UNIT V

BATTERIES

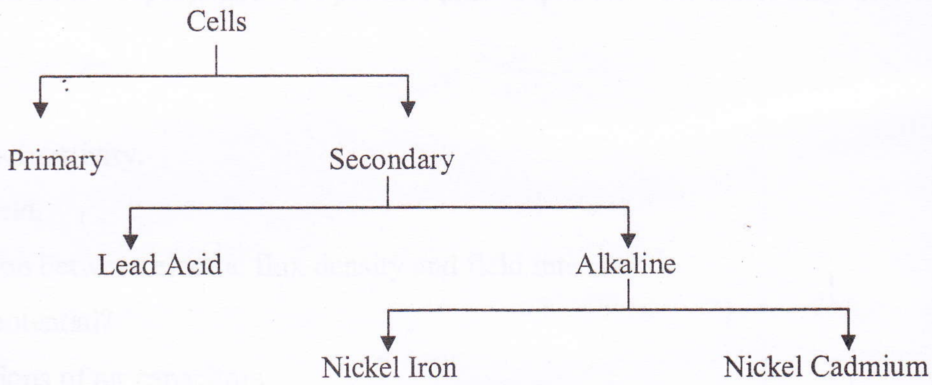
(Qualitative Treatment only)

5.1 Introduction

A Battery is an electrochemical cell (or enclosed and protected material) that can be charged electrically to provide a static potential for power or released when needed.

A Battery generally consists of an anode, a cathode and an electrolyte.

5.2 Classification of Batteries (or) Cells:



(i) Primary Cell:

It is the one that can convert its chemical energy into electricity only once and then must be discarded. Ex. Voltaic cell, Daniel cell, Dry cell, etc.

(ii) Secondary Cell:

It has electrodes that can be reconstructed by passing electricity back through it. It is also called as storage or rechargeable battery; it can be reused many times.

5.3 Construction of Lead Acid Battery:

The construction details of lead acid battery is shown in figure 5.1

1.18 Secondary Cells

It is seen that the secondary cells are rechargeable cells as the chemical reactions in it are reversible. The two types of secondary cells are,

1. Lead acid cell
2. Alkaline cell

Let us discuss these cells in detail.

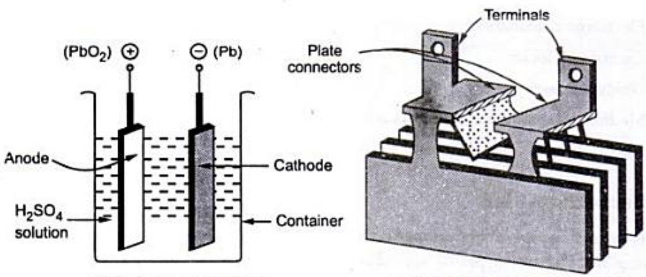
1.19 Lead Acid Battery

The various parts of lead acid battery are,

1. **Positive plate or Anode :** It is **lead peroxide** (PbO_2) plate of chocolate, dark brown colour.
2. **Negative plate or Cathode :** It is made up of **pure lead** (Pb) which is grey in colour.

3. **Electrolyte :** For the necessary chemical action aqueous solution of **sulphuric acid** (H_2SO_4) is used as an electrolyte.
4. **Seperators :** The positive and negative plates are arranged in groups and are placed alternately. The seperators are used to prevent them from coming in contact with each other short circuiting the cell.
5. **Container :** The entire assembly of plates along with the solution is placed in the plastic or ceramic container.
6. **Bottom blocks :** To prevent the short circuiting of cell due to the active material fallen from the plates, the space known as bottom blocks is provided at the bottom of the container.
7. **Plate connector :** The number of negative and positive plates are assembled alternately. To connect the positive plates together seperate connectors are used which are called plate connectors. The upward connections of the plate connectors are nothing but the terminals of the cell.
8. **Vent-plug :** These are made up of rubber and screwed to the cover of the cell. Its function is to allow the escape of gases and prevent escape of electroyte.

The Fig. 1.22 shows the construction of lead acid battery.



(a) Battery construction

(b) Assembly of – ve and + ve plates

Fig. 1.22 Construction of lead acid battery

The various plates are welded to the plate connectors. The plates are immersed in H_2SO_4 solution. Each plate is a grid or frame work. Except some special assemblies, wide space between the plates is provided. In an alternate assembly of plates, the **negative plate is one more in number than positive.** So all the positive plates can work on both the sides.

1.19.1 Functions of Separators

The **separators** used have the following functions in the construction of lead acid battery :

1. Acting as mechanical spacer preventing the plates to come in contact with each other.
2. Prevent the growth of lead trees which may be formed on the negative plates and due to heavy accumulation may reach to positive plate to short circuit the cell.
3. Help in preventing the plates from shedding of the active material. The separators must be mechanically strong and must be porous to allow diffusion of the electrolyte through them.

1.19.2 Chemical Action in Lead Acid Battery

The chemical action in the lead acid battery can be divided into three processes :

1. First charging 2. Discharging 3. Recharging

Let us discuss these processes in detail.

1. First charging : When the current is passed for the first time through electrolyte, the H_2O in the electrolyte is electrolysed as,

$$H_2O \longrightarrow 2\,H^+ + O^-$$

The hydrogen ions as positively charged get attracted towards one of the electrodes which acts as cathode (negative). The hydrogen does not combine with lead and hence cathode retains its original state and colour.

The oxygen ion as negatively charged gets attracted towards the other lead plate which acts as anode (positive). But this oxygen chemically combines with the lead (Pb) to form lead peroxide (PbO_2). Due to the formation of lead peroxide the anode becomes dark brown in colour.

Thus anode is dark brown due to the layer of lead peroxide deposited on it while the cathode is spongy lead electrode.

So there exists a potential difference between the positive anode and the negative cathode which can be used to drive the external circuit. The electrical energy obtained from chemical reaction is drawn out of the battery to the external circuit, which is called discharging.

2. Discharging : When the external supply is disconnected and a resistance is connected across the anode and cathode then current flows through the resistance, drawing an electrical energy from the battery. This is **discharging.** The direction of current is opposite to the direction of current at the time of first charging. The discharging is shown in the Fig. 1.23.

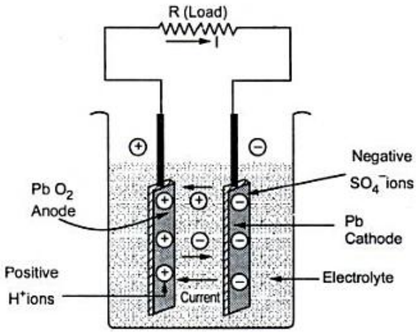


Fig. 1.23 Discharging

During the discharging, the directions of the ions are reversed. The H^+ ions now move towards anode and the SO_4^{--} ions move towards cathode.

This is because $H_2 SO_4$ decomposes as,

$$H_2 SO_4 \longrightarrow 2 H^+ + SO_4^{--}$$

At the anode, the hydrogen ions become free atoms and react with lead peroxide alongwith the H_2SO_4 and ultimately lead sulphate Pb SO_4 results as,

$$PbO_2 + H_2 SO_4 + 2H \longrightarrow Pb SO_4 + 2 H_2 O \quad \text{... At Anode}$$

At the cathode, each SO_4^{--} ion become free SO_4 which reacts with the metallic lead to get lead sulphate.

$$Pb + SO_4 \longrightarrow PbSO_4 \quad \text{... At Cathode}$$

Thus discharging results into formation of whitish lead sulphate on both the electrodes.

3. Recharging : The cell provides the discharge current for limited time and it is necessary to recharge it after regular time interval. Again an e.m.f. is injected through the cell terminals with the help of an external supply.

The charging is shown in the Fig. 1.24.

Due to this recharging current flows and following reactions take place,

At the cathode, $PbSO_4 + 2H \longrightarrow Pb + H_2 SO_4$

At the anode, $PbSO_4 + SO_4 + 2H_2O \longrightarrow PbO_2 + 2H_2SO_4$

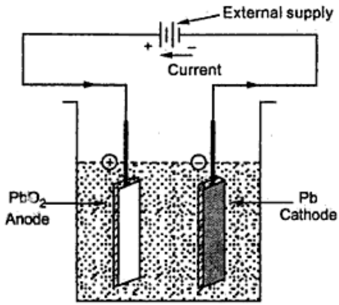


Fig. 1.24 Recharging the lead acid battery

Thus the PbO_2 gets formed at anode while lead sulphate layer on the cathode is reduced and gets converted to grey metallic lead. So the strength of the cell is regained. It can be seen from the reaction that water is used and H_2SO_4 is created. Hence the specific gravity of H_2SO_4 which is the charging indicator of battery, increases.

Key Point: *More the specific gravity of H_2SO_4, better is the charging.*

The specific gravity is 1.25 to 1.28 for fully charged battery while it is about 1.17 to 1.15 for fully discharged battery. The voltage also can be used as a charging indicator. For fully charged battery it is 2.2 to 2.5 volts.

The chemical reaction during charging and discharging can be represented using single equation as,

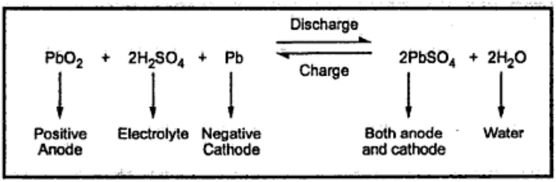


Fig. 1.25

1.19.3 Features of Lead Acid Battery

The various features of lead acid battery are,

1. The capacity is about 100 to 300 ampere-hours.
2. The voltage is 2.2 V for fully charged condition.
3. The cost is low.

4. The internal resistance is very low.
5. The current ratings are high.
6. The ampere-hour efficiency is about 90 to 95% with 10 hour rate.

1.26 Alkaline Cells

The secondary cells can be alkaline cells. These are of two types.

1. Nickel - iron cell or Edison cell
2. Nickel - cadmium or Nife Cell or Junger cell

1.27 Nickel - Iron Cell

In this cell,

Positive Plate → Nickel hydroxide [(Ni(OH) $_3$]
Negative Plate → Spongy iron (Fe)

The electrolyte is an alkali of 21 % solution of **potassium hydroxide solution** (KOH).

The insulated rods are used to seperate the positive and negative plates.

The Fig. 1.38 shows the construction of Nickel-iron cell.

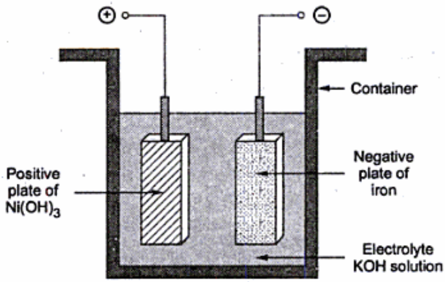


Fig. 1.38 Construction of Nickel-iron cell

1.27.1 Chemical Reaction

In a charged condition, the material of positive plate is $Ni(OH)_3$ and that of negative plate is iron. When it is connected to load and starts discharging, the nickel hydroxide gets converted to lower nickel hydroxide as $Ni(OH)_2$ while the iron on negative plate gets converted to ferrous hydroxide $Fe(OH)_2$. When charged again, reversible reaction takes place, regaining the material on each plate.

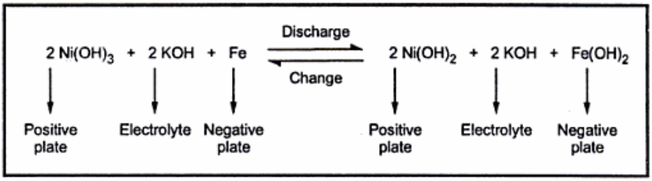


Fig. 1.39 Total reaction

Key Point: *An electrolyte does not undergo any chemical change. Hence its specific gravity remains constant at about 1.2.*

By connecting various Nickel-iron cells properly, the Nickel-iron battery is obtained.

1.27.5 Advantages

The various advantages of Nickel-iron cell are,

1. Light in weight compared to lead acid cell.
2. Compact construction.
3. Mechanically strong and can sustain considerable vibrations.
4. Free from sulphatation and corrosion.
5. Less maintenance is required
6. Do not evolve dangerous attacking fumes.
7. Gives longer service life.

1.27.6 Disadvantages

The various disadvantages of Nickel-iron cell are,

1. High initial cost.
2. Low voltage per cell of about 1.2 V.
3. High internal resistance.
4. Lower operating efficiency.

1.27.7 Application

The Nickel-iron batteries are used in,

1. Mine locomotives and mine safety lamps
2. Space ship
3. Repeater wireless station
4. To supply power to tractors, submarines, aeroplanes etc.
5. In the railways for lighting and airconditioning purposes.

1.28 Nickel - Cadmium Cell

The construction of this cell is similar to the nickel-iron cell except the active material used for the negative plate.

Positive plate $\rightarrow$	Nickel hydroxide [$Ni(OH)_3$]
Negative plate $\rightarrow$	Cadmium (Cd)

The electrolyte used is again 21 % solution of potassium hydroxide (KOH) in distilled water. The specific gravity of the electrolyte is about 1.2.

Little iron is added to cadmium to get negative plate. The iron prevents the caking of active material and losing its porosity.

The Fig. 1.42 shows the construction of Nickel-cadmium cell.

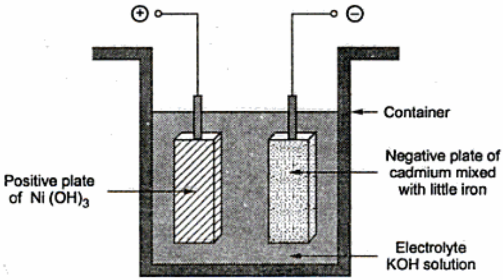


Fig. 1.42 Construction of Nickel-Cadmium cell

1.28.1 Chemical Reaction

In this cell also, in working condition $Ni(OH)_3$ gets converted to lower nickel hydroxide as $Ni(OH)_2$ while cadimum hydroxide $Cd(OH)_2$ gets formed at the negative plate. During charging reverse reaction takes place. The electrolyte does not undergo any chemical change.

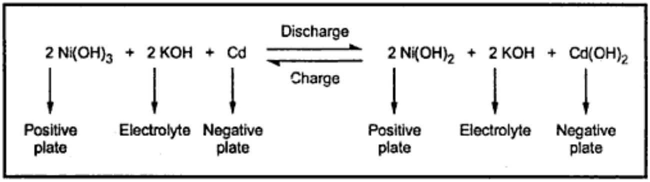


Fig. 1.43 Total reaction

1.28.2 Features

1. The electrical characeristics are similar to the Nickel-iron cell.
2. Due to use of cadmium, internal resistance is low.
3. The efficiencies are little bit higher than Nickel-iron cell.
4. Advantages and disadvantages are same as that of Nickel-iron cell.
5. The various charging methods such as constant current, constant voltage, trickel charging can be used.

1.28.3 Applications

The various applications of Nickel-cadmium battery are,

1. In railways for lighting and air conditioning systems.
2. In millitary aeroplanes, helicopters and commerical airlines for starting engines and provide emergency power supply.
3. In photographic equipments such as movie cameras and photoflash.
4. In electric shavers.
5. Due to small size in variety of cordless electronic devices.

1.29 Comparison of Various Batteries

Sr. No.	Particular	Lead acid cell	Nickel-Iron cell	Nickel-Cadmium Cell
1.	Positive plate	Lead peroxide (PbO_2)	Nickel hydroxide $Ni(OH)_3$	Nickel hydroxide $Ni\ (OH)_3$
2.	Negative plate	Lead (Pb)	Iron (Fe)	Cadmium (Cd)
3.	Electrolyte	Sulphuric acid H_2SO_4	Potassium hydroxide KOH	Potassium hydroxide KOH
4.	Average e.m.f.	2.0 V/cell	1.2 V/cell	1.2 V/cell
5.	Internal resistance	Low	High	Low
6.	Ah efficiency	90 to 95 %	70-80 %	70-80 %
7.	Wh efficiency	72 to 80%	55-60%	55-60%
8.	Ah capacity	Depends on discharge rate and temperature	Depends only on temperature	Depends only on temperature
9.	Cost	Less expensive	Almost twice the lead acid cell	Almost twice the lead acid cell
10.	Life	1250 charges and discharges	About 8 to 10 years	Very long life
11.	Weight	Moderate	Light	More heavy
12.	Mechanical strength	Poor	Good	Good

1.30 Comparison of Primary and Secondary Cells

Sr. No.	Primary Cells	Secondary Cells
1.	Electrical energy is directly obtained from chemical energy.	Electrical energy is present in the cell in the form of chemical energy and then converted to electrical energy.
2.	The chemical actions are irreversible.	The chemical actions are reversible.
3.	Cell is completely replaced when it goes down.	The cell is recharged back when it goes down.
4.	Polarisation is present.	Polarisation is absent.
5.	Low efficiency.	Efficiency is high

6.	Capacity is low.	Higher capacity.
7.	Less cost.	High initial cost.
8.	No maintenance required.	Frequent charging and other maintenance is required.
9.	Examples are dry cell, mercury cell, zinc-chloride cell	Examples are Nickel-iron, lead acid and Nickel-cadmium

1.20 Battery Capacity

The battery capacity is specified in ampere-hours (Ah).

Key Point : *It indicates the amount of electricity which a battery can supply at the specified discharge rate, till its voltage falls to a specified value.*

For a lead acid battery, the discharge rate is specified as 10 hours or 8 hours while the value of voltage to which it should fall is specified as 1.8 V.

Mathematically the product of discharge current in amperes and the time for discharge in hours till voltage falls to a specified value is the capacity of a battery.

$$\text{Battery capacity} = I_D \times T_D \text{ (Ah)}$$

Where I_D = Discharge current in amperes

T_D = Time of discharge in hours till voltage falls to a specified value.

Sometimes it is specified as **watt-hours (Wh)**. It is the product of the average voltage during discharge and the ampere hour capacity of a battery.

The battery capacity depends on the following factors,

1. **Discharge rate :** As the rate of discharge increases, the battery capacity decreases.
2. **Specific gravity of electrolyte :** More the specific gravity of electrolyte, more is the battery capacity as it decides internal resistance of the battery.
3. **Temperature :** As temperature increases, the battery capacity increases. This is shown in the Fig. 1.28.

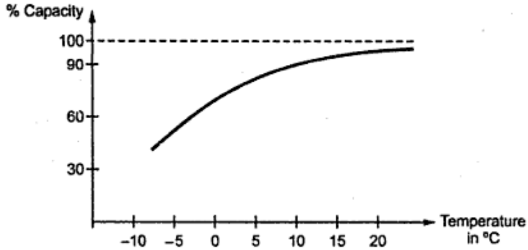


Fig. 1.28 Effect of temperature on battery capacity

4. **Size of the plates :** This is related to the amount of active material present in the battery.

1.21 Battery Efficiency

Mainly the battery efficiency is defined as the ratio of output during discharging to the input required during charging, to regain the original state of the battery.

It is defined in many ways as,

1. Ampere-hour efficiency or quantity efficiency
2. Watt-hour efficiency or energy efficiency

1.21.1 Ampere-hour Efficiency

It is defined as ratio of output in ampere-hours during discharging to the input in ampere-hours during charging. It is denoted as η_{Ah}.

$$\therefore \quad \eta_{Ah} = \frac{\text{Ampere-hours on discharge}}{\text{Ampere-hours on charge}}$$

$$\therefore \quad \boxed{\% \, \eta_{Ah} = \left[\frac{\text{Current} \times \text{Time on discharge}}{\text{Current} \times \text{Time on charge}}\right] \times 100}$$

For lead acid battery, it ranges between 80 % to 90 %.

1.21.2 Watt-hour Efficiency

It is defined as the ratio of output in watt-hours during discharging to the input in watt-hours during charging. It is denoted as η_{Wh}.

$$\therefore \quad \eta_{Wh} = \frac{\text{Watt-hours on discharge}}{\text{Watt-hours on charge}}$$

$$\therefore \ \% \ \eta_{Wh} = \left\{ \frac{[\text{Voltage during discharge (average)}] \times [\text{Current} \times \text{time at discharge}]}{[\text{Voltage during charge (average)}] \times [\text{Current} \times \text{time at charge}]} \right\} \times 100$$

$$= \eta_{Ah} \times \frac{\text{Average voltage during discharge}}{\text{Average voltage during charge}}$$

Key Point: *It can be seen that as average voltage during discharge is less than the average voltage during charge, the watt-hour efficiency is always less than the ampere-hour efficiency.*

For lead acid battery, watt-hour efficiency ranges between 70 % to 80 %.

5.6 Torpedo Batteries:

It is a high power and high energy battery system and mainly used in defence applications.

5.6.1 Types of Torpedo Batteries:

There are three types of Torpedo Batteries namely,

a) Silver-zinc Torpedo batteries
b) Primary Torpedo Batteries
c) Secondary Torpedo Batteries

(a) Silver-zinc Torpedo Batteries:

A silver-zinc battery is composed of a pressed or plastic zinc (Zn) powder for the anode and silver oxide (AgO/Ag_2O) for cathode. A gaseous potassium hydroxide (KOH) is the electrolyte for this battery.

(b) Primary Torpedo Batteries:

Silver-zinc batteries are available as primary cell for single use (combat battery application), providing the needed power within seconds even after a long period of storage, by inserting the electrolyte.

(c) Secondary Torpedo Batteries:

In addition, secondary torpedo rechargeable cells are for multiple use (exercise torpedo application), which allows the torpedo to run with the same power and duration as a combat battery provider.

5.6.2 Range of Torpedo Batteries:

Combat: SLST – C3, SLST – C1 → designed according to the German Military

Exercise: SLST – E1, SLST – MK53 → Heavy weight

5.6.3 Construction:

It consists of the following components and sub units.

(i) Cells

(ii) Battery blocks

(iii) Electrolyte tank

(iv) Gas tank

(v) Activation unit

(vi) Electronic safety device

(vii) Embedded elastic potting material

The type of construction method makes it possible for the torpedo battery withstand all forces coming from outside which will be absorbed by the resin, tie rods and end plates so that all forces coming from outside will be absorbed. So, no environmental loads can affect the functional parts inside the housing. This combat battery is designed to withstand the specified loads like temperature, shock and vibration requirements and to serve the torpedo with excellent electrical performance.

The existence of only one moving part in the entire battery ensures very high reliability. In case of activation of the battery, a built-in resistor system will discharge the battery without external load and ensure safe handling of the battery. During operation, the battery's built-in electronic safety devices, monitor all the critical functions and parameters, SLST – C3 Battery.

5.6.4 Features of Torpedo Batteries:

Some of the salient features of Torpedo Batteries are listed below:

1. Sintered silver electrodes
2. One moving part only needed for activation
3. No maintenance during total shelf life.
4. Hermetically sealed design provides trouble free service under trophical conditions.
5. All parts fixed by potting material.

6. Two independent electrolyte absorbing system.
7. Heating of battery electrolyte only necessary at temperature 15°C.
8. Aluminum battery housing.
9. Electronic safety logic system.
10. Analogue gas tank pressure sensor.
11. Compressed gas refilling capability.
12. High capacity retention during self life.
13. Electromagnetic compatibility (EMC) compliance.

5.6.5 Specifications:

Storage temperature (°C)	- 15 to + 35 *
Transport temperature (°C)	- 15 to + 35 *
Operating temperature (°C)	+ 15 to + 47 (Heating system 'OFF')
Operating temperature (°C)	- 4 to + 15 (Heating system 'ON")
Operating relative humidity (%)	Up to 95

Technical characteristics:

Nominal capacity	-	120Ah
Nominal voltage	-	1, 5V
Minimum charging current	-	6A
Maximum charging current	-	12A
Charging time	-	approx. 10h for 12A
	-	approx. 20h for 6A
Application loads	-	120A, 480A, 600A, 780A
Typical Dry Storage life	-	5 years
Typical Wet Storage life	-	12 months

* Up to one month per year, the storage is allowed to deviate by ±10°C from the specified temperature range.

5.7 Automotive Battery:

It is a type of battery (rechargeable) that supplies electric energy to an automobile. It is commonly called as SLI batteries (start, lighting, ignition).

5.7.1 Types:

There are four types of automotive battery:

(a) Maintenance-free Batteries:

These are designed with durability in mind. These batteries are designed to reduce water loss and provide excellent cranking performance.

(b) Hybrid Batteries:

Hybrid Batteries have one calcium and one low-antimony plate. These batteries typically loose water at much higher rate than a calcium battery and in return they loose cranking power.

(c) Wet or Flooded Batteries:

These are ready to install batteries. They are convenient however, they lack durability and need to be replaced more frequently.

(d) Dry-charged Battery:

It has to be filled with electrolyte before use. This will activate the battery, allowing it to be used. If the battery is not activated, it can stay on the shelf indefinitely.

5.7.2 Construction of Automotive Battery:

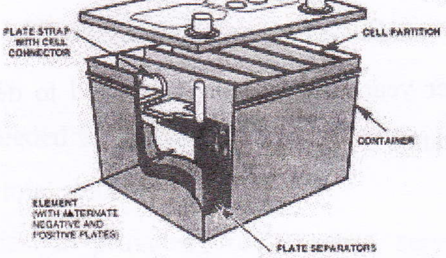


Figure 5.3 Construction of Automotive Battery

Case:

Container which holds and protects all battery components and electrolyte, separates cells, and provides space at the bottom for sediment (active materials washed off plates). Translucent plastic cases allow checking electrolyte level without removing vent caps.

Cover:

Permanently sealed to the top of the case; provides outlets for terminal posts, vent holes for venting of gases and for battery maintenance (checking electrolyte, adding water).

Plates:

Positive and negative plates have a grid framework of antimony and lead alloy. Active material is pasted to the grid. Brown-colored lead dioxide (Pb02) on positive plates, gray-colored sponge lead (Pb) on negative plates. The number and size of the plates determine current capability .Batteries with large plates or many plates produce more current than batteries with small plates or few plates.

Separators:

Thin, porous insulators (woven glass or plastic envelopes) are placed between positive and negative plates. They allow passage of electrolyte, yet prevent the plates from touching and shorting out.

Cells:

An assembly of connected positive and negative plates with separators in between is called a cell or element. When immersed in electrolyte, a cell produces about 2.1 volts (regardless of the number or size of plates).Battery cells are connected in series, so the number of cells determines the battery voltage.

Cell connectors:

Heavy, cast alloy metal straps are welded to the negative terminal of one cell and the positive terminal of the adjoining cell until all six cells are connected in series.

Cell Partitions: Part of the case, the partitions separate each cell.

Terminal posts:

Positive and negative posts (terminals) on the case top have thick, heavy cables connected to them. These cables connect the battery to the vehicle's electrical system (positive) and to ground (negative).

Vent caps:

Types include individual filler plugs, strip-type, or box-type. They allow controlled release of hydrogen gas during charging (vehicle operation). Removed, they permit checking electrolyte and, if necessary, adding water.

Electrolyte:

A mixture of sulpuric acid (H_2SO_4) and water (H_2O). It reacts chemically with the active materials in the plates to create an electrical pressure (voltage). And, it conducts the electrical current produced by that pressure from plate to plate. A fully charged battery will have about 36% acid and 64% water.

5.7.3 Electrochemical Reaction

A lead-acid storage battery can be partially discharged and recharged many times. There are four stages in this discharging/charging cycle.

Charged:

A fully charged battery contains a negative plate of sponge lead (Pb), a positive plate of lead dioxide (Pb02), and electrolyte of sulfuric acid (H2SO4) and water (H20).

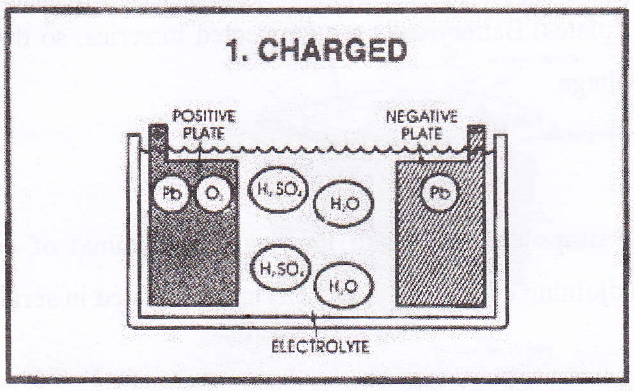


Figure 5.4 Charged Automotive Battery

Discharging:

As the battery is discharging, the electrolyte becomes diluted and the plates become sulfated. The electrolyte divides into hydrogen (H_2) and sulfate(SO_4) . The hydrogen (H_2) combines with oxygen (0) from the positive plate to form more water ($H2_0$). The sulfate combines with the lead (Pb) in both plates to form lead sulfate ($PbSO_4$).

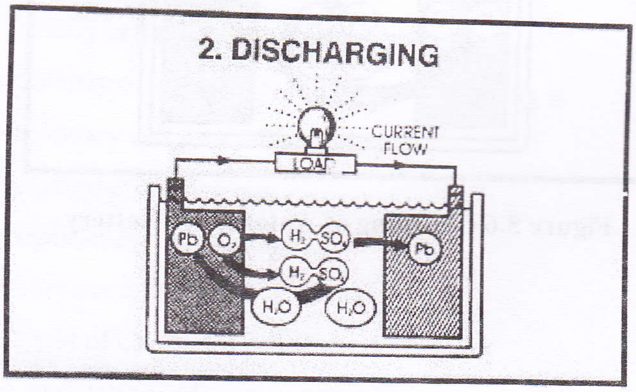


Figure 5.5 Discharging of Automotive Battery

Discharged:

In a fully discharged battery, both plates are covered with lead sulfate ($PbSO_4$) and the electrolyte is diluted to mostly water (H_2O).

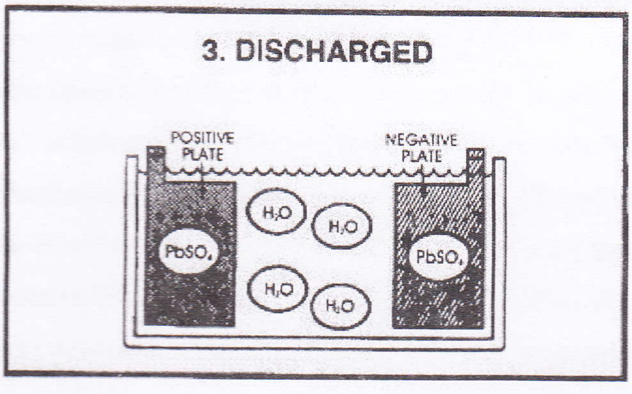


Figure 5.5 Discharged of Automotive Battery

Charging:

During charging, the chemical action is reversed. Sulfate (SO_4) leaves the plates and combines with hydrogen (H_2) to become sulfuric acid (H_2SO_4). Free oxygen (0_2) combines with lead (Pb) on the positive plate to form lead dioxide (PbO_2). Gassing occurs as the battery nears full charge, and hydrogen bubbles out at the negative plates, oxygen at the positive.

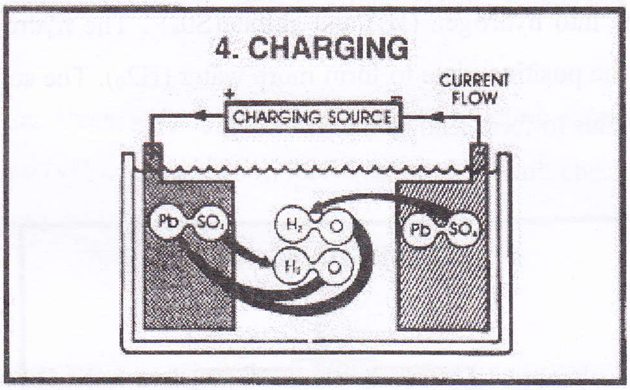


Figure 5.6 Charging of Automotive Battery

Review Questions:

1. What is a Battery?
2. Classify Batteries.
3. What is the use of vent cap in a battery?
4. State the significance of separator.
5. Mention the electrolyte and active materials used in lead acid battery.
6. Define capacity of battery.
7. What is primary cell give some examples?
8. Define efficiency of a battery and ways of expressing it.
9. What is secondary cell give some examples?
10. Define Ampere-hour efficiency.
11. State the significance of separator.
12. Define Watt-hour efficiency.
13. What are types of Cadmium cells?
14. List some applications of storage batteries.
15. What is automotive battery?
16. What are the types of automotive batteries?
17. Explain the construction of lead acid battery with neat sketches.
18. Explain briefly chemical changes in an lead acid battery during charging and discharging.
19. Write short notes about (i) physical changes during charging and discharging in a lead acid battery (ii) capacity and efficiency.
20. Describe the operation of Edison cell with necessary equations.
21. How nickel cadmium cell differ from Edison cell and explain its operation.
22. Compare lead acid cell and nickel iron cells and list its applications.
23. Explain the construction of Torpedo battery and elaborate its technical characteristics.
24. How the automotive batteries are classified. Explain it briefly.
25. Explain the construction and operation of automotive batteries with neat sketches and necessary equations.
26. How the charging of an affected by various factors and explain the causes of battery failure.