

Experimental research on benzene detection using ion mobility spectrometer with a laser ionization source

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An ion mobility spectrometer equipped with a laser ionization source is used for the sensitive detection of benzene. Mobility spectra of the benzene are presented. We also discussed the mobility spectra at various concentrations and drift voltages. Detection limits are determined to be in the upper ppb, range. In the end, the advantages and possibilities of this technique are briefly discussed.

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Benzene and its derivatives in polluted air are supposed to be carcinogenic agents for human beings. Many research institutions in some countries have been developing high sensitive detecting methods for benzene during last several decades^[1,2]. Monitoring may be accomplished using several analytical approaches such as ion mobility spectrometers. A simple method for the fast determination of benzene is described in this paper, which uses an ion mobility spectrometer with a laser ionization source.

Ion mobility spectra(IMS) was introduced in the early 1970s^[3], and its major industrial and environmental applications are the monitoring of toxic chemicals, stack gases and chemicals that are considered hazardous to man or to the environment. More recently, the number of applications in industry and environment has increased, not only because of the simplicity of the instrumentation but also due to the excellent lower detection limits in the range of some mg/l or sometimes down to ppb,^[4-6].

The most commonly used spectrometers are equipped with ⁶³Ni ionization sources^[7]. Besides the radioactive ionization sources, other sources like photo-ionization, corona or partial discharges, electrospray ionization and flames have become increasingly popular^[8-10]. However, despite the rising number of regulatory requirements which go along with the use of radioactive material, no non-radioactive ionization source has so far managed to phase out ⁶³Ni sources, mainly because of their unique combination of simplicity, unsurpassed long-term stability and robustness. However, the application of IMS in environmental analysis is up to now mainly restricted to the analysis of more or less volatile contaminants. We are developing a laser-based IMS technique, in which an excimer laser (in the UV-spectral region, KrF, PSX-100, $\lambda=248$ nm) will be used as the ionization source.

Ion mobility is characteristic of substances and can

provide a means for detecting and identifying vapours. The mobility of an ion ($K, \text{cm}^2 \text{s}^{-1} \text{V}^{-1}$) is determined by the velocity ($V_d, \text{cm}^2 \text{s}^{-1}$) attained under the influence of an electric field gradient ($E, \text{V cm}^{-1}$) in the presence of a drift gas. By measuring the drift time t_d which ions need to overcome the distance L between the shutter grid and the detector (a Faraday plate), mobilities K are determined according to Eq. (1):

$$K = \frac{L}{t_d E} \quad (1)$$

where L is the length of ion drift region, t_d is the drift time.

Ion mobility is related to the experimental conditions and the analyte is characterized by the simplified equation^[11]:

$$K = (3e/16N)(2\pi/\mu k T_{eff})^{1/2} [(1 + \alpha)/\Omega_D(T_{eff})] \quad (2)$$

Where e is the ion charge, N is the number density of the drift gas, μ is the reduced mass of the ion defined as $\mu = m * M / (m + M)$, m is the mass of the ion, M is the mass of the neutral molecule, k is the Boltzmann constant, T_{eff} is the temperature of the drift gas, α is a correction factor which is generally less than 0.02 for $m < M$, and Ω_D is the collision cross section of the ion which depends on the effective temperature. The mobility of an ion at a given drift gas pressure and temperature is therefore determined by the reduced mass, charge and collision cross section of the ion. The drift velocity is related to the electric field strength by the mobility. Therefore, the mobility is proportional to the inverse drift time, which will be measured at fixed drift length. Theoretical considerations deliver that the mobility has a relation to the collision rate with the gas molecules (reduced mass), the temperature, the dimensions of the ion (structure dependencies) and the collision integral. The collision integral is influenced by the size of ions or molecules, their structure and polarisability. If the same drift gas is used, the mobility is largely controlled by the re-

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duced mass. In case of very large ions μ is in the range of M . In this case the mobility depends on the collision integral, which is influenced by the ion structure. Therefore, a dependence of ion mobility values on mass and structure is observed commonly, like linear < branched, primary < secondary < tertiary, aliphatic compounds < aromatic compounds and amines < amides^[12].

A schematic diagram of the measurement system is shown in Fig. 1, which consists of a unit for sample preparation, an IMS and a data acquisition system. The drift tube of IMS is constructed from stainless steel and Teflon.

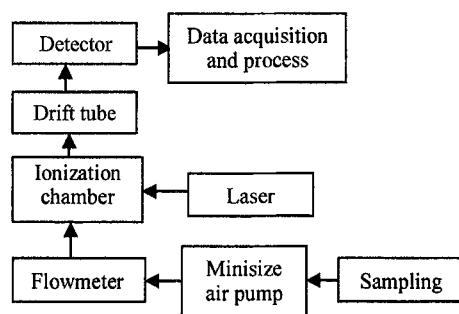


Fig. 1 Schematic diagram of the experimental detection system

Ion mobility spectrometers consist of three parts, namely an ionization region, a drift region separated from that by an ion gate (shutter grid), and an ion detector (Faraday plate). Gaseous samples are transported by a carrier gas into the ionization region, where carrier gas molecules are ionized by laser. So-called reactant ions are created which undergo a series of reactions with molecules of the analyte to generate product ions. Directed by an electric field E , the ions travel towards the ion gate that periodically opens to permit a swarm of ions to enter the drift tube. While colliding with a counterflow of uncharged drift gas molecules, the ion swarm is separated into small clouds of ions according to their individual mobilities. Spectra were collected by a TDS 3054B Digital Phosphor Oscilloscope (America Tektronix Co.) and stored in the computer with the help of special software (escape).

Using the IMS equipped with a laser ionization source, the mobility spectra of benzene was acquired as shown in Fig. 2.

In the first experiment we changed the drift voltage of the drift tube and the effect on the reactant ion peaks (RIP) as shown in Fig. 3. The anticipated behavior was observed, i. e. ion speed increased with increasing electric field, and the signal intensity increases with the increasing of drift voltage. The results of Fig. 3 suggest that the gas phase chemistry is comparatively simple when ions move rapidly through the drift region. However, as the

ions are allowed to move slowly through the drift tube, the chemistry becomes more complex. This suggests that formation for new ions occurs on the same time scale as drift time and provides an early indication that one overlooked facet of analytical IMS; namely, the time of residence of ions in the drift tube. In short, ion separation in IMS can be attributed not only to diffusion but to drift tube reactions that are dependent directly upon residence time and indirectly on electric field via Equation (1).

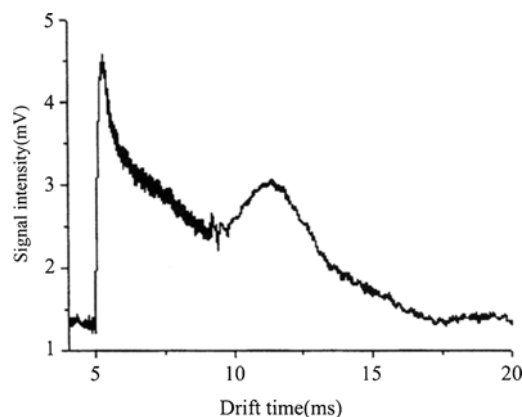


Fig. 2 Ion mobility spectrometry of benzene

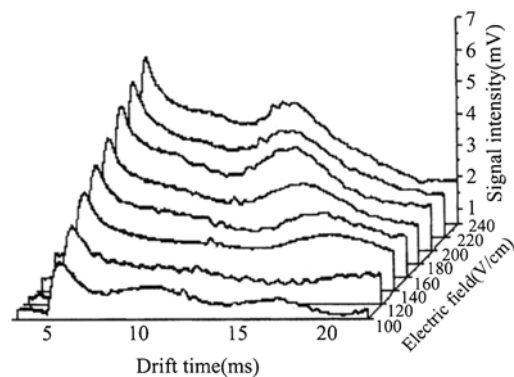


Fig. 3 Effect of electric field on signal intensity of benzene

The ion mobility spectra of benzene were obtained in a concentration range of magnitude between 100 ppb, and 20 ppm. Fig. 4 shows the spectra at various concentrations. From the figure we get the conclusion that the signal intensity of benzene increases with the increasing of concentration. The figure also shows that the value of 100 ppb, is not the limit of detection, and the lower concentration is still attainable.

An IMS system with a laser ionization source was presented. The experimental results of the system used to detect traces of benzene have been discussed. It has been shown that ion mobility spectrometry using laser ionization sources is a useful detector of benzene. Never-

theless the use of IMS with laser ionization source leads to an increase in the scope of application. They provide linear ranges of response over at least two orders of magnitude with the characteristic mobilities staying constant. With detection limits down to the upper ppb range, IMS could provide a cheap and easy operating tool for the rapid detection of benzene.

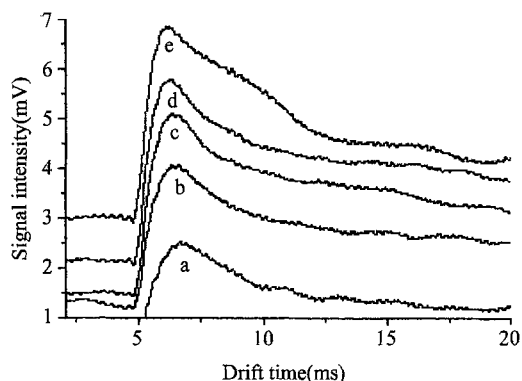


Fig. 4 Ion mobility spectra for benzene in a concentration range between 100 ppb and 20 ppm. a: 100 ppb; b: 400 ppb; c: 700 ppb; d: 1 ppm; e: 20 ppm

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