ELECTRIC POWER AND HOUSEHOLD CIRCUITS

HEATING EFFECT OF CURRENT

Heating effect of electricity is one of the widely-used effects in the world. When electric current is passed through a conductor, it generates heat due to the resistance it offers to the current flow. The work done in overcoming the resistance is generated as heat. In the 19th century, this was studied by James Prescott Joule and he enunciated various factors that affect the heat generated. According to him, "when an electric current flow through the filament of a bulb, it generates heat, and so the bulb becomes hot". This property is named the heating effect of electric current.

Factors Affecting Production of Heat

The heat produced by a heating element is directly proportional to

- the square of the electric current (I) passing through the conductor,
- the resistance (R) of the conductor,
- time (t) for which current passes through the conductor.

It is given by the expression $H = I^2Rt$, and is well known as Joule's Law. The other factors that affect the production of heat in a wire through which an electric current is passing are the length and thickness of the wire, the duration of flow of current, and the material of the wire.

Applications of Heating Effect of Electric Current

Applications of the heating effect of electric current include appliances like electric immersion water heater, electric iron box, etc.

All of these have a heating element in it. Heating elements are generally made of specific alloys like, nichrome, manganin, constantan, etc. A good heating element has high resistivity and high melting point. An electric fuse is an example for the application of heating effect of electric current. The rating of 3 A of an electric fuse implies the maximum current it can sustain is 3A.

Heating Elements

Appliances like electric iron box, immersion water heater, etc., have coils of wire that produce heat, which are known as heating elements. As current flows through these electrical appliances, the coils of wire inside turn bright orange red in colour. This is because a huge amount of heat is produced. Different appliances have different types of heating elements. The type of heating element depends on the function of the appliance. Some appliances are required to produce more heat than others.

Electric Fuse

The electric fuse works on the principle of the heating effect of electric current. An electric fuse is a safety device to prevent damage to an electrical circuit when excessive current flows through it. It has a wire made of an alloy of tin and lead. As the current increases beyond a limit, the wire in the electric fuse melts and breaks off. The fuse is then said to have blown off. The circuit is broken and current stops flowing through it. Thus, a fuse prevents fires. There are various types of fuses. Some fuses are used only in buildings, while others are used in appliances.

Reasons for Excessive Current

When all the appliances are connected to the same socket, they draw more current, and so the load increases. When the insulation on the wires is torn, two wires carrying current may touch each other directly. This causes a spark, which leads to fire. This is termed as a short circuit. If a fuse is not used, overloading and short circuits occur which results in fire.

The fuses used for domestic purposes are rated as 1 A, 2 A, 3 A, 5 A, 10 A, etc. For an electric iron which consumes 1 kW electric power when operated at 220 V, a current of (1000/220) A, that is, 4.54 A will flow in the circuit. In this case, a 5 A fuse must be used.

Electric Energy and Power

The rate of doing work is called power. This is also the rate of consumption of energy. The equation $H = I^2 Rt$ gives the rate at which electric energy is dissipated or consumed in an electric circuit. This is also termed as electric power. The power P is given by $P = VI = P = I^2R = V\ ^2R$.

The SI unit of electric power is watt (W). It is the power consumed by a device that carries 1 A of current when operated at a potential difference of 1 V. 1 W = 1 volt x 1 ampere = 1 V A. The unit 'watt' is very small. Therefore, in actual practice we use a much larger unit called 'kilowatt'. 1 kilowatt = 1000 watts. Since electrical energy is the product of power and time, the unit of electric energy is, therefore, watt hour (W h). One watt hour is the energy consumed when 1 watt of power is used for 1 hour.

The commercial unit of electric energy is kilowatt hour (kW h), commonly known as 'unit'. 1 kW h = 1000 watt × 3600 second = 3.6×10^6 watt second = 3.6×10^6 joule (J). We pay the electricity board or electric company to provide energy to move electrons through the electric gadgets like electric bulb, fan and engines. We pay for the energy that we use and not for the electrons. Electrons are not consumed in a circuit, as many people think.

Compact Fluorescent Lamps (CFL's)

We use electric bulbs to obtain light. Due to the heating effect, some part of the energy received by the bulb is used up, and hence, some electricity is wasted. CFL's do not depend on the heating effect of electricity to produce light, since they do not use filaments. Using CFL's instead of ordinary bulbs minimises wastage of electricity. In CFL's, light is generated using two electrodes. The fluorescent coating inside each tube makes the light brighter.

We use every day many appliances that work on the property of the heating effect of electric current. For example, the electric room heater, electric roti maker, electric iron, toaster, hair dryer, electric stove, immersion water heater, food warmer, electric coffee maker, electric rice cooker and geyser work on the property of the heating effect of electric current.

ELECTROMAGNETIC INDUCTION

Electromagnetism created a revolution by leading to the devices called motors which convert electrical energy to mechanical energy. Experiments by scientists like Oersted and Faraday made a long leap by converting mechanical energy to electrical energy. When a straight conductor is moved in a magnetic field an electric current is induced in it and the phenomenon is electromagnetic induction. The emf caused is the induced emf and the current is induced current.
Oersted found the same by relative motion of a magnet with respect to a coil. Faraday's experiment proved that the strength of the induced current depends on several factors like the strength of the magnet, the speed of motion of the magnet, its orientation, the number of turns in the coil and the diameter of the coil. The induced current can be detected by a galvanometer. Fleming's right hand rule gives the direction of the induced current in a conductor when it is moved in a magnetic field. Transformers are based on this principle, which consist of a primary coil and a secondary coil. The number of turns in the coils is selected based on the type of the transformer to be made, namely, step-up or step-down.

Electric generators work on the same principle. They have an armature which is free to rotate in a magnetic field. Its terminals are connected to two slip rings, which are further connected to two brushes and they are connected across a load resistance through which the generated electricity can be trapped. The rotation of the armature in the magnetic field changes the magnetic flux in the coil of the armature and an electric current is induced. As the direction of the induced current changes for every half rotation, it is called alternating current. The current at the power plants is distributed through transmission lines at a high voltage and hence the lines are referred to as high tension power lines. At the substations, these are stepped down to a lower voltage and supplied to houses at a low voltage. A domestic electric circuit essentially contains mains, a fuse, live or line, neutral and earth wires. From the poles supply cables bring the current to the mains. Within the house, all the equipment is connected in parallel combination.

Electromagnetic induction (EMI) is the process of generating an electromotive force by moving a conductor through a magnetic field.

The electromotive force generated due to electromagnetic induction is called induced emf.
The current due to induced emf is called induced current. Fleming's right hand rule states that if the index finger points in the direction of the magnetic field and the thumb indicates the direction of the motion of the conductor, then the middle finger indicates the direction of the induced current flow in the conductor.

An electric generator is used to convert mechanical energy into electrical energy, using electromagnetic induction.

Alternating current (AC) is the current induced by an AC generator. AC current changes direction periodically. Direct current (DC) always flows in one direction, but its voltage may increase or decrease.

Electrical components and wires fitted in a household to supply electricity to various appliances form a domestic electric circuit. The main supply cable has two wires: Live wire and neutral wire. Domestic electric circuits have earth wires to save users from severe electric shocks. An electric fuse is a safety device used to protect an electric circuit against excessive current.

POWER TRANSMISSION

In a country like India economic growth depends not only on the amount of power produced, but also on how efficiently it is transmitted.

Electricity is generated at thermal or hydro-electric power stations. In power stations, mechanical energy is converted into electrical energy using generators.

The advantage with the A.C. voltage over the D.C. voltage is that its magnitudes can be easily varied with the help of a transformer.

Generators work on the principle of a dynamo, and produce large AC voltages. The advantage of AC voltage over DC voltage is that its magnitude can be easily varied with the help of a transformer. Hence, power stations have generators that produce AC voltage.

Transmitting AC is more advantageous than DC. Say a power of 44,000 watts is to be transmitted from a generating station to a city or town hundreds of miles away.

Since Power P = VI, where V is the voltage and I is the current, it can be transmitted at a voltage of 440 volts and current 100 amperes, or at a voltage of 11,000 volts and current 4 amperes.

The heat (H) produced in a resistance R due to the flow of current 'I' through it is

$H = I^2R\ t.$

Thus, if I is more, then the heat losses are more. Thus, the voltage of AC power can be increased to reduce the current for the same amount of power to reduce heat losses. That is why it is advantageous to transmit AC power at high voltage and low current. In the example, it will be better to transmit 44,000 watts of power at 11,000 volts at 4 amperes than transmitting it at 440 volts and 100 amperes.

Electricity is transmitted to our homes through a power grid system. The grid consists of pylons or towers to which high-tension (HT) transmission lines called HT bare conductors are attached.

A group of pylons can receive power from different generating stations. They, therefore, form an integrated power supply system. Such a network of HT supply system in a region is called a power grid. Power stations from different parts of the country are connected to the grid. This form of over-head transmission of electricity is employed for covering large distances.

Here is a schematic diagram of power transmission. At the generating station G, a voltage of 11,000 volts (11 kV) is produced. A step-up transformer (T) is used to convert this AC voltage into a higher voltage, of 220 Kilovolts or 132 Kilovolts.

This high voltage is transmitted to a branch station outside a city called a 'major load centre’. At the major load centre, the high voltage is reduced to 33 kV using a step-down transformer.

Feeders

At an intermediate load centre, it is further stepped down to 11 kV and is supplied to substations. This 11 kV power is stepped down by local transformers to either 415 volts or 220 volts and then supplied to industrial or domestic consumers.

Houses or industries are connected in parallel to main supply.

Note that all houses or industries are connected in parallel to the main supply. Thus, power transmission is done efficiently using step-up and step-down transformers.

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HEATING EFFECT OF ELECRIC CURRENT

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A good heating element has high resistivity and high melting point. An electric fuse is an example for the application of heating effect of electric current. The rating of 3 A of an electric fuse implies the maximum current it can sustain is three amperes.

The chemical reaction within the cell generates the potential difference between its two terminals that sets the electrons in motion to flow the current through a resistor or a system of resistors connected to the battery. To maintain the current, the source has to keep expending its energy.

Part of the source energy in maintaining the current may be consumed into useful work (like in rotating the blades of an electric fan). Rest of the source energy may be expended in heat to raise the temperature of gadget. For example, an electric fan becomes warm if used continuously for longer time, etc.

If the electric circuit is purely resistive, that is, a configuration of resistors only connected to a battery, the source energy continually gets dissipated entirely in the form of heat. This is known as the heating effect of electric current. When a conductor offers resistance to the flow of current the work done by the electric current in overcoming this resistance is converted into heat energy.

The generation of heat in a conductor is an inevitable consequence of electric current. In many cases, it is undesirable as it converts useful electrical energy into heat. In electric circuits, the unavoidable heating can increase the temperature of the components and alter their properties.

The electric heating is also used to produce light, as in an electric bulb. Here, the filament must retain as much of the heat generated as is possible, so that it gets very hot and emits light. It must not melt at such high temperature. A strong metal with high melting point such as tungsten (melting point 3380°C) is used for making the filaments of the bulb. The filament should be thermally isolated as much as possible, using insulating support, etc. The bulbs are usually filled with chemically inactive nitrogen and argon gases to prolong the life of filament. Most of the power consumed by the filament appears as heat, but a small part of it is in the form of light radiated.

Devices which work on the heating effect of electric current have a heating element or filament. Good heating elements have high resistivity, high melting point and negligible variation in resistance due to temperature changes.

The three metal alloys most commonly used as heating elements are:

Nichrome (80% Ni + 20% Cr); Manganin (86% Cu + 12% Mn + 2% Ni); Constantan (60% Cu + 40% Ni).

Joule's law

The Joule's law states that the quantity of heat produced in a resistor is directly proportional to: (i)the square of current for a given resistance, (ii) the resistance for a given current, and (iii) the time for which the current flows through the resistor, i.e., $H = I^2Rt$.

Consider a current I flowing through a resistor of resistance R.
Let the potential difference across it be V.
Let t be the time during which a charge Q flows across.

The work done in moving the charge Q through a potential difference, V =VQ.
⇒ The source must supply energy equal to VQ in time t.
⇒ The power input to the circuit by the source is
$P = \frac{VQ}{t} = VI$.
Or the energy supplied to the circuit by the source in time t
$\Rightarrow H = P \times t$,
$\Rightarrow H = VIt$
This energy gets dissipated in the resistor as heat.
Thus for a steady current I, the amount of heat H produced in time t is $H = VIt$.
Applying Ohm's law, $H = I^2 Rt$.

In practical situations, when an electric appliance is connected to a known voltage source, current can be calculated using the relation $I = \frac{V}{R}$. Using this value in $H = I^2Rt$, the heat produced can be calculated.

One of the common applications of Joule's heating is the fuse used in electric circuits. An electric fuse is a safety device used to protect circuits and appliances by stopping the flow of any unduly high electric current. It works on the heating effect of electric current.

Electric Fuse

The electric fuse works on the principle of the heating effect of electric current. An electric fuse is a safety device to prevent damage to an electrical circuit when excessive current flows through it.

An electric fuse consists of a piece of wire made of a metal or an alloy of appropriate melting point, for example aluminium, copper, iron, lead, etc. If a current larger than the specified value flows through the circuit, the temperature of the fuse wire increases. This melts the fuse wire and breaks the circuit.

The fuse wire is usually encased in a cartridge of porcelain or similar material with metal ends. As the current increases beyond a limit, the wire in the electric fuse melts and breaks off. The fuse is then said to have blown off. The circuit is broken and current stops flowing through it. Thus, a fuse prevents fires.

Note
The fuse is placed in series with the device.
There are various types of fuses. Some fuses are used only in buildings, while others are used in appliances.

Reasons for Excessive Current

- If all the appliances are connected to the same socket, these appliances draw more current, and so the load increases.
- If the insulation on the wires is torn, two wires carrying current touch each other directly. This causes a spark, which leads to fire. This is termed as a SHORT CIRCUIT.

- If a fuse is not used, then overloading and short circuits result in fire.

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1 W = 1 volt × 1 ampere = 1 V A.

The unit 'watt' is very small. Therefore, in actual practice we use a much larger unit called 'kilowatt'. It is equal to 1000 watts.

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Heating Elements

These appliances have coils of wire that produce heat, which are known as heating elements. As current flows through these electrical appliances, the coils of wire inside turn bright orange red in colour. This is because a huge amount of heat is produced. Different appliances have different types of heating elements. The type of heating element depends on the function of the appliance. Some appliances are required to produce more heat than others.

ISI Mark

We should purchase only appliances that bear an ISI mark. ISI stands for Indian Standards Institute. If an appliance bears the ISI mark, it means that it is safe and will not waste electrical energy. Moreover, it is a mark of quality.

Factors Affecting Production of Heat

The factors that affect the production of heat in a wire through which an electric current is passing are the length and thickness of the wire, the duration of flow of current, and the material of the wire.

Miniature Circuit Breakers (MCB)

Instead of fuses, MCBs are used nowadays because these are switches that turn off automatically when there is an overload or a short circuit. After solving the problem in the circuit, the switch can be turned back on, and then the current flows as usual.