00	0.1182	0.6079	0.2871	522.2
145.00	0.1827	0.6014	0.4294	515.8
150.00	0.2731	0.5948	0.6228	509.4
155.00	0.3967	0.5881	0.8789	502.7
160.00	0.5611	0.5812	1.210	495.9
165.00	0.7754	0.5742	1.631	488.9
169.41	1.01325	0.5679	2.089	482.6
170.00	1.049	0.5671	2.157	481.7
175.00	1.392	0.5598	2.802	474.3
180.00	1.816	0.5524	3.585	466.5
185.00	2.332	0.5448	4.524	458.5
190.00	2.952	0.5371	5.640	450.2
195.00	3.688	0.5292	6.952	441.5
200.00	4.553	0.5211	8.487	432.4
205.00	5.560	0.5128	10.27	422.8
210.00	6.723	0.5043	12.33	412.8
215.00	8.054	0.4956	14.71	402.2
220.00	9.568	0.4865	17.44	391.0
225.00	11.28	0.4771	20.57	379.1
230.00	13.20	0.4673	24.16	366.4
235.00	15.35	0.4570	28.29	352.7
240.00	17.73	0.4461	33.05	338.0
245.00	20.38	0.4344	38.55	321.9
250.00	23.30	0.4219	44.97	304.4
255.00	26.51	0.4083	52.53	284.9
260.00	30.04	0.3932	61.58	263.0
265.00	33.90	0.3762	72.66	237.9
270.00	38.13	0.3562	86.79	208.1
275.00	42.75	0.3311	106.2	170.4
280.00	47.83	0.2916	139.9	111.5
282.343	50.404	0.2146	214.8	0

Table T10.4-5: Helium-4

T in [K]	p_D in [bar]	φ_{fl} in $[kg \cdot l^{-1}]$	φ_{gasf} in $[kg{\cdot}m^{-3}]$	ΔH_{vap} $[J \cdot g^{-1}]$
2.177	$5.035 \cdot 10^{-2}$	0.1462	1.177	
2.20	$5.326 \cdot 10^{-2}$	0.1441	1.235	22.22
2.30	$6.717 \cdot 10^{-2}$	0.1458	1.503	22.33
2.40	$8.337 \cdot 10^{-2}$	0.1453	1.805	22.47
2.50	0.1021	0.1448	2.144	22.62
2.60	0.1235	0.1442	2.521	22.76
2.70	0.1479	0.1435	2.939	22.88
2.80	0.1753	0.1428	3.401	22.97
2.90	0.2060	0.1420	3.908	23.049
3.00	0.2402	0.1411	4.463	23.093
3.10	0.2780	0.1402	5.070	23.104
3.20	0.3197	0.1393	5.731	23.081
3.30	0.3655	0.1383	6.452	23.024
3.40	0.4155	0.1372	7.235	22.931
3.50	0.4699	0.1360	8.085	22.803
3.60	0.5289	0.1348	9.008	22.627
3.70	0.5927	0.1335	10.01	22.413
3.80	0.6614	0.1321	11.09	22.149
3.90	0.7354	0.1306	12.28	21.833
4.00	0.8147	0.1290	13.56	21.464
4.10	0.8995	0.1273	14.96	21.040
4.20	0.9902	0.1254	16.49	20.564
4.224	1.013	0.1250	16.89	20.413
4.3	1.087	0.1235	18.18	19.981
4.4	1.190	0.1213	20.05	19.318
4.5	1.299	0.1189	22.13	18.564
4.6	1.416	0.1163	24.49	17.678
4.7	1.539	0.1134	27.19	16.639
4.8	1.670	0.1101	30.37	23.081
4.9	1.808	0.1061	34.24	13.875
5.0	1.954	0.1011	39.30	11.890
5.1	2.109	0.0941	46.80	9.017
5.201	2.275	0.0696	69.94	0

Table T10.4-6: Helium-3

T in [K]	p_D in [bar]	φ_{fl} in $[kg \cdot l^{-1}]$	φ_{gasf} in $[kg \cdot m^{-3}]$
3.19616	1.018	$5.7533 \cdot 10^{-2}$	25.342
3.23627	1.062	$5.5216 \cdot 10^{-2}$	27.688
3.26910	1.099	$5.2592 \cdot 10^{-2}$	30.332
3.28374	1.116	$5.0941 \cdot 10^{-2}$	31.986
3.29737	1.131	$4.8778 \cdot 10^{-2}$	34.242
3.30116	1.136	$4.7927 \cdot 10^{-2}$	34.965
3.30400	1.139	$4.7180 \cdot 10^{-2}$	35.758
3.30685	1.142	$4.6094 \cdot 10^{-2}$	36.675
3.30910	1.145	$4.46 \cdot 10^{-2}$	38.3

Table T10.4-7: i-Butane

T in [K]	**p_D in [bar]**	**φ_{fl} in [$kg \cdot l^{-1}$]**	**φ_{gasf} in [$kg{\cdot}m^{-3}$]**	**ΔH_{vap} [$J \cdot g^{-1}$]**
113.55	$1.948 \cdot 10^{-7}$	0.7417	$1.199 \cdot 10^{-6}$	484.6
120.00	$9.564 \cdot 10^{-7}$	0.7351	$5.572 \cdot 10^{-6}$	479.2
130.00	$8.016 \cdot 10^{-6}$	0.7255	$4.310 \cdot 10^{-5}$	471.2
140.00	$4.819 \cdot 10^{-5}$	0.7158	$2.406 \cdot 10^{-4}$	463.3
150.00	$2.225 \cdot 10^{-4}$	0.7062	$1.037 \cdot 10^{-3}$	455.5
160.00	$8.306 \cdot 10^{-4}$	0.6965	$3.630 \cdot 10^{-3}$	447.9
170.00	$2.606 \cdot 10^{-3}$	0.6869	$1.071 \cdot 10^{-2}$	440.3
180.00	$7.073 \cdot 10^{-3}$	0.6772	$2.750 \cdot 10^{-2}$	432.8
190.00	$1.703 \cdot 10^{-2}$	0.6674	$6.281 \cdot 10^{-2}$	425.2
200.00	$3.708 \cdot 10^{-2}$	0.6576	0.1301	417.5
210.00	$7.411 \cdot 10^{-2}$	0.6476	0.2484	409.8
220.00	0.1377	0.6375	0.4422	401.9
230.00	0.2405	0.6273	0.7424	393.9
240.00	0.3980	0.6169	1.185	385.6
250.00	0.6286	0.6063	1.813	377.0
260.00	0.9537	0.5954	2.672	368.1
261.54	1.01325	0.5937	2.827	366.7
270.00	1.397	0.5842	3.816	358.7
280.00	1.983	0.5727	5.305	348.9
290.00	2.741	0.5607	7.205	338.6
300.00	3.697	0.5484	9.595	327.6
310.00	4.884	0.5354	12.57	315.9
320.00	6.331	0.5218	16.24	303.3
330.00	8.071	0.5074	20.75	289.7
340.00	10.14	0.4920	26.29	274.8
350.00	12.57	0.4754	33.15	258.3
360.00	15.41	0.4571	41.71	239.7
370.00	18.70	0.4367	52.63	218.4
380.00	22.49	0.4130	67.03	193.2
390.00	26.85	0.3837	87.28	161.4
400.00	31.90	0.3418	120.6	115.9
407.85	36.40	0.2244	224.4	0

Table T10.4-8: Carbon dioxide

T in [K]	p_D in [bar]	φ_{fl} in $[kg \cdot l^{-1}]$	φ_{gasf} in $[kg \cdot m^{-3}]$	ΔH_{vap} $[J \cdot g^{-1}]$
216.58	5.180	1.1784	14.042	344.23
218.00	5.508	1.1734	14.840	342.88
220.00	5.996	1.1662	16.034	340.73
222.00	6.515	1.1590	17.315	338.27
224.00	7.068	1.1516	18.686	335.59
226.00	7.654	1.1442	20.150	332.73
228.00	8.276	1.1367	21.712	329.68
230.00	8.935	1.1291	23.375	326.48
232.00	9.632	1.1214	25.142	323.18
234.00	10.368	1.1136	27.951	319.75
236.00	11.146	1.1056	29.015	316.25
238.00	11.966	1.0976	31.131	312.62
240.00	12.830	1.0894	33.371	308.91
242.00	13.739	1.0811	35.745	305.10
244.00	14.695	1.0727	38.265	301.21
246.00	15.698	1.0642	40.924	297.21
248.00	16.752	1.0554	43.739	293.10
250.00	17.856	1.0466	46.722	288.90
252.00	19.013	1.0375	49.878	284.60
254.00	20.223	1.0283	53.219	280.17
256.00	21.489	1.0189	56.757	275.63
258.00	22.812	1.0093	60.505	270.97
260.00	24.194	0.99943	64.478	266.17
262.00	25.635	0.98939	68.691	261.24
264.00	27.138	0.97907	73.164	256.15
266.00	28.705	0.96847	77.920	250.90
268.00	30.336	0.95759	82.978	245.52
270.00	32.034	0.94639	88.376	239.93
272.00	33.801	0.93483	94.125	234.13
274.00	35.638	0.92287	100.28	228.14
276.00	37.549	0.91048	106.88	221.9
278.00	39.533	0.89761	113.97	215.4
280.00	41.595	0.88419	121.63	208.6
282.00	43.737	0.87016	129.91	201.5
284.00	45.960	0.85539	138.93	194.0
286.00	48.269	0.83980	148.80	186.0
288.00	50.665	0.82321	159.66	177.5
290.00	53.152	0.80542	171.75	168.3
292.00	55.734	0.78614	185.32	158.4
294.00	58.415	0.76496	200.83	147.4
296.00	61.198	0.74119	218.90	135.2
298.00	64.090	0.71373	240.68	121.0
300.00	67.095	0.69031	268.35	103.7
302.00	70.220	0.63508	307.70	80.67
304.21	73.825	0.466	466.01	0

Table T10.4-9: Carbon monoxide

T in [K]	**p_D in [bar]**	**φ_{fl} in [kg · l^{-1}]**	**φ_{gasf} in [kg · m^{-3}]**	**ΔH_{vap} [J · g^{-1}]**
68.127	01540	0.84731	0.769	232.56
70.000	0.2100	0.83981	1.023	230.33
72.000	0.2866	0.83171	1.362	227.87
74.000	0.3839	0.82356	1.783	225.34
76.000	0.5055	0.81530	2.297	222.73
78.000	0.6552	0.80692	2.917	220.03
80.000	0.8372	0.79844	3.658	217.22
81.638	1.0133	0.79141	4.364	214.84
84.000	1.3153	0.78113	5.558	211.28
86.000	1.6206	0.77225	6.751	208.12
88.000	1.9762	0.76320	8.127	204.84
90.000	2.3870	0.75398	9.706	201.43
92.000	2.8581	0.74457	11.509	197.87
94.000	3.3944	0.73496	13.559	194.16
96.000	4.0011	0.72513	15.879	190.30
98.000	4.6834	0.71505	18.497	186.27
100.000	5.4466	0.70471	21.444	182.07
102.000	6.2960	0.69404	24.754	177.68
104.000	7.2370	0.68303	28.466	173.09
106.000	8.2753	0.67166	32.625	168.28
108.000	9.4165	0.65987	37.285	163.24
110.000	10.6664	0.64757	42.507	157.92
112.000	12.0310	0.63474	48.366	152.31
114.000	13.5166	0.62127	54.955	146.37
116.000	15.1294	0.60701	62.390	140.02
118.000	16.8764	0.59186	70.821	133.21
120.000	18.7647	0.57559	80.454	125.83
122.000	20.8020	0.55788	91.577	117.73
124.000	22.9969	0.53830	104.627	108.70
126.000	25.3591	0.51609	120.327	98.35
128.000	27.9002	0.48985	140.029	86.01
130.000	30.6356	0.45623	166.900	70.13
131.000	32.0835	0.43380	185.727	59.57
132.000	33.5920	0.40184	213.524	44.68
132.500	34.3729	0.37523	237.354	32.48

Table T10.4-10: Krypton

T in [K]	p_D in [bar]	φ_{fl} in $[kg \cdot l^{-1}]$	φ_{gasf} in $[kg \cdot m^{-3}]$	ΔH_{vap} $[J \cdot g^{-1}]$
115.777	0.73055	2.442	6.5280	109.05
116.000	0.74439	2.440	6.6413	108.96
117.000	0.80901	2.433	7.1673	108.56
118.000	0.87786	2.426	7.7249	108.15
119.000	0.95112	2.418	8.3135	107.75
119.802	1.01325	2.413	8.8102	107.41
120	1.03035	2.4134	8.9518	107.40
125	1.49660	2.3749	12.610	105.58
130	2.10904	2.3354	17.292	103.64
135	2.89387	2.2947	23.170	101.54
140	3.87803	2.2530	30.424	99.30
145	5.08894	2.2098	19.257	96.90
150	6.55452	2.1652	49.898	94.30
155	8.30354	2.1189	62.613	91.50
160	10.3656	2.0704	77.724	88.47
165	12.7720	2.0196	95.639	85.17
170	15.5547	1.9659	116.87	81.56
175	18.7478	1.9085	142.09	77.57
180	22.3856	1.8468	177.21	73.15
185	26.5044	1.7790	208.51	68.17
190	31.1422	1.7026	252.93	62.47
195	36.3421	1.6135	308.60	55.77
200	42.1583	1.5043	383.14	47.44
205	48.6701	1.354	507.02	34.98
209	54.4597	1.108	783.21	12.32

Table T10.4-11: Methane

T in [K]	p_D in [bar]	φ_{fl} in $[kg \cdot l^{-1}]$	φ_{gasf} in $[kg \cdot m^{-3}]$	ΔH_{Vap} $[J \cdot g^{-1}]$
90.68	0.1174	0.4515	0.2515	543.2
92.00	0.1388	0.4499	0.2936	541.3
94.00	0.1770	0.4472	0.3672	538.5
96.00	0.2234	0.4445	0.4545	535.6
98.00	0.2790	0.4418	0.5573	532.7
100.00	0.3451	0.4390	0.6774	529.7
102.00	0.4232	0.4362	0.8165	526.6
104.00	0.5146	0.4335	0.9766	523.4
106.00	0.6208	0.4306	1.160	520.1
108.00	0.7433	0.4278	1.368	516.7
110.00	0.8840	0.4249	1.604	513.3
111.63	1.01325	0.4226	1.817	510.3
112.00	1.044	0.4220	1.868	509.7
114.00	1.226	0.4191	2.165	506.0
116.00	1.431	0.4161	2.496	502.1
118.00	1.662	0.4131	2.864	498.2
120.00	1.919	0.4101	3.271	494.1

Table T10.4-11: (*continued*)

122.00	2.205	0.4070	3.720	489.9
124.00	2.523	0.4039	4.214	485.5
126.00	2.873	0.4008	4.756	481.0
128.00	3.258	0.3976	5.348	476.4
130.00	3.681	0.3943	5.995	471.5
132.00	4.142	0.3910	6.700	466.5
134.00	4.645	0.3877	7.466	461.3
136.00	5.191	0.3842	8.297	456.0
138.00	5.783	0.3808	9.198	450.4
140.00	6.422	0.3772	10.17	444.6
142.00	7.112	0.3736	11.23	438.6
144.00	7.853	0.3699	12.37	432.3
146.00	8.649	0.3661	13.60	425.8
148.00	9.502	0.3622	14.93	419.0
150.00	10.41	0.3583	16.36	411.9
152.00	11.39	0.3542	17.91	404.6
154.00	12.42	0.3500	19.58	396.9
156.00	13.53	0.3457	21.38	388.8
158.00	14.70	0.3413	23.33	380.4
160.00	15.94	0.3367	25.44	371.5
162.00	17.26	0.3319	27.72	362.2
164.00	18.65	0.3270	30.20	352.4
166.00	20.12	0.3218	32.90	342.1
168.00	21.67	0.3165	35.85	331.1
170.00	23.31	0.3108	39.08	319.5
172.00	25.03	0.3049	42.64	307.0
174.00	26.85	0.2986	46.58	293.6
176.00	28.76	0.2918	50.98	279.2
178.00	30.77	0.2845	5.94	263.4
180.00	32.88	0.2765	61.61	246.0
182.00	35.10	0.2676	68.23	226.4
184.00	37.44	0.2574	76.20	203.7
186.00	39.89	0.2450	86.26	176.4
188.00	42.47	0.2285	100.3	140.1
190.00	45.20	0.1965	127.1	74.32
190.555	45.98	0.1628	162.8	0

Table T10.4-12: Neon

T in [K]	p_D in [bar]	φ_{fl} in $[kg \cdot l^{-1}]$	φ_{gasf} in $[kg \cdot m^{-3}]$	ΔH_{vap} $[J \cdot g^{-1}]$
24.562	0.4338	1.2491	4.409	89.1422
25	0.5089	1.2420	5.101	88.6114
26	0.7165	1.2257	6.968	87.3735
27	0.9831	1.2089	9.309	86.0731
27.100	1.01325	1.2071	9.569	85.9393
28	1.318	1.1913	12.19	84.6875
29	1.732	1.1731	15.69	83.1969
30	2.234	1.1541	19.88	81.5829
31	2.835	1.1341	24.86	79.8275
32	3.546	1.1132	30.75	77.9152
33	4.378	1.0912	37.67	75.827
34	5.342	1.0681	45.77	73.543
35	6.449	1.0438	55.23	71.041
36	7.713	1.0182	66.31	68.292
37	9.146	0.99103	79.30	65.254
38	10.760	0.96199	94.64	61.872
39	12.571	0.93053	112.9	58.028
40	14.592	0.89564	134.9	53.718
41	16.841	0.85587	162.0	48.632
42	19.336	0.80787	196.4	38.500
43	22.101	0.74507	242.75	34.528
44	25.166	0.65386	314.91	23.008
44.448	26.638	0.48288	482.88	0

Table T10.4-13: Propane

T in [K]	p_D in [bar]	φ_{fl} in $[kg \cdot l^{-1}]$	φ_{gasf} in $[kg \cdot m^{-3}]$	ΔH_{vap} $[J \cdot g^{-1}]$
85.47	$1.639 \cdot 10^{-9}$	0.7333	$1.048 \cdot 10^{-8}$	562.6
90.00	$9.697 \cdot 10^{-9}$	0.7285	$5.714 \cdot 10^{-8}$	558.0
95.00	$5.416 \cdot 10^{-8}$	0.7233	$3.924 \cdot 10^{-7}$	553.0
100.00	$2.513 \cdot 10^{-7}$	0.7182	$1.333 \cdot 10^{-6}$	548.0
105.00	$9.964 \cdot 10^{-7}$	0.7132	$5.033 \cdot 10^{-6}$	543.1
110.00	$3.448 \cdot 10^{-6}$	0.7081	$1.662 \cdot 10^{-5}$	538.2
115.00	$1.061 \cdot 10^{-5}$	0.7031	$4.893 \cdot 10^{-5}$	533.4
120.00	$2.946 \cdot 10^{-5}$	0.6981	$1.302 \cdot 10^{-4}$	528.6
125.00	$7.479 \cdot 10^{-5}$	0.6931	$3.173 \cdot 10^{-4}$	523.9
130.00	$1.753 \cdot 10^{-4}$	0.6880	$7.154 \cdot 10^{-4}$	519.3
135.00	$3.832 \cdot 10^{-4}$	0.6830	$1.506 \cdot 10^{-3}$	514.7
140.00	$7.870 \cdot 10^{-4}$	0.6779	$2.982 \cdot 10^{-3}$	510.1
145.00	$1.528 \cdot 10^{-3}$	0.6729	$5.593 \cdot 10^{-3}$	505.6
150.00	$2.825 \cdot 10^{-3}$	0.6678	$9.994 \cdot 10^{-3}$	501.1
155.00	$4.992 \cdot 10^{-3}$	0.6627	$1.709 \cdot 10^{-2}$	496.6
114.00	1.226	0.4191	2.165	506.0
116.00	1.431	0.4161	2.496	502.1
118.00	1.662	0.4131	2.864	498.2
120.00	1.919	0.4101	3.271	494.1

Table T10.4-13: (*continued*)

122.00	2.205	0.4070	3.720	489.9
124.00	2.523	0.4039	4.214	485.5
126.00	2.873	0.4008	4.756	481.0
128.00	3.258	0.3976	5.348	476.4
130.00	3.681	0.3943	5.995	471.5
132.00	4.142	0.3910	6.700	466.5
134.00	4.645	0.3877	7.466	461.3
136.00	5.191	0.3842	8.297	456.0
138.00	5.783	0.3808	9.198	450.4
140.00	6.422	0.3772	10.17	444.6
142.00	7.112	0.3736	11.23	438.6
144.00	7.853	0.3699	12.37	432.3
146.00	8.649	0.3661	13.60	425.8
148.00	9.502	0.3622	14.93	419.0
150.00	10.41	0.3583	16.36	411.9
152.00	11.39	0.3542	17.91	404.6
154.00	12.42	0.3500	19.58	396.9
156.00	13.53	0.3457	21.38	388.8
158.00	14.70	0.3413	23.33	380.4
160.00	15.94	0.3367	25.44	371.5
162.00	17.26	0.3319	27.72	362.2
164.00	18.65	0.3270	30.20	352.4
166.00	20.12	0.3218	32.90	342.1
168.00	21.67	0.3165	35.85	331.1
170.00	23.31	0.3108	39.08	319.5
172.00	25.03	0.3049	42.64	307.0
174.00	26.85	0.2986	46.58	293.6
176.00	28.76	0.2918	50.98	279.2
178.00	30.77	0.2845	5.94	263.4
180.00	32.88	0.2765	61.61	246.0
182.00	35.10	0.2676	68.23	226.4
184.00	37.44	0.2574	76.20	203.7
186.00	39.89	0.2450	86.26	176.4
188.00	42.47	0.2285	100.3	140.1
190.00	45.20	0.1965	127.1	74.32
190.555	45.98	0.1628	162.8	0

Table T10.4-14: Propene

T in [K]	**p_D in [bar]**	**φ_{fl} in $[kg \cdot l^{-1}]$**	**φ_{gasf} in $[kg \cdot m^{-3}]$**	**ΔH_{vap} $[J \cdot g^{-1}]$**
87.89	$9.5402 \cdot 10^{-9}$	0.76884	$5.4938 \cdot 10^{-8}$	569.23
90	$2.0530 \cdot 10^{-8}$	0.76643	$1.1545 \cdot 10^{-7}$	566.18
95	$1.0871 \cdot 10^{-7}$	0.76067	$5.7918 \cdot 10^{-7}$	560.31
100	$4.8055 \cdot 10^{-7}$	0.75483	$2.4321 \cdot 10^{-6}$	555.58
105	$1.8242 \cdot 10^{-6}$	0.74898	$8.7929 \cdot 10^{-6}$	551.38
110	$6.0789 \cdot 10^{-6}$	0.74313	$2.7969 \cdot 10^{-5}$	547.34
115	$1.8097 \cdot 10^{-5}$	0.73730	$7.9646 \cdot 10^{-5}$	543.30
120	$4.8828 \cdot 10^{-5}$	0.73150	$2.0594 \cdot 10^{-4}$	539.16
125	$1.2084 \cdot 10^{-4}$	0.72570	$4.8927 \cdot 10^{-4}$	534.96
130	$2.7707 \cdot 10^{-4}$	0.71996	$1.0788 \cdot 10^{-3}$	530.68
135	$5.9371 \cdot 10^{-4}$	0.71423	$2.2260 \cdot 10^{-3}$	526.28
140	$1.1977 \cdot 10^{-3}$	0.70851	$4.3307 \cdot 10^{-3}$	521.82
145	$2.2895 \cdot 10^{-3}$	0.70282	$7.9938 \cdot 10^{-3}$	517.32
150	$4.1697 \cdot 10^{-3}$	0.69714	$1.4976 \cdot 10^{-2}$	512.76
155	$7.2705 \cdot 10^{-3}$	0.69146	$2.3759 \cdot 10^{-2}$	508.17
160	$1.2189 \cdot 10^{-2}$	0.68579	$3.8606 \cdot 10^{-2}$	503.86
165	$1.9723 \cdot 10^{-2}$	0.68010	$6.0606 \cdot 10^{-2}$	498.93
170	$3.0903 \cdot 10^{-2}$	0.67441	$9.2234 \cdot 10^{-2}$	494.27
175	$4.7023 \cdot 10^{-2}$	0.66871	0.13647	489.59
180	$6.9671 \cdot 10^{-2}$	0.66299	0.19684	484.89
185	0.10075	0.65724	0.27739	480.13
190	0.14249	0.65146	0.38272	475.23
195	0.19747	0.64565	0.51799	470.48
200	0.26860	0.63979	0.68889	465.59
205	0.35915	0.63387	0.90159	460.60
210	0.47272	0.62791	1.1628	455.54
215	0.61322	0.62189	1.4798	450.36
220	0.78488	0.61579	1.8601	445.08
225	0.99223	0.60962	2.3121	439.66
225.46	1.01325	0.60905	2.3577	439.16
230	1.2401	0.60337	2.8446	434.10
235	1.5334	0.59702	3.4665	428.40
240	1.8775	0.59059	4.1883	422.50
245	2.2778	0.58404	5.0201	416.42
250	2.7401	0.57737	5.9735	410.15
255	3.2701	0.57058	7.0606	403.64
260	3.8737	0.56364	8.2949	396.91
265	4.5573	0.55655	9.5907	389.88
270	5.3269	0.54930	11.264	382.58
275	6.1889	0.54186	13.033	374.98
280	7.1499	0.53422	15.015	367.02
285	8.2165	0.52636	17.239	358.72
290	9.3954	0.51826	19.725	350.02
295	10.694	0.50989	22.505	340.85
305	13.676	0.49220	29.097	321.06
310	15.376	0.48280	33.001	310.29

Table T10.4-14: (*continued*)

315	17.225	0.47296	37.394	298.84
320	19.231	0.46261	42.351	286.60
325	21.404	0.45165	47.977	273.46
330	23.751	0.43996	54.407	259.27
335	26.284	0.42736	61.827	243.77
340	29.015	0.41360	70.505	226.7
345	31.956	0.39822	80.853	207.4
350	35.121	0.38047	93.569	185.2
355	38.529	0.35889	110.03	158.2
360	42.202	0.32291	133.82	121.9
365	46.174	0.26249	188.48	45.06
365.57	46.646	0.22339	223.39	0

Table T10.4-15: Oxygen

T in [K]	**p_D in [bar]**	**φ_{fl} in $[kg \cdot l^{-1}]$**	**φ_{gasf} in $[kg \cdot m^{-3}]$**	**ΔH_{vap} $[J \cdot g^{-1}]$**
54.359	$1.478 \cdot 10^{-3}$	1.306	$1.062 \cdot 10^{-2}$	242.3
56	$2.434 \cdot 10^{-3}$	1.299	$1.673 \cdot 10^{-2}$	241.1
58	$4.291 \cdot 10^{-3}$	1.290	$2.849 \cdot 10^{-2}$	239.6
60	$7.267 \cdot 10^{-3}$	1.281	$4.666 \cdot 10^{-2}$	238.0
62	$1.187 \cdot 10^{-2}$	1.273	$7.379 \cdot 10^{-2}$	236.5
64	$1.876 \cdot 10^{-2}$	1.264	0.1130	234.9
66	$2.877 \cdot 10^{-2}$	1.255	0.1682	233.4
68	$4.294 \cdot 10^{-2}$	1.246	0.2439	231.8
70	$6.251 \cdot 10^{-2}$	1.237	0.3453	230.2
72	$8.894 \cdot 10^{-2}$	1.228	0.4783	228.6
74	0.1240	1.218	0.6496	227.0
76	0.1695	1.209	0.8655	225.3
78	0.2276	1.200	1.137	223.6
80	0.3009	1.190	1.469	221.9
82	0.3919	1.181	1.872	220.1
84	0.5035	1.171	2.356	218.3
86	0.6387	1.162	2.931	216.5
88	0.8007	1.152	3.607	214.6
90	0.9931	1.142	4.396	212.6
90.19	1.01325	1.141	4.477	212.5
92	1.219	1.132	5.308	210.6
94	1.483	1.122	6.357	208.6
96	1.789	1.112	7.555	206.4
98	2.139	1.101	8.916	204.2
100	2.540	1.091	10.45	201.9
102	2.994	1.080	12.18	199.5
104	3.506	1.069	14.12	197.1
106	4.081	1.058	16.27	194.5
108	4.722	1.047	18.67	191.8
110	5.434	1.035	21.34	189.1
112	6.222	1.024	24.28	186.2
114	7.090	1.012	27.53	183.1
116	8.043	0.9995	31.11	180.0

Table T10.4-15: (*continued*)

118	9.085	0.9869	35.06	176.7
120	10.22	0.9739	39.39	173.2
122	11.46	0.9606	44.16	169.5
124	12.80	0.9468	49.40	165.7
126	14.25	0.9326	55.15	161.7
128	15.81	0.9178	61.49	157.4
130	17.49	0.9025	68.47	152.9
132	19.29	0.8864	76.18	148.1
134	21.23	0.8696	84.72	142.9
136	23.30	0.8519	94.21	137.4
138	25.51	0.8331	104.8	131.6
140	27.88	0.8131	116.7	125.2
142	30.39	0.7916	130.3	118.2
144	33.07	0.7681	145.8	110.5
146	35.92	0.7421	164.1	101.9
148	38.96	0.7126	186.0	92.00
150	42.19	0.6775	213.7	80.09
152	45.63	0.6316	252.4	64.44
154	49.30	0.5495	329.1	36.34
154.581	50.43	0.4361	436.1	0

Table T10.4-16: Nitrogen

T in [K]	**p_D in [bar]**	**φ_{fl} in [kg · l^{-1}]**	**φ_{gasf} in [kg · m^{-3}]**	**ΔH_{vap} [J · g^{-1}]**
63.15	0.1246	0.8679	0.6803	215.2
64	0.1455	0.8617	0.7745	214.3
66	0.2059	0.8570	1.066	212.2
68	0.2847	0.8490	1.435	210.0
70	0.3854	0.8408	1.896	207.7
72	0.5121	0.8324	2.462	205.3
74	0.6689	0.8237	3.147	202.9
76	0.8604	0.8148	3.067	200.4
77.36	1.01325	0.8085	4.612	198.6
78	1.091	0.8057	4.939	197.8
80	1.367	0.7963	6.080	195.1
82	1.692	0.7867	7.410	192.3
84	2.072	0.7769	8.948	189.4
86	2.512	0.7669	10.71	186.4
88	3.019	0.7566	12.74	183.2
90	3.597	0.7461	15.04	179.9
92	4.254	0.7352	17.64	176.4
94	4.994	0.7241	20.59	172.8
96	5.823	0.7127	23.92	169.0
98	6.749	0.7009	27.66	164.9
100	7.777	0.6887	31.87	160.6
102	8.913	0.6761	36.61	156.0
104	10.16	0.6630	41.94	151.1
106	11.54	0.6494	47.94	145.9
108	13.04	0.6351	54.73	140.3

Table T10.4-16: (*continued*)

110	14.67	0.6201	62.43	134.3
112	16.45	0.6042	71.23	127.8
114	18.38	0.5872	81.37	120.6
116	20.46	0.5688	93.20	112.6
118	22.71	0.5484	107.3	103.6
120	25.13	0.5252	124.5	93.09
122	27.74	0.4971	146.6	80.34
124	30.55	0.4588	178.3	63.16
126.26	33.991	0.3141	314.1	0

Table T10.4-17: **N**-hydrogen

T in [K]	**p_D in [bar]**	**φ_{fl} in $[kg \cdot l^{-1}]$**	**φ_{gasf} in $[kg \cdot m^{-3}]$**	**ΔH_{vap} $[J \cdot g^{-1}]$**
13.95	0.072	0.0770235	0.1254	449.1
14	0.074	0.0768554	0.1388	449.7
15	0.127	0.0759963	0.2228	451.8
16	0.204	0.0751030	0.3385	452.9
17	0.314	0.0741710	0.4922	453.1
18	0.461	0.0731950	0.6902	452.2
19	0.654	0.0721693	0.9395	450.0
20	0.901	0.0710870	1.2474	446.5
20.390	1.01325	0.0707864	1.3378	445.6
21	1.208	0.0699403	1.6189	441.8
22	1.585	0.0687200	2.0711	435.2
23	2.039	0.0676149	2.6119	426.8
24	2.579	0.0660112	3.2548	416.5
25	3.213	0.0644917	4.0171	404.0
26	3.950	0.0628337	4.9215	389.0
27	4.800	0.0610065	5.9999	371.0
28	5.770	0.0589665	7.2979	349.4
29	6.872	0.0566460	8.8866	323.0
30	8.116	0.0539303	10.8872	290.5
31	9.510	0.0505892	13.5411	248.4
32	11.068	0.0459927	17.4983	188.5
33.180	13.130	0.0314285	31.4285	0

Table T10.4-18: P-hydrogen

T in [K]	**p_D in [bar]**	**φ_{fl} in $[kg \cdot l^{-1}]$**	**φ_{gasf} in $[kg \cdot m^{-3}]$**	**ΔH_{vap} $[J \cdot g^{-1}]$**
13.80	$7.042 \cdot 10^{-2}$	$7.704 \cdot 10^{-2}$	0.1275	448.9
14	$7.896 \cdot 10^{-2}$	$7.687 \cdot 10^{-2}$	0.1392	449.2
15	0.1343	$7.600 \cdot 10^{-2}$	0.2227	450.8
16	0.2153	$7.512 \cdot 10^{-2}$	0.3378	452.1
17	0.3284	$7.419 \cdot 10^{-2}$	0.4907	452.5
18	0.4807	$7.322 \cdot 10^{-2}$	0.6879	451.8
19	0.6796	$7.220 \cdot 10^{-2}$	0.9362	449.9
20	0.9326	$7.111 \cdot 10^{-2}$	1.243	446.6
20.28	1.01325	$7.079 \cdot 10^{-2}$	1.339	445.2
21	1.247	$6.996 \cdot 10^{-2}$	1.617	441.8

Table T10.4-18: (*continued*)

22	1.632	$6.873 \cdot 10^{-2}$	2.067	435.4
23	2.094	$6.741 \cdot 10^{-2}$	2.606	427.2
24	2.642	$6.600 \cdot 10^{-2}$	3.246	417.1
25	3.284	$6.447 \cdot 10^{-2}$	4.006	404.7
26	4.029	$6.280 \cdot 10^{-2}$	4.907	389.8
27	4.885	$6.097 \cdot 10^{-2}$	5.982	371.9
28	5.861	$5.892 \cdot 10^{-2}$	7.276	350.4
29	6.967	$5.659 \cdot 10^{-2}$	8.861	324.2
30	8.214	$5.385 \cdot 10^{-2}$	10.86	291.7
31	9.615	$5.046 \cdot 10^{-2}$	13.54	249.2
32	11.19	$4.570 \cdot 10^{-2}$	17.65	186.9
32.938	12.838	$3.136 \cdot 10^{-2}$	31.36	0

Table T10.4-19: Xenon

T in [K]	**p_D in [bar]**	**φ_{fl} in $[kg \cdot l^{-1}]$**	**φ_{gasf} in $[kg \cdot m^{-3}]$**	**ΔH_{vap} $[J \cdot g^{-1}]$**
161.396	0.81668	2.963	8.2032	96.716
162.000	0.84687	2.959	8.4808	96.496
163.000	0.89868	2.953	8.9551	96.127
164.000	0.95283	2.946	9.4481	95.757
165.066	1.01325	2.939	9.9954	95.359
170	1.3371	2.907	12.905	94.67

10.5 Constants of the Vapour Pressure Equation

According to Eq. (2.2.2-5) the vapour pressure curve is a series expansion of the decadal logarithm according to the functions of T

$$\lg p_D = A + \frac{B}{C+T} + D \cdot T + ET^2 + F \cdot \lg T$$

The values listed in the following tables for the constants A to F only apply in the given temperature region between T_{min} and T_{max} in K. The values were taken from the gas handbook (Messer Griesheim 1989).

Table T10.5-1: Constants of the vapour pressure equation

substance	**T_{min}** **T_{max}**	**A**	**B**	**C**	**D**	**E**	**F**
acetylene	223 308	4.567	–858.9	0	0	0	0
ammonia	198 403	10.4181	–1606.27	0	$-9.13817 \cdot 10^{-3}$	$9.58119 \cdot 10^{-5}$	–0.87152
Antimony hydride	213 256	4.35043	–1112.44	0	0	0	0
argon	84 150	5.789122	–411.161	0	$-1.66606 \cdot 10^{-2}$	$5.00808 \cdot 10^{-5}$	0
arsine	157 211	26.95315	–1403.32	0	$8.037 \cdot 10^{-3}$	0	–9.43935

Table T10.5-1: (*continued*)

Boron fluoride	193 285	1.4218	–1364.8	0	$-3.273 \cdot 10^{-3}$	0	1.75
Boron trifluoride	173 260	5.1056	–889.6	0	0	0	0
Bromochlorodifluoromethane	178 283	3.97618	–940.155	–32.356	0	0	0
Bromomethane	203 278	4.21313	–1044.42	–28.466	0	0	0
Bromotrifluormethane	165 216	4.27870	–869.048	–11.907	0	0	0
Hydrogen bromide	206 294	14.778	–1290	0	0	0	–3.679
Buta-1.3-diene	215 288	3.97479	–930.546	–34.2960	0	0	0
i-Butane	114 407	15.43263	–1689.71	0	$-7.08956 \cdot 10^{-3}$	$9.096872 \cdot 10^{-6}$	–3.19907
n-Butane	135 425	24.23151	–1901.16	0	$3.688122 \cdot 10^{-4}$	$3.851243 \cdot 10^{-6}$	–7.24233
Butene	205 305	4.10681	–988.75	–40.140	0	0	0
But-1-ene	198 398	5.201178	–1298.72	0	$-1.24829 \cdot 10^{-3}$	0	0
cis-But-2-ene	200 296	4.00948	–967.32	–35.2770	0	0	0
trans-But-2-ene	197 293	4.00817	–967.50	–32.310	0	0	0
Carbonyl difluoride	162 189	28.21171	–1682.18	0	0	0	–8.47543
Carbonyl sulphide	162 378	7.346479	–1255.76	0	$-1.01933 \cdot 10^{-2}$	$1.137583 \cdot 10^{-5}$	0
Chlorine	203 417	2.17122	–1290.95	0	$-1.38369 \cdot 10^{-2}$	$1.23633 \cdot 10^{-5}$	2.45407
Chlorine cyanide	267 286	4.82	–1377	0	0	0	0
Chlorodifluoromethane (R22)	213 308	8.0923	–1590.1	0	$-1.04 \cdot 10^{-2}$	$9.8 \cdot 10^{-6}$	0
Chloro-1.1-difluoroethane (R142b)	212 366	25.1201	–1638.82	0	$5.1838 \cdot 10^{-3}$	0	–8.1418
Chloroethane (R160)	207 305	4.07394	–1012.77	–36.48	0		0
Chloomethane (R40)	183 333	21.4466	–1687.58	0	$2.8390 \cdot 10^{-3}$	0	–6.41725
Chloropentafluorethane (R115)	178 346	38.9555	–1932.13	0	$1.00647 \cdot 10^{-2}$	0	–13.9492
Chlorosilane	156 396	60.96043	–2542.59	0	$1.610 \cdot 10^{-2}$	0	–22.8033

Table T10.5-1: (*continued*)

1-Chloro-2.2.2-trifluoroethane (133a)	223 323	4.80583	–1332.14	0	–3.37672 $\cdot 10^{-4}$	3.54715 $\cdot 10^{-7}$	0
Chlorotrifluoroethene (R1113)	273 353	4.50683	–1101.41	0	0	0	0
Chlorine trifluoride	226 303	4.49191	–1096.92	–40.400	0	0	0
Chlorotrifluoromethane (R13)	134 298	7.8087	–1109.12	0	–1.4127 $\cdot 10^{-2}$	1.883 $\cdot 10^{-2}$	0
Hydrogen chloride	273 324	5.42325	–1443.20	87.19	0	0	0
Hydrogen cyanide	260 299	5.89594	–1600.8	0	–1.7835 $\cdot 10^{-3}$	0	0
Cyclopropane	258 373	4.08987	–1238.49	0	–8.87772 $\cdot 10^{-3}$	8.38326 $\cdot 10^{-6}$	1.14196
Deuterium	19 24	1.8560	–58.4619	0	2.671 $\cdot 10^{-2}$	0	0
Diborane	195 289	3.847423	–724.162	0	–8.84279 $\cdot 10^{-4}$	0	0
Dichloro-Difluoromethane (12)	173 382	35.53881	–1909.24	0	8.51479 $\cdot 10^{-3}$	0	0
cis-But-2-ene	200 296	4.00948	–967.32	-35.2770	0	0	0
trans-But-2-ene	197 293	4.00817	–967.50	-32.310	0	0	0
Carbonyl difluoride	162 189	28.21171	–1682.18	0	0	0	–8.47543
Carbonyl sulphide	162 378	7.346479	–1255.76	0	–1.01933 $\cdot 10^{-2}$	1.137583 $\cdot 10^{-5}$	0
Chlorine	203 417	2.17122	–1290.95	0	–1.38369 $\cdot 10^{-2}$	1.23633 $\cdot 10^{-5}$	2.45407
Chlorine cyanide	267 286	4.82	–1377	0	0	0	0
Chlorodifluoromethane (R22)	213 308	8.0923	–1590.1	0	–1.04 $\cdot 10^{-2}$	9.8 $\cdot 10^{-6}$	0
Chloro-1.1-difluoroethane (R142b)	212 366	25.1201	–1638.82	0	5.1838 $\cdot 10^{-3}$	0	–8.1418
Chloroethane (R160)	207 305	4.07394	–1012.77	-36.48	0		0
Chlor0methane (R40)	183 333	21.4466	–1687.58	0	2.8390 $\cdot 10^{-3}$	0	–6.41725
Chloropentafluorethane (R115)	178 346	38.9555	–1932.13	0	1.00647 $\cdot 10^{-2}$	0	–13.9492

Table T10.5-1: (*continued*)

Chlorosilane	156 396	60.96043	–2542.59	0	$1.610 \cdot 10^{-2}$	0	–22.8033
1-Chloro-2.2.2-trifluoroethane (133a)	223 323	4.80583	–1332.14	0	$-3.37672 \cdot 10^{-4}$	$3.54715 \cdot 10^{-7}$	0
Chlorotrifluoroethene (R1113)	273 353	4.50683	–1101.41	0	0	0	0
Chlorine trifluoride	226 303	4.49191	–1096.92	–40.400	0	0	0
Chlorotrifluoromethane (R13)	134 298	7.8087	–1109.12	0	$-1.4127 \cdot 10^{-2}$	$1.883 \cdot 10^{-2}$	0
Hydrogen chloride	273 324	5.42325	–1443.20	87.19	0	0	0
Hydrogen cyanide	260 299	5.89594	–1600.8	0	$-1.7835 \cdot 10^{-3}$	0	0
Cyclopropane	258 373	4.08987	–1238.49	0	$-8.87772 \cdot 10^{-3}$	$8.38326 \cdot 10^{-6}$	1.14196
Deuterium	19 24	1.8560	–58.4619	0	$2.671 \cdot 10^{-2}$	0	0
Diborane	195 289	3.847423	–724.162	0	$-8.84279 \cdot 10^{-4}$	0	0
Dichloro-Difluoro-methane (12)	173 382	35.53881	–1909.24	0	$8.51479 \cdot 10^{-3}$	0	0
Dichlorosilane	152 282	1.0270	–1297.2	0	$-2.4827 \cdot 10^{-3}$	0	1.75
1.2-Dichloro-1.1.2.2-tetrafluoromethane (R114)	233 333	5.6185	–1419.72	0	$-1.746 \cdot 10^{-3}$	0	0
Dicyanogen	245 273	19.42563	–1818.55	0	0	0	–5.0813
1.1-Difluoroethane (R152a)	247 381	4.604	–1141	0	0	0	0
1.1-Difluoroethene (R1132a)	233 302	4.3016	–805	0	0	0	0
Dimethylamine	194 289	5.4960	–1968.40	0	$-9.8042 \cdot 10^{-3}$	0	1.75
Dimethyl ether	250 294	4.666	–1162	0	0	0	0
2.2-Dimethylpropane	259 303	3.86292	–950.84	–36.15	0	0	0
Dinitrogen Oxide (R744a)	243 303	8.65383	–1184.59	0	$-1.59136 \cdot 10^{-2}$	$2.04376 \cdot 10^{-5}$	0
Ethane (R170)	91 305	17.77276	–1133.46	0	$-4.214195 \cdot 10^{-5}$	$6.751740 \cdot 10^{-6}$	–5.227982

Table T10.5-1: (*continued*)

Ethylamine (R631)	213 303	4.5110	–1137.30	–37.300	0	0	0
Ethene (R1150)	104 282	20.94610	–1096.210	0	$2.859707 \cdot 10^{-3}$	$5.662132 \cdot 10^{-6}$	–6.781872
Oxirane	273 303	4.784	–1355	0	0	0	0
Fluorine	59 91	3.93021	–310.128	–5.9900	0	0	0
Fluoroethane (R161)	201 339	4.832	–1162	0	0	0	0
Fluoromethane (R41)	164 289	8.878705	–1042.191	0	0	0	–1.541142
Hydrogen fluoride	193 378	5.50516	–1952.55	62.370	0	0	0
Germane	110 190	4.260	–782.7	0	0	0	0
Helium-4	2.2 5.2	$3.198061 \cdot 10^{-2}$	–4.010245	0	0.2528742	$-8.130637 \cdot 10^{-3}$	0
Helium-3	3.2 3.3	0.8852865	–3.774784	0	$9.495172 \cdot 10^{-2}$	0	0
Hexafluoroethane (R116)	175 290	9.07076	–1227.05	0	$-1.94001 \cdot 10^{-2}$	$2.66394 \cdot 10^{-5}$	0
Isobutylene	273 417	4.38164	–1163.34	0	0	0	0
Hydrogen iodide	223 256	2.7337	–416.04	–85.5	0	0	0
Carbon dioixide	217 304	9.380923	–1265.853	0	$-1.799864 \cdot 10^{-2}$	$2.2944259 \cdot 10^{-5}$	0
Carbon monoxide	69 132	10.18059	–433.1550	0	$-1.330754 \cdot 10^{-2}$	$5.773483 \cdot 10^{-5}$	–2.179747
Krypton	116 209	5.757867	–567.6016	0	$-1.144069 \cdot 10^{-2}$	$2.483518 \cdot 10^{-5}$	0
Methane	91 190	7.030889	–523.9767	0	$-8.218194 \cdot 10^{-3}$	$2.323305 \cdot 10^{-5}$	0
Methylacetylene	250 385	4.612	–114	0	0	0	0
Methylamine (R630)	199 283	4.6217	–1079.15	–32.92	0	0	0
Methyl mercaptane	222 280	15.39909	–1769.05	0	0	0	–3.70248
Methylsilane	143 216	4.4037	–948.4	0	0	0	0
Neon	25 44	4.650627	–106.8598	0	$-3.748236 \cdot 10^{-2}$	$4.276740 \cdot 10^{-4}$	0
Nitrosyl chloride	214 285	4.48634	–1094.73	–23.45	0	0	0
Octafluoro Cyclobutane (RC318)	234 303	4.712561	–1255.3	0	0	0	0

Table T10.5-1: (*continued*)

Octafluoro Propane (R218)	213 341	17.0010	–1435.89	0	2.82492 $\cdot 10^{-3}$	0	–4.88280
Carbonyl Dichloride (phosgene)	244 343	4.686	–1315	0	0	0	0
Phosphine	243 313	3.13152	–639.649	0	2.01628 $\cdot 10^{-3}$	0	0
Phosphorus pentafluoride	181 189	4.771	–898.9	0	0	0	0
Propa-1.2-diene	238 377	4.253	–997.3	0	0	0	0
Propane	86 369	17.79011	–1482.367	0	–3.347221 $\cdot 10^{-3}$	7.554073 $\cdot 10^{-6}$	–4.653021
Propene	88 365	12.94762	–13.81908	0	–7.590480 $\cdot 10^{-3}$	1.062665 $\cdot 10^{-5}$	–2.397088
Propylen oxide	225 340	3.77936	–915.310	-64.87	0	0	0
Oxygen	55 154	10.33044	–470.1225	0	–6.224342 $\cdot 10^{-3}$	3.181815 $\cdot 10^{-5}$	–2.459931
Sulphur dioxide	198 430	41.01012	–2378.72	0	8.3319 $\cdot 10^{-3}$	0	–14.11350
Sulphur hexafluoride	223 313	167.696	–4900.88	0	5.2679 $\cdot 10^{-2}$	0	–66.9220
Sulphur tetrafluoride	168 223	4.871	–1132	0	0	0	0
Hyrogen sulphide	258 313	117.741	–3178.29	0	7.04853 $\cdot 10^{-2}$	–3.83477 $\cdot 10^{-5}$	–49.8589
Selane f	231 382	4.60	–1067	0	0	0	0
Monosilane	162 269	2.285326	–488.4050	0	4.499724 $\cdot 10^{-3}$	0	0
Silicon tetrafluoride	187 198	5.578	–975.0	0	0	0	0
Nitrogen	64 126	28.49829	–531.4788	0	4.190300 $\cdot 10^{-2}$	–4.133023 $\cdot 10^{-5}$	–13.0394
Methylethyl ether	190 315	3.40479	–859.999	-25.15	0	0	0
Water	274 373	9.758496	–2755.526	0	–8.410066 $\cdot 10^{-3}$	5.529658 $\cdot 10^{-6}$	0
n-Hydrogen	14 33	1.743678	–44.58217	0	2.253048 $\cdot 10^{-2}$	2.678964 $\cdot 10^{-5}$	0
p-Hydrogen	14 32	1.736035	–44.02651	0	2.210977 $\cdot 10^{-2}$	-1.847698 $\cdot 10^{-5}$	0
Tungsten hexafluoride	276 291	4.690	–1361.5	0	0	0	0
Xenon	162 270	5.818996	–790.3561	0	–8.375883 $\cdot 10^{-3}$	1.312938 $\cdot 10^{-5}$	0

10.6 Compressibility Factor

Table 10.6.-1: Real gas factors for compressed gases under the real pressure of 200 bar at temperatures between 0 and 30 °C.

Gas	**0 °C**	**10 °C**	**20 °C**	**30 °C**
Argon	0.913	0.930	0.944	0.956
Helium	1.106	1.102	1.098	1.094
Carbon monoxide	1.035	1.048	1.059	1.069
Krypton	0.656	0.689	0.722	0.753
Methane	0.757	0.787	0.813	0.837
Neon	1.094	1.093	1.093	1.092
Oxygen	0.913	0.931	0.947	0.960
Nitrogen	1.037	1.046	1.054	1.061
Nitric Oxide	0.776	0.800	0.824	0.850
Hydrogen	1.132	1.129	1.126	1.123

The values were taken from the gas handbook of (Messer Griesheim 1989) and were calculated according to the BWR-state equation. Exceptions are the details for helium, neon and nitrogen monoxide. Which were calculated using the details of the 2nd virial coefficients from the data sheets.

It must be pointed out that the real gas factors show minor differences when calculated using different methods.

10.7 Vapour Pressure over Ice

This table was produced using the formula according to (Sonntag 1990) see section 2.4.

Table T10.7-1: Vapour pressure over ice

T_{Frost} in [°C] at 1013.25 mbar	**$p_{D.Subl}$ in [mbar]**	**$C_{v.H2O}$ in [ppm] at 1013.25 mbar**	**$C_{abs.H2O}$ [mg · m^{-3}] Normal Conditions**
0	6.1115	6031.6210	4844.7
–10	2.5983	2564.3326	2059.7
–20	1.0324	1018.8904	818.4
–30	0.3800	375.0246	301.2
–40	0.1284	126.6910	101.8
–42	0.1022	100.8324	80.99
–44	0.08099	79.9336	64.20
–46	0.06394	63.1087	50.69
–48	0.05027	49.6174	39.85
–50	0.03936	38.8433	31.20
–52	0.03068	30.2751	24.32
–54	0.02380	23.4904	18.87
–56	0.01838	18.1418	14.57

Table T10.7-1: (*continued*)

–58	0.01413	13.9443	11.20
–60	0.01081	10.6656	8.567
–62	0.008224	8.1168	6.519
–64	0.006227	6.1451	4.936
–66	0.004689	4.6277	3.717
–68	0.003512	3.4659	2.784
–70	0.002615	2.5812	2.073
–72	0.001937	1.9112	1.535
–74	0.001425	1.4067	1.130
–76	0.001043	1.0290	0.826
–78	$757.8 \cdot 10^{-6}$	0.74792	0.601
–80	$547.2 \cdot 10^{-6}$	0.54009	0.434
–82	$392.5 \cdot 10^{-6}$	0.38740	0.311
–84	$279.6 \cdot 10^{-6}$	0.27595	0.222
–86	$197.7 \cdot 10^{-6}$	0.19515	0.157
–88	$138.8 \cdot 10^{-6}$	0.13700	0.110
–90	$96.7 \cdot 10^{-6}$	0.09544	0.0767
–92	$66.8 \cdot 10^{-6}$	0.06597	0.0530
–94	$45.8 \cdot 10^{-6}$	0.04522	0.0363
–96	$31.2 \cdot 10^{-6}$	0.03074	0.0247
–98	$21.0 \cdot 10^{-6}$	0.02072	0.0166
–100	$14.0 \cdot 10^{-6}$	0.01384	0.0111
–102	$9.27 \cdot 10^{-6}$	0.009156	0.00735
–104	$6.08 \cdot 10^{-6}$	0.006000	0.00482
–106	$3.94 \cdot 10^{-6}$	0.003893	0.00313
–108	$2.53 \cdot 10^{-6}$	0.002500	0.00201

10.8 Student Fischer Factor (t Distribution)

The following table was taken from the monograph by (Doerffel 1990). The t value is a function of the chosen probability W and the degrees of freedom f_{FG}.

Table 10.8-1: T distribution

W f_{FG}	**0.75**	**0.90**	**0.95**	**0.99**
1	2.41	6.31	12.7	63.7
2	1.60	2.92	4.30	9.92
3	1.42	2.35	3.18	5.84
4	1.34	2.13	2.78	4.60
5	1.30	2.01	2.57	4.03
6	1.27	1.94	2.45	3.71
7	1.25	1.89	2.36	3.50
8	1.24	1.86	2.31	3.36
9	1.23	1.83	2.26	3.25
10	1.22	1.81	2.23	3.17
11	1.21	1.80	2.20	3.11

Table 10.8-1: (*continued*)

12	1.21	1.78	2.18	3.05
13	1.20	1.77	2.16	3.01
14	1.20	1.76	2.14	2.98
15	1.20	1.75	2.13	2.95
16	1.19	1.75	2.12	2.92
17	1.19	1.74	2.11	2.90
18	1.19	1.73	2.10	2.88
19	1.19	1.73	2.09	2.86
20	1.18	1.73	2.09	2.85
25	1.18	1.71	2.06	2.79
30	1.17	1.70	2.04	2.75
40	1.17	1.68	2.02	2.70
60	1.16	1.67	2.00	2.66
∞	1.15	1.64	1.96	2.58

10.9 C-t Values of Toxicity

A look at the data sheets in chapter 9 makes it clear that some of the listed gases are very toxic. So it is understandable that questions should be asked about their relationship with chemical weapons. For this reason our thoughts go back to 22nd April 1915. This was the day when the Imperial German army under favourable wind conditions opened 5000 cylinders of liquefied chlorine. The result was approx. 6000 deaths on the Allied side.

The further development of military chemistry was determined by the production of special chemical substances, the milestones are as follows:

- The industrial production of sulfur yperite (2.2-dichlordiethylsulfide, mustard gas) by the German chemist Fritz Haber in 1916. It was first used on 12th July 1917 at Ypers by artillery fire.
- The production of the phosphorous organic chemical weapons tabun, sarin and soman in Nazi Germany. However, no chemical weapons were used in World War Two.
- The production of the phosphorous organic chemical weapon VX in the UK in 1952. The Iraqi government extensively used the VX chemical weapon in its own country against the Kurds.

The above-mentioned chemical substances are liquids, but not compressed or liquefied gases in the sense of this book. For chemical weapons, there are special requirements concerning physical and chemical characteristics.

- Liquids with sufficiently high vapour pressure.
- Sedentariness (adhesiveness) and low tendency to hydrolysis.
- Secure storage, preferably not under pressure.
- Usage in explosive missiles in order to achieve a large range and to minimise dependence on the wind.

Due to the physiological effect of chemical weapons. it is intended to produce not only an intake by inhaling (partially oral) but also by a percutaneous absorption.

To quantify the biological and medical consequences of exposure to chemical weapons the so-called concentration time product c t value, also known as the fatality product. was introduced. In a limited time period it is assumed that this product is a constant dependent on the substance and provides information about mortality. As most experimental examinations intend to produce a 50% mortality rate in the group of experimental animals. this has led to the development of a LC_{50} t value. Extrapolating this to human beings is done by comparing body weight and other special medical models of comparison with the experimental animals. There are different LC_{50} t values for the inhaling effect and the percutaneous effect. The usual unit for both is $mg \cdot min \cdot m^{-3}$. If one takes as an example 1000 $mg \cdot min \cdot m^{-3}$. then there would be the same effect for a concentration of 1000 $mg \cdot m^{-3}$ for one minute as for 100 $mg \cdot m^{-3}$ for 10 minutes.

According to the standard work by (Franke 1977) the constancy of the C t product only applies for relatively short exposure times. e.g. for hydrocyanic acid for a few minutes, for phosgene for about one hour. For small concentrations or longer exposure times the C t values are bigger. especially for substances which partially detoxify in the body. are excreated or only incompletely reabsorbed. The abovementioned hydrocyanic acid has an LC_{50} t value of 1000 for high concentrations. but 4000 for low concentrations.

In chapter 9 we assumed an exposure time of 1 hour for gases with an (inhalatory) LC_{50} value in ppm amounts or vol. ppm (there are only marginal differences!). We now intend to convert and so compare the values in military chemistry and in the data sheets. Here it is necessary to convert the value in ppm amounts to mg . m^{-3}. Analogous to Eq. (2.4-8) this applies fort he absolute moisture concentration.

$$\begin{aligned} LC_{50}\left[mg \cdot m^{-3}\right] &= \frac{LC_{50}\left[\nu - ppm\right] \cdot 10^{-6} \cdot M_{Mol}\left[g\right] \cdot 10^{3}}{V_{Norm}\left[l\right] \cdot 10^{-3}} \\ &= \frac{LC_{50}\left[\nu - ppm\right] \cdot M_{Mol}\left[g\right]}{22.4138\left[l\right]} \end{aligned} \tag{10.9-1}$$

Dividing by 60 produces the LC_{50}t value.

$$\left(LC_{50}\text{–t–Wert}\right) = \frac{(LC_{50}/1h) \cdot M_{Mol} \cdot 1000}{22.4138 \cdot 60}\left[mg \cdot m^{-3} \cdot min\right] \tag{10.9-2}$$

Phosgene’s very different LC_{50} t values show that this table is only suitable for estimating the amount of toxicity!

Table T10.9-1: Inhalatory LC_{50} t values.

Substance	**TLV [ppm]**	**LC_{50}/1h [ppm]**	**LC_{50} t values in [mg · m^{-3} · min]**	
VX				10[1]
Soman			80[2]	35–50[1]
Sarin			150[2]	75–100[1]
Tabun			450[2]	150–400[1]
S-Yperit (Senfgas, Mustard Gas)			1,500[2]	1,500[1]
Chlorcyan			4,000[2]	
Arsin	0.05	20		1,200[3]
Phosgen	0.1[4]	5	5,000[2]	400[3]
Chloracetophenon			8,500[2]	
Diphenylchlorarsin			15,000[2]	
Chlorpikrin			20,000[2]	
Chlor	0.5	293		14,500[3]

[1] From the internet 2003

[2] According to (Franke 1977)

[3] Calculated from the LC_{50}

[4] MAK value (Germany): 0.02 ppm

10.10 Marking Gas Cylinders

The European norm EN 1089 provides compulsory regulations for marking gas cylinders in Europe. Marking gas containers with different colours and forms in medicine and industry in different countries was regarded to be an increasing risk and therefore from 1997 a single system was developed. The individual parts are:

- Stamping the cylinder
- Precautionary labels
- Colour coding

To introduce these regulations in each country. there was a long deadline until 2006.

Other regulations apply in the USA and Canada which will be dealt with in the individual descriptions.

10.10.1 Precautionary Labels

The only compulsory marking of the gas content is on the precautionary label. (ISO 7225 2005)

- Precautionary labels shall be in accordance to the United Nations Recommendations on the transport of dangerous goods as (ADR 2001) or other applicable regulations.

- Precautionary labels shall be designed. attached and maintained so they are clearly visible and legible.

Precautionary labels shall consist of two components:

a) a diamond-shaped part or parts. i.e. a primary hazard label and – in cases where two or three kinds of hazard require identification – one or two subsidiary hazard labels
b) a panel.

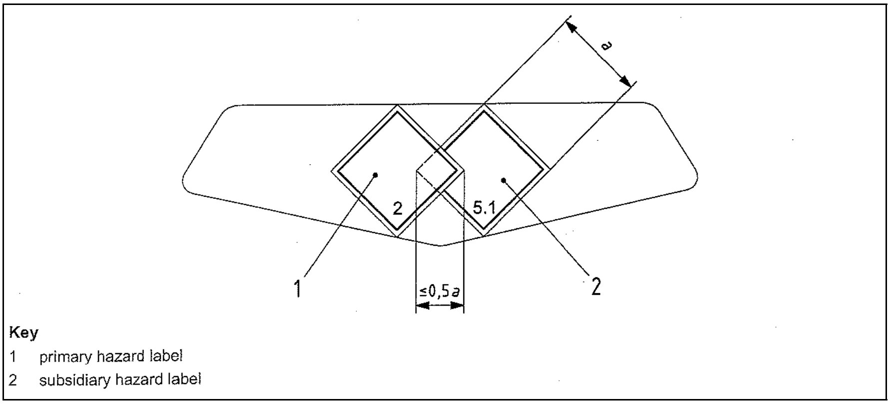


Illustration P10.10.1-1: Example of primary and subsidiary hazard label and panel (ISO 7225 2005)

Here are two examples from Europe.

Example E10.10.1-1: Germany

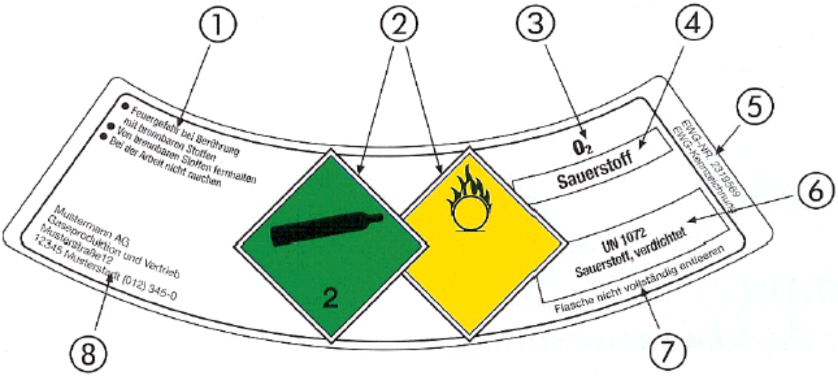
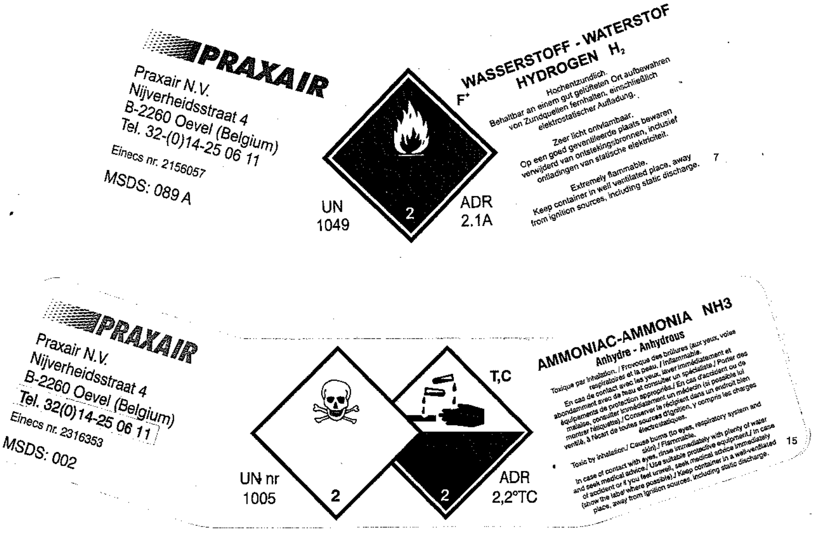


Illustration P10.10.1-2: Precautionary label “oxygen” of Linde AG. publication (IGV/Linde 1997)

Example E10.10.1-3: Belgium



PRAXAIR

Praxair N.V.
Nijverheidsstraat 4
B-2260 Oevel (Belgium)
Tel. 32-(0)14-25 06 11
Einecs nr. 2156057
MSDS: 089 A

UN
1049

2

ADR
2.1A

F+

WASSERSTOFF - WATERSTOF
HYDROGEN H_2

Hochentzundlich.
Behaltbar an einem gut gelüfteten Ort aufbewahren von Zundquellen fernhalten, einschließlich elektrostatischer Aufladung.

Zeer licht ontvlambaar.
Op een goed geventileerde plaats bewaren verwijderd van ontstekingsbronnen, inclusief ontladingen van statische elektriciteit.

Extremely flammable.
Keep container in well ventilated place, away from ignition sources, including static discharge.

7

PRAXAIR

Praxair N.V.
Nijverheidsstraat 4
B-2260 Oevel (Belgium)
Tel. 32(0)14-25 06 11
Einecs nr. 2316353
MSDS: 002

UN nr
1005

2

2

T,C

ADR
2,2°TC

AMMONIAC-AMMONIA NH3
Anhydre - Anhydrous

Toxique par inhalation. / Provoque des brûlures (aux yeux, voies respiratoires et la peau. / Inflammable.
En cas de contact avec les yeux, laver immédiatement et abondamment avec de l'eau et consulter un spécialiste./ Porter des équipements de protection appropriés./ En cas d'accident ou de malaise, consulter immédiatement un médecin (si possible lui montrer l'étiquette)./ Conserver le récipient dans un endroit bien ventilé, à l'écart de toutes sources d'ignition, y compris les charges électrostatiques.

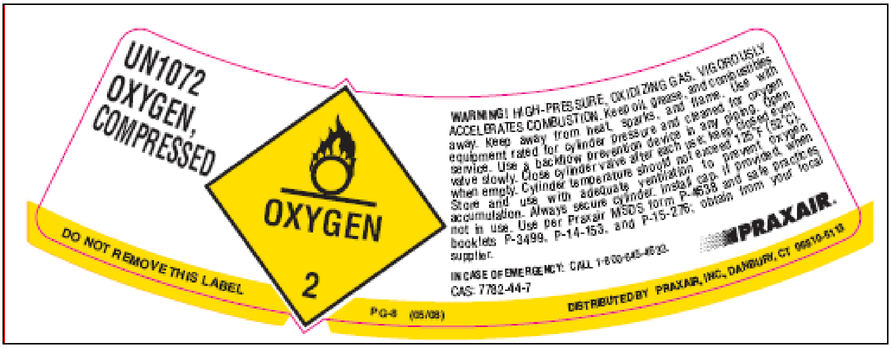
Toxic by inhalation./ Cause burns (to eyes, respiratory system and skin)./ Flammable.
In case of contact with eyes, rinse immediately with plenty of water and seek medical advice./ Use suitable protective equipment./ In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible)./ Keep container in a well-ventilated place, away from ignition sources, including static discharge.

15

Illustration P10.10.1-3: Precau*ti*onary labels "hydrogen" and "Ammonia" of Praxair N.V.

In North America (USA and Canada) Oxygen labels do not require 2 diamonds as in Europe.

Example E10.10.1-4: Precautionary label "oxygen" in USA



UN1072
OXYGEN,
COMPRESSED

OXYGEN

2

WARNING! HIGH-PRESSURE, OXIDIZING GAS. VIGOROUSLY ACCELERATES COMBUSTION. Keep oil, grease, and combustibles away. Keep away from heat, sparks, and flame. Use with equipment rated for cylinder pressure and cleaned for oxygen service. Use a backflow prevention device in any piping. Open valve slowly. Close cylinder valve after each use; keep closed even when empty. Cylinder temperature should not exceed 125 °F (52 °C). Store and use with adequate ventilation to prevent oxygen accumulation. Always secure cylinder. Install cap, if provided, when not in use. Use per Praxair MSDS form P-4638 and safe practices booklets P-3499, P-14-153, and P-15-276; obtain from your local supplier.

IN CASE OF EMERGENCY: CALL 1-800-645-4633.
CAS: 7782-44-7

PRAXAIR.

DO NOT REMOVE THIS LABEL

PG-6 (05/08)

DISTRIBUTED BY PRAXAIR, INC., DANBURY, CT 06810-5113

Illustration P10.10.1-4: Precautionary label "oxygen" of Praxair, Inc./USA

10.11 Gas Cylinders – Colour Coding

Colour coding is covered in Europe by (EN 1089-3 1997) published in February 1997.

Colour coding applies solely to the shoulder. or curved part. at the top of the cylinder and is used to identify the properties of the gas in the cylinder. A number of gases have assigned a specific colour and these are shown below. Where a gas does not have a specific colour. the properties of the gas are indicated. Two concentric bands may be used where a gas has more than one property. or the two colours may be painted in quarters around the shoulder is preferred.

Table 10.11-1: Colour classification by hazard property and for specific gases.

Gas type	Colours	RAL (colour number)
Inert	Bright green	6018
Argon (Ar)	Dark green	6001
Carbon dioxide (CO_2)	Grey	7037
Nitrogen (N_2)	Black	9005
Oxidising	Light blue	5012
Oxygen (O_2)	White	9010
Nitrous oxide (N_2O)	Blue	5010
Flammable	Red	3000
Hydrogen (H_2)	Red	3000
Acetylene (C_2H_2)	Maroon colour	3009
Toxic and/or corrosive	Yellow	1018
Chlorine (Cl_2)	Yellow	1018

RAL number refer to the register RAL 840 HR. obtainable from RAL. Siegburger St. 39. D-53757 Sankt Augustin. Germany.

There is no colour coding in the USA or Canada for industrial gases. Medical gases have colour coding as prescribedby the FDA

The CGA has made a strong point in both the USA and Canada: "It has long been and continues to the CGA's position that best means to identify the content of any gas cylinder is by some form of the printed word. This is why CGA recommends the use of product labels or tags affixed to be shoulders of compressed gas cylinders at the time of filling to indicate the content."

So. the gas manufacturer can paint the cylinder any colour they choose.

10.12 Cylinder Valve Outlets

10.12.1 Filling Pressure 200 Bar

In the 20th century national connection systems for filling pressure up to 200 bar were used in many countries.

Example E10.12.1-1: German norm for valve connections up to 200 bar

The construction measurements and the side thread connections of the cylinder valves are regulated in the (DIN 477-1 1990) for operating pressure up to 200 bar. Under normal circumstances conical threads are used as screw threads for connection with the pressure gas container with a nominal size of 19.8 mm for small cylinders. 28.8 mm for normal 10l to 50l cylinders and 31.3 mm for acetylene cylinders. The outlet connections are numbered and can be taken from the following table.

Table T10.12.1-1: Cylinder valve outlets in Germany with service pressure of 200 bar

Number	Nominal size	thread	Typical gases
1	28.8 19.8	W 21.8x1/14" LH	H_2. C_nH_m. flammable HC´s . PH_3 . SiH_4 . flammable or otherwise non-classifiable gas mixtures
2	19.8	W 21.8x1/14" LH	n- and i-Butane. Propane in container with $V_{geom} \leq 33$ l
3	31.3	Outlet with tension arm	Acetylene (dissolved)
4	19.8	G 3/8" LH	Acetylene (dissolved). n- and i-Butane. Propane in containers with $V_{geom} \leq 1$ l
5	28.8 19.8	1" LH	CO. H_2S. dichlorsilane. cyanogen. methylmmercaptane. cyanogen
6	28.8 19.8	W 21.8x1/14"	Rare gases. NH_3 . nonflammable HC´s. CO_2. SF_6 . mixtures with $O_2 \leq 20$ Vol.-% in rare gases or N_2
7	28.8 19.8	G 5/8"	SO_2
8	28.8 19.8	1"	F_2 . Cl_2 . BCl_3 . BF_3 . HBR. HCl. NO. NF_3 .WF_6 . chlo-ro cyanogen. bromoethene
9	28.8 19.8	G ¾"	O_2 . mixtures with $O_2 > 20$ Vol.-% in rare gases (no Xe). N_2 or CO_2
10	28.8 19.8	W 24.32x1/14"	N_2 . mixtures with $O_2 \leq 20$ Vol.-% in N_2
11	28.8 19.8	G 3/8"	N_2O
12	19.8	G ¾" Internal thread	N_2O in $V_{geom} \leq 3$ l
13	28.8 19.8	G 5/8" Internal thread	Compressed air
14	28.8 19.8	M 19x1.5 LH	Calibration gases. $O_2 \leq 20$ Vol.-% (No.9)
15	28.8 19.8	W 21.8x1/14" internal	Mixtures propene- propadiene

W = Withworth-thread. G = cylindric gas pipe thread (in inch). M = metric thread.

10.12.2 Filling Pressure 300 Bar

Towards the end of the 20th century increasing demands were made.

- Introduction of an internationally valid standardisation of cylinder valve connections
- To enable filling pressure up to 300 bar.

The international norm (ISO/FDIS 5145 2002) was introduced which is frequently taken over in the national legal system. e.g. in Germany (DIN477-5 2002).

The following referenced documents are indispensable for the application for the ISO/FDIS 5145:

- ISO 286-1. 1988: ISO system and fits - part 1: bases of tolerances deviations and fits.
- ISO 286-2. 1988: ISO system and fits - part 2: tables of standard grades and limit deviations for holes and shafts.
- ISO 10156. 1996: Gases and mixtures – determination of the potential and oxidising ability for the selection of cylinder valve outlets.
- ISO 10286. 1996: Gas cylinders – terminology.
- ISO 10298. 1995: Determination of toxicity of gas and gas mixture.
- ISO 13338. 1995: Determination of tissue corrosiveness of a gas or gas mixture.

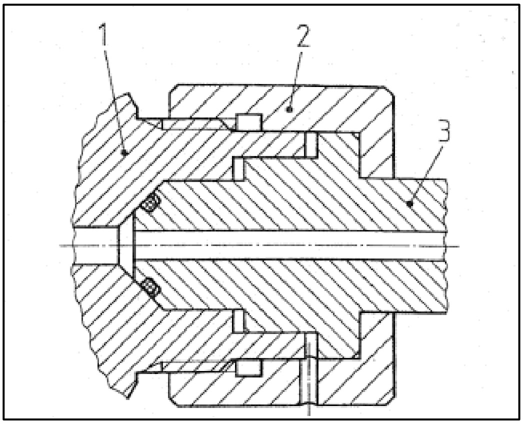


Illustration P10.12.2-1: Cross-section of a outlet connection for the operating pressure of 300 bar. as per (ISO/FDIS 5145 2002). Explanation: 1 valve body. 2 connecting nut. 3 gland or “nipple”. As can be seen. there are three diameters at the gland. The external is 27 mm and supported by the thread W 30x2. and so it does not change. The two others provide a multiplicity of combination possibilities. In this example the extraction support is sealed against the valve body by an O ring made of elastomers.

Table T10.12-2: Side connections of bottle valves with operating pressure up to 300 bar. The nominal measurements of the conical screw threads are 28.8 and 19.8 mm.

Number	Thread	Diameter graduation	Gases and gas mixtures with their characteristics
54	W 30x2	15.9 / 20.1	Non-inflammable. non-toxic. non-oxidising
55	W 30x2	15.2 / 20.8	Non-inflammable. toxic and/or corrosive
56	W 30x2	16.6 / 19.4	Compressed air
57	W 30x2 LH	15.2 / 20.8	Flammable. non-toxic
58	W 30x2 LH	15.9 / 20.1	Flammable. toxic. corrosive(acidic) or non- corrosive
59	W 30x2	17.3 / 18.7	Oxidising. non-toxic. non- corrosive Oxygen
60	W 30x2	18 / 18	Oxidising. toxic and/or corrosive

10.12.3 DISS Connections

The micro electronic industry sets very high demands for gases and therefore it is necessary to use a more suitable seal to connect the outlet connection and the gland. The often tested VCR seal was chosen. This seal was integrated into the outlet supports. There is the international norm (EN ISO/FDIS 10692 2001).

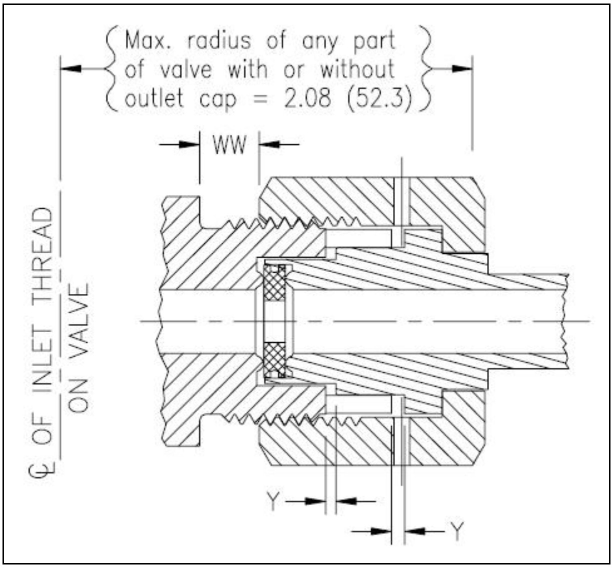


Illustration P10.12.3-1: DIS connection. also known as “UHP CGA” (ultra high purity compressed gas association (USA). as per (EN/FDIS 10692 2001).

Table T10.12-3: DIS connections. The diameter graduation shows only the admissible maximum values.

Number	Valve external thread*)	Diameter graduation in [mm]	Gases allocated
632	d = 1.030“ = 26.162 mm	16.58 / 20.32	AsH_3 . B_2H_6 . Si_2H_6 . GeH_4 .PH_3 . SiH_4 . $SiH(CH_3)_3$
634	„	16.94 / 19.96	BCl_3 . HBr. HCl
636	„	17.30 / 19.61	SiH_2Cl_2 . $SiCl_4$. $SiHCl_3$
638	„	17.65 / 19.25	HF. WF_6 .
640	„	18.00 / 18.89	NF_3
642	2	18.36 / 18.36	BF_3 . SiF_4 . As_2F_5 . PF_5 . GeF_4
712	d = 1.125“ = 28.575 mm	16.58 / 22.52	N_2O
714	„	16.94 / 22.17	O_2
716	„	17.29 / 21.81	CO_2 . FCKW. SF_6
718	„	17.65 / 21.46	Rare gases. N_2
720	„	18.00 / 21.10	NH_3
722	„	18.36 / 20.75	H_2S
724	„	18.71 / 20.39	CO. H_2 . CH_3F. CH_2F_2 . CH_4
726	„	19.07 / 20.04	$Al(C_2H_5)_3$. $Te(C_2H_5)_2$. $Zn(C_2H_5)_2$
728	„	19.43 / 19.43	Cl_2 . ClF_3 . NO

*) Shown is the nominal diameter in inches. flank angle 60^0.
Inclination 1/14“. only right-hand thread!

10.13 Initials for CFCs

If an insider looks at the description of a gas of type R134a. he will realize that this is 1.1.1.2 tetra fluoro ethane $CF_3 - CH_2F$ with the total formula $C_2H_2F_4$. For encryption in the R134a (Ashrae 34 2001) apply as well as other national documents. e.g. in Germany (DIN 9860 1998).

10.13.1 Carbon Compounds

The initials allocated to the HC’s and CFC’s are so created to enable the structure of the compounds to be unequivocally derived. The following rules apply:

a) The first figure from the right gives the number of fluoride atoms (F).
b) The second figure from the right is 1 larger than the number of hydrogen atoms (H)
c) The third figure from the right is 1 smaller than the number of carbon atoms (C). If the compound only contains one carbon atom then the resultant “0” is not written.

d) The number of chlorine atoms (Cl) contained in the compound is calculated by deducting the sum of the fluorine and hydrogen atoms from the total amount of the atoms which can be bound by the carbon atoms.

Table 10.13.1-1: Total number of bound atoms

Unsaturated carbons	Simple unsaturated and cyclically saturated carbons
4 atoms for 1 C	4 atoms for 2 C
6 „ „ 2 C	6 „ „ 3 C
8 „ „ 3 C	8 „ „ 4 C
10 „ „ 4 C	10 „ „ 5 C
(2n+2) „ „ n C	2n „ „ n C

e) The cyclical derivatives are designated by the letter C before the cooling agent code number (example RC318 follows below)

f) If the compound contains bromine (Br) the same rules apply with the exception that the letter B behind the code number for the hydrogen and fluorine amounts indicates the presence of bromine. The number after the B shows the number of bromine atoms. example is R13B1.

g) When calculating the code number using (d) it is necessary to be aware of the fact that the number of chlorine atoms decreases by the number of bromine atoms.

h) The isomers of the ethane and propane groups all have the same code number. whereby the most symmetrical isomer is only designated by the number. As the asymmetry increases the isomers are designated by adding the letters a. b. c. etc.

i) The same rules apply for unsaturated organic compounds with the exception that 1 is used as the fourth figure from the right when there is a double bond.

Other representations use a mathematical formula.
Assuming $C_xH_yCl_nF_z$ then R(x–1) (y+1)(z) is formed

$$C(x-1)\cdot H(y+1)\cdot F(z) \tag{10.13-1}$$

Example 10.12.1-1: Decryption of RC318. Decryption follows from the right.

- *8* $\rightarrow$ *(z).* $\rightarrow$ F_8
- *1* $\rightarrow$ *(y+1). y=0. so no H*
- *3* $\rightarrow$ *(x–1)=3 . x=4* $\rightarrow$ C_4
- *C stands for cyclo*
- *One obtains* C_4F_8*. the octofluorcyclobutane.*
- *Testing for Cl: the formula* C_4F_8 *needs no Cl atoms when the four-way carbon ring is taken into consideration.*
- *It is different with R318:* $C_4Cl_2F_8$ *(octofluordichlorbutane). as 4 C atoms bond to 10 atoms of fluorine or chlorine.*

10.13.2 Azeotropic and Non-azeotropic Mixtures

Azeotropic mixtures are allocated numbers in the series 500 and non-azeotropic mixtures are allocated numbers in the series 400.

Example E10.12.2-1:

- *R500: R12 / R152a* $CCl_2F_2 + CF_2HCH_3$
- *R401A: R22 /R152a / R124* $CHClF_2 + CHF_2CH_3 + CF_3CHClF$

10.13.3 Various Organic and Inorganic Compounds

The series 600 is allocated to organic compounds which are not contained in 10.13.1.

The series 700 is allocated to inorganic compounds. Here the molar mass (rounded up to a whole number) is added to 700.

Example 10.13.3-1: 700 series

- *Water R718. as molar mass* $H_2O = 18$
- *Argon R740*

Symbols and Abbreviations

Symbol, Abbreviation	**Content, Meaning**
$\tilde{\lambda}$	wave length
$\tilde{\nu}$	wave number
α	gas expansion coefficient
β	2.virial coefficient
γ	3.virial coefficient
ε	molar heat capacity ratio
η	dynamic viscosity coefficient
λ	thermal conductivity
ν	number of moles, amount of substance
σ	experimental standard deviation
τ	tube-friction factor
φ	density, general in $kg \cdot m^{-3}$ or $lb \cdot ft^{-3}$
ψ	reflux ratio (rectification)
ω	circular frequency, angular velocity
σ^2	variance
σ_B	standard deviation method B (assignment)
σ_{komb}	combined standard deviation
σ_{rel}	RSD (relative standard deviation)
φ_{bulk}	bulk density
ΔC	analysis error, uncertainty of measurement, also concentration difference
ΔC^*	expanded uncertainty
φ_{Cr}	critical density (gas), gas density at critical point
Γ_G	surface coverage of gas G
$\varphi_{G,ideal}$	ideal gas density at STP
$\varphi_{G,liq}$	density of liquefied gas G at T and p

$\varphi_{G,Mol}$	molar density of gas G
$\varphi_{G,p,T}$	density of gas G at p and T
$\varphi_{G,STP}$	density of gas G at STP
δ_{Henry}	Henry coefficient of solubility
ΔH_{vap}	enthalpy of vaporization
ΔH_{Subl}	sublimation enthalpy
δ_{Perm}	solubility coefficient by permeation
$\delta_{techn.}$	technical solubility coefficient
a	year
A	plane, area
A.H.	Absolute humidity
AAS	Atomic adsorption spectrometer
amu	Atomic mass unit
APIMS	Atmospheric Pressure Ionization Mass Spectrometer
ASU	Air Separation Unit
BET	Brunner-Emmer-Teller isotherm
BS	Bursting disc, rupture disc
C	heat capacity
C	concentration, general
$C_{v,G}$	molar concentration of gas G in mixture
$C_{v,G,sol}$	molar concentration of dissolved phase of gas G
$C_{v,H2O}$	molar concentration of water vapour in gases under 1013.25 mbar (14.7 psi)
$C_{abs,H2O}$	absolute humidity (A.H.)
C_{light}	speed of light in vacuum
$C_{M,G}$	mass concentration of gas G in mixture
$C_{V,G}$	volume concentration of gas G in mixture
c_W	drag coefficient
CFC	chlorofluorocarbon
CLD	chemo luminescence detector
C-V	check valve
d	Diameter
d_a	outer diameter

D	diffusion coefficient
d_{Cri}	critical pore diameter in adsorption
d_{Por}	pore diameter of adsorbent
D_{Thermo}	thermal diffusion coefficient
DM	Pressur regulator
DN	Nominal diameter
DOT	Department of Transportation (USA)
E	energy (general)
E_m	Root mean sqare energy of particle Average kinetic energy
E_{pot}	Potential energy of a molecule or atom
Eq., Eqs	Equation, -s
EPA	Environmental Protection Agency (USA)
f	mathematical function (general)
F	power (general)
$f_{Analysis}$	analysis function
f_{FG}	number degree of freedom
f_{fill}	filling density
f_{Freq}	frequency
$F_{friction}$	Friction force
FDA	Federal and Drug Administration (USA)
FID	Flame ionization detector
FP	Liquid-pump (pump for liquefied gases)
F-V	Filling valve
g	acceleration (general)
g_{earth}	earth acceleration
G	indices (or subscript) for gases
GC	Gas chromatography
G_R	purity = content = concentration
GHCV	Gaseous hourly space velocity (ν_v)
GLP	Good laboratory practice
GMP	Good manufacturing practice
GUM	Guide to the expressions of uncertainty in measurement
h	Planck constant
H	enthalpy

H_{energy}	energy value
H_{heat}	heating value
HC	Hydrocarbon (=C_nH_m)
I	numerical subscript
I	electrical current
I_{mv}	Impulse
IC	Ion chromatography
ICP	Inductively coupled plasma
j	numerical subscript
k	numerical subscript
k	constant (general)
K, C	capacity (general)
$K_{AM,G}$	adsorption capacity, gas G, adsorbent AM
$k_{Avogadro}$	Avogadro constant
$k_{Boltzmann}$	Boltzmann constant
$k_{Faraday}$	Faraday constant
k_W	coverage (uncertainty) factor by confidence W
l	numerical subscript
L	leakage rate (at normal pressure)
L_p	Pressure leakage rate,
L_{vac}	Vacuum leakage rate
Ld, $\log_2$, lg	binary logarithm
Lg, log, $\log_{10}$	decimal logarithm
ln	natural logarithm
LEL	Lower explosion limit
LOD	limit of detection
m	numerical subscript
M	mass (general)
M1, M2, …	Manometer with number
$M_{G,Mol}$	molar mass (molecular weight), gas G
M_{ads}	Mass of adsorbence
$M_{particle}$	Mass of one molecule or atom
M_{cat}	Mass of catalyst
MAWP	Maximum allowable working pressure (=p_{plant})

MFC	Mass flow controller
MOP	Maximum operating pressure(USA) (= p_{work})
n	numerical subscript
NDIR	Nondispersive Infrared Spectrometry
NIR	Near Infrared Spectrometry
OECD	Orgnisation of Economic Cooperation and Development (EC)
$n_{particle}$	number of particles
p	pressure (absolute or gauge)
P	specific permeability
p_{Cri}	critical pressure (abs.)
p_{plant}	Pressure of plant (filling station) USA: MAWP (maximum allowable working pressure), EC: PS (maximum allowable pressure)
p_{sat}	saturation vapour pressure
p_{stand}	standard pressure (abs.) = 1013.25 mbar (=14.7 psi)
$p_{service}$	Service pressure of cylinder
p_{Tri}	pressure at the triple point
p_v	vapour pressure (abs.)
$p_{v,Ads,G}$	saturation pressure(abs.) of adsorbate , gas G
PS	Maximum allowable pressure (EC) (= p_{plant})
PDID	Pulsed discharge ionization detector
PN	Nominal pressure
Q	quantity product per unit of time, quantity flow
Q_{bottom}	Bottom product quantity per unit of time
$Q_{D,}$ Q_v	vapour quantity per unit of time
Q_{electr}	electrical charge
Q_{input}	Rough product quantity per unit of time, input flow
$Q_{liq,output}$	product quantity liquid per unit of time
$Q_{liq,reflux}$	reflux flow per time
Q_M	mass flow dM/dt
Q_{output}	Output product quanity per unit of time, Output flow
Q_V	volume flow dV/dt at STP

r	radius
Ra	roughness height
Re	Reynolds number
RMS	Root mean square (=v_m)
RSD	Relative standard deviation
R-V	Control valve
R_G	special gas constant, gas G
R_{Mol}	molar universal gas constant
R_{MS}	resolution of mass spectrometer
s	length, path (general)
S	Entropy
SCF	Standard cubic foot (USA)
S/N	signal to noise ratio
Si-V	Safety valve
$s_{particle}$	mean free path
STP	standard temperature and pressure
t	time (general)
T	temperature in K or °C or °F
TCD	Thermal conductivity detector
THC	Total hydrocarbons (= C_{CnHm})
TLV	Threshold limit value
TS	Maximum/minimum allowable temperature (EC)
$t(W,f_{FG})$	T – distribution (Student-Fischer-statistics)
T_{bp}	boiling point at 1013,25 mbar (14.7 psi)
T_{cri}, T_{kri}	Critical temperature
T_{dew}	dew point temperature (vapour above liquid)
t_{dwell}	dwelling time (general, residence time))
T_{Frost}	frost point (freezing point) temperature
t_{HW}	Half-life (radioactivity)
T_{mp}	melting point
$t_{resorption}$	Resorption time
$t_{R,G}$	retention time of gas G in gas chromatography
T_{stand}	standard temperature = 0 °C
T_{Subl}	sublimation temperature at 1013.25 mbar (14.7 psi)

T_{Tri}	temperature at the triple point
U	internal energy of a thermodynamic system
UEL	Upper explosion limit
UV/VIS	UV/visible spectrum
U_{elektr}	electrical voltage
v	velocity (general)
V	volume (general)
V1, V2	Valve with number
Va	Valence number
VIM	International vocabulary of basics and terms in metrology
VP	Vacuum pump
$V_{G,Mol}$	molar volume of gas G, T and p to be indicated
$V_{G,STP}$	volume of gas G at STP
V_{geom}	geometric volume
v_{lin}	linear velocity
v_m, v_{rms}	root mean square velocity
v_{Reak}, v_{react}	reaction rate
$V_{reference}$	Volume at r4ference conditions
V_{STP}	molar volume of the ideal gas at STP
v_V	space velocity or inverse residence
w	electron valency
W	probability $0 < W < 1$
WCOT	Wall coated open tubular (GC)
X_i , Y_i	measurements
z	ion valence, charge number of ions
$Z_{p,T}$	compressebility factor
$Z_{reference}$	Compressibility factor at reference conditions

Subject Index