Module 12: Current, Current Density, Resistance and Ohm's Law

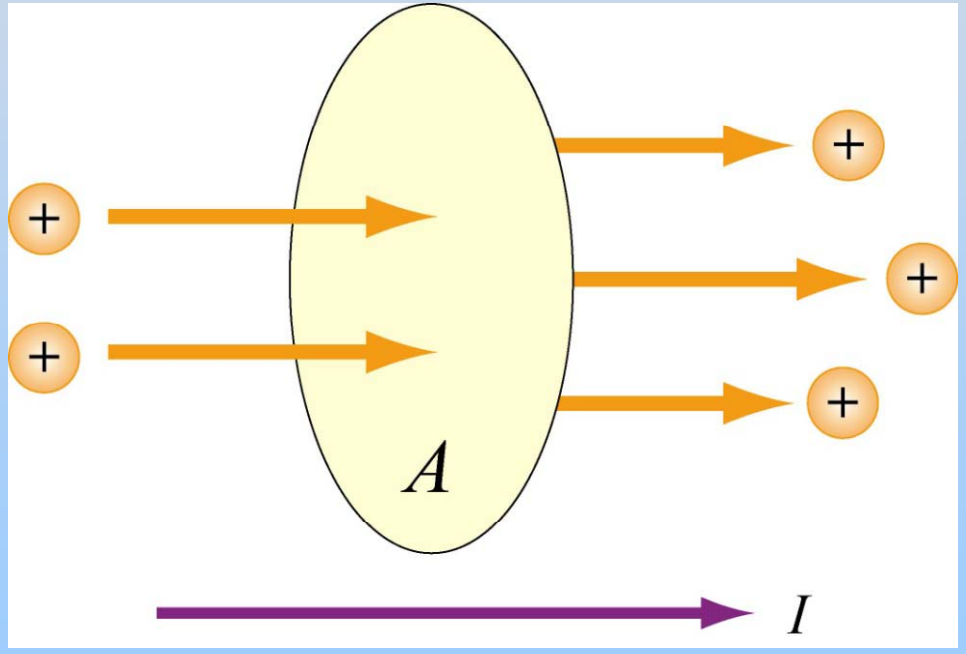
Current: Flow Of Charge

Average current I_{av}: Charge ΔQ flowing across area A in time Δt

$$I_{av} = \frac{\Delta Q}{\Delta t}$$

Instantaneous current: differential limit of I_{av}

$$I = \frac{dQ}{dt}$$



Units of Current: Coulomb/second = Ampere

How Big is an Ampere?

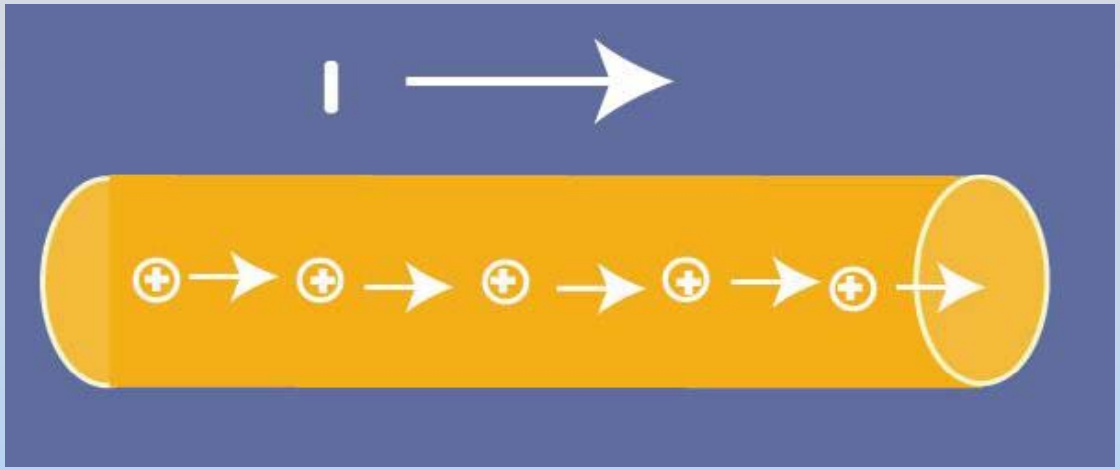
- Household Electronics ~1 A
- Battery Powered ~100 mA (1-10 A-Hr)
- Household Service 100 A
- Lightning Bolt 10 to 100 kA

- To hurt you 40 (5) mA DC(AC)
- To throw you 60 (15) mA DC(AC)
- To kill you 0.5 (0.1) A DC(AC)

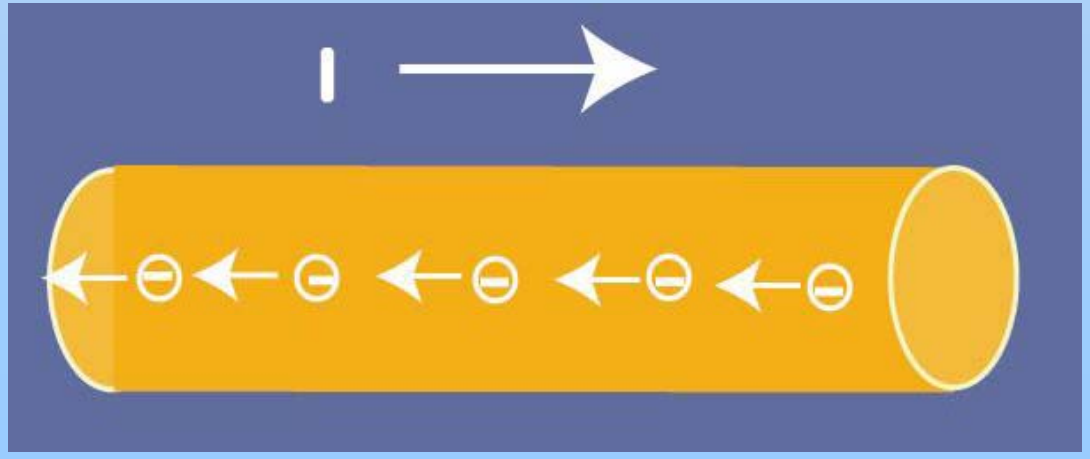
- Fuse/Circuit Breaker 15-30 A

Direction of The Current

Direction of current is direction of flow of pos. charge



or, opposite direction of flow of negative charge

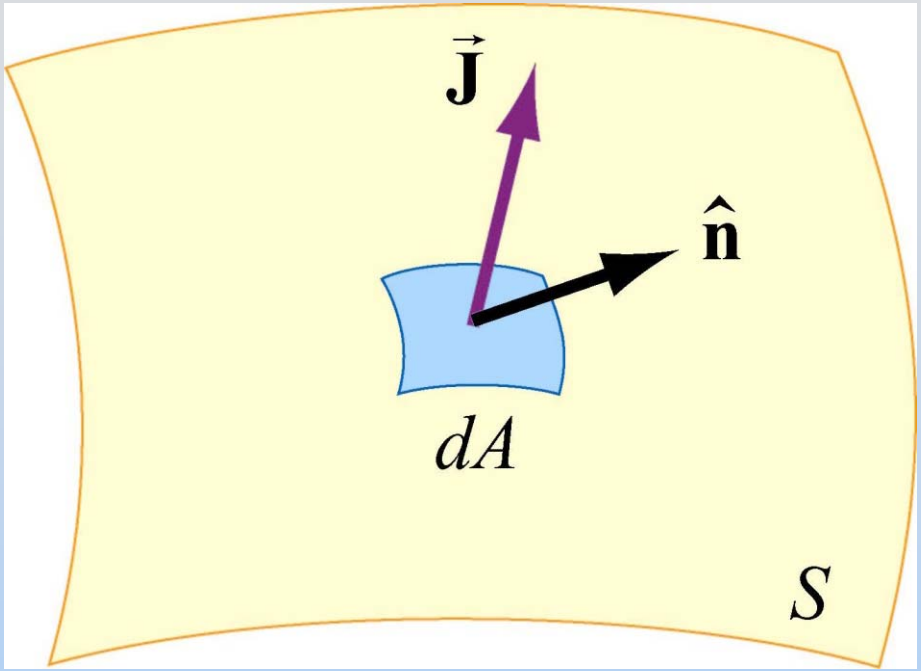


Current Density J

J: current/unit area

$$\vec{\mathbf{J}} \equiv \frac{I}{A}\hat{\mathbf{I}}$$

$\hat{\mathbf{I}}$ points in direction of current

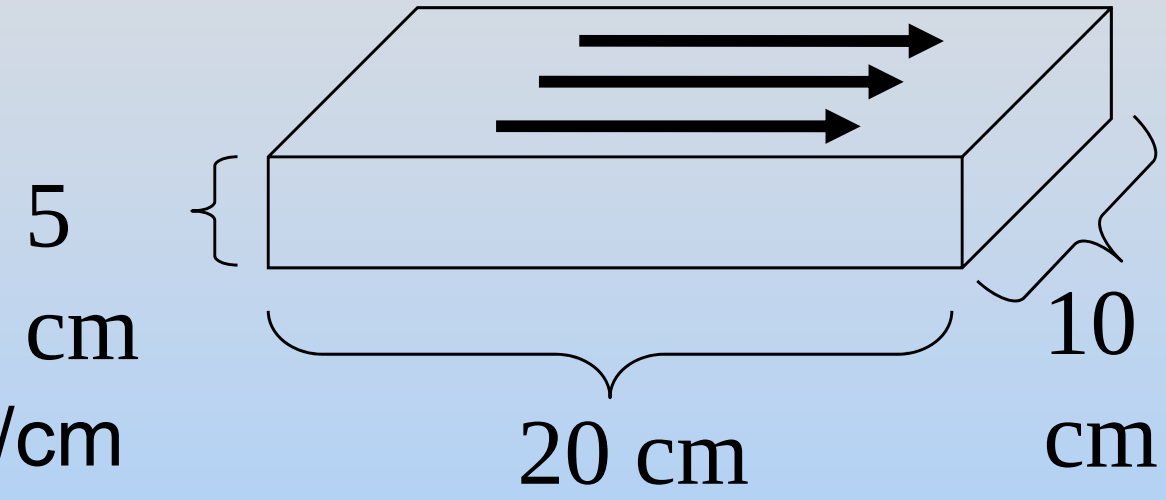


$$I = \int_S \vec{\mathbf{J}} \cdot \hat{\mathbf{n}}\, dA = \int_S \vec{\mathbf{J}} \cdot d\vec{\mathbf{A}}$$

Concept Question Question: Current Density

Concept Question: Current Density

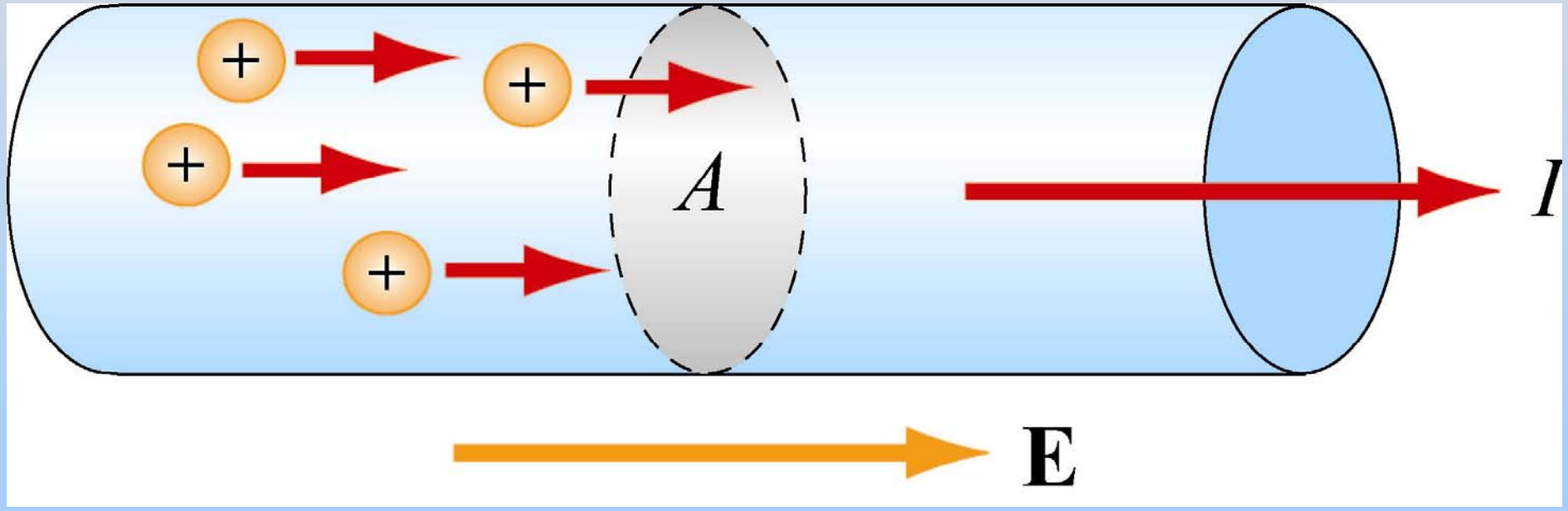
A current *I* = 200 mA flows in the above wire. What is the magnitude of the current density J?



1. J = 40 mA/cm
2. J = 20 mA/cm
3. J = 10 mA/cm
4. J = 1 mA/cm^2
5. J = 2 mA/cm^2
6. J = 4 mA/cm^2
7. I don't know

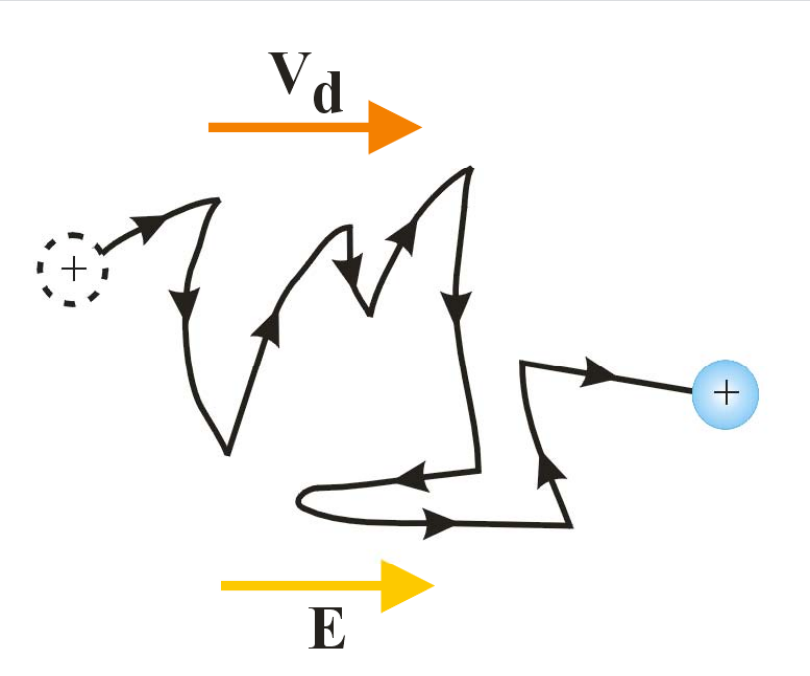
Why Does Current Flow?

If an electric field is set up in a conductor, charge will move (making a current in direction of E)



Note that when current is flowing, the conductor is not an equipotential surface (and $E_{inside} \neq 0$)!

Microscopic Picture



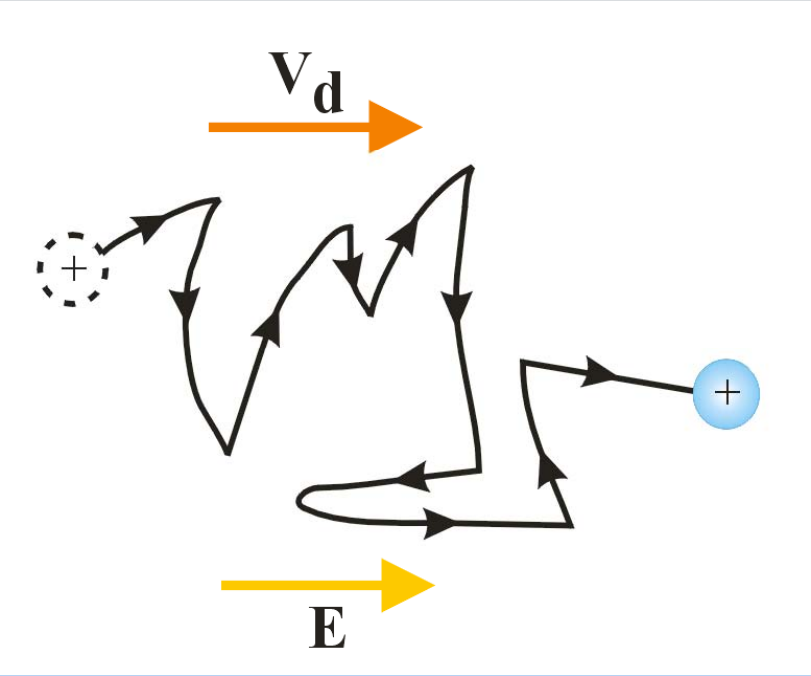
Drift speed is velocity forced by applied electric field in the presence of collisions.

It is typically 4×10^{-5} m/sec, or 0.04 mm/second!

To go one meter at this speed takes about 10 hours!

How Can This Be?

Conductivity and Resistivity



Ability of current to flow depends on density of charges & rate of scattering

Two quantities summarize this:

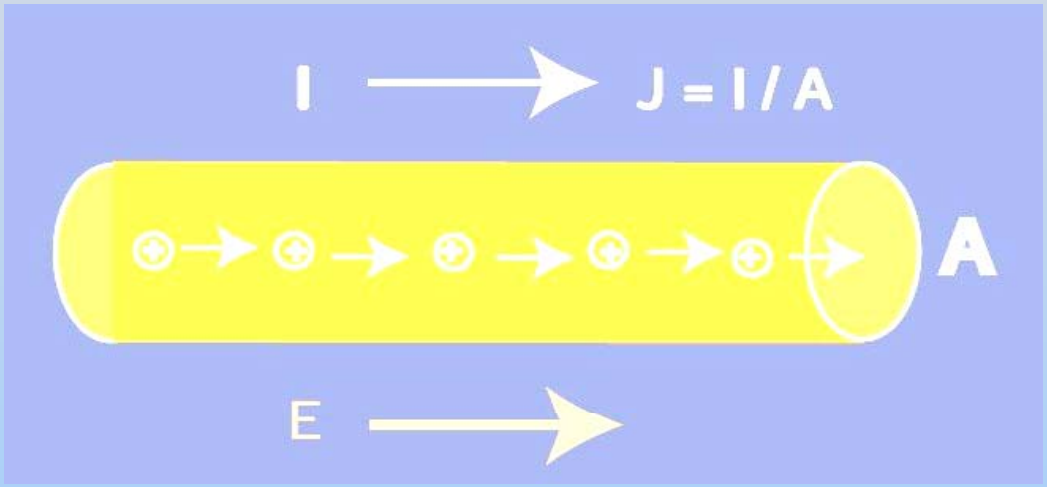
σ: conductivity

ρ: resistivity

Microscopic Ohm's Law

$$\vec{\mathbf{E}} = \rho \vec{\mathbf{J}} \quad \text{or} \quad \vec{\mathbf{J}} = \sigma \vec{\mathbf{E}}$$

$$\rho \equiv \frac{1}{c}$$



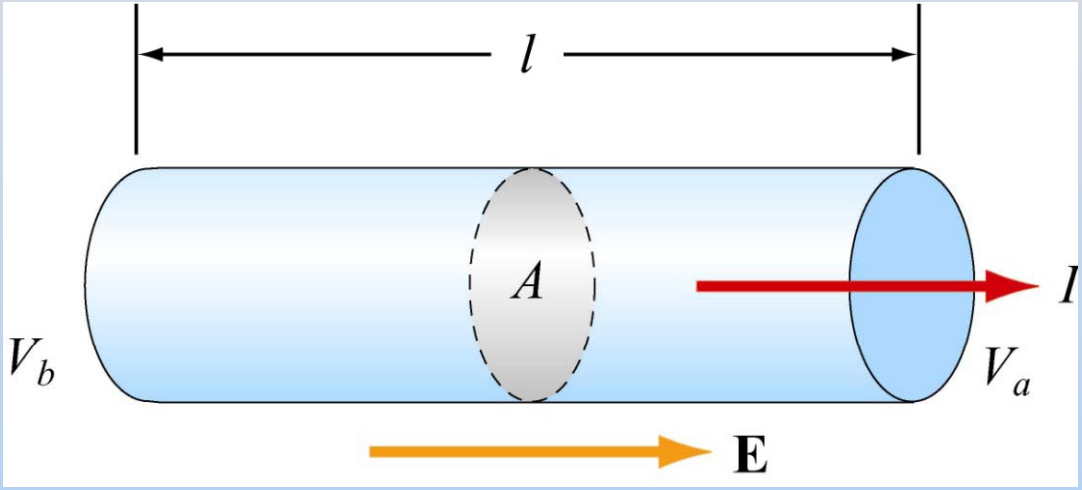
ρ and c depend only on the microscopic properties of the material, not on its shape

Demonstrations:
Water
Temperature Effects on ρ

Concept Question Question: Resistance?

Concept Question: Resistance

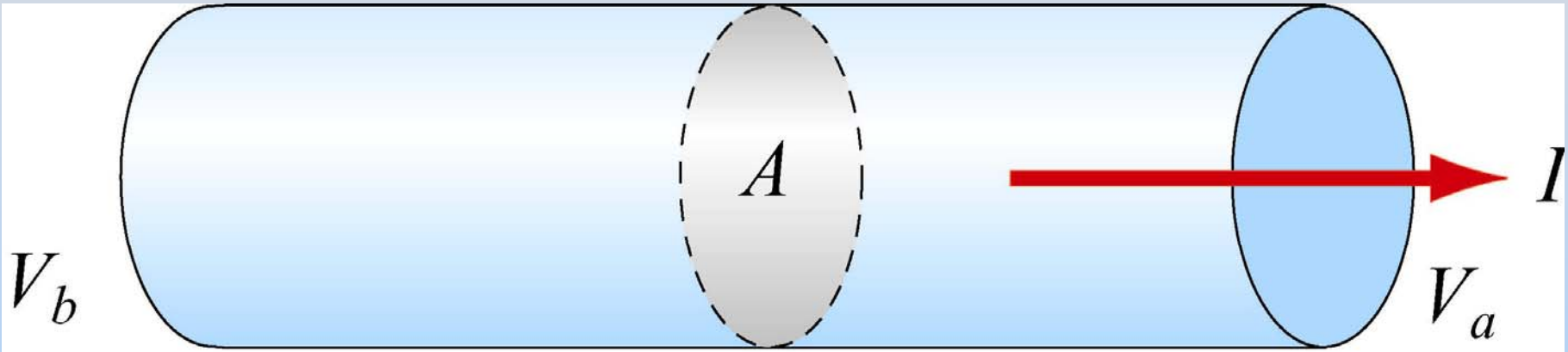
When a current flows in a wire of length *L* and cross sectional area *A*, the resistance of the wire is



1. Proportional to *A*; inversely proportional to *L*.
2. Proportional to both *A* and *L*.
3. Proportional to *L*; inversely proportional to *A*.
4. Inversely proportional to both *L* and *A*
5. Do Not Know

Why Does Current Flow?

Instead of thinking of Electric Field, think of potential difference across the conductor

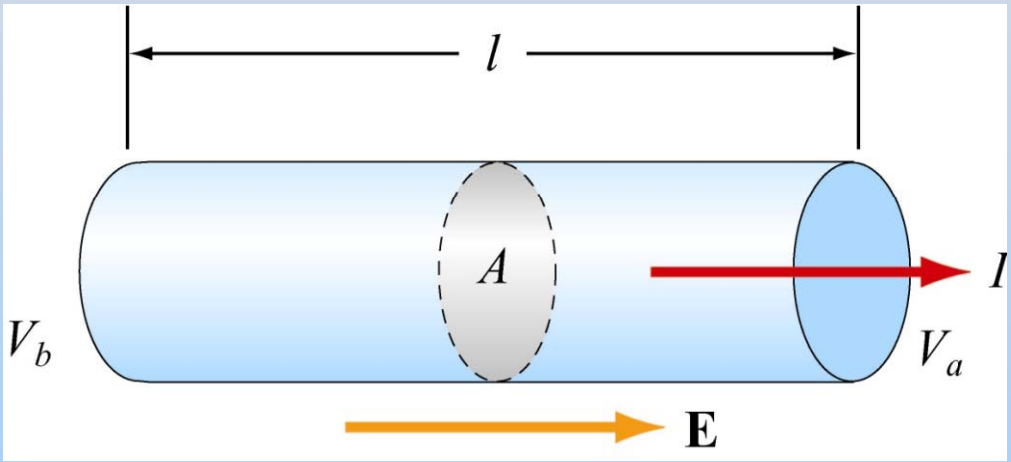


$$\Delta V = V_b - V_a$$

Ohm's Law

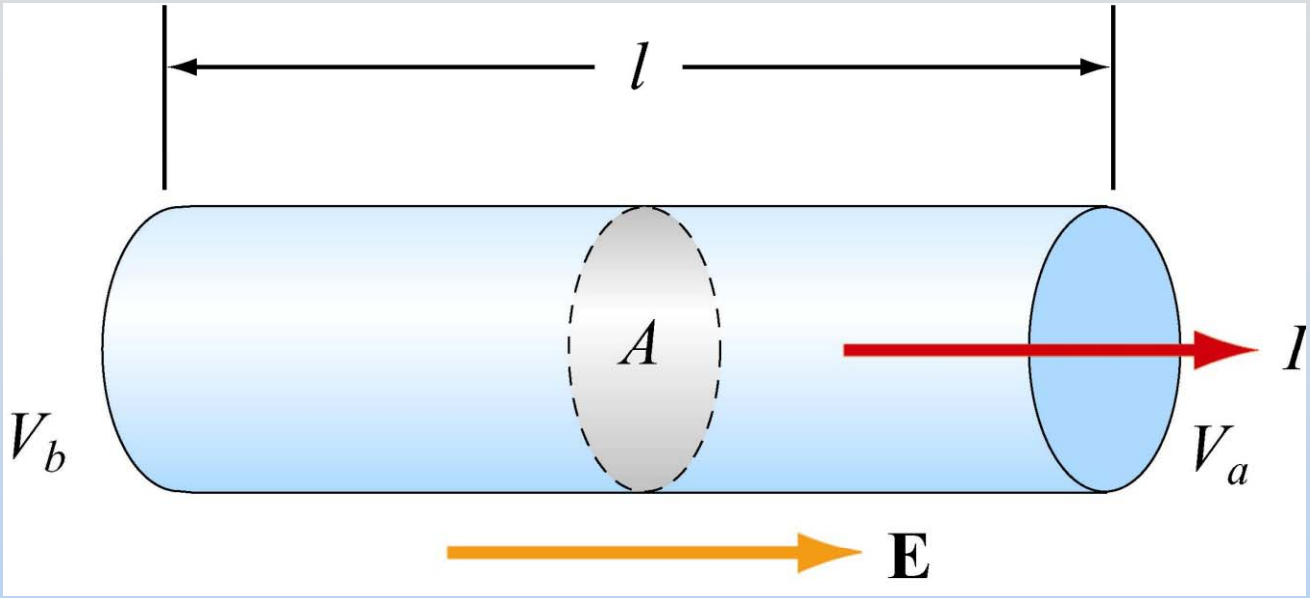
What is relationship between ΔV and current?

$$\Delta V = V_b - V_a = -\int_a^b \mathbf{E} \cdot d\mathbf{s} = El$$



$$\left.\begin{aligned} J &= \frac{E}{\rho} = \frac{\Delta V / l}{\rho} \\ J &= \frac{I}{A} \end{aligned}\right\} \Rightarrow \Delta V = I\left(\frac{\rho l}{A}\right) \equiv IR$$

Ohm's Law



$$\Delta V = IR$$

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

R has units of Ohms (Ω) = Volts/Amp

How Big is an Ohm?

- Short Copper Wire milliohms (mΩ)
- Notebook paper (thru) ~1 GΩ
- Typical resistors Ω to 100 MΩ

- You (when dry) 100 kΩ
- You (when wet) 1 kΩ
- Internally (hand to foot) 500 Ω

Stick your wet fingers in an electrical socket:

$I = V / R : \ 120\,\mathrm{V} / 1\mathrm{k}½ : \ 0.1\mathrm{A}$ You're dead!

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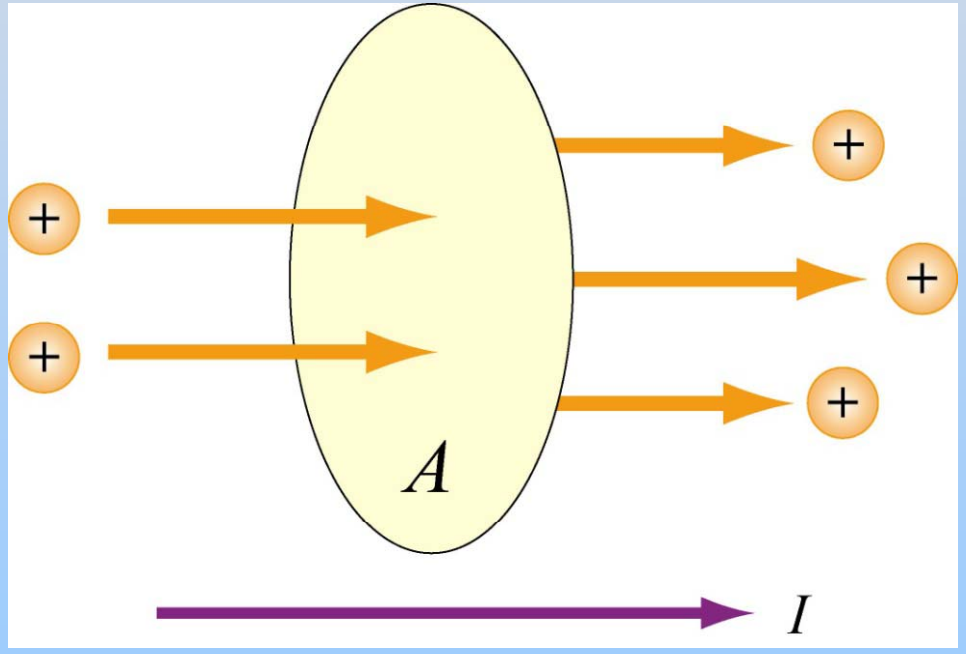

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8.02SC Physics II: Electricity and Magnetism

Fall 2010