ELECTRICITY
Electrical Power and Heating Energy of Electric Current

HEATING EFECT OF CURRENT:

When the ends of a conductor are connected to a battery, then free electrons move with drift velocity and electric current flows through the wire. These electrons collide continuously with the positive ions of the wire an thus the energy taken from the battery is dissipated. To maintain the electric current in the wire, energy is taken continuously from the battery. This energy is transferred to the ions of the wire by the electrons. This increases the thermal motion of the ions, as a result the temperature of the wire rises. The effect of electric current due to which heat is produced in a wire when current is passed through it is called heating effect of current or Joule heating. In 1841 Joule found that when current is passed through a conductor the heat produced across it is :

(i) Directly proportional to the squire of the current through the conductor i.e. $H \propto I^2$

(ii) Directly proportional to the resistance of the conductor i.e. $H \propto R$

(iii) Directly proportional to the time for which the current is passed i.e. $H \propto t$

Combining the above three equations we have $H \propto I^2Rt$

$$\text{or} \quad H = \frac{I^2Rt}{J}$$

Where J is called Joule's mechanical equivalent of heat and has a value of $J = 4.18\ cal^{-1}$. The above equation is called Joule's law of heating.

In some cases, heating is desirable, while in many cases, much as electric motors, generators or transformers, it is highly undesirable. Some of the devices in which heating effect of an electric current is desirable, are incandescent lamps, toasters, electric irons and stoves. The tungsten filament of an incandescent lamp operates at a temperature of 2700^0 c. Here, we see electrical energy being converted into both heat and light energy.

(a) Electric Energy:

The fact that conductors offer resistance to the flow of current, means that work must be continuously done to maintain the current. The role of resistance in electrical circuits in analogous to that of friction in mechanics. To calculate the amount of work done by a current I, flowing through a wire of resistance R, during the time t, the amount of work done is given by-

$$W = QV$$

but as $$Q = I \times t$$

therefore, the amount of work done, W is

$$W = V \times I \times t$$

By substituting the expression for V from Ohm's law,

$$V = IR$$

we finally get $$W = I^2 Rt$$

This shows that the electrical energy dissipated or consumes depends on the product of the square of the current I. flowing through the resistance R and the time t.

(i) Commercial unit of electrical energy (Kilowatt - hour):

The S.I. unit of electrical energy is joule and we know that for commercial purposes we use a bigger unit of electrical energy which is called **"kilowatt - hour".** One kilowatt - hour is the amount of electrical energy consumed when an electrical appliance having a power rating of 1 kilowatt and is used for 1 hour.

(ii) Relation between kilowatt hour and Joule:

Kilowatt-hour is the energy supplied by a rate of working of 1000 watts for 1 hour.
1 kilowatt-hour = 3600000 joules

$\Rightarrow$ 1 kWh = 3.3×10^6 J

(b) Electric Power:

The rate at which electric energy is dissipated or consumed, is termed as electric power. The power P is given by,

$$P = W/t = I^2 R$$

The unit of electric power is watt, which is the power consumed when 1 A of current flows at a potential difference of 1 V.

(i) Unit of power: The S.I. unit of electric power **'watt'** which is denoted by the letter W. The power of 1 watt is a rate of working of 1 joule per second.
A bigger unit of electric power is kilowatt.
1 kilowatt (kW) = 1000 watt.
Power of an agent is also expressed in horse power (hp).
1 hp = 746 watt.

(ii) Formula for calculating electric power:

We know, Power, $P = \frac{\text{Work}}{\text{Time}}$

and Work, W = V × I × t joules

$\therefore$ $P = \frac{V \times I \times t}{t}$

$P = V \times I$

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Power P in timers of I and R :

Now from Ohm's law we have $\frac{V}{I} = R$

$V = I \times R$

$P = I \times R \times I$

$\therefore$ $P = I^2 \times R$

Power P in terms of V and R:

We know, $P = V \times I$

From Ohm's low $I = \frac{V}{R}$

$$P = V \times \frac{V}{R}$$

$$P = \frac{V^2}{R}$$

(c) Power - Voltage Rating of Electrical Appliances:

Every electrical appliance like an electric bulb, radio or fan has a label or engraved plate on it which tells us the voltage (to be applied) and the electrical power consumed by it. For example, if we look at a particular bulb in our home it may have the figures **220 V, 100W** written on it. Now **220 V** means that this bulb is to be used on a voltage of **220 volts** and **100 W** Which means it has a power consumption of 100 watts or 100 joules per second.

(d) Application of Heating Effect of Current:

Domestic electric appliances such as electric bulb, electric iron geyser, room heater etc work on heating effect of current and are rated in terms of voltage and wattage. The coils of these devices are made of a material of a very high resistance, (for instance, nichrome or tungsten) such that when a current passes through the coil, heat is generated. Generally the potential difference applied to the electrical appliance is the same as the of the mains i.e. **220-230 V** in India an d**110 V** is U.S.A. Canada etc.

(e) Electric Fuse:

An electric fuse in an easily fusible wire of short length put into an electric circuit for protection purpose. It is arranged to melt ("blow") at a definite current. It is an alloy of lead and tin (**37% lead + 63% tin**). It has a low resistivity and low melting point. As soon as the safe limit of current exceeds, the fuse "blows" and the electric circuit is cut off.
Consider a wire of length **L**, radius r and resistivity **p.** Let I be the current flowing through the wire. Now rate at which heat is produced in the wirem.

$$P = I^2 R = \frac{I^2 \rho L}{\pi r^2} \qquad \left[\therefore \frac{\rho L}{A} = \frac{\rho :}{\pi r^2}\right]$$

This heat increases the temperature of the wire. Due to radiation some heat is lost. The temperature of the fuse becomes constant when the heat lost due to the radiation becomes equal to the heat produced due to the passage of current. This given the value of current which can safely pass through the fuse. In other words we have,

$$I \propto r^{3/2}$$

Illustration:

1. 15 bulbs of 60W each, run for 6 hours daily and a refrigerator of 300 W runs for 5 hours daily. Work out per day bill at 3 rupees per unit.

Sol. Total wattage of 15 bulbs = 15 ” 60 W = 900 W
$\therefore$ Electrical energy consumed by bulbs per day = P × t = 900 × 6 = 5400 Wh
And electrical energy consumed by refrigerator per day = 300 × 5 = 1500 Wh
Total electrical energy consumed per day = (5400 + 1500) Wh = 6900 Wh

$\therefore$ Electrical energy consumed per day = $\frac{6900}{1000}$ KWh = 6.9KWh

Here, per day bill = Rs. 6.9 × 3 = Rs. 20.7

ELECTRIC BULB

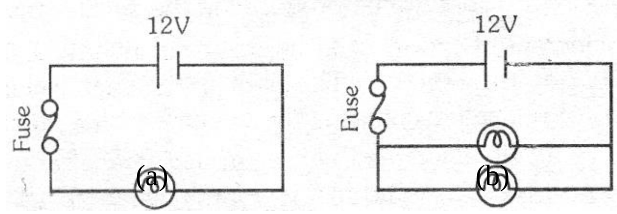
An electric bulb has a simple structure. It consists of a sealed glass bulb that has a tungsten filament connected to two electrical contacts. The bulb is filled with a an uncreative gas like argon or nitrogen. To produce white light, the filament has to be heated to about 3000^0 C by passing a currant though it. Obviously, the material of the filament should such that it does not melt at this temperature . Tungsten is used for the filament because its melting point is about 3400^0 C. The sealed glass bulb serves two purposes. First, it protects the filament from oxidation and the effects of humidity. Secondly, the small enclosed volume makes it easier to maintain the required temperature, as without it the loss of heat would be more.

FUSE

A fuse is a safety device that does not allow excessive current to flow through an electric circuit. It consists of a metallic wire of low melting, fixed between the two terminals of a fuse plug. The fuse plug fits into a fuse socket connoted in the circuit. Fuses are available in various shapes. The fuse plug is used in household wiring. it is made f porcelain.

A fuse is connected in series with an appliance (such as a TV) or a group of appliances (such as the lights and fans in room). So, the current through the fuse is the same as the current through the appliance or the group of appliance. If this current exceeds a safe value, the heat produced in the fuse wire causes it to melt immediately. This brakes the circuit, preventing any damage. Figure shows examples of how a fuse is connected in circuits.

Good-quality fuse wires are made of tin, as it has low melting point. Some fuse wires are made of an alloy of tin and copper. The thickness of the fuse wire depends on the circuit in which it is to be used. If a section of the circuit is meant to carry a maximum of 5A current, the fuse wire should also be able to carry currents up to 5A. Similarly, for wiring meant for 15A, the fuse wire should be thicker, and should be able to carry current up to 15 A.



DISADVANTAGES OF THE HEATING EFFECT OF CURRENT

A current always produces some neat, whether we use the heat or not. If the neat produced cannot be utilized, it represents a wastage of energy. A considerable amount of energy is thus wasted in the transmission of electricity from the generating station to out homes. Sometimes, the heat reduced in a device is so much that it can damage the device, unless power proper cooling arrangements are made. To dissipate the heat produced in TV sets, monitors, etc., their cabinets have grills for air to pass. Certain components of computer get so not that they have fans to cool them.