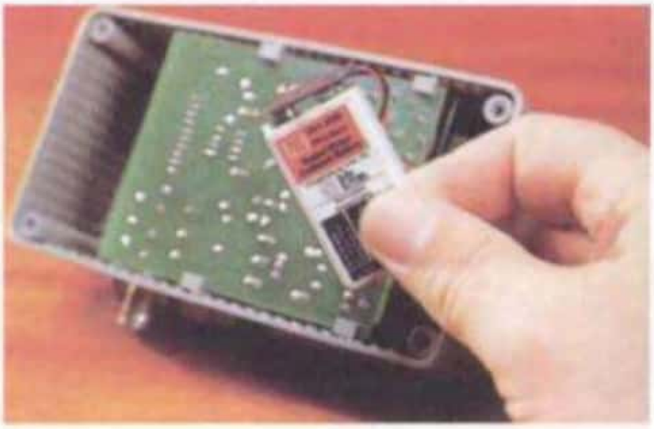
CHAPTER 6

Energy Sources

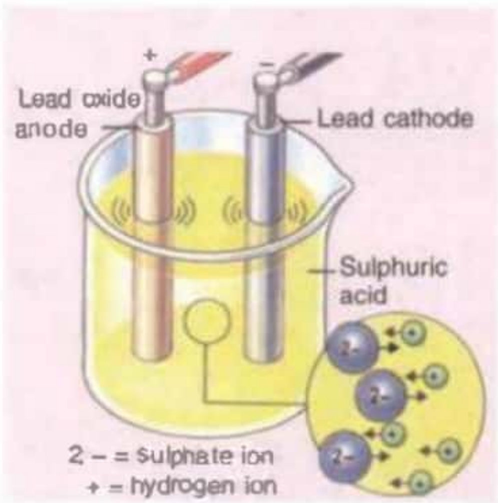


6.1. Primary and Secondary Cells

A voltaic chemical cell is a combination of materials which produce direct-current (dc) electrical energy from its *internal* chemical reactions. These cells can be sub-divided into the following two classes :

(*a*) **Primary Cell.** In this cell, chemical reactions are irreversible. During the generation of electric energy, it consumes materials which cannot be replenished by recharging. Hence, such cells cannot be recharged back to their original condition after being discharged.

(*b*) **Secondary Cell or Storage Cell or Accumulator.** In these cells, chemical reactions are reversible. After discharge, such a cell can be restored to its original condition by passing an electric current through it in a direction opposite to that of the discharge current.



Secondary cell.

Further points of comparison between the two classes are tabulated given on next page.

	Primary Cells	Secondary Cells
1.	low cost	expensive
2.	small size	reasonably small
3.	short life	comparatively long life
4.	useless when discharged	rechargeable
5.	light weight	heavier

6.2. Cell and Battery

A battery consists of two or more cells connected either in series or parallel or both. Often, many people call a flashlight cell a flash light battery which is technically incorrect.

6.3. Voltage and Current of a Cell

The voltage rating of a cell is given by its open-circuit voltage *i.e.*, voltage it can produce when not connected to a load circuit. This voltage depends on the types of materials used and not on the physical size of the cell.

The capacity of a cell is given by the amount of current it can supply to an external load circuit. It depends on the condition and quantity of electrolyte and physical size of the electrodes. Everything else being the same, a larger cell can deliver more current for a longer period of time than a smaller one.

6.4. Cell Life

It is given by the period of time during which the cell can be stored on a shelf without losing more than approximately 10% of its original capacity. The loss of capacity occurs even when cell is not in use and is primarily due to partial drying up of paste electrolyte and to other chemical actions which change the materials within the cell. Since heat helps both these processes, it is advisable to keep a cell in a cool place in order to extend its life.

6.5. Different Types of Dry Cells

We will consider the following primary and secondary cells :

(*a*) carbon-zinc cell

(*b*) alkaline cell

1. manganese-alkaline cell
2. nickel-cadmium cell
3. mercury cell
4. silver-oxide cell
5. lead-acid cell

6.6. Carbon Zinc Cell

It is the oldest and most widely used commercial dry cell (Fig. 6.1).

(*a*) Construction

1. The zinc can functions both as a container to hold the electrolyte and as the negative electrode.
2. The positive electrode is a carbon rod down the centre but not low enough to touch the zinc bottom.
3. The electrolyte is a paste of ammonium chloride and manganese dioxide.

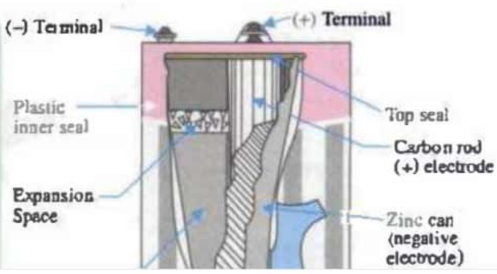
(*b*) Size and Voltage

Such cells are available in several sizes and have open-circuit voltage from 1.4 to 1.6 V, regardless of size. Larger cells with more zinc, electrolyte and depolarizer have a higher current rating upto 0.25 A or 250 mA. The flashlight cell has a current rating of 50 mA for nearly 60 hours of

service. The cell has a height of about 57 mm and a diameter of about 32 mm.

Carbon-zinc batteries are made in many types having voltages of 3, 4, 5, 6, 9, 13.5, 22.5 and 45 V (all multiples of 1.5 V). In some batteries, cells are cylindrical in shape and in others they are flat.

(*c*) Operating Efficiency



(b) Size and Voltage

Such cells are available in several sizes and have open-circuit voltage from 1.4 to 1.6 V, regardless of size. Larger cells with more zinc, electrolyte and depolarizer have a higher current rating upto 0.25 A or 250 mA. The flashlight cell has a current rating of 50 mA for nearly 60 hours of

service. The cell has a height of about 57 mm and a diameter of about 32 mm.

Carbon-zinc batteries are made in many types having voltages of 3, 4, 5, 6, 9, 13.5, 22.5 and 45 V (all multiples of 1.5 V). In some batteries, cells are cylindrical in shape and in others they are flat.

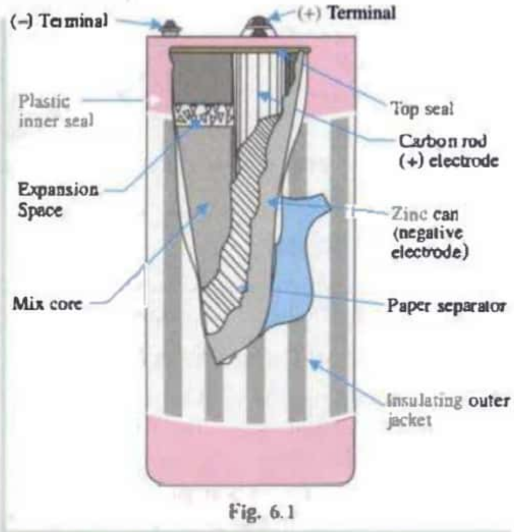


Fig. 6.1

(c) Operating Efficiency

Carbon-zinc cells and batteries render efficient service provided they are used *intermittently* for short periods at a time at relatively low currents. Such operation helps to keep them sufficiently depolarised.

(d) Recharging

The dry cell can be recharged if certain precautions are taken :

1. voltage should not be below 1 V when removed for service,
2. charging rate should be kept low and spread over 10 to 15 hours,
3. recharged cells should be used at one in view of their limited shelf life.


This walkman is powered by batteries of the primary cell type. Typically, they have to be replaced every two or three months.

6.7. Alkaline Cells

All those cells which use a caustic electrolyte are called alkaline cells. We will consider

1. manganese-alkaline cell
2. nickel-cadmium cell
3. mercury cell and
4. silver-oxide cell.

Fig. 6.2

6.8. Manganese Alkaline Cell

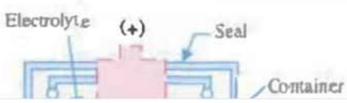
It is a *primary* cell having zinc as anode and manganese dioxide as cathode in a leak-proof steel can (Fig. 6.2). The electrolyte is potassium hydroxide (KOH) or sodium hydroxide (NaOH). Because of the high conductivity of the electrolyte, this cell has higher current rating than a carbon-zinc cell. It provides an output voltage of 1.5 V. Some alkaline batteries can be recharged a few times and have voltages of 4.5, 7.5, 13.5 and 15 V.

6.9. Nickel Cadmium Cell

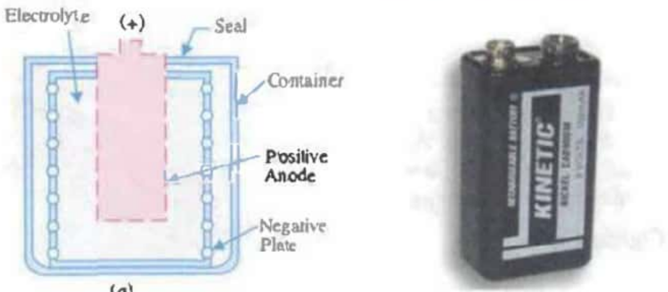
It is a *dry* cell but is *rechargeable*. In present-day electronics, it has superseded both lead-acid cell and nickel-iron (NiFe) alkaline cell.

(a) Construction

The action material cadmium (a metal akin to zinc), in powder form, is pressed (*i.e.*, sintered) into perforated steel plates which then form the negative electrode of the cell (Fig. 6.3). The positive anode is a steel mesh coated with solid nickel hydroxide (NiOH). The electrolyte is potassium hydroxide (caustic potash) usually in jelly form. The container is a steel can which is sealed after the cell is placed in it. These cells are also available in flat button shape.



droxide (caustic potash) usually in jelly form. The container is a steel can which is sealed after the cell is placed in it. These cells are also available in flat button shape.



(a) (b)

Fig. 6.3

(b) Voltage and Current

The open-circuit voltage of such cells is from 1.25 to 1.5 V. They have much longer life when they are rapidly discharged at intervals. In fact, long periods of inactivity can cause the cells to fail. Such cells need to be charged at constant current and can be recharged upto 1000 times or more.

These cells have very low internal resistance and can deliver high currents without much loss of terminal voltage. The most common nickel-cadmium batteries have voltages of 6, 9.6 and 12 V.

Their chemical reaction is given by the following equation :

$$Cd + 2\,NiOH + 2\,KOH = Cd\,(OH)_2 + 2\,Ni + 2\,KOH$$

Fig. 6.4 shows the range of rectangular nickel-cadmium (Nicad) cells and batteries. These Nicad cells have a normal no-load voltage of 1.2 V, are capable of high current loads and 1000 cycles of discharge, can tolerate overcharge and general electrical abuse like short circuit.

Fig. 6.4

(c) Uses

Since such cells can easily supply high current, they are widely used as sources of energy in radios, TV sets, tape recorders, cameras and cordless type home appliance such as electric toothbrush or electric carving knife etc. They give good service under extreme conditions of shock, vibration and temperature.

6.10. Mercury Cell

It is a *primary* cell and is widely used in miniaturised electronic gadgetry.

(a) Construction

The cathode is made of compressed mercuric oxide and graphite whereas anode is made of highly purified zinc powder.

The two are separated by a porous material. The electrolyte is a paste mixture of potassium hydroxide and zinc oxide. The flat pallet construction of a mercury cell is shown in Fig. 6.5.

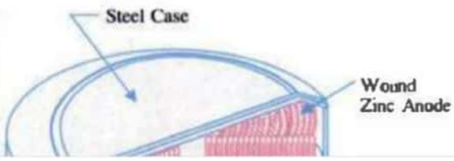
(b) Size and Voltage

Such cells are available in wide range of shapes and sizes—the smallest being about 3 mm thick and 12.5 mm in diameter. Open-circuit voltage at room temperature varies from 1.35 to 1.4 V depending on the electrolyte mixture. With pure mercuric oxide for cathode, voltage output is extremely stable at 1.35 V. Mercury batteries are available in a variety of voltage ratings.

(c) Uses

Mercury cells enjoy a long shelf life without deterioration and are extremely rugged.

Since they can provide almost constant voltage under varying load conditions, mercury



stable at 1.35 V. Mercury batteries are available in a variety of voltage ratings.

(c) Uses

Mercury cells enjoy a long shelf life without deterioration and are extremely rugged.

Since they can provide almost constant voltage under varying load conditions, mercury cells and batteries are widely used in electronic watches, hearing aids and test instruments etc.

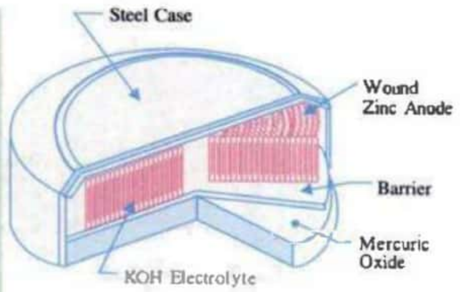


Fig. 6.5

6.11. Silver Oxide Cell

It is a *primary* cell with an open-circuit voltage of 1.5 V. It has a cathode of silver oxide and an anode of zinc in an alkaline electrolyte. As shown in Fig. 6.6, it is generally made in button size for use in cameras, hearing aids and electronic watches.

6.12. Lead Acid Cell

It is a *wet* secondary cell mostly used for making automobile batteries.

(a) Construction

Its anode plate (brown coloured) is a grid made of a lead-antimony alloy into which is pressed the active material : lead peroxide (PbO_2). The cathode is a similar plate having pure porous (sponge like) lead as active material. The two plates are immersed in a solution of dilute sulphuric acid of specific gravity 1.21 or so.

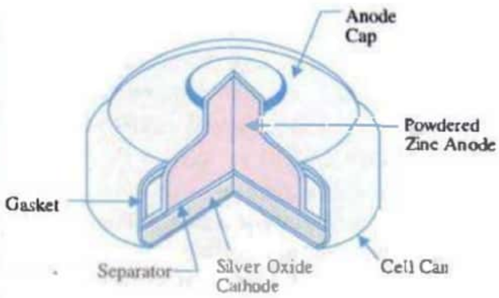


Fig. 6.6

(b) Voltage

It has an open-circuit voltage of 2 to 2.2 V when fresh. It should not be used after its voltage has fallen to 1.85 V when it should be put on charge. It has much larger current capacity as compared to dry cells, considered earlier.

A mercury cell in section.

(c) Use

Principal use of these cells is in the manufacture of portable lead-acid batteries used in automobiles (car and motor vehicles). For car battery, 6 cells are connected in series to give a total voltage of 12 V or more. For traction batteries, the voltages vary from 12 V (6 cells) to 64 V (32 cells) for industrial trucks and from 30V (15 cells) to 72 V (56 cells) for dairy and bakery road vehicles.

6.13. Battery Rating

Lead-acid batteries are rated in terms of discharge current, they can supply continuously for a specified period of time. It is usually expressed in ampere-hours (Ah). The capacity is always given at a specified rate of discharge

usually 20 hour rate. It means that a battery which is rated at 100 Ah should deliver 5 A of current continuously for 20 hours and maintain at least 1.75 V per cell. Of course, battery can supply less current for longer time or more current for a shorter time.

6.14. Testing Dry Cells

A mercury cell in section.

for a specified period of time. It is usually expressed in ampere-hours (Ah). The capacity is always given at a specified rate of discharge

usually 20 hour rate. It means that a battery which is rated at 100 Ah should deliver 5 A of current continuously for 20 hours and maintain at least 1.75 V per cell. Of course, battery can supply less current for longer time or more current for a shorter time.

6.14. Testing Dry Cells

The condition of a dry cell or battery can be checked by the terminal voltage developed *when it is connected to a load*. If this voltage is less than 80% of the open-circuit voltage, it should be rejected. The basic reason is that a bad cell has high internal resistance which will become detectable when cell is tested *on load*. Due to normal current flow, there would be a large internal drop and hence terminal voltage would drop by a considerable amount. Such would not be the case when cell is tested on no-load.

6.15. Photoelectric Devices

As the name shows, these devices convert light energy directly into electric energy. We will consider the following semiconductor devices only because they are self-generating.

1. photovoltaic cell
2. solar cell

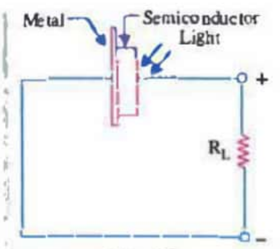
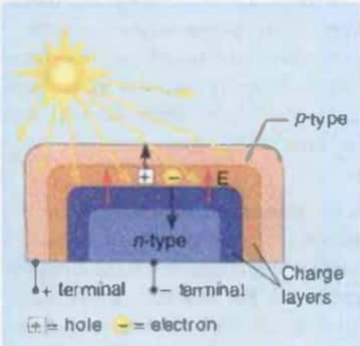


Fig. 6.7

6.16. Photovoltaic Cell

In this cell, light energy is used to create a potential difference which is directly proportional to the frequency and intensity of the incident light. Fig. 6.7 shows a basic photovoltaic cell.



A solar cell formed from a p-n junction. When sunlight strikes the solar cell it acts like a battery, with positive and negative terminals.

It consists of a piece of semiconductor material such as selenium (Se), silicon (Si) or germanium (Ge) which is bonded to a metal plate.

When light falls on the semiconductor, valence electrons and holes are liberated from its crystal structure. These electrons flow out of the semiconductor into the metals whereas holes flow in the opposite direction. It creates a potential difference between the semiconductor and the metal which is sufficient to cause current flow through a load resistor as shown in Fig. 6.7.

These cells are used in devices like portable exposure meters and direct-reading illumination meters.

6.17. Solar Cell

It is also called solar energy converter and is basically a P-N junction device which converts solar energy into electric energy.

(a) Construction and Working

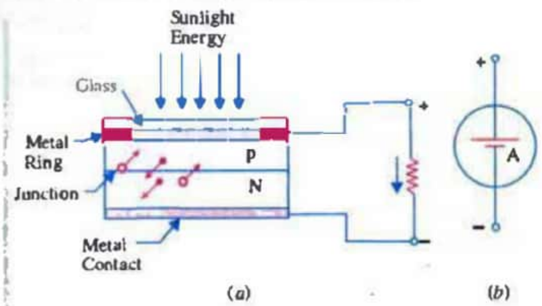


Fig. 6.8

As shown in Fig. 6.8 (*a*), it essentially consists of a silicon P-N junction diode generally packaged in TO-type can with a glass window on top. Surface layer of P-material is made extremely thin so that incident light photons may easily reach the P-N junction.

When these photons collide with valence electrons, they impart them sufficient energy as to leave their parent atoms. In this way, free electrons and holes are generated on both sides of the junction and their flow constitutes the minority current. This current is directly proportional to

verter and is basically a P-N junction device which converts solar energy into electric energy.

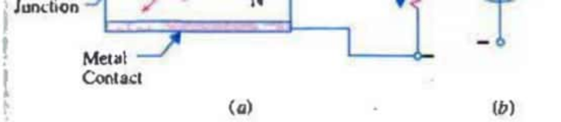


Fig. 6.8

(a) Construction and Working

As shown in Fig. 6.8 (*a*), it essentially consists of a silicon P-N junction diode generally packaged in TO-type can with a glass window on top. Surface layer of P-material is made extremely thin so that incident light photons may easily reach the P-N junction.

This calculator makes use of solar energy.

When these photons collide with valence electrons, they impart them sufficient energy as to leave their parent atoms. In this way, free electrons and holes are generated on both sides of the junction and their flow constitutes the minority current. This current is directly proportional to the illumination (lumen/metre^2 or mW/cm^2) and also depends on the size of the surface area being illuminated. The open-circuit voltage V_{oc} is a function of illumination. Consequently, power output of a solar cell depends on the level of sunlight illumination. Power cells are also available in flat strip form so as to cover sufficiently large surface area.

The nickel-plated ring around the P-layer acts as the positive output terminal (*i.e.*, anode) and the metal contact at the bottom serves as the negative output terminal (*i.e.*, cathode). The symbol is shown in Fig. 6.8 (*b*). Si and Ge are the most widely used semiconductor materials for solar cell although gallium arsenide (GaAs), indium arsenide (In As) and cadmium arsenide (Cd As) are also being used now-a-days.

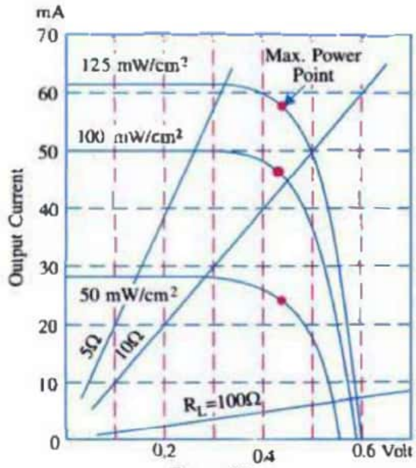


Fig. 6.9

(b) Characteristics

Typical V-I characteristics of a solar cell corresponding to different levels of illumination are shown in Fig. 6.9.

Consider the characteristic for incident illumination of 100 mW/cm^2 in Fig. 6.9. If we short-circuit the cell, current is maximum and equals 50 mA. Since output voltage is zero, power output is also zero. On open-circuit, current is zero though output voltage is nearly 0.57 V. Hence, power output is again zero. For obtaining maximum power output, the cell must be operated at the 'knee' of the curve.

(c) Uses

Solar cells are being used on board satellites to recharge their batteries. Since their sizes are small, a large number of cells are required to do the charging job for which purpose series-parallel cell combinations are employed. For example, about 9,000 solar cells were used to charge nickel-cadmium batteries of Tiros weather satellite for around the clock operation. Their present-day efficiency level is around 15% but it is hoped that higher efficiencies would be reached in the near future. Scientists are planning to orbit large banks of solar cells outside the Earth's atmosphere for converting solar energy into electricity. This energy would then be sent to Earth in the form of a powerful microwave beam which would be reconverted into electricity for terrestrial use.

Example 6.1. *An Earth satellite has 12 V nickel-cadmium batteries which supply a continuous current of 0.5 A throughout the day. Solar cells having V-I characteristics of Fig. 6.9 are employed to keep the batteries fully charged. If illumination from the Sun for 12 hours in every 24 hours is 125 mW/cm^2, determine the approximate number of solar cells required.*

Solution. The circuit for the solar cell battery charger is shown in Fig. 6.10. Let there be n cells connected in series to provide higher voltage and let m such series-groups be connected in parallel to provide the necessary current. Total number of cells required = $m \times n$.

As seen from the V-I characteristics of Fig. 6.9, each cell supplies 56 mA at 0.45 V. If we allow a drop of 1.5 V for series resistor etc., we need (12 + 1.5) = 13.5 V from each series group.