CHAPTER

3

BATTERIES

3.1. INTRODUCTION

A cell is a source of Electrical Energy. It produces **direct current**. The *e.m.f.* and current obtained from a single cell are generally small. For example, an ordinary dry cell has an *e.m.f.* of 1·5 volt and can deliver about 0·125 ampere current. Thus, a cell can supply electrical energy to a circuit which requires only 1·5 volt. There are many situations where we require high voltages or high currents or both. High voltages or high currents can be obtained by connecting the cells in series or parallel or series-parallel. The combination of cells is known as a **battery**. The batteries are necessarily used in telephones, motor cars, buses and other automobiles as well as in portable radio receivers etc.

1. Cell : *A cell is a source of e.m.f. (d.c.) in which chemical energy is converted into electrical energy.*

A cell essentially consists of two conducting plates of different materials immersed in an electrolyte. These conducting plates are known as *electrodes*. The +ve plate is known as **anode** and the –ve plate is known as **cathode**. Due to chemical action which takes place between the electrodes and the electrolyte, an electric potential difference is established. When any external load (*Resistance*) is connected between the +ve and –ve terminals of the cell, current I starts flowing through the load as shown in Fig. 3.1. The flow of current produces a gradual change in the chemical composition of electrodes and electrolyte. The process of delivering current continues till one of the electrodes is completely consumed. After this the potential difference between electrodes falls to a very small value and the current ceases to flow. At this stage the cell is said to be discharged.

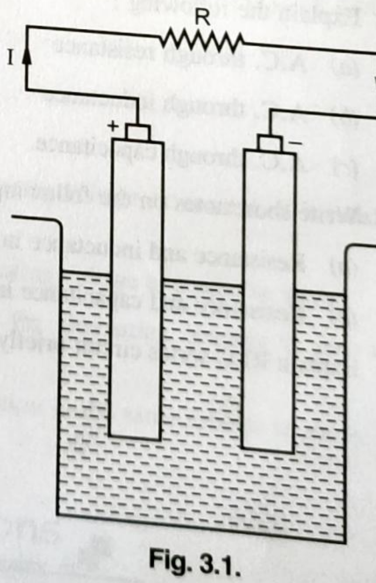


Fig. 3.1.

2. Battery : *When a number of cells are connected in series, parallel or series and parallel, they form a* **battery.** In electrical circuits the battery is represented by the symbol shown in Fig. 3.2.

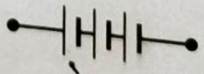


Fig. 3.2.

3.2. BASIC IDEA ABOUT PRIMARY AND SECONDARY CELLS

3.2.1. Primary Cells

The cells in which chemical action is not reversible i.e., once discharged cannot be recharged are called primary cells. One of the plates (generally –ve plate) is completely consumed which cannot be recovered. For example in case of a voltaic cell, there are two plates, one is of copper and the other is of zinc. The electrolyte is a dilute solution of sulphuric acid (H_2SO_4). When it delivers current to the load as shown in Fig. 3.1, zinc dissolves in H_2SO_4 forming $ZnSO_4$. As a result of the chemical reaction, zinc plate goes on consuming. When zinc plate is completely dissolved, the current ceases to flow through the load. In order to revive the process, the –ve plate *i.e.,* zinc plate and electrolyte are replaced with fresh active materials.

The other major drawback of this cell is that the *e.m.f.* developed and the current supplied are very-very small. Therefore, the use of these cells is limited to torches and other electronic toys etc.

3.2.2. Secondary Cells

The cells in which chemical action is reversible are called secondary cells i.e., once exhausted, can be recharged.

When current is delivered to the external load, the chemical process changes the composition of the plates. When the cell is exhausted, the chemical action can be reversed by passing current in the reverse direction through the cell.

In this case, the current is supplied to the cell from some external *d.c.* source and the process is known as *recharging of the cell.*

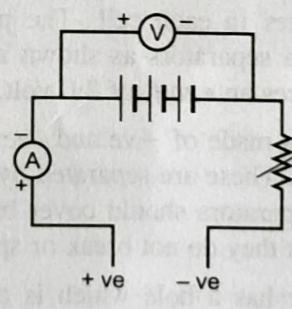


Fig. 3.3.

When a cell delivers current to the external load (*Resistance*), chemical energy is converted into electrical energy, whereas during recharging, the cell receives electrical energy from the *d.c.* source which is converted into chemical energy and is stored in the cell. Secondary cells are also known as storage batteries or accumulators.

3.3. LEAD ACID BATTERY

Due to low initial and overall costs, the lead acid batteries are used in industries. It has one more additional advantage that it can work satisfactorily over a wide range of temperature. Moreover lead is available in plenty and is the main raw material required.

3.3.1. Construction of a Lead Acid Battery

Lead acid battery consists of the following parts :

1. Container
2. The plates
3. Separators
4. Vent caps
5. Connectors
6. Electrolyte
7. Terminals.

No. of –ve plates = 3

No. of +ve plates = 2

No. of separators = 4

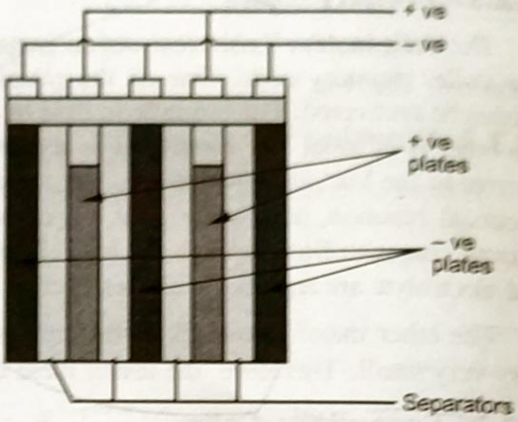


Fig. 3.4.

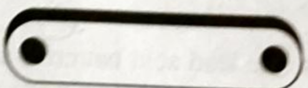
1. Container : Container forms the outer body of the battery. It is made up of some insulating material such as hard rubber. The container material should not have chemical reaction with the electrolyte *i.e.*, sulphuric acid and should be robust and strong. A sufficient space is left at the bottom of the container, so that the sediments that drop from plates are collected here and may not short circuit the +ve and –ve plates.

2. Plates : There are two types of plates. The positive plates and negative plates. The +ve plates of a fully charged cell consist of **Lead Peroxide** (PbO_2). These appear dark chocolate in colour. The colour of negative plates is slate grey and these are *spongy lead* (Pb). To increase the capacity of the battery, we use a large number of plates in each cell. The positive and the negative plates are alternatively placed and sandwiched with separators as shown in Fig. 3.4. One set of positive and negative plates forms a cell which produces an *e.m.f.* of 2·0 volt.

3. Separators : When an assembly is made of +ve and –ve plates, it is necessary to ensure that they do not touch each other at any point. These are separated by a rubber sheet having large number of small holes called *separators*. The separators should cover both sides of the plates. They should have adequate mechanical strength so that they do not break or split.

4. Vent Cap : The lid of container has a hole which is covered with a cap called *vent cap*. The vent cap has small hole called vent hole which provides passage for the escape of gases. It can be removed from the lid for adding water and also for checking the specific gravity of the electrolyte with the help of hydrometer.

5. Connectors : The connectors are thick strips of lead alloy used to connect two cells *i.e.*, +ve terminal of one cell with –ve of the other to put them in series. They have low resistance and high current carrying capacity.



Connector

Fig. 3.5.

6. **Electrolyte :** Dilute sulphuric acid is used as an electrolyte in lead acid batteries. The internal resistance of the cell depends upon the electrolyte and it is found that this value is minimum when the solution has specific gravity of 1·25. So the acid is made dilute by adding acid to distilled water.

7. **Terminals :** Each cell has two terminals, which are marked as +ve terminal and –ve terminal. The +ve terminal of the battery is marked with RED.

3.3.2. Working Principle of Lead Acid Cell

When a lead acid cell is fully charged, its +ve plate is of lead peroxide (PbO_2) and the –ve plate is of spongy lead (Pb). The colour of +ve plate is chocolate brown and that of –ve plate is grey. The specific gravity of electrolyte is 1·28. The plates are immersed in a dilute solution of sulphuric acid (H_2SO_4). When a load is connected across the cell, it starts delivering current to the load. If this process is continued, then the cell gets discharged. During discharging, the chemical energy of the cell is converted into electrical energy which is given to the load.

Chemical action during discharging : During discharging process, the electrolyte gets dissociated into its hydrogen and sulphate ions. The hydrogen ions of the electrolyte (H_2SO_4) move towards the anode and the sulphate ions towards the cathode where they react with anode and cathode and the chemical action takes place as,

At Cathode :

$$\underset{\text{(grey in colour)}}{Pb + SO_4} \longrightarrow \underset{\text{(white in colour)}}{PbSO_4}$$

Fig. 3.6 shows the movement of sulphate ions towards the cathode and hydrogen ions towards the anode. Each hydrogen ion takes one electron which is given up by the sulphate ions to form the hydrogen gas which reacts with the anode and again further PbO reacts with the sulphuric acid (H_2SO_4) to form $PbSO_4$.

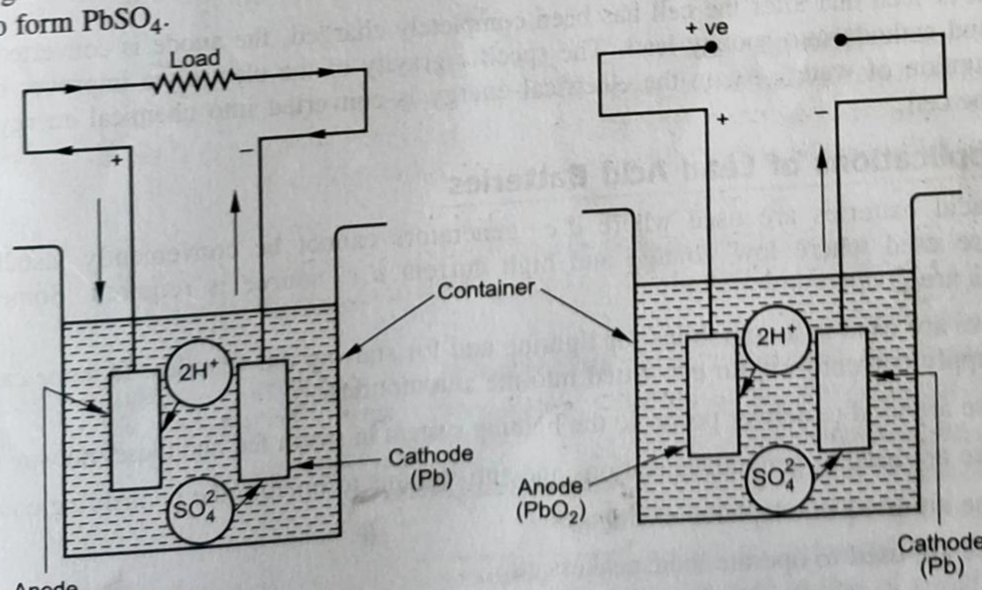


Fig. 3.6.

At Anode :

$$PbO_2 + 2H \longrightarrow PbO + H_2O$$

(chocolate brown in colour)

$$PbO + H_2SO_4 \longrightarrow PbSO_4 + H_2O$$

(white in colour)

It is seen that as the cell is discharged, the lead of the electrodes is converted into white lead sulphate. Moreover, the SO_4 of sulphuric acid being used up, combines with oxygen to produce water. Thus as the cell is discharged, the density of the electrolyte goes down.

Chemical action during charging : The lead acid cells can be recharged by connecting their anode terminal to the +ve terminal of the supply and cathode terminal to the –ve terminal of the supply. During recharging of the cell, the hydrogen ions move towards the cathode and the sulphate ions move towards the anode. Thus the following chemical reactions take place.

At Anode :

$$SO_4 + H_2O \longrightarrow H_2SO_4 + O$$

The oxygen gas appears at the anode and reacts with the anode material ($PbSO_4$).

$$PbSO_4 + O + H_2O \longrightarrow PbO_2 + H_2SO_4$$

(white in colour) (chocolate brown)

Each ion of hydrogen on reacting with cathode takes one electron which is given up by the sulphate to form hydrogen gas, which is liberated at cathode and also reacts with cathode material ($PbSO_4$).

$$\therefore \quad PbSO_4 + 2H \longrightarrow Pb + H_2SO_4$$

(white in colour) (grey in colour)

Thus it is seen that after the cell has been completely charged, the anode is converted into lead peroxide and cathode into spongy lead. The specific gravity of the electrolyte improves because of the consumption of water. Again the electrical energy is converted into chemical energy which is stored in the cell.

3.3.3. Applications of Lead Acid Batteries

Lead acid batteries are used where *d.c.* generators cannot be conveniently installed. Such batteries are used where low voltage and high current *d.c.* source is required. Some of these applications are given below :

1. These are used in automobiles for lighting and for starting the vehciles. In some cases, these batteries supply current to radio etc. fitted into the automobiles.
2. These are used to deliver power to the lighting system in steam fed and diesel railway trains.
3. These are used at generating stations and sub-stations to operate the controlling equipment.
4. These are used in telephone exchanges.
5. These are used to operate loudspeakers etc.
6. These are used to provide emergency lights.

3.4. NICKEL-CADMIUM CELL

Nickel-Cadmium cell was developed by Waldermar Junger in 1899.

When the nickel-cadmium cell is in the charged condition, the active material of the +ve plate (*Anode*) is $Ni(OH)_4$ and the negative plate (*Cathode*) is cadmium (Cd). The electrolyte is a solution of potassium hydroxide (KOH) with a small addition of lithium hydrate. The specific gravity of electrolyte is 1·2. When the cell is discharged, the positive plate is converted to $Ni(OH)_2$ and the negative plate to $Cd(OH)_2$. When the cell is recharged, the chemical process is reversed *i.e.*, positive plate is converted into $Ni(OH)_4$ and negative plate to Cd.

Discharging : When the cell discharges, the potassium hydroxide (KOH) is dissociated into potassium (K^+) and hydroxal (OH^-) ions. The hydroxal ions go to cathode and potassium ions go to anode. The following chemical reactions take place during discharging.

At cathode : $Cd + 2OH \longrightarrow Cd(OH)_2$

At anode : $Ni(OH)_4 + 2K \longrightarrow 2KOH + Ni(OH)_2$

Thus, anode is converted from $Ni(OH)_4$ to $Ni(OH)_2$ and cathode is converted from cadmium (Cd) to cadmium hydroxide $Cd(OH)_2$, the strength of the electrolyte remains same.

Charging : When the cell is placed on charging, the hydroxal (OH^-) ions move towards anode, whereas the potassium (K^+) ions move towards cathode. During charging the following chemical reactions take place.

At anode : $Ni(OH)_2 + 2OH \longrightarrow Ni(OH)_4$

At cathode : $Cd(OH)_2 + 2K \longrightarrow Cd + 2KOH$

Thus, anode and cathode regain their previous compositions without changing the strength of electrolyte.

The *e.m.f.* of nickel-cadmium cell is 1·2 volt when charged and reduces to 1·0 volt when discharged. The specific gravity of electrolyte remains same in charged as well as in discharged conditions. The internal resistance of the cell is very low, even less than lead acid cell. A nickel-cadmium cell can be charged in a very short time *i.e.*, say 1 hour. A nickel-cadmium cell can be used upto 20 years of service.

Small Nickel-Cadmium Cells : The parts of a small nickel-cadmium cell are the same as that of the large size of the **Nickel-Cadmium Cell**. In a small nickel-cadmium cell, the plates are woven in the form of a screen and a paste of active material is pressed into the space within the screen. A separator is put in between the +ve and –ve plates and complete assembly is covered by a small can for protection purpose. The negative plate of the cell is connected with the body of the can which forms the terminal. The +ve plate of the cell is connected to an insulated metal button which is placed at the top. This button forms the positive plate. However, the initial cost of this cell is high as compared to carbon zinc cell (Dry cell), but it is less expensive. The main property of this cell is that it can be recharged and have longer life, whereas dry cells cannot be recharged this is why, these cells have been developed in small sizes *i.e.*, these are of the same size as that of small carbon zinc cell (Dry cell). The *e.m.f.* developed by these cells is 1·2 V.

The main characteristics of small nickel-cadmium cells are as the following :

1. These cells have very low internal resistance.
2. These cells have low maintenance.
3. These cells are less expensive.
4. These cells have very long life.

Applications :

These days small sized **nickel-cadmium cells** find their applications in electric shavers, tape recorders, photography equipment, radios and hearing aids etc.

3.5. SILVER OXIDE BATTERY

The Fig. 3.7 shows the constructional details of a silver oxide cell. It consists of a cathode of silver oxide and an anode of powdered zinc with in an electrolyte of alkaline (*potassium hydro-oxide*). Such type of cells are generally made in small size *i.e.*, button size. The dimensions of diameter of such cell are 0·76 to 1·27 cm where as the thickness is 0·2 to 1·5 cm. The working voltage of the primary cells is 1·5 V.

These cells are leak proof *i.e.*, sealed type and have very small internal resistance. They supply current at a constant voltage of 1·5 volts. Since they are tiny in size interfere, they are very handy and occupy less space.

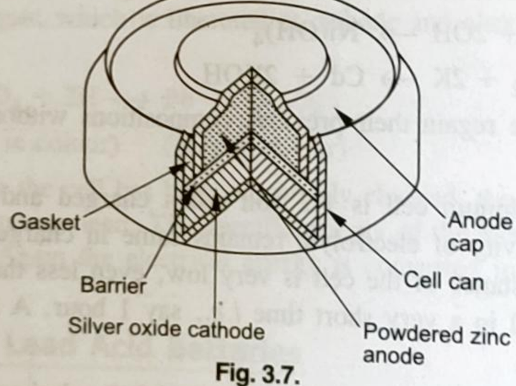


Fig. 3.7.

Chemical reaction during discharging

$AgO + Zn + H_2O \longrightarrow Ag + Zn(OH)_2$

Applications. These cells are suited for hearing aids, electronic watches cameras, small electronic toys and other electronic circuits.

3.6. CHARGING METHODS FOR LEAD ACID BATTERY

When the terminal voltage of the battery falls to about 1·8 volt per cell, it is put under recharging. While charging the batteries, the following points should be kept in mind :

(*i*) The charging voltage of the source should be approximately 2·5 volt/cell.

(ii) D.C. supply is required for charging the batteries. If *d.c.* supply is not available, then *a.c.* is converted into *d.c.* by means of full wave bridge rectifier or by *a.c.* motor *d.c.* generator set.

(iii) Ensure that +ve terminal of the battery is connected with the +ve terminal of the source and –ve terminal of the battery with –ve terminal of the source.

There are two methods for charging the batteries.

1. Constant Current Method : In this method, the charging current supplied to the battery is kept constant throughout the charging process by adjusting the value of variable resistance R as shown in Fig. 3.8.

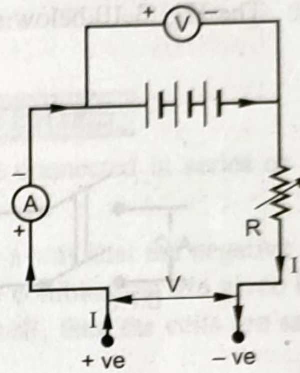


Fig. 3.8.

In the beginning, the battery is discharged. The applied voltage V sends a charging current I against the back *e.m.f.* of the battery. At the start the back *e.m.f.* of the battery is very low, therefore for a particular value of current, higher value of resistor (R_1) is used, then starting current.

$$I_1 = \frac{V - E_{b1}}{(R_1 + r)}, \text{ where } E_{b1}, \text{ is the back } e.m.f. \text{ of the cell.}$$

As the battery is charged, the *e.m.f.* developed in the cells of the battery increases and hence the current decreases. When the battery is fully charged, the back *e.m.f.* (E_{b2}) is increased and hence the current is decreased. Therefore, to keep the current constant the variable resistor is varied from R_1 to R_2 during the charging of the battery.

This method of charging the battery is safe and causes less damage to the plates than constant voltage method. The only drawback of this system is that it takes longer time for complete charging. So this method is not commercially used for battery charging

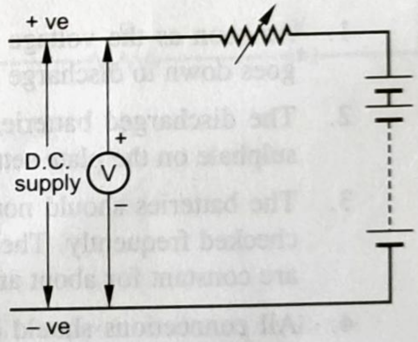


Fig. 3.9.

2. Constant Voltage Method : In this method, the battery is charged from constant *d.c.* supply. The voltage applied must be more than *e.m.f.* of the battery. Generally the voltage applied is 2·5 V per cell for charging the battery. In the beginning there is large charging current, when the back *e.m.f.* of the battery is small. Current drawn by the battery in the beginning is given as :

$$I_1 = \left[\frac{V - E_{b1}}{R + r}\right]$$

The current reduces gradually when the battery is charged. When the battery is fully charged the current may reduce to zero ampere. Then the battery is said to be floating on the supply than the current drawn by the battery when it is fully charged.

$$I_2 = \left[\frac{V - E_{b2}}{R + r}\right]$$

where E_{b2} is back *e.m.f.* of the battery, when fully charged and r is internal resistance of the battery.

In this case the charging current in the beginning is very high, which may loosen the joints of the plate but this method has the advantage that the total time required for charging the batteries is quite small $\left(\frac{1}{2}\text{ of constant voltage method}\right)$. So, this method is commercially used for charging the batteries.

The Fig. 3.10 below shows a practical circuit used to charge a battery.

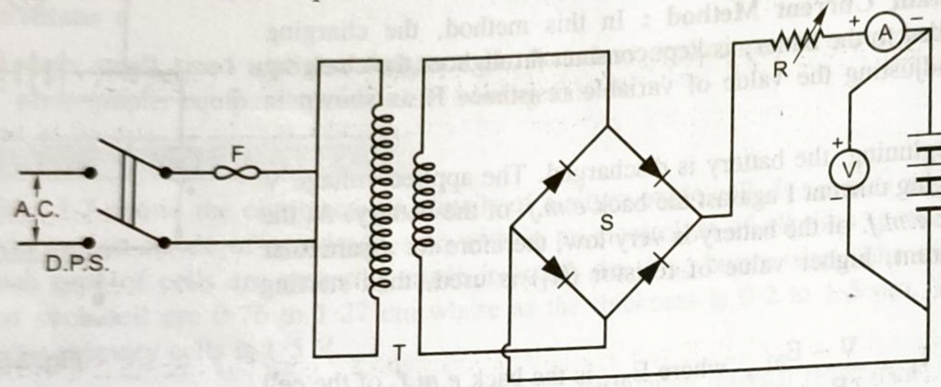


Fig. 3.10.

3.7. CARE AND MAINTENANCE OF LEAD ACID BATTERY

The life of a lead acid battery varies from two to four years depending upon its quality and the care taken during its use. However to get maximum life of the battery, the following points should be noted :

1. As soon as the voltage of the cell reaches 1·8 volt, the specific gravity of its electrolyte goes down to discharge level. The cell should be immediately put on charge.
2. The discharged batteries should be put on charge without any delay otherwise, the lead sulphate on the plate settles down which may damage the batteries.
3. The batteries should not be overcharged. For this, voltage and specific gravity should be checked frequently. The charging should be disconnected when voltage and specific gravity are constant for about an hour.
4. All connections should be tight. The battery room should be free from dirt and dust and should be dry.
5. Since some gases are evolved from the lead acid batteries, therefore, these should be placed in a ventilated room.
6. The charging rate should not be high as this may cause the plates to buckle and the active material may come out off the plates.
7. The level of the electrolyte should be proper. Normally shortage of level of electrolyte is due to evaporation and gassing. It should be checked at a regular interval and should be 1 cm above the plates and separators as this prevents the decay of separators. As only water evaporates therefore, distilled water should be added.

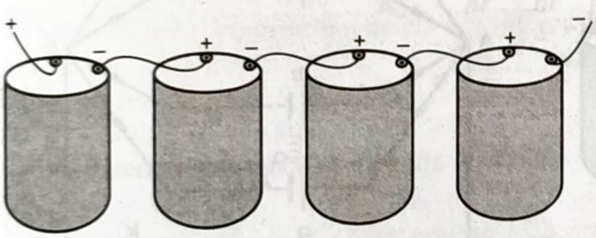
8. Check the vent holes and see that these are open and not blocked by dust and dirt.
9. While preparing electrolyte from sulphuric acid and distilled water, it is the acid which should be added to water. The addition of water to acid causes the mixture to boil dangerously with excessive evolution of heat.
10. Since the internal resistance of the lead acid battery is very low, (being 0·01 Ω) a short circuit will give a damaging current of several hundred ampere. This will damage the plates of the battery.

3.8. SERIES AND PARALLEL CONNECTIONS OF BATTERIES

In order to get maximum current, a number of cells should either be connected in series or in parallel or in mixed grouping.

***(i)* Grouping of cells in series.** If a number of cells are joined in such a way that the negative of one cell is joined to the positive of the other cell and two terminals of the combination are given by free positive terminal of 1st cell and the free negative terminal of the last cell, then the cells are said to be connected in series.

Let n cells, each of E.M.F. E volt and internal resistances r ohm be connected in series through external resistance R.



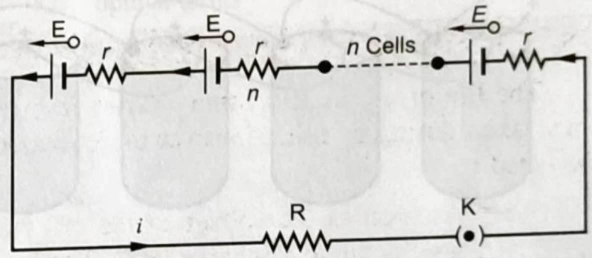


Fig. 3.11.

$$\therefore \quad \text{Total E.M.F.} = nE$$

$$\text{Total internal resistance of cells} = nr$$

$$\text{So total resistance in circuit} = nr + R$$

$$\text{Current, I} = \frac{\text{Total E.M.F.}}{\text{Total resistance}} = \frac{nE}{R + nr}$$

If R << r then external resistance R is negligible as compared to internal resistance r. So current

$I = \frac{nE}{nr} = \frac{E}{r}$. It is equal to current given by one cell and hence this grouping is of no use.

If R >> r so that nr is negligible as compared to R then

$$I = \frac{nE}{R}$$

This current is n times the current due to one cell.

Thus, *always connect cells in series if total internal resistance of cells is negligible as compared to external resistance in the circuit.*

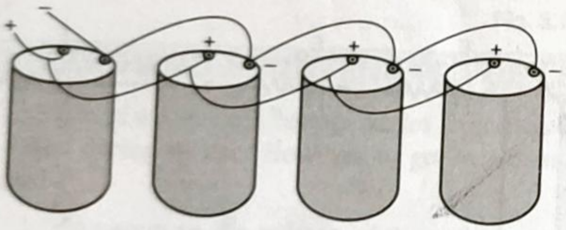
***(ii)* Grouping of cells in parallel.** Cells are grouped in parallel if a number of cells are connected in such a way that all the positive poles are connected at one point and all the negative poles at an other point. Connect m cells, each of E.M.F. E volt and internal resistance r ohm in parallel with external resistance R ohm.

Total E.M.F. = E volt

Let total internal resistance of the combination of all cells be R_i then

$$\frac{1}{R_i} = \frac{1}{r} + \frac{1}{r} + \frac{1}{r} + \ldots \text{ upto } m \text{ terms}$$

$$\frac{1}{R_i} = \frac{m}{r}$$



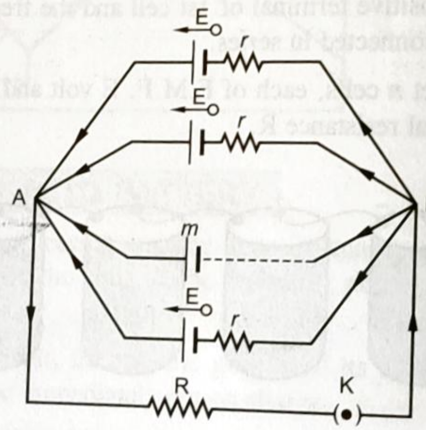


Fig. 3.12.

$$\therefore \quad R_i = \frac{r}{m}$$

$$\text{Total resistance} = R + \frac{r}{m}$$

$$\text{Current, I} = \frac{\text{Total E.M.F.}}{\text{Total resistance}} = \frac{E}{R + \frac{r}{m}} = \frac{mE}{mR + r}$$

If internal resistance $\frac{r}{m}$ is negligible as compared to external resistance R, then I = E/R. It is same as given by one cell. So, it is of no use.

When external resistance R is negligible as compared to internal resistance r, then $I = \frac{mE}{r}$. It is equal to m times the current given by one cell.

The cells must be connected in parallel if external resistance in circuit is negligible as compared to total internal resistance of cells.

(iii) **Mixed grouping.** In this grouping, a number of cells are connected in series in a row and then a number of rows are connected in parallel.

Let n cells each of E.M.F. E volt and internal resistance r ohm be connected in series so as to form a row. Connect m such rows in parallel with external resistance R and key K as shown in Fig. 3.13.

Total E.M.F. = Potential difference between A and B = nE.

Let internal resistance of n cells connected in series in 1 row be R_1, then $R_1 = nr$.

m rows of this type are connected in parallel. If total resistance of all the cells is R_2, then

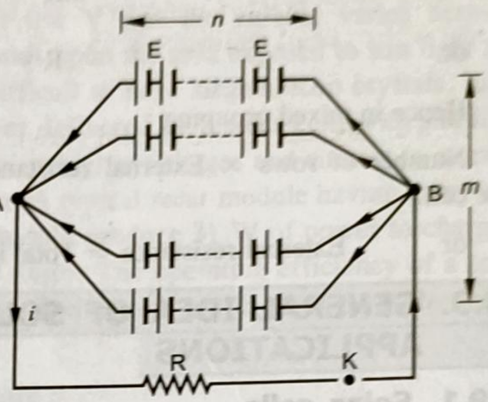


Fig. 3.13.

$$\frac{1}{R_2} = \frac{1}{nr} + \frac{1}{nr} + \frac{1}{nr} + \ldots \text{ upto } m \text{ terms}$$

$$= \frac{m}{nr}$$

$$\text{Total internal resistance of all cells} = \frac{nr}{m}$$

$$\text{Total resistance in circuit} = \frac{nr}{m} + R$$

$$\text{Current, } I = \frac{\text{Total E.M.F.}}{\text{Total resistance}} = \frac{nE}{\frac{nr}{m} + R} = \frac{mnE}{nr + mR}$$

Cells should be combined in mixed grouping if total internal resistance of cells is comparable with external resistance, mn (total number of cells and E.M.F., E is constant, so current will be maximum if mR + nr is minimum).

$$mR + nr = \left(\sqrt{mR}\right)^2 + \left(\sqrt{nr}\right)^2 - 2\sqrt{mnRr} + 2\sqrt{mnRr}$$

$$= \left(\sqrt{mR} - \sqrt{nr}\right)^2 + \sqrt{2mnRr}$$

mn, R and r are constant, so mR + nr is minimum if $\left(\sqrt{mR} - \sqrt{nr}\right)^2$ has minimum value. Minimum value of a square is zero as it cannot have negative value.

So, I is maximum if $\left(\sqrt{mR} - \sqrt{nr}\right)^2 = 0$

or if $$\sqrt{mR} - \sqrt{nr} = 0$$

$$mR = nr$$

or $$R = \frac{nr}{m}$$

Hence in mixed grouping :

Number of rows × External resistance = No. of cells in one row × Internal resistance of one cell.

or External resistance = Total internal resistance of battery for getting maximum current.

3.9. GENERAL IDEA OF SOLAR CELLS, SOLAR PANELS AND THEIR APPLICATIONS

3.9.1. Solar cells

A *device which converts light energy (e.g. sun light) directly into electrical energy is called* **solar cell.**

The construction of a simple solar cell is as shown in Fig. 3.14(*a*). A pure silicon (semiconductor) wafer is dopped (*the process of adding a suitable impurity to a pure semiconductor is called dopping*) with a specific amount of arsenic as (*donor impurity which has 5 electrons in its outermost orbit*). This makes it an N-type semiconductor containing number of free electrons.

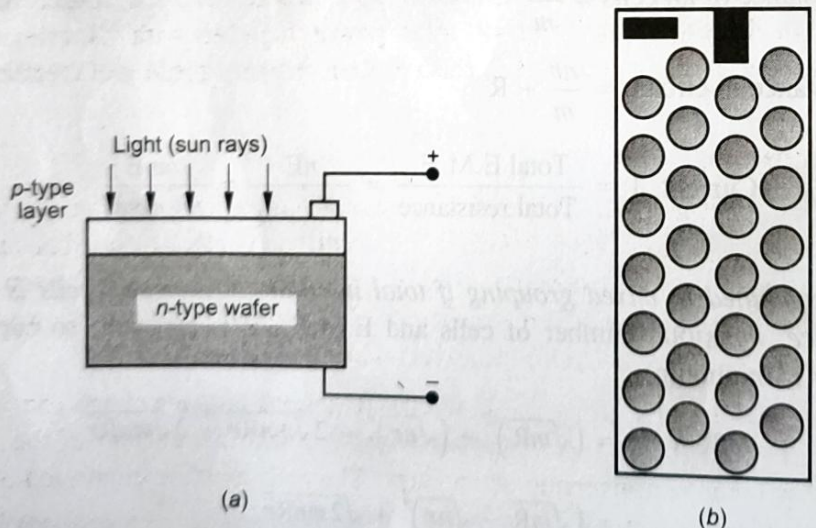


Fig. 3.14.

The wafer is coated at its top with a thin layer of silicon dopped with appropriate amount of boron (*acceptor impurity having 3 electrons in its outermost orbit*). This makes the top layer a P-type semiconductor. Thus, a contact surface becomes a P-N junction. A spot on the P-type layer and bottom of wafer (*N-type material*) are tinned for connecting the leads.

When light (sun rays) falls on the top of P-type layer and penetrates into the N-type material just below it, the free electrons in N-type material gain energy and move across the P-N junction into P-type semiconductor. This continuous movement of charge carriers (*free electrons from N-type and holes from P-type*) constitutes electric current.

The operating voltage of one solar cell is about 0·4 V and the current varies between 30 to 40 mA. The power developed by a solar cell depends upon the area exposed to sun light and the intensity of light falling on its surface. Since it is difficult to have large silicon crystals, hight power can not be developed. The maximum output power delivered by a solar cell, with sun light directly on a clear day is about 8 to 9 mW/cm^2. To develop higher voltages and current, a number of solar cells are connected in series parallel combination. A typical solar module having thirty six, 90 mm diameter silicon cells-on this 1100 × 42·5 cm module produce 31 W of power to charge a 12 V battery at 13·8 V and 2·25 A ; is shown in Fig. 3.14*(b)*. The operating efficiency of a solar cell is quite low (about 10%). Since, they do not deteriorate when not in use, therefore, they have very long life.

Applications : The major applications of solar cells are :

(i) To charge nickel cadmium or silver oxide cadmium batteries in satellites.

(ii) To provide power to calculators, radio transistors, clocks etc.

(iii) To provide power to control devices such as aperture control for movie cameras, microwave relay stations etc.

3.9.2. Solar Panel

Solar panel refers to a panel designed to absorb the sun's rays as the source of energy for generating electricity or heating. The price of solar power together with batteries for storage, has continued to fall so that in many countries is cheaper than ordinary fossil fuel electricity from the grid.

Theory and Construction :

Solar modules use light energy from the sun to generate electricity through the photo-voltaic effect. The majority of mudules use wafer based crystalline silicon cells or thin film cells based on cadmium telluride or silicon. The structural member of a module can either be the top layer or the back layer. Cells must also be protected from mechanical damage and moisture. Most solar modules are rigid, but semi-flexible ones are available, based on thin film cells.

Electrical connections are made in series to achieve a desired output voltage and in parallel to provide a desired current capability. The conducing wires that take the current of the module may contain silver, copper or other non-magnetic conductors. The cells must be connected electrically to one another and the rest of the system.

Applications :

There are many practical applications for the use of solar panels on photovoltaics. It can first be used in agriculture, as a power source for irrigation. In health care, solar panels can be used to refrigerate medical supplies.

3.10. MAINTENANCE FREE BATTERIES

It is also known as a VRLA (Valve-Regulated Lead Acid) battery. More commonly called as a 'Sealed Battery (SLA) or Maintenance Free Battery. It is a type of lead acid rechargeable battery. Due to their construction, the Gel and AGM types of VRLA can be mounted in any orientation and do not require constant maintenance. The term "maintenance free" is a misnomer as VRLA batteries still require cleaning and regular functional testing. They are widely used in large portable electrical devices of grid power, similar roles, where large amount of storage are needed at a lower cost other than low maintenance technology like lithium ion.

Important and Expected Questions

Q.1. What are the applications of lead acid batteries ?

Ans. Lead acid batteries are used where *d.c.* generators cannot be conveniently installed. Such batteries are used where low voltage and high current *d.c.* source is required. Some of these applications are given below :

1. These are used in automobiles for lighting and for starting the vehciles. In some cases, these batteries supply current to radio etc. fitted into the automobiles.
2. These are used to deliver power to the lighting system in steam fed and diesel railway trains.
3. These are used at generating stations and sub-stations to operate the controlling equipment.
4. These are used in telephone exchanges.
5. These are used to operate loudspeakers etc.
6. These are used to provide emergency lights.

Q.2. Discuss the construction and working of nickel cadmium cell.

Ans. Nickel-Cadmium cell was developed by Waldermar Junger in 1899.

When the nickel-cadmium cell is in the charged condition, the active material of the +ve plate (*Anode*) is $Ni(OH)_4$ and the negative plate (*Cathode*) is cadmium (Cd). The electrolyte is a solution of potassium hydroxide (KOH) with a small addition of lithium hydrate. The specific gravity of electrolyte is 1·2. When the cell is discharged, the positive plate is converted to $Ni(OH)_2$ and the negative plate to $Cd(OH)_2$. When the cell is recharged, the chemical process is reversed *i.e.,* positive plate is converted into $Ni(OH)_4$ and negative plate to Cd.

Discharging : When the cell discharges, the potassium hydroxide (KOH) is dissociated into potassium (K^+) and hydroxal (OH^-) ions. The hydroxal ions go to cathode and potassium ions go to anode. The following chemical reactions take place during discharging.

At cathode : $Cd + 2OH \longrightarrow Cd(OH)_2$

At anode : $Ni(OH)_4 + 2K \longrightarrow 2KOH + Ni(OH)_2$

Thus, anode is converted from $Ni(OH)_4$ to $Ni(OH)_2$ and cathode is converted from cadmium (Cd) to cadmium hydroxide $Cd(OH)_2$, the strength of the electrolyte remains same.

Charging : When the cell is placed on charging, the hydroxal (OH^-) ions move towards anode, whereas the potassium (K^+) ions move towards cathode. During charging the following chemical reactions take place.

At anode : $Ni(OH)_2 + 2OH \longrightarrow Ni(OH)_4$

At cathode : $Cd(OH)_2 + 2K \longrightarrow Cd + 2KOH$

Thus, anode and cathode regain their previous compositions without changing the strength of electrolyte.

The *e.m.f.* of nickel-cadmium cell is 1·2 volt when charged and reduces to 1·0 volt when discharged. The specific gravity of electrolyte remains same in charged as well as in discharged conditions. The internal resistance of the cell is very low, even less than lead acid cell. A nickel-cadmium cell can be charged in a very short time *i.e.*, say 1 hour. A nickel-cadmium cell can be used upto 20 years of service.

Q.3. What precautions would you observe in the maintenance of a battery.

Ans. The life of a lead acid battery varies from two to four years depending upon its quality and the care taken during its use. However to get maximum life of the battery, the following points should be noted :

1. As soon as the voltage of the cell reaches 1·8 volt, the specific gravity of its electrolyte goes down to discharge level. The cell should be immediately put on charge.
2. The discharged batteries should be put on charge without any delay otherwise, the lead sulphate on the plate settles down which may damage the batteries.
3. The batteries should not be overcharged. For this, voltage and specific gravity should be checked frequently. The charging should be disconnected when voltage and specific gravity are constant for about an hour.
4. All connections should be tight. The battery room should be free from dirt and dust and should be dry.
5. Since some gases are evolved from the lead acid batteries, therefore, these should be placed in a ventilated room.

Q.4. What are the major applications of solar cells ?

Ans. The major applications of solar cells are :

(i) To charge nickel cadmium or silver oxide cadmium batteries in satellites.

(ii) To provide power to calculators, radio transistors, clocks etc.

(iii) To provide power to control devices such as aperture control for movie cameras, microwave relay stations etc.

Q.5. What are maintenance free batteries ?

Ans. It is also known as a VRLA (Valve-Regulated Lead Acid) battery. More commonly called as a "Sealed Battery (SLA) or Maintenance Free Battery. It is a type of lead acid rechargeable battery. Due to their construction, the Gel and AGM types of VRLA can be mounted in any orientation and do not require constant maintenance. The term "maintenance free" is a misnomer as VRLA batteries still require cleaning and regular functional testing. They are widely used in large portable electrical devices of grid power, similar roles, where large amount of storage are needed at a lower cost other than low maintenance technology like lithium ion.

Objective Type Questions

1. .... cells can be recharged.

2. In lead acid battery, electrolyte is ....

3. The *e.m.f.* developed by a small nickel cadmium cell is ....

4. The small nickel cadmium cell requires very less ....
5. .... batteries are leak proof.
6. .... method is most suitable for charging a battery.
7. Series grouping is preferred when internal resistance of a cell is .... than external resistance.
8. Parallel grouping is preferred when internal resistance of cell is .... than external resistance.
9. The top layer of the solar cell is of .... semiconductor.
10. The operating voltage of one solar cell is about ....

Answers

1. Secondary	2. H_2SO_4	3. 1·2 V	4. maintenance
5. silver oxide	6. constant voltage	7. very less	8. much higher
9. *p*-type	10. 0·4 V.		

Review Questions

1. What is a cell ? What is the difference between primary cell and secondary cell ?
2. Explain construction and working of a lead acid battery.
3. Write the important applications of a lead acid battery.
4. Describe the following :
   (*a*) Nickel cadmium battery
   (*b*) Silver oxide battery.
5. Explain the various methods of charging the batteries
6. What precautions would you observe in the care and maintenance of a lead acid battery ?
7. Describe the series and parallel connections of batteries.
8. What are the major applications of solar cells ?
9. What is a solar panel ? Explain its construction.
10. Write a short note on maintenance free batteries.

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