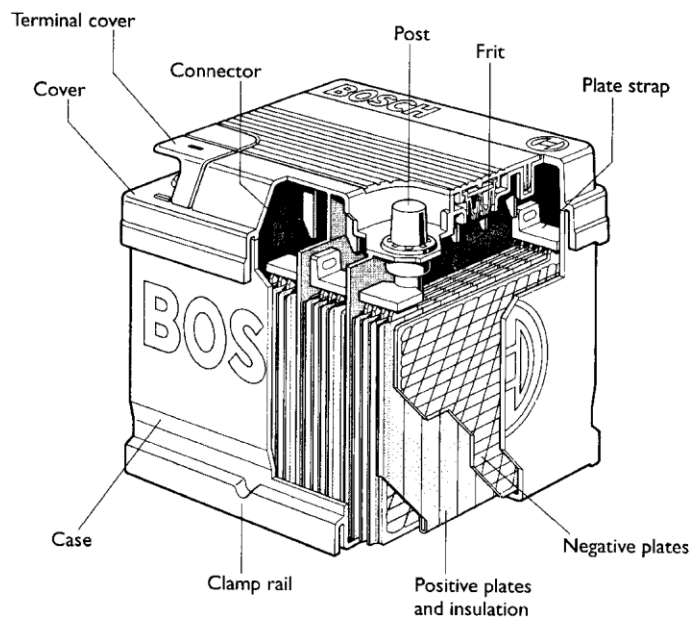


## UNIT I TYPES OF BATTERIES

### Lead-acid batteries

#### Construction

Even after well over 100 years of development and much promising research into other techniques of energy storage, the lead-acid battery is still the best choice for motor vehicle use. This is particularly so when cost and energy density are taken into account. Incremental changes over the years have made the sealed and maintenance-free battery now in common use very reliable and long lasting. This may not always appear to be the case to some end-users, but note that quality is often related to the price the customer pays. Many bottom-of-the-range cheap batteries, with a 12 month guarantee, will last for 13 months! The basic construction of a nominal 12 V leadacid battery consists of six cells connected in series. Each cell, producing about 2 V, is housed in an individual compartment within a polypropylene, or similar, case. Figure shows a cut-away battery showing the main component parts.



#### Lead Acid Battery

The active material is held in grids or baskets to form the positive and negative plates. Separators made from a microporous plastic insulate these plates from each other. The grids, connecting strips and the battery posts are made from a lead alloy. For many years this was lead antimony (PbSb) but this has now been largely replaced by lead calcium (PbCa). The newer materials cause less gassing of the electrolyte when the battery is fully charged. This has been one of the

main reasons why sealed batteries became feasible, as water loss is considerably reduced. However, even modern batteries described as sealed do still have a small vent to stop the pressure build-up due to the very small amount of gassing. A further requirement of sealed batteries is accurate control of charging voltage.

### **Battery rating**

In simple terms, the characteristics or rating of a particular battery are determined by how much current it can produce and how long it can sustain this current. The rate at which a battery can produce current is determined by the speed of the chemical reaction.

This in turn is determined by a number of factors:

- Surface area of the plates.
- Temperature.
- Electrolyte strength.
- Current demanded.

The actual current supplied therefore determines the overall capacity of a battery. The rating of a battery has to specify the current output and the time.

### **Ampere hour capacity**

This is now seldom used but describes how much current the battery is able to supply for either 10 or 20 hours. The 20-hour figure is the most common. For example, a battery quoted as being 44 Ah (ampere-hour) will be able, if fully charged, to supply 2.2 A for 20 hours before being completely discharged (cell voltage above 1.75 V).

### **Reserve capacity**

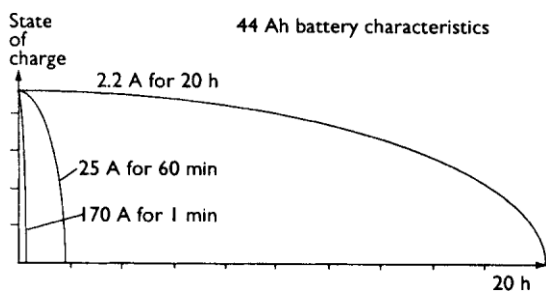
A system used now on all new batteries is reserve capacity. This is quoted as a time in minutes for which the battery will supply 25 A at 25 ° C to a final voltage of 1.75 V per cell. This is used to give an indication of how long the battery could run the car if the charging system was not working. Typically, a 44 Ah battery will have a reserve capacity of about 60 minutes.

### **Cold cranking amps**

Batteries are given a rating to indicate performance at high current output and at low temperature. A typical value of 170 A means that the battery will supply this current for one

minute at a temperature of  $-18^{\circ}\text{C}$ , at which point the cell voltage will fall to 1.4 V (BS – British Standards).

Note that the overall output of a battery is much greater when spread over a longer time. As mentioned above, this is because the chemical reaction can only work at a certain speed. Figure 5.3 shows the above three discharge characteristics and how they can be compared.



**Battery discharge characteristics compared**

## **Maintenance and charging**

### **Maintenance**

By far the majority of batteries now available are classed as 'maintenance free'. This implies that little attention is required during the life of the battery. Earlier batteries and some heavier types do, however, still require the electrolyte level to be checked and topped up periodically.

Battery posts are still a little prone to corrosion and hence the usual service of cleaning with hot water if appropriate and the application of petroleum jelly or proprietary terminal grease is still recommended. Ensuring that the battery case and, in particular, the top remains clean, will help to reduce the rate of self-discharge.

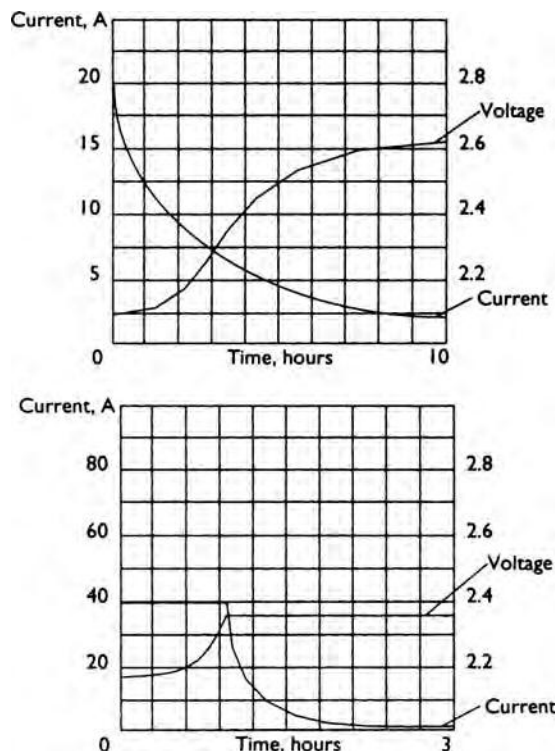
The state of charge of a battery is still very important and, in general, it is not advisable to allow the state of charge to fall below 70% for long periods as the sulphate on the plates can harden, making recharging difficult. If a battery is to be stored for a long period (more than a few weeks), then it must be recharged every so often to prevent it from becoming sulphated. Recommendations vary but a recharge every six weeks is a reasonable suggestion.

### **Battery Charging**

The recharging recommendations of battery manufacturers vary slightly. The following methods, however, are reasonably compatible and should not cause any problems. The recharging process must 'put back' the same ampere-hour capacity as was used on discharge plus

a bit more to allow for losses. It is therefore clear that the main question about charging is not how much, but at what rate.

The old recommendation was that the battery should be charged at a tenth of its ampere-hour capacity for about 10 hours or less. This is assuming that the ampere-hour capacity is quoted at the 20 hour rate, as a tenth of this figure will make allowance for the charge factor. This figure is still valid, But as ampere-hour capacity is not always used nowadays, a different method of deciding the rate is necessary. One way is to set a rate at 1/16 of the reserve capacity, again for up to 10 hours. The final suggestion is to set a charge rate at 1/40 of the cold start

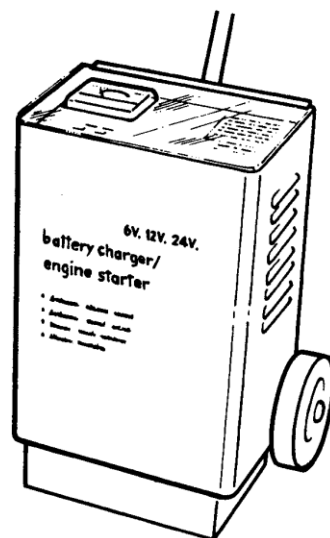


**Two ways of charging a battery showing the relationship between charging voltage and charging current**

Charging method	Notes
Constant voltage	Will recharge any battery in 7 hours or less without any risk of overcharging (14.4 V maximum).
Constant current	Ideal charge rate can be estimated as: 1/10 of Ah capacity, 1/16 of reserve capacity or 1/40 of cold start current (charge time of 10–12 hours or pro rata original state).

Boost charging            At no more than five times the ideal rate, a battery can be brought up to about 70% of charge in about one hour.

Performance figure, also for up to 10 hours. Clearly, if a battery is already half charged, half the time is required to recharge to full capacity. The above suggested charge rates are to be recommended as the best way to prolong battery life. They do all, however, imply a constant current charging source. A constant voltage charging system is often the best way to charge a battery. This implies that the charger, an alternator on a car for example, is held at a constant level and the state of charge in the battery will determine how much current will flow. This is often the fastest way to recharge a flat battery. The two ways of charging are represented in Figure. This shows the relationship between charging voltage and the charging current. If a constant voltage of less than 14.4 V is used then it is not possible to cause excessive gassing and this method is particularly appropriate for sealed batteries. Boost charging is a popular technique often applied in many workshops. It is not recommended as the best method but, if correctly administered and not repeated too often, is suitable for most batteries. The key to fast or boost charging is that the battery temperature should not exceed 43° C. With sealed batteries it is particularly important not to let the battery create excessive gas in order to prevent the build-up of pressure. A rate of about five times the 'normal' charge setting will bring the battery to 78–80% of its full capacity within approximately one hour. Table summarizes the charging techniques for a lead-acid battery. Figure shows a typical battery charger.



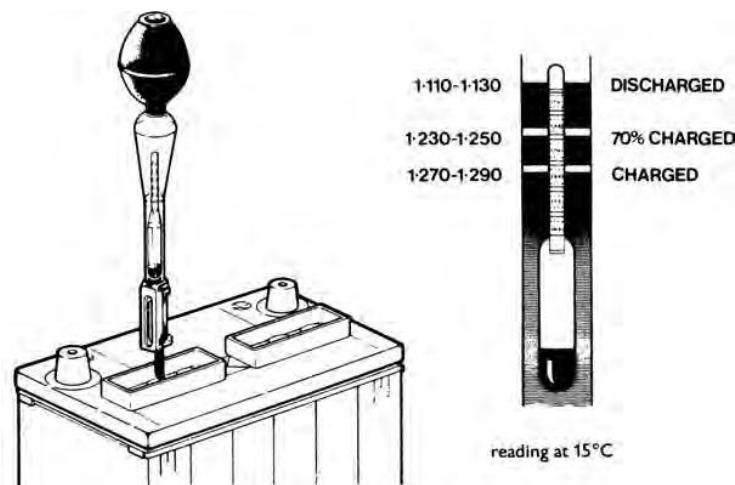
**Battery Charger**

## Various Tests on Battery

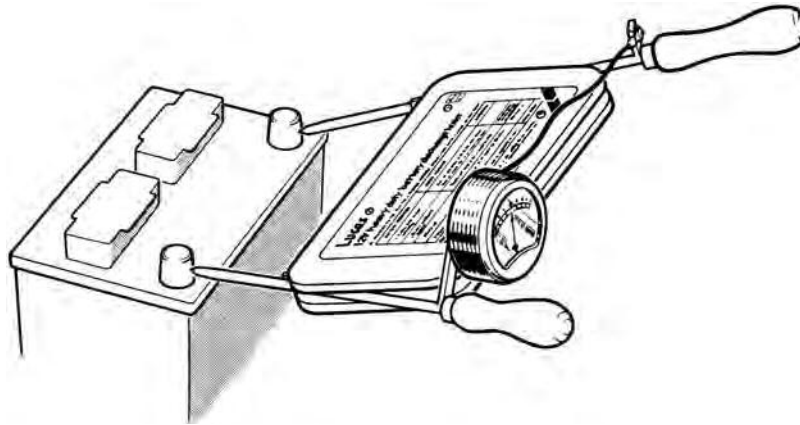
For testing the state of charge of a non-sealed type of battery, a hydrometer can be used, as shown in Figure. The hydrometer comprises a syringe that draws electrolyte from a cell, and a float that will float at a particular depth in the electrolyte according to its density. The density or specific gravity is then read from the graduated scale on the float. A fully charged cell should show 1.280, 1.200 when half charged and 1.130 if discharged.

Most vehicles are now fitted with maintenance free batteries and a hydrometer cannot be used to find the state of charge. This can only be determined from the voltage of the battery, as given in Table. An accurate voltmeter is required for this test. A heavy-duty (HD) discharge tester as shown in Figure is an instrument consisting of a low-value resistor and a voltmeter connected to a pair of heavy test prods. The test prods are firmly pressed on to the battery terminals. The voltmeter reads the voltage of the battery on heavy discharge of 200–300 A. Assuming a battery to be in a fully charged condition, a serviceable battery should read about 10V for a period of about 10 s. A sharply falling battery voltage to below 3 V indicates an unserviceable cell. Note also if any cells are gassing, as this indicates a short circuit. A zero or extremely low reading can indicate an open circuit cell. When using the HD tester, the following precautions must be observed:

- Blow gently across the top of the battery to remove flammable gases.
- The test prods must be positively and firmly pressed into the lead terminals of the battery to minimize sparking.
- It should not be used while a battery is on charge.



**Hydrometer Test of a Battery**



### Heavy Duty Discharge Test

State of charge of a battery

Battery volts at 20 ° C

State of charge

12.0

Discharged (20% or less)

12.3

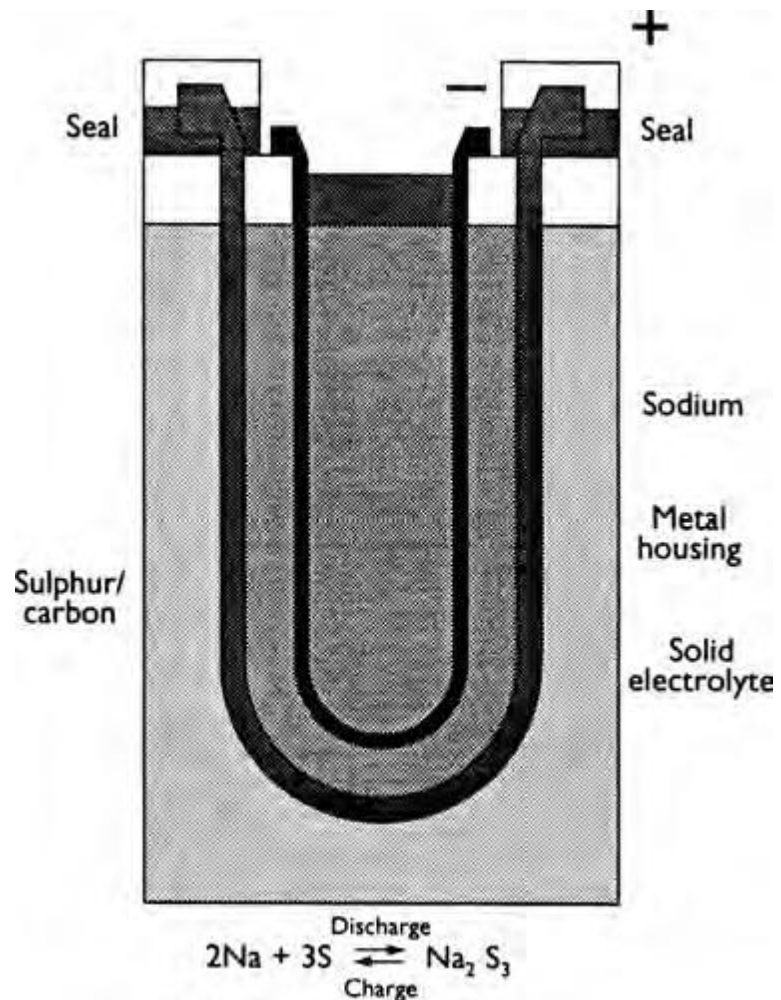
Half charged (50%)

12.7

Charged (100%)

### SODIUM SULPHUR BATTERY

Much research is underway to improve on current battery technology in order to provide a greater energy density for electric vehicles. A potential major step forwards however the sodium sulphur battery, which has now reached production stage. Sodium-sulphur batteries have recently reached the production stage and, in common with the other types listed, have much potential; however, all types have specific drawbacks. For example, storing and carrying hydrogen is one problem of fuel cells.



The sodium-sulphur or NaS battery consists of a cathode of liquid sodium into which is placed a current collector. This is a solid electrode of  $\beta$ -alumina. A metal can that is in contact with the anode (a sulphur electrode) surrounds the whole assembly. The major problem with this system is that the running temperature needs to be 300–350 ° C. A heater rated at a few hundred watts forms part of the charging circuit. This maintains the battery temperature when the vehicle is not running. Battery temperature is maintained when in use due to  $I^2 R$  losses in the battery.

Each cell of this battery is very small, using only about 15 g of sodium. This is a safety feature because, if the cell is damaged, the sulphur on the outside will cause the potentially dangerous sodium to be converted into polysulphides – which are comparatively harmless. Small cells also have the advantage that they can be distributed around the car. The capacity of each cell is about 10 Ah. These cells fail in an open circuit condition and hence this must be taken into account, as the whole string of cells used to create the required voltage would be rendered inoperative. The output voltage of each cell is about 2V. A problem still to be overcome is the casing material, which is prone to fail due to the very corrosive nature of the sodium. At present, an expensive chromized coating is used.

This type of battery, supplying an electric motor, is becoming a competitor to the internal combustion engine. The whole service and charging infrastructure needs to develop but looks promising. It is estimated that the cost of running an electric vehicle will be as little as 15% of the petrol version, which leaves room to absorb the extra cost of production.

### **Alkaline batteries (Nickel – Cadmium Battery)**

Lead-acid batteries traditionally required a considerable amount of servicing to keep them in good condition, although this is not now the case with the advent of sealed and maintenance-free batteries.

However, when a battery is required to withstand a high rate of charge and discharge on a regular basis, or is left in a state of disuse for long periods, the lead-acid cell is not ideal. Alkaline cells on the other hand require minimum maintenance and are far better able to withstand electrical abuse such as heavy discharge and over-charging.

The disadvantages of alkaline batteries are that they are more bulky, have lower energy efficiency and are more expensive than a lead-acid equivalent. When the lifetime of the battery



and servicing requirements are considered, the extra initial cost is worth it for some applications. Bus and coach companies and some large goods-vehicle operators have used alkaline batteries.

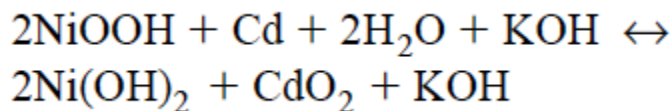
Alkaline batteries used for vehicle applications are generally the nickel-cadmium type, as the other main variety (nickel-iron) is less suited to vehicle use. The main components of the nickel-cadmium – or Nicad – cell for vehicle use are as follows:

\_ positive plate – nickel hydrate (NiOOH);

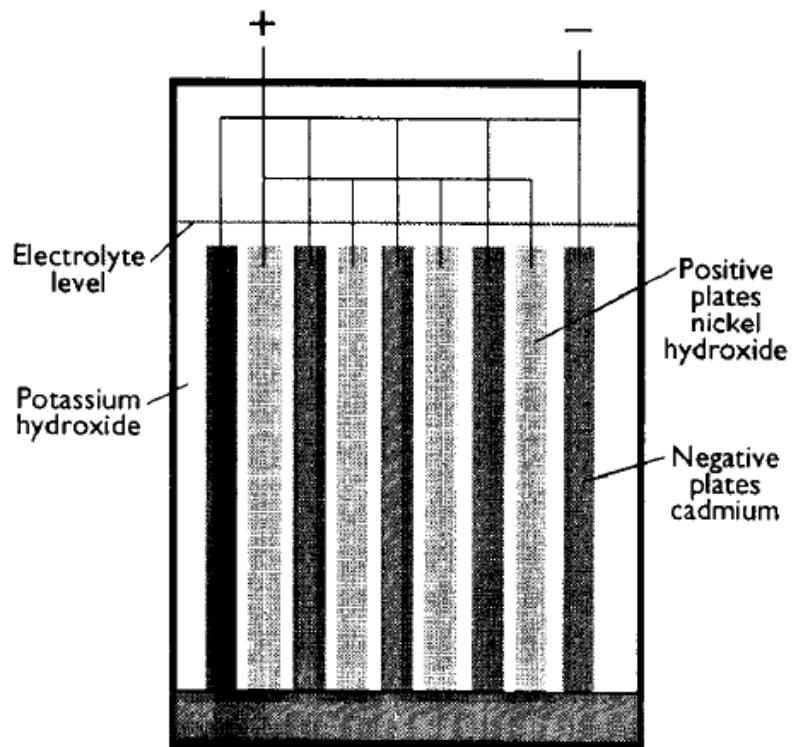
\_ negative plate – cadmium (Cd);

\_ electrolyte – potassium hydroxide (KOH) and water (H<sub>2</sub>O).

The process of charging involves the oxygen moving from the negative plate to the positive plate, and the reverse when discharging. When fully charged, the negative plate becomes pure cadmium and the positive plate becomes nickel hydrate. A chemical equation to represent this reaction is given next but notes that this is simplifying a more complex reaction.



The 2H<sub>2</sub>O is actually given off as hydrogen (H) and oxygen (O<sub>2</sub>) as gassing takes place all the time during charge. It is this use of water by the cells that indicates they are operating, as will have been noted from the equation. The electrolyte does not change during the reaction. This means that a relative density reading will not indicate the state of charge. These batteries do not



**Figure 5.10** Simplified representation of a Nicad alkaline battery cell

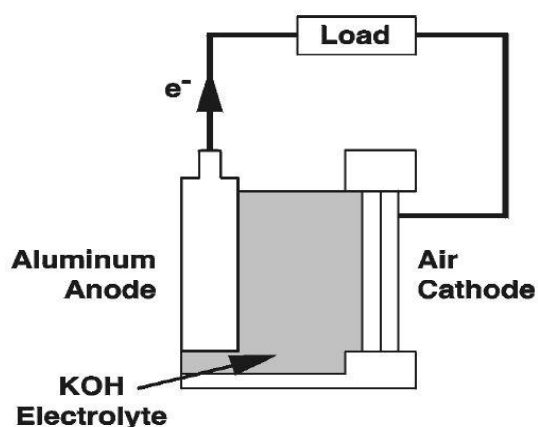
suffer from over-charging because once the cadmium oxide has changed to cadmium, no further reaction can take place. The cell voltage of a fully charged cell is 1.4V but this falls rapidly to 1.3 V as soon as discharge starts. The cell is discharged at a cell voltage of 1.1V.

## ALUMINIUM–AIR BATTERY

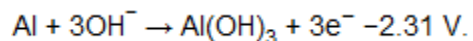
Aluminium–air batteries or Al–air batteries produce electricity from the reaction of oxygen in the air with aluminium. They have one of the highest energy densities of all batteries, but they are not widely used because of problems with high anode cost and byproduct removal when using traditional electrolytes and this has restricted their use to mainly military applications. However, an electric vehicle with aluminium batteries has the potential for up to eight times the range of a lithium-ion battery with a significantly lower total weight.

Aluminium–air batteries are primary cells; i.e., non-rechargeable. Once the aluminium anode is consumed by its reaction with atmospheric oxygen at a cathode immersed in a water-based electrolyte to form hydrated aluminium oxide, the battery will no longer produce electricity. However, it is possible to mechanically recharge the battery with new aluminium anodes made from recycling the hydrated aluminium oxide. Such recycling would be essential if aluminium–air batteries are to be widely adopted.

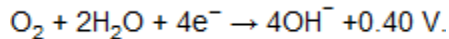
### Electrochemistry



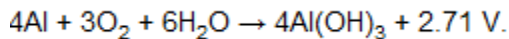
The anode oxidation half-reaction is



The cathode reduction half-reaction is



The total reaction is



About 1.2 volts potential difference is created by these reactions, and is achievable in practice when potassium hydroxide is used as the electrolyte. Saltwater electrolyte achieves approximately 0.7 volts per cell.

## NICKEL–METAL HYDRIDE BATTERY

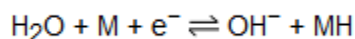
A nickel–metal hydride battery, abbreviated NiMH or Ni–MH, is a type of rechargeable battery. Its chemical reactions are somewhat similar to the largely obsolete nickel–cadmium cell (NiCd). NiMH use positive electrodes of nickel oxyhydroxide (NiOOH), like the NiCd, but the negative electrodes use a hydrogen-absorbing alloy instead of cadmium, being in essence a practical application of nickel–hydrogen battery chemistry. A NiMH battery can have two to three times the capacity of an equivalent size NiCd, and their energy density approaches that of a lithium-ion cell.

The typical specific energy for small NiMH cells is about 100 W·h/kg, and for larger NiMH cells about 75 W·h/kg (270 kJ/kg). This is significantly better than the typical 40–60 W·h/kg for NiCd, and similar to the 100–160 W·h/kg for lithium-ion batteries. NiMH has a volumetric energy density of about 300 W·h/L (1,080 MJ/m<sup>3</sup>), significantly better than NiCd at 50–150 W·h/L, and about the same as lithium-ion at 250–360 W·h/L.

NiMH batteries have replaced NiCd for many roles, notably small rechargeable batteries. NiMH batteries are very common for AA (penlight-size) batteries, which have nominal charge capacities (C) of 1.1–2.8 A·h at 1.2 V, measured at the rate that discharges the cell in five hours. Useful discharge capacity is a decreasing function of the discharge rate, but up to a rate of around 1×C (full discharge in one hour), it does not differ significantly from the nominal capacity. NiMH batteries normally operate at 1.2 V per cell, somewhat lower than conventional 1.5 V cells, but will operate most devices designed for that voltage.

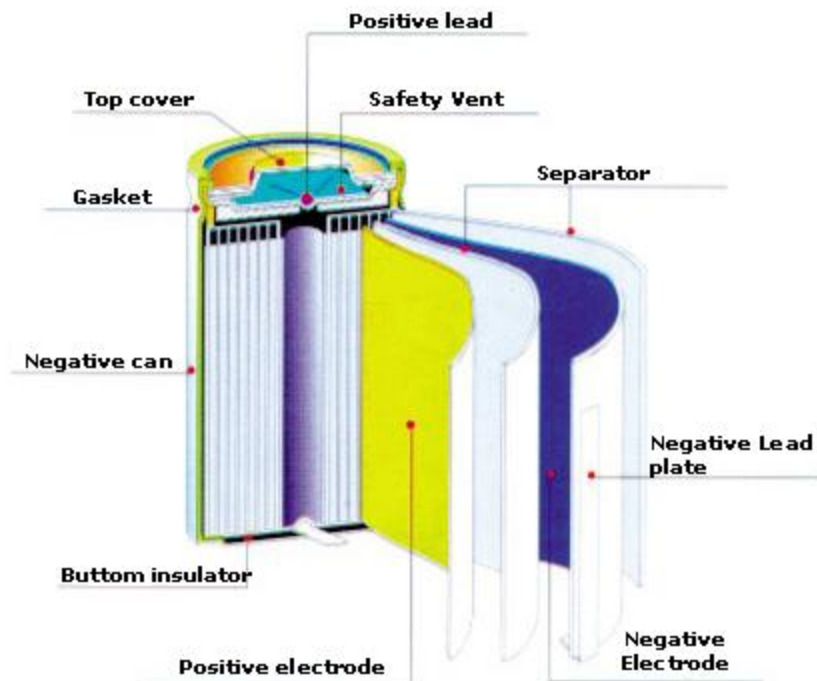
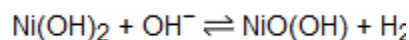
## Electrochemistry

The negative electrode reaction occurring in a NiMH cell is:



The charge reaction is read left-to-right and the discharge reaction is read right-to-left.

On the positive electrode, nickel oxyhydroxide,  $\text{NiO}(\text{OH})$ , is formed:



The "metal" M in the negative electrode of a NiMH cell is actually an intermetallic compound. Many different compounds have been developed for this application, but those in current use fall into two classes. The most common is  $\text{AB}_5$ , where A is a rare earth mixture of lanthanum, cerium, neodymium, praseodymium and B is nickel, cobalt, manganese, and/or aluminium. Very few cells use higher-capacity negative electrode materials based on  $\text{AB}_2$  compounds, where A is titanium and/or vanadium and B is zirconium or nickel, modified with chromium, cobalt, iron, and/or manganese, due to the reduced life performances. Any of these compounds serve the same role, reversibly forming a mixture of metal hydride compounds.

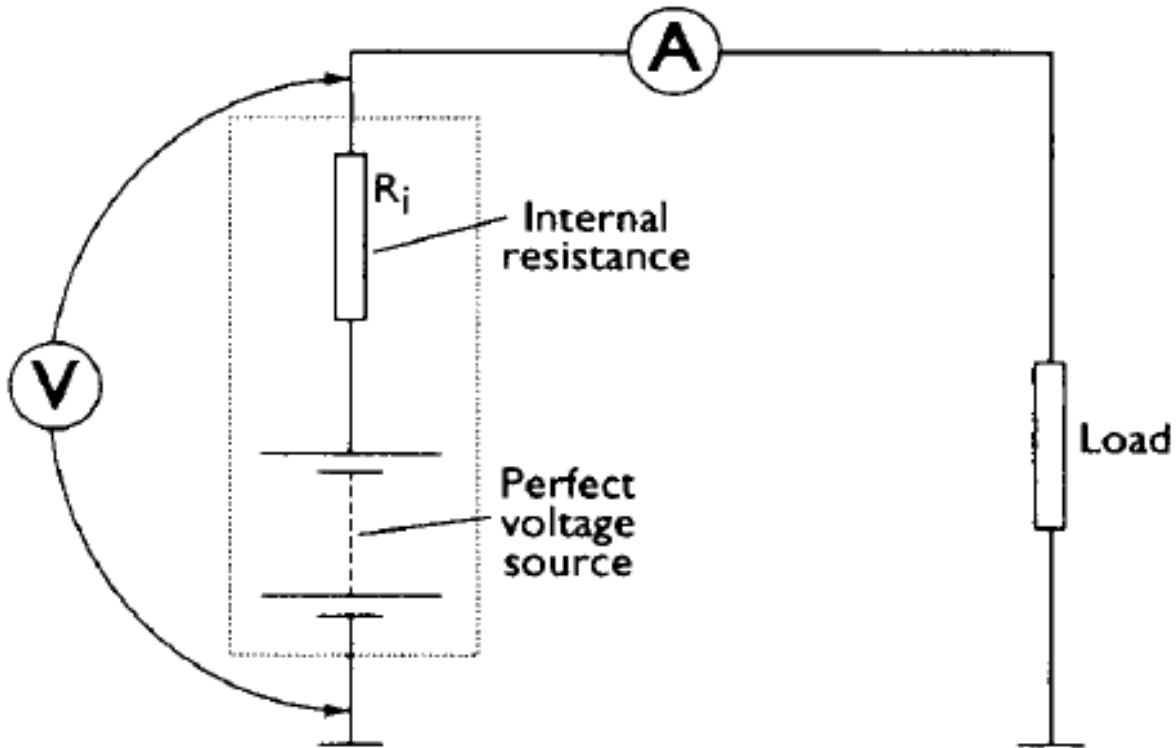
When overcharged at low rates, oxygen produced at the positive electrode passes through the separator and recombines at the surface of the negative. Hydrogen evolution is suppressed and the charging energy is converted to heat. This process allows NiMH cells to remain sealed in normal operation and to be maintenance-free.

NiMH cells have an alkaline electrolyte, usually potassium hydroxide. For separation hydrophilic polyolefin nonwovens are used.

## Characteristics of Battery

### Internal Resistance

- Temperature and state of charge affect the internal resistance of a battery.
- The internal resistance can also be used as an indicator of battery condition –the lower the figure, the better the condition.



### Efficiency

- The efficiency of a battery can be calculated in two ways, either as the ampere-hour efficiency or the power efficiency.

### Ahr (or charge) efficiency

- In an ideal world a battery would return the entire charge put into it, in which case the amp hour efficiency is 100%. However, no battery does; its charging efficiency is less than 100%.

### Energy efficiency

It is defined as the ratio of electrical energy supplied by a battery to the amount of electrical energy required to return it to the state before discharge.

### Self-discharge

- All batteries suffer from self-discharge, which means that even without an external circuit the state of charge is reduced.
- The rate of discharge is of the order of 0.2–1% of the Ah capacity per day. This increases with temperature and the age of the battery.
- The chemical process
- Leakage current across top of the battery