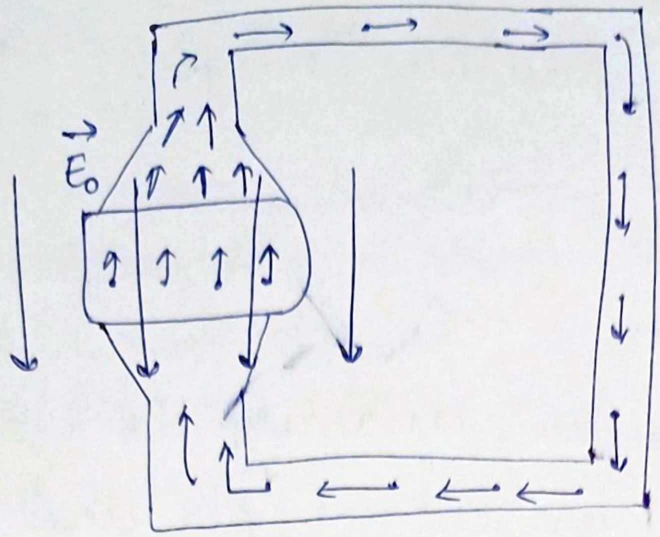
A conductor in an Electric field -



the electric field $\vec{E}_0$ moves electrons through the slab of copper. the electrons can be collected at the top of the slab and transported through an external path to the bottom of the copper slab.

let us examine the flow of electric charge past a particular point in the interior of the material.

A quantity of charge dq will pass through a small surface of area A in a time dt. the electric current i is defined as the net charge that flows through the surface per unit time interval:-

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

for electric current to exist there must be a net flow of charge across the surface. If electrons are traveling randomly through the material, with equal numbers crossing the surface in either direction, no current flows because the net charge crossing the surface is zero.

the electric current has a direction which is defined to be the direction of the flow of positive charge.

$$i = \frac{q}{t} \quad -(1)$$

$$q = \int i\, dt \quad -(2)$$

A related vector quantity is the current density $\vec{j}$ or current per unit area

$$\vec{j} = \frac{i}{A} \quad -(3)$$

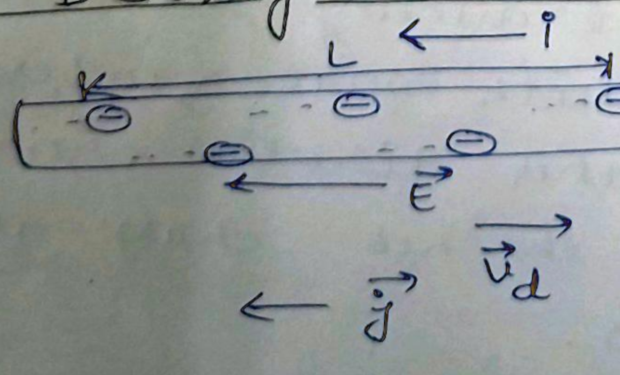
the current passing through any surface can be determined by integrating the current density over the surface,

$$i = \int \vec{j} \cdot d\vec{A} \quad -(4)$$

$d\vec{A}$ is the surface area element

the vector $d\vec{A}$ is taken to be perpendicular to the surface element such that $\vec{j} \cdot d\vec{A}$ is positive corresponding to a positive current i.

<u>Current Density and Drift speed</u> -



Consider the motion of electrons in a portion of the conductor of length L. the electrons are moving with drift speed u_d, so they travel the length L in a time $t = \frac{L}{u_d}$.

the conductor has a cross-sectional area A, so in time t all of the $\bar{e}$s in the volume AL will travel through a surface at the right end of the conductor. If the density of $\bar{e}$s is n, then the magnitude of the net charge passing through the surface is

$q = enAL$ and $j = \frac{q}{At} = \frac{enAL}{At}$

$$j = \frac{enAL}{AL/u_d} = enu_d.$$

in vector notation $\boxed{\vec{j} = -enu_d}$ — (5)

Here -ve sign represents that the direction of the current density is opposite to the motion of the electrons.

the $\bar{e}$s collide with the ions of the lattice and transfer energy to them. the motion of individual $\bar{e}$s is very irregular, consists of a short interval of acceleration in opposite direction of electric field followed by a collision with an ion. the net effect is a drift of electrons in a direction opposite to the field.

Ohmic Materials - the drift velocity v_d is proportional to $\vec{E}$. the current density $\vec{J}$ is also proportional to $\vec{v}_d$, so it is reasonable that $\vec{J}$ should be proportional to $\vec{E}$.

the proportionality constant b/w the current density and electric field is the electrical conductivity σ of the material:

$$\vec{J} = \sigma\vec{E} \quad — (6)$$

A large value of σ indicates that the material is a good conductor of electric current.

the SI unit for conductivity is siemens/metre (S/m) while the Siemens is defined

as $1 \text{ Siemens} = \dfrac{1 \text{ Ampere}}{\text{volt}}$

$$\rho = \frac{1}{\sigma} \quad — (7)$$

ρ resistivity — (8)

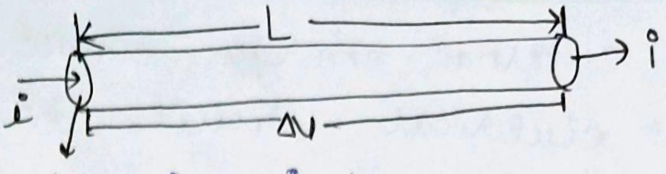
$$\vec{E} = \rho\vec{J}$$

Unit of ρ is ohm × metre

1 ohm = 1 volt / ampere

the resistivity (or conductivity) of a material is independent of the magnitude and direction of the applied electric field.

Resistance



Here we are considering a block of copper of certain A dimensions. this is a homogeneous, isotropic conductor of length L and uniform cross-sectional area A to which we have applied a potential difference ΔV. Inside the object there is a uniform electric field $E = \frac{\Delta V}{L}$. If the current density is also uniform over the area A then $j = \frac{i}{A}$. the resistivity is.

$$\rho = \frac{E}{j} = \frac{\Delta V / L}{i / A}$$

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

$$\boxed{R = \rho \frac{L}{A}} \quad \text{—} (1)$$

the resistance R is characteristic of a particular object and depends on the material of which it is made as well as on its length and cross-sectional area.

the resistance of an object is independent of the magnitude or sign of the applied potential difference.

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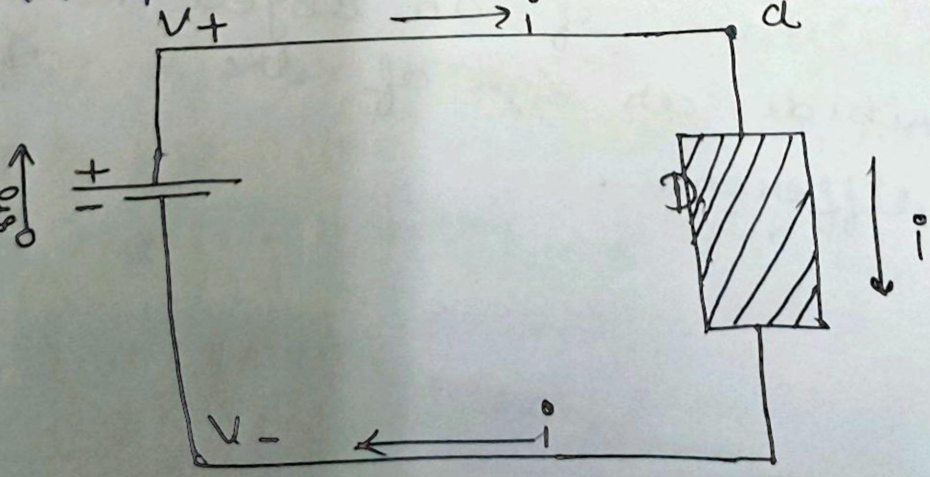
Electromotive force →

An external energy source is required by most electrical circuits to move charge through the circuit. the circuit therefore must include a device that maintains a potential difference b/w two points in the circuit, just as a circulating fluid requires an analogous device which maintains a pressure difference b/w two points.

Any device that performs this task in an electrical circuit is called a source of electromotive force (emf). It is sometimes useful to consider a source of emf as a mechanism that creates a hill of potential and moves charge uphill from which the charge flows "downhill" through the rest of circuit.

A common source of emf is the ordinary battery, another is the electric generator found in power plants.



In figure a source of emf connected to an electronic device, which might be a resistor, capacitor or other circuit element. the emf is represented in the circuit by an arrow (small circle on the tail of the emf arrow) that is placed next to the source and points in the direction in which the emf, acting alone would cause a positive charge carrier to move in the external circuit. the source of emf sets up a clockwise current in the circuit.

When a steady current has been established in the circuit. A charge dq passes through any cross section of the circuit in time dt. In particular, this charge enters the source of emf ξ at its low - potential end and leaves at its high- potential end. the source must do an amount of work dW on the (positive) charge carriers to force them to go to the point of higher potential. the emf ξ of the source is defined as the work per unit charge.

$$\xi = \frac{dW}{dq}$$

the unit of emf is joule / coulomb which is same as the volt.

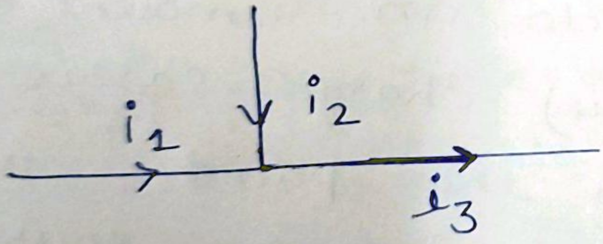
Note - the electromotive force is not actually a force.

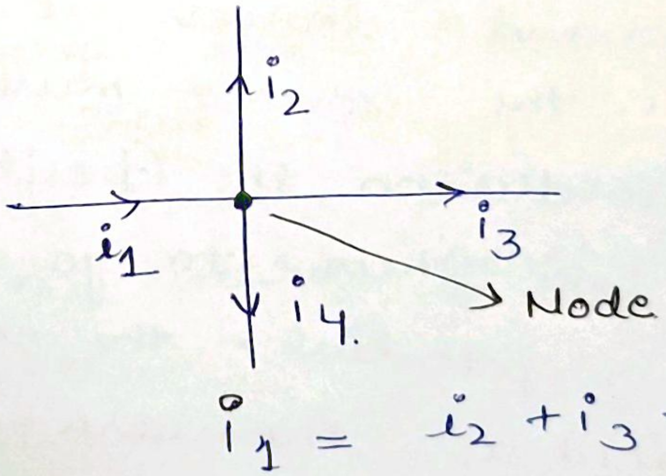
Kirchhoff's law -

Kirchhoff's law of current

Kirchhoff's law of voltage

Kirchhoff's law of current is also known as Kirchhoff's junction rule which state that the algebraic sum of currents in a network of conductors meeting at a point is zero. this law can be restated that the sum of currents entering a junction equals the sum of currents leaving that junction.



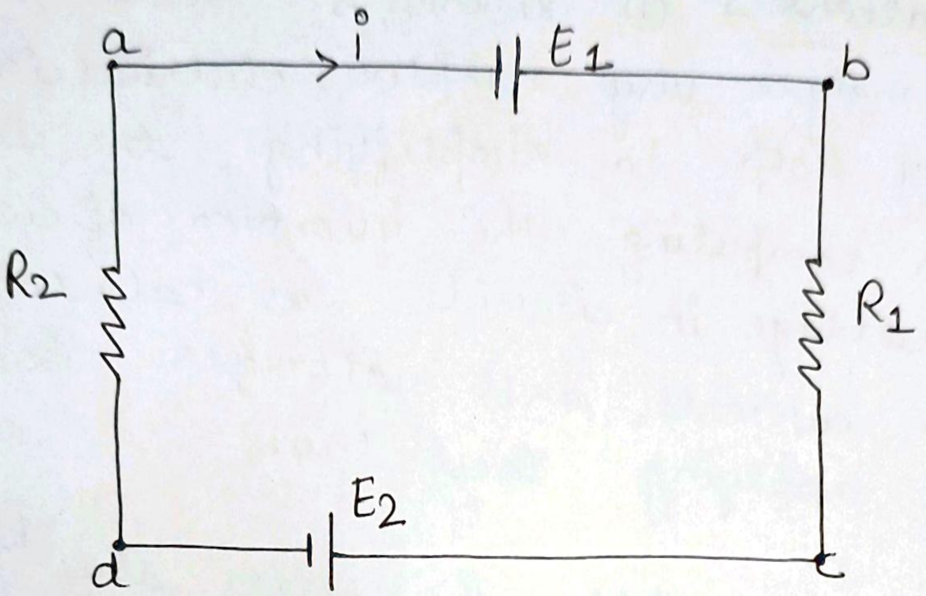


$i_1 + i_2 = i_3$

$i_1 = i_2 + i_3 + i_4$

Kirchhoff's voltage law - this is Kirchhoff's loop rule which states that the sum of electromotive forces in a loop equals the sum of potential drops in the loop.

It could be stated that the directed sum of voltages around any closed loop is zero. the sum of potentials difference across all components in a closed loop is zero.



$$\left.\begin{aligned} V_b - V_a &= E_1 \\ V_c - V_d &= -E_2 \end{aligned}\right] \text{--(1)}$$

from ohm's law.

$$\left.\begin{aligned} V_b - V_c &= iR_1 \\ V_d - V_a &= iR_2 \end{aligned}\right] \text{--(2)}$$

Now loop equations (2) becomes.

$V_b = iR_1 + V_c \qquad V_a = V_d + iR_2$

$iR_1 + V_c - V_d + iR_2 = E_1$

$V_c - V_d = E_1 - iR_1 - iR_2$

$-E_2 = E_1 - iR_1 - iR_2$

$iR_1 + iR_2 = E_1 + E_2$.

or $E_1 - E_2 - iR_1 - iR_2$

If $E_2 > E_1$ solution for current i is zero.
(current flows in opposite direction)

It's Applications → ① Kirchoff's laws are used to analyze very complex electrical circuits as they help in simplifying the circuits and in computing the quantum of current and voltage in circuits as calculating unknown currents and voltages become easy by applying these laws.

② when we apply Kirchhoff's law of current we consider the current leaving a junction to be positive and the currents entering the junction to be negative in sign.

③ when we apply Kirchhoff's law of voltage we maintain the same clockwise or anti-clockwise direction from the point we started in the loop and account for all voltage drops as negative and rises as positive. this leads that to the point while the final sum is zero.