10. ELECTRICITY

Static Electricity

A hard rubber comb can attract small bits of paper after it has been used on a dry hair. This happens because the comb, after rubbing with hair, becomes charged with electricity. The same phenomenon is noticed when a plastic pen is rubbed on a coat sleeve. The friction of textiles can also produce electrification. If after a dry day, one takes off terylene clothes in a dark room, one can see electric sparks and even hear their crackling sound.

Electricity produced by friction between two dissimilar objects is known as **static electricity.** Depending on the nature of the objects, one acquires a positive charge and the other an equal negative charge. For example, if a glass rod is rubbed with silk, the rod acquires positive charge and the silk an equal negative charge. On the other hand, when an ebonite rod is rubbed with flannel, the rod acquires negative charge and the flannel an equal positive charge. It is found that like charges repel and unlike charges attract.

Electrification by friction can be explained on the basis of transfer of electrons. When a glass rod is rubbed with silk, some electrons from the rod attach themselves to the silk. Thus by losing, electrons, glass become positively charged and by gaining the same number of electrons silk acquires an equal negative charge.

When a hollow metallic conductor is charged with static electricity it is found experimentally that the charge resides entirely on the outside of the conductor; the inner surface remains uncharged.

If a car is struck by lightning, persons sitting inside are shielded from the electricity and not harmed at all since the charge remains on the outer surface and may arc to the ground through the lowest metallic part of the car.

If a pear-shaped conductor is charged, it is found that concentration of change on and near the pointed end is much greater. If the charge on the conductor is increased, the pointed end starts losing charge. It can be shown that a pointed end not only enables a conductor to lose charge, it can also act as a collector of charge. The lightning conductor is based on this principle.

Lightning Conductor Lightning is a gigantic electric discharge occurring between two charged clouds or between a charged cloud and the earth. Lightning conductors are used to protect tall buildings from lightning damage. A lightning conductor is a thick copper strip fixed to an outside wall of the building. The upper end of the strip is in the form of several sharp spikes reaching above the highest part of the building in the earth. When charged clouds pass overhead, the lightning conductor accepts any discharge which may occur and conducts it harmlessly to earth.

CONDUCTORS, INSULATORS, INDUCTION

When electrons are deposited on certain materials, they can make their way freely in and out among the atoms. In certain other substances they cannot move freely. They remain more or less at the same point on the material at which they were deposited. Substances that allow electrons to pass freely through them are called conductors. They include such metals as silver and copper. We give the name of insulator to a substance that does not allow electrons to move through it freely. Hard rubber, mica, glass, and porcelain are all good insulators.

Dielectrics are insulating substances through which electrical attraction is maintained. Examples are glass, wax, water, oil, wood, rubber, stone, plastics, etc. In these substances, an applied electric field causes a displacement of charge but not a flow of charge.

Induction takes place when an electrical charge of one kind produces a charges of another kind on a nearby body when there is no direct contact. The principle of induction is used in a condenser, a device for storing electricity.

CURRENT ELECTRICITY

Current electricity exists when electrons flow between two charged objects. An electric current, to put it simply, is the flow of electrons along a conductor. There are two types of currents. Direct current (DC), usually obtained from a battery, flows in one directions only; from the negative terminal of the power sources, through conductors, to the positive terminal. Alternating current (AC), on the other hand, flows first in one direction and then in the opposite direction. It always flows from negative to positive terminals, but the polarity (charge) of each terminal alternates from negative to positive. Each set of two reversals is called a cycle.

Alternating current is used more widely than DC. Its main advantage is that its driving force (voltage) can be readily increased or decreased by transformers. Also, AC machinery is generally simpler to design and build than DC machinery. DC, however, is needed in certain electronic devices and for such processes as charging storage batteries, and electroplating. Also, DC can be produced by batteries, which can be carried about.

A path along which the current travels is called a circuit. A current will only flow if there is a complete circuit to flow around.

The magnitude of current (I) is the charge (Q) flowing in the circuit in one second

$I = Q/t = \frac{charge}{time}$

Current is measured in amperes (A). One ampere of current flows around a circuit if one coulomb of charge passes around the circuit in one second.

The charge on an individual electrons is -1.6×10^{-19} C, so a current of one ampere means something like 6.2×10^{18} electrons are moving through the conductor in one second.

POTENTIAL DIFFERENCE (P.D)

A current will only flow it there is a complete circuit to flow around. The current can only get through a conductor in the circuit if there is a potential difference across the conductor. As a current moves through the conductor, it gives up some of its energy to the conductor. The greater the potential difference, the greater is the amount of energy given up. The electrostatic potential at any point is defined as the work done in bring a single positive charge from infinity to that point. The unit of potential is volt and has the symbol V.

$$p.d (V) = \frac{work\ done}{charge\ moved} = \frac{W}{Q}$$

$$= \frac{joule}{coulomb}$$

Thus, W = V.Q = V.I.t. A potential difference of one volt means that one joule of energy is given up by each coulomb of charge passing through the conductor.

Electrical Resistance

When electric current flows through a conductor, e.g. a metallic wire, it offers some obstruction to the current. This obstruction offered by the wire is called its electrical resistance. The resistance (R) of a wire of a given material depends on its length (l) and area of cross-section (a).

$$R = p\frac{l}{a}$$

If the wire has a circular cross-section of radius r, then a = ðr2. Thus

$$R = p\frac{l}{\pi r2}$$

p is a constant called the resistivity of the material of the wire. Resistivity of good conductor (e.g. copper, silver, etc.) increases with temperature. Whereas, resistivity of a semiconductor (e.g. carbon) decreases with increasing temperature.

ELECTRICAL POWER

Power is the rate at which work is done. In an electric circuit, the work done in a time t is

W = V.I.t

Therefore,

$$\text{Power } P = \frac{W}{t} = VI$$

If potential difference is measured in volts, and current in ampere, the unit of power is a volt ampere, also called a watt. Thus a unit of electric power is watt. Electric power is the rate at which energy is consumed by the circuit. A convenient unit to measure electric power is the kilowatt hour or kWh. This is often simply called a unit.

1kWh = 1000 watt x 3600 seconds.

Effects of Electric Current

(i) Magnetic Effect A current-carrying wire has a magnetic field around it. If the current-carrying wire is wound on a bar of soft iron, it becomes strongly magnetised. When the current is stopped, the iron loses magnetism. Electromagnets, produced in this way, are extremely useful. Strong electromagnets are used in industry for lifting and transporting steel plates, girders, scrap iron etc. These are also used in electric bells, telephone receivers, etc.

(ii) Chemical Effect, Electrolysis An electric current passed through a solution results in the decomposition of the solution into negative and positive ions. Negative ions collect at the positive electrode (anode) and the positive ions collect at the negative electrode (cathode). This phenomenon is known as electrolysis.

Electrolysis is widely used in **electroplating**, i.e. coating of a base metal with a layer of more expensive metal. Electroplating with gold and silver is quite common. Contacts of electronic components used in computers, etc. are gold plated to avoid atmospheric corrosion. Electrolysis plays an important role in metallurgy.

(iii) Heating Effect When a charge moves in a conductor it does work, which results in heating the conductor. Thus electric energy in the form of electric current is converted into heat energy. If the resistance of a wire is R ohms and the current flowing through it is I amperes, the heat produced per second in the wire is I^2R joules. Heat produced, H, in time t is given by $H = I^2Rt$

The heating effect of electric current is made use of in a variety of appliances, such as a geyser, iron, toaster, oven, room heater, and so on. These appliances have coils of nichrome (an alloy of nickel and chromium), which are heated when current is passed. Whenever electricity is used for heating water or other liquids, the heating element is well insulated and enclosed in a tube. Otherwise the liquids will become live and therefore dangerous. In an electric iron, the heating element is sandwiched between two thin sheets of mica, which is highly insulating and can withstand high temperatures.

(iv) Motor Effect When a current-carrying conductor is placed at right angles to a magnetic field, a force acts on the conductor. If a current-carrying rectangular coil is placed in a magnetic field, a couple acts on the coil and it starts rotating. This is the principle of an **electric motor.** Thus in an electric motor, electrical energy is converted into mechanical energy. Electric fans, mixers, washing machines, etc., work on electric motors.

A running motor also acts as a generator producing emf and a current in the reverse direction. This reverse current increases with the speed of the motor. Thus the starting or initial current of an electric motor is much greater than the current flowing after the motor reaches its running speed. If for any reason, the motor armature is brought to rest while the current is still on, the motor may burn out. To avoid damage, a **starter** (a variable resistance) is used in large motors.

The moving coil loudspeaker used in radio receivers etc., works by the force exerted on a current-carrying coil situated in a magnetic field. In a **loudspeaker**, energy is transferred from electric current into mechanical energy of vibration in a cone and then to sound energy.

Though out of place, it would be interesting to note that in a moving coil **microphone**, sound energy is converted into mechanical energy of a vibrating diaphragm and then into electrical energy.

(v) Electric Generator (Dynamo) The construction of a generator is in principle identical to that of a motor. In a generator the armature is rotated in the magnetic field and an emf is induced in it due to electromagnetic induction. Thus a generator converts mechanical energy into electrical energy.

With a minor difference in construction, a generator can produce alternating emf or direct emf the corresponding currents produced are called alternating current (ac) and direct current (dc).

(vi) Inverter An inverter is a device which converts DC to AC. The inverters used in homes and offices are specially designed to

(i) Convert DC from a battery to AC, and

(ii) Charge the battery.

An inverter is fitted in the main power line. When there is a power failure, the inverter automatically switches on the AC, converted from the battery's DC, for lighting and running electrical gadgets. When the mains supply is restored, the inverter automatically switches to a mode where it starts charging the battery depleted due to use during the period of power break-down.

POWER GENERATION AND TRANSMISSION

Electric power stations are, generally, situated in remote areas where it is cheaper to produce electric power. This power has to be transmitted to the cities and areas where it is needed. This is done by transmission lines which consist of two parallel wires for carrying current from and to the power station.

To avoid the loss of power in the line wire, the output voltage of the generator is first transformed to a much higher value by a step-up transformed. It converts the electric power at low voltage and high current to the same power at higher voltage and lower current. Due to reduction in the value of current, the losses in the lines are reduced.

A typical power generator gives an output of 1000 KW at 6.6 kilo-volts. In practice this voltage is stepped up to 132 kilo-volts before transmission. The cables used for transmitting power over long distances are suspended by large porcelain insulators from large steel structures (pylons). The main transmission lines from power stations form part of a common system called the 'grid' which covers a large region of the country. Power from all the power stations in the region is fed into the grid which forms a common pool from which power can be drawn where needed. This allows an efficient power distribution and acts as a safeguard for ensuring a minimum power supply to consumers in the event of failure of power generation at some station. From the grid, the power is fed to the cities at 33KV; the stepping down is done outside the city. Then again at a sub-station, the supply is stepped down to 6.6 KV. Power is supplied to the big consumers like factories at this voltage which they can further step-down according to their needs. For ordinary domestic consumers the voltage is again reduced to 220 V. Since the voltage is alternating, 220 is actually the effective value of the voltage. The peak value of the voltage is 311V.

Domestic Electric Installation

From the local substation, electricity is supplied to a house by two cable, the "live" cable and the "neutral" cable. The neutral cable is earthed at the substation so that it is at earth potential. In domestic supplies, a third cable is introduced for safety. This is called the "earth" and is connected to the earth terminal provided in the building.

Inside the house, the supply is through a meter, which measures the electrical energy consumption in kilowatt hour. From the meter, connections are made to the distribution board through a main fuse and a main switch. There are fuses is each distribution line.

Fuse A fuse is a short piece of wire made of a tin-lead alloy, which has a low melting point. When current in a circuit exceeds the specified value due to short circuiting, overloading, voltage fluctuation, etc., the fuse melts and breaks, thereby protecting expensive electrical appliances and also preventing fire accidents. Fuses are always connected in the live wire.

Nowadays, fuses have been replaced with miniature circuit breakers (MCBs). A circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by overload or short circuit. Unlike a fuse, which operates once and then has to be replaced, a circuit breaker can be reset manually to resume normal operation.

The tin-lead alloy is also used as **soldering material** for joining metals in electronic circuits.

Earth The earth wire is used for earthing the metal casings of electrical appliances and is a safeguard against shocks

Flexible Cables All electrical appliances are provided with three-core flexible cables. The insulations on the three wires are coloured red or brown (for live connection), black or light blue (for neutral connection), and green or yellow (for earth connection).

Plugs, Sockets and Switches A three-pin plug has one pin which is longer and thicker than the other two identical pins. It is for earthing and is connected to the green (or yellow) wire of the appliance. The other two are connected to the red (or brown) and the black (or blue) wires. The earth pin is longer so that an appliance is earthed before it is connected to the live circuit. It is thicker so that it cannot be inserted in the live hole of the socket even by mistake.

In a socket, the top bigger hole is for the earth, the lower right hole is for the live connection and the left hole is for the neutral connection.

All switches in a house are put in the live wires. If they were in the neutral wire, the sockets would remain live even when the switches were in the off position. In such a situation one would get a shock from the element of a heater or a stove even when it was cold.

Electric Light

Incandescent Lamp or Filament Lamp An electric lamp produces light energy electrical energy. It has a tungsten filament connected between two lead-in wires. When current is passed, the tungsten filament is heated and emits light. Tungsten is used because it has a high melting point of 3,400ºC. The lamp contains a small quantity of argon (an inert gas) to prevent evaporation of tungsten. Air could not be used as this would oxidise the tungsten. The lead-in wires of the lamp are not heated much because they have very low resistance.

Fluorescent Tubes A fluorescent tube contains mercury vapours at low pressure. When the tube is switched on, the mercury vapours emit invisible ultraviolet rays. These ultraviolet rays fall on the fluorescent coating on the inside of the tube and emit visible light. Since very little heat is produced in a tube, almost the whole of the electrical energy is converted to light energy. Thus these tubes are more efficient and cheaper.

Compact Fluorescent Lamps The problem with incandescent light bulb is that they waste lot of electricity in the form of heat. On the other hand, no electric energy is wasted as heat in a fluorescent tube. A CFL (compact fluorescent lamp) is a miniature fluorescent tube and works on the same principle. A CFL is 4 to 6 times more efficient than an incandescent bulb. That's why one can buy a 15W fluorescent bulb that produces the same amount of light as a 60W incandescent bulb. Although the initial cost of CFL is more, it more than compensates by saving enormous amount of energy and lasting nearly 15 times longer.

Fluorescent lamps contain mercury which is a hazardous substance. Most light sources including fluorescent bulbs emit a small amount of UV, but the UV produced by fluorescent bulbs is far less than the amount produced by natural daylight.

In terms of light emission: 40W incandescent bulb = 10W CFL, 60W incandescent bulb = 15W CFL, and 100W incandescent bulb = 26- 29W CFL