5. ELECTRICITY & MAGNETISM.

5.1 ELECTRIC FEILDS

ELECTRIC CHARGE
↳ A property of matter

A charge can be positive or negetive & the process of rubbing involves the transfer of charge from one body to another.

There is a force between charged bodies. It can be attractive or repulsive.
→ between charges of same sign. (repulsive)
↳ between charges of opposite sign (attractive)

The magnitude of the force becomes smaller as the distance between the charged bodies increases.

PROPERTIES OF ELECTRIC CHARGE

1. Negetive Charge → Property of electrons
Positive Charge → Property of protons.

2. Electric charge is quantised.
↳ the amount of electric charge on a body is always an integral multiple of a basic unit.
↳ Charge of proton: 1.6×10^{-19} C
↳ symbolised by 'e'
(Charge on electron is -e).

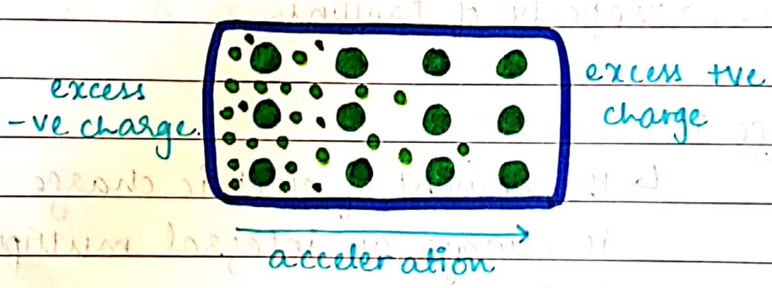
If we take quarks into account, the basic unit of charge is e/3.

3. Charge is conserved.
↳ In any process, the total charge cannot change.

In solid metals, 'free electrons' carry charge through the metal
↳ Materials with free electrons are called conductors.
(Materials that don't have free electrons so charge cannot move freely, are insulators)

In liquids & especially in gases, positive ions can also transport charge.

THE TOLMAN - STEWART EXPERIMENT.
↳ Proved that 'charge carriers' in metals are electrons.



• are free & floating. ● (positive charges) are anchored to to fixed positions.

Therefore, if the metal is accelerated, the electrons would be 'thrown back'. Excess negative charge is created at the back of the metal.
This charge was consistent with the charge of electrons.

COULOMB'S LAW states that the electric force between 2 point charges q_1 & q_2 is:

$$F = \frac{kq_1q_2}{r^2}$$

$k = \frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^9\ Nm^2C^{-2}$ (in vacuum)

ε_0 = permittivity of vacuum.
↳ $= 8.85 \times 10^{-12}\ C^2N^{-1}m^{-2}$.

ELECTRIC FEILD
↳ space around a charge or an arrangement of charges.

The electric feild strength is defined as the electric force per unit charge experienced by a small, point charge q:
↳ has to be small so that its presence doesn't disturb the electric feild it is trying to detect.
↳ Also called a 'test charge'.

$$E = \frac{F}{q}$$ unit = NC^{-1}

Electric feild strength is a vector.

The direction of the electric feild is the same as the direction of force experienced by a positive charge at that given point.

$$E = \frac{k(Qq/r^2)}{q}$$

$$E = \frac{kQ}{r^2}$$

$E = \frac{kQ}{r^2}$

Q → Charge inside is 0
↳ net charge on the sphere is distributed on the surface

Whenever there is a potential difference, there has to be an electric feild.

ELECTRIC CURRENT

Electric feild ~~is~~ inside a conductor is zero under static situations (0 current)

↳ Because electrons have a random motion.

↓

as many electrons move in one direction as in another.

When an electric feild is applied across the conductor, free electrons experience a push in the opposite direction.

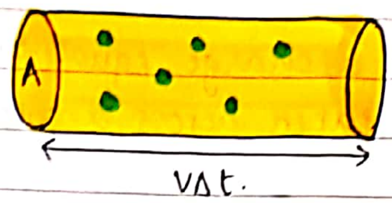
↓ Opposite direction because electron has a negetive charge.

↳ this direction is the direction of direct current.

Current is the rate of flow of charge.

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

The average speed with which the electrons move in the direction opposite to the electric feild is called the drift speed



Volume = $A V \Delta t$

No. of electrons per unit volume = n.

Charge on each electron = q.

Total charge = $n A v q \Delta t$.

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

$$I = nAvq$$

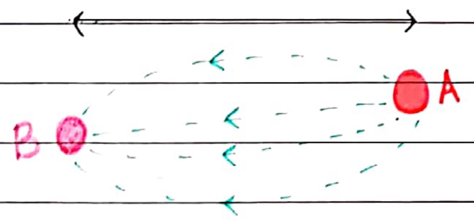
ELECTRIC POTENTIAL DIFFERENCE

The potential difference (V) between 2 points is the work done per unit charge to move a point charge from one point to another.

$$V = \frac{W}{q}$$

The actual path taken doesn't affect W.
The seperation matters.

xm.



Whenever there is a potential difference, there has to be an electric feild.

THE ELECTRONVOLT (eV)

↳ Work done when a charge equal to one electron charge is taken across a potential difference of 1 V.

$$1eV = 1.6 \times 10^{-19} J$$

5.2 HEATING EFFECT OF ELECTRIC CURRENT.

Effect of an electric feild within a conductor → Accelerate free electrons.

↓

Electric current is created. When V is constant, size of current is different in different conductors.

↑

Electric resistance determines how much I will flow for a given V.

Accelerate free electrons.

↓

Electrons gain Ek & have inelastic collisions with metal atoms

↓

Energy is lost to these atoms.

↓

They vibrate about their equilibrium position.

↓

Macroscopically, there is an increase in temp.

Just Ask

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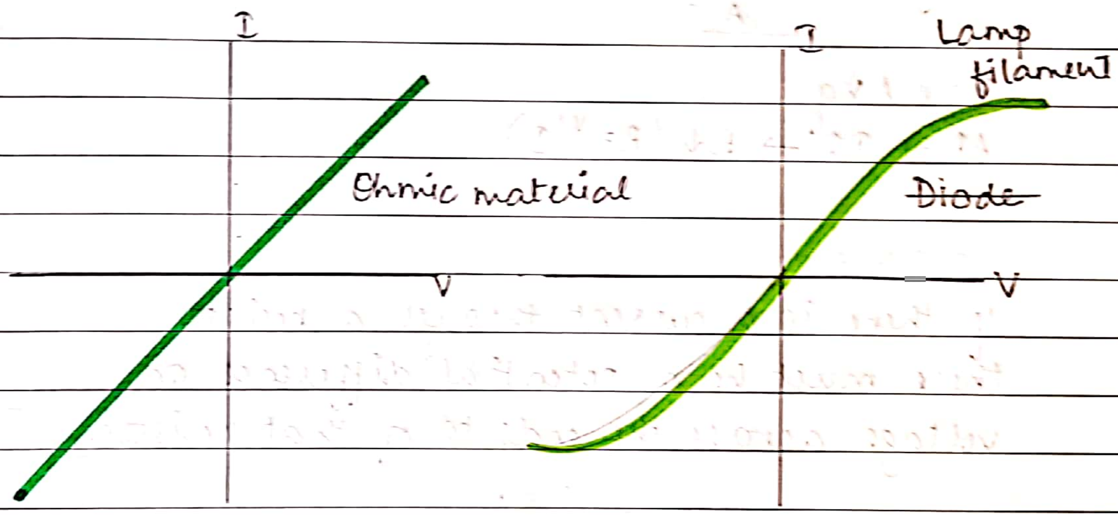
ELECTRIC RESISTANCE

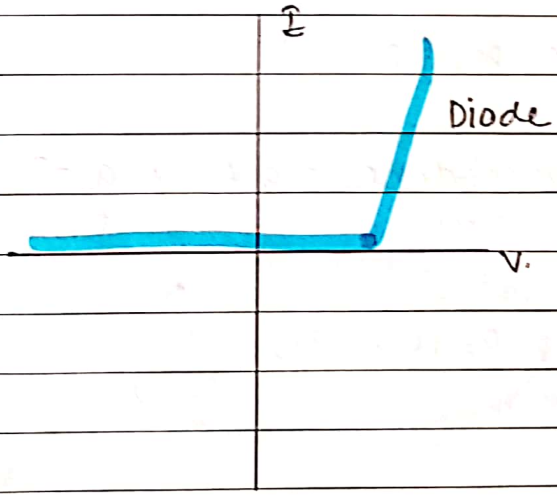
↳ Electric resistance of a conductor is the potential difference across its ends divided by the current passing through it.

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

$$\boxed{\text{At constant temperature, } I \propto V}$$

↳ OHM'S LAW





$R = \rho \frac{L}{A}$ → ρ = resistivity
↳ depends on the material of the conductor & the temperature.

Why is $R \propto L$?

$W = FL \rightarrow F = Eq \rightarrow W = EqL$.

$V \propto W$.

Therefore, $L\uparrow \rightarrow W\uparrow \rightarrow V\uparrow \rightarrow R\uparrow \; (R = V/I)$.

Why is $R \propto \frac{1}{A}$?

$I = nAvq$.

$A\uparrow \rightarrow I\uparrow \rightarrow R\downarrow \; (R = V/I)$.

VOLTAGE

If there is a current through a resistor, there must be a potential difference or voltage across the ends of that resistor.

$$V = IR$$

ELECTRIC POWER:

$$\text{Power} = \frac{\text{workdone}}{\text{time}} = \frac{qV}{t} \; ; \; \frac{q}{t} = I$$

$$P = IV = I^2R = \frac{V^2}{R}$$

ELECTROMOTIVE FORCE (emf)

Charges need to be pushed in order to drift inside a conductor. For this, we need an electric feild. To have an electric feild, we need potential difference.

Cells use energy from chemical reactions to provide a potential difference.

ε = emf = work done per unit charge in moving a charge across the battery terminals.
↳ a collection of cells.

Emf is also the power provided by the ~~pa~~ battery per unit current.

$$\text{emf} = \frac{W}{q} = \frac{P}{I}$$

SIMPLE CIRCUITS.

Resistors in series:

Adding resistors in series increases the total resistance.

$$R_{total} = R_1 + R_2 + R_3$$

Current remains constant, Voltage is divided.

Resistors in parallel: (Constant V, Changing I)

Adding resistors decreases the total resistance. (∴ so increases the current leaving the battery).

Total resistance < individual resistances being added.

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

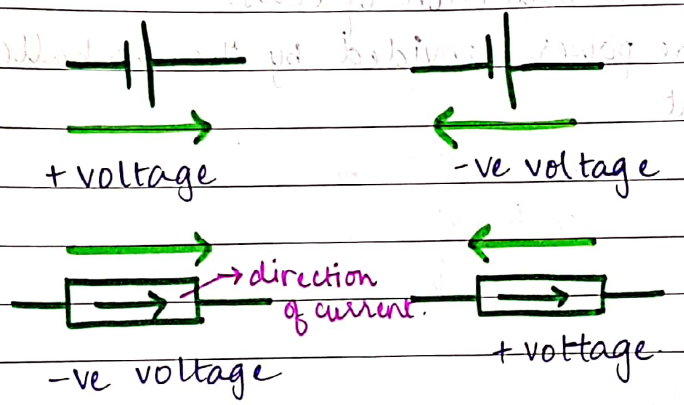
Kirchhoff's current law (Kirchhoff's 1st law):

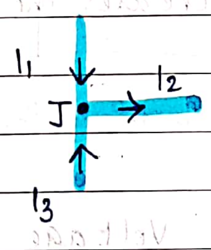
$$\sum I_{in} = \sum I_{out}$$

Kirchhoff's loop law (Kirchhoff's second law)

$$\sum V = 0$$

MULTILOOP CIRCUITS:





Currents at a junction J

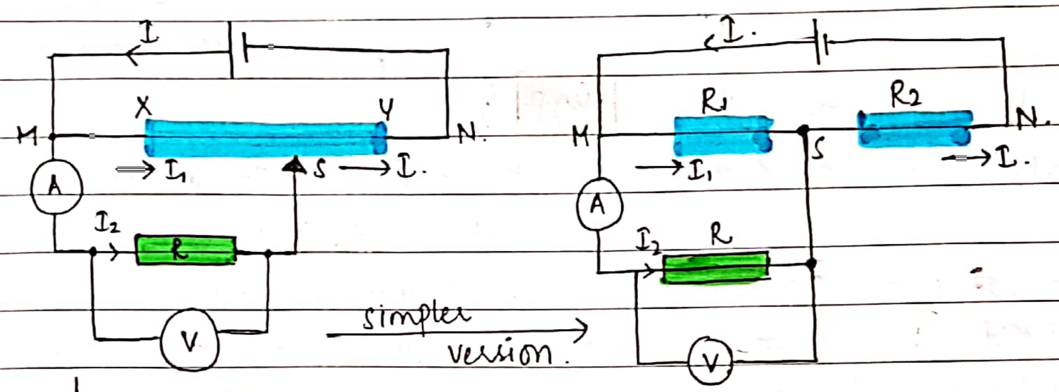
AMMETERS & VOLTMETERS → An ideal voltmeter has infinite resistance. It is connected in parallel to the device.

An ideal ~~ame~~ ammeter has zero resistance. It is connected in series to the resistor/device

Voltmeters & ammeters are based on a current sensor— galvanometer.

An ammeter has small resistance connected in parallel to the galvanometer

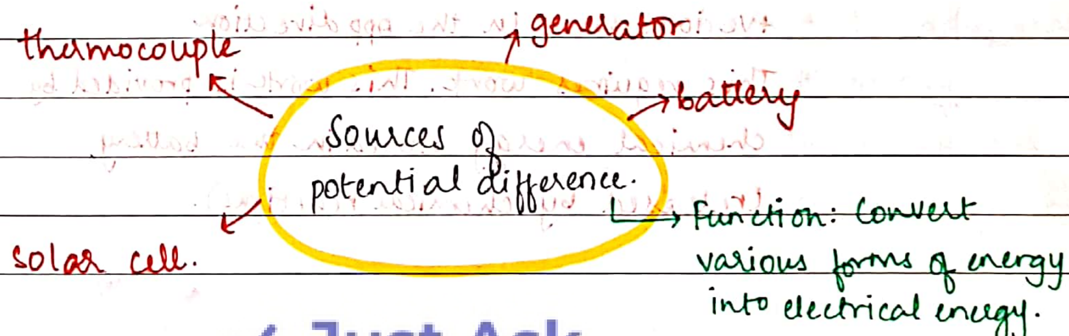
A voltmeter is a galvanometer connected to a large resistance in series.



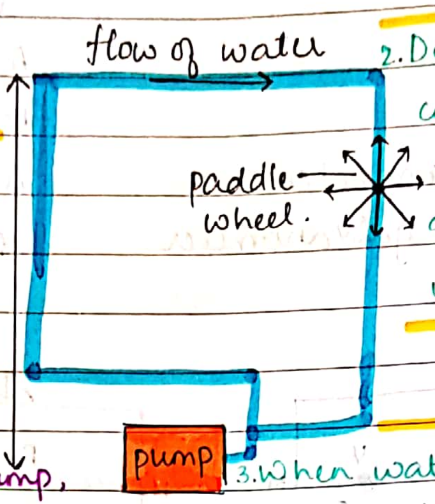
This circuit uses a potential divider. The voltage & current in the device with resistance R can be varied by varying the point where the slider S is attached to the variable resistor.

Advantage:
By placing S at Y, the maximum emf of the battery (at Y) can be known (assuming 0 internal resistance). In conventional arrangement, the voltage can only be varied up to some maximum value less than the emf.

5.3 ELECTRIC CELLS



Comparing battery to a Pump.



1. The pump raises the water & provides it (E_p) Gravitational Potential Energy.

2. Descending water converts the Ep to thermal energy (F_f) & mechanical work.

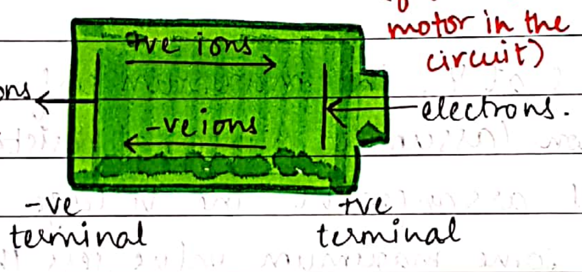
3. When water reaches the pump, the Ep has been exhausted. So the pump again performs work to raise the water.

- In absence of the pump, water flow would stop.

- Work done by pump = work done to overcome frictional forces + work done to operate the paddle wheel

Chemical energy of the battery $\xrightarrow[\text{to}]{\text{converted}}$ thermal energy (wires heat up) + mechanical work (if there's a motor in the circuit) + chemical energy (to charge another battery in the external circuit)

1. A battery will force electrons in the circuit.



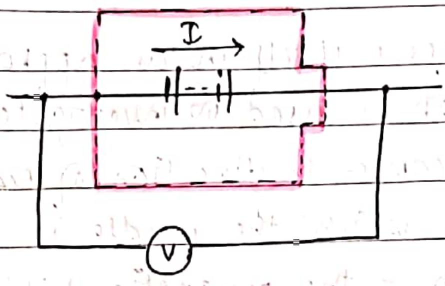
In the battery:

- -ve ions pushed ~~out~~ from -ve to +ve terminal
- +ve ions move in the opp direction
- This requires work. This work is provided by chemical energy stored in the battery (released by chemical reactions).

INTERNAL RESISTANCE & TERMINAL POTENTIAL DIFFERENCE

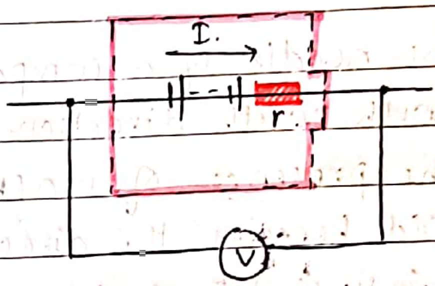
emf (ε) is the work done per unit charge in moving charge from 1 terminal of the battery to the other.

Ideal Battery



$V = \varepsilon$

Real Battery



$V = \varepsilon - Ir$

r → internal resistance (inside the battery, so, cannot be isolated).

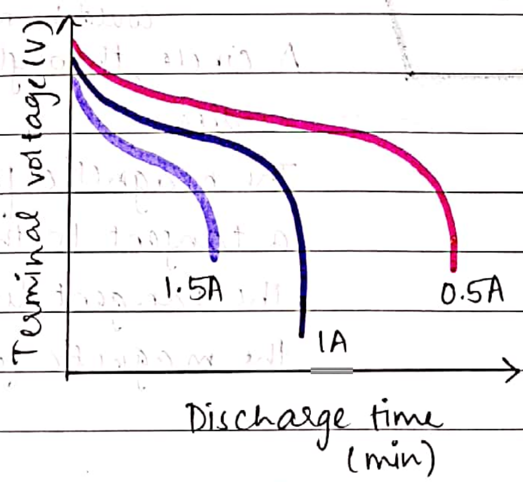
PRIMARY & SECONDARY CELLS:

Primary: ↳ can only be used once

Secondary: ↳ rechargable & can be used again.

DISCHARGING A CELL

Capacity is the amount of charge it can deliver to an external circuit in its lifetime.



The bigger the current, faster the cell discharges.

After an initial sudden drop, the terminal voltage remains almost constant until the capacity of the cell is exhausted. Then again there is a sudden drop.