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ELECTRIC CURRENT

1. Electric Current:

"Rate of flow of charge through a conductor is called electric current."

or "The charge flowing per second through any section of the conductor is called electric current."

Suppose a charge dq flows through any section of the conductor in time dt. Then current in the conductor is

$$i = \frac{dq}{dt} \quad \text{— (1).}$$

Unit of Current: The S.I unit of current is Ampere.

It is given as

$$1\,\text{Amp} = \frac{1\,\text{coulomb}}{1\,\text{Second}}.$$

"The current is said to be one Ampere if one coulomb charge flows through any section of a conductor in one second."

The net charge passing through the surface in any time interval is obtained from (1) as

$$\int dq = \int i\,dt.$$

$$q = \int i\,dt.$$

If current is constant in time then

$$q = i\int dt.$$

$$q = it$$

$$i = q/t.$$

The electric current i is the same at all points of a circuit irrespective of the cross sectional area at different points.

A +ve charge moving in one direction is equivalent to a -ve charge moving in the opposite direction. Hence for simplicity we adopt the following convention.

"The direction of current is the direction in which +ve charge moves even if the actual current is due to -ve charge."

The current due to motion of electrons is called electronic current and current due to motion of +ve charges is called Conventional current. There is no experimental difference b/w electronic current and conventional current. So both electronic and conventional current are equivalent. Current is a scalar quantity because it does not obey laws of vector addition.

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2. Current Density:

It is defined as,

"Current flowing per unit area held ⊥ to the direction of flow of current."

It is a vector quantity. It is denoted by $\vec{J}$

If we have a conductor of uniform area of cross section 'A' and the current i is uniformly distributed across the conductor, then the magnitude of current density is given by,

$$J = \frac{i}{A}$$

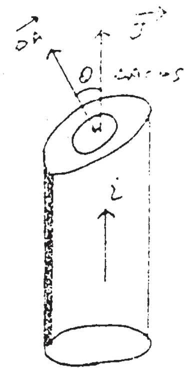
Current is a macroscopic quantity while current density is microscopic quantity.

The direction of $\vec{J}$ at any point is the direction in which +ve charge moves at that point. Its S.I unit is Amp/m^2.

us consider small current, flowing normally through an area ΔA. Then current density is

$$J = \lim_{\Delta A \to 0} \frac{\Delta i}{\Delta A} = \frac{di}{dA}.$$

If the plane of area makes an angle θ with the direction of flow of current, then



$$J = \lim_{\Delta A \to 0} \frac{\Delta i}{\Delta A \cos\theta} = \frac{di}{dA\cos\theta}$$

$$di = J\,dA\cos\theta.$$

$$di = \vec{J}\cdot\vec{dA}.$$

Then the total current is

$$\int di = \int \vec{J}\cdot\vec{dA}$$

$$i = \int \vec{J}\cdot dA$$

$$i = \int J\,dA\cos\theta$$

If the plane of area is $\perp$ to flow of current, then $\theta = 0$

$$i = \int J\,dA\cos 0$$

$$i = \int J\,dA$$

If the current density is uniform over the whole area then

$$i = J\int dA.$$

$$i = JA.$$ where A is the area of cross section of the conductor.

Thus $J = \frac{i}{A}$.

Relation b/w Drift Velocity and Current Density

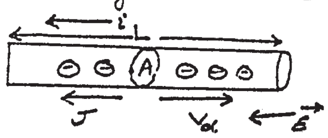
"The constant average velocity with which the electrons move (drift) in a conductor under the action of an applied electronic field is called average drift velocity" and is denoted by V_d.

Let us find the relation b/w drift speed V_d and current density $\vec{J}$

Consider a conductor of length L and area of cross section. Then volume of the conductor is $= AL$.

... be the number of conduction electrons per unit volume in the conductor.

Then total number of electrons in length L is $= nAL$. If e is the charge one one electron then total charge on these electrons $= nALe$.



$$\therefore q = nALe.$$

If the electrons cover this length L in t sec, then magnitude of average drift velocity is given by.

$$V_d = \frac{L}{t}.$$

$$\therefore t = \frac{L}{V_d}$$

Then current i is given by,

$$i = \frac{q}{t}.$$

$$= \frac{nALe}{L/V_d} = \frac{nALeV_d}{L}$$

$$i = nAeV_d.$$

Now current density J is given by

$$J = \frac{i}{A}$$

$$= \frac{nAeV_d}{A}$$

$$\boxed{J = neV_d}$$

This is the relation of current density and drift velocity. Since $\vec{J}$ and $\vec{V_d}$ both are vectors in opposite directions, then the above relation in vector form becomes

$$\vec{J} = -ne\vec{V_d}.$$

Sample Problem: 1

Sample Problem 1 One end of an aluminum wire ... diameter is 2.5 mm is welded ... end of a copper wire whose ...

... wire carries a steady current ...

Sol:- $d_{Al} = 2.5\,mm.$

$$r_{Al} = \frac{2.5}{2} = 1.25\,mm = 1.25\times10^{-3}\,m.$$

$$d_{cu} = 1.8\,mm, \quad r_{cu} = \frac{1.8}{2} = 0.9\,mm = 0.9\times10^{-3}$$

current $i = 1.3\,Amp.$

(i) current density in Al wire $= J_{Al} = ?$

(ii) current density in Cu wire $= J_{cu} = ?$

As $J_{Al} = \frac{i}{A_{Al}} = \frac{i}{\pi r_{Al}^2} = \frac{1.3}{3.14\times(1.25\times10^{-3})^2}$

$$J_{Al} = \frac{1.3\times10^{6}}{4.90625}.$$

$$J_{Al} = 0.26\times10^{6}\,Amp/m^2.$$

$$= 0.26\times10^{6}\,\frac{Amp}{(10^2\,cm)^2} = 0.26\times10^{6}\,\frac{Amp}{10^4\,cm^2}.$$

$$= 0.26\times10^{2}\,Amp/cm^2.$$

$$\boxed{J_{Al} = 26\,A/cm^2}\ \text{Ans}$$

Now $J_{cu} = \frac{i}{A_{cu}} = \frac{i}{\pi r_{cu}^2} = \frac{1.3}{3.14\times(0.9\times10^{-3})^2}$

$$J_{cu} = \frac{1.3\times10^{6}}{2.5434}. = 0.51\times10^{6}\,A/m^2.$$

$$= 0.51\times10^{6}\,\frac{A}{(10^2\,cm)^2} = 0.51\times\frac{10^{6}A}{10^4\,cm^2}$$

$$= 0.51\times10^{2}\,A/cm^2$$

$$\boxed{J_{cu} = 51\,A/cm^2}\ \text{Ans.}$$

Sample Problem 3

Sample Problem 3 A strip of silicon, of width w = 3.2 mm and [illegible] thickness d = 250 μm, carries a current i of 190 mA. The si[illegible] is an n-type semiconductor, having been "doped" with a [illegible] trolled amount of phosphorus impurity. The doping has [illegible] effect of greatly increasing n, the number of charge carriers (ele[illegible] trons, in this case) per unit volume, as compared with the va[illegible] for pure silicon. In this case, n = 8.0 × 10[illegible] m[illegible]. (a) What is [illegible] current density in the strip? (b) What is the drift speed?

Sol:- Width $= w = 3.2\,mm = 3.2\times10^{-3}\,m.$

Thickness $= d = 250\,\mu m = 250\times10^{-6}\,m$

current $= i = 190\,mA = 190\times10^{-3}\,Amp.$

number of electrons per unit volume $= n = 8\times10^{21}/m^3.$

(a) $J = ?$ (b) $V_d = ?$

As $J = \frac{i}{Area} = \frac{i}{wd}$.

$= \frac{190 \times 10^{-3}}{3.2 \times 10^{-3} \times 250 \times 10^{-6}}$

$= \frac{190}{3.2 \times 250} \times 10^{6}. = 0.2375 \times 10^{6}.$

$= 0.2375 \times 10^{6}. = 0.24 \times 10^{6}$

$\boxed{J = 2.4 \times 10^{5}\ Amp/m^{2}}$ Ans

(b) As $J = ne V_d$.

$\therefore V_d = \frac{J}{ne}$

$= \frac{2.4 \times 10^{5}}{8 \times 10^{21} \times 1.6 \times 10^{-19}} = \frac{2.4}{8 \times 1.6} \times 10^{3}$

$= 0.1875 \times 10^{3} = 0.19 \times 10^{3}$

$\boxed{V_d = 190\ m/s}$ Ans

3. Resistante, Resistivity & Conductivity:

Resistance "It is the opposition offered by the atoms of the conductor to the motion of free electrons."

If we apply the same potential difference to similar rods of wood and copper then different amounts of current flow in them. The currents are different due to different resistances of wood and Cu. If a potential difference V is applied b/w two ends of a conductor, then current flowing is proportional to the potential difference

i.e $V \propto i$.

$V = iR.$

or $R = V/i$

Where R is a constant of propotionality called resistance of the conductor. Its value depends on nature, temperature and dimensions of the conductor.

Unit of Resistance: The S.I unit of resistance is ohm

It is given as

$$1\,\Omega = \frac{1\,\text{Volt}}{1\,\text{Amp}}.$$

"The resistance of a conductor is one ohm. if a potential difference of one volt across the conductor produces a current of one ampere in it.".

Resistivity: The resistance 'R' of a conductor of uniform area of cross section depends on its length L and area of cross section A as

$$R \propto L.$$

$$R \propto \frac{1}{A}.$$

$$R \propto \frac{L}{A}.$$

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

$$\rho = \frac{RA}{L}.$$

Here ρ is the constant of propotionality and is called resistivity. It is a characteristic of material rather than a particular specimen of the material. It is independent of dimensions and depends on nature and Temperature only. It is also called specific resistance.

If $A = 1\,m^2$.

$L = 1\,m.$

then $\rho = R.$

So it is defined as

"Resistance of a meter cube of a substance".

[illegible]

1m and area of cross section.

Unit of Resistivity:

The S.I unit of resistivity is Ohm-meter (Ω-m). It is defined from

$$\rho = \frac{RA}{L} \text{ as.}$$

$$1\ \Omega\text{-m} = \frac{\Omega\text{-m}^2}{m} = \Omega\text{-m}.$$

Conductivity:

"It is the reciprocal of resistivity"

It is denoted by σ

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

Unit of Conductivity:

The S.I unit of resistivity is $\frac{1}{\text{ohm-m}} = (\Omega\text{-m})^{-1}$

$$= \text{mho-m}^{-1}.$$

Relation b/w Conductivity & Current-density:

We know that potential difference across a conductor sets up an electric field in it. If V is the potential difference and E is the electric field then

$$V = EL \quad -(i)$$

$$\text{But } V = IR.$$

$$\therefore EL = IR$$

$$\therefore EL = I\frac{\rho L}{A}. \qquad \because R = \frac{\rho L}{A}.$$

$$E = \frac{I\rho}{A}.$$

$$E = \rho\left(\frac{I}{A}\right).$$

$$E = \rho J. \qquad \text{But } \frac{I}{A} = J.$$

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

$$J = \frac{1}{\rho}E.$$

$$\therefore J = \sigma E. \qquad \text{But } \frac{1}{\rho} = \sigma$$

In vector form $\boxed{\vec{J} = \sigma\vec{E}}$

This is the relation b/w conductivity and current density ... is also called microscopic form of Ohm's law
This shows that current density is directly proportional to electric intensity.

Sample Problem: 2

Sample Problem 2 What is the drift speed of the conduction electrons in the copper wire of Sample Problem 1?

From S.P 1

$J_{cu} = 0.51 \times 10^6 \, A/m^2$

Sol:. $V_d = ?$; $e = 1.6 \times 10^{-19} C$

$M = 63.5 \times 10^{-3} \, kg/mol$

$d = 8.96 \times 10^3 \, kg/m^3$

As $J = n e V_d$

$$V_d = \frac{J}{ne}$$

$$V_d = \frac{0.51 \times 10^6}{n \times 1.6 \times 10^{-19}} \quad \text{—①}$$

Let V be the volume of one mole of Cu.

$\therefore$ number of electrons per unit vol is given as

$$n = \frac{N_A}{V}$$

$$n = \frac{6.02 \times 10^{23}}{\frac{M}{d}} \qquad \because V = \frac{M}{d}$$

$$= \frac{6.02 \times 10^{23} \times d}{M}$$

$$= \frac{6.02 \times 10^{23} \times 8.96 \times 10^3}{63.5 \times 10^{-3}}$$

$$n = 8.55 \times 10^{28} \text{ electrons}/m^3$$

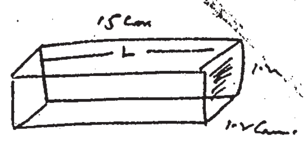
putting the value of n in ① we get.

$$V_d = \frac{0.51 \times 10^6}{8.55 \times 10^{28} \times 1.6 \times 10^{-19}}$$

$$\boxed{V_d = 3.8 \times 10^{-5} m/s} \text{ Ans.}$$

Sample Problem. 4

Sample Problem 4 A rectangular block of iron has dimensions 1.2 cm × 1.2 cm × 15 cm. (a) What is the resistance of the block measured between the two square ends? (b) What is the resistance between two opposing rectangular faces? The resistivity of iron at room temperature is $9.68 \times 10^{-8}\ \Omega \cdot m$.



Sol: $\rho = 9.68 \times 10^{-8}\ \Omega\text{-}m$, $L = 15\,cm = 0.15\,m$.

(a) Resistance of block b/w square ends = ?

Area of square End = $1.2 \times 1.2 = 1.44\,cm^2 = 1.44 \times 10^{-4}\,m^2$.

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

$$= \frac{9.68 \times 10^{-8} \times 0.15}{1.44 \times 10^{-4}} = \frac{9.68 \times 0.15}{1.44} \times 10^{-4}.$$

$$= 1.0 \times 10^{-4}\,\Omega = 100 \times 10^{-6}\,\Omega$$

$$\boxed{\Omega = 100\,\mu m}\ \text{Ans.}$$

(b) Resistance of two opposite rectangular faces = ?

Area of rectangular face = $15 \times 1.2 = 18.0\,cm^2$.

$$A = 18 \times 10^{-4}\,m^2.$$

$$\text{As } R = \frac{\rho L}{A} = \frac{9.68 \times 10^{-8} \times 1.2 \times 10^{-2}}{18 \times 10^{-4}}$$

$$= \frac{9.68 \times 1.2}{18} \times 10^{-6} = 0.65 \times 10^{-6}$$

$$\boxed{R = 0.65\,\mu\Omega}\ \text{Ans}$$

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4. Microscopic & Macroscopic Quantities:

V, I and R are macroscopic quantities. The corresponding microscopic quantities are $\vec{E}$, $\vec{J}$ and ρ or σ. $\vec{E}$, $\vec{J}$ and ρ or σ have values at every point of body.

The macroscopic quantities are related as $V = IR$.

The microscopic quantities are related as

$$\rho = \frac{E}{J} \quad \text{—(i)}$$

$$E = \rho J. \quad \text{—(ii)}$$

$$J = \sigma E \quad \text{—(iii)}.$$

he macroscopic quantities can be found by integrating over the microscopic quantities.

$$\text{e.g.} \quad i = \int \vec{J} \cdot d\vec{A} \quad -(A)$$

$$V = \int \vec{E} \cdot d\vec{s} \quad -(B)$$

In eq. (A) integral is a surface integral while in eq. (B) integral is a li integral.

Resistance R can be found by dividing (B) by (A)

$$\text{i.e} \quad R = \frac{V}{i}.$$

$$R \; \frac{\int \vec{E} \cdot d\vec{s}}{\int \vec{J} \cdot d\vec{B}}$$

If the conductor is a long wire of length L and area of cross section 'A'. Then the above relation becomes

$$R = \frac{EL}{JA}. \qquad \text{But } \frac{E}{J} = \rho$$

$$\therefore \; R = \frac{\rho L}{A}.$$

The macroscopic quantities V, i and R are important when we measure electrical quantities in real conductors. Their values are indicated on voltmeter, Ammeter and ohm meter. The microscopic quantities E, ρ and J are important when we are erned with behaviour of matter rather than specimens of matter The microscopic quantities are also important while studying the interior behaviour of irregular shaped conducting bodies

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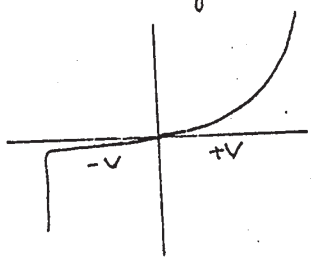
5. Ohm's Law:

"A conducting deice obeys Ohm's law if the resistance b/w any pair of points is independent of magnitude and polarity of the applied pot. difference"

A material or a circuit that obeys Ohm's law is called ohmic material.

... electronic devices like Pn-junction does not obey Ohm's law ... Pn-junction the current does not increase linearly with the voltage. It is also clear from fig.
... behaviour of Pn-junction for +ve voltage is different than at -ve voltage.



It should be noted that the relation $V = iR$ is not a statement of Ohm's law. Acceleration to this relation $R = \frac{V}{I}$. So from this relation we ... get a general definition of resistance of a conductor whether the conductor is ohmic or non-ohmic.

A conductor obeys Ohm's law if the graph b/w i and V for this conductor ... straight line i.e R is independent of V and r.

... macroscopic form of the relation $V = iR$ is $\vec{E} = \rho\vec{J}$.

... conducting material is said to obey Ohm's law if graph b/w E and J ... straight line i.e ρ is independent of E and J.

Ohm's law ... specific property of certain materials. It is not a general law of electromagnetism like Gauss's law.

6 Analogy between Current and Heat Flow

... establish an analogy b/w current (flow of charge) and ... of heat.

Consider a thin electrically conducting slab of thickness Δx and area A. If a potential difference ΔV is applied b/w the opposite faces then the current flowing through the slab according to Ohm's law is ...

$$i = \frac{\Delta V}{R}$$

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

$$R = \frac{\rho \Delta x}{A}$$

$$i = \frac{\Delta V A}{\rho \Delta x}$$

If the thickness is very small i.e dx then the above relation becomes,

$$i = \frac{dVA}{\rho dx}$$

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

$$\therefore i = \sigma A \frac{dv}{dx}$$

$$i = -\sigma A \frac{dv}{dx}.$$

Where -ve sign shows that +ve charge moves in the direction of decreasing V i.e i is +ve when $\frac{dv}{dx}$ is -ve.

$$\because i = \frac{dq}{dt}.$$

$$\therefore \frac{dq}{dt} = -\sigma A \frac{dv}{dx} \quad -(A)$$

This equation shows the flow of charge. The analogue of equation A for heat flow is given by

$$\frac{dQ}{dt} = -KA \frac{dT}{dx} \quad -(B).$$

Where K is thermal conductivity which corresponds to electrical conductivity σ. The -ve sign stands for the loss of heat.

Comparing (A) and (B) we see that thermal conductivity K corresponds to electrical conductivity σ and temperature gradient $\frac{dT}{dx}$ corresponds to potential gradient $\frac{dv}{dx}$.

Moreover, heat and charge are carried by the free electrons in metal. A good electric conductor is also a good conductor of heat.

7. Microscopic View of Ohm's Law

Ohm's law is not a fundamental law of electromagnetism because it depends on the properties of conducting medium.

In a metal, the current is due to motion of free electrons called conduction electrons.

In the absence of electric field, these conduction electrons move

...many are ... in ... gas. The electrons collide with ionic core of the lattice and suffers a change in direction of motion.

Now we define two terms.

(i) Mean free path λ (ii) Mean free time T.

λ is the distance b/w two consecutive collisions and T is the time b/w two consecutive collisions.

When we apply an electric field to a metal, the elections change their random motion. Such that they drift with speed V_d opposite to electric field. The electron experiences a force $F = eE$

So acceleration produces due to electric force is

$$a = \frac{F}{m} = \frac{eE}{m}.$$

$$\therefore \; a = \frac{eE}{m} \quad \text{— (i)}.$$

Consider an electron that has just collided with an ion core. So this electron has acquired a drift speed V_d. given as,

$$V_d = aT$$

Putting the value of (a) from (i) we get,

$$V_d = \frac{eE}{m} T \quad \text{— (ii)}$$

In terms of current density V_d is given by,

$$J = neV_d.$$

$$V_d = \frac{J}{ne}. \quad \text{— (iii)}$$

Comparing (ii) and (iii) we get

$$\frac{J}{ne} = \frac{eE}{m} T.$$

By cross-multiplication we get,

$$mJ = ne^2 E T.$$

or

$$\frac{m}{ne^2 T} = \frac{E}{J}.$$

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

$$\therefore \; \rho = \frac{m}{ne^2 T} \quad \text{— (iv)}$$

In equation m, n, e are constants.

ow from this equation we can say that metals obey Ohm's law if τ is constant. This is only possible when τ does not depend on E and so ρ is independent of E. τ depends on the distribution of conduction electrons. This distribution is affected very slightly by very very large electric field. So value of τ remains unchanged when field is applied. So R.H.S of eq.(iv) is independent of E. Hence ρ is independent of E. So the metals obey Ohm's law.

Sample Problem 5

Sample Problem 5 (*a*) What is the mean free time τ between collisions for the conduction electrons in copper? (*b*) What is the mean free path λ for these collisions? Assume an effective speed of 1.6×10^6 m/s.

Sol:- $m = 9.11 \times 10^{-31}$ kg, $e = 1.6 \times 10^{-19}$ C, $\rho = 1.69 \times 10^{-8}\ \Omega \cdot m$

$n = 8.49 \times 10^{28} / m^3$ (from Sample prob. 2), $\bar{V} = 1.6 \times 10^6$ m/s

(a) $\tau = ?$

As $\tau = \dfrac{m}{ne^2\rho}$

$$= \frac{9.11 \times 10^{-31}}{(8.49 \times 10^{28})(1.6 \times 10^{-19})^2(1.69 \times 10^{-8})}$$

$$= \frac{9.11}{36.73} \times 10^{-13} = 0.248 \times 10^{-13}$$

$$\boxed{\tau = 2.48 \times 10^{-14}\ \text{Sec}} \text{ Ans.}$$

(b) $\lambda = ?$

As $\lambda = \tau \bar{V}$

$$= 2.48 \times 10^{-14} \times 1.6 \times 10^{6}$$

$$= 3.968 \times 10^{-8} = 4 \times 10^{-8}\ m.$$

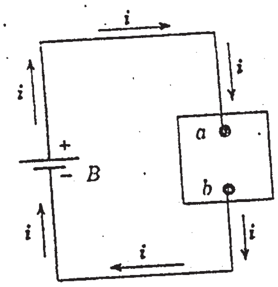
$$\lambda = 40 \times 10^{-9}\ m = \boxed{40\ nm} \text{ Ans}$$

8. Energy Transfer in an Electric Circuit.

Consider a circuit c of a battery B connected to a black box.

"The black box is a box, whose contents are unknown".

A constant current i is flowing in the connecting wires and a constant potential difference V_{ab} exists b/w the terminals 'a' and 'b'. The black box may contain a resistor, a motor or a battery etc.



The potential energy of charge dq that flows through the box from a higher potential at (a) to a lower potential at (b) decreases by

According to law of conservation of energy this energy is transferred from electrical energy to some other form.
The other form of energy depends on the content of the box.
The energy transferred inside the box in time dt is given by

$$du = dq\, V_{ab}$$

$$\because i = \frac{dq}{dt}$$

$$dq = i\,dt.$$

$$\therefore \quad du = i\,dt\, V_{ab}.$$

Now the power is defined as rate of transfer of energy

$$\therefore \quad P = \frac{du}{dt}.$$

$$\therefore \quad P = \frac{i\,dt\, V_{ab}}{dt}.$$

$$P = i V_{ab} \qquad V_{ab} = V.$$

$$\boxed{P = iV} \quad — (1)$$

If the box contains a motor, then this energy appears as mechanical energy.
If the box contains a battery; then energy appears as chemical energy of this 2nd battery.
If the box contains a resistor, then this energy appears as internal energy due to which temperature of resistor increases.

The other forms of equation① are

$$\boxed{P = i^2 R} \quad \text{— ②}$$

$\because V = iR$.

$$\boxed{P = \frac{V^2}{R}} \quad \text{— ③}$$

Eq. ① deals with transfer of electrical energy to all other kinds. Equation ② and ③ deal with transfer of electrical energy to internal energy of the resistor.

The equations ② and ③ represent Joule's law and the energy dissipated is called Joule heating.

The S.I unit of power is Watt.

There is another unit from the expression

$P = Vi$ which is Volt Amp.

Watt and Volt ampere are indentical. It can be shown as follows.

$$1\,\text{Volt - Amp} = \frac{1\,\text{Joule}}{\text{coulomb}} \times \text{amp}$$

$$= \frac{\text{Joule}}{\text{coul}} \times \frac{1\,\text{coul}}{\text{Sec}}$$

$$= \frac{\text{Joule}}{\text{sec}}$$

$$\boxed{\therefore\ 1\,\text{Volt-amp} = \text{Watt}}$$

Sample Problem-6

Sample Problem 6 You are given a length of heating wire made of a nickel–chromium–iron alloy called Nichrome; it has a resistance R of 72 Ω. It is to be connected across a 120-V line. Under which circumstances will the wire dissipate more heat: (*a*) its entire length is connected across the line, or (*b*) the wire is cut in half and the two halves are connected in parallel across the line?

Sol. $R = 22\,\Omega$; $V = 120\,\text{Volt}$.

(a) Power dissipated by the entire wire is

$$P = \frac{V^2}{R} = \frac{120 \times 120}{72}$$

$$\boxed{P = 200\,\text{Watt}} \quad \text{Ans}$$

(b). Power dissipated by half length of wire is

$$P' = \frac{V^2}{\frac{1}{2}R} = \frac{120 \times 120}{72 \times \frac{1}{2}} = \frac{120 \times 120}{36}$$

As there are two halves

∴ Total power from both halves is = $\boxed{800 \text{ Watt}}$ Ans.

9. Semiconductors:

"A semiconductor material is that whose resistivity lies b/w those of conductors and insulators."

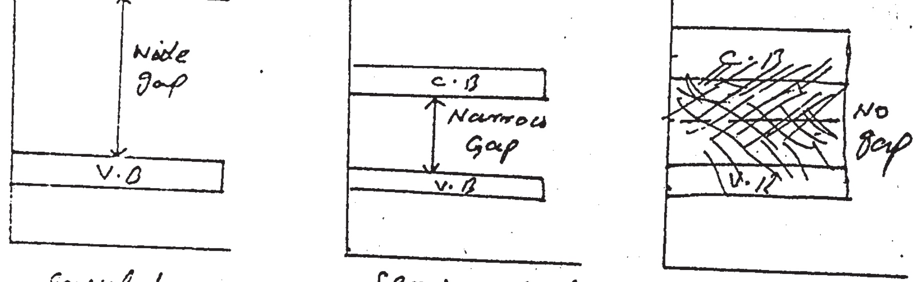
They are neither good conductors nor good insulators. These are the elements of 4th group of the periodic table. It means they have four electrons in their outermost orbit.

The important examples are Si and Ge. These semi conductors are in the form of crystals. The important property of semi-conductor is that their conductivity can be changed by

(i) Increasing the temperature of semiconductor.
(ii) Applying voltage.
(iii) Falling light energy.
(iv) Doping the semiconductors with impurities.

With the help of band theory of solids, we can distinguish among conductors, semiconductors and insulators. So properties of conductors, semi conductors and insulators can be studied by band theory.

The following figures show energy bands in insulators, semi-conductors and conductors.



Insulator Semiconductor. Conductor

In an insulator the valence band is completely filled while conduction band is empty. The electrons in the valence band are tightly bound by the nucleus. Also there is a wide gap b/w valence band and conduction band. Thus the number of electrons which can be excited from the valence band to the conduction band is also zero. This explains the poor conductivity of insulators.

In Semi conductors, the gap b/w valence band and conduction band is small ≈ 1eV as compared to insulators. In semi-conductor, valence band is almost filled and conduction band is almost empty.

In conductors the valence band and conduction bands overlap and there is no gap b/w them.

Properties of Semiconductors:

(i) The resistivity of semiconductor is less than an insulator but more than a conductor.

(ii) Semiconductors have negative temperature coefficient of resistivity. i.e. the resistivity of semiconductors decreases with the increase in temperature and vice versa. e.g Ge is an insulator at low temperature but it becomes a good conductor at high temperatures.

(iii) When a suitable impurity is added to a semi conductor, its conductivity increases.

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10. Superconductors:

When we decrease the temperature of a conductor, its resistance decreases.

Let us see what happens, when we approach the absolute zero of the temperature.

According to Quantum mechanics the atoms of a conductor retain a minimum resistance due to lattice defects and impurities and due to minimum vibrational motion. Many materials show this type of behaviour.

But some materials show a different kind of behaviour at low temperatures.

In 1911 the Dutch physicist Kamerling onnes discovered that the resistance of Hg drops abruptly to zero at about 4K. He declared that Hg has passed into a new state in which its resistance has vanished. This state of Hg is called superconductive state and the phenomenon is called superconductivity. Electronic currents flow in the superconductors in the absence of potential difference and there is no heating effect due current in a superconductor.

The temperature at which a material becomes superconductor is called critical temperature T_c.

It is different for different materials when a superconductor is cooled below critical temperature, there is not only abrupt loss of resistivity but also changes in magnetic properties i.e at the critical temp, the resistance vanishes and at the same time the material shows diamagnetism.

The properties of the material are different above and below the critical temperature. e.g

Properties of Superconductors:

(i) At the critical temperature T_c the d.c resistance vanishes and below T_c it remains zero.

(ii) At the critical temperature, the specific heat of materials increases rapidly. Below T_c the variation of specific heat is different from that above T_c.

So at the critical temperature there is a change from one set of properties to matter.

So we say that below T_c, the material is in the superconductive