Adani Public School

Class X _ Physics Notes

Current Electricity

Electric charge: Electric charge is a physical quantity which causes force in matter.

Types of Charges: Positive Charge and Negative Charge

S.I unit of Charges is **coulomb** which is denoted by the letter **C**.

Calculate the number of electrons constituting one coulomb of charge.

Solution: Here Q = 1 C and e = 1.6×10^{-19}C

$n = \frac{Q}{e} = \frac{1}{1.6x10^{-19}}$ = 6.25×10^{18} electrons. Thus, 6.25×10^{18} electrons constitute 1 C of charge.

Properties of Electric Charges:

1. Unlike (Opposite) charges attract each other and like (similar) charges repel each other.
2. Electric charge is a scalar quantity.
3. Electric charge is conserved, i.e., it can neither be created nor be destroyed.
4. Electric charge is additive i.e., total charge is the algebraic sum of the individual charges.
5. Electric charge is quantised and the quantum of charge is equal to that on an electron. Any other charged body will have a charge, Q where
   Q = ne where n = $\pm 1, \pm 2, \pm 3$ .... etc and e = charge on an electron = 1.6×10^{-19} coulomb.

Conductors, Insulators and Semi – Conductors:

Conductors: Substances through which charges can easily pass are known as conductors. Metals, aqueous solutions of salts and ionized gases are all conductors.

Insulators: Substances through which charges cannot pass are called insulators. Glass, porcelain, pure water and all gases are insulators.

In insulators, the electrons are strongly bound to their atoms and cannot get themselves freed. Thus, free electrons are absent in insulators.

Semi–Conductors: Those materials whose electrical conductivity lies in between conductors and insulators are called semi – conductors. For example- silicon, germanium etc.

Electricity is broadly classified as:

Electrostatics or Static Electricity: The branch of physics which deals with the study of electric force, electric field, electric potential and electric energy due to charge at rest is known as electrostatics. In simple words 'branch of electricity, deal with the study of charge at rest'.

Current Electricity: When charges are in motion, they constitute what is called an electric current. Current electricity deals with the fundamental concepts and the physical effects of electric current.

Electric Current:

The electric current is defined as the rate of flow of charges across any cross sectional area of a conductor is known as electric current. OR An electric current is defined as the ordered motion of electric charges.

The magnitude of electric current in a conductor is the amount of electric charge passing through a given point of the conductor in one second. If a charge of Q coulombs flow through a conductor in time t seconds, then the magnitude of the electric current I flowing through it is given by:

$$I = \frac{Q}{t}$$

Electric current is a **scalar quantity**. Electric current is a ratio of charge and time, as both of them are scalar; therefore, electric current is a scalar quantity. Moreover, it does not obey the laws of vector algebra also.

An electric current is due to the drift of:

1. Electrons in a metallic conductor.
2. Positive and negative charges in an electrolyte.
3. Electrons and ions in gases in discharge tubes.
4. Electrons and holes in a semiconductor.

S.I unit of Current: The S.I unit of current is ampere (A) in honour of French scientist, Andre-Marie Ampere.

One ampere: Current flowing through a conductor is said to be one ampere if one coulomb of charge flows through it in one second.

$$1 ampere = \frac{1 coulomb}{1 second} = 1Cs^{-1}$$

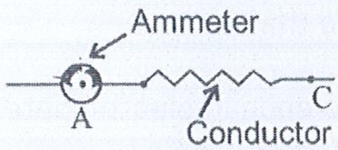
Small quantities of current are measured in milliampere (mA) and in micro ampere(μA)

1mA (milliampere)= 10^{-3} A 1μA(microampere)=10^{-6} A

One coulomb: One coulomb of charge is that quantity of charge which flows through a circuit when one ampere of current flows through it in one second.

1 coulomb = 1 ampere x 1 second.

Current is measured by an instrument called **ammeter.** The ammeter is always connected in **series** with the circuit in which the current is to be measured. Its positive terminal should be connected with the positive terminal of a cell or battery and its negative terminal should be connected with the negative terminal of the cell or battery. Since the entire current passes through the ammeter, therefore, an ammeter should have **very low resistance** so that it may not change the value of the current flowing in the circuit. Resistance of an **ideal** ammeter is ***zero.***



Direction of Electric current: The conventional direction of electric current is from positive terminal of a cell (or battery) to the negative terminal, through the outer circuit. So, in our circuit diagrams, we put the arrows on the connecting wires pointing from the positive terminal of the cell towards the negative terminal of the cell, to show the direction of conventional current.

The actual flow of electrons (which constitute the current) is, however, from negative terminal to positive terminal of a cell, which is opposite to the direction of conventional current.

Electric Field: The electric field due to a charge is the space around the charge in which any other charge experiences a force of attraction or repulsion. Theoretically, electric field due to a charge extends up to infinity. However, the effect of electric field dies quickly as the distance from the charge is increased. A charge does not experience any force due to electric field produced by it.

Electric field is a **vector quantity**. Its S.I unit is **newton per coulomb**. $\frac{N}{C}$ or NC^{-1}

Electric Potential: The electric potential at a point in an electric field is defined as the work done in moving a unit positive charge from infinity to that point.

OR

The electric potential at a point in an electric field is defined as the amount of work done in moving a unit positive charge from infinity to that point, without acceleration or without a change in K.E., against the electric force due to the electric field.

Potential is denoted by a symbol V and its S.I unit is volt. In honour of the scientist **Alessandra Volta** (the inventor of the voltaic cell). Electric potential is a scalar quantity.

A potential of 1 volt at a point means that 1 joule work is done moving 1 unit positive charge from infinity to that point.

~~A potential of 1 volt at a point means that 1 joule of work is done in moving 1 coulomb of positive charge from infinity to that point.~~

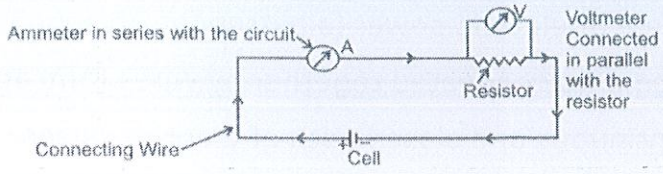
- **Potential Difference**: The difference in electric potential between two points is known as potential difference. The potential difference between two points in an electric circuit is defined as the amount of work done in moving a unit charge from one point to the other point. The electrons move only if there is a difference of electric pressure called the **potential difference** along the conductor.

$$\text{Potential difference} = \frac{Work\ Done}{Quantity\ of\ Charged\ moved}\ \text{i.e.,}$$

$V = \frac{W}{Q}$ Where W = work done and Q = quantity of charged moved. The S.I unit of potential difference is volt which is denoted by the letter V. The potential difference between two points is said to be 1 volt if 1 joule of work is done in moving 1 coulomb of electric charge from one point to the other.

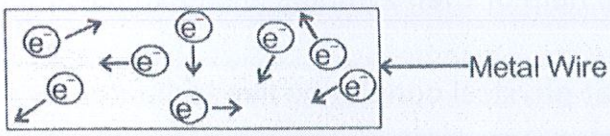
$$1\ \text{volt} = \frac{1\ joule}{1\ coulomb} \quad \text{or } 1V = JC^{-1}$$

The potential difference is measure by voltmeter. The voltmeter is always connected parallel across the two points where the potential difference is to be measured. A voltmeter has a high resistance so that it takes a negligible current from the circuit. **Voltage is the other name for potential difference.**

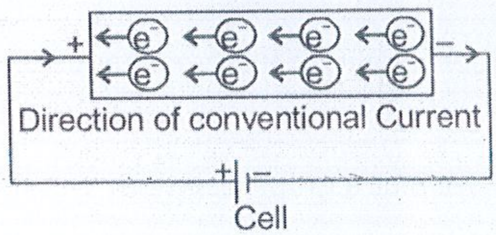


How the Current Flows in a Wire:

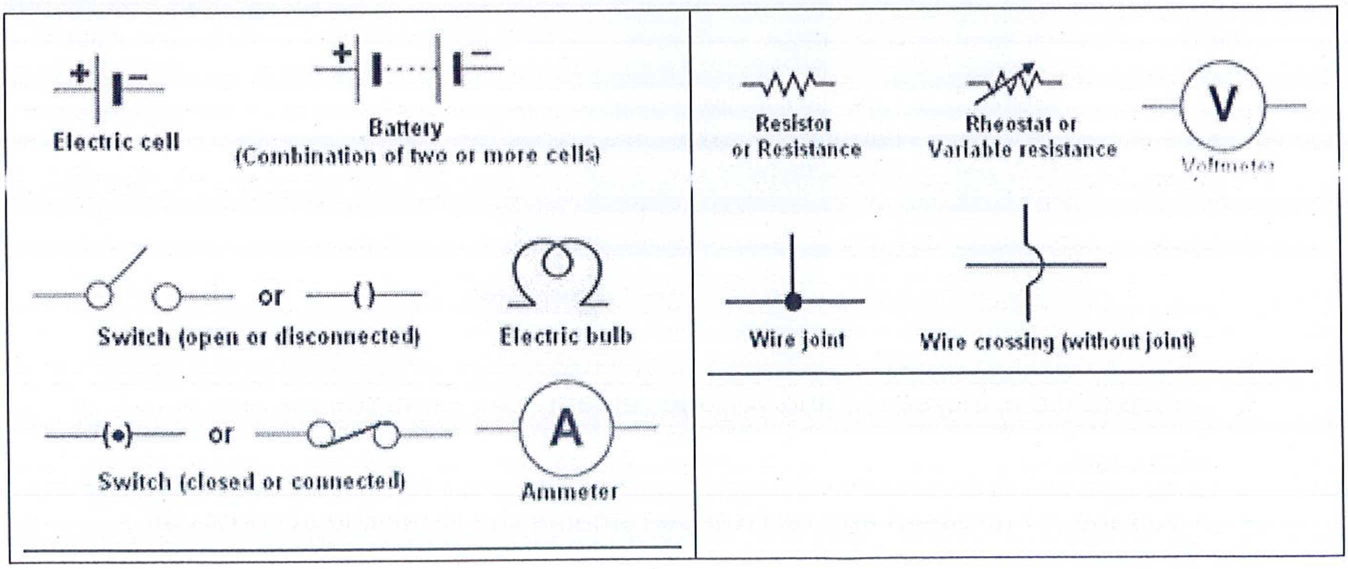
As electric current is the flow of electrons in a metal wire (or conductor) when a cell or battery is connected across its ends. A metal wire has plenty of free electrons in it. When the metal wire has not been connected to a source of electricity like a cell or a battery, then the electrons present in it move at random in all the directions between the atoms of the metal wire as shown in figure below.



When a source of electricity like a cell or a battery is connected between the ends of the metal wire, then and electric force acts on the electrons present in the wire. Since the electrons are negatively charged, they start moving from negative end to the positive and of the wire and this flow of electrons constitutes the electric current in the wire.



Circuit Symbols:



Electric Circuit: A source of electric power (a battery or AC source), loads and switches and other elements connected together by wires form an electric circuit. Electric circuit is a continuous and closed path of electric current.

Open electric circuit: An open electric circuit is one in which the key is open and there is no flow of current.

Closed electric circuit: A closed electric circuit is one in which the key is closed and the current flows continuously.

Circuit Diagram: A diagram showing the arrangement of various components in an electric circuit, with the help of their symbols is known as circuit diagram.

Ohm's Law: It states that physical conditions like temperature pressure etc. remaining constant, the current flowing through a conductor is always directly proportional to the potential difference across the conductor.

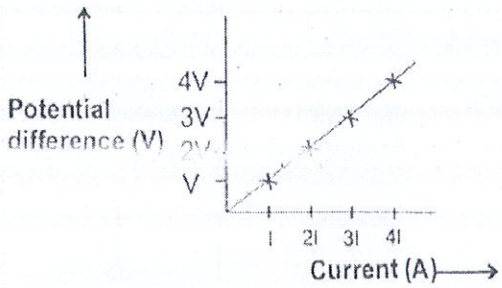
i.e. $I \propto V$

or $V \propto I$

or **V = IR** ←---------(1)

Where R is constant of proportionality, called resistance of conductor at a given temperature.

From (1) $\frac{V}{I}$ = constant. So, if we plot a graph between V and I it will be a Straight line as shown in figure passing through the origin.



- If resistance is increased and voltage remains the same the current will decrease.
- If voltage is increased and resistance remains the same the current will increase.

- From the expression of Ohm's Law it is obvious that electric current through a resistor is inversely proportional to resistance. This means electric current will decrease with increase in resistance and vice versa.

Three activities given in NCERT Book – very important topic

Resistance: Resistance of a conductor is the property of a conductor to oppose the flow of charge through it. The resistance of a conductor is given by:

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

Thus, resistance of a conductor is defined as the ratio of the potential difference across the ends of a conductor to the current flowing through the conductor.
Component that is used to resist the flow of electric current in a circuit is called resistor. In practical applications, resistors are used to increase or decrease the electric current.
The S.I unit of resistance is ohm (Ω – a Greek letter omega)
One ohm: Resistance of a conductor is said to be one ohm if a potential difference of one volt across the ends of the conductor makes a current of one ampere to flow through it.

Variable Resistance: The component of an electric circuit which is used to regulate the current; without changing the voltage from the source; is called variable resistance.

Rheostat: This is a device which is used in a circuit to provide variable resistance.

Cause of Resistance: As we know that there are large numbers of free electrons in a conductor.
When a potential difference is applied across the ends of conductor the free electrons moves with
higher energy and collide among themselves and with the atoms of conductor and causes obstacle to flow of current. This obstacle produces the opposition to flow of electrons *i.e.* produces resistance.

Important Point:

- Resistance of a conductor does not depend upon the potential difference applied across the ends of the conductor.
- Poor conductors and Insulators offer **very high resistance**.

Difference between Resistor and Resistance: A resistor is an object of some conducting material having resistance of a desired value. Thus, a resistor is an object and resistance is its electrical property due to which it opposes electric current. Whenever we say that we have a resistance of 5Ω it means there is a resistor which offers a resistance of 5Ω.

Factor affecting resistance: The factors on which the resistance of a conductor depends are:

Resistance of conductor is directly proportional to Length (l) of the conductor i.e.

$R \propto l$

Resistance of conductor is inversely proportional to area of cross – section (A) of the conductor $R \propto \frac{1}{A}$

$R \propto \frac{l}{A}$; $R = \frac{\rho l}{A}$ where ρ is constant of proportionality and is known as resistivity or specific resistance of a conductor.

Important Point:

Resistance of a conductor depends upon the length l and area of cross section A of the conductor. In addition to these two factors, resistance of a conductor also depends upon:

- The nature of the material of the conductor
- The temperature of the conductor.
- Silver is the best conductor of electricity as its resistivity is least.

Resistivity: Resistivity of a conductor is defined as the resistance of the conductor of unit length and unit area of cross-section.

$$\rho = \frac{RA}{l} \text{ if } A = 1 \text{ and } l = 1 \text{ then } \rho = R.$$

In other words, resistivity of a conductor is defined as the resistance offered by a cubical conductor of 1 m side to the flow of current across the opposite faces of the conductor.

OR

Resistivity of a material is also defined as the resistance offered by a cylindrical conductor of the material of cross-section area one meter^2 and length one metre when the current flows perpendicular to the opposite ends of the cylinder.

The **S.I unit** of resistivity or specific resistance is **ohm-metre** (Ω m).

$$unit\ of\ resistivity\ (\rho)$$

$$= \frac{\Omega \times m^2}{m} = \Omega m$$

Resistivity of a substance does not depend upon its length, shape and area of cross-section. Resistivity of a substance depends on the nature of the material of which the substance is made up of. The resistivity of material changes with temperature.

Importance of resistivity: a good conductor of electricity should have a low resistivity and poor conductor of electricity should have a high resistivity. The resistivities of alloys are much higher than those of the pure metals. It is due to their high resistivity that manganin and constantan alloys are used to make resistance wires used in electronic appliances to reduce the current in an electrical circuit.

Nichrome alloy is used for making the heating elements of electrical appliances like electric irons, room heaters, water heaters and toasters etc because it has very high resistivity and it does not undergo oxidation (or burn) even when red-hot.

Materials having resistivity in the range of 10^{-8} Ω m to 10^{-6} Ω m are considered as very good conductors. Silver has resistivity equal to 1.60 X 10^{-8} Ω m and copper has resistivity equal to 1.62 X 10^{-8} Ω m.

Rubber and glass are very good insulators. They have resistivity in the order of 10^{12} Ω m to 10^{17} Ω m

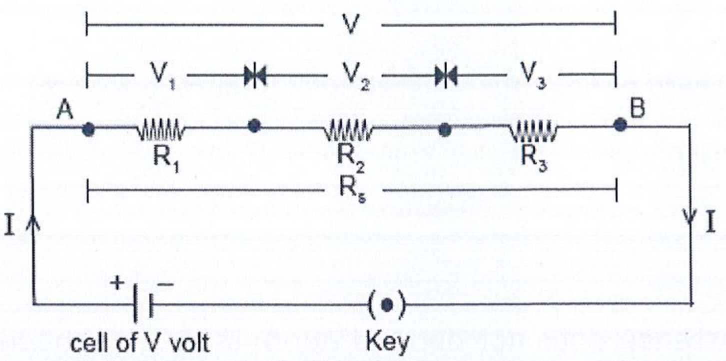
Resistivity of materials varies with temperature.

Resistance of Human Body: Dry Human Body offer 50,000 Ω resistance whereas wet Human Body offer resistance about 10,000 Ω.

Combination of resistance:

Resistors (or Resistance) in Series: A number of resistors are said to be connected in series if these are joined end to end and the same (i.e. total) current flow through each one of them when a potential difference is applied across the combination.

Derivation:



Consider three conductors having Resistance R_1, R_2 and R_3 respectively connected in series across a cell. Let the current I be flowing through each resistance and V be the potential difference across the combination of the resistances.

If V_1, V_2 and V_3 be the potential difference across resistances R_1, R_2 and R_3 respectively, then potential difference across AB.

$$V = V_1 + V_2 + V_3$$

According to Ohm's law: $V_1 = IR_1$, $V_2 = IR_2$ and $V_3 = IR_3$

$V_1 = IR_1$
$V_2 = IR_2$
$V_3 = IR_3$

Hence, we can write $V = IR_1 + IR_2 + IR_3 = I(R_1 + R_2 + R_3)$

If R_s = effective resistance of series combination of R_1, R_2 and R_3

$$V = IR_s$$

$$IR_s = I(R_1 + R_2 + R_3)$$

$$R_s = R_1 + R_2 + R_3$$

If n resistors are connected in series instead of three resistances, then the effective resistance or equivalent resistance of the series combination is given by:

$$R_s = R_1 + R_2 + R_3 .... + R_n$$

Important Points:

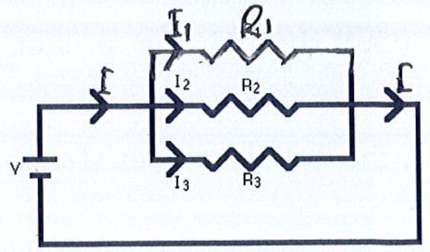
1. If n resistors, each of value R Ω are connected in series, their equivalent resistance (R_s) is given by:

   $R_s = R + R + ... n \text{ times} = nR$

2. The current flowing through each resistor is the same and is equal to the total current in the circuit because there is no other path along which the current can flow.
3. The potential difference across ends of the combination is distributed across the ends of each one of the resistors. The potential difference across any one of the resistors is directly proportional to its resistance.
4. In series combination, the equivalent resistance is greater than the greatest resistance in the combination.
5. The series combination of resistors is used when the resistance in the circuit is to be increased or the current is to be decreased.

Resistor (or Resistance) in Parallel: A number of resistors are said to be connected in parallel if one end of each resistor is connected to one point and the other end is connected to another point so that the potential difference across each resistor is the same and is equal to the applied potential difference between the two points.

Derivation:



A parallel combination of three resistors R_1, R_2 and R_3 connected across a cell. Let V be the applied potential difference. The current I drawn from the cell divide into three parts I_1, I_2 and I_3. Current I_1 flows through R_1, current I_2 flowing through R_2 and current I_3 flows through R_3.

$$I = I_1 + I_2 + I_3$$

According to Ohm's law:

$$I_1 = \frac{V}{R_1},\ I_2 = \frac{V}{R_2} \text{ and } I_3 = \frac{V}{R_3}$$

$$\text{Now, } I = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$I = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

If R_p = effective resistance of the parallel combination of R_1, R_2 and R_3. Then, $I = \frac{V}{R_P}$

$$\frac{V}{R_P} = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

$$\frac{1}{R_P} = \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

Important points:

1. If there are n resistors, each of value R and if these are connected in parallel, their equivalent resistance is given by:

   $\frac{1}{R_P} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R} + \text{..........}ntimes = \frac{n}{R}$, Hence $R_P = \frac{R}{n}$
2. The potential difference across each resistor is the same and is equal to the total potential difference across the combination.
3. The main current divides itself and different current flows through each resistor. The maximum current flows through the resistor with minimum resistance and vice-versa,
4. In parallel combination, the equivalent resistance is lesser than the least of all the resistance.
5. The parallel combination is used where resistance is to be decreased or current to be increased.

Series Combination	Parallel Combination

In series circuit, if one electrical appliance stops working due to some defect, then all other appliance also stop working.	In parallel circuit, if one electrical appliance stops working due to some defect, then all other appliances keep working normally.
In series circuit, all the electrical appliance have only one switch due to which they cannot be turned on or off separately.	In parallel circuits, each electrical appliance has its own switch due to which it can be turned on or turned off independently, without affecting other appliances.
In series circuit, the appliances do not get the same voltage as that the of the power supply line.	In parallel circuits, each electrical appliance gets the same voltage as that of the power supply one.
In series connection of electrical appliance, the overall resistance of the circuit increases too much due to which the current from the power supply is low.	In the parallel connection of electrical appliances, the overall resistance of the household circuit is reduced due to which the current from the power supply is high.
In series connection of electrical appliance, each appliance will get same amount of current.	In parallel connection of electrical appliance, each appliance will get the current as per requirement.

Heating Effect of electric current: The production of heat in a conductor due to the flow of electric current through it is called heating effect of electric current.

Cause of heating effect of electric current: Electric current generates heat to overcome the resistance offered by the conductor through which it passes. Higher the resistance, the electric current will generate higher amount of heat. Thus, generation of heat by electric current while passing through a conductor is an inevitable consequence. This heating effect is used in many appliances, such as electric iron, electric heater, electric geyser, etc.

Joule's Law of Heating:

Joule's law can be stated as:

The amount of heat produced in a conductor is:

- ✓ directly proportional to the square of the electrical current flowing through it. i.e. $H \propto I^2$
- ✓ directly proportional to the resistance of the conductor i.e. $H \propto R$

- ✓ directly proportional to the time for which the electric current flows through the conductor. i.e. $H \propto t$

Hence we get $H \propto I^2Rt$

or $H = KI^2Rt$, where K is a constant of proportionality

If K = 1 then $H = I^2Rt$ this is known as Joule's law of heating.

Why the electric bulb is filled with argon or nitrogen?

Answer: If air is present in an electric bulb, then the extremely hot tungsten filament would burn up quickly in the oxygen of air. So, the electric bulb is filled with a chemically unreactive gas like argon or nitrogen (or a mixture of both).

Electric Energy: The work done by a source of electricity to maintain a current in an electrical circuit is known as electrical energy.

Derivation: When electric current flows through the resistance element, the flowing charges suffer resistance. Work has to be done to overcome this resistance which is converted into heat energy. The complete sequence is, electrical energy does work which converts into heat energy.

If Q amount of charge flows through a potential difference of V, then

Work done is W = QV ----------------- (1) But Q = I t -------------------------- (2)

From equation --------------------- (1) and (2)

W = VIt   Also, by Ohm's law V = IR

$W = H = I^2Rt$

This work is converted into heat energy. This effect is also called **Joule's heating effect**.

Electric Power: Electric power is defined as the amount of electric energy consumed in a circuit per unit time.

$$P = \frac{W}{t} = \frac{VIt}{t} = VI = I^2R = \frac{V^2}{R}$$

NOTE:

- If bulbs of different wattages are joined in parallel, then the bulb with the highest wattage glows with maximum brightness. And in case such bulbs are joined in series, reverse is the case, i.e., the bulb with lowest wattage glows with maximum brightness.

- As electrical appliances are connected in parallel, all of them are having the same potential difference across their ends. As such, power of an appliance at constant voltage $P = \frac{V^2}{R} or P \propto \frac{1}{R}$. Thus, more the power of an appliance less is its resistance. Further, as V = IR, $I = \frac{V}{R}$. Therefore, an appliance of greater power (having less resistance) will consume more current.

<u>Commercial unit of electric energy:</u> The commercial unit of electric energy is called kilowatt hour (kWh) or Board of Trade Unit (BOTU) or Unit in brief.

The electrical energy consumed when an electric appliance of power one kilowatt works for one hour is called one kilowatt hour.

$$1kWh = 1kW \times 1h = 1000\ W \times 3600\ s = 3.6 \times 10^6\ J = 3.6\ MJ$$

<u>Rating of an electric appliance:</u> An electric appliance for example an electric bulb is rated with power and voltage. If an electric bulb is rated 100W-250V, it means that if the bulb is lighted on 250V supply, it consumes a power of 100W (an electrical energy of 100 J is converted into heat and light by the bulb in 1 second).

From this rating we can calculate the resistance of the appliance and the current flowing through it.

$R = \frac{V^2}{P} = \frac{(250)^2}{100} = 625\Omega$ the resistance of the bulb is much less than this value when it is not glowing (when the filament is cold). This is due to the reason that the resistance of the filament increases with temperature.

$I = \frac{P}{V} = \frac{100}{250} = 0.4A$ this is the maximum value of the current that can flow through the bulb without causing it to fuse (melting its filament).

Application of heating effect of current:

Electric Bulb: An electric bulb (called incandescent lamp) is used to provide light by heating its filament. The filament is made of a strong metal with high melting point and high resistivity such that it does not melt at high temperature. The filament is thermally isolated and the bulb is filled with inactive gas to prolong the life of filament.

Fuse: Electric fuse is used to protect the electric appliances from high voltage; if any. An electric fuse used as a safety device in household circuits and is based on heating effect of current. It connected in series with the main supply. A fuse consists of an alloy which has appropriate melting point and high resistivity.

When the current flowing through the circuit exceeds the safe limit, the temperature of the fuse wire increases the fuse wire melts and break the circuit. This helps to protect the other circuit elements from hazards caused by heavy current.

Suppose, if an electric heater consumes 1000W at 220V.

Then electric current in circuit I = P/V

Or, I = 1000 W – 220 V = 4.5 A

Thus, in this case a fuse of 5A should be used to protect the electric heater in the case of flow of higher voltage.

Short Circuiting: When live wire and neutral wire comes in direct contact, the resistance of the circuit becomes very small. Hence huge current flows through the circuit. This huge current produces large amount of heat in the circuit and the circuit catches fire. This is known as short circuiting.

Earthing: Many electric appliance of daily use like electric press, heater, toaster, refrigerator etc have a metallic body. It the insulation of any of these appliances melts and makes contact with the metallic casing, the person touching it is likely to receive a severe electric shock. This is due to the reason that the metallic casing will be at the same potential as the applied one. Obviously, the electric current will flow through the body of the person who touches the appliance. To avoid such serious accidents, the metal casing of the electric appliance is earthed. Since the earth does not offer any resistance, the current flows to the earth through the earth wire instead of flowing through the body of the person. Also, due to very low resistance (almost nil) offered by the earth wire, the current in the circuit rises to a very high value, thereby melting fuse in that circuit and cutting off its electric supply.

Colour coding of wires: An electric appliance is provided with a three-core flexible cable. The insulation on the three wires is of different colours. The old convention is red for live, black for neutral and green for earth. The new international convention is brown for live, light blue for neutral and green (or yellow) for earth.

Q. Why does resistance of a conductor increase with increase in temperature?

Ans. When metallic conductor is heated the atoms in the metal vibrate with greater amplitude and frequency. Due to increase in temperature, the thermal velocities of free electrons also increase. Therefore, the number of collisions between free electrons and atoms increases. This increases the resistance of the conductor.

Q. Though the same current flows through live wires or the filament of a bulb, yet only the latter glows. Why?

Ans. The filament of electric lamp has high resistance whereas the line wires are of negligible resistance. Since amount of heat generated is proportional to the resistance, the filament acquires more heat and hence high temperature making it bright hot.

Q. Explain why an electric bulb becomes dim when an electric heater in parallel circuit is made on. Why dimness decreases after sometime?

Ans. The resistance of a heater coil is less than that of electric bulb filament. When heater is switched on in parallel, more current start flowing through the heater coil and current through the bulb filament decreases, making it dim.

After sometime, when heater coil becomes hot its resistances increases. As a result current through the heater coil decreases and the current through the bulb filament increases and thus dimness of the bulb decreases.

Q. Heat is generated continuously in an electric heater but its temperature becomes constant after sometime. Why?

Ans. When the temperature of the heater becomes greater than the temperature of the surrounding some of the heat is lost to the surroundings in the form of thermal radiations.

After sometime rate at which heat is being produced becomes equal to the rate of which heat is lost. Then the temperature becomes constant.