# PHY-112
# Principles of Physics-II

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# Define Electric Current

An **electron current** is a net motion of electrons (in a conductor) sustained by an internally established electric field.
An **electric current** is the net (positive) charge flowing per unit time, through a cross-section of a conducting wire.

Defining Electric Current in terms of Charge flowing, Drift Velocity:

$$I = q_e i_e = \frac{\Delta Q}{\Delta t}$$
$$I = q_e i_e = n_e q_e A v_d$$

Suppose an electron just had a collision with an ion and has rebounded with velocity $\vec{v}_0$. The acceleration of the electron between collisions is

$$a_x = \frac{F_E}{q_e} = \frac{m_e E}{q_e}$$

$E$ causes the $x$-component of the electron's velocity to increase linearly with time:

$$v_x = v_{0x} + a_x \Delta t = v_{0x} + \left(\frac{q_e E}{m_e}\right) \Delta t$$

The electron speeds up, with increasing $K$, until its next collision with an ion.

The average speed at which the electrons are pushed along by the electric field is

$$v_d = \bar{v}_x = \left(\frac{q_e \tau}{m_e}\right) E,$$

where $\tau$ is the average value of $\Delta t$ is the mean time between two successive collisions.

The average speed at which the electrons are pushed along by the electric field is

$$i_e = n_e \left( \frac{q_e \tau A}{m_e} \right) E,$$

where $\tau$ is the average value of $\Delta t$ is the mean time between two successive collisions.
**The electron current is directly proportional to the electric field strength**.

The electron current in a wire of cross-section area $A$ to be

$$I = q_e i_e = (n_e q_e v_d) A$$

Define Electric Current Density:

$$J = \frac{I}{A} = n_e q_e v_d$$

measured in $\mathrm{A\,m^{-2}}$.
Current Density is a **vector**. It points in the direction the charge carriers feel a net drift motion due to the applied $\vec{E}$.

$$I = \int \vec{J} \cdot \vec{A} = JA$$

# Testing Concepts (1)

Q: A $1.0$ A current passes through a $1.0$ mm-diameter copper wire. What are the current density and the drift speed of the electrons in the wire? The electron density for copper as $8.5 \times 10^{28}$ m$^{-3}$.

Relating Current Density with Electric Field Intensity

$$J = \left(\frac{n_e q_e^2 \tau}{m_e}\right) E$$

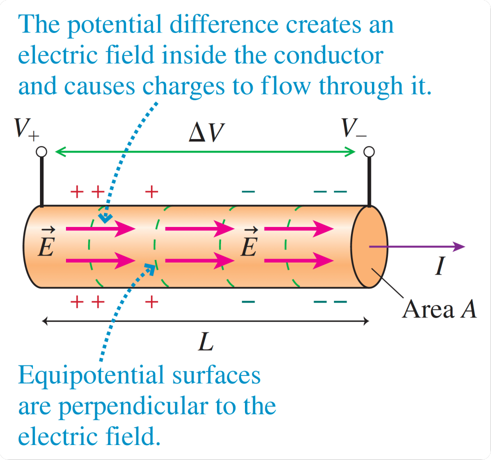
$$J = \sigma E$$

$$E = \rho J; \quad \therefore \sigma = \frac{1}{\rho}$$

$\sigma = \dfrac{n_e q_e^2 \tau}{m_e}$ is conductivity; measured in $\Omega^{-1}\,\mathrm{m}^{-1}$,

$\rho = \dfrac{m_e}{n_e q_e^2 \tau}$ is resistivity; measured in $\Omega\,\mathrm{m}$.

# What is Resistance?

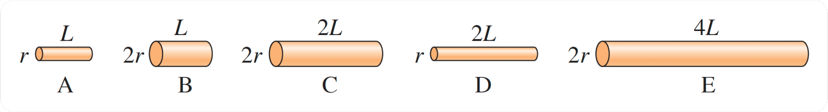


$$\text{Ohm's Law in 3D, } E = \frac{\Delta V}{L} = \rho\frac{I}{A} \quad \Rightarrow \Delta V = \left(\frac{\rho L}{A}\right) I$$

$$\text{with Resistance, } \quad R = \frac{\rho L}{A}; \ \text{ measured in } \Omega$$

$$\text{Ohm's Law (Experimental Form) } I = \frac{\Delta V}{R}$$

Q: The wires are all made of the same material. Rank in order, from largest to smallest, the resistances $R_A$ to $R_E$ of these wires. Explain.



# What does Ohm's Law Say about Circuits?

- Current is caused by an electric field exerting forces on the charge carriers
- The current density, and hence the current $I = JA$, depends linearly on the strength of the electric field. To double the current, you must double the strength of the electric field that pushes the charges along
- The current density also depends on the ***conductivity*** of the material. Different conducting materials have different $\sigma$ because they have different values of the electron density $n_e$ and, especially, different values of the mean time $\tau$ between electron collisions with the lattice of atoms.

# Testing Concepts (3)

Q: A $2.0$ mm-diameter Aluminum wire carries a current of $800$ mA. The conductivity of the Aluminum wire is $3.5 \times 10^7 \Omega^{-1}$ m$^{-1}$.

- What is the electric field strength inside the wire?
- What is the resistivity of the wire?
- Find the resistance of $1$m section of that same wire.

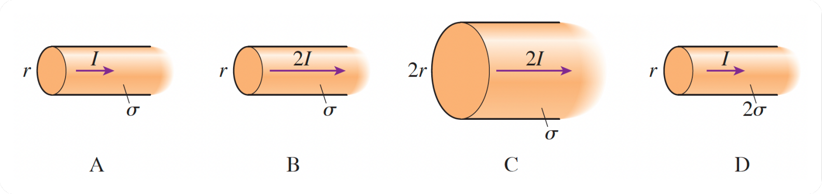
# Testing Concepts (4)

Q: A $15$ cm-long Nichrome wire is connected across the terminals of a $1.5$ V battery. The conductivity of the Nichrome wire is $6.7 \times 10^5 \Omega^{-1}$ m$^{-1}$.

- What is the electric field inside the wire?
- What is the current density inside the wire?
- If the current in the wire is $2.0$ A, what is the wire's diameter?

# Testing Concepts (5)

Q: Rank in order, from largest to smallest, the current densities $J_A$ to $J_D$ in these four wires.



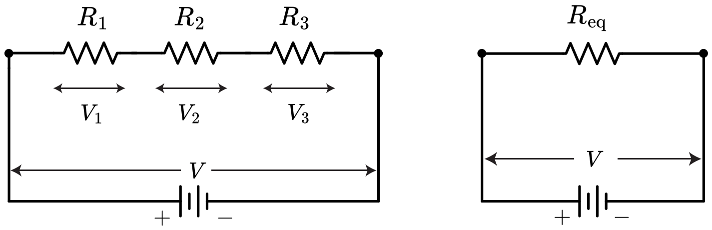
# Next Stop: Kirchhoff's Rules and Circuit Analysis

To analyze a circuit means to find:

- The potential difference across each circuit component.
- The current in each circuit component.

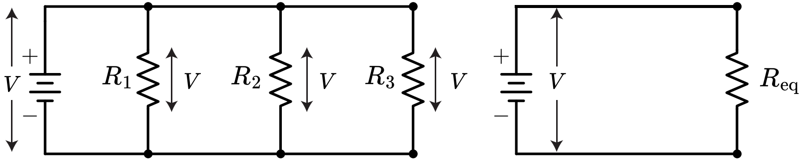
Resistors in Series and Parallel connection in a circuit. Follow the same procedure adopted in Capacitor connection from **Class-13**.

The voltage across each resistor is not the same. The total voltage across the series combination equals the sum of the voltages across each resistor.




$$R_{eq} = R_1 + R_2 + R_3 = \sum_i^n R_i$$

The voltage across each resistor is the same. The total current through the parallel combination is the sum of the currents through each individual resistor.




$$\frac{1}{R_{\text{eq}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \sum_{i}^{n} \frac{1}{R_i}$$