Starter batteries

The starter battery is an electrochemical storage facility for the excess electrical energy that is generated by the alternator while the engine is running. This stored energy is needed during vehicle operation in the phases when the energy required by the active consumers is greater than the energy that is generated by the alternator (e.g. at idle speed). The battery also provides the energy that is required by the electrical consumers when the engine is stopped and for starting the engine. The battery can be recharged again when it has discharged. It is therefore a storage battery accumulator, in this case a lead storage battery.

Function and requirements

The starter battery is the electrical energy storage facility in the vehicle electrical system. It has the following tasks:

- Provide electrical energy for the starter
- Compensate for the deficit between generation and consumption if the vehicle electrical system is not being supplied with an adequate amount of energy by the alternator (e.g. at idle speed or if the engine is stopped)
- Damping of voltage peaks from the vehicle system voltage to protect sensitive electronic and electrical components (e.g. bulbs, semiconductors)

1 Design of a lead storage battery (example: maintenance-free battery)

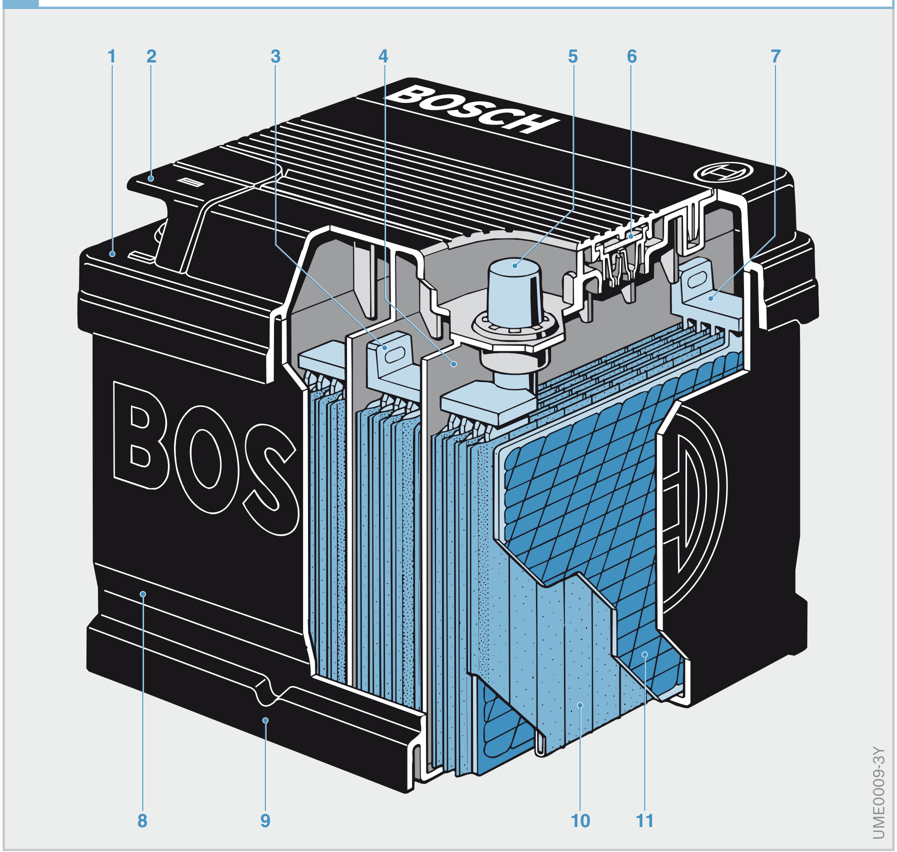

Fig. 1
1 One-piece cover
2 Terminal-post cover
3 Direct cell connector
4 Cell partition
5 Terminal post
6 Sealing plugs underneath the cover plate
7 Plate connector
8 Battery case
9 Bottom rail
10 Positive plates inserted into envelope-type separators
11 Negative plates

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The starter is only switched on for a short time, but it has the highest power input of all electrical consumers (passenger cars with gasoline engines: 0.7 to 2.0 kW; passenger cars with diesel engines: 1.4 to 2.6 kW; busses, commercial vehicles: 2.3 to 9.0 kW). The battery terminal voltage drops during starting because of the high current. It must not drop below a certain level so that the operation of the various control units such as the engine management system is not affected. These will not work if the supply voltage is too low.

A large number of electrical consumers must be supplied with energy when the vehicle is being driven (e.g. the engine management system, the lighting system, the air-conditioning system, the electronic stability program). If the alternator does not generate enough power to supply every electrical consumer that is switched on (e.g. when idling or at low engine speeds), the vehicle system voltage drops to the battery voltage level and electrical energy is drawn from the battery. The battery must therefore be able to provide the vehicle electrical system components with some of their power for a limited period or time or, if the engine and therefore the alternator is switched off, with all of their power. If an adequate amount of power is being generated, the battery can be recharged via the voltage regulator. The procedures that are described are known as the charging cycle and the discharging cycle.

The amount of power that is drawn from a starter battery varies considerably. The power requirements of the vehicle electrical system with the engine and the alternator stationary is approximately 10 to 50 mA (e.g. for the clock, the antitheft alarm system or the remote-controlled central locking system). When the engine is running at idle speed or the vehicle is being driven slowly, 20 to 70 A is required from the battery at certain times. The engine starting procedure requires about 300 A for a period of 0.3 to 3 s, and peak currents of 1,000 A are even possible. The amount of power that is required and the time that is taken to start the engine are significantly greater at low temperatures (by up to a factor of 2).

The power demand, which results from the electrical load requirements of a given vehicle, is determined in accordance with the vehicle operating conditions. It is decisive not only for the dimensioning of the battery but also of the alternator.

If auxiliary equipment is chosen for the vehicle, this can lead to considerable increases in power demand. Such equipment includes comfort and convenience systems with additional servomotors for power sunroof and power-window drives, seat and steering-column adjustment; as well as seat heating, air-conditioning system, cooler unit or similar. These electrical load requirements are taken into consideration in the vehicle by the manufacturer when the electrical components are dimensioned. This means that a vehicle equipped with such auxiliary equipment is delivered with a larger battery, and in some cases with a more powerful alternator. Other mechanical, cyclical, or climatic loadings are also taken into consideration depending upon the vehicle's application. For example, special vibration-proof batteries with a mat pressed between the plates are frequently used for all-terrain commercial vehicles. AGM batteries, for example, are extremely suitable for special cyclic loading. A corrosion-resistant lead alloy is required for warmer climates.

Caravans and mobile homes are often equipped with such electrical appliances as lighting, refrigerator, heating, radio and TV. Here, it is common to fit extra batteries with a separate electric circuit of their own.

Generally speaking, the lead-acid storage battery is sufficient for meeting these demands, as well as at present still being the most cost-effective energy-storage medium for such assignments. Typical voltages are 12 volts for passenger cars (with a 14-volt vehicle electrical system) and 24 volts for commercial vehicles (two 12-volt batteries connected in series).

Design

Classification

Starter batteries can be subdivided into two types:

- *Closed batteries:*
  These are EN 50 342 batteries with freely moving electrolytes in which any gas that builds up can escape through holes in the cover. The vast majority of all starter batteries are closed batteries.
- *Sealed batteries:*
  These EN 50 342 batteries only allow gas to escape if the pressure in the battery exceeds a certain value. The battery cannot be topped up with sulfuric acid. The electrolyte is fixed, i.e. it is not free-moving. This can be achieved by absorbing the electrolyte in a glass fiber mat (AGM battery) or by using a gel electrolyte.

The following distinctions also exist:

- Car batteries, the dimensions of which are defined as per the EN 60 095-2 standard and
- Commercial vehicle batteries (mainly in accordance with EN 60 095-4)

With regard to maintenance, starter batteries are categorized into

- Conventional and low-maintenance batteries
- Maintenance-free batteries (in accordance with EN) and
- Completely maintenance-free batteries

The basic design of these batteries is essentially the same, the main difference between them being the alloy from which the structural and discharge materials (grids) of the electrode plates are made.

Components

A 12 V starter battery contains six series-connected individually partitioned cells in a polypropylene case (Fig. 1). Each cell comprises a plate block consisting of a positive and negative plate set which are composed of lead plates (lead grid and an active material), together with a microporous insulating material (separators) between plates of opposite polarity. The electrolyte is in the form of diluted sulfuric acid which fills the pores in the plates and separators, and the voids in the cells. Terminals, cell connectors, and plate connectors are made of lead. The openings in the partitions for the cell connectors are sealed. A hot-molding process is employed to permanently bond the one-piece cover to the battery case thus providing the battery's top seal.

Each cell of a conventional battery has its own sealing plug that permits initial battery filling, topping-up during maintenance and removes the gasses that occur during charging. Only maintenance-free batteries are installed in new vehicles nowadays because they do not require regular checking of the electrolyte by the driver. They appear to be completely sealed. However, they contain ventilation openings so that the small amounts of gas that occur when the battery is charged by the alternator can escape.

Battery case

The battery case (Fig. 1, Item 8) – the housing of the battery – consists of acid-resistant insulating material (polypropylene) and many versions have bottom rails (9) at the sides for securing the battery in the vehicle.

The battery case is subdivided into cells by partitions. These cells are the basic elements of a battery. They contain the plate blocks (10, 11) with positive and negative plates, as well as the separators inserted between them. The cells are connected in series using cell connectors (3), which provide the connection through openings in the cell walls.

One-piece cover
The cells with the plate blocks are covered and sealed by a shared one-piece cover (Fig. 1, Item 1). The one-piece cover consists of a cap and a basic cover (Fig. 2).

Plate blocks
The plate blocks consist of negative and positive plates (grid plates) connected in parallel, with intermediate separators (Fig. 1, Item 10 and Fig. 3). The capacity of the cells essentially depends on the number of plates and their surface area. The thickness of the plates is selected depending on the battery application and is normally between 1 and 3 mm.

The plates (also known as grid plates) consist of lead grids and active material with which the grids are coated (pasted). The active material of the positive plate contains porous lead dioxide (PbO_2, orange-brown in color), and that of the negative plate contains pure lead in the form of "sponge lead" (Pb, gray-green in color). In other words, the pure lead is also in an extremely porous form. All negative and positive plates are connected via a plate strap (and/or plate connector), which is located above the set of plates in the battery. This plate strap consists of solid lead. The plates and the plate strap are securely connected together in a melted joint.

Each plate block usually has one negative plate more than it has positive plates.

Active material
The active material is that part of the grid plates that changes chemically when current flows, i.e. during the charging and discharging processes (see DIN 40 729). The material is porous and therefore forms a large effective inner surface area. For example, the negative plates of a battery with 100 Ah have an inner surface area of about 2,000 m², and the negative plates have approximately 30,000 m². During battery manufacture, the active material is produced by putting lead oxide (PbO) containing 5 to 15 % of finely distributed metallic lead ("gray oxide") into a mixer with water (H_2O), dilute sulfuric acid (H_2SO_4) and possibly other additional materials and short synthetic fibers to form a dough-like paste. This produces basic lead sulfates. Some lead oxide and metallic lead is retained. The paste, which still has a dough-like consistency, is coated onto the lead grids and is left to harden.

The active material of the finished plate is created during subsequent forming, i.e. the electrochemical conversion of this material when the battery is charged for the first time, which all takes place at the battery manufacturer's.

2 One-piece cover of the Bosch Silver battery

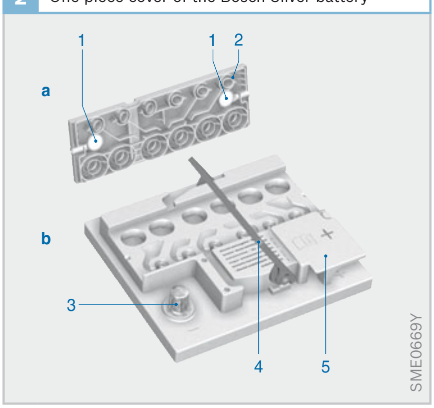


Fig. 2
a Cap
b Basic cover

1 Integrated frits
2 Labyrinth for drying the gas and returning the electrolyte
3 Terminal post
4 Handle
5 Terminal protection cap

3 Plate block

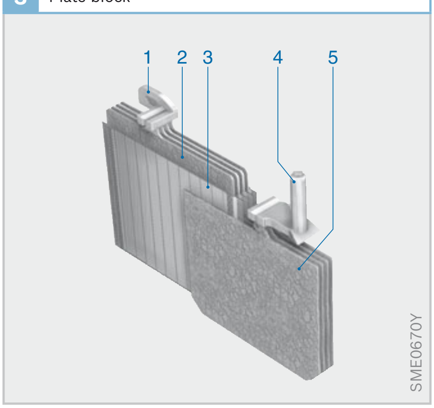


Fig. 3
1 Cell connector
2 Positive plate
3 Separator
4 Terminal post
5 Negative plate

Separators

Since vehicle batteries have to be as small and light as possible the positive and negative plates are extremely close together, usually 0.8 to 1.5 mm apart. However, they must not come into contact with each other neither when they bend nor when particles crumble away from their surface. Otherwise the battery will be destroyed immediately by the resulting short-circuit. This is why batteries had ribs on the bottom for fixing the plates until recently. Separating walls (*Separators*) were also inserted between the individual plates in a plate block.

The envelope-like separators (Fig. 4) in modern batteries ensure that plates with different polarity are an adequate distance apart and are electrically isolated (galvanically isolated). The bottom ribs are therefore no longer needed. Porous polyethylene foil which is resistant to the effects of oxidation and acid is used as the separator material. This is formed into envelopes which surround (and separate) the positive and negative plates in the plate block. The separators must not produce any significant resistance to the migration of ions in the electrolyte (sulfuric acid). They must also consist of an acid-resistant but permeable (microporous) material so that they can be penetrated by the electrolyte. The microporous structure is also needed because fine lead fibers that could penetrate the separators would cause short circuiting and therefore have to be held back.

Cell connectors

The individual battery cells are connected in series by the cell connectors (Fig. 1, Item 3 and Fig. 3, Item 1). To decrease the battery's internal resistance and weight, direct cell connectors are used in high-quality batteries. The plate connectors of individual cells are connected by the shortest path, that is directly through the cell partition. This also reduces the danger of short-circuits due to external contact.

Terminal posts and battery-cable terminals

The plate connector of the positive plates in the first cell is connected to the positive terminal post of the battery, and the plate connector of the negative plates in the last cell is connected to the negative terminal post (Fig. 1, Item 5). The two terminal posts are the connecting links between the vehicle electrical system and the battery (Figs. 5 and 6) and consist of a lead alloy. Their conical shape provides a firm seating and a good contact with the battery terminals. The terminal voltage is then available between these two battery terminal posts (i.e. approx. 12 V).

4 Battery plate with envelope-type separator

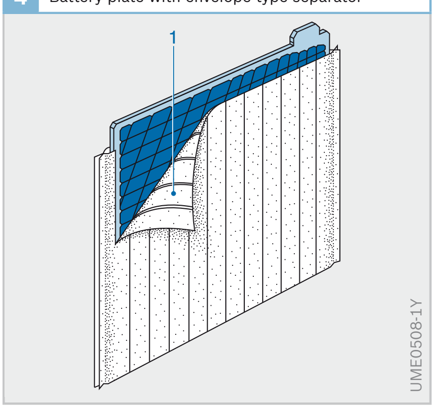
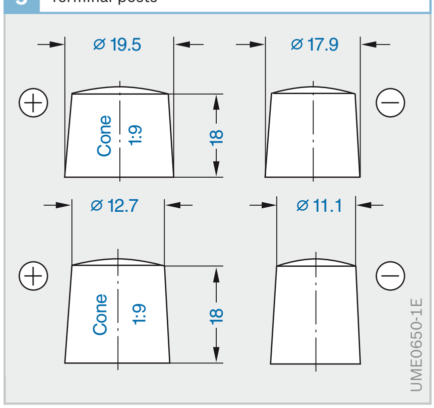


Fig. 4
1 Envelope-type separator cut open

5 Terminal posts



The vehicle connecting cables are attached to the terminal posts by special battery terminals. To prevent one pole from being mistaken for the other (polarity reversal), the posts are specially marked and designed differently (the positive post is thicker than the negative post). The battery terminals that are needed to connect the battery in the vehicle come in two versions (Fig. 6):
- Screw-type terminals and
- Solder-type terminals

Designs
All batteries are described in standard lists which contain the electrical specifications and stipulations for the geometrical dimensions of the battery case and the terminal posts (EN 60 095-2 for passenger cars). In addition, in order to ensure full interchangeability irrespective of manufacturer, details of mounting variants are given, as well as of the cell configuration and interconnection. When ordering batteries from the Aftermarket Program, they are listed with these design variants as product features. The design variants are discussed in more detail in the following chapters.

Electrical connections
Depending upon the available space and the equipment layout in the vehicle, a wide variety of batteries with different dimensions and terminal post configurations is required. A wide range of battery dimensions is possible depending on cell arrangement (lengthwise or transverse installation) and interconnection design. An overview of the most common connection designs is given in Figure 7.

Battery covers
Passenger car batteries
Depending on the battery type there are two battery-cover versions for passenger car batteries (Figs. 8 and 9):
- One-piece cover and
- Mono cover

In one-piece covers with a gas passage, the gas that is given off during charging is led out of the battery centrally via a hose. One-piece covers have a sealing plug for each cell that can be removed for topping up with electrolyte and for maintenance purposes. Many maintenance-free batteries no longer have sealing plugs.

6 Battery terminals

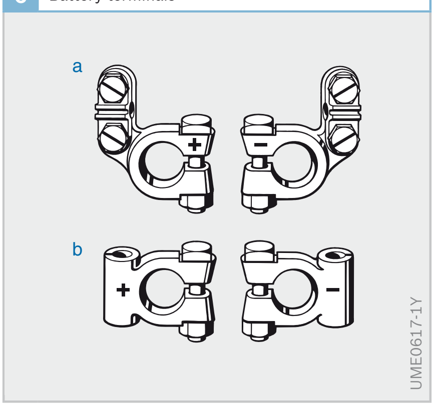
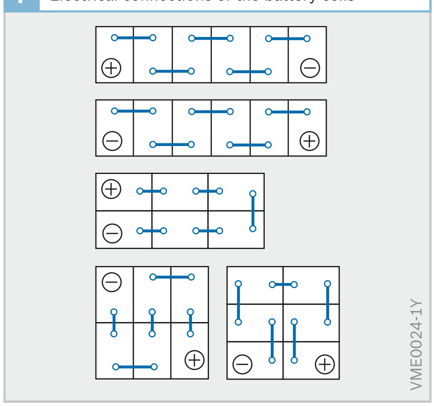


Fig. 6
a Screw-type terminals
b Solder-type terminals

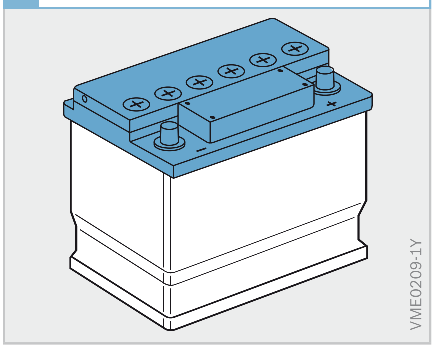
7 Electrical connections of the battery cells



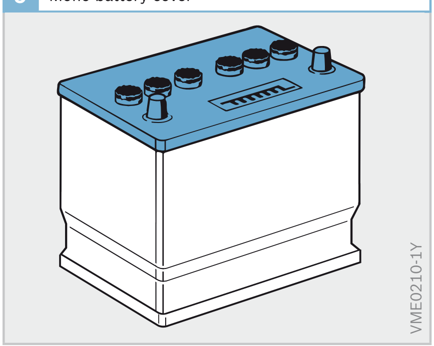
The one-piece cover of a maintenance-free Bosch Silver battery has the following characteristics:
- Continuous, smooth cover surface (no plugs)
- Handles for easy transportation (Fig. 11)
- Labyrinth for avoiding loss of water by evaporation
- Frits (sintered microporous elements made from polyethylene) in the gas passage to prevent backfiring. This means that sparks or flames occurring in the immediate vicinity of the battery cannot reach the interior.
- Labyrinth and frits to help prevent electrolyte from escaping

The mono cover has neither a gas passage nor a labyrinth. The gas escapes through plugs with ventilation openings.

8 One-piece cover



9 Mono battery cover



Commercial vehicle batteries
There are two main types of commercial vehicle battery:
- Mono cover and
- Labyrinth cover

The gasses that occur during charging are removed via openings in the plug in mono covers. There are no frits.

The labyrinth cover essentially has the advantages of a passenger car one-piece cover, except for the fact that the labyrinth is lower down because of the external dimensions that are required for a commercial vehicle battery. The advantages are essentially the same:
- Frits to prevent backfiring
- Labyrinth to help prevent electrolyte from escaping and
- Central gas removal

Mounting
The battery must be mounted in the vehicle so that it cannot move of its own accord. It is therefore clamped to a base using one of the following methods:
- Clamping frame
- Bracket, each with clamping screw or
- Secured at the base with a clamping claw or clamping screw (Fig. 10)

The various forms of recess in the base of the battery case for the above forms of mounting are common, and are therefore

10 Battery mountings (examples)

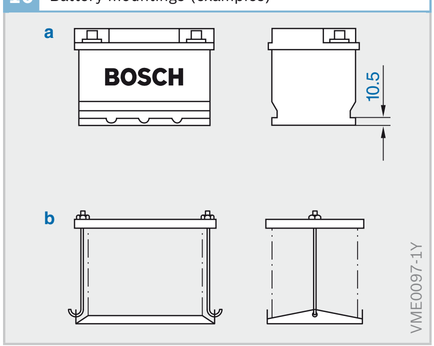


Fig. 10
a Base mounting
b Clamping frame mounting

also regulated by standardization. Reliable mounting is important for safety. Incorrectly mounted batteries can move in the event of minor accidents or even during sudden maneuvers and cause a fire due to short-circuiting.

The form of attachment provided complies with all safety regulations and should therefore not be modified.

Operating principle

Electrochemical processes in the lead cell

Generation of the cell voltage

If a metal electrode (e.g. made from lead) is immersed in an electrolyte (e.g. sulfuric acid), metal ions are released into the electrolyte. These metal ions are positively charged and leave electrons in the electrode.

1 Comparison of different battery versions

		EN-water consumption (g/Ah)	Battery case	Cover/plug	Separator	Grid alloy Positive	Grid alloy Negative	Miscellaneous
Conventional starter battery		> 4.0	Bottom ribs	Mono cover and degassing plug	Plate separator	Lead/antimony	Lead/antimony	Extremely deep-cycle resistant; commercial vehicle use: some separators on fiberglass mats
Low-maintenance		Usually < 4.0	Smooth base		Envelope-type separator	Antimony < 3.5 %	Lead/antimony	
Maintenance-free in acc. with EN		< 4.0, usually < 2.0	Smooth base	One-piece cover with central degassing; plugs	Envelope-type separator	Lead/antimony	Lead/calcium	Hybrid battery; negligible OEM use
Completely maintenance free	Liquid electrolyte	< 1.0	Smooth base	One-piece cover [1] with central degassing [7]; frit [2]	Envelope-type separator	Lead/calcium/silver [4]	Lead/calcium	State of the art [5] OEM and IAM
	AGM [3]	< 1.0	Reinforced structure, smooth base	One-piece cover with central degassing; valve and frit	Microporous fiberglass mat or gel [6] and plate separator	Lead/calcium/silver	Lead/calcium	Extremely deep-cycle resistant; luxury class vehicles and 2-battery vehicle electrical systems

[1]) Frequently with labyrinth for optimum electrolyte retention, [2]) Frits provide backfiring protection, [3]) Absorbent Glass Mat,
[4]) With Bosch batteries, [5]) Increasingly used for commercial vehicles, [6]) Not as passenger car starter battery,
[7]) OEM with plugs, aftermarket without plugs

11 Bosch Silver battery and its components

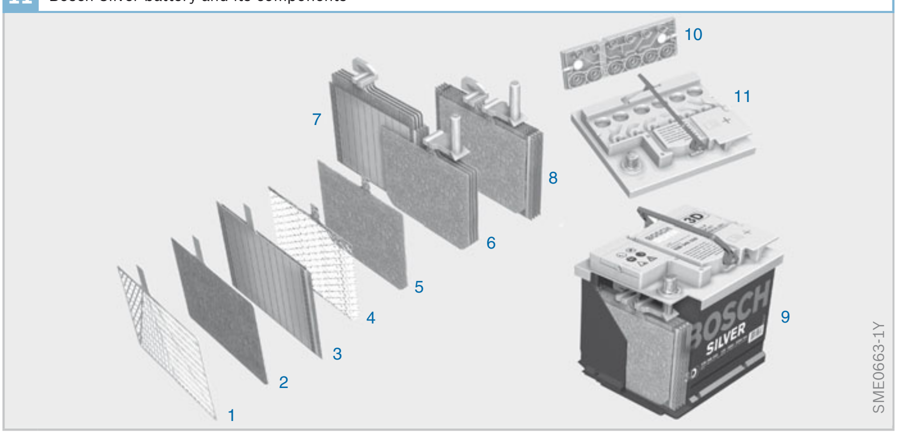


Fig. 11
1 Positive grid
2 Positive plate
3 Positive plate in plate separator (separator)
4 Negative grid
5 Negative plate
6 Negative plate set
7 Positive plate set
8 Plate block
9 Case with bottom rails
10 Cap
11 Basic cover

The electrode therefore has electrical potential. This counteracts the release of additional ions, creating an equilibrium between the release and depositing of metal ions whilst absorbing electrons.

A PbO_2 electrode behaves in a similar way, except for the fact that a conversion of differently charged lead ions takes place (Pb^{2+} and Pb^{4+}). Different electrodes have different potential, resulting in a cell voltage as a difference between these potentials. In a charged lead cell (Fig. 12) the positive electrode essentially consists of lead oxide (PbO_2), and the negative electrode consists of pure lead (Pb). Dilute sulfuric acid is used as the electrolyte (H_2SO_4 plus H_2O). The sulfuric-acid component means that the pure water becomes conductive so that it can be used as an electrolyte.

The electricity is transported via ion conduction. In the water-based solution the sulfuric acid molecules split into positively charged hydrogen ions (H+) and negatively charged residual-acid ions (S_4^{2-}). The splitting is the prerequisite for the electrolyte's conductivity and therefore for the flow of charge or discharge current.

The particle transfers involved in the charge and discharge of the lead cell are described in the two paragraphs below in more detail.

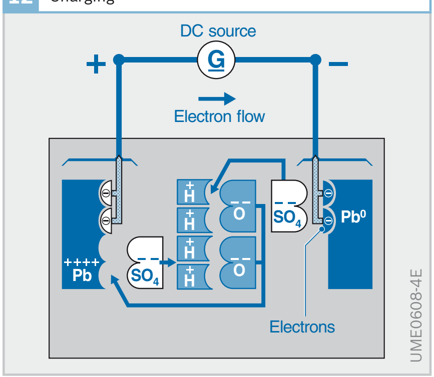
Charging a battery

The battery is charged while the vehicle is being driven, provided that the alternator is supplying enough charging current. A discharged battery can also be recharged using a battery charger.

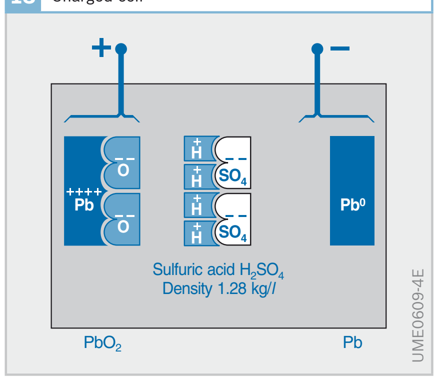
During the charging procedure, the positive electrode of the lead cell is connected to the positive terminal, and the negative electrode is connected to the negative terminal of the DC source (alternator or battery charger). Unlike the discharging process that is described later, the charging process introduces electrical energy so that all cells achieve a higher energy level after charging. Figures 12 to 15 demonstrate in schematic form the processes which take place between the individual particles in the electrode mass and the electrolyte.

The charging voltage source transports a charge from the positive electrode to the negative electrode in the cell. It forces the electrons of the negative electrode, which turns the bivalent positive lead (Pb^{2+}) into "zero value" (metallic) lead (Pb) at this electrode by breaking up the lead sulfate molecules. At the same time, the negatively charged residual-acid ions (SO_4^{2-}) are transferred from the negative electrode to the electrolyte (Fig. 12).

12 Charging



13 Charged cell



At the positive electrode, bivalent positive lead (Pb^{2+}) is turned into tetravalent positive lead (Pb^{4+}) due to the removal of electrons. The lead sulfate ($PbSO_4$) is electrochemically split by the applied charge voltage. The tetravalent positive lead combines with the oxygen removed from the water (H_2O) to form lead dioxide (PbO_2). At the same time, the sulfate ions released at the positive electrode during this oxidation process (SO_4^{2-}, from the lead sulfate $PbSO_4$) and hydrogen ions (H^+, from the water) pass into the electrolyte. The reaction equation of the charging procedure is:

$$2PbSO_4 + 2H_2O \rightarrow PbO_2 + 2H_2SO_4 + Pb$$

The charging procedure increases the number of hydrogen ions (H^+) and sulfate ions (SO_4^{2-}) in the electrolyte. This means that sulfuric acid (H_2SO_4) is formed, whereby the density ρ of the electrolyte increases (normally $\rho = 1.28$ kg/l for a charged cell). This corresponds to a sulfuric acid content of approx. 37 %. This means that the state of charge of the battery can be determined by measuring the electrolyte density.

Charging is complete (Fig. 13), when
- The lead sulfate ($PbSO_4$) has been converted into lead dioxide (PbO_2) at the positive electrode and
- The lead sulfate ($PbSO_4$) has been converted into metallic lead (Pb) at the negative electrode
- The charge voltage and the electrolyte density ρ no longer increase, even if charging continues

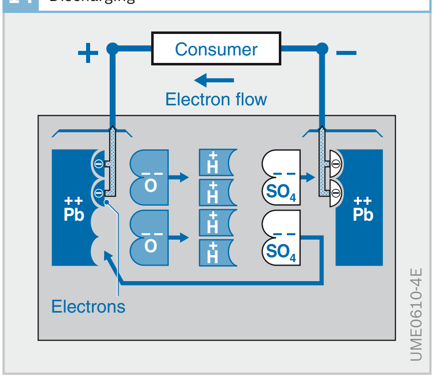
Gassing
The charging process causes the supplied electrical energy to be converted into chemical energy and stored. If charging continues after the battery has been fully charged, only electrolytic water decomposition takes place. Oxygen forms at the positive plate (O_2), and hydrogen (H_2) forms at the negative plate. This procedure is known as gassing. Water may subsequently need to be added.

Overcharging can be reduced by restricting the charging time, for example. Overcharging in the vehicle can be prevented by means of charge status-controlled charging, which requires some form of battery status detection, however.

Impact of engine speed
The battery charge largely depends on how the vehicle is driven (e.g. in traffic jams, stop-and-go, or without stopping). The alternator is driven by the engine, and the amount of current that is generated by the alternator increases together with the engine speed. Long waiting times in traffic jams and at traffic lights when the engine is only running at idle speed result in low alternator speeds and a low battery charge current. Short-distance driving has a negative effect on the battery's charge balance. However, if longer distances are driven on a highway or interstate, the engine speed is in the medium to upper range and the battery charge current is accordingly high.

Discharge (current drain from the battery)
Compared to the battery-charging process, the direction of current flow and the electrochemical process are reversed when discharge takes place. If a consumer (e.g. a lamp bulb) is connected between the poles

14 Discharging

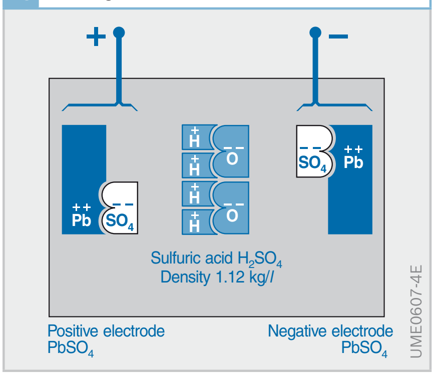


of a battery, due to the potential difference between the poles (6 times the cell voltage) electrons flow from the negative pole through the consumer to the positive pole.

This electron transition causes the tetravalent positive lead (Pb^{4+}) of the positive electrode to be converted into bivalent positive lead (Pb^{2+}), and the binding of the previously tetravalent lead at the oxygen atoms (O) is canceled out (Fig. 14). The oxygen atoms that have been released combine with hydrogen atoms (H^+) that have been taken from the sulfuric acid (H_2SO_4) and form water (H_2O). The density of the electrolyte therefore drops. Depending on the type of battery, this is usually significantly below ρ = 1.12 kg/*l*. This corresponds to a sulfuric acid content of approx. 17 %.

At the negative electrode, bivalent positive lead also forms as a result of electrons moving from the metallic lead to the positive electrode (Pb^{2+}). The bivalent negatively charged sulfate ions (SO_4^{2-}) from the sulfuric acid combine with the bivalent positive lead at both electrodes so that lead sulfate ($PbSO_4$) is formed as a discharge product at each electrode (Fig. 15).

15 Discharged cell



The reaction equation of the discharging procedure is:

$$PbO_2 + 2H_2SO_4 + Pb \rightarrow 2PbSO_4 + 2H_2O$$

Both electrodes have now returned to their initial state: the chemical energy stored in the cell has been transformed back into electrical energy by the discharge process.

An overview of the battery discharging procedure is shown in Table 2.

2 Overview of the discharge processes

	Positive electrode	Electrolyte	Negative electrode
Lead cell, charged	Active material: lead dioxide (PbO_2, brown)	High-density sulfuric acid (H_2SO_4)	Active material: lead (Pb, metallic gray)
Current drain Electron stream from negative electrode (via consumers) to positive electrode	Electron absorption reduces the tetravalent lead dioxide ($Pb^{4+}O_2$) to bivalent positive lead ions (Pb^{++}), which combine with the residual sulfuric acid (sulfate ions SO_4^{--}) to form the light-colored lead sulfate ($PbSO_4$).	The oxygen (O_2) of the lead dioxide (PbO_2) of the positive electrode forms water with the liberated positively charged hydrogen ions (H^+, H_3O^+) of the sulfuric acid; it becomes diluted.	Electron emission oxidizes the neutral metallic lead (Pb) to bivalent positive lead ions (Pb^{++}), that combine with the residual sulfuric acid (sulfate ions SO_4^{--}) to form light-colored lead sulfate ($PbSO_4$).
Lead cell discharged	Lead sulfate ($PbSO_4$) from the Pb^{++} +SO_4^{--} ions	Low-density sulfuric acid	Lead sulfate ($PbSO_4$) from the Pb^{++} +SO_4^{--} ions

Table 2

Battery designs

Conventional and low-maintenance batteries

Conventional batteries are hardly ever installed in new vehicles any more, since they are not maintenance-free and their fluid level has to be checked at regular intervals. Since the gassing voltage (voltage at which the gassing process occurs) is lower than it is in any of the other popular battery versions, the gassing process starts sooner, and more charge gas escapes (see section entitled "Electrochemical processes in the lead cell"). For this reason, water has to be added through the sealing plug at regular intervals.

Low-maintenance batteries are slightly better. Because of the low water consumption (< 4 g/A·h), the maintenance intervals are longer, and they then depend on the type of vehicle use and the battery installation location.

Characteristics

Conventional batteries

Conventional batteries have ridges on the inner floor surface of the case, on which the plate feet rest. The spaces between the element rests, and below the bottom edges of the plates, form sediment chambers which serve to accumulate the solid material which, in the course of time, is sloughed off from the plates and falls to the bottom of the case. The sediment, which contains lead and is electrically conductive, accumulates in the sediment chambers without contacting the plates. Short-circuits are thus avoided. The design with ridges and sediment chamber is needed in conventional batteries, since there are plate separators between the plates that do not surround them at the bottom.

Low-maintenance batteries

However, low-maintenance batteries use envelope-type separators. Because of their envelope shape they surround the positive or negative plate completely. Material particles that become detached drop to the bottom inside the envelope and can therefore not cause short circuiting. No ridges are therefore needed on the base of the battery – the bottom of the case is smooth. This means that the available plate surface can be increased (more current drain possible) and the plates rest on their entire underside (greater stability).

Plate grid alloy material

Lead-antimony alloy (PbSb)

In order to improve the casting capability of the thin lead grids (extremely important in high-performance starter batteries), accelerate the hardening process and give the lead plates the stability that is required when driving (*Deep-cycle resistance*), the lead of the grid consists of a lead-antimony alloy (PbSb). In other words, the antimony acts as a hardener (this is where the term "hard lead" comes from). However, during the battery's service life the antimony is increasingly separated out due to positive-grid corrosion. It migrates to the negative plate, passing through the electrolyte and the separators on the way, and "poisons" it by forming local voltaic couples. These local voltaic couples increase the self-discharge of the negative plate and reduce the gassing voltage. Both cause increased water consumption when overcharging occurs, which encourages the release of antimony. This self-energizing mechanism leads to a continuous drop in power throughout the battery's service life.
The reduced charging current leads to charging problems, particularly in winter. The battery does not achieve the required state of charge, and the electrolyte has to be checked at frequent intervals.

The self-discharging of the negative plates that is caused by the antimony content of 4 to 5 % in the grid lead is therefore one of the main causes of failure in conventional starter batteries. Depending upon driving conditions, water consumption (> 4 g/A·h) resulting from increased gassing in older batteries used to mean the battery had to be checked every four to six weeks. The proportion of antimony in the positive plate is lower in low-maintenance batteries (< 3.5 %). This slows down the increase in the self-discharging of the battery during the course of its service life.

Since batteries with lead-antimony alloy are extremely deep-cycle resistant, they are mainly used in commercial vehicles and taxis. Batteries for motorcycles are also based on antimony technology, since frequent use during good weather and long park-up times during winter require extremely deep-cycle resistant batteries.

However, the advantages of deep-cycle resistance are frequently counteracted by grid corrosion during service life. This is caused by the fact that grids with lead-antimony are subject to more corrosion than the lead-calcium alloy or the even better lead-calcium-silver alloy that are described below.

However, since maintenance-free batteries and not extremely deep-cycle resistant batteries are required for the majority of passenger cars, antimony batteries are seldom used in new vehicles.

Maintenance-free battery (as per EN)

Plate grid alloy material

The negative grid of maintenance-free batteries (hybrid batteries) consists of a lead-calcium alloy (PbCa) – with added silver in some versions – and the positive grid is made from an antimony alloy (PbSb).

Calcium takes over from antimony as the hardener for the negative plates. Calcium is electrochemically inactive under the potential conditions that exist in lead storage batteries. This means that negative plate poisoning is avoided and self-discharging is prevented. However, what is more important is the high gassing voltage which is stable over the usage period, and the associated water consumption, which is lower compared to lead-antimony alloy.

Another advantage of a hybrid battery is ease of manufacture. The negative grids with the calcium alloy can usually be manufactured using a simple drawing process, and the positive grids, which are subjected to greater mechanical stresses through corrosion, are produced in antimony alloy using a more complicated casting process. However, due to the antimony content, hybrid batteries can seldom meet the high demand for low water consumption in passenger cars (< 1 $g/A \cdot h$). Only completely maintenance-free batteries, in which both positive and negative grids are made of a lead-calcium alloy, are capable of meeting these demands.

Under the high cyclical loading conditions encountered in taxis in densely populated areas, in town buses, and in delivery vehicles, maintenance-free starter batteries have come to the forefront due to the advantages inherent in their separator concept (envelope-type separators) and the reliable protection against failure that they provide.

Characteristics

The water loss of a maintenance-free battery is lower over its entire service life than a conventional battery (< 4 $g/A \cdot h$, usually < 2 $g/A \cdot h$). The liquid level only needs to be checked during the normal service intervals in the workshop. Porous polyethylene foil which is resistant to the effects of oxidation and acid is used as the separator material. This is formed into envelopes which surround (and separate) the positive and negative plates in the plate block.

Other features are:

- Labyrinth one-piece cover with central gas vent. This minimizes water consumption caused by evaporation and prevents electrolyte from escaping if the battery is briefly tipped over.
- Frits provide protection from backfiring when sparks are present: this means

that they prevent escaping charge gas from being ignited by an external influence (naked flame) or igniting and flashing back into the battery.
- The terminal posts are protected from inadvertent short circuiting by caps.
- The cover plate over the plug trough covers the sealing plugs and prevents the accumulation of dirt and moisture.
- The bottom of the case is smooth on the inside because envelope-type separators are used. The plates reach down to the floor of the case (= increased plate surface) with which they are in contact along their complete length (increased stability).
- Microporous envelope-type separators prevent the loss of active material, as well as the formation of short circuits at the bottom and at the side edge of the plates. The mean pore diameter of the envelope-type separators is smaller than that of conventional plate separators by a factor of 10, thereby effectively preventing short-circuits as well as providing reduced electrical resistance.

Maintenance-free Bosch starter batteries comply with the minimum performance values stipulated by DIN, and also fulfill the following requirements:
- No impairment of performance data and charging characteristics as a result of water consumption.
- The performance data and charging characteristics remain consistent during the entire service life of the battery.
- After exhaustive discharge and a subsequent park-up period under vehicle electrical system conditions, the battery can be charged again.
- In case of seasonal operation without intermediate charging (but with disconnected ground cable), no reduction in usable life is to be expected compared to all-year-round operation.
- The battery must be able to be stored for long periods after filling.

Completely maintenance-free battery

Completely maintenance-free batteries have a longer service life for extremely long distance driving and are more resistant to continuous overcharging. This is achieved by means of a further development of the plate alloy.

Plate grids

Lead-calcium-silver alloy (PbCaAg)
The higher performance of modern car engines combined with more compact and streamlined body shapes has resulted in an increase in the average engine-compartment temperature. This change in conditions also has an effect on the starter battery, as a result of which the most recent development in battery design has seen the use of an improved lead alloy for the grids of the positive plates. In addition to having a lower calcium content and a higher tin content, they also contain a proportion of silver (Ag). This lead-calcium-silver alloy (PbCaAg) has a refined grid structure and has proven itself to be extremely durable, even under the influence of high temperatures that accelerate corrosive decay. This is true when destructive overcharging occurs with high electrolyte density and also during (equally undesirable) periods of disuse with low electrolyte density.

The alloy material for the negative plates is a lead-calcium alloy. These batteries are also antimony-free.

Characteristics

The optimized geometry of the grid structure with optimized electric conductivity allows better use to be made of the active material. The connection (center tab) for the cell connector ensures that the grid plates inside the battery casing are uniformly fixed. This method provides the possibility of creating plates that are about 30 % thinner (but more stable) than maintenance-free batteries and, as a result, of increasing their number. That makes it possible to increase cold-starting power without sacrificing quality.

Versions with the “robust design” have shorter and thicker positive plates with a stable frame, meaning that a high volume of electrolyte is needed above the plates. Consequently, they are always covered by electrolyte and thus protected against corrosion. These properties generally make this type of battery tougher in practical applications.

The completely maintenance-free battery does not require electrolyte level monitoring and does not usually provide a facility for doing this. It is completely sealed apart from two ventilation openings. As long as the vehicle electrical system is operating normally (i.e. constant voltage limited to a maximum level), water decomposition is reduced to such an extent ($< 1\ g/\mathrm{A \cdot h}$) that the electrolyte reserves above the plates will last for the entire service life of the battery. A completely maintenance-free battery also has the advantage of extremely low self-discharging. This makes it possible to store the fully charged battery for several months after delivery.

Because of the low self-discharging, all completely maintenance-free batteries are filled with electrolyte in the manufacturing plant. This avoids dangerous spillages in workshops or on dealer premises when mixing and adding electrolyte.

If a completely maintenance-free battery is recharged outside the vehicle electrical system, the charge voltage must not exceed 2.3 to 2.4 volts per cell, since overcharging with constant current or using chargers with a W characteristic (constant resistance) leads to water decomposition (gassing).

The completely maintenance-free batteries that are currently on the market have a safety labyrinth cover with side ventilation openings that prevent electrolyte from escaping if the battery is tilted at angles of up to 70° and, with the frits, also provide protection against backfiring. Sealing plugs are no longer required.

The Bosch battery with silver alloy in the positive plates has a 20 % longer service life than conventional batteries. There are more plates per cell because the plates are thinner. The resulting greater surface area increases the starting power by 30 % in comparison with conventional batteries. This type of battery also has a “power control system” which is located in the battery cover and indicates the state of charge by displaying different colors.

- Green: state of charge is OK
- Dark gray: battery needs to be recharged. After recharging, the indicator changes back to “green”
- White: battery defective, must be replaced

For applications in commercial vehicles there are Bosch batteries with silver alloy which offer the advantages of the completely maintenance-free, passenger car starter battery (“Bosch TECMAXX”). The complete freedom from maintenance that has cost benefits that should not be underestimated in the commercial vehicle area is combined with new battery cover technology: a new type of labyrinth cover prevents the electrolyte from escaping. The use of central degassing instead of degassing via the plugs means that a frit can be installed, which prevents backfiring into the inside of the battery from external flames or sparks.

Completely maintenance-free batteries are used in almost all new vehicles nowadays. They make maintenance intervals longer and have proven themselves millions of times over.

AGM technology

AGM batteries (Absorbent Glass Mat, i.e. batteries with electrolyte bound in fiberglass mats) have proven themselves in cases where greater demands are made of the vehicle battery. These batteries differ from batteries with free electrolyte by the fact that the electrolyte is bound in a fiberglass mat that is located between the positive and negative plates instead of separators.

The battery is separated from the environment by valves (airtight). By means of internal circulation inside the battery, the oxygen that occurs at the positive electrode due to gassing is used up again, the amount of hydrogen that is produced is suppressed and the amount of water loss is therefore minimized. This circulation is made possible because of the formation of small gas channels between the positive and negative plates, through which the oxygen is transported. The valves only open in the event of considerable overpressure. The sealed AGM battery therefore has extremely low water loss and is therefore completely maintenance-free.

This technology also has other benefits. The mat is flexible, meaning that the plate set can be installed under pressure. Pressing the mat onto the plates reduces the shedding and separation effect of the active material considerably. This produces a load throughput that is usually up to three times greater than that of comparable starter batteries. This battery type also has the advantage that even if the battery case is destroyed as a result of an accident, for example, electrolyte does not usually escape, because it is bound in the fiberglass mat. No electrolyte escapes from the battery, even if it is turned 180 ° for long periods. High cold start currents are achieved because of the high porosity of the fiberglass mat.

Another advantage of the AGM battery is that electrolyte stratification is prevented. When a battery with free electrolyte is being cyclically charged and discharged, an electrolyte density gradient gradually builds up from top to bottom. This is because when the battery is charged, electrolyte with a higher concentration occurs at the plates, drops to the bottom because of its greater specific density and collects there, whereas the electrolyte with lower concentration remains in the upper part of the battery cell. Among other things, this electrolyte stratification reduces both the battery capacity and the service life. The electrolyte stratification effect occurs to varying extents in all batteries with free electrolyte. In AGM batteries, however, electrolyte stratification is prevented by absorbing the electrolyte in fiberglass mats.

When an installation location is being chosen for an AGM battery it must be ensured that high temperatures are avoided, since the thermal capacity is lower than it is for a battery with free electrolyte.

Gel-electrolyte batteries

Another type of sealed and therefore completely maintenance-free battery uses a multi-component gel in which the electrolyte is incorporated, instead of fiberglass mats. Here too, the internal gas circuit prevents gassing and therefore water consumption. This means that this battery is also completely maintenance-free.

The battery cell sealing plugs incorporate a safety valve that releases pressure in the event of continuous overcharging. These gel-electrolyte batteries only have a self-discharge rate of 2 % per month at 20 °C.

The short, thick plates and the gel electrolyte also guarantee high deep-cycle resistance. It is also completely sealed and completely spill-proof. This means that the electrolyte cannot escape, even if the battery is rotated 180°.

Completely maintenance-free batteries for motorcycles

Leak-proof batteries with mat technology are becoming increasingly popular. These batteries do not use gel technology. The battery is filled at the required time from an electrolyte bottle which is included in the sale. After initial filling, the electrolyte is bound in mat-like separators. The gas circulation inside the battery prevents gassing. If the battery is overcharged with high charge voltages over along period, gassing may occur in spite of the mat technology. In this case the gas escapes via a safety valve. After initial filling, the battery is sealed so that electrolyte cannot escape, even if the battery is tilted or rotated 180° for short periods.

Batteries for special applications

It is impossible to completely cover the wide range of different operating conditions which can be encountered in the field with one single standard battery. Such a battery would be far too large for normal operation and far too expensive.

Batteries with additional starting power are required for extremely low temperatures in cold countries. The starting temperatures are often below –20 °C. These batteries feature an increased number of thinner plates and separators.

The situation in tropical climates is just the opposite, since there is a risk of electrolyte "thickening" because of increased water consumption (electrolysis and evaporation). In temperate and cold zones, there is no need to change the electrolyte's density from its fully-charged freezing limit of –68 °C. In tropical regions, however, the electrolyte density must be reduced.

In the industrial and commercial sectors (bus, taxi, ambulance, delivery van, etc.), the fact that the vehicle is repeatedly driven only short distances means that the current taken from the battery is correspondingly higher. In addition, there are further cyclical loadings during high power demands when the vehicle is stationary. These are caused by the air-conditioning system, the lighting system, fans, electrohydraulically operated platform lifts, cooling units, auxiliary heaters etc.

As well as cyclical loading, batteries in all-terrain vehicles, commercial vehicles, construction machinery, towing vehicles and agricultural/forestry vehicles must be able to withstand severe vibration and impacts on slopes, construction sites or off-road conditions.

Deep-cycle resistant battery

Due to their design characteristics, starter batteries are poorly suited for applications in which frequent, extreme discharges occur (so-called cyclic loading), since high rates of wear occur at the positive plates due to the separation and "shedding" (sedimentation) of the active material. In the commercial area (e.g. in commercial vehicles), the battery is subjected to extremely high loading because of the short distances traveled between engine starts, and the associated high power consumption. Because of continuous power consumption, the battery can become extremely discharged and may not be adequately recharged by the alternator. Additional loading can also be caused by high power consumption whilst the vehicle is stationary by the fan, the air conditioning system, the auxiliary heater, the lighting system, the car radio, radio equipment, etc. In these cases, it is often advisable to use an AGM battery. If an AGM battery cannot be used, a deep-cycle resistant starter battery with free electrolyte is an alternative. It can be "deep"-discharged more often than a normal battery without impairing its service life.

In the deep-cycle resistant starter battery, separators with additional fiberglass mats are used to give the positive material the extra support needed to prevent premature sludge formation. The service life of such a battery, measured in charge/discharge cycles, is approximately double that of a standard battery.

Vibration-proof battery

In the vibration-proof battery, an anchor of cast resin and/or plastic prevents the plate blocks from moving inside the battery case. According to specified standards, this type of battery must withstand 20 hours of sinusoidal vibration at a frequency of 22 Hz and a maximum acceleration of 6 *g*. Requirements are therefore about 10 times greater than for standard batteries. Vibration-proof batteries are installed primarily on commercial vehicles, construction machinery and tractors used on building sites, on ski slopes, and for off-road applications in agriculture, and forestry.

Heavy-duty battery

Commercial vehicles have a considerable number of additional electrical consumers such as a lift platform, radio equipment, a television or a coffee machine. The dry-charged (i.e. the battery is ready for use after filling with electrolyte) heavy duty battery (HD battery) is maintenance-free in accordance with EN and includes a combination of measures for making the battery deep-cycle resistant and vibration-proof. It ensures a reliable power supply even under conditions of high continuous loading caused by a large number of electrical consumers. This type of battery is installed in commercial vehicles which are subject to high levels of vibration and cyclical loading.

The HD-Extra battery features even more far-ranging characteristics. These are needed in order to withstand unusually high levels of loading:

- Extreme cold-start reliability (up to 20 % higher starting reserve)
- Extremely long service life
- Extremely vibration-proof (100 % more than EN)
- Extremely deep-cycle resistant (four times greater than standard batteries)

Battery for extended current output

This battery shares the basic design of the deep-cycle resistant version. However, it has thicker plates, though there are less of them. No low-temperature test current is specified for these batteries, since they are not suitable for starting. Their starting power is considerably lower (by approximately 35 to 40 %) than starter batteries of the same size.

These batteries are used in cases of heavy cyclic loading, sometimes even for traction purposes (drive battery). One example of this type of use is in fork-lift trucks, which do not need any starting power but have to be recharged at frequent intervals. These batteries are also used to provide the drive energy for small drive units (e.g. in street sweepers and wheelchairs), and the energy for signaling systems, construction-site lighting, boats, ancillaries and for leisure time and hobby applications.

The proportion of antimony makes Bosch drive and lighting batteries with liquid electrolyte particularly deep-cycle resistant. The negative effects of the antimony are limited to a tolerable level.

Battery characteristics

The European standard EN 50 342 and national standards define the characteristics and test procedures for starter batteries. Although these tests are suitable for evaluating and monitoring the quality of new starter batteries, they do not claim to fully represent the wide range of load demands which can be encountered in the field.

One of the characteristics of a chemical battery is that the amount of current that can be drained (capacity) depends on the magnitude of the discharge current I_E. This means that the higher the current that is drained, the smaller the available capacity at the defined cutoff voltage. In order to be able make a comparison between starter batteries at all, their capacity is related to the strength of discharge current which the battery can deliver during a discharge time of 20 hours at a defined cutoff voltage (10.5 V) (nominal capacity K_{20}).

Cell voltage

The cell voltage U_Z is the difference between the potentials which are generated between the positive and negative plates in the electrolyte. These potentials depend on the plate materials and on the electrolyte and its concentration. The cell voltage is not a non-variable figure but depends on the state of charge (electrolyte density) and the electrolyte temperature.

Nominal voltage

The nominal voltage U_N of a cell for lead storage batteries has been defined by standards (DIN 40 729) to a value of 2 V. The nominal voltage of the complete battery results from multiplying the individual cell nominal voltages by the number of cells connected in series. According to the EN 50 342 the nominal voltage for starter batteries is 12 V.

Open-circuit and steady-state voltage

The open-circuit voltage is the voltage across the unloaded battery. After completion of the charging and discharging processes, due to polarization and diffusion, it changes to become a final value which is referred to as the steady-state voltage U_0 (Fig. 16). The steady-state voltage is the actual voltage obtained by multiplying the number of series-connected cells by the cell voltage U_{Z0}. For six cells, the following applies:

$U_0 = U_{Z01} + U_{Z02} + \dots + U_{Z06} \approx 6 \cdot U_{Z0}$

Similar to the cell voltage, the steady-state voltage is also dependent upon the state of charge and the electrolyte temperature. No conclusions can be drawn about the state of charge from a voltage that has been measured immediately after charging or dis-

16 Steady-state voltage of a battery

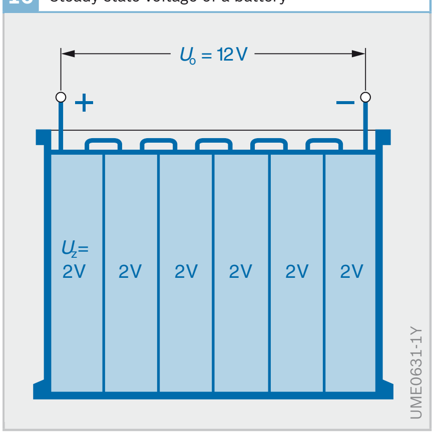


Fig. 16
U_Z Cell voltage
U_0 Steady-state voltage

17 Battery voltages

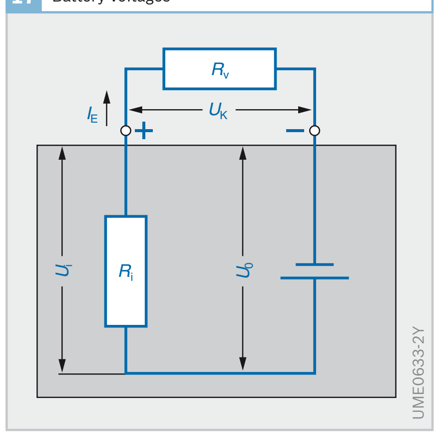


Fig. 17
I_E Discharge current
R_i Internal resistance
R_v Consumer resistance
U_0 Steady-state voltage
U_K Terminal voltage
U_i Voltage drop across internal resistance

charging procedures. It may take several days for a steady-state voltage to arise which can then be used to evaluate the state of charge. The electrolyte density is a more suitable indicator of the battery charge level.

Internal resistance R_i

The internal resistance R_i of a cell is made up of a number of individual resistances. Essentially these are the contact resistance R_{i1} between the electrodes and the electrolyte (polarization resistance). Then there is the resistance R_{i2} of the electrodes (plates with separator) to the electrode flow and the resistance R_{i3} of the electrolyte to the ion current. And when a number of cells are connected in series, the resistances of the individual cell connectors R_{i4} must be added. This results in $R_i = R_{i1} + R_{i2} + R_{i3} + R_{i4}$.

As the number of plates increases (greater surface area), the internal resistance of the cell decreases. In other words, the greater the capacity of a cell, the smaller the internal resistance (with the same plate thickness). On the other hand, the more the battery discharges, and at low temperatures (sulfuric acid becomes more viscous), the internal resistance increases again R_i.

The internal resistance of a 12 volt starter battery comprises the series connection of the internal resistances of the individual cells, together with the resistances presented by the internal connecting elements (cell connectors and plate connectors). The resistance for a fully charged 50-Ah battery at 20 °C is 5 to 10 mΩ; with a charge status of 50 % and at –25 °C, it increases to about 25 mΩ. It is a characteristic variable for the starting response. The internal resistance of the battery in combination with other sources of resistance in the starter-motor circuit determines the speed at which the engine is turned over when being started.

Terminal voltage U_K

The terminal voltage U_K is the voltage measured between the two terminal posts of a battery. It is dependent on the open-circuit voltage and the voltage drop U_i across the battery's internal resistance R_i (Fig. 17):

$U_K = U_0 - U_i$ with $U_i = I_E \cdot R_i$

If a discharge current I_E is taken from a battery by a consumer with a load resistance of R_L, a lower terminal voltage is measured than in the no-load state. This is due to the battery's internal resistance. If a current I_E flows through the cells, a voltage drop U_I takes place across R_i which increases together with the current. Since internal resistance is a function of temperature and the state of charge (among other things), this means that a loaded battery's terminal voltage drops at low temperatures and when it is inadequately charged.

Information about the state of charge and degree of wear of a battery that is under load can be derived by measuring its terminal voltage.

Gassing voltage

The gassing voltage according to DIN 40729 is the charge voltage at which a battery starts to gas significantly. This will result in water loss from the battery and the risk of gas detonation. According to DIN VDE 0510, a gassing voltage of 2.40 to 2.45 volts per cell applies as a rough limit depending on the particular battery design. For 12 volt batteries, this voltage limit is therefore between 14.4 and 14.7 volts, depending on the electrolyte temperature. In order to reduce water loss when driving and also ensure that rapid recharging is possible, temperature-dependent controller characteristic curves must be used. For completely maintenance-free batteries these stipulate a maximum value of 16 V at temperatures that are significantly lower than 0 °C and about 13.5 V at temperatures that are significantly above 30 °C. This takes into consideration the fact that the charging capability of the lead storage battery is inhibited at low temperatures, which means that the charge voltage has to be increased in this case. The charge voltage must be set to a lower level at high temperatures in order to restrict water loss and battery corrosion. The latter has a greater effect at high temperatures and high voltages.

A charge voltage of 14.1 V (2.35 V/cell) for a maximum charging time of 48 hours is specified for maintenance-free, sealed gel batteries.

Capacity

Available capacity *K*

The capacity *K* is the quantity of electricity which the battery can deliver under specified conditions. It is the product of current intensity and time (ampere hours Ah). The quantity of active material that is used and the quantity of electrolyte essentially determines the capacity of the battery. For high powers (such as are needed when starting an IC engine), the active material must have large internal and external surfaces (large number of large-area plates). The large internal surface area is produced during electrochemical pretreatment known as "forming". However, the battery's capacity is not a fixed parameter, but depends, among other things, on the following influencing variables (Figs. 18 and 19):

- Discharge current strength
- Density and temperature of the electrolyte
- Discharging process as a function of time (capacity is higher when a pause is made during discharge, than when discharge is continuous)
- Battery age (due to the loss of active material from the plates, capacity decreases as the battery approaches the end of its service life) and
- Degree of battery electrolyte stratification

The discharge current strength is extremely important. The greater the discharge current strength, the smaller the available capacity. In the example shown in Fig. 19, a discharge current of 2.2 amps means that the available 44 Ah capacity can be used for up to 20 hrs. With a mean starter current of 150 amps at a temperature of 20 °C and a discharge time of approximately 8 minutes, the available capacity drops to approximately 20 Ah. The reason for this is that with a small discharge current, the electrochemical processes slowly penetrate deep into the pores of the plates and the electrolyte on the outside of the plates can also be used (approx. 50 %) , whereby the conversion mainly takes place on the surface of the plates using the electrolyte that is in the pores when discharging takes place at a higher current.

Effect of temperature on capacity

The capacity and the discharge voltage of a battery increase together with the temperature because of, among other things, the lower viscosity of the electrolyte and the lower internal resistance that this causes. However, as the temperature drops, they also reduce because the chemical processes are then less efficient.

Therefore, when selecting a starter battery, the capacity should not be too low. Otherwise, with a wrongly dimensioned battery, there is the danger that at very low temperatures, an internal-combustion engine will not be cranked fast enough and long enough to start it. This fact is demonstrated in Figure 20:

Curve 1a shows the starter speeds as a function of the temperature with the battery

18 Available capacity as a function of temperature and discharge current

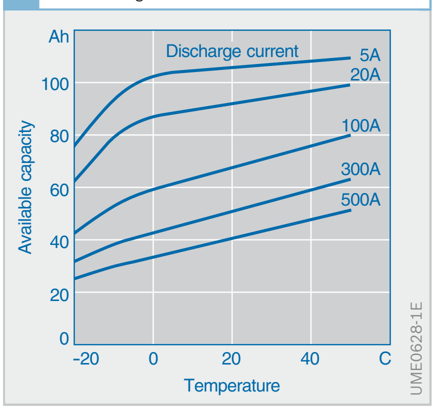


Fig. 18
Battery: 12 V, 100 A·h
(in relation to discharge time of 20 hrs and 100 % state of charge)

20 % discharged (curve 1b is for a heavily discharged battery). Curve 2 shows the minimum starting speed required by an internal-combustion engine. This engine speed is relatively high at low temperatures because of the high frictional resistance in the vehicle engine and the transmission (due to greater lube oil viscosity, for example).

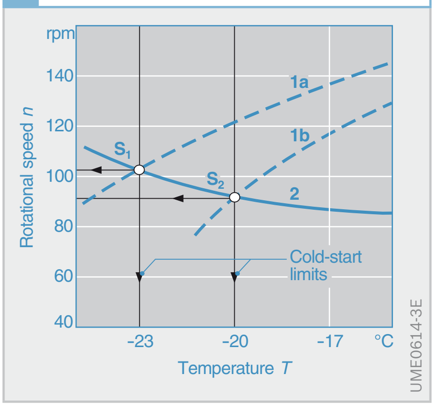
The intersection S_1 of curves 1a and 2 shows the cold start limit (limit temperature) of the 20 % discharged battery. This means that starting is no longer possible at lower temperatures or with a lower battery charge because the output that can be produced by the battery and the starter is less than the starting power that is required by the internal-combustion engine. The more the battery is discharged, the more the cold-start limit (intersection S_2) is shifted to higher temperatures.

Nominal capacity K_{20}

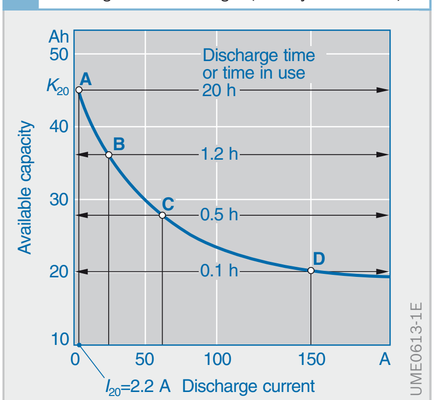
The nominal capacity K_{20} is the battery's rated electrical charge in ampere hours (Ah). According to EN 50 342, this is the electrical charge that can be taken from the battery within 20 h at a fixed discharge current of I_{20} until the specified cutoff voltage of 10.5 V at (25 ±2) °C is reached. The discharge current I_{20} is the current that is allocated to the nominal capacity, and must be delivered by the battery during the total discharge period: $I_{20} = K_{20}/20$ h.

The nominal capacity is a measure for the energy which can be stored by the battery in the as-new condition. It depends on the quantity of active material and upon the electrolyte's specific gravity. For instance, a new 44 Ah battery can be discharged at a current of 2.2 A for at least 20 hours (44 Ah/20 h = 2.2 A) until the cutoff voltage of 10.5 V is reached. The nominal capacity must be taken into consideration in the design of the continuous consumers in the vehicle electrical system of a motor vehicle (Fig. 19).

20 Influence of temperature on starter speed and the engine's minimum start speed



19 Available battery capacity as a function of discharge current strength (battery: 12 V 44 Ah)



21 Discharge of a 12 V battery with a low-temperature test current I_{CC} at −18 °C and at 27 °C

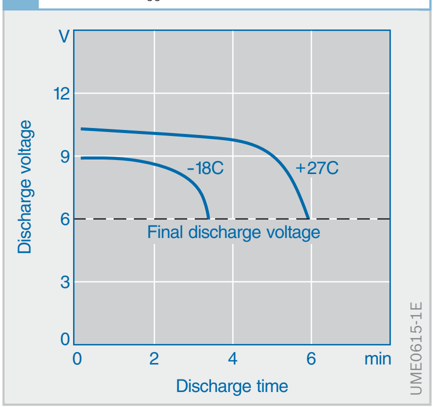


Fig. 19
Current requirement:
- A 20-hour discharging
- B Ignition and lighting
- C In addition, fan, windshield and rear-window heating, fog lamps, wipers and radio
- D Mean starter current

Fig. 20
Example:
- 1a Starter speed Battery discharged by 20 %
- 1b Starter speed Battery heavily discharged
- 2 Minimum engine start speed
- S_1, S_2 Cold-start limit

Low-temperature test current I_{CC}

The low-temperature test current I_{CC} (previously I_{KP}) indicates the battery's current output capability at low temperatures. According to EN 50 342, the battery terminal voltage at I_{CC} and –18 °C and 10 seconds after discharging has started, must be at least 7.5 V (1.25 V per cell). Other details relating to discharge period are specified in the standard. The determining factors of the short-term behavior indicated by I_{CC} are the number of plates, the plate surface area, the plate spacing and the separator material.

A variable that indicates the starting response is the internal resistance R_i. For –18 °C and a full 12-V battery the following applies: $R_i = 4{,}000/I_{CC}$, whereby I_{CC} in amps must be used. The internal resistance R_i is measured in the units mΩ.

The internal resistance of the battery in combination with other sources of resistance in the starter-motor circuit determines the speed at which the engine is turned over when being started. However, the low-temperature test current is defined according to a variety of different testing conditions in different countries so that it is not always possible to make a direct comparison of the cited figures.

For an automotive battery which must provide the electrical energy for the starter, startability at low temperatures is usually more important than the capacity. Since it refers to low-temperature current delivery, the low-temperature test current is therefore a measure for startability. It is extremely dependent on the total surface area (number of plates and plate area) of the active material. The bigger the contact surface there is between the lead material and the electrolyte, the greater the amount of current that can be drained in short bursts. Plate spacing and separator materials are important influencing variable which affect the rapidity of the chemical processes in the electrolyte and which also determine the low-temperature test current.

Type designations

The design specifications and designations of the various types of starter battery are defined by standards in order to make the products of different manufacturers interchangeable (compatibility). Bosch batteries are generally labeled with the following information:

- Characteristics according to EN standard
- European type number (ETN) and general safety instructions for handling batteries
- Bosch part number (TTNR number)
- Customer search number KSN (specially for Bosch Silver)

Characteristic quantities

The battery characteristics defined by European Standard EN 50 342 characterize the specifications/properties of a starter battery. The most important starter battery rating parameters are

- Nominal voltage (e.g. 12 Volts),
- Nominal capacity (e.g. 44 Ah) and
- Low-temperature test current (e.g. 360 amps).

In the USA, a code such as an SAE (Society of Automotive Engineers) number, and in Japan, a JIS (Japanese Industrial Standard) number is used.

European type number (ETN number)
The European type number (ETN) replaced the DIN number in Germany in 1998. It indicates the voltage, capacity and low-temperature test current of the battery concerned.
Example: 5 44 059 036

Code number for battery type:
The first digit of the ETN is a code number for the battery voltage (in the above example, “5” for 12 V). The various code numbers used indicate the following:

1 to 4:	6-Volt batteries
5 to 7:	12-Volt batteries
8:	Specialized batteries
9:	Small traction batteries

Code number for battery capacity:
The second and third digits of the ETN are code numbers for the battery capacity (20 hours) in Ah (44 for 44 Ah in the above example). For capacities over 100 Ah, the first digit is increased by 1 for each 100 Ah (in the range 5 to 7).

Sequence number
The fourth, fifth and sixth digits of the ETN form a serial number (in the above example 059). Various items of information about the battery can be read off on the basis of this number using a list (e.g vibration resistance).

Code number for low-temperature test current:
The seventh, eighth and ninth digits of the ETN form a code number for the low-temperature test current to EN. The figure represents one tenth of the current (in the above example, 036 for 360 A).

Bosch part number (TTNR number)
The alphanumeric Bosch part number (TTNR number) consists of a Bosch combination number for the battery type and a Bosch-coded ETN.
Example: 0 093 S 544 1N

Code number for battery type:
The second and third digits of the TTNR number indicate whether the battery contains antimony or not. 09 corresponds to antimony-free batteries and 18 corresponds to batteries with antimony.

Code number for voltage and capacity:
Digit 6 of the TTNR specifies the battery voltage, and digits 7 and 8 specify the capacity. Digits 1 to 3 have the same coding as the ETN.

Customer search number (KSN number)
For Bosch Silver batteries, there is a customer search number (KSN) which makes it easier for customers to identify the correct battery for a particular vehicle model.

Practical and laboratory battery testing

Various laboratory endurance tests are described in EN 50 342. The standard also describes charge acceptance testing, water consumption testing and vibration resistance testing. Car manufacturers also frequently require other testing to be performed. The charging and discharging cycles of the battery are simulated at extreme temperatures, followed by an engine start. One example is the J240 test, which is oriented to the American SAE standard. It tests the service life of a battery at high temperatures (75 °C).

Useful life
Various claimed battery characteristics can be tested in the laboratory. However, the interaction of the battery characteristics for achieving optimum usage in the vehicle can only be tested in the field. Batteries are therefore tested in driving mode. One example is the taxi test in Las Vegas. Special demands are made of the battery in Las Vegas. High temperatures occur because of the climate, and the battery is also subjected to high cyclic loading due to the nature of taxi driving. The usage time of lead-calcium batteries is 1.4 times longer than conventional batteries, and 3 times longer for lead-calcium-silver alloy.

Self-discharge
The self-discharge of the positive and negative plates is inherent in the principle of the lead storage battery. The effects of temperature and other factors lead to the battery becoming electrically “empty” after a given period of time. Considering conventional starter batteries, antimony poisoning leads to an increase of the self-discharge reaction at the negative plates, and the rate of discharge climbs considerably along with increasing battery age. In the field, this means that after a six-month storage period at room temperature, new, conventional-type starter batteries only

have a state of charge of approximately 65 %. This corresponds to an electrolyte density of 1.20 kg/*l*. Under certain circumstances, old batteries drop to this value within a few weeks. The state of charge of maintenance-free starter batteries after six months is 90 %. The corresponding electrolyte density is 1.26 kg/*l*. It takes 18 months for the state of charge to reach 65 % (electrolyte density ρ = 1.20 kg/*l*) (Fig. 22).

Because the lead-calcium grids have a purer alloy system, completely maintenance-free batteries discharge at a considerably slower rate. The low self-discharge rate of the positive plate and negative plate remains constant during the entire usage period. The self-discharge phenomenon is of particular significance for vehicles used only during specific seasons (agriculture, forestry, and construction sites). It is also important, however, for second cars and mobile homes which are not driven in winter, or only rarely. It also applies to new vehicles which, since there is no stop in production, are manufactured but have to be parked for long periods due to seasonal fluctuations in sales trends or the transportation time to the salesroom (export vehicles).

Starting power

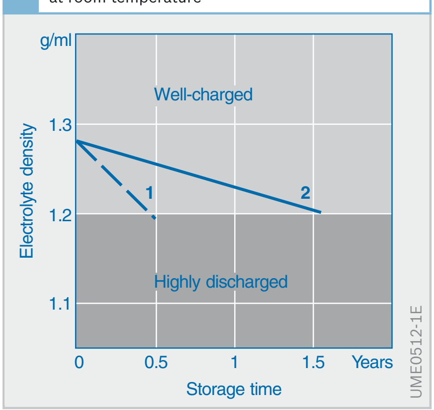
Completely maintenance-free starter batteries with lead-calcium-silver technology have 30 % more starting power than conventional batteries. Basically speaking, this is due to the envelope-type separators with their low specific resistance, and to the increase in plate surface due to the omission of the sediment chamber.

Furthermore, thanks to the lead-calcium alloy used for the plate grids, the maintenance-free battery's starting power remains practically unchanged for years. It does not drop to below the setpoint value for new batteries until towards the end of its useful life. Whereas the completely maintenance-free starter battery is still above the setpoint value after 75 % of its useful life, the conventional battery drops far below this setpoint value considerably sooner (at approx. 40 % of useful life). In practice, it has already lost about a third of its original starting power after only 75 % of its useful life (Fig. 23).

Current draw

Low-antimony and antimony-free batteries behave almost identically during the EN 50342 current draw test. Completely maintenance-free starter batteries have major advantages when charging with regulators that take the battery temperature

22 Electrolyte density as a function of storage time at room temperature



23 Starting power as a function of useful life

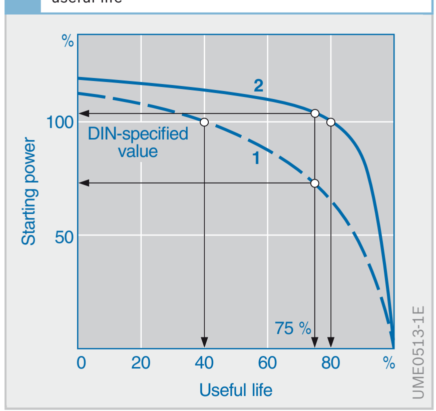


Fig. 22
1 Conventional starter battery (PbSb)
2 Maintenance-free starter battery (PbCa)

Fig. 23
1 Conventional starter battery (PbSb)
2 Maintenance-free starter battery (PbCa)

into consideration and can exceed the voltage of 14.5 V (higher gassing voltage, less water loss). In practice, the differences between the most commonly used regulator characteristic curves (see section "Battery/gassing voltage characteristics") are small, apart from the better current draw of maintenance-free batteries with lead-calcium alloy with a state of charge of less than 50 %. This is due to the phenomenon applying to every battery, namely the fact that the lower the temperature, the higher the charging voltage required for a given state of charge. Since its gassing curve is higher during charging, the completely maintenance-free battery stores the increased charging current without losses due to gassing. In other words it achieves a higher state of charge and therefore provides more starting power.

Resistance to overcharge
Overcharge is a decisive factor with regard to battery life. It applies for instance to vehicles which have very high annual mileages, as well as to courier and agricultural vehicles, construction-site machinery, and long-distance haulage trucks. In such cases, the battery is fully charged, the engine turns at high speed, and the alternator only supplies a few consumers. Under these circumstances, the charging current leads to overcharging, corrosion, and loosening of the active material. In laboratory tests, when these conditions are simulated at an electrolyte temperature of 40 °C and a charge voltage of 14 or 16 V, the maintenance-free starter battery has a considerably longer service life than a battery containing antimony.

Resistance to exhaustive discharge
To check the battery's resistance to exhaustive discharge, lamps are used to discharge it completely, after which it is left 4 weeks in the short-circuit condition. The battery must then be recharged under vehicle electrical system conditions. It must still be operational and it must only display certain specified reductions in performance. For example, a loss of battery capacity that is smaller than a specified limit.

Water consumption
When they are new, starter batteries with and without antimony show a far lower water consumption than the maximum 6 *g*/Ah as stipulated by DIN. As a rule, the lead-calcium battery has a long-term figure of less than 1 *g*/Ah.

The fact that the gassing voltage remains at its high initial level throughout the battery's complete useful life is responsible for the water-consumption figures for completely maintenance-free starter batteries being so favorable. High gassing voltage leads to minimum water decomposition.

This confines the electrolyte checks to
- Every 15 months or 25,000 km for all low-maintenance batteries, and
- Every 25 months or 40,000 km for completely maintenance-free batteries (as per EN)

Summary
Completely maintenance-free batteries have the following benefits.
- The charge voltage only exceeds the gassing voltage at high temperatures. This means that gassing rarely occurs, meaning that topping up with distilled water is unnecessary throughout the battery's useful life.
- Maintenance errors such as forgetting to top up with distilled water or filling with contaminated water cannot occur.
- The risk of skin contact with sulfuric acid and the damage that this causes is avoided.
- Longer service life and durability.
- Consistently high starting power.
- Better short-distance driving performance.
- Better performance capability in all temperature ranges.
- Cheaper maintenance and care.
- Possibility of locating the battery in areas that are difficult to access in the vehicle.

History of the battery

When considering the history of the battery, a number of renowned scientists and inventors deserve particular credit. Above all, such personalities as Luigi Galvani (1789), Alessandro Graf Volta (around 1800), Johan Ritter (around 1800), Gaston Planté (1859) and Camille Faure were decisive in driving on the development of the battery.

At the end of the 19th century grid plates were already being manufactured. Their basic principles are still found in today's lead batteries. In other words, basically speaking the lead battery has hardly changed up to the present day: It still contains cells, grid plates, and sulfuric acid. If we examine the battery more closely, we find that not only has the energy density increased immensely, but also that the previously used materials (in some cases, separators and the housing were made of wood) have been superseded to a great extent by plastic, and complete freedom from maintenance is today standard practice for starter batteries. In exceptional cases, these can achieve a service life comparable to that of the vehicle itself.

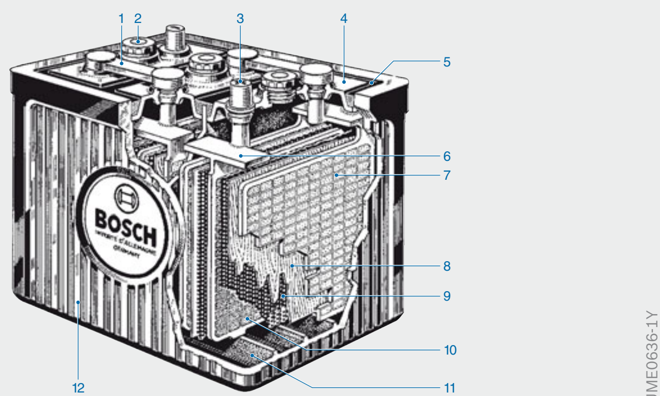
The history of batteries in figures

- 1905: The first batteries were fitted in a motor vehicle (at first only for lighting purposes)
- 1914: The first starter battery was fitted in a motor vehicle
- 1922: The first Bosch motorcycle batteries were installed, and 4 years later the first Bosch battery charger was introduced
- From 1927 onwards, Bosch also developed automotive starter batteries, and mass production started nine years later

After the Second World War, the development of Bosch automotive batteries was marked by the

- Introduction of plastics in battery manufacture (e.g. polystyrene in 1955; polypropylene in 1971)
- The improvement of individual battery components (e.g. the folded-rib separator in 1956; the one-piece battery cover for 6-V batteries in 1964 and for 12-V batteries in 1966; direct cell connectors in 1971; expanded-metal technology for the negative grid in 1985) and
- The production of special-type batteries (e.g. "deep-cycle resistant" in 1969; "low-maintenance" in 1979; "vibration-proof" in 1980; "maintenance-free" in 1982, and "completely maintenance-free" in 1988)

Starter battery: 1951 version



1 Joining bar
2 Sealing plug
3 Terminal post
4 Cell cover
5 Sealing compound
6 Plate strap
7 Negative plate
8 Wooden separator
9 Hard-rubber separator
10 Positive plate
11 Cell connector
12 Battery case

Battery maintenance

Maintenance and care of batteries

Batteries are usually filled in the as-delivered condition, i.e. initial filling with electrolyte is no longer required. Filling may only be needed for certain battery types such as motor cycle batteries and commercial vehicle batteries. In these cases, the operating instructions must be followed.

In many cases, maintenance is not longer needed, and may even no longer be possible, e.g. for maintenance-free batteries such as the Bosch Silver. These batteries lose so little water that topping up with distilled water is not required.

Batteries that do not require maintenance can be detected by the fact that the battery plugs are no longer accessible.

Electrolyte density and state of charge

The electrolyte density is the major indicator for the battery's state of charge. Table 1 shows a number of density figures and the associated freezing thresholds at different states of charge.

Electrolyte density and operating temperature

High temperatures have the effect of accelerating chemical processes in the battery. However, the increase in temperature not only increases the capacity and starting system power, it also has a greater negative effect on the plates (active material falls away and grid corrosion occurs). The self-discharge rate is also accelerated.

Electrolyte density and freezing point

The more the battery is discharged, the more the electrolyte is diluted. This leads to the freezing point rising to more unfavorable temperatures. The electrolyte in a fully charged battery with a specific density of 1.28 kg/*l* has a freezing point of –60 to –68 °C. However, a discharged battery with a specific density of 1.04 kg/*l* has a freezing point of –3 to –11 °C and can freeze when outside temperatures are low (see Table 1).

A battery with frozen electrolyte can only deliver a very low current and cannot be used for starting. A polypropylene battery case remains stable even with frozen electrolyte. Since the fluid does not fully crystallize out, it is unlikely that the housing will fracture. A frozen battery is not to be charged because the frozen electrolyte then starts to swell. The battery must first thaw out before it can be recharged.

Measuring the electrolyte density

The electrolyte density is seldom measured in workshops because maintenance-free batteries are used in the majority of vehicles. A battery syringe is occasionally used to check the electrolyte density of conventional batteries. This is used to draw electrolyte up into the glass tube. The hydrometer (a float with a scale) measures the density of the electrolyte and the measurement can be read off the scale.

Modern acid refractometers use the refraction of the electrolyte to determine the density. Just a small drop of electrolyte is required to perform this measurement. This device can also be used to check the frost protection of the coolant and the washing system water.

On conventional batteries, the electrolyte level should be regularly checked, and if necessary the battery topped-up with distilled water to the “Max” mark. Before the cold season starts, the state of charge should be checked by measuring the electrolyte density. If this is below 1.20 kg/*l*, the battery should be recharged.

1 Electrolyte values of the diluted sulfuric acid

State of charge	Electrolyte density in kg/*l* [1]	Freezing threshold in °C
Charged	1.28	–68
Semi-charged	1.16/1.20 [2]	–17 to –27
Discharged	1.04/1.12 [2]	–3 to –11

Table 1

[1]) At 20 °C: the electrolyte density drops by approximately 0.01kg/*l* for every 14K that the temperature rises and vice-versa when the temperature drops

[2]) Lower value: high electrolyte utilization; higher value: low electrolyte utilization

The electrolyte density of maintenance-free batteries cannot be measured, nor does the battery need to be topped up with distilled water. The Bosch Silver battery provides an indication of the electrolyte density and therefore the charge via the "Power Control System" (Fig. 1). If the indicator in the transparent window is green, the battery is adequately charged. If the indicator is dark, the electrolyte density and therefore the state of charge is too low and the battery needs recharging. If the window is light, the electrolyte has dropped below the minimum level and the battery must be replaced.

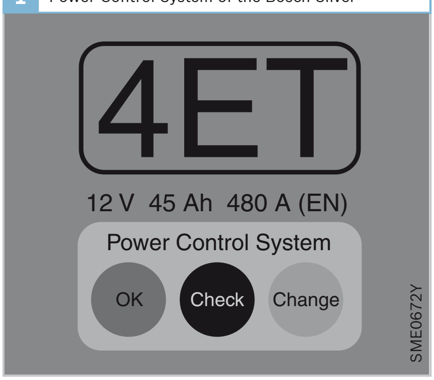
Battery storage

The following storage times are specified for new batteries on the aftermarket:

- Unfilled: unlimited
- Filled, conventional: 3 (max. 6) months
- Filled, completely maintenance-free: 18 months

If the battery is to be stored for longer periods, it must be regularly recharged following the normal charging procedure. Batteries must be stored in a cool and dry state and in a good state of charge. The older a battery gets, the less time it can be stored. As far as possible, the battery is to be trickle-charged with a very low current. If the battery is to remain in the vehicle during the storage period, its ground cable is to be disconnected.

1 Power Control System of the Bosch Silver



Battery charging

If it is impossible for the alternator to charge the battery adequately, a battery charger must be used. This applies when the battery has been out of use for a long time, or directly before it is removed from the vehicle and put into storage.

Charging methods

Normal charging

Generally speaking, normal charging takes place using a battery charge current of I_{10}, which corresponds to 10 % of the battery's nominal capacity:

$$I_{10} = 0.1 \cdot K_{20} \cdot \text{A/Ah}.$$

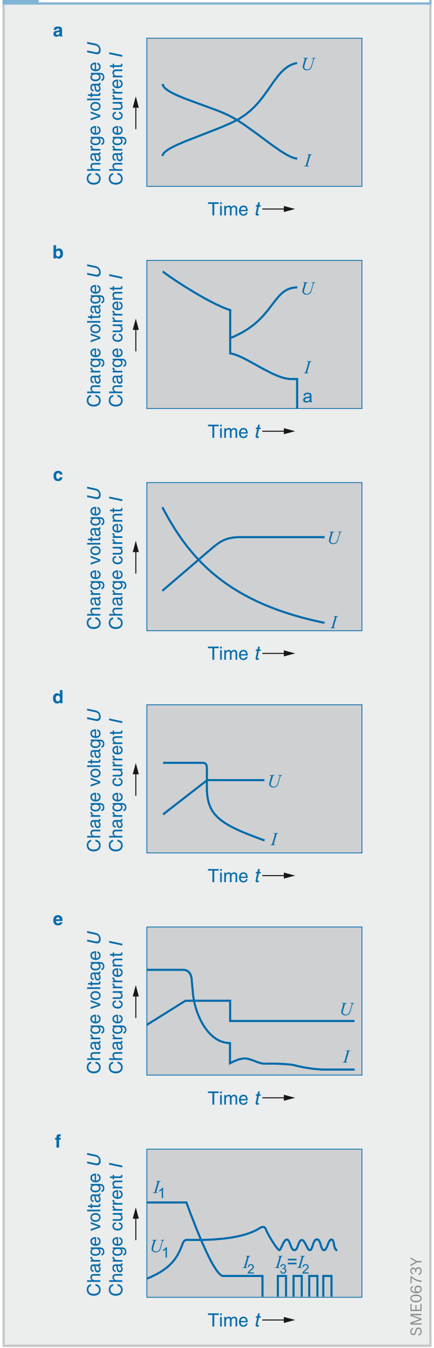
Depending upon the process used, the charging time can be up to 14 hours.

Boost charging

Boost charging can bring a discharged intact battery back up to about 80 % of its nominal capacity so that it can handle loadings which are typical in automotive applications. A high charging current can be used without problems below the gassing voltage – e.g. in the range of the numerical value for the nominal capacity (relative battery charge current $I_1 = K_{20} \cdot \text{A/Ah}$). Once the gassing voltage is reached, the boost charge must either be switched off or changed to normal charging.

The gassing voltage depends on the design of the battery, its age and the electrolyte temperature. If the charge voltage exceeds this value during charging, the battery starts to gas. This leads to water loss in the battery and the production of oxyhydrogen gas. Controlled chargers therefore restrict the charge to a typical 14.4 V (2.4 V/cell) with a cold battery and 13.8 V (2.3 V/cell) with a warm battery.

2 Charging characteristics



Trickle charging
To compensate for the self-discharge losses in stored batteries (for instance when caravan or mobile-home batteries are stored during the winter), the battery is left connected to a battery charger for an extended period of time, whereby charging current is limited to 1 mA/Ah.

Floating-mode operation
With floating-mode operation, the battery charger and the consumers are permanently connected to the battery. This means that energy is drawn from the battery by consumers during charging. The electronics of the charger prevent the battery from becoming overcharged.

Charging characteristics

There are various methods for charging the battery, each of which is characterized by its own charging characteristics (DIN 41 722):

W	Constant resistor (battery charge current drops when the charge voltage increases)
U	Constant charge voltage
I	Constant charging current
a	Automatic shut-off
e	Automatic restart
o	Automatic switch-over to other characteristic curve

The different characteristic curves can also be combined. For instance:

W	Like W characteristic curve but charge voltage remains constant above a given value (e.g. just below the gassing voltage)
IU	Constant charging current up to a value from which voltage remains constant and the charging current falls
WoW	Switch from one W characteristic curve to another

Fig. 2
a W charging characteristic (normal charge)
b WoWa charging characteristic
c WU charging characteristic
d IU charging characteristic (boost charge)
e IUoU charging characteristic
f $I_1U_1I_2aI_3$... charging characteristic

With the W charging characteristic (Fig. 2a) the charging current is determined by the charge circuit resistance and the driving voltage difference according to Ohm's law ($I = \Delta U/R$). Since the charge voltage slowly increases during charging, the driving voltage difference becomes smaller as does the battery charge current.

The W charging characteristic is easiest to achieve, i.e. it leads to cheaper chargers. However, the uncontrolled end of charging and the long charging time taken to fully charge the battery are a disadvantage. The battery charge current drops long before the gassing voltage has been reached.

Both disadvantages are avoided by using the IU charging characteristic (Fig. 2d). A constant high battery charge current I is maintained until the final charging voltage U is reached. This method permits a high level of charge in a short time whereby an overcharge is avoided.

With the IUoU charging characteristic (Fig. 2e) the system U (2.3 to 2.4 V per cell) is permanently switched to a lower voltage (2.23 V per cell) when the final charge voltage is reached (trickle charge).

Battery overcharging is also prevented on equipment with a limited charge voltage (WU characteristic curve, Fig. 2c) or which automatically switches to weaker W charging characteristics when a limit stress is reached (Fig. 2b) or stops charging altogether (Wa characteristic curve).

The $I_1U_1I_2aI_3aI_3$... charging characteristic (Fig. 2f) starts like IU charging. As soon as the battery charge current drops below a certain limit in the U-phase, the system switches to recharging with I_2. This is for a limited time and with a limited voltage. Batteries with defined electrolyte (mat or gel technology) are fully charged, and normal starter batteries with free electrolyte ("wet" batteries) undergo a defined gassing phase with electrolyte mixing. The final trickle charge (I_3aI_3a...) charges at approx. 1A/100 Ah until an upper limit stress is reached, and then shuts off. As soon as the battery voltage has reached a lower limit stress by means of self-discharging, the recharging current I_3 starts again.

Safety requirements

In order to avoid the risk of accidents the charger must have reliable potential separation between the 230V mains and the accessible charging terminals. Additional reverse-polarity protection prevents battery short-circuiting and the destruction of the battery charger if the battery terminals are wrongly connected.

Battery testers

The condition of installed starter batteries can also be checked with battery testers. They mainly measure and evaluate the high-current capability of the battery. The Bosch BAT121 battery tester also makes it possible to print out the result of the test on the built-in thermal printer.

The battery tester is connected to the battery via cables. The low-temperature test current of the battery is selected on the tester, then the test can be started. The digital display shows the following information when the test is complete:

- The available starting power as a percentage of the input value
- The battery voltage
- The evaluation "good" or "replace"
- A charge recommendation if a low state of charge has been detected

Battery chargers

Highly sensitive electronic components such as airbags, car telephones, car radios and electronic control units must be protected from voltage peaks when the battery is being charged. Previously, the battery had to be disconnected from the vehicle electrical system. However, when modern electronic chargers are being used, the battery can be charged with the consumers connected (floating-mode operation). Since charging is faster and there is no danger to the vehicle's electronic consumers, this is of course a considerable help in the vehicle repair shop because:

- Expensive battery removal or disconnection is not required
- Stored data from the car radio, electronic control units, the telephone, the on-board computer etc. is retained
- Electrical consumers (airbags, control units etc.) are protected
- No damage caused by erroneous operation

Electronic charger

Bosch electronic chargers supply an output voltage that is free of damaging voltage peaks. Batteries can therefore be charged while they are installed in the vehicle. The equipment is protected from overcharging, overcurrents and polarity reversal.

The BML2415 electronic charger charges the battery with a WU charging characteristic. The battery charge current is infinitely adjustable. The charger is suitable for trickle charging and floating-mode operation. Discharged batteries are charged at a lower current to begin with, then the current is increased.

The BAT415 electronic charger is suitable for charging conventional batteries and batteries with fixed electrolyte (gel battery or mat battery). This is made possible by the microprocessor-controlled $I_1U_1I_2aI_3aI_3$... charging characteristic. The currents I_1, I_2 and I_3 are optimally adapted to the battery by entering the battery capacity in Ah.

Rapid-start charger

The BSL2470 rapid-start charger BSL2470 has enough power reserves to rapidly charge 12 V and 24 V batteries and provide mains-powered start assistance. Electrical components in the vehicle electrical system are protected from damage during charging and starting. The battery charge current is infinitely adjustable, even deeply discharged batteries can be charged.

The BSL2470 rapid-start charger charges using the WU charging characteristic, and the SL24100E uses the WoWa charging characteristic.

3 Bosch battery service equipment

Fig. 3
a BAT121 battery tester
b BAT415 electronic charger
c BSL2470 rapid-start charger

Important! Start assistance is only permitted on vehicles for which the manufacturer has not imposed limitations or bans on start assistance in the operating instructions.

Start assistance with jumper cables

The battery from another vehicle can be used to provide start assistance. This procedure should only be used if the batteries are installed in both vehicles and the manufacturer's instructions are followed.
For efficient starting assistance, only standardized jumper cables (DIN 72 553) with a conductor cross section of at least 16 mm² must be used for petrol engines and 25 mm² for diesel engines. Both of the batteries (or battery chargers) which are to be connected must have the same nominal voltage. The following operations are required:

- Determine the cause of battery discharge. If the fault is in the electrical system, do not use start assistance since this can damage the battery charger, or the battery and alternator of the vehicle providing the assistance.
- Connect the positive terminal of the discharged battery to the positive terminal of the external power source.
- Connect the negative terminal of the external power source to a bare metallic surface away from the battery (such as the engine ground strap) on the vehicle receiving assistance.
- Check that the battery jumper cables are firmly attached (good electrical contact).
- Start the vehicle with the sound battery. After a brief pause also start the disabled vehicle.
- Once start assistance is complete, disconnect the cable clamps in the reverse order.

Malfunctions

Faults in the battery

Malfunctions caused by internal battery faults (such as short-circuits due to separator wear or loss of active material, open circuit in cell or plate connectors) are irreparable and the battery must be replaced. A cell short-circuit is recognizable from the battery voltage, which is too low by approx. 2 V. When an open circuit occurs in the cell connectors, low currents can often be taken from the battery and it can also be charged, but even when fully charged, the voltage collapses when an attempt is made to start the engine.

Faults in the vehicle electrical system

If no battery defect can be found but the battery remains continuously overcharged (high water consumption, battery voltage permanently above 14.5 V with engine running) or is extremely discharged (no starting power, low electrolyte density in all cells, battery voltage less than approx. 12.3 V, battery voltage continuously less than approx. 13.9 V with engine running), there is a fault in the vehicle electrical system. Reasons for faults may be defects or malfunctions in the following components:

- Alternator (permanent exhaustive discharge, starting no longer possible)
- V-belt (missing alternator drive)
- Regulator (fluctuation in lamp brightness when engine is accelerated, loss of battery water)
- Shutoff relay (consumers remain on when the engine has been switched off)
- Accessories (e.g. radio, clock, alarm system) consuming excessive no-load current

In many cases it may be worth checking the alternator voltage if a battery frequently shows a low state of charge.

Sulfation

If a battery is left discharged for a long period, the fine crystalline lead sulfate that occurs when the battery is discharged may turn into large crystals under unfavorable circumstances. This is difficult or even impossible to revert. Such a battery is then described as "sulfated".

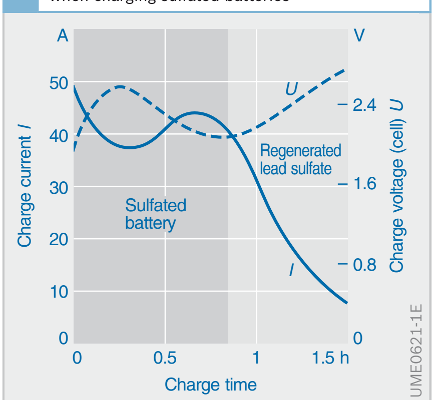
Sulfation is a result of careless maintenance. It causes an increase in the battery's internal resistance which impedes the chemical processes and makes charging more difficult.

A sulfated battery gets very hot when charged with a "W" charging characteristic. The charge voltage rises sharply as soon as charging starts. If sulfation is only slight, the lead sulfate is broken down slowly and the charge voltage drops steadily. As soon as the lead sulfate has been broken down completely (regenerated), the voltage climbs again the same as it does when charging a serviceable, non-sulfated, battery (Fig. 4).

Troubleshooting

If the starter battery fails to start the engine, this can be due to insufficient charge or to a battery defect. If a battery's state of charge is less than 50 %, startability at very low temperatures (-20 °C) can no longer be taken for granted. The battery's exact state of charge can be determined by measuring the electrolyte density and also by precise measurement of the steady-state voltage. This makes it extremely easy to differentiate between a poorly charged battery and a defective but properly charged battery. A state of charge of 50 % is approximately equivalent to a steady-state voltage of 12.3 V. Excessive water consumption, and/or charging immediately before the test will falsify the results in the direction of a more favorable verdict. The charge on the surface of the plates that is falsifying the result can be removed by brief discharging to the extent of 5 % of the nominal capacity.

4 Curve of charge voltage and charging current when charging sulfated batteries



Safety instructions

Short-circuits (e.g. with the tool) can create sparks and cause burning. For this reason the earthing strap must be disconnected before starting work on the electrical system or in the vicinity of the battery (after all consumers have been switched off). Particular care must be taken when connecting/disconnecting battery-charger cables or jumper cables in order to avoid a short-circuit. The following basic rules concerning safety must be followed when working with batteries:

- When handling sulfuric acid or when topping-up batteries which are not maintenance-free with distilled water, always wear protective goggles and rubber gloves
- Do not fill up with electrolyte to above the MAX mark
- Do not tilt batteries to extreme angles from the vertical for long periods
- Due to the risk of electrolytic-gas detonation, smoking and naked flames are not allowed and sparks must be avoided when batteries are being charged (connect and disconnect cables in the prescribed order with the battery charger switched off)
- Battery-charging rooms must be well ventilated