(marks - 7)

UNIT No - 2.
Current Electricity

E The study of electric charges in motion is called current electricity.

Electric current ↦ The flow of electric charges through a conductor constitutes an electric current.

mathematically, the rate of flow of electric charge through a conductor is called electric curr

If q charge flow through a conductor in time t, then

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

But if flow of charge is not uniform then t dq charge flows through a conductor in a very small time dt then instanteneous value of cur is

$$\boxed{I = \frac{dq}{dt}}$$

Units ↦ $I = \frac{q}{t} = \frac{C}{s} = Cs^{-1} = \text{Ampere } (A)$

if $q = 1C$ and $t = 1s$

then $I = \frac{1C}{1s} = 1A$

Thus current is said to be 1 ampere ~~1coulo~~ 1 coulomb of charge flows through a conductor in 1 second.

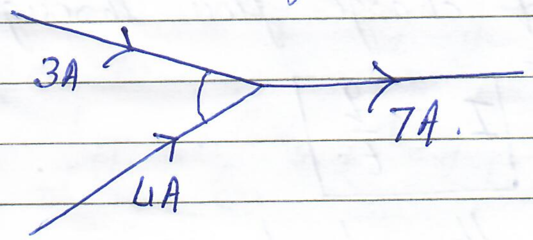
By convention, the direction of motion of +ve charge is taken as the direction of current.

However direction of flow of electrons gives the direction of electronic current.

In magnitude ... conventional current - Electronic cur

Electric current is a scalar quantity :→ Altho current has both magnitude and direction, yet i a scalar quantity, because currents are a up algebraically and not vectorily.

eg ~~...~~ wires carrying currents 3A an always ~~produce~~ adds up to give 7A current what so ever be the angle b/w the wires.



Charge / Current carriers ↦

1. In solids ↦ free electrons are the charge ca in solids.
2. In Liquids / Electrolytes ↦ In ~~a~~ liquids current due to movement of ions.
3. In gases ↦ In ~~...~~ gases current flows due movement of ions and electrons produ due to ionization of gases.

Drift Velocity ↦ The average velocity with which f $\bar{e}$s get drifted towards the +ve ~~...~~ termin the battery is called drift velocity.

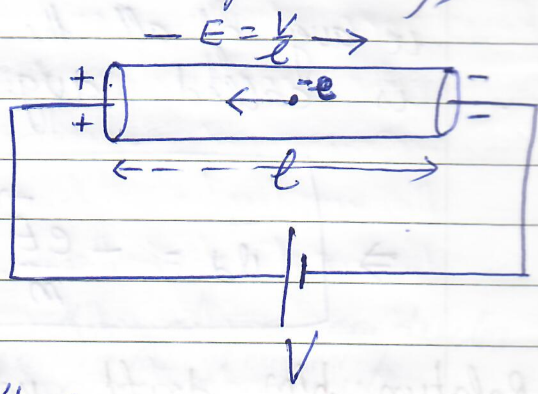
Expression for drift velocity ↦

In the absence of any external electr free ~~eq~~ electrons move inside the conductor randomly with a ~~...~~ very large thermal v But since motion of these electrons random therefore their average velocity i

$$\text{ie}\quad \frac{\vec{u}_1 + \vec{u}_2 + \text{———} + \vec{u}_n}{n} = 0. \quad \text{——} (1)$$

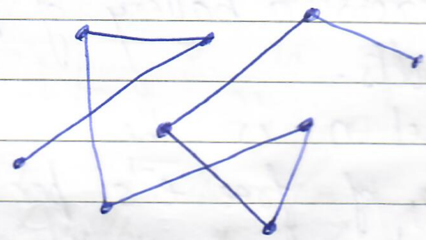
But when external electric field $\vec{E}$ is applied by applying the pot. diff. V, then all electrons get accelerated towards the +ve terminal of battery, which can be given as

$$\vec{a} = \frac{\vec{F}}{m} = \frac{-e\vec{E}}{m} \quad \text{—②}$$



But this acceleration acts on the electron for a very small time. Because while travelling towards the +ve terminal, it suffers frequent collisions with the ions or atoms or electrons of the conductor.

The average time b/w two successive collisions of an electron is called relaxation time.



If $\tau_1, \tau_2, ---\tau_n$ are the relaxation times for n free electrons resp. the velocity of the first electron can be given as

$$\vec{v}_1 = \vec{u}_1 + \vec{a}\,\tau_1$$

||ly $$\vec{v}_2 = \vec{u}_2 + \vec{a}\,\tau_2$$

$$\vdots$$

||ly $$\vec{v}_n = \vec{u}_n + \vec{a}\,\tau_n$$

Thus from the defination of drift velocity

$$\vec{v}_d = \frac{\vec{v}_1 + \vec{v}_2 + --- + \vec{v}_n}{n}$$

$$= \frac{\vec{u}_1 + \vec{u}_2 + --- + \vec{u}_n}{n} + \vec{a}\frac{(\tau_1 + \tau_2 + --- + \tau_n)}{n}$$

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$\Rightarrow \vec{v}_d = 0 + \vec{a}\,\tau$ {$\because$ using ①}

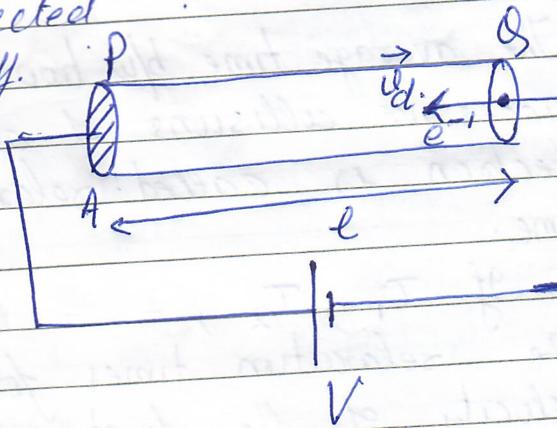
where $\tau = \frac{\tau_1 + \tau_2 + \cdots \tau_n}{n}$ = avg. relaxation

ie avg of all the relaxation times of free elect
is called avg. relaxation time.

$$\Rightarrow \boxed{\vec{v}_d = -\frac{e\vec{E}}{m}\tau}$$ {using ②}

Relation b/w drift velocity and electric current

Consider a conductor of length l and area
cross-section A is connected
across a battery of pot. diff.
V volts.



Let n is the no. of free e^{-1}'s per unit volume of the conductor. Thus

Total free electrons in the conductor, $N = nAl$
Thus total charge in the conductor due to these
free electrons is (mag. only

$$q = Ne$$

$$\Rightarrow q = nAle \quad \text{——} ①$$

This entire charge will flow through the
when free e^{-1} at end Q will reach at e
Thus time taken for the entire charge q to

$$t = \frac{l}{v_d} \quad \text{——} ②$$

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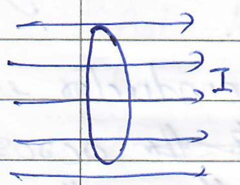
Thus current flowing through the conductor

$$I = \frac{\text{Total charge flowing}}{\text{Time taken}}$$

$$I = \frac{nAle}{l/v_d}$$

$$\boxed{I = neAv_d}$$

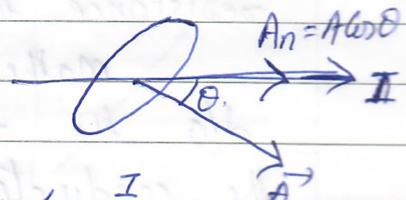
Current Density ↦ Current flowing through a conductor per unit area held normal to the dirn of flow of current is called current density.



ie $j = \frac{I}{A} = \frac{neAv_d}{A}$

$\Rightarrow \boxed{j = nev_d}$

or $\vec{J} = ne\vec{v_d}$



then $j = \frac{I}{A_n} = \frac{I}{A\cos\theta}$

$\Rightarrow I = JA\cos\theta = \vec{J}\cdot\vec{A}$

Electron mobility ↦ The mobility of the free e^-'s is d/a the drift velocity acquired by the free e^-'s on applying unit electric field.

ie $\mu = \frac{v_d}{E}$

since $v_d = \frac{eE\tau}{m}$ (mag. only)

$\therefore \boxed{\mu = \frac{e\tau}{m}}$

Ohm's Law ↦ According to Ohm's law, current flowing through a conductor is directly proportional to the pot. diff. applied across the ends of the conductor

ie $V \propto I$

$\Rightarrow \boxed{V = RI}$

where R is const. of proportionality and its value

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depends upon the nature of the conductor, its le
and area of cross-section.

Resistance of the conductor ↦ is the obstruction posse
the conductor to the flow of current.

Cause of resistance ↦ When pot. diff. is applied a
the conductor, free e⁻'s get accelerated towards the +
terminal of battery. While moving towards the +ve term
~~their motio~~ they collide against the atoms and ion
the conductor and their motion get obstructed cau
resistance to the flow of charge/current.

Mathematically resistance of the conductor
d/a the ratio of the pot. diff. applied ~~to the~~ ac
the conductor to the value of current flowing th

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

Units

$$R = \frac{\text{Volt}}{\text{Ampere}} = VA^{-1} = \text{ohm } (\Omega)$$

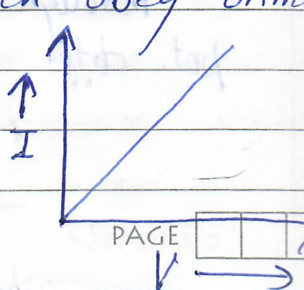
if $V = 1\,\text{Volt}$ and $I = 1\,\text{Amp}$.

then $$R = \frac{1\,\text{Volt}}{1\,\text{Amp}} = 1\,VA^{-1} = 1\,\Omega$$

Thus resistance of the conductor is said t
be $1\,\Omega$ if 1 Ampere of current flow throu
on applying a pot. diff of 1 volt.

Ohmic Conductors ↦ The conductors which obey ohm
law are called ohmic conductors.

for ohmic conductors, the graph
b/w V and I is a straight line



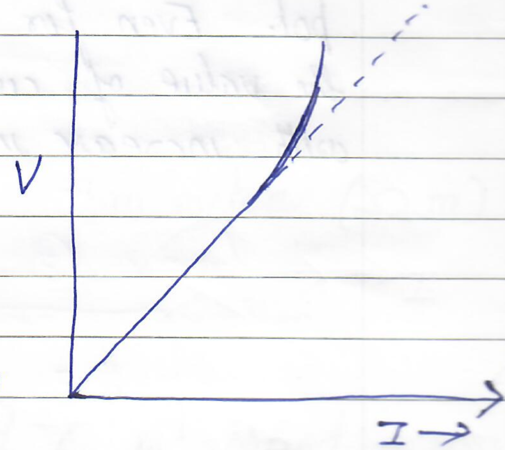
Non ohmic conductors or Failure of Ohm's Law ↦

Ohm's law is not a fundamental law in nature. There are many conductors which do not obey Ohm's law. Such conductors are called non ohmic conductors. For non ohmic conductors, graph b/w V and I is not a straight line.

Examples of Non-ohmic conductors ↦

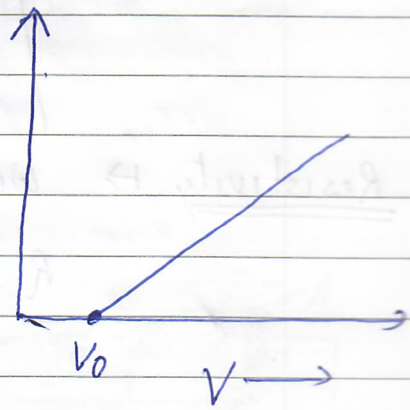
(1) Metallic conductors ↦

For small value of current, metallic conductors obey Ohm's law. But when large current flows through them, due to heating effect of current their resistance increases and hence current flowing through the conductor does not remain proportional to the pot. diff. applied. Hence graph b/w V and I becomes non linear.



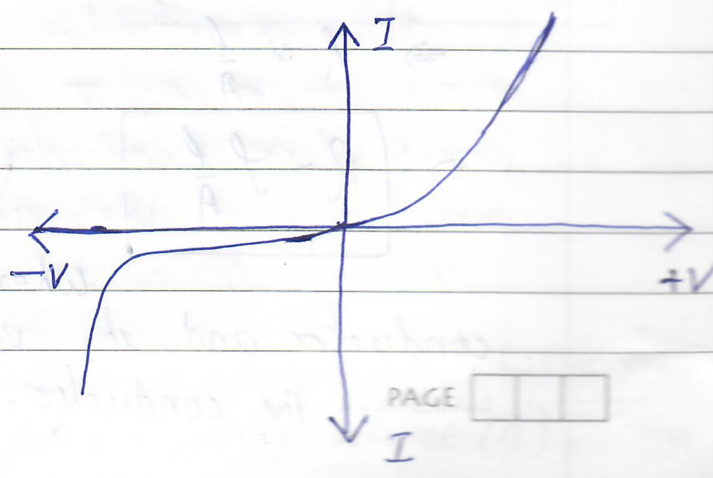
2. Water Voltameter :→

In case of water voltameter no current flows through it, untill applied pot. is more than the back emf V_0. The cause of back emf is liberation of hydrogen at cathode and oxygen at anode.



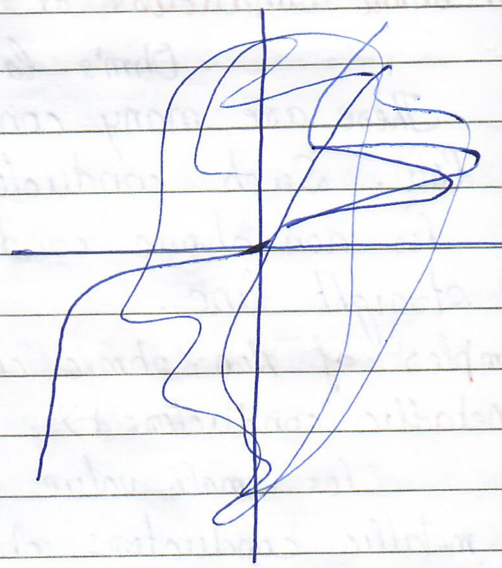
3 p-n junction diode :→

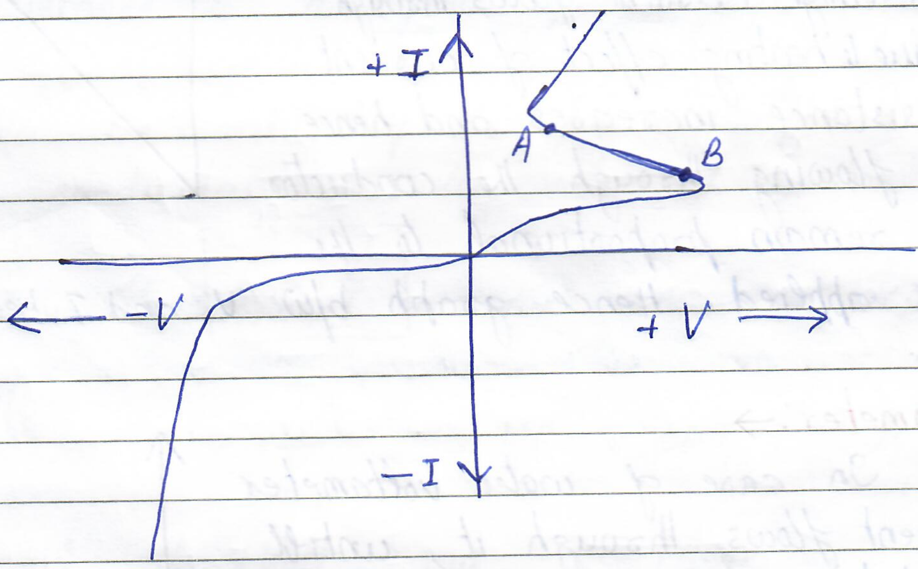
In case of p-n junction diodes, the current flowing through the diode is not proportional to the pot. applied across the diode.



Thyristors :→

In case of thyristors the graph b/w V and I is non linear. In certain portions there are more than one value of current for the same value of applied pot. Even for the region AB the value of current decreases with increase in pot. applied.





Resistivity ↦ We know that

$R \propto l$ (length of the conductor)

$\propto \frac{1}{A}$ (A is area of cross-section of conductor.)

$\Rightarrow R \propto \frac{l}{A}$

$\Rightarrow \boxed{R = \rho \frac{l}{A}}$

where ρ is resistivity of the conductor and its value depends upon the nat[ure of] the conductor.

If $l = 1m$ and $A = 1m^2$

then $R = \rho \times \frac{1}{1} \Rightarrow R = \rho.$

Thus resistivity or specific resistance of the conductor is equal to the resistance of the conductor of unit length and unit area of cross-sect

Units of resistivity :-

we know that

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

$$\Rightarrow \rho = \frac{RA}{l} = \frac{ohm \times m^2}{m} = ohm\ metre\ (\Omega m)$$

Factors effecting electrical resistivity :→

Deduction of Ohm's law ↦

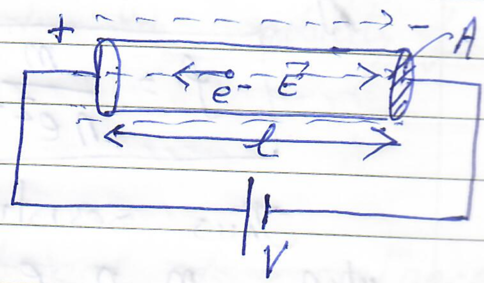
We know that, when electric field E is applied across the conductor of length l and area of cross-sect A, then drift velocity is given as,

$$v_d = \frac{eE\tau}{m} \quad \text{—— ①} \quad (\text{mag. only})$$

Also

$$I = neAv_d \quad \text{——} \quad (\text{mag only})$$

$$\Rightarrow v_d = \frac{I}{neA} \quad \text{—— ②}$$



from ① and ②.

$$\frac{eE\tau}{m} = \frac{I}{neA}$$

$$\Rightarrow \frac{eV}{l}\frac{\tau}{m} = \frac{I}{neA} \qquad \{\because V = Ed\}$$

$$\Rightarrow \frac{V}{I} = \frac{m}{ne^2\tau} \times \frac{l}{A} \quad \text{—— ③}$$

for a given conductor mass of electron(m), charge on electron (e), no. of free e^-'s per unit volume (n),

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avg. relaxation time (τ), length (l) and area of cross-section (A) of the conductor ~~senar~~ is con

$$\therefore \frac{V}{I} = \text{Const.}$$

$$\Rightarrow V = \text{Const} \times I \quad \text{——— (3)}$$

$$\Rightarrow V \propto I$$ which is Ohm's law Hence derived.

Also $V = RI$ ——— (3)

$$\Rightarrow \frac{V}{I} = R \quad \text{——— (4)}$$

from (3) and (4)

$$\boxed{R = \frac{m}{ne^2\tau}\frac{l}{A}} \quad \text{——— (5)}$$

Thus resistance of the conductor depends ~~of~~ upo m, n, e, τ (nature of the conductor) and l, A of the conductor.

Also $R = \rho \frac{l}{A}$ ——— (6)

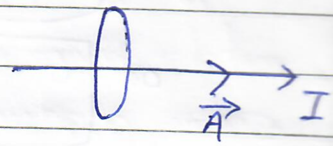
from (5) and (6)

$$\boxed{\rho = \frac{m}{ne^2\tau}}$$

Thus resistivity of the conductor depends upon m, n, e, τ ~~of ie~~. Since n and τ varies from conductor to conductor. Therefore resistivity of the conductor is diff. for diff. conductors.

Resistivity in terms of current density ↦ We know that current density is d/o the value of current flowing through the conductor per unit area held normal to the flow of current.

ie $$j = \frac{I}{A}$$



$$= \frac{n e v_d A}{A}$$

$$\boxed{j = n e v_d}$$

$$= ne\left(\frac{eE\tau}{m}\right) \qquad \left\{\because v_d = \frac{eE\tau}{m}\right.$$

$$\Rightarrow j = \frac{ne^2\tau}{m} E$$

$$\Rightarrow j = \frac{E}{\rho} \qquad \left\{\because \rho = \frac{m}{ne^2\tau}\right\}$$

$$\therefore \boxed{\rho = \frac{E}{j}}$$

$$\text{or } \rho = \frac{E}{n e v_d}$$

$$\Rightarrow \boxed{\rho = \frac{1}{n e \mu}} \qquad \text{where } \mu = \frac{v_d}{E} = \text{mobility of } e^-\text{s}$$

Conductance and conductivity ↦ The reciprocal of resistance of the conductor is called its conductance.

ie $$G = \frac{1}{R}$$

units $G = \frac{1}{\text{ohm}} = \text{ohm}^{-1} = \text{mho} = \mho$ = siemen

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The reciprocal of resistivity of the condu
is called conductivity of the conductor.

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

or $\boxed{\sigma = \frac{J}{E}}$ $\Rightarrow$ $\boxed{J = \sigma E}$

or $\boxed{\sigma = ne\mu}$

Units $\sigma = \frac{1}{\rho} = \frac{1}{\text{ohm metre}} = \text{ohm}^{-1}\ m^{-1}$

$= \text{siemen}\ m^{-1} = Sm$

Temperature dependance of resistance and resistivity ↦

We know that

$\rho = \frac{m}{ne^2\tau}$ or $R = \frac{m}{ne^2\tau}\frac{l}{A}$

for a metallic conductor no. of free e^- per unit volume is almost ~~constant~~ independent of temp. Thus resistivity or resistance of the is inversly proportional to avg. ~~relation to~~ relaxation time.

ie $\rho \propto \frac{1}{\tau}$ or $R \propto \frac{1}{\tau}$

with increase in temp, velocity of the free e increase, therefore avg. relaxation time (time b/w two successive collisions) decreases. Hence resi or resistance of the metallic conductor increses linearly with increase in temp.

ie $\boxed{\rho \propto T}$ or $\boxed{R \propto T}$

But incase of semiconductors or insulators

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the no. of free e^-'s per unit volume increases ~~exponentially~~ exponentially with increase in temp. Since resistivity is inversely proportional to n, therefore resistivity decreases exponentially with increase in temp.

$$\text{ie}\quad \rho(T) = \rho_0\, e^{E_g/kT}$$

for metallic conductors

$$R = R_0(1+\alpha\Delta T) \quad \text{or} \quad \rho = \rho_0(1+\alpha\Delta T)$$

$$\Rightarrow R - R_0 = \alpha R_0 \Delta T \quad \text{or} \quad \rho - \rho_0 = \alpha \rho_0 \Delta T$$

$$\Rightarrow \alpha = \frac{R-R_0}{R_0\Delta T} \qquad \alpha = \frac{\rho-\rho_0}{\rho_0\Delta T}$$

$$\Rightarrow \alpha = \frac{\Delta R}{R_0\,\Delta T} \qquad \Rightarrow \alpha = \frac{\Delta\rho}{\rho_0\,\Delta T}$$

Thus temp. coeff. of resistance (or resistivity) (α) is defined as the change in resistance (or resistivity) of the conductor per unit resistance (or resistivity) per unit change in temp. of the conductor.

Note ↦

Alloys like constantan or manganin are used to make standard resistance coils because
(1) they have very high value of resistivity and
(2) they have very small value of temp. coeff. ie variation in resistivity / resistance with temp. for these alloys is very small (negligible)

Super conductivity ↦ The phenomenon of complete loss of resistance of the metal or alloy by lowering its temp. below a certain value is called super conductivity

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The temp. at which resistance/resistivity of the ~~co~~ metal or alloy becomes zero is called critical temp.

ie at critical temp., ~~metal~~ resistance of the metal becomes zero and conductor becomes a super conductor.

Critical temp. for Hg is 4.2K
" " " $YBa_2Cu_3O_7$ is 90K
" " " $Tl_2Ca_2Ba_2Cu_3O_{10}$ is 120K.

Scientists are working to find out an alloy whose critical temp is equal to room temp ie 30
Because current once set up in a super condu loop can persist for years without any applied em

Heat loss ($H = I^2Rt$) in long distance power trans will become zero over the wires made up of sup conducting materials.

Cause of super conductivity ↦ It is believed that at critical temp. all the ionic vibrations cease a hence e^{-}'s move in pairs towards the +ve terminal witho being deflected by the ions. Thus resistance of th conductor becomes zero and it becomes a super conductor.

Colour coding of carbon resistors ↦
The value of high resistant carbon res is marked on them in the form of colour codes.
A carbon resistor has usually four rings o

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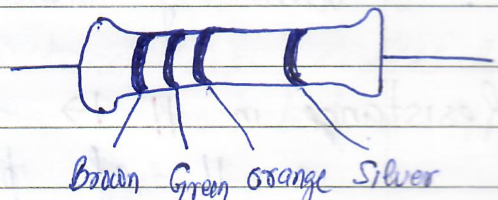
different colours. Each colour has a particular code from 0 to 9. A line ~~BB ROY of GB has VGW~~
BB ROY of Great Britain has Very Good Wife helps us to remember the codes.

Black	Brown	Red	Orange	Yellow	Green	Blue	Violet	Grey	White
0	1	2	3	4	5	6	7	8	9.

Colour of the first ring gives Ist significant digit.
" " " 2nd " " IInd " "
" " " 3rd " " no of zero that will follow 2 digit
" " " 4rth " " %age variation / % accuracy or %age tolerance

4rth rings is either of silver colour or of golden colour or there is no fourth ring (ie no colour)
~~Sil~~ Golden coloured ring indicates $\pm 5\%$ variation/accuracy.
Silver " " " $\pm 10\%$ " / "
No " " " $\pm 20\%$ " / "

e.g. for a carbon resistor Brown, green, orange and silver coloured rings
the value of resistance will be



$R = 15 \times 10^3 \pm 10\%$

Resistors in series $\mapsto$

Resistances are said to be connected in series if they are connected end to end so that same current flow through them.

Consider three resistors having resistances R_1, R_2 and R_3 are connected in series across a battery of pot. diff. V volts as shown.

Since same current flows through all the

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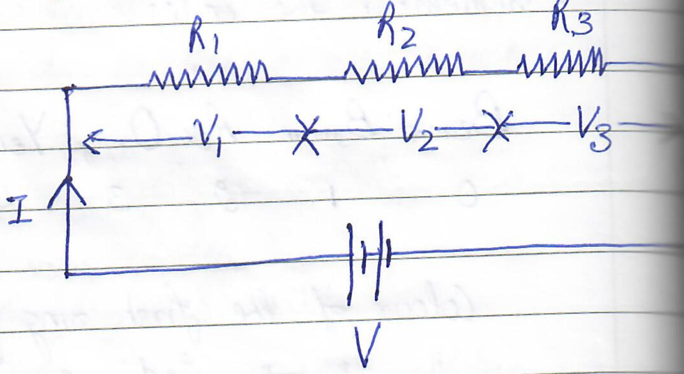
resistances, therefore pot. drop across each resistor can be given as

$V_1 = IR_1$ —— ① {ohms law}



||ly $V_2 = IR_2$ —— ②

" $V_3 = IR_3$ —— ③

If R_S is the equivalent resistance of the series combination then

$V = IR_S$ —— ④

Also

$V = V_1 + V_2 + V_3$

$\Rightarrow IR_S = IR_1 + IR_2 + IR_3$ {using ①, ②, ③ and ④

$\Rightarrow \boxed{R_S = R_1 + R_2 + R_3}$

Equivalent resistance is more than the largest value of resistance connected in series.

Resistance in || ↦ Resistances are said to be connected in || if pot ~~drop~~ difference across each resistance is same and is equal to applied potential.

Consider three resistors having resistance R_1, R_2 and R_3 are connected in || across a battery of pot. diff. V. volts.

~~Since resistances are connected in ||~~

Since pot. diff. across each resistance is same, therefore different currents depending on the value of resistance will flow through them

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ie $I_1 = \frac{V}{R_1}$ —— ① { ohms law)

||ly $I_2 = \frac{V}{R_2}$ —— ②

" $I_3 = \frac{V}{R_3}$ —— ③

If R_p is the equivalent resistance of the || combination then

$I = \frac{V}{R_p}$ —— ④

Also

$I = I_1 + I_2 + I_3$

$\Rightarrow \frac{V}{R_p} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$ { using ①, ②, ③ & ④ }

$\Rightarrow \boxed{\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$

The value of equivalent resistance R_p is less than the smallest value of resistance connected in ||.

Note ⇒ For two resistance R_1, R_2 connected in ||.

$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}$

$\frac{1}{R_p} = \frac{R_2 + R_1}{R_1 R_2}$

$\Rightarrow \boxed{R_p = \frac{R_1 R_2}{R_1 + R_2}} \Rightarrow \boxed{R_p = \frac{\text{Product of two}}{\text{Sum of two}}}$

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Internal Resistance of the cell ↦ The resistance offered electrolyte of the cell ~~is called~~ to the flow electric current b/w its electrodes is called internal resistance of the cell.

It depends upon.

(1) Nature of the electrolyte and its concentration.
2. It is directly ∝ to the distance b/w electrod
3. It is inversely ∝ to area of the electrodes immers in the electrolyte.

Electromotive force or emf of the cell ↦ The pot. diff the two terminals of the cell in an open circ (when no current is drawn from the cell) i called emf of the cell. (E)

It is also d/a the work done to derive a unit charge round the complete circ

emf of the cell is said to be 1 Volt if 1 J of work is done by the cell to drive 1 C charge round the circuit.

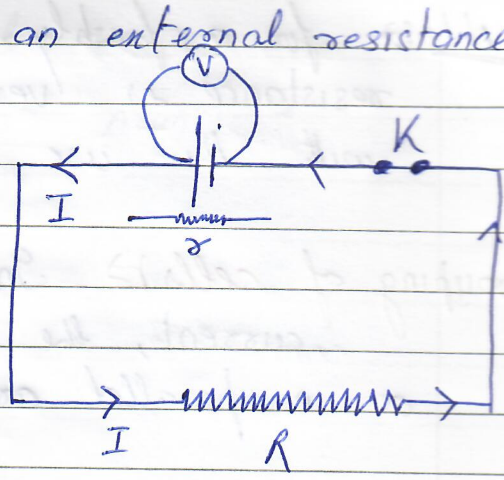
Also emf is not a force but it is work done per unit charge.

Terminal potential Difference ↦ The pot. diff. b/w the te terminals of the cell in a closed circuit (when current is drawn from the cell) is called terminal pot. diff. of the cell. (V)

Expression for internal resistance of the cell ↦

Consider a ~~ce~~ cell of EMF E and in

resistance r is connected to an external resistance R and key K as shown.



When key is kept open ie no current is drawn from the cell, voltmeter reading gives the emf of the cell E.

When key K is closed, the entire emf of the cell get dropped across the ext. resistance R and internal resistance r of the cell

Thus E = Pot. drop across R + Pot. drop. across r.

$$\Rightarrow E = IR + Ir$$

$$\Rightarrow E = I(R+r)$$

$$\Rightarrow I = \frac{E}{R+r} \quad \text{———} \quad (1)$$

$E = Ir + IR$
$V = Ir$
$V = I$

Also when key is closed, the voltmeter reads the pot. drop across ext. resistance R ie term. pot. diff. of the cell.

ie $V = IR$

$$\Rightarrow V = \frac{E}{(R+r)} R \quad \{\text{using } (1)\}$$

$$\Rightarrow R + r = \frac{E}{V} R$$

$$\Rightarrow r = \frac{E}{V} R - R$$

$$\Rightarrow \boxed{r = \left(\frac{E}{V} - 1\right) R}$$

or $\boxed{r = \left(\frac{E-V}{V}\right) R}$

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Note ↦ for a freshly prepared cell, the value of internal resistance is very low but it goes on increasing with the use of cell.

Grouping of cells ↦ In order to have larger value of current, the cells are usually connected in series or in parallel or are mixed grouped.

~~Cells in Series~~ ↦ When cells are connected in series. Then equivalent emf of the cells and equivalent internal resistance of the combination can be given as

$$E_{eq} = E_1 + E_2 + \cdots + E_n$$

and $$r_{eq} = r_1 + r_2 + \cdots + r_n$$

refer to S.L. Arora
Dhanpat rai & Sons
page no - 3.51 - 3.52

If all cells are identical of emf E and internal resistance r then

$$E_{eq} = E + E + \cdots \text{ n times}$$

$$\boxed{\begin{aligned} \text{ie}\quad E_{eq} &= nE \\ \text{and}\quad r_{eq} &= nr. \end{aligned}}$$

When cell are connected in parallel, then equivalent emf and int. resistance of the combination can be given as,

$$\frac{E_{eq}}{r_{eq}} = \frac{E_1}{r_1} + \frac{E_2}{r_2} + \cdots + \frac{E_n}{r_n}$$

and $$\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2} + \cdots + \frac{1}{r_n}$$

refer to S.L. Arora
Dhanpat Rai & Sons
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If all the cells are identical

then $\frac{1}{r_{eq}} = \frac{1}{r} + \frac{1}{r} + \text{---}$ n times

$\Rightarrow \frac{1}{r_{eq}} = \frac{n}{r}$

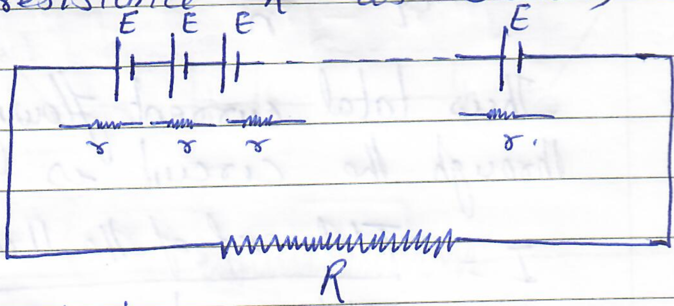
$\therefore \boxed{r_{eq} = \frac{r}{n}}$

and $\frac{E_{eq}}{r_{eq}} = \frac{E}{r} + \frac{E}{r} + \text{----}$ n times.

$\Rightarrow \frac{E_{eq}}{r/n} = \frac{nE}{r}$

$\Rightarrow \boxed{E_{eq} = E.}$

Cells in series ↦ Consider n cells of emf E each and internal resistance r each are connected in series across an external resistance R as shown,



Thus total current flowing through the circuit is given as

$$I = \frac{\text{Total emf of the combination}}{\text{Total resistance of the circuit.}}$$

$$\Rightarrow \boxed{I = \frac{nE}{R + nr}}$$

Sp. Cases ↦

① when $R << nr$

then $I = \frac{nE}{nr}$ $\Rightarrow I = \frac{E}{r}$ = Current due to a single cell.

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② when $R >> nr$

then $I = \frac{nE}{R}$ = n time the current due to a sing

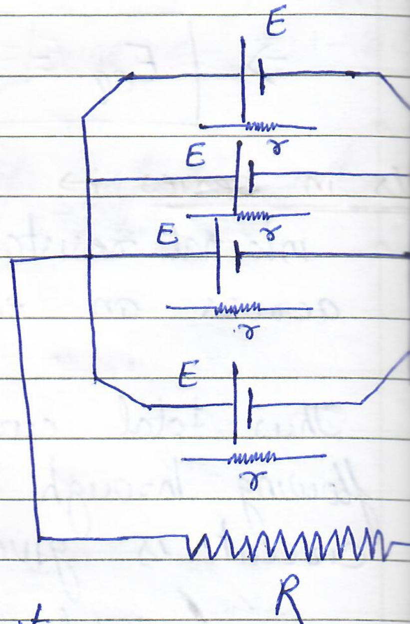
Thus for a heavy external load (R), cell are connected in series to have larger current through circuit.

Cells in || ↦ Consider n cells each of EMF E internal resistance r are connected in || acro an external load resistance R as shown.

We know that for a || combination

Total emf of the combination

$$E_{eq} = E$$



and total int. resistance of the combination

$$r_{eq} = \frac{r}{n}$$

Thus total current flowing through the circuit is

$$I = \frac{\text{Total emf of the || combination}}{\text{Total resistance of the circuit}}$$

$$\Rightarrow \boxed{I = \frac{E}{R + \frac{r}{n}}}$$

Sp. cases

① when $R << r$

then $I = \frac{E}{r/n} = n\frac{E}{r}$ = n times current due to a single cell

② for $R >> r$

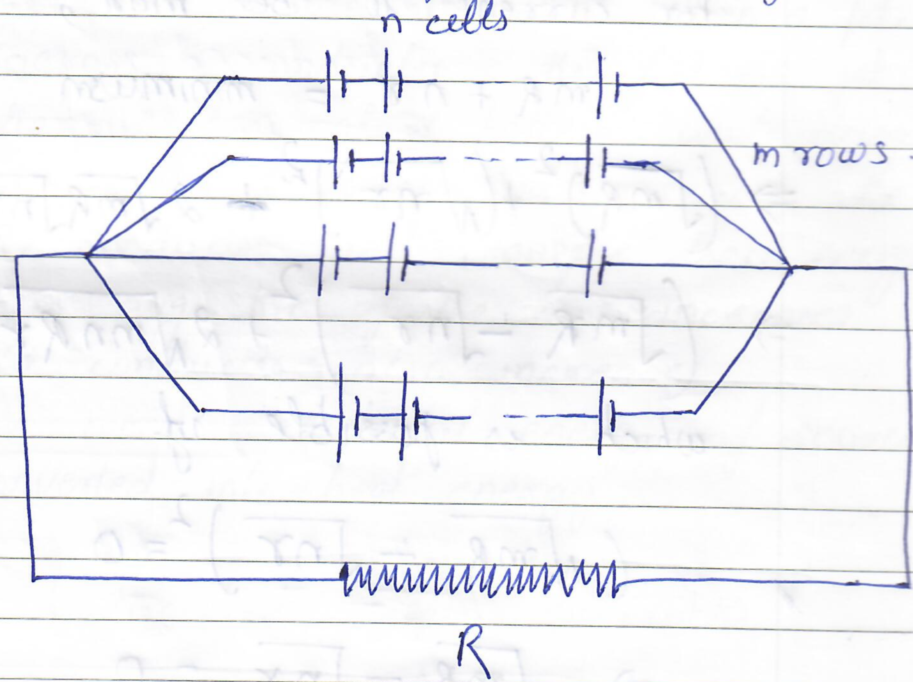
$$I = \frac{E}{R} = \text{current due to a single cell.}$$

Thus for a small value of load resistance (R), cells are connected in $\parallel$ to have larger current through the circuit.

Mixed grouping of the cells ↦

If load resistance is of the order of internal resistance of the combination then mixed grouping is done to have larger value of current through the circuit.

Consider a number of cells each of emf E and internal resistance r are connected in mixed grouping having m rows and each row having n cells as shown,



Thus total emf of the combination.

$$E_{eq} = nE$$

and total int. resistance of the combination

$$r_{eq} = \frac{nr}{m}$$

Thus total current flowing through the circuit is

$$I = \frac{\text{Total emf}}{\text{Total resistance}} \Rightarrow I = \frac{nE}{R + \frac{nr}{m}}$$

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$$\Rightarrow I = \frac{nE}{\frac{mR+nr}{m}}$$

$$\Rightarrow I = \frac{mnE}{mR+nr}$$

$$\Rightarrow \boxed{I = \frac{NE}{mR+nr}} \qquad \{\because mn = N($$

$$\Rightarrow \boxed{I = \frac{NE}{\text{rows time } R + \text{columns time } r}}$$

for current to be max,

$$mR + nr = \text{minimum}$$

$$\Rightarrow (\sqrt{mR})^2 + (\sqrt{nr})^2 - 2\sqrt{mR}\sqrt{nr} + 2\sqrt{mR}\sqrt{nr} = min$$

$$\Rightarrow (\sqrt{mR} - \sqrt{nr})^2 + 2\sqrt{mnRr} = min.$$

which is possible if

$$(\sqrt{mR} - \sqrt{nr})^2 = 0$$

$$\Rightarrow \sqrt{mR} - \sqrt{nr} = 0$$

$$\Rightarrow \sqrt{mR} = \sqrt{nr}$$

$$\Rightarrow mR = nr$$

$$\Rightarrow R = \frac{nr}{m}$$

$$\Rightarrow \boxed{R = r_{eq}}$$

Thus in mixed grouping, c
through the circuit will be
when load resistance is equ
the total int. resistance of the c

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