in chemical action. It was the first cell in which a depolarizer was used to avoid polarization and amalgamated zinc rod for preventing local action.

This cell consists of an outer copper vessel (Fig. 9.5) which serves as a positive electrode of the cell. This vessel contains a concentrated solution of copper sulphate ($CuSO_4$) which acts as the depolarizer. Inside this vessel is a porous pot containing dilute sulphuric acid ($H_2SO_4$) and an amalgamated zinc rod. This zinc rod acts as the negative electrode of the cell. The copper sulphate solution is kept saturated by placing crystals of copper sulphate in the solution.

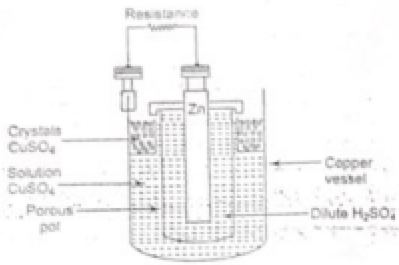


Fig. 9.5 *Daniell cell*

When the terminals of the cells are joined to form a closed circuit, the zinc electrode in the porous pot begins to dissolve in the dilute sulphuric acid ($H_2SO_4$) and thus hydrogen ions ($H^+$) are liberated. These hydrogen ions pass through the porous pot, thus entering the copper sulphate solution ($CuSO_4$) and forming $H_2SO_4$ and copper ions ($Cu^{++}$). These copper ions are deposited over the copper vessel. The chemical reaction inside the porous pot may be represented as follows:

$$\underset{\text{(Zinc)}}{Zn^{++}} + \underset{\text{(Sulphuric acid)}}{H_2SO_4} \rightarrow \underset{\text{(Zinc sulphate)}}{ZnSO_4} + \underset{\text{(Hydrogen)}}{2H^+}$$

The chemical reaction outside the porous pot is

$$\underset{\text{(Hydrogen)}}{2H^+} + \underset{\text{(Copper sulphate)}}{CuSO_4} \rightarrow \underset{\text{(Sulphuric acid)}}{H_2SO_4} + \underset{\text{(Copper)}}{Cu^{++}}$$

In this manner, polarization is prevented. When the cell is not in use, it must be dismantaled. This is because the copper sulphate solution passes through the porous pot and is replaced by the zinc with the result that the copper is deposited on the zinc electrode causing local action.

The emf of the cell is about 1.12 V and its internal resistance varies from 2 to 6 Ω. It is cheap and gives constant voltage and is therefore, still used in laboratories for experiments.

## 9.7 LECLANCHE CELL

This cell consists of a glass jar which contains a solution of ammonium chloride ($NH_4Cl$) and a zinc rod amalgamated with mercury immersed in it (Fig. 9.6). The figure also shows a porous pot containing a carbon rod. The pot is tightly packed with manganese dioxide and powdered carbon particles. The zinc rod works as the negative electrode, the carbon rod as the positive electrode, ammonium chloride as the electrolyte and manganese dioxide as the depolarizer. The carbon particles along with manganese dioxide serves as a conductor. A hole is provided on the top of the porous pot for the gases to escape during the chemical reaction.

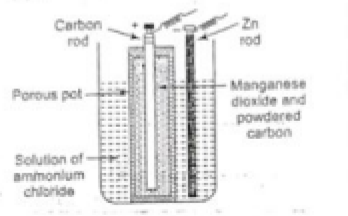


Fig. 9.6 *Leclanche cell*

When the cell is working, ammonium chloride reacts with the zinc forming zinc chloride and thus liberates ammonia and hydrogen ions ($H^+$). The chemical reaction outside the porous pot is as follows:

$$\underset{\text{(Zinc)}}{Zn^{++}} + \underset{\text{(Ammonium chloride)}}{2NH_4Cl} \rightarrow \underset{\text{(Zinc chloride)}}{ZnCl_2} + \underset{\text{(Ammonia gas)}}{2NH_3} + \underset{\text{(Hydrogen ionized)}}{2H^+}$$





Ammonia gas is soluble in water. When the water becomes saturated with ammonia, the gas is given off and can be detected by its smell. The hydrogen which passes through the porous pot reacts with the manganese dioxide ($MnO_2$) and is converted into water ($H_2O$) taking oxygen from $MnO_2$.

The chemical reaction inside the porous pot is

$$\underset{\text{(Manganese dioxide)}}{2MnO_2} + \underset{\text{(Hydrogen)}}{H_2} \rightarrow \underset{\text{(Manganese peroxide)}}{Mn_2O_3} + \underset{\text{(Water)}}{H_2O}$$

In this cell, polarization has been removed but not completely because the hydrogen is liberated at a quicker rate than the action of the depolarizer. Therefore, some hydrogen gas gets accumulated around the carbon rod. If a little rest is given to the cell, it becomes depolarized and the cell returns to its normal condition. Therefore, the cell is useful for intermittent currents as required in electric bells, telephones, etc.

The emf of this cell is 1.45 V and its internal resistance varies from 1 to 5 Ω depending upon the size of the cell.

- *Advantages* The advantages of the Leclanche cell are given below:
  - (i) It is very cheap as only ammonium chloride is to be changed occasionally.
  - (ii) There is only one kind of solution and hence no diffusion takes place.
- *Disadvantages* The disadvantages of the cell are given below:
  - (i) It is not portable.
  - (ii) It cannot be used for constant long service.

## 9.8 DRY CELL

The dry cell is a modification of the Leclanche cell. It is portable. In a dry cell the electrolyte is in the form of a paste which prevents spilling.

Figure 9.7 shows the parts of a dry cell. It consists of a zinc container which forms the negative plate of the cell. The positive electrode is a carbon rod kept in the centre of the zinc container. The carbon rod is surrounded with a mixture of manganese dioxide and ground carbon which is enclosed in a canvas bag. This canvas bag works as a porous pot. The space outside the canvas bag is filled with a

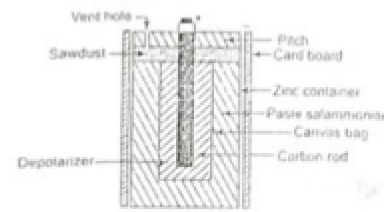


Fig. 9.7 *Dry cell*

paste of plaster of paris, flour, sal ammoniac, zinc chloride and water. This paste serves the function of an electrolyte in the cell. The zinc chloride is added in the paste as it has a tendency to absorb moisture from the atmosphere and thus help to keep the paste damp. The top of the cell is covered with saw dust and sealed with a pitch compound leaving a vent hole for the gases to escape due to chemical action.

The chemical action is exactly the same as in the Leclanche cell. The emf of the cell is about 1.5 V but the internal resistance is 0.1 to 0.5 Ω, which is much lower than the Leclanche cell due to the large surface area of the zinc container. These cells are generally used in radio sets, portable transistors, torch lights, electric bells, horns, telegraph, etc.

Figure 9.8 shows the zinc-carbon cell.

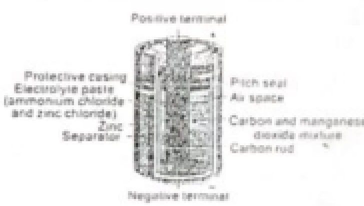


Fig. 9.8 *Zinc-carbon cell*

## 9.9 CHARACTERISTICS OF A GOOD CELL

A good cell should have the following characteristics:

(i) High and constant emf,

(vi) Very small internal resistance,
(vii) Completely inactive when the circuit is opened.
(viii) Able to give constant current for a long time,
(ix) Free from polarization.
(x) No emission of corrosive fumes during chemical action, and
(xi) Cheap and of durable materials.

## 9.10 CARE AND MAINTENANCE OF PRIMARY CELLS

To get best service results from primary cells, they should be given regular attention and should be maintained in the following conditions:

(i) The terminals and electrodes of the cell should be kept thoroughly cleaned to avoid corrosion and to reduce contact resistance to a low value.
(ii) The zinc plate should be amalgamated with mercury to prevent local action.
(iii) The strength of the depolarizer should be maintained.
(iv) The porous pot should be kept outside the cell when it is not in use after washing it in clean water.
(v) The positive and negative plates of the cell should not touch each other in the electrolyte. They should be kept apart by at least a distance of 15 mm.

## 9.11 DIFFERENCE BETWEEN EMF AND PD OF A CELL

• *EMF of a Cell* As seen in Chapter 3, the force which causes current to flow in the circuit is called emf. It is the PD between the terminals of a cell on open circuit, i.e. when the cell is not delivering any current. If a voltmeter is connected across the two terminals of a cell which is not delivering any current to the external load, the voltage indicated by the voltmeter is called the emf as the current drawn by the voltmeter is very small (because the voltmeter has high resistance). Therefore, the voltage drop in the internal resistance of the cell is also very small and hence the voltage indicated by the voltmeter is called emf.

• *Potential Difference (PD)* It is the difference of electrical potential between the two points in an electric circuit. If a cell is delivering current to the external load and a voltmeter is connected across its terminals, the voltage indicated by the voltmeter is now known as the potential difference and is always less than the emf of the cell due to the voltage drop in the internal resistance of the cell. Internal resistance is the resistance within the cell offered by the positive plate, negative plate and the electrolyte.

$$\text{emf} = V_T + I \cdot r \qquad (9.1)$$

where $I$ = current of the cell in amperes

$r$ = internal resistance of the cell in ohms

$V_T$ = voltage drop across the terminal of external resistance.

## 9.12 GROUPING OF CELLS

Cells may be grouped in three ways:
(i) series combination,
(ii) parallel combination, and
(iii) series-parallel combination.

• *Series Combination* When it is required to have a higher voltage than that given by one cell, many cells are connected in series. In that case the positive terminal of one cell is connected to the negative terminal of the other, and so on as shown in Fig. 9.9.

If $n$ number of cells are joined in series each having an emf of $E$ V, an internal resistance of $r$ Ω and if a load of $R$ Ω resistance is connected across them, then

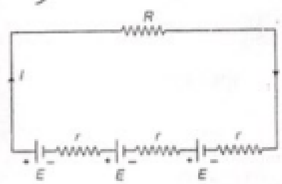


Fig. 9.9 *Cell in series*

Internal resistance of the battery = $nr$ Ω

Load resistance = $R$ Ω



Total resistance = $R + nr$ Ω

Total emf = $nE$ V

$$\therefore \quad \text{Current in load} = \frac{nE}{R + nr}\,\text{A} \qquad (9.2)$$

**Example 9.1** *Twenty dry cells of emf 1.5 V and internal resistance 0.5 Ω each are joined in series. If a 5 Ω external resistance is connected across the group, find the value of the current flowing.*

*Solution*

We know that

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

$$\therefore \quad \text{Current flowing} = \frac{20 \times 1.5}{5 + (20 \times 0.5)} = \frac{30}{15} = 2\text{A} \quad \text{Ans.}$$

**Example 9.2** *25 dry cells of 1.5 V emf and internal resistance of 0.25 Ω each are connected in series. When an external resistance is connected in series with the battery, the value of current flow is 1 A. What is the value of external resistance?*

*Solution* The value of external resistance is

$$R = \frac{nE}{I} - nr = \frac{25 \times 1.5}{1} - 25 \times 0.25 = 31.25\,\Omega$$

**Example 9.3** *Assume that 20 dry cells of 1.45 V emf are connected in series. When an external resistance of 12 Ω is connected in series with the battery, the value of current flow is 2 A. What is the value of internal resistance of each cell?*

*Solution* The value of internal resistance is

$$r = \frac{nE}{nI} - \frac{R}{n} = \frac{20 \times 1.45}{20 \times 2} - \frac{12}{20} = 0.125\,\Omega$$

• *Parallel Combination* If it is required to have a high current output given by the cells, several cells are joined in parallel as shown in Fig. 9.10. In the parallel connection of cells, all the positive terminals of the cells are connected together at one junction. Similarly, the negative terminals of the cells are joined together at the other junction.

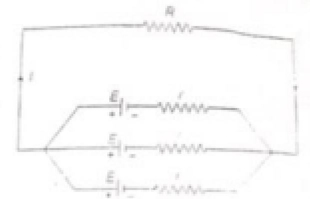


Fig. 9.10 *Cells in parallel*

If $n$ cells are joined in parallel each having an emf of $E$ V, internal resistance $r$ Ω and connected to a load of $R$ Ω, then

Internal resistance of the battery = $\frac{r}{n}$ Ω

Load resistance = $R$ Ω

Total resistance = $R + \frac{r}{n}$ Ω

emf of the battery = $E$ V

∴ Current in load

$$= \frac{E}{R + \frac{r}{n}} = \frac{nE}{nR + r}\,\text{A} \qquad (9.3)$$

**Example 9.4** *Ten dry cells each of 1.5 V emf and 1 Ω internal resistance are joined in parallel. If 4.9 Ω resistance is connected across the group, find the value of the current passing through it.*

*Solution* We know that

$$I = \frac{nE}{nR + r}$$

$$I = \frac{10 \times 1.5}{10 \times 4.9 + 1} = \frac{10 \times 1.5}{49 + 1}$$

$$= \frac{10 \times 1.5}{50} = 0.3\,\text{A} \quad \text{Ans.}$$

**Example 9.5** *18 dry cells of 1.5 V emf and internal resistance of 0.2 Ω each are connected in parallel. When an external resistance is connected in series with the battery, the value of current flow is 1.5 A. What is the value of external resistance?*

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**Solution** The value of external resistance is

$$R = \frac{nE}{nI} - \frac{r}{n} = \frac{E}{I} - \frac{r}{n} = \frac{1.5}{1.5} - \frac{0.2}{18} = 0.9888\ \Omega$$

**Example 9.6** *Assume that 10 dry cells of 1.45 V emf are connected in parallel. When an external resistance of 1.42 Ω is connected in series with the battery, the value of current flow is 1 A. What is the value of internal resistance of each cell?*

**Solution** The value of internal resistance is

$$r = \frac{nE}{I} - nR = \frac{10 \times 1.45}{1} - 10 \times 1.42 = 0.3\ \Omega$$

**Series-Parallel Combination** A group of same number of cells connected in series may be joined in parallel, thus making a series-parallel combination of cells as shown in Fig. 9.11. The total emf of such a combination is equal to the total emf of one of the series group.

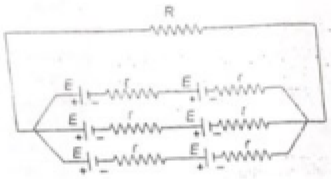


Fig. 9.11 *Cells in series and parallel*

If there are $m$ sets of cells in series-parallel combination, each set having $n$ cells in series and joined to a load of resistance $R$ Ω then

Internal resistance of each series group = $nr$ Ω

Internal resistance of $m$ set of battery = $\frac{nr}{m}$ Ω

Load resistance = $R$ Ω

Total resistance of the battery = $R + \frac{nr}{m}$ Ω

emf of the series-parallel combination = $nE$ V

Current in the load

$$= \frac{nE}{R + \frac{nr}{m}} = \frac{mnE}{mR + nr} \text{ A} \qquad (9.4)$$

The current in such an arrangement will be maximum when the total internal resistance of the battery is equal to the load resistance.

**Example 9.7** *Thirty cells each having an 1.5 V emf and 0.5 Ω internal resistance are connected ten in series per row; three rows in parallel. If a 2.5 Ω resistance is connected across the battery, find the value of the current passing through the external load.*

**Solution** We know that

$$I = \frac{mnE}{mR + nr} = \frac{3 \times 10 \times 1.5}{3 \times 2.5 + 10 \times 0.5}$$

$$= \frac{3 \times 15}{7.5 + 5} = \frac{45}{12.5} = 3.6 \text{ A Ans.}$$

## 9.13 SECONDARY CELL

The construction of the secondary cell and its working principle is explained below.

If two lead plates are dipped in dilute sulphuric acid as shown in Fig. 9.12 and connected to the dc supply mains, the current flowing through the electrolyte splits it up into hydrogen and sulphate ions. The hydrogen ion travels towards the negative plate as it has positive charge where gives up its charge and liberates. Thus, the negative plate remains as pure spongy lead which is metallic grey in colour. The negatively charged sulphate ion goes to the positive plate where it gives up its charge and reacts with the water of the electrolyte to form sulphuric acid.

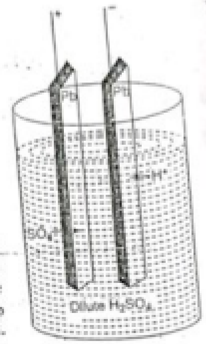


Fig. 9.12 *Secondary cell*

The chemical action is as given below:

$$SO_4^{--} + H_2O \rightarrow H_2SO_4 + O^{-}$$



The liberated oxygen attacks the positive lead plate and changes it into lead peroxide giving the plate a dark-brown colour:

$$O_2 + Pb \rightarrow PbO_2$$

After the flow of this charging current, an elementary accumulator is developed. When the two plates are connected to an external load with an ammeter in the circuit, a discharging of electricity is observed due to the chemical reaction in the cell. During discharging, the electrodes are converted into lead sulphate. Such type of cells are called secondary cells.

In a lead acid cell, the cell is only capable of supplying electrical energy to the external load due to its secondary action. The primary action of the cell is to store electrical energy in the form of chemical energy. During the secondary action, cell converts the chemical energy stored into electrical energy.

The following two types of secondary cells are in use nowadays:

(i) lead acid cell, and
(ii) nickel-iron alkaline cell.

- *Advantages* The advantages of secondary cell over primary cell are as follows:
  (i) A secondary cell gives a strong current as its internal resistance is very low.
  (ii) It gives a constant current.
  (iii) Its efficiency is very high, i.e. it gives back the most of the energy used in charging it.

- *Characteristics of a Good Secondary Cell* A good secondary cell has the following characteristics:
  (i) Low internal resistance,
  (ii) High efficiency,
  (iii) Fairly constant emf,
  (iv) Durable,
  (v) Cheap,
  (vi) Good mechanical strength, and
  (vii) Large storage capacity.

## 9.14 DIFFERENTIATION BETWEEN CELL AND BATTERY

A cell is a single unit of source of supply, whereas a battery is a combination of two or more than two cells joined in series, in parallel or in series-parallel combination so as to supply together.

## 9.15 CONSTRUCTION OF LEAD-ACID BATTERY

A lead acid battery consists of three cells, six cells or 12 cells in series giving 6 V, 12 V and 24 V respectively. Positive and negative plates are immersed in dilute sulphuric acid and kept apart by separators in each of its cells. Figure 9.13 shows the parts of a lead-acid cell.

- *Positive Plate* The positive plates are of two types:
  (i) plante plate, and
  (ii) faure plate

- *Plante Plate* In the plante plate type, the plates are formed of pure lead by a process of repeated charging and discharging. These plates are also called formed plates. Such type of plates take a long time to manufacture and are very costly. Therefore, they are not manufactured commercially.

- *Faure Plate* For the commercial manufacture of lead-acid batteries, faure plates are in use and are generally made of rectangular lead grid into which the active material, i.e. lead peroxide ($PbO_2$), is filled in the form of paste.

- *Negative Plate* The negative plates are also of a rectangular lead grid and the active material in the form of paste is held firmly in these lead grids. The active material on the negative plate is spongy lead (Pb).

Number of Negative Plates Due to possibility of buckling of lead on positive plate in the multiplate lead acid cell, there is always one more negative plate than the number of positive plates. The other reason is that the positive plate will have negative plates on both the sides, so efficiency increases.

- *Separators* In the lead-acid cell, separators are used to insulate the plates from one another. These are generally made from thin sheets of wood which is a porous material and allows electrolytic conduction, but keeps the negative and positive plates apart. Nowadays wooden separators have been

(ii) area of the plates and their assembly (i.e. the number of positive plates), and

(iii) temperature and specific gravity of the electrolyte.

## 9.22 INTERNAL RESISTANCE OF A LEAD–ACID CELL

The internal resistance is the resistance within the cell offered by the positive plates, negative plates and the electrolyte. Due to this internal resistance, there is always some power loss inside the cell which is converted into heat and reduces the terminal voltage of the cell. Therefore, to overcome the above loss and to reduce the temperature (because at high temperatures the plates and cell may get damaged), the internal resistance of the cell is kept as low as possible. This internal resistance can be calculated as explained below. In Sec. 9.11, we have seen that

$$\text{emf} = V_T + I \cdot r$$

The emf ($E$) of a given cell is constant but the terminal voltage ($V_T$) depends upon the value of the load current which further depends on the load resistance. If the voltmeter readings are recorded (*i*) when there is no load on the cell (i.e. $E$) and (*ii*) when it is delivering the load current (i.e. $V_T$), then the internal resistance can be calculated as

$$\text{Internal resistance, } r = \frac{E - V_T}{I}$$

But $$I = \frac{V}{R}$$

$$r = \left(\frac{E - V_T}{V}\right) R \qquad (9.5)$$

**Example 9.8** *Ten similar cells are connected in series to a load resistance of 4 Ω. On connecting a high resistance voltmeter across the battery, it shows 12 V. But on open circuit the voltmeter indicates 18 V. Find (a) the internal resistance of each cell, and (b) the current flowing through the external resistance.*

*Solution* *Method 1:*

We know that

$$r = \frac{(E - V_T)}{V} \times R$$

$$10r = \frac{(18-12)}{12} \times 4 = \frac{6 \times 4}{12}$$

$$\therefore \text{Internal resistance, } r = \frac{6 \times 4}{12 \times 10} = 0.2\ \Omega \qquad \text{Ans.}$$

Current through external load

$$I_L = \frac{V}{R} = \frac{12}{4} = 3\text{ A} \qquad \text{Ans.}$$

*Method 2:*

Load current,

$$I_L = \frac{V}{R} = \frac{12}{4} = 3\text{ A} \qquad \text{Ans.}$$

emf of $N$ number of cells ($nE$) = 18 V

But $$I = \frac{nE}{R + nr}$$

$$3 = \frac{18}{4 + 10r}$$

By cross multiplying,

$$12 + 30r = 18$$

$$30r = 18 - 12 = 6$$

Internal resistance,

$$r = \frac{6}{30} = 0.2\ \Omega \qquad \text{Ans.}$$

**Example 9.9** *A battery is formed of six cells connected in series. When the external resistance of 3 Ω is joined across its terminals, the current is found to be 2.5 A and when it is 9 Ω, the current falls to 1.25 A. Find the emf of each cell and its internal resistance.*

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*Solution* In the first case,

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

$$\therefore \quad 2.5 = \frac{6 \times E}{3 + 6r}$$

By cross multiplying, we have

$$7.5 + 15r = 6E$$

In the second case,

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

$$1.25 = \frac{6E}{9 + 6r}$$

Again cross multiplying, we have

$$11.25 + 7r = 6E \qquad \text{(iii)}$$

From Eqs. (i) and (ii) we have

$$7.5 + 15r = 11.25 + 7.5r$$

$$15r - 7.5r = 11.25 - 7.5$$

$$7.5r = 3.75$$

$\therefore$ Internal resistance,

$$r = \frac{3.75}{7.5} = 0.5\ \Omega \quad \text{Ans.}$$

Putting the value of internal resistance ($r$) in Eq. (iii)

$$11.25 + 7.5 \times 0.5 = 6E$$

$$11.25 + 3.75 = 6E$$

$$6E = 15$$

$\therefore$ emf of each cell

$$E = \frac{15}{6} = 2.5\text{ V} \quad \text{Ans.}$$

## 9.23 CAPACITY OF A BATTERY

The capacity of a battery is a term used to express the ability of the battery to discharge at normal voltage, specific gravity and normal discharging current and it is expressed in ampere-hours (A-h).

The ampere-hour capacity of a battery is the product of current in amperes and the time in hours in which it can discharge. The capacity of the battery decreases with an increase in the discharging rate.

It should be noted that a battery should never be discharged at a higher rate than that specified by the manufacturer as the plates become curved and the active material falls down.

The capacity of the battery depends upon the following factors:

(i) number and area of the positive plate,
(ii) discharging (and charging) voltage,
(iii) discharging rate,
(iv) specific gravity of electrolyte,
(v) quantity of electrolyte,
(vi) design of separators,
(vii) temperature (capacity increases with the increase of temperature), and
(viii) age and life chart of the battery.



**Example 9.10** *Find the ampere-hour capacity of a battery if it supplies a current of 20 A for 15 h.*

*Solution* Ampere-hour capacity of a battery

= Current in amperes × Time of discharge in hours

= 20 × 15

= 300 A-h Ans.

## 9.24 TYPES OF EFFICIENCY OF A SECONDARY CELL

There are two types of efficiency:

(i) quantity efficiency or ampere-hour efficiency, and

(ii) energy efficiency

- *Quantity Efficiency* The quantity efficiency is the ratio between the quantity of electricity during discharge and the quantity of electricity during charging. However, the quantity of electricity is the product of current in amperes and time in hours. Therefore, the quantity efficiency is also known as the ampere hour efficiency.

$\therefore$ Ampere-hour efficiency, $\eta_{A\text{-}H}\%$

$$= \frac{\text{Ampere-hours on discharging}}{\text{Ampere-hours on charging}} \times 100\%$$

- *Energy Efficiency* It is the ratio between the energy which a cell gives out during discharging and the energy which it requires to regain the original condition during charging.

Energy efficiency in percentage

$$\eta_E\% = \frac{\text{Energy during discharging}}{\text{Energy during charging}} \times 100\%$$

$$\frac{V_d \times I_d \times t_d}{V_c \times I_c \times t_c} = \frac{\text{Watt-hours on discharging}}{\text{Watt-hours on charging}} \times 100\%$$

As the energy efficiency is the ratio of watt-hours, it is also known as the watt-hour efficiency.

As the voltage on discharge is always less than the voltage on charge, the watt-hour efficiency is always less than the quantity efficiency (or $\eta_{A\text{-}H}$).

For a normal lead acid cell, the quantity efficiency varies between 90 to 95% whereas the watt-hour efficiency varies between 80 to 85%.

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**Example 9.11** Calculate the (a) ampere-hour efficiency and (b) the watt-hour efficiency of a secondary cell which is discharged at a uniform rate of 30 A for 6 h at an average terminal voltage of 2 V. It is then charged at the uniform rate of 40 A for 5 h to restore it to its original condition. The terminal voltage during charging is 2.5 V.

**Solution** Ampere-hour output = 30 × 6 = 180 Ah

Ampere-hour input = 40 × 5 = 200 Ah

Percentage ampere-hour efficiency

$$(i)\ \text{A-h} = \frac{\text{Ampere-hours on discharging}}{\text{Ampere-hours on charging}} \times 100\%$$

$$= \frac{180}{200} \times 100\% = 90\% \text{ Ans.}$$

Terminal voltage during charging = 2.5 V

Watt-hour output = voltage × current × time in hours

$$= 2 \times 30 \times 6 \text{ Ah}$$

Watt-hour input = 2.5 × 40 × 5 Ah

Watt-hour efficiency in percentage

$$= \frac{\text{Watt-hours on discharging}}{\text{Watt-hours on charging}} \times 100\%$$

$$= \frac{2 \times 30 \times 6}{2.5 \times 40 \times 5} \times 100\% = 72\% \text{ Ans.}$$

**Example 9.12** An alkaline cell is discharged at a steady-state current of 5 A for 12 hours and the average terminal voltage is 1.22 V. To restore it to its original state of charge, a steady current of 4 A for 20 hours is required, and the average terminal voltage is 1.44 V. Find the ampere-hour (Ah) efficiency and Wh efficiency.

**Solution**

$$\text{Ah efficiency} = \frac{\text{Ah of discharge}}{\text{Ah of charge}}$$

$$= \frac{12 \times 5}{20 \times 4} = 0.75 = 75\%$$

Wh efficiency = Ah efficiency

$$\times \frac{\text{Average voltage on discharge}}{\text{Average voltage on charge}}$$

$$= \frac{0.75 \times 1.22}{1.44} = 0.6354 = 63.54\%$$

LP 4

**Example 9.13** A discharge battery is charged at 10 A for 2 hours after which it is discharged through a resistance. When the discharge period is 5 hours and the terminal voltage remains fixed at 12 V, find the value of resistance. Assume that the Ah efficiency of the battery is 80%.

**Solution** Input ampere-hours = 10 × 2 = 20 Ah

Efficiency = 0.8, Ampere-hour output = 20 × 0.8 = 16 Ah

$$\text{Discharge current} = \cancel{\frac{16}{5} = 3.2\text{ A}} \quad \frac{16}{5} = 3.2\text{ A}$$

$$\text{Resistance } R = \frac{12}{3.2} = 3.75\ \Omega \quad \frac{12}{3.2} = 3.75\ \Omega$$

## 9.25 PRECAUTIONS FOR BATTERY CHARGING

The current required for charging a battery is direct current (dc). If the available supply is alternating current (ac) then it should be converted into dc either by a motor-generator set or by a rectifier. The undermentioned precautions should be observed before putting a battery on charge.

- *Topping Up* If the level of the electrolyte on the surface of the plate is less than 10 to 15 mm then some distilled water should be added in the cell. This process is known as topping up. It should be remembered that for topping up, sulphuric acid or prepared electrolyte should never be poured into the cell.
- *dc Voltage* For charging a battery, dc voltage 10% higher than the full charged battery voltage is required.
- *Connection* The positive terminal of the dc supply should be connected to the positive terminal of the battery, and similarly, the negative terminal of the supply to the negative terminal of the battery.
- *Ventilation* The room where batteries are to be charged should be well ventilated as the gases liberated during charging are of flammable and explosive nature. Therefore, burning flame should not be brought near charging batteries.
- *Charging Rate* The safe rate of current at which the battery is to be charged is called the charging rate. It is always better to charge a battery at the rate specified by the manufacturer. In case it is not known, it should be charged at a low rate, say 0.75 A per positive plate (or 5% of the capacity of the battery).

6

## 9.26 CHARGING A BATTERY

The following three systems of charging batteries are in practice

(i) constant current charging system

(ii) constant potential charging system, and

(iii) trickle charging system

- **Constant Current Charging System** In this system, the charging current is controlled by inserting either carbon filament lamps or resistance rheostat in series with the battery and thus varying the supply voltage to overcome the increased back emf of the batteries. In this system many batteries connected in series can be charged considering that the total voltage of the battery should not increase the main applied voltage otherwise the batteries would discharge.

Charging current

$$I = \frac{V - E_b}{R + r}\ \text{A} \tag{9.6}$$

where

$V$ = charging applied voltage in volts

$E_b$ = total counter emf of the battery in volts

$R$ = external resistance of the lamp or rheostat in ohms

$r$ = internal resistance of the battery in ohms

$I$ = charging current in amperes.

The value of the charging current is varied by varying the number of lamps by switching ON and OFF the lamps in the battery circuit taking care that the temperature of the battery does not exceed 43°C. An ammeter shown in series with the circuit indicates the charging current. The connection diagram of a lamp charging board is shown in Fig. 9.18.

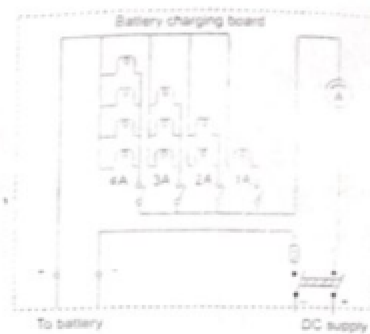


Fig. 9.18 Lamp-charging board for constant-current method

- *Advantage* This system of charging the battery increases the life of the battery.
- *Disadvantage* It takes longer time to charge a battery and needs constant observation for checking the charging current.

- **Constant Potential Charging System** To charge a battery with the help of a motor-generator set (or metal rectifier which will be discussed later on) is based on this system. Figure 9.19 shows the connection of this system. The generated voltage is kept constant at 10% higher than the full charged voltage of the battery. The charging current in this system is either varied by controlling the field regulator of the dynamo or by the speed of the primemover. In the beginning, the value of the charging current will be very high as the counter emf of the battery is very low. But after some time, the charging current decreases to a very small value as the back emf of the battery increases on being charged.

- *Advantage* In this system, the time required for charging is less than that in the constant current system but this reduces the efficiency.
- *Disadvantage* This system of charging reduces the life of the battery up to some extent.

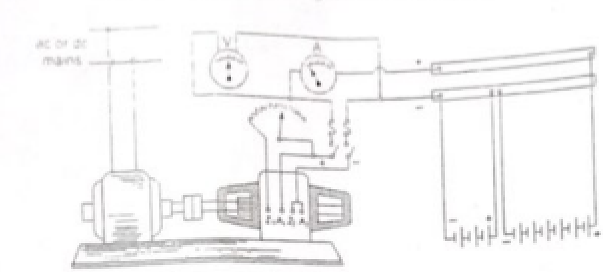


Fig. 9.19 Constant potential method of battery charging

□ ***Trickle-Charging System*** The continuous charging of a battery at a low rate for keeping the battery ready in good working condition is called trickle charging. This value of charging current is approximately 2% of the full charging current of the battery.

## 9.27 LAMP FOR CHARGING

The best type of lamp for charging a battery is a carbon filament lamp and is preferred because it allows greater amount of current to the given size (i.e. 3.5 W/candle power). Moreover, there is no brightness in the light as compared to other types of lamps.

**Example 9.14** *A battery of 50 cells connected in series is to be charged from 250 V dc supply mains. The battery has been discharged to 1.8 V per cell and in the final charged condition its value is 2.2 V per cell. The internal resistance of each cell is 0.01 Ω connecting leads has a resistance of 0.1 Ω and there is an external resistance of 19.4 Ω connected in the circuit. Find the (a) initial charging current, and (b) final charging current.*

Solution

(a) Internal resistance of battery = 0.01 × 50 = 0.5 Ω

Resistance of connecting leads = 0.1 Ω

Total resistance of battery and leads = 0.5 + 0.1 = 0.6 Ω

emf of the battery ($E_b$) = 1.8 × 50 = 90 V

We know that

$$I = \frac{E - E_b}{R + r}$$

∴ Initial charging current,

$$I = \frac{250 - 90}{19.4 + 0.6} = \frac{160}{20} = 8 \text{ A} \quad \text{Ans.}$$

(b) emf of the battery at the end of charge

= 2.2 × 50 = 110 V

∴ Final charging current,

$$I = \frac{250 - 110}{19.4 + 0.6} = \frac{140}{20} = 7 \text{ A} \quad \text{Ans.}$$

**Example 9.15** *A 6-cell 12 V battery is charged at constant current of 10 A from a 24 V dc supply. At the beginning of charge, the emf of each cell is 1.95 V and after completion of charging, the emf of each cell is 2.4 V. What will be the maximum value of resistance which will be connected in series with the battery? Assume the internal resistance of the battery is negligible.*

Solution At the beginning of charging, total back emf of battery = 6 × 1.95 = 11.7 V

Net driving voltage = (24 − 11.7)V = 12.3 V, the maximum resistance $R_{max} = \frac{12.3}{10} = 1.23\ \Omega$

At the end of charging, total back emf of battery = 6 × 2.4 = 14.4 V

Net driving voltage = (24 − 14.4) V = 9.6 V, the minimum resistance $R_{min} = \frac{9.6}{10} = 0.96\ \Omega$



**Example 9.16** *A battery of 60 cells is charged from a supply voltage of 230 V. Each cell has an emf of 1.9 V at the start and 2.5 V at the end of charging. If the internal resistance of each cell is 0.15 Ω and if there is an external resistance of 18.5 Ω in the circuit, determine (a) the initial charging current, and (b) final charging current. (c) What will be the additional resistance which must be passed to provide a finishing charge of 2 A?*

Solution Input voltage is 230 V.

At the beginning of charging, total back emf of battery = 60 × 1.9 = 114 V

At the end of charging, total back emf of battery = 60 × 2.5 = 150 V

Internal resistance of battery is 60 × 0.15 = 9 Ω

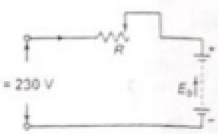


Fig. E9.16

Total resistance of circuit is = 18.5 + 9 = 27.5 Ω

Net driving voltage = (230 − 114) V = 116 V

The initial charging current is $= \frac{116}{27.5} = 4.218$ A

The final charging current is $= \frac{230 - 150}{27.5} = 2.909$ A

Assume that the external resistance is $R$ for charging a current of 2 A

Then $2 = \frac{230 - 150}{R + 9}$, and $R = 31\ \Omega$

Additional resistance required is 31 − 18.5 = 12.5 Ω

**Example 9.17** *Assume that a storage battery consists of 80 series-connected cells with each of 0.002 Ω internal resistance and 2.2 V emf. Each cell has 21 plates with 10 positive plates and 11 negative plates, and each plate measures 25 cm × 30 cm. When the full-load current per cell is 0.015 A/cm² of positive plate surface, determine (a) full-load terminal voltage of the battery, and (b) power wasted in the battery if the total resistance of the connector is 0.025 Ω.*

Solution The total area of 10 positive plates (both sides) = 2 × 25 × 30 × 10 = 15000 cm²

Full-load current is 15000 cm² × 0.015 A/cm² = 225 A

The voltage drop in the battery and across connectors = 225 × (80 × 0.002 + 0.025) = 41.625 V

Total battery emf is 80 × 2.2 = 176 V

The battery terminal voltage on full-load is 176 − 41.625 = 134.365 V

Total resistance 80 × 0.002 + 0.025 = 0.185 Ω

Power loss in resistance is

$I^2r = 225^2 \times 0.185 = 9365.625$ Watt

## 9.28 TESTING OF A BATTERY

The condition of the battery can be examined either by checking the specific gravity of the electrolyte or by the per cell voltage. The voltage does not change much from the discharged condition to the fully charged condition of the battery. Therefore, to find the condition of the battery, the specific gravity is checked with the help of a hydrometer as discussed earlier.

The specific gravity value alone cannot give the internal condition of a lead cell because it can also be increased by putting concentrated sulphuric acid in the electrolyte of the cell. Therefore to find the condition of the cell, its voltage when supplying high current is measured. The instrument which is used for this purpose is known as the high rate discharge cell tester.

## 9.29 HIGH RATE DISCHARGE CELL TESTER

It consists of a wooden handle having two pointed metal strips parallel to each other (Fig. 9.20). Between them is provided a load of low resistance across which is fixed a voltmeter of zero centered is fixed.

When pointed strips of the tester are pressed on each of the terminals of the battery, this resistance takes a current of 150 to 300 A. The tester should not be applied for more than 10 s on each cell and the voltmeter readings are recorded in each case. The voltage of a fully charged cell of a battery should not be less than 1.8 V when delivering high current. If it falls rapidly, this indicates that either