CURRENT ELECTRICITY

P1

Objectives

- **Learning outcomes :**
- • defines electric current as the rate of flow of charges.
- • explains the mechanism of conduction of electric current through a metallic conductor.
- • derives an expression for the relationship between current and drift
- velocity.
- • deduces an expression for current density.
- • defines resistance.
- • states factors which affect the resistance.
- • defines resistivity.
- • explains variation of resistance of conductors and insulators with temperature.
- • appreciates the properties and uses of superconductors.
- • states Ohm's law.
- • explains the behavior of ohmic and non-ohmic conductors using. *I- V*
- curves.
- • uses potential divider circuit to obtain variable voltages.
- • finds equivalent resistance of simple networks.
- • solves problems using Ohm's law.
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- **Suggested learning/teaching process:**
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- • Define electric current and give the expression *I=Q/t* for a steady current that can be measured as C s-1.
- • State that the SI unit of electric current is ampere (A).
- • Explain the existence of free electrons and the random motion of free electrons in a metallic conductor.
- • Explain the mechanism of conduction of electric current through a metallic conductor.
- • Introduce drift velocity of free electrons.
- • Guide students to derive the expression (*I = AvNe*) for the relationship between drift velocity and electric current introducing other relevant terms.
- • Define current density and guide students to deduce the expression
- *J= vNe*.

- Recall the definition of potential difference and explain it in relation to a current carrying conductor.
- Define resistance of a conductor and introduce its units.
- Guide students to investigate the factors affecting the resistance through activities.
- Obtain the expression, $R = \rho \frac{l}{A}$.
- Define the resistivity ρ and guide students to obtain its units.
- Define conductivity σ and guide students to obtain its units.
- Explain how resistance increases in metallic conductors with temperature.
- Define temperature coefficient of resistance for a specified reference temperature.
- Give the relationship $R_\theta = R_0(1 + \alpha\theta)$ introducing terms (α is defined for the above reference temperature).
- Represent graphically the variation of resistance of conductors with temperature.
- Explain how resistance decreases in semiconductors and insulators with temperature.

- Represent graphically the variation of resistance of conductors with temperature.
- Explain how resistance decreases in semiconductors and insulators with temperature.
- Describe the conditions under which a metal behaves as a superconductor.
- Introduce transition temperature of a metal using resistance- temperature curve.
- Explain uses and properties of superconductors.
- Give transition temperatures of several superconductors.
- Assign students to derive expressions for equivalent resistance of series and parallel combinations of resistors.
- Guide students to find equivalent resistance of resistor networks.
- State Ohm's law giving conditions under which it is valid.
- Differentiate between ohmic and non-ohmic conductors using relevant
- *I*-*V* curves.
- Introduce voltage divider circuits and guide students to derive relevant expressions.
- Guide students to solve problems related to above fundamental concepts of current electricity.

Electric current

The flow of electric charges in a particular direction constitutes electric current.

The electric current is defined as *the rate of flow of charges across any cross sectional area* held normal to the direction of flow of charge *of a conductor*.

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

Where, I = electric current

q= charge passed through any cross section of conductor

t= time

A current whose magnitude does not change with time is called steady current.

A current whose magnitude changes with time is called varying current.

$I = q / t$ (if the rate of flow of charge is steady)

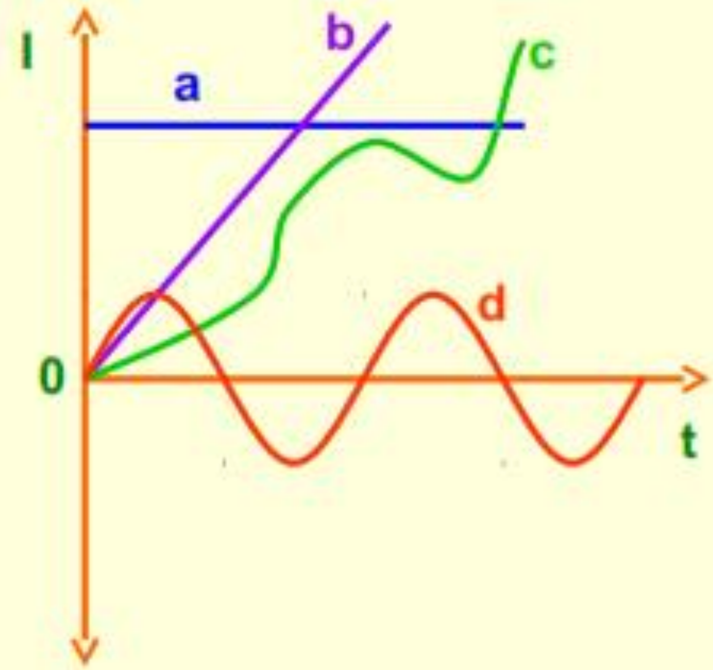
$I = dq / dt$ (if the rate of flow of charge varies with time)

Different types of current:

a) Steady current which does not vary with time

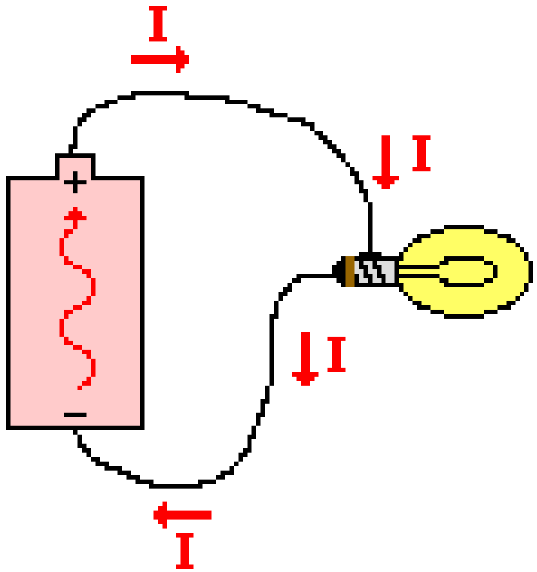
b) & c) Varying current whose magnitude varies with time

d) Alternating current whose magnitude varies continuously and direction changes periodically



Conventional Current Direction

The particles that carry charge through a wire are mobile electrons which move in a direction opposite the electric field.



Electric current in the external circuit is directed from the positive to the negative terminal.

The direction of conventional current is taken as the direction of flow of positive charges or opposite to the direction of flow of electrons.

Problem

A long wire is connected to the terminals of a battery. In 5.0 sec, 5.8 x 10^{20} electrons pass a cross section along the wire.

a) Determine the current in the wire (if you need any extra information, ask your classmates).

$$Q = 5.8x10^{20}\,e- = 5.8x10^{20}\,e^{-}\,x\,\frac{1.6x10^{-19}C}{1e^{-}} = 92.8C$$

$$I = \frac{Q}{t} = \frac{92.8}{5} = 1.86A$$

b) If the electrons flow from left to right, in which direction is the current?

Opposite, right to left

- Current is a scalar quantity.

- **Unit of current: Ampere (A)**

$$1\ A = 1\ C/s$$

- *One ampere represents the passage of one coulomb of charge per second.*

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 ionized gases in discharge tubes.
4. Electrons and holes in a semiconductor.

The net flow of electric charges in any direction inside the solid conductor is zero.

<u>The current carries</u>

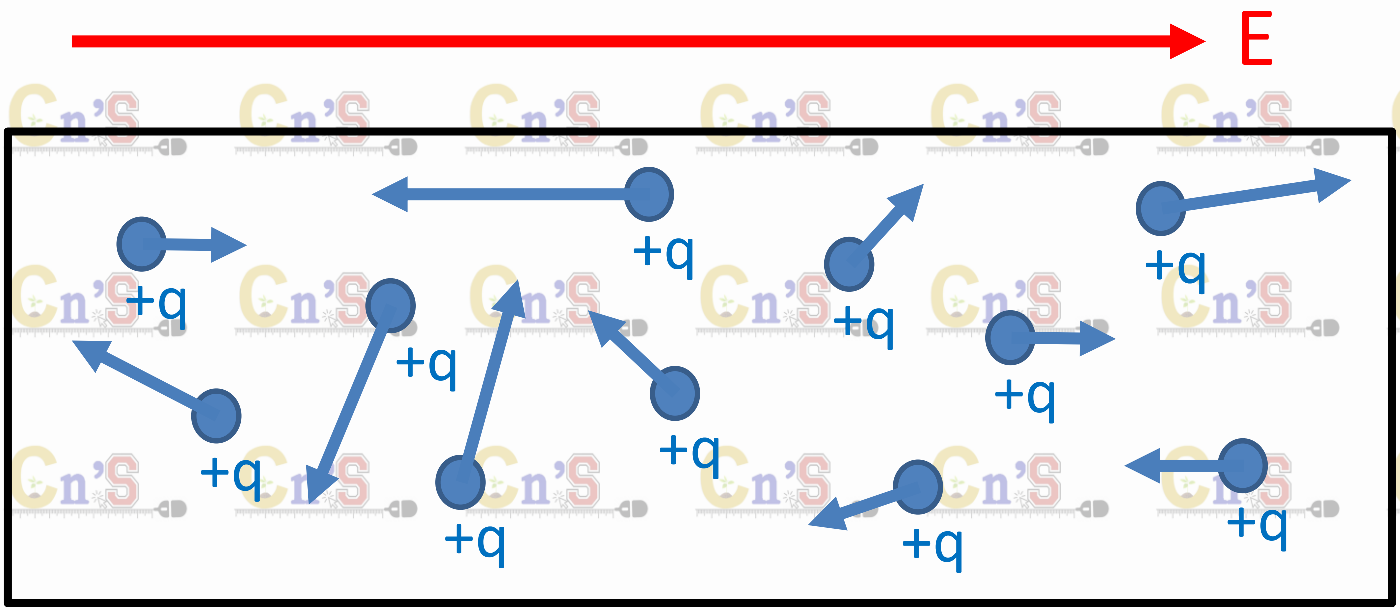
-in metals (solid conductors), - Free electrons

-In electrolytic solutions (liquid conductors) - positively and negatively charged ions

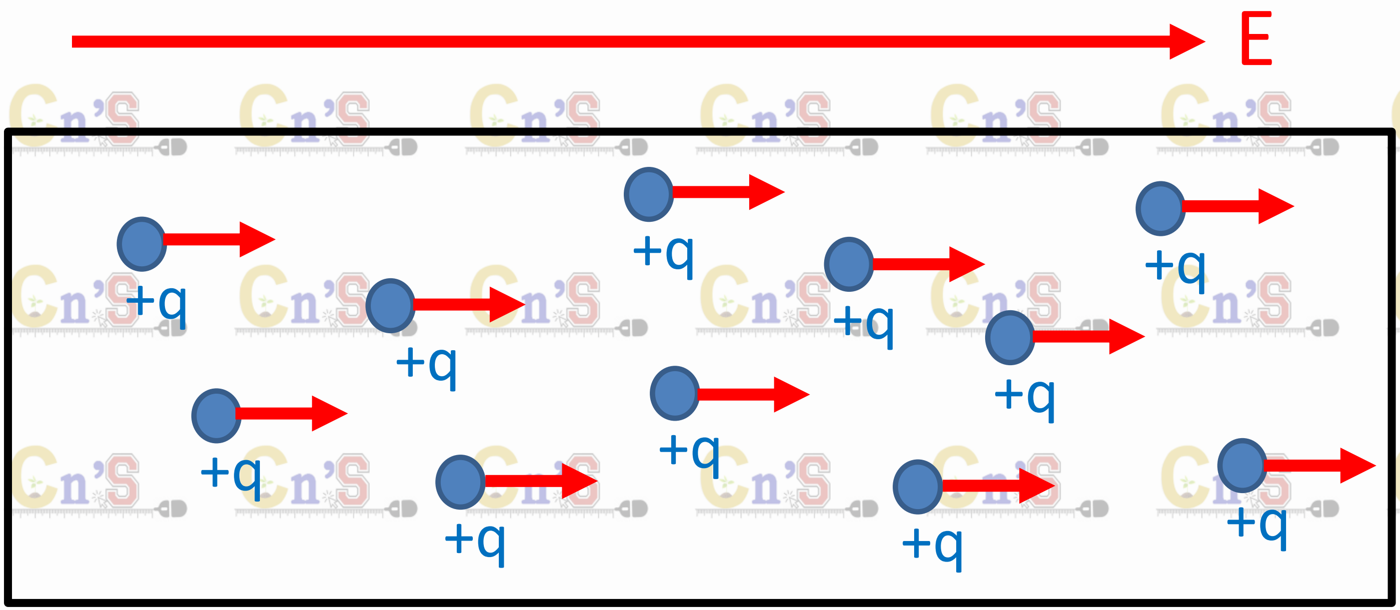
- in discharge tubes (gaseous conductors) - positive ions and electrons

What really happens when a battery is connected to a conductor?

- (1) Particles are in constant thermal motion, initially.
- (2) The battery supplies a potential difference hence electric field

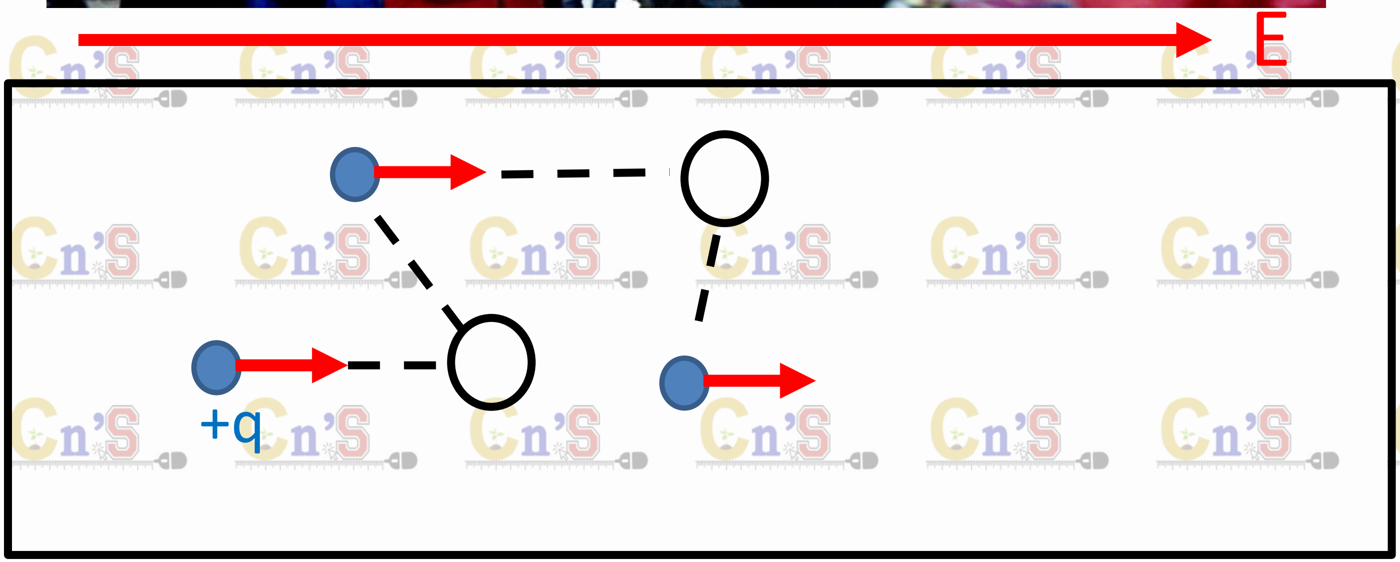


(3) The charges feel a force from the electric field and start to accelerate



(4) The charges undergo collisions with the other particles in the material which slows their motion

(5) These collisions produce a resistance to motion which results in an equilibrium drift velocity



Drift Velocity

When no Electric field is applied across a conductor, the electrons are in random motion. The average velocity of electrons is zero. Thus the motion of electrons does not constitute any transport of charge in any direction. The current in the conductor is zero.But when Electric field is applied, the free electrons at negative end experience a force $F = eE$ in a direction opposite to the electric field *i.e.* towards positive end. Thus due to collision, there act backward force on electron. So, the electron drift slowly towards positive end with a constant average velocity called, drift velocity v_d ,

So, *drift velocity is defined as the velocity with which free electrons get drifted towards the positive terminal, when electric field is applied .*

Drift velocity

When electric field is established across the ends of a conductor, the free electrons modify their random motion and drift slowly with a constant velocity in the direction opposite to E. This constant velocity is known as drift velocity.

Define drift velocity.

Ans. It is defined as the average velocity gained by the free electrons of a conductor in the opposite of the externally applied electric field.

What is the average velocity of free electrons in a metal at room temperature?

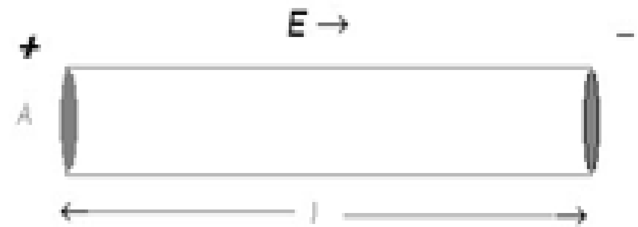
Ans. Zero.

What is the effect of temperature on the drift speed of electrons in a metallic conductor?

Ans. The drift speed decreases with increase in temperature.

Relation between current and drift velocity

Consider a conductor of length l and area of cross section A. An electric field E is applied between its ends. Let n be the number of free electrons per unit volume. The free electrons move towards the left with a constant drift velocity v_d.



The number of conduction electrons in the conductor = nAl

The charge of an electron = e

The total charge passing through the conductor $q = (nAl)\,e$

The time in which the charges pass through the conductor, $t = \frac{l}{v_d}$

Current flowing through the conductor, $I = \frac{q}{t} = \frac{(nAl)\,e}{l/v_d}$

So, $\quad I = nAev_d$

Or $\quad \frac{I}{A} = nev_d$

Or $\quad \boldsymbol{J = nev_d}$

This is the relation between current and drift velocity.

Microscopic nature of current

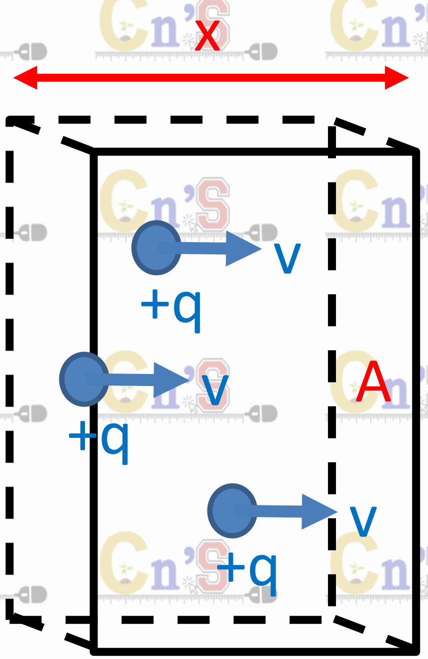
- The current density (symbol J) is the current flowing per unit area ("concentration of current")

$$\boxed{J = \frac{I}{A} = nqv}$$

- The units of J are A/m^2
- Used in a microscopic description of current

Microscopic nature of current

- How much current is produced by drift velocity v?



Number density of charges = n

- How much charge Q flows through the area A in time t?

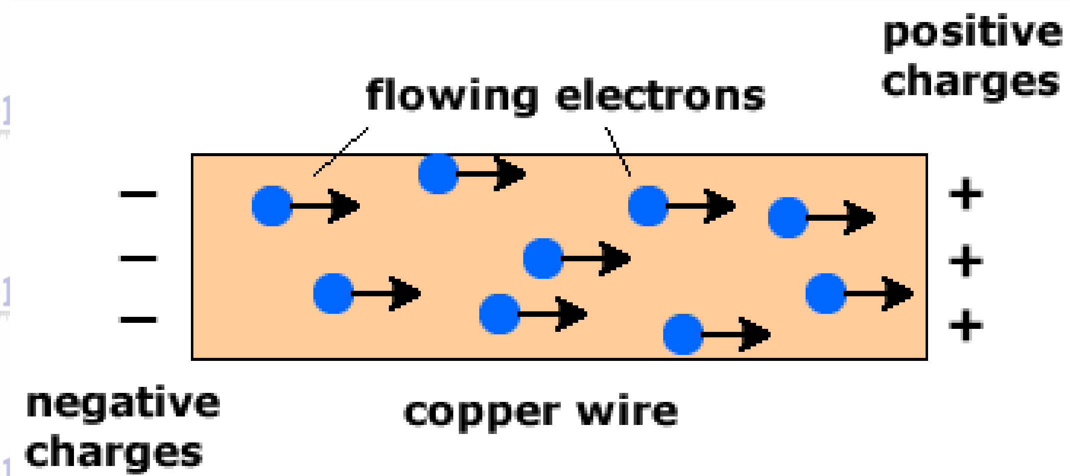
- It's contained with a length x where $x = v\,t$, which means a volume $V = A\,x = A\,v\,t$

- So, charge $Q = q\,n\,V = q\,n\,A\,v\,t$

- Current $I = \frac{Q}{t} = q\,n\,A\,v$

Microscopic nature of current

<u>Exercise:</u> A 5-A current flows in a copper wire with cross-sectional area 1 mm^2, carried by electrons with number density 1.1 x 10^{29} m^{-3}. What is the electron drift speed?



$$\boxed{I = q\, n\, A\, v}$$

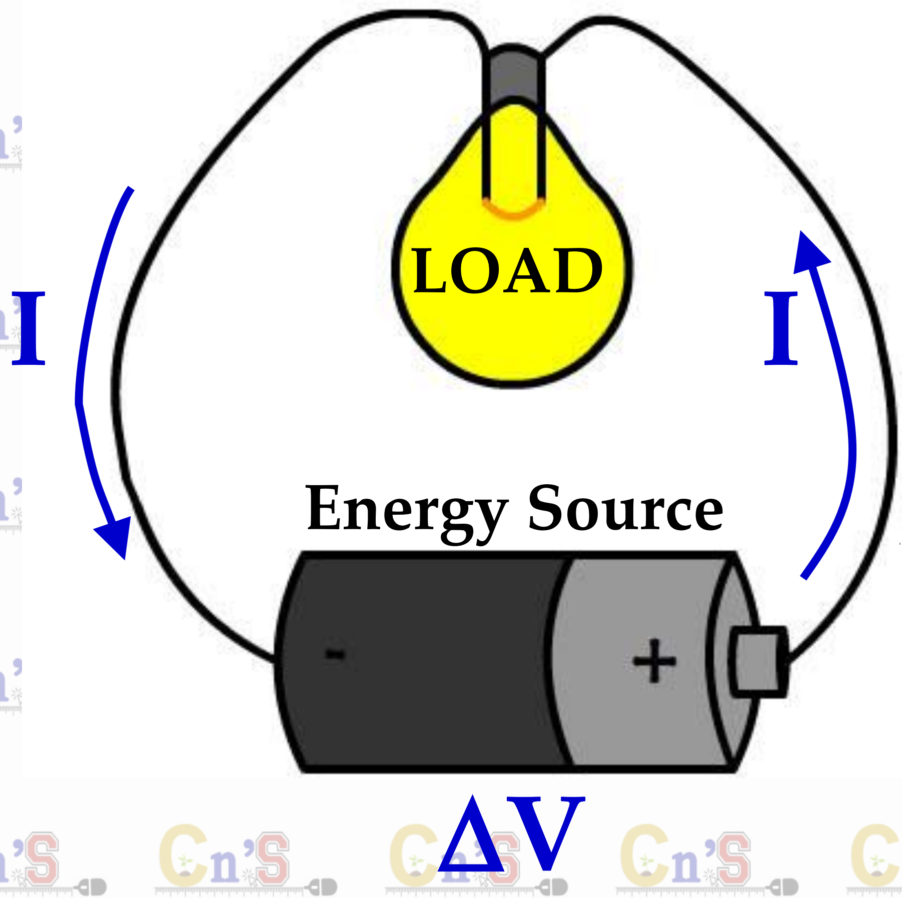
$$I = 5\ A$$
$$q = 1.6 \times 10^{-19}\ C$$
$$n = 1.1 \times 10^{29}\ m^{-3}$$
$$A = 1\ mm^2 = 10^{-6}\ m^2$$

$$v = \frac{I}{q\, n\, A} = \frac{5}{(1.6 \times 10^{-19}) \times (1.1 \times 10^{29}) \times (10^{-6})} = 0.28\ mm/s$$

Isn't this incredibly slow? Yes – but the electric field itself is established at the speed of light.

Resistance

An electron traveling through the wires and loads of a circuit encounters <u>*resistance, R*</u>. Resistance is a hindrance to the flow of charge.



The amount of current in a circuit depends on **BOTH** the potential difference across the circuit, **ΔV**, AND the total resistance in the circuit, **R.**

17.What is the cause of resistance of a conductor?

Ans. While drifting, the free electrons collide with the ions and atoms of the conductor i.e., motion of the electrons is opposed during the collisions, this is the basic cause of resistance in a conductor.

18. A large number of free electrons are present in metals. Why there is no current in the absence of electric field across?

Ans.. In the absence of an electric field, the motion of electrons in a metal is random. There is no net flow of charge across any section of the conductor. So no current flows in the metal .

Electric Resistance

- Property of the conducting medium that weakens the transmission of electric current.
- Denoted as *R* and its unit is *Ohm* (Ω).

$$R = \frac{\rho L}{A}$$

Where:

R = Resistance (Ohm, Ω)

ρ = resistivity (Ωm)

L = Length of the wire (m)

A = cross-sectional area of a wire(m^2)

Resistance

The table lists some of the factors that impact resistance.

Factor	Description	Proportionailty
Length	Longer the conductor, the greater resistance	Length ↑ Resistance ↑ $\frac{R1}{R2} = \frac{L1}{L2}$
Cross-sectional area	The large the cross-sectional area or thickness of the conductor, the less resistant it has to charge flow	Area or thickness ↑ Resistance ↓ $\frac{R1}{R2} = \frac{A2}{A1}$
Type of material	General measure of the resistance of a substance is resistivity ([p] Greek rho)	Resistivity [P] ↑ Resistance ↑ $\frac{R1}{R2} = \frac{p1}{p2}$
Temperature	Greater molecular motion (higher temperature) tend to increase resistance	Usually, temperature of the conductor increase, the resistance increase, but not for all substances.

The relation between the resistance and resistivity

.The resistance R of a conductor is given by $$R = \rho \frac{\ell}{A}$$

L- length of the conductor, A- area of cross section of the conductor

<u>The resistivity of material of a conductor at a given temperature is equal to resistance of unit length of the conductor having unit area of cross section.</u>

The SI unit of resistivity is ohm-meter

. A wire of resistivity **ρ** is stretched to three times its length .What will be its new resistivity?

There will be no change in its resistivity, because resistivity does not depend on length (dimension) of wire.

- **Conductivity**
  - Measure of how the material is capable of conducting electricity.
  - Reciprocal of resistivity.

i.e. $\sigma = 1/\rho$

The inverse of conductivity is **resistivity**[3] ρ:

$$\rho = \frac{1}{\sigma}$$

- The current density J flowing for a given electric field E depends on the resistivity ρ of the material (or its inverse – conductivity $\sigma = 1/\rho$)

$$\boxed{J = \frac{E}{\rho} = \sigma E}$$

High resistivity ρ means low current!

Define electrical conductance.

The reciprocal of resistance is called electrical conductance.

$G = 1/R$

- Measure by placing the material between two plates with constant electric field (*E*) and taking the ratio of electric field and current density (*J*).

$$\rho = \frac{E}{J}$$

Where:

ρ = resistivity (Ωm)

E = electric field (N/c)

J = current density (A/m²)

Varies with temperature

Table 5.1 Values of Resistivity of Materials

Material	Resistivity (Ω · m)
Metals:	
Silver	1.47×10^{-8}
Copper	1.72×10^{-8}
Gold	2.44×10^{-8}
Aluminum	2.63×10^{-8}
Tungsten	5.51×10^{-8}
Steel	20×10^{-8}
Lead	22×10^{-8}
Mercury	95×10^{-8}
Semiconductors:	
Pure carbon	3.5×10^{-5}
Pure germanium	0.60
Pure silicon	2300
Insulators:	
Amber	5×10^{14}
Mica	10^{11}–10^{15}
Teflon	10^{16}
Quartz	7.5×10^{17}

The **resistivity**, and hence the resistance, of a conductor depends on a number of factors. One of the most important is the temperature of the metal. For most metals, resistivity increases with increasing temperature.

Good electric conductors have very low resistivity, and good insulators have very high resistivity. Table lists the resistivities of a variety of materials at 20°C.

Material	Resistivity ($\Omega \cdot m$)
Silver	1.59×10^{-8}
Copper	1.7×10^{-8}
Gold	2.44×10^{-8}
Aluminum	2.82×10^{-8}
Tungsten	5.6×10^{-8}
Iron	10.0×10^{-8}
Platinum	11×10^{-8}
Lead	22×10^{-8}
Nichrome[b]	150×10^{-8}
Carbon	3.5×10^{5}
Germanium	0.46
Silicon	640
Glass	$10^{10} - 10^{14}$
Hard rubber	$\approx 10^{13}$
Sulfur	10^{15}
Quartz (fused)	75×10^{16}

	Material	Resistivity (Ω m)
Conductors	Silver	1.60×10^{-8}
	Copper	1.62×10^{-8}
	Aluminium	2.63×10^{-8}
	Tungsten	5.20×10^{-8}
	Nickel	6.84×10^{-8}
	Iron	10.0×10^{-8}
	Chromium	12.9×10^{-8}
	Mercury	94.0×10^{-8}
	Manganese	1.84×10^{-6}
Alloys	Constantan (alloy of Cu and Ni)	49×10^{-6}
	Manganin (alloy of Cu, Mn and Ni)	44×10^{-6}
	Nichrome (alloy of Ni, Cr, Mn and Fe)	100×10^{-6}
Insulators	Glass	$10^{10} - 10^{14}$
	Hard rubber	$10^{13} - 10^{16}$
	Ebonite	$10^{15} - 10^{17}$
	Diamond	$10^{12} - 10^{13}$
	Paper (dry)	10^{12}

How does the resistance of a conductor vary with temperature?

Ans. The resistance of a conductor increases linearly with increase of temperature and vice-versa.

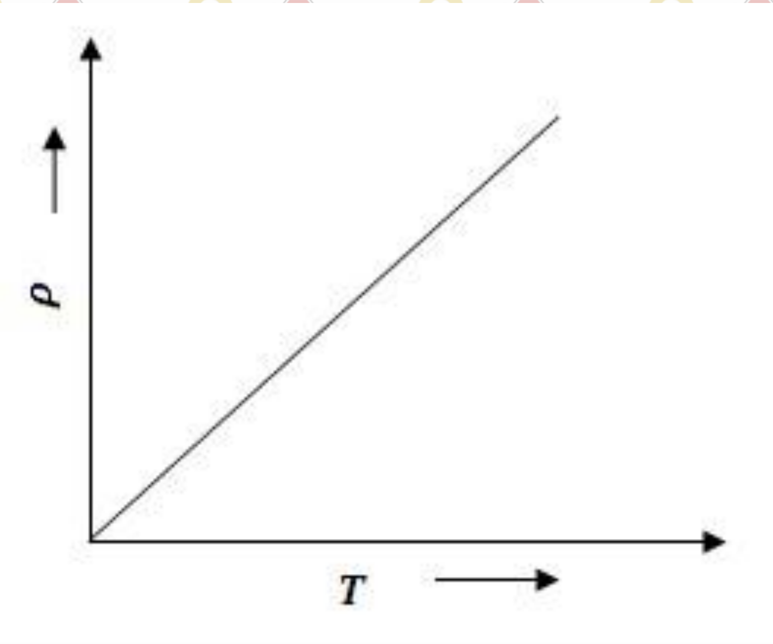
How does the resistivity of a conductor vary with temperature?

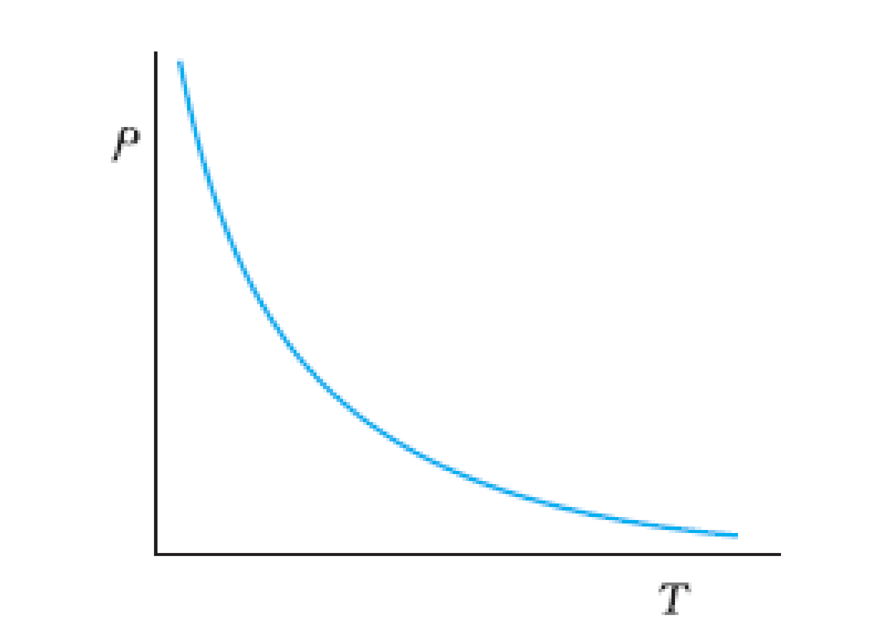
Ans. The resistivity of a conductor increases linearly with increase of temperature and vice-versa.

How does the resistivity of a semi conductor vary with temperature?

Ans. The resistivity of a semi conductor decreases exponentially with increase of temperature.

Temperature—resistivity graph for a Conductor.





Temperature—resistivity graph for a semiconductor.

. Name two materials whose resistivity decreases with the rise of temperature.

Germanium and Silicon.

How does the resistance of an insulator change with temperature?

The resistance of an insulator decreases with the increase of temperature.

Name a material which exhibit very weak dependence of resistivity with temperature?

Nichrome , an alloy of nickel, iron and chromium exhibit very weak dependence of resistivity with temperature.

Superconductors

When few metals are cooled, then below a certain critical temperature their electrical resistance suddenly becomes zero. In this state, these substances are called **superconductors and this phenomena is called superconductivity.**

Mercury become superconductor at 4.2 K, lead at 7.25 K and niobium at 9.2 K

In the early 20th century physicists developed new laboratory techniques to cool materials to temperatures near absolute zero (-273 °C), and began investigating how the ability to conduct electricity changes in such extreme conditions. In some simple elements such as mercury and lead they noticed something remarkable – below a certain temperature these materials could conduct electricity with no resistance.

A superconductor conducts electricity perfectly, meaning an electrical current in a superconducting wire would continue to flow round in circles for billions of years, never degrading or dissipating.

Electrons in the fast lane

On a microscopic level the electrons in a superconductor behave very differently from those in a normal metal. Superconducting electrons pair together, allowing them to travel with ease from one end of a material to another. The effect is a bit like a priority commuter lane on a busy motorway. Solo electrons get stuck in traffic, bumping into other electrons and obstacles as they make their journey. Paired electrons on the other hand are given a priority pass to travel in the fast lane through a material, able to avoid congestion.

Superconductors have already found applications outside the laboratory in technologies such as Magnetic Resonance Imaging (MRI). MRI machines use superconductors to generate a large magnetic field that gives doctors a non-invasive way to image the inside of a patient's body.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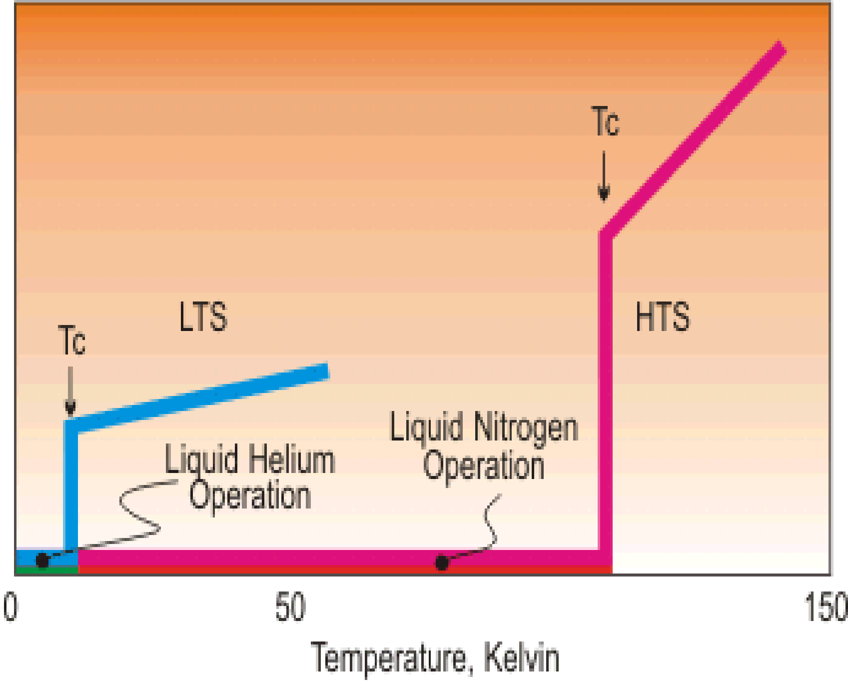
Critical Temperature

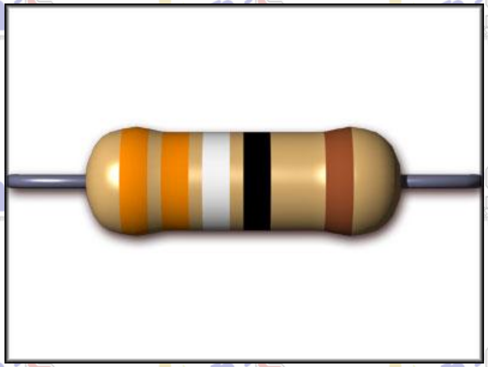
Superconducting materials known today, including both high temperature superconductor (“HTS”) and low temperature superconductor (“LTS”) materials, need to be cooled to critical temperatures in order to exhibit the property of superconductivity.



The differences between high and low temperature superconductors can best be explained using the figure 1. This graph illustrates the complete loss of resistance to the flow of electricity through wires of an LTS material (niobium-titanium alloy) and an HTS material (bismuth-based, copper oxide ceramic) at the critical temperature T_c which is different for each superconducting material. The specific HTS material in this chart has no electrical resistance below 108K (-265°F) as opposed to the specific LTS material in this chart, which has no electrical resistance below 10K (-441°F).

Resistors

- **Resistors** are devices designed to have a *<u>specific</u>* resistance.
- Resistors are devices put in circuits to reduce the current flow
- Resistors may be made of graphite, semiconductors, or wires that are long and thin.



Resistance and temperature

When a material is heated its resistance will change. This is due to the thermal motion of the atoms within the specimen

The equation for this variation is:

$$R_\theta = R_o[1+ \alpha\theta + \beta\theta^2 + . .$$

where R_θ is the resistance of the specimen at some temperature θ °C and R_o the resistance at 0°C. In this equation β<<α and so the change by the following simplified equation as long as the temperature change is not too great.

$$R_\theta = R_o[1+ \alpha\theta]$$

Here α is called the temperature coefficient of resistance and is defined as the increase in resistance per degree rise divided by the resistance at 0 °C

$$\alpha = [R_\theta - R_o]R_o\theta$$

Resistivity of Various Materials

Depending on resistivity, the materials can be classified as conductor, semiconductors and insulators.

The conductors (metals) have low resistivities in the range of 10^{-8} Ωm to 10^{-6} Ωm .

The insulators have very high resistivities in the range of 10^{8} Ωm to 10^{14} Ωm.

The semiconductors have resistivities between conductors and insulator *i.e.* in the range of 10^{-2} Ωm to 10^{4} Ωm.

Temperature Dependence of Resistance

For metallic conductor

$$R = \frac{ml}{nAe^2 \tau}$$

$$R \; \alpha \; \frac{1}{\tau}$$

So, when temperature of a conductor is increased, the thermal energy of electron increases. Due to which the frequency of collision of free electrons with atoms or ions also increase and hence τ decreases. Hence, resistance increases. If

R_0 = resistance of conductor at 0^0C

R_t = resistance at t^0C

t = rise in temperatue.

Then $R_t = R_0 (1 + \alpha t)$

- The *Temperature coefficient of resistivity (α)* determines how much resistivity increases with temperature.
- Its unit is (per Kelvin)K^{-1}.

$$R_t = R_0 + R_0 \alpha t$$

$$\alpha = \frac{R_t - R_o}{R_0 t} \quad (1)$$

i.e. α= Temperature coefficient of resistance =

$$\frac{\text{change in resistance}}{\text{Original resistance} \times \text{rise in temperature}}$$

Hence α is defined as the change in resistance per unit original resistance per degree rise in temperature.

Unit of $\alpha = {}^0C^{-1}$ or kelvin^{-1}

For metals: **α** is positive. So, from (1) $R_t > R_0$
Therefore resistance of metals increases with rise of temperature.(this implies that conductivity decreases with rise in temperature.)

For insulators and semiconductors: **α** is negative.
So, from (1) $R_t < R_0$
Therefore resistance of insulators or semiconductors decrease with rise of temperature.(this implies that conductivity increases with rise in temperature.)

For Alloys: for alloys like Nichrome, Manganin etc **α** *is very-very small*. So, from (1) $R_t \approx R_0$
Therefore resistance of alloys almost remains same with rise in temperature. *That is why we use these alloys to make standard resistance coil.*
Similarly **resistivity** of a metallic conductor is given by

$$\rho_t = \rho_0 (1 + \alpha t)$$

Resultant of Resistances connected in Series

- The figure shows three resistances R_1,R_2,R_3 connected in series. Now suppose potential difference across resistance R_1 is V_1 , R_2 is V_2 and R_3 is V_3. Let potential difference across battery be V, then :

$$V = V_1+V_2+V_3.$$

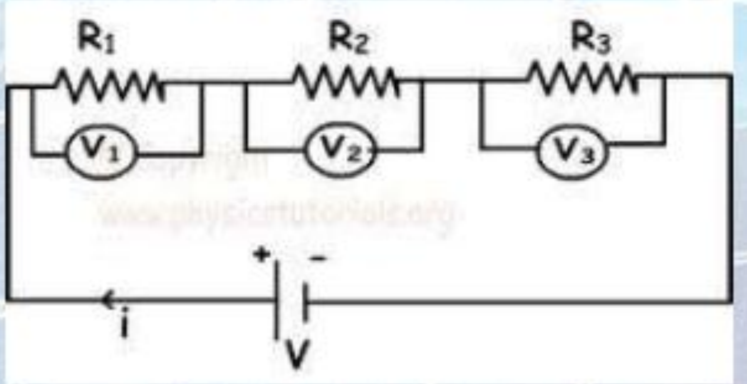
Applying Ohm's law to the whole circuit : V = IR. ……….(1)

Applying Ohm's law to the three resistors separately, we get:

$V_1 = I \times R_1$. ………………….. (2)

$V_2 = I \times R_2$. ………………….. (3)

$V_3 = I \times R_3$. ………………….. (4)



Substituting (2), (3), (4) in (1)

$IR = IR_1 + IR_2+ IR_3$

OR, $IR= I (R_1+R_2+R_3)$

Or, $R = R_1+R_2+R_3$.

Therefore we conclude that the sum total resistance in a series resistance connection is equal to the sum of all the resistances.

Resultant of Resistances connected in Parallel

- The figure shows three resistances R_1,R_2,R_3 connected in series. Now suppose currant across resistance R_1 is I_1 , R_2 is I_2 and R_3 is I_3. Let total current in the circuit be I, then:

$$I = I_1+I_2+I_3.$$

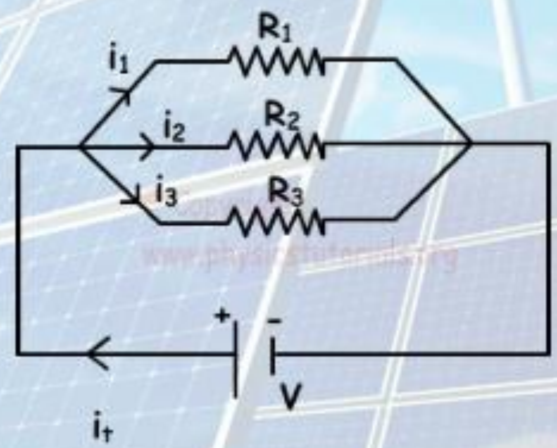
Applying Ohm's law to the whole circuit : I = V/R. ....(1)

Applying Ohm's law to the three resistors separately, we get:

$I_1 = V / R_1$. .... (2)

$I_2 = V / R_2$. .... (3)

$I_3 = V / R_3$. .... (4)



Substituting (2), (3), (4) in (1)

$V/R = V/R_1 + V/R_2+ V/R_3$

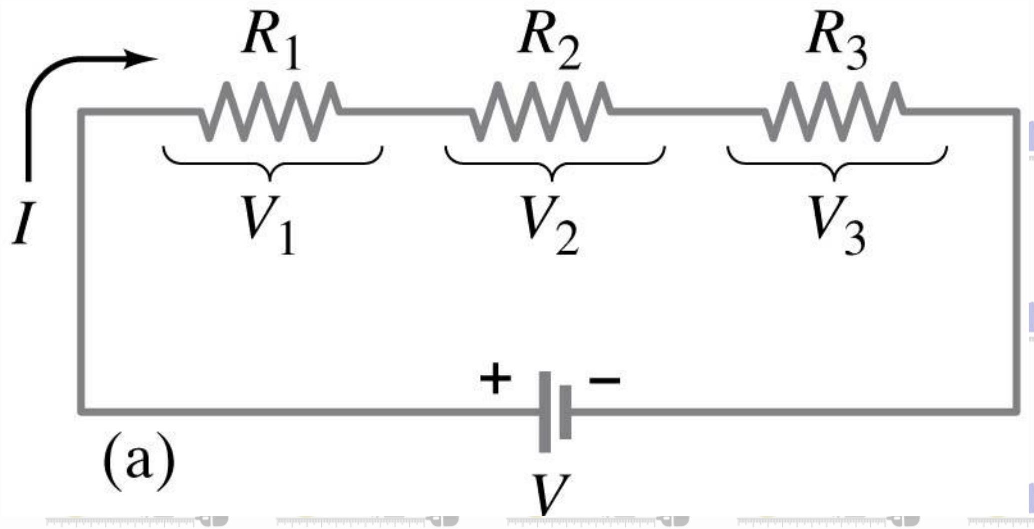
OR, $V/R= I\,(1/R_1 +1/R_2 + 1/R_3)$

Or, $1/R = 1/R_1+1/R_2+1/R_3$.

Therefore we conclude that the sum total resistance in a parallel resistance connection is equal to the sum of reciprocal of all the resistances.

Resistors in Series

A series connection has a single path from the battery, through each circuit element in turn, then back to the battery.

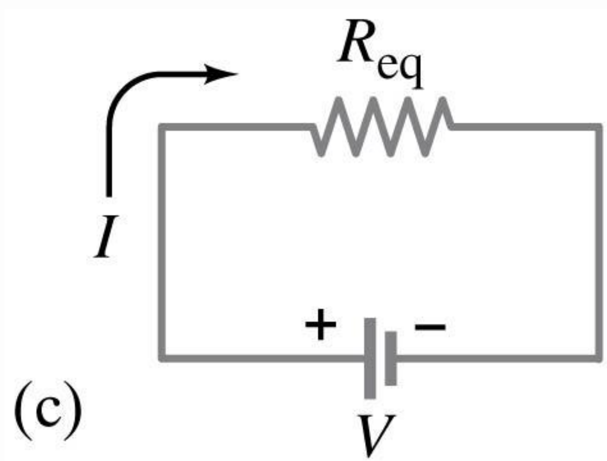


The current through each resistor is the same; the voltage depends on the resistance. The sum of the voltage drops across the resistors equals the battery voltage

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

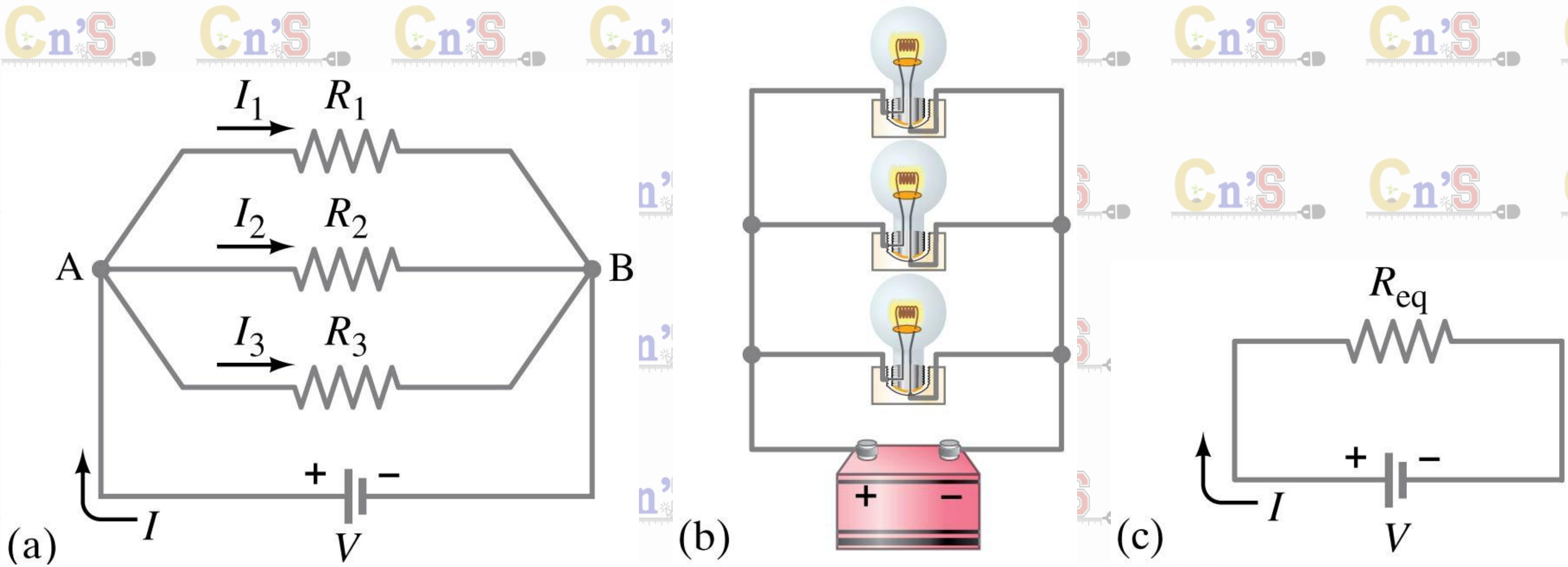
From this we get the equivalent resistance (that single resistance that gives the same current in the circuit).

$$R_{\text{eq}} = R_1 + R_2 + R_3.$$



Resistors in Parallel

A parallel connection splits the current; the voltage across each resistor is the same:



The total current is the sum of the currents across each resistor:

$$I = I_1 + I_2 + I_3,$$

$$I = \frac{V}{R_{eq}}$$

$$\frac{V}{R_{eq}} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

This gives the reciprocal of the equivalent resistance:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}.$$

Parallel and Series connection

Parallel connection

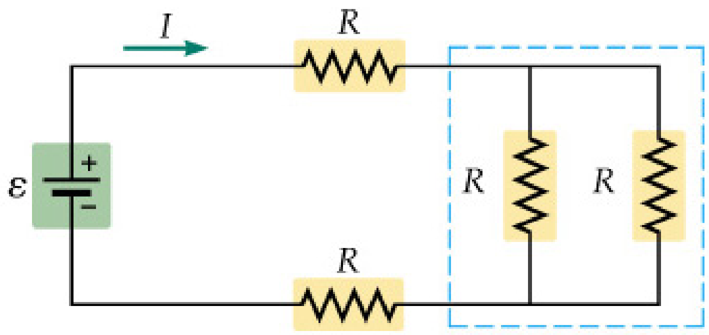
- If one electric appliance stops working due to some defect, then all other appliances keep working normally.
- In parallel circuits, each electric appliance has its own switch due to which it can be turned on or off independently.
- Each appliance gets same voltage as that of power source.
- Overall resistance of household circuit is reduced due to which the current from power supply is high.

Series connection

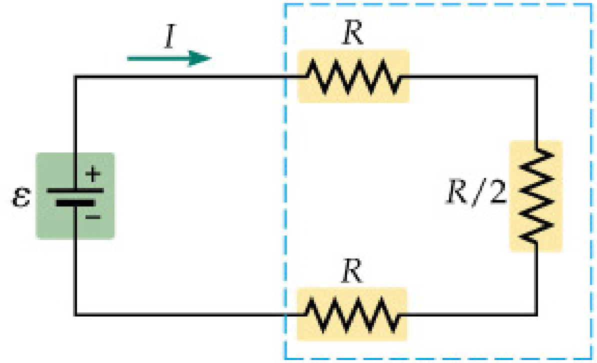
- If one electric appliance stop working due to some defect, then all other appliances stop working.
- All the electric appliances have only one switch due to which they cannot be turned on or off separately.
- In series circuit, the appliances do not get same voltage (220 V) as that of the power supply line.
- In series circuit the overall resistance of the circuit increases due to which the current from the power source is low.

Analyzing a complex circuit of resistors

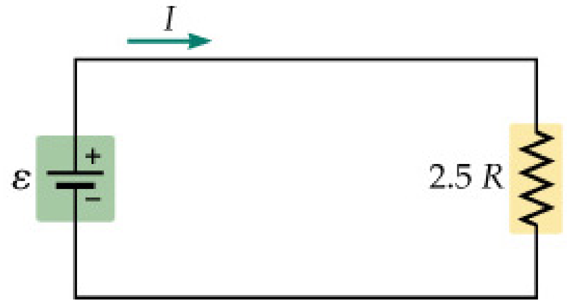
All resistors are the same in Figure (a).



(a)



(b)



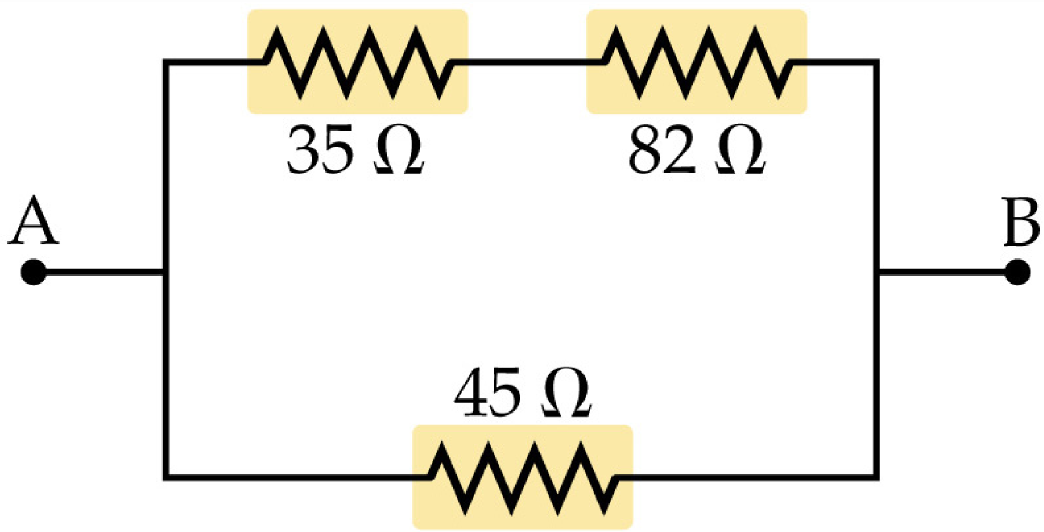
(c)

(a) The two vertical resistors are in parallel with one another, hence they can be replaced with their equivalent resistance, R/2.

(b) Now, the circuit consists of three resistors in series. The equivalent resistance of these three resistors is 2.5 R.

(c) The original circuit reduced to a single equivalent resistance.

What is the equivalent resistance?



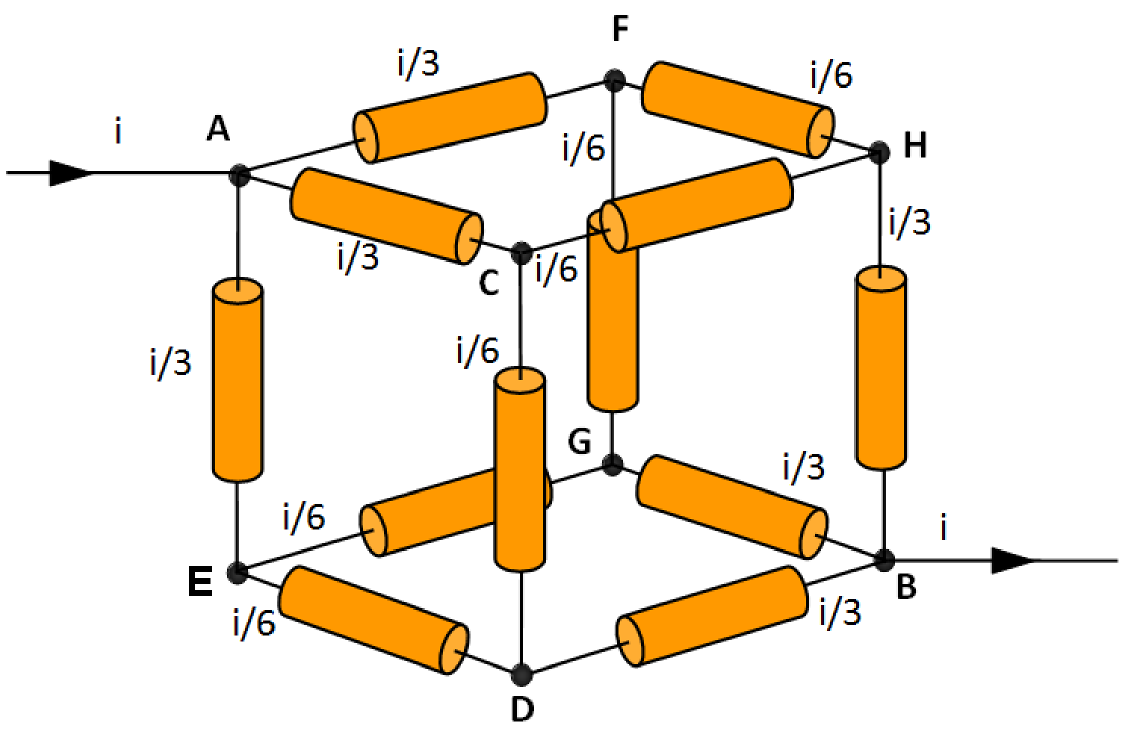
Twelve resistors in the form of a cube.

The problem is to find the resistance (R) between the points A and B on each cube.

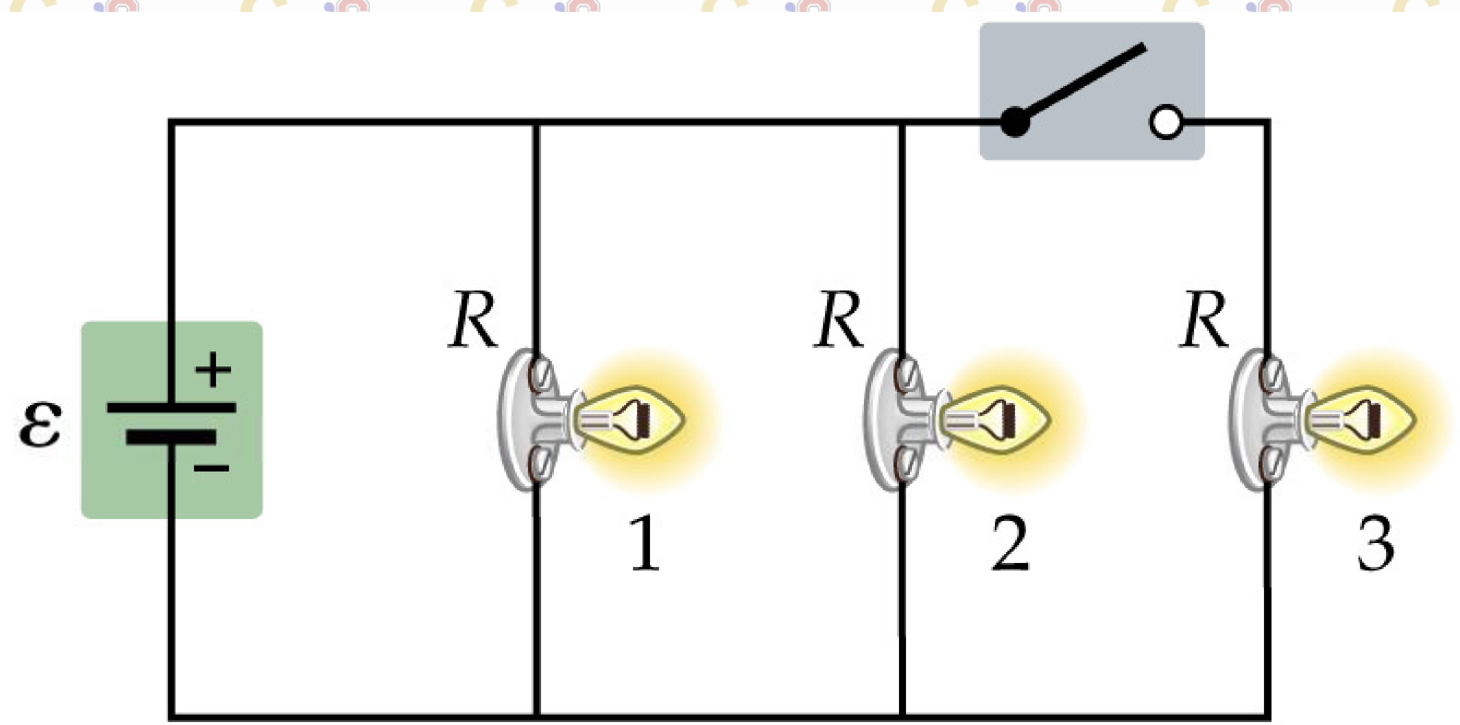
Each arm of the cube has a resistance r.

We can take any path through the network between the points A and B. Such a path could be ACDB.

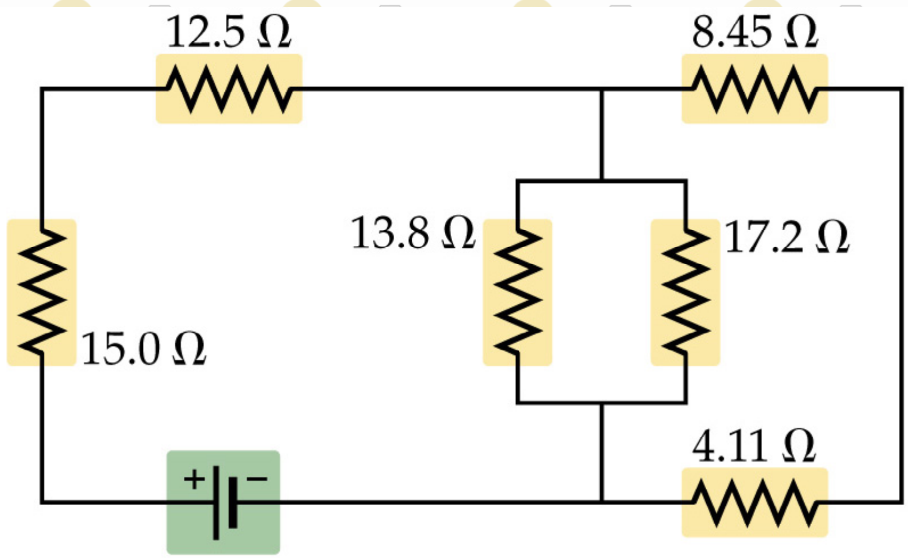
IR = i/3 r + i/6 r + i/3 r = I 5/6 r Therefore: Total resistance (R) = 5/6 r



Consider the circuit shown in the figure, in which three lights, each with a resistance R, are connected in parallel. What happens to the intensity of light 3 when the switch is closed? What happens to the intensities of lights 1 and 2?



The current in the 13.8 Ω resistor is 0.750 A.
Find the current in the other resistors in the circuit.



Ohm's Law

$$V = IR$$

Resistance
Units: Ohms (Ω)

Current
Units: Amperes (A)

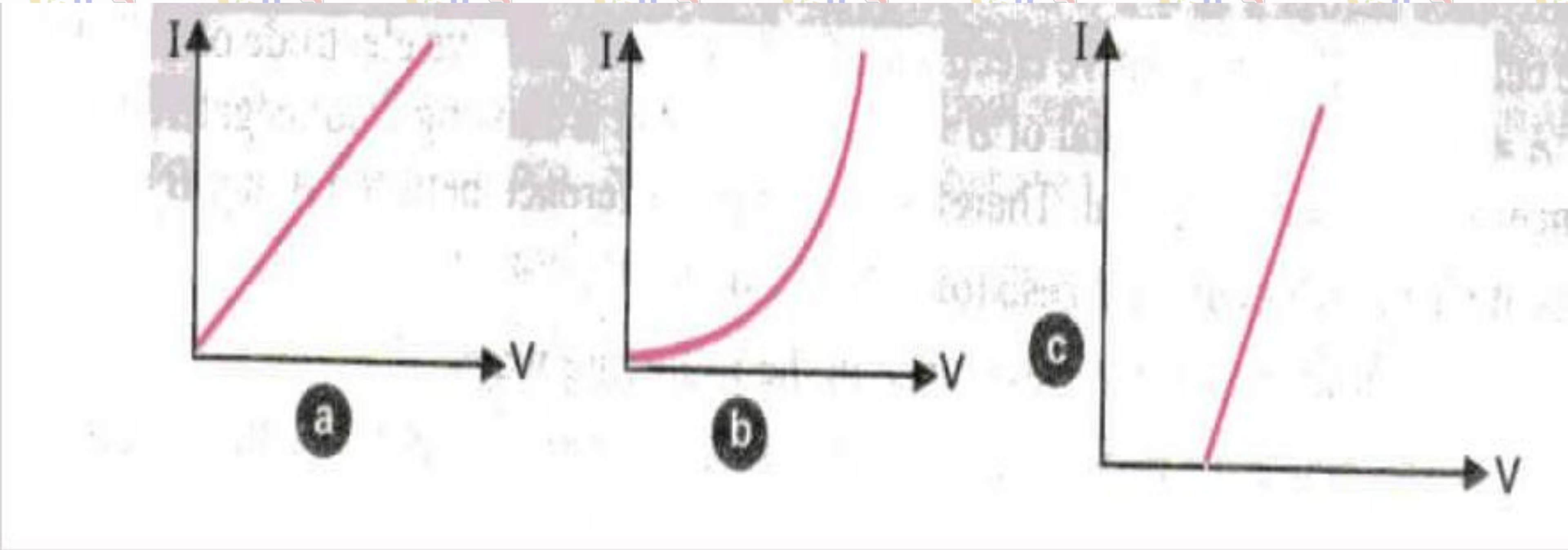
Electric potential
Units: Volts (v)

The current (I) flowing through a conductor is directly proportional to the potential difference (V) applied across its ends, provided the temperature and other physical conditions remain constant".

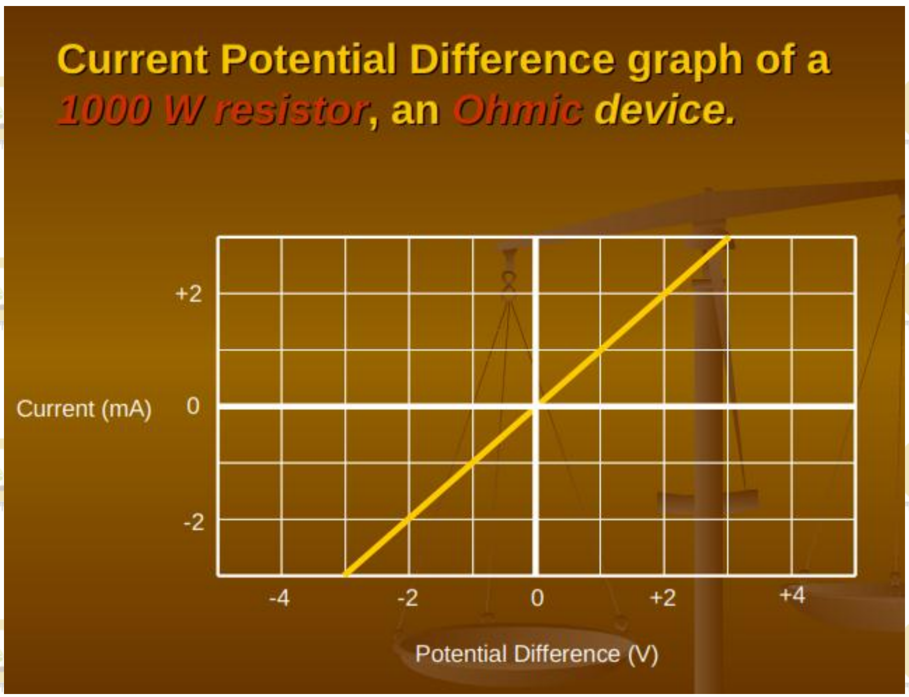
Every element in a circuit obeys Ohm's Law

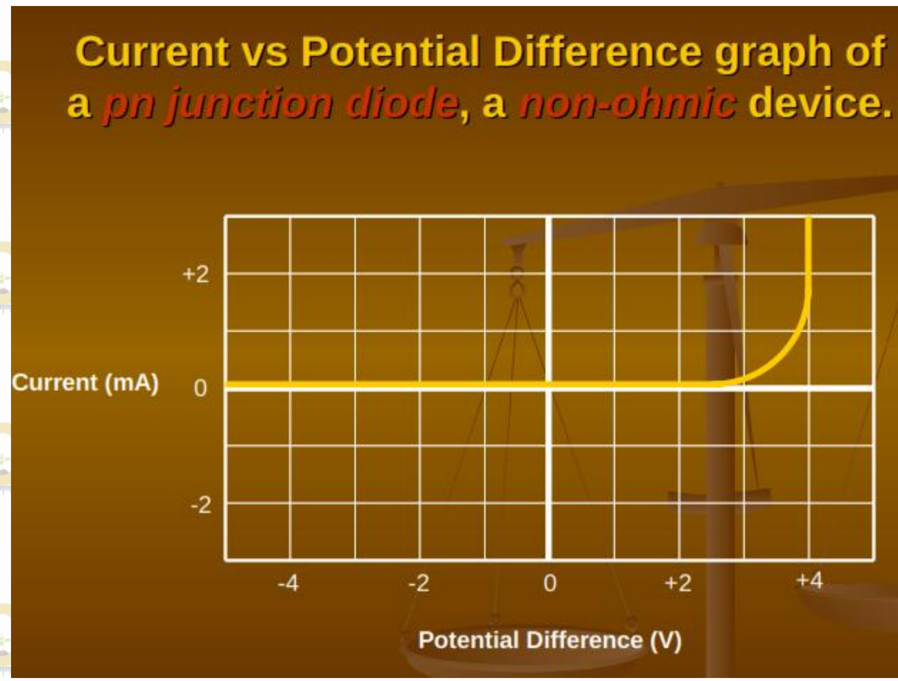
V-I graph for ohmic material is a straight line passing through origin.(a)

V-I graph for non-ohmic material is a curve i.e. non linear or straight line not passing through origin(b and c)



- Not all conducting material follow "Ohm's Law". Those are follow are said to be ***ohmic*** , while those that do not are said to be ***non ohmic***.

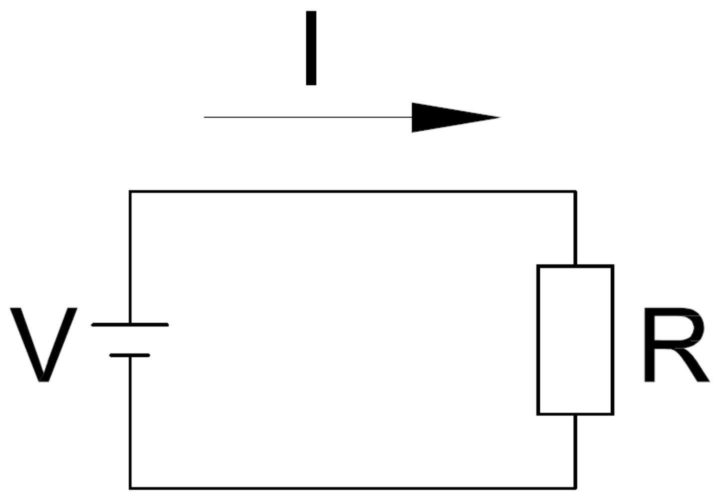




Note: the conductors which do not obey ohm's law completely are called non-ohmic conductor e.g. semiconductors, and diodes.

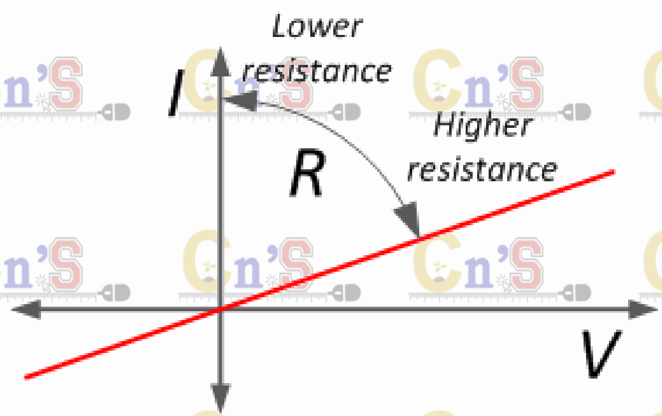
Ohm’s Law : macroscopic version

- Ohm’s law describes the resistance of a material to the flow of current (or its inverse – conductance)



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

$$\boxed{V = IR}$$



- The greater the resistance, the less current can flow for a given potential difference

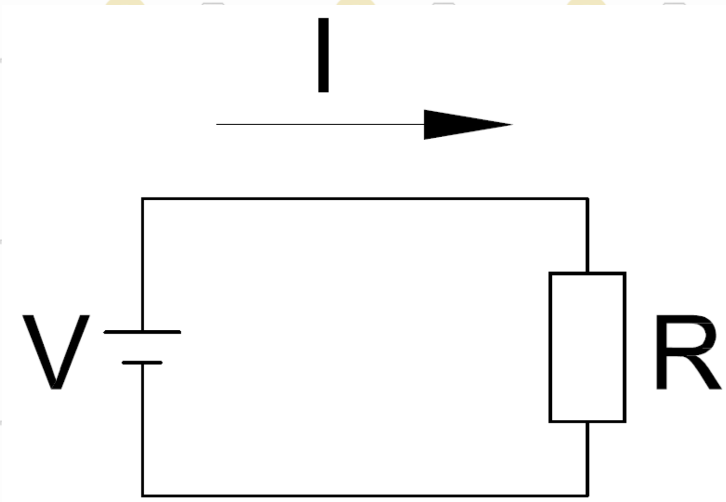
- Resistance is measured in units of Ohms (symbol: Ω)

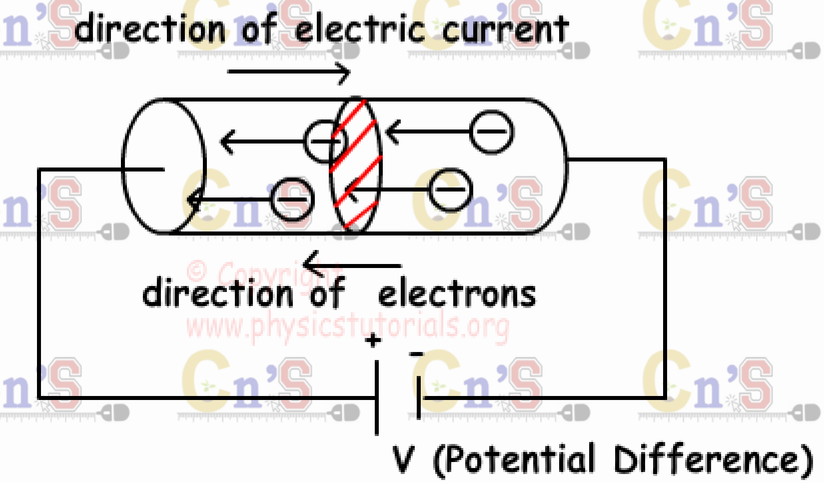
Electric shock

- Current of "only" 100 mA can be fatal to humans

- Luckily, resistance between points on human skin $= 10^5\ \Omega$
- So, fatal voltage = V = I R = 0.1 x 10^5 = 10,000 V
- If skin is wet, resistance is reduced. Be careful!

Macroscopic vs. Microscopic





- Current I driven by potential difference V
- Experiences resistance R
- Ohm's law $I = V/R$

- Current density J driven by electric field E
- Experiences resistivity ρ
- Ohm's law $J = E/\rho$

Limitations of Ohm's law:

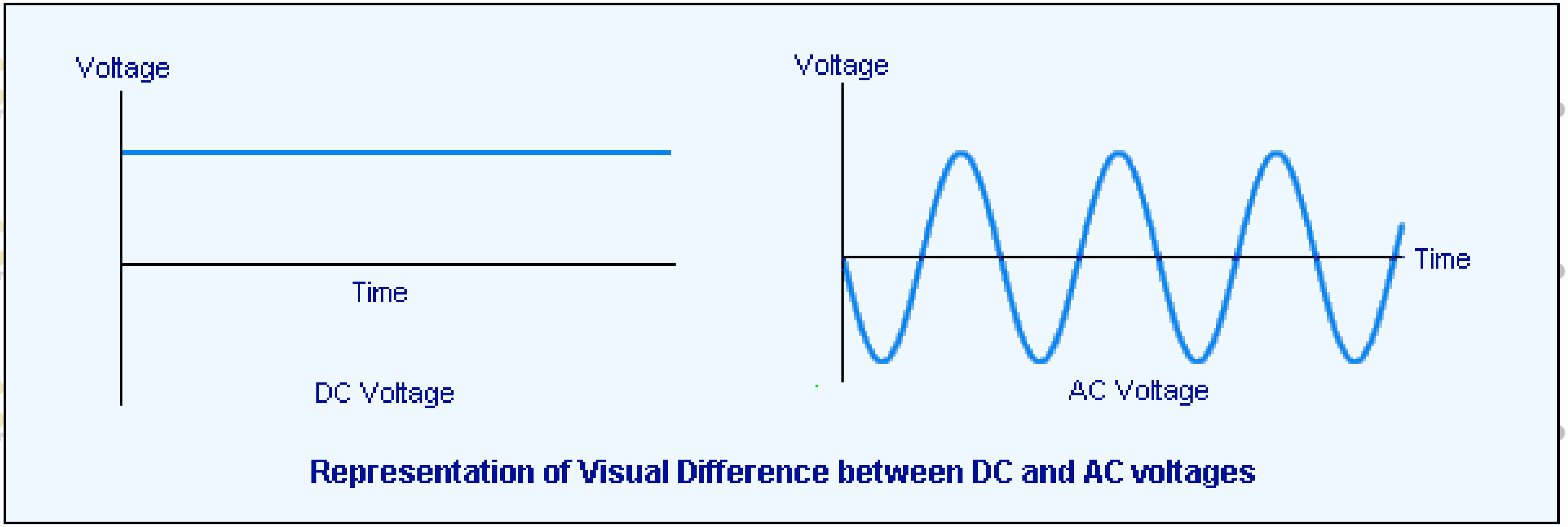
1. Ohm's law applicable only for good conductors.
2. Ohm's law applicable only, when the physical conditions like temperature,

pressure and tension remains constant.

3. Ohm's law is not applicable at very low temperature and very high temperature.
4. Ohm's law is not applicable for semiconductors, thermistors, vacuum tubes, discharge tubes.

Electric current

- Electrical power may be supplied as either a direct current or an alternating current



- We will only cover direct current in this topic

Filament Lamp

- As the current through the filament increases, the heating effect caused in the lamp also increases and so the temperature of the filament rises.

- This increase in the filament's temperature also increases the resistance of the filament.

- As a result the rate of increase of the current decreases and a greater change in the potential difference is required to cause a change in the current.

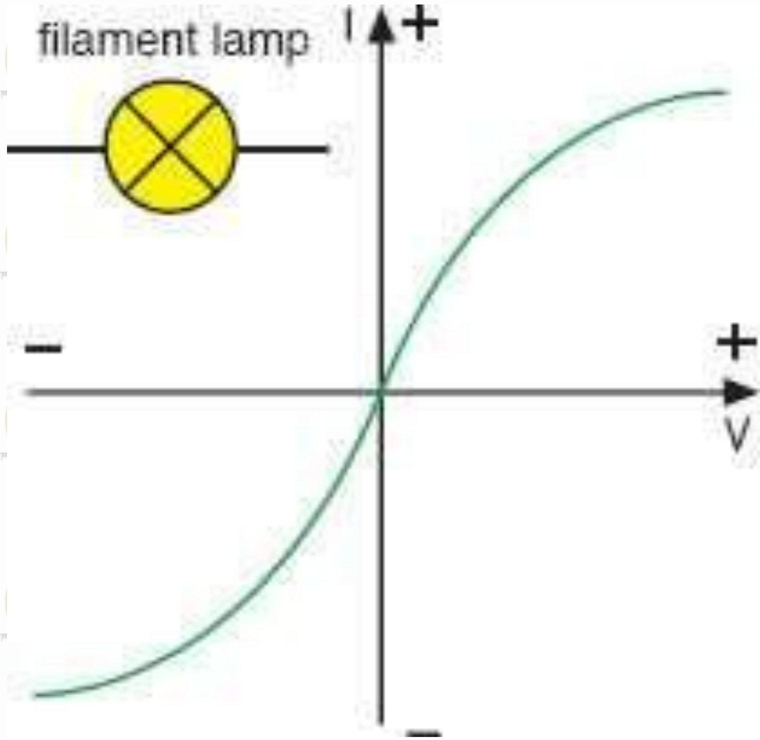
Filament Lamp

 When X is a filament lamp, the graph is a curve.

 Current I is not proportional to potential difference V.

 V increases more than I.

 It does not obey Ohm’s law and its resistance increases as the current increases



When a filament lamp is switched on, there is a current in the lamp. As the temperature of the filament rises, its resistance changes.

Which pair of graphs shows how the resistance R of the filament and the current I vary with time after the lamp is switched on?