Electricity and Magnetism

- Physics 259 – L02
- Lecture 32

Chapter 26

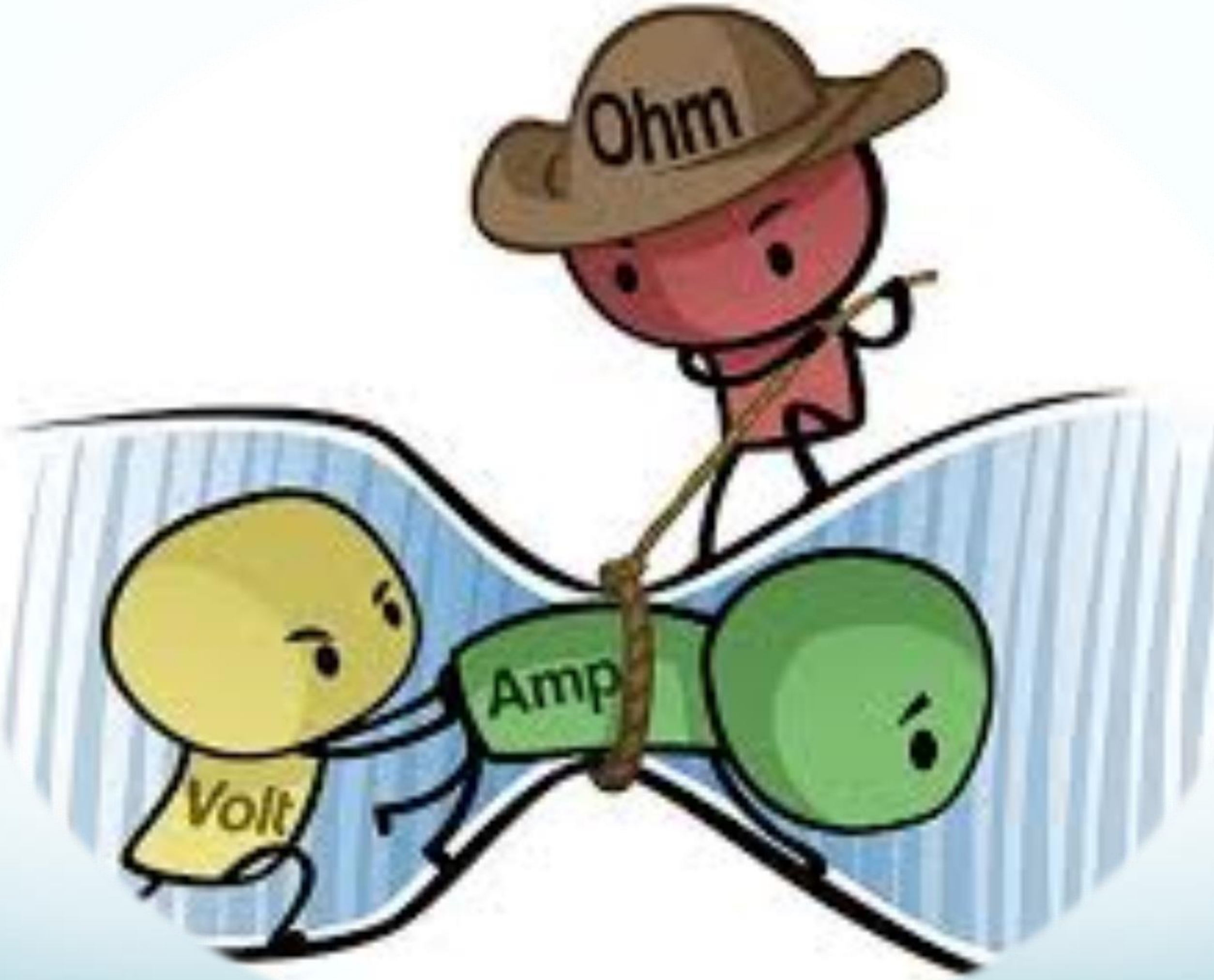
Last time

- Chapter 25- Capacitance

This time

- Chapters 26 and 27

26-1 Electric Current



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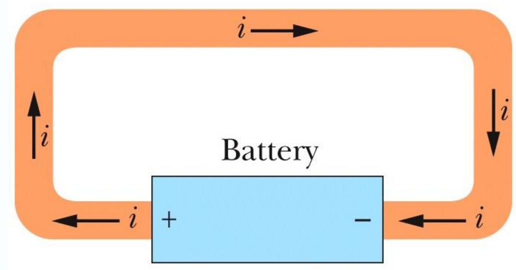
Where we're going?

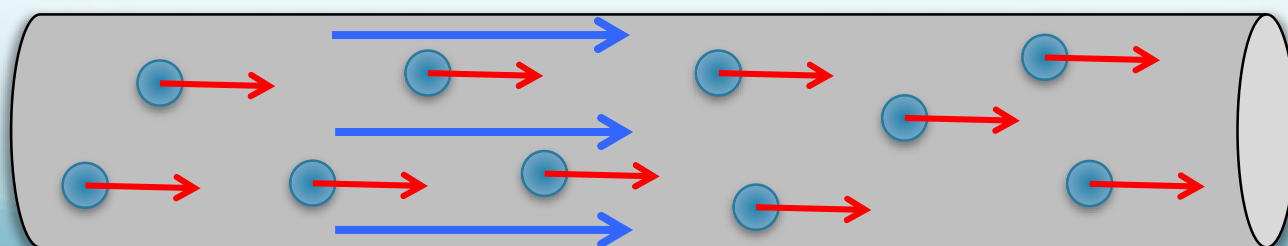


(b)

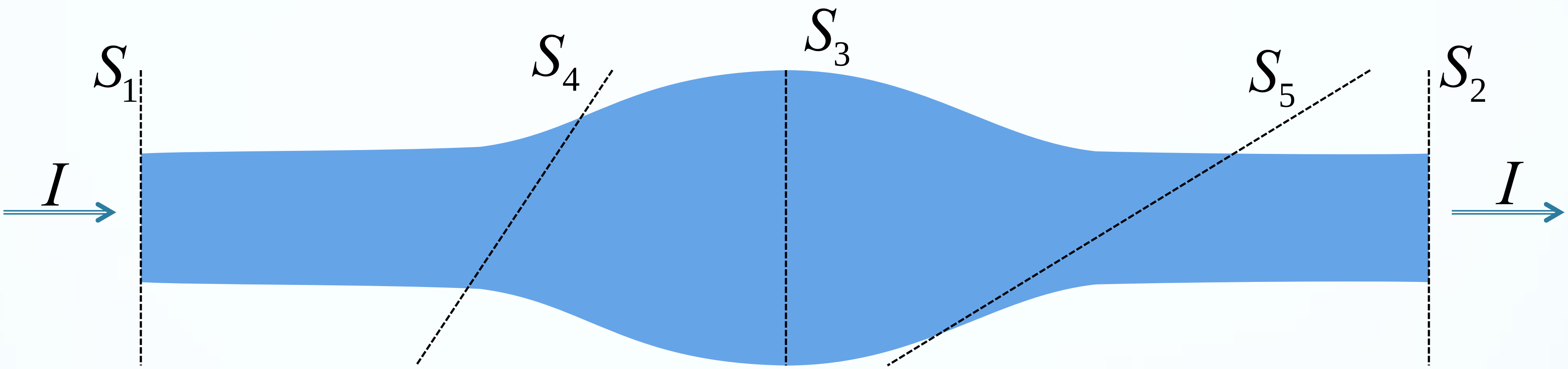
Moving charges in electric circuits → no electrostatic equilibrium→

conductors are allowed to have non-zero electric field inside

(this is what causes the charges to move).



Definition of current



Total amount of charge flowing past this surface in a time Δt

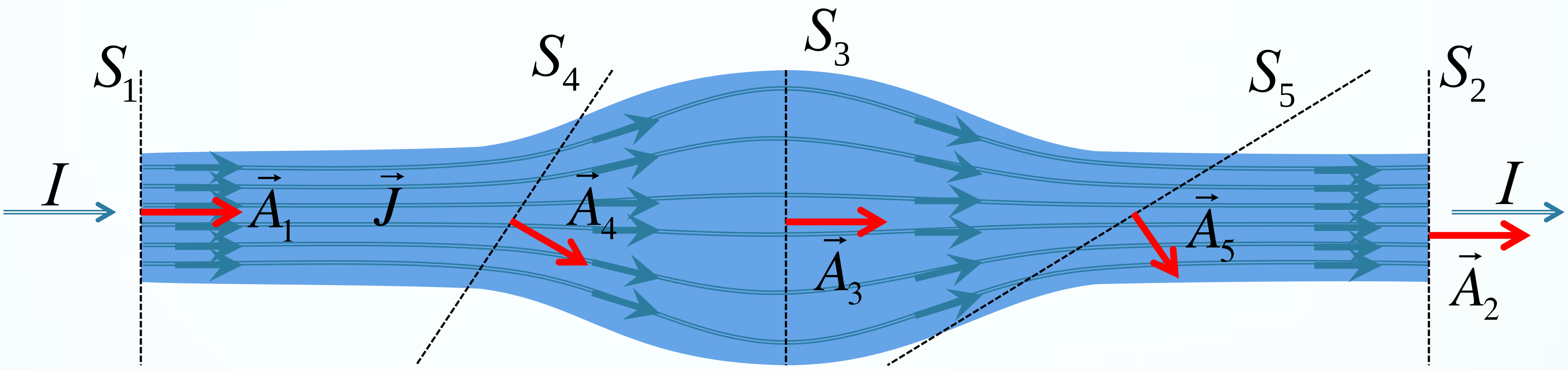
Total amount of charge flowing past this surface in the same time Δt

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

Total amount of charge flowing through **ANY** surface in a time Δt must be constant, otherwise charges would begin to accumulate.

Current in a wire is constant.

26-2 Current Density

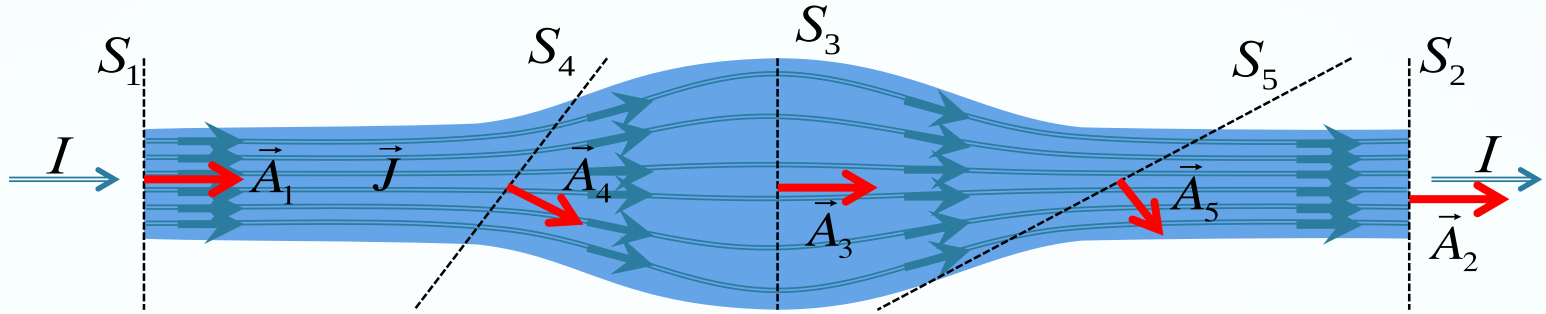


The current in a wire is the flux of charge carriers (i.e. electrons) through a surface.

$$I = \oint_S \vec{J} \cdot d\vec{A}$$

$\vec{J}$ → current density

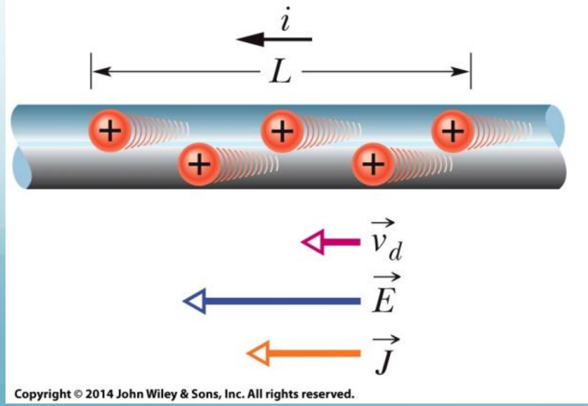
The current I is then interpreted as the number of charges passing through a surface in a specified direction.



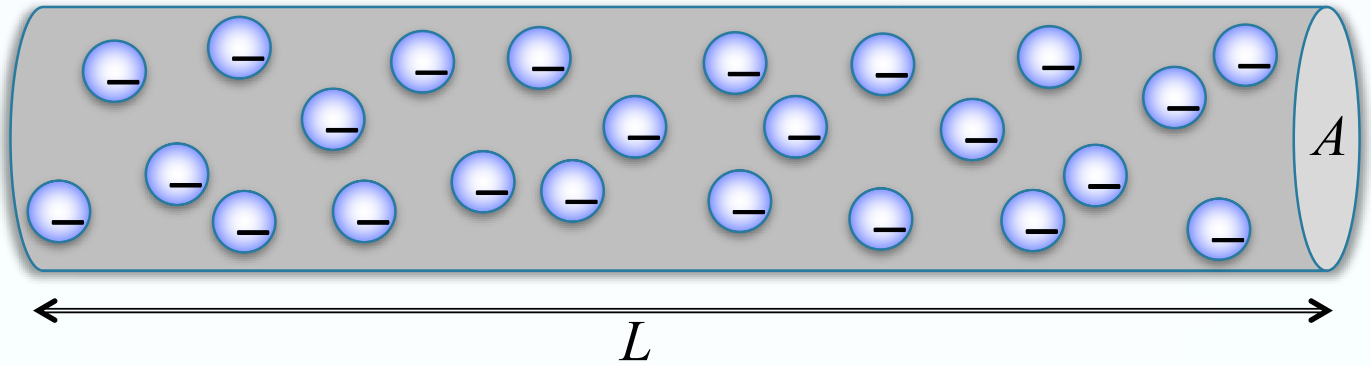
$\vec{J}$ encodes information about:

- The density of conduction electrons in the conductor
- The net velocity of these conduction electrons

Current density *J* → same direction as the velocity of the positive moving charges and opposite direction if the moving charges are negative.



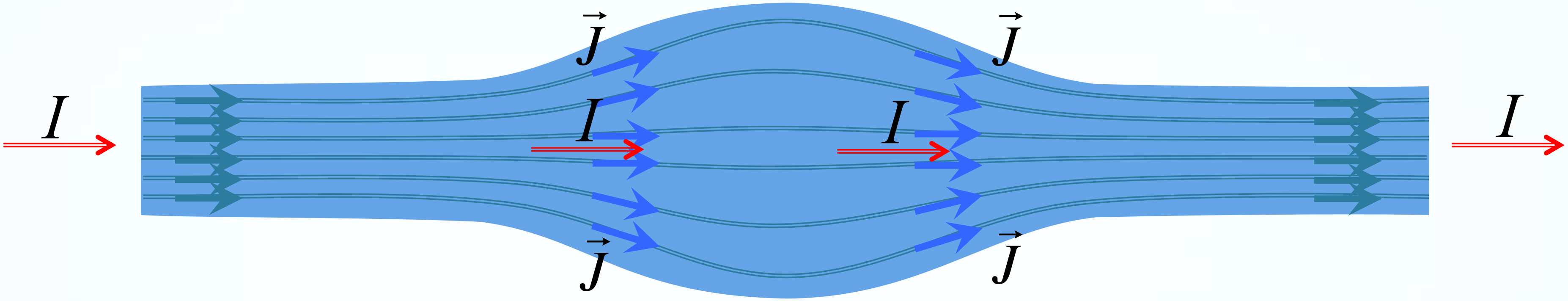
Conduction electrons are actually moving to the right but the conventional current *i* is said to move to the left.



Current → $i = \dfrac{q}{t} = JA$

- ✓ volume density of conduction electrons → n_e
- ✓ Amount of charge contained in a length L of the wire → $q = n(AL)e$
- ✓ Time it takes each charge to travel a distance L → $t = L/v_d$

Current → $\boxed{i = \dfrac{q}{t} = \dfrac{n(AL)e}{L/v_d} = nAev_d}$ → $\boxed{\vec{J} = ne\vec{v}_d}$



$\vec{J}$ **is a vector**→ is always in the direction of the "streamlines" of the electrons at any given location in the wire.

I **is a scalar**→ just has a magnitude.

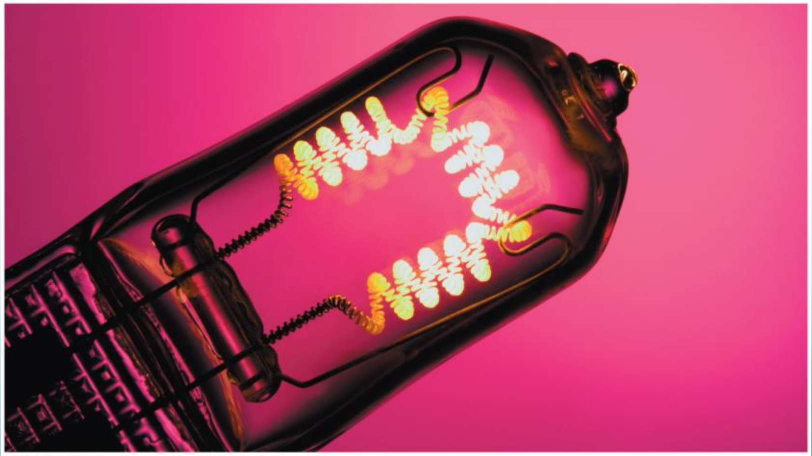
Direction→ is the average displacement of all the charges in the wire, and so always points along the general direction of the wire.

26-3 Resistance and Resistivity

Resistance is a property of conductors that are not ideal:

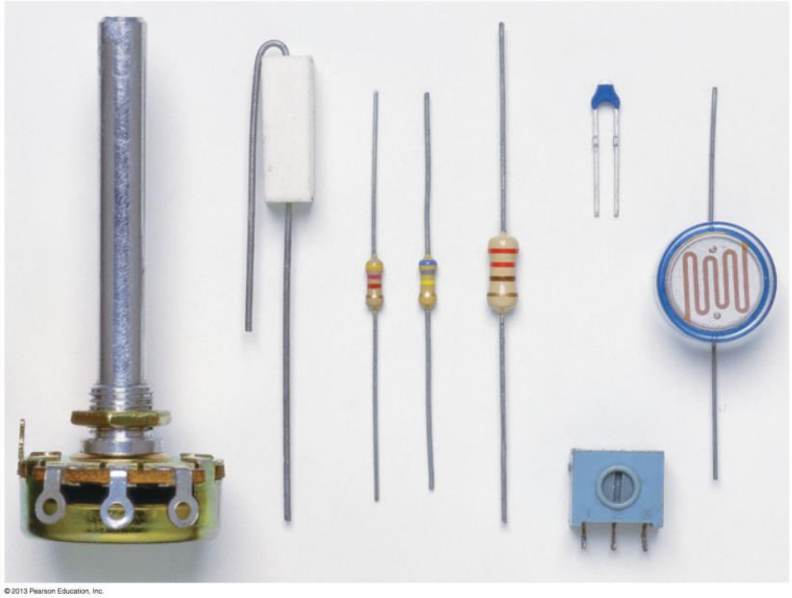
- Electrons have frequent collisions with atomic nuclei.
- When a voltage difference is created across the conductor, this accelerates the electrons, making their collisions more energetic.
- This gets dissipated as heat inside the metal

Tungsten filament:



Resistors

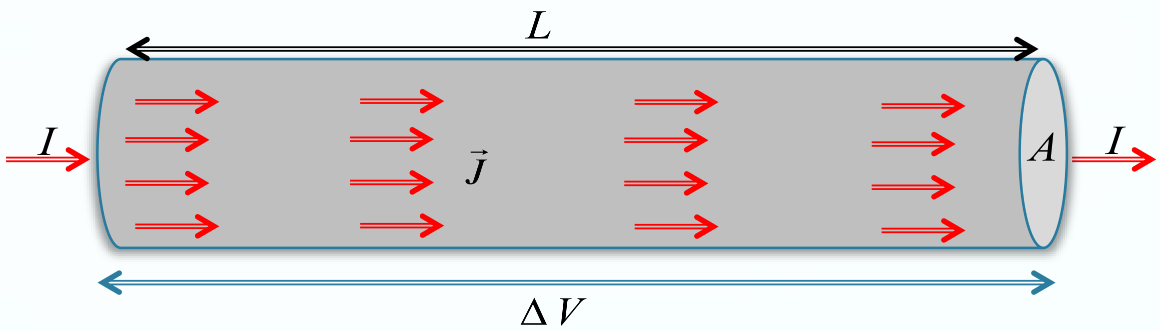
A resistor is any circuit element that dissipates energy. Light bulbs are the classic example, but there are others:

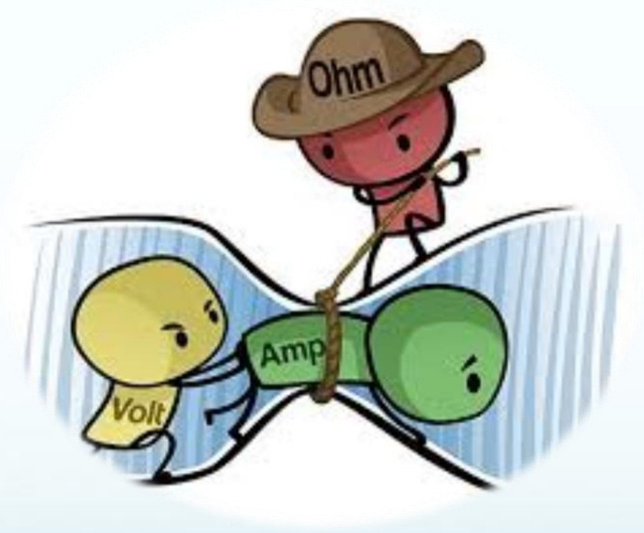


How much energy is dissipated by a given resistor is encoded in a property called its resistance R.

The resistance is dependent on the particular material used as well as the geometry.

How can we quantify resistance?





$$\boxed{\Delta V = IR}$$

Proof→ Appendix 21-1

Resistance is a property of an object. Resistivity is a property of a material.

Instead of the resistance R of an object, we may deal with the **resistivity** ρ of the material:

$$\rho = \frac{E}{J} \quad \text{(definition of } \rho\text{).}$$

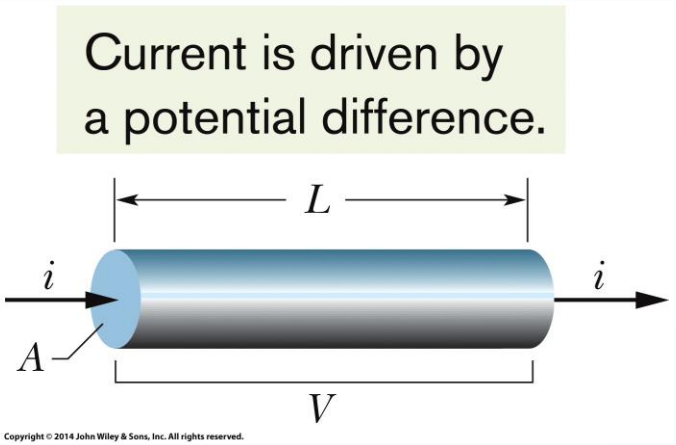
The reciprocal of resistivity is **conductivity** σ of the material:

$$\sigma = \frac{1}{\rho} \quad \text{(definition of } \sigma\text{).}$$

The resistance *R* of a conducting wire of length *L* and uniform cross section is

$$R = \rho \frac{L}{A}.$$

Here *A* is the cross-sectional area.



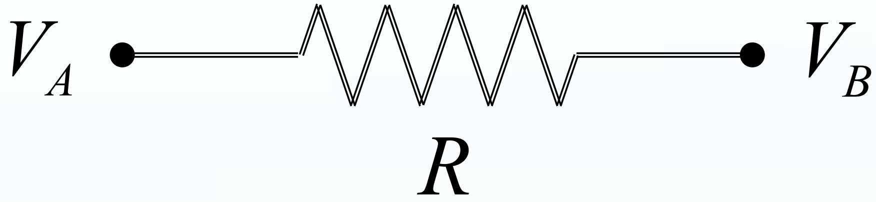
The resistivity *ρ* for most materials changes with temperature.

$$\rho - \rho_0 = \rho_0 \alpha (T - T_0).$$

Here T_0 is a reference temperature, ρ_0 is the resistivity at T_0, and α is the temperature coefficient of resistivity for the material.

Ohm's Law

When a voltage difference Δ*V* is applied across a resistor *R*, the voltage difference causes electrons to flow through the resistor



This flow of electrons is the electric current *I*. These quantities are related by Ohm's Law:

$$\Delta V = IR$$

Ideal wires & batteries

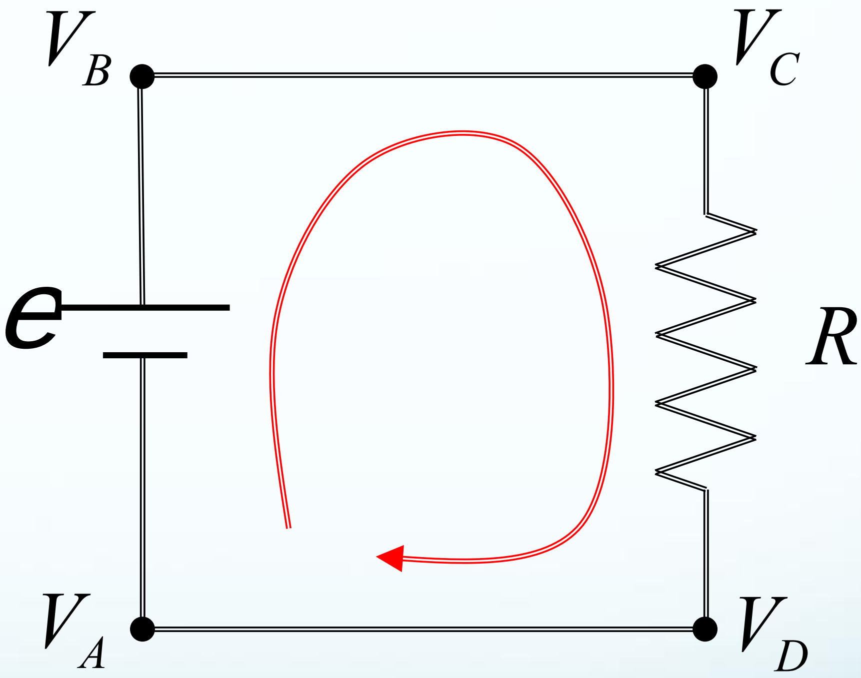
In this class we will usually treat wires as **ideal**, meaning $\Delta V = 0$ across any wire segment even if there is a current flowing.

A battery is any **source** that supplies a **voltage difference** in an electric circuit. The voltage is either specified by *V* or by the symbol ε which stands for **electromotive force** (EMF)
Real batteries also have a resistance to them and we will see later how to account for this.

Current convention: the flow of positive charge (opposite the flow of negative charge)

A Basic Circuit

The simplest circuit has an ideal battery, ideal wires, and a single resistor.

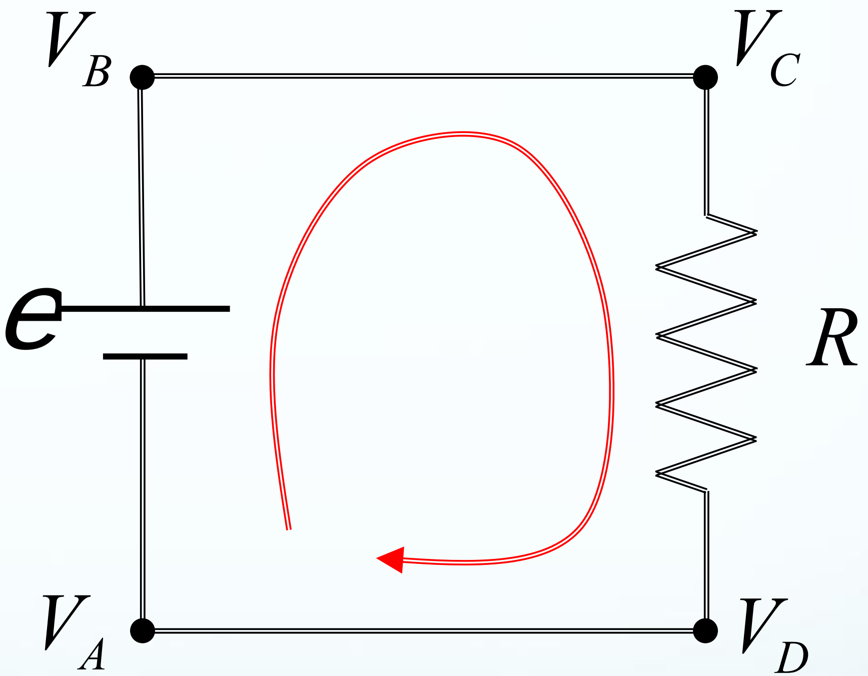


Kirchhoff's Loop Rule:
The sum of the voltage differences around a closed loop in a circuit must be zero.
(conservation of energy)

$$\boxed{\Delta V_{AB} + \Delta V_{BC} + \Delta V_{CD} + \Delta V_{DA} = 0}$$

The voltage across a resistor is **negative** if you are going around the loop in the **direction of the flow of current**.

Current flows **from the negative** terminal **to the positive** terminal



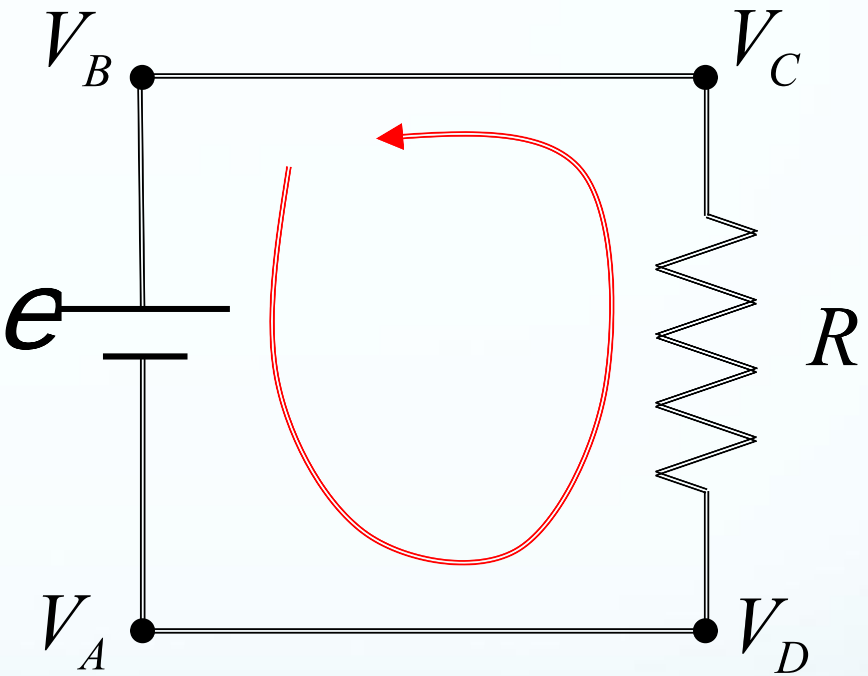
ideal wires

$$\Delta V_{AB} + \cancel{\Delta V_{BC}} + \Delta V_{CD} + \cancel{\Delta V_{DA}} = 0$$

$$e - IR = 0$$

Ohm's Law

The voltage across a resistor is **positive** if you are going around the loop in the **opposite direction of the flow of current**. Voltage across a battery is **negative** going **from positive to negative**



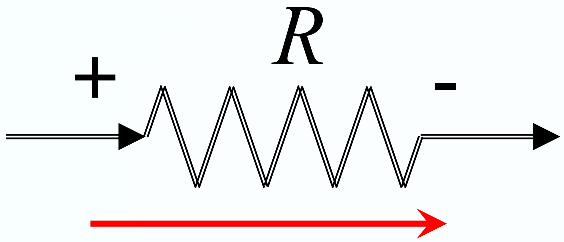
ideal wires

$$\Delta V_{BA} + \cancel{\Delta V_{AD}} + \Delta V_{DC} + \cancel{\Delta V_{CB}} = 0$$

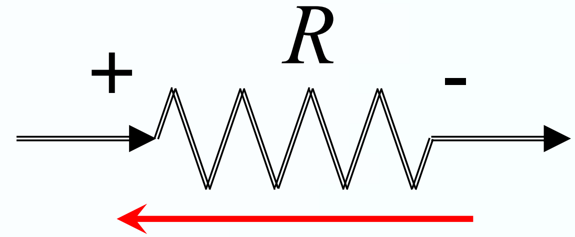
$$-e + IR = 0$$

Same as before

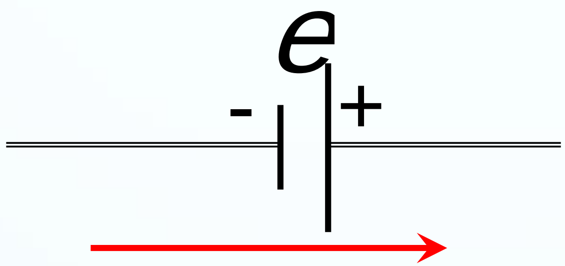
Kirchhoff's Loop Rule



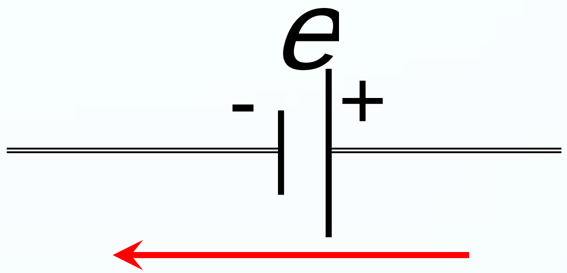
Higher to lower V: $\Delta V = -IR$



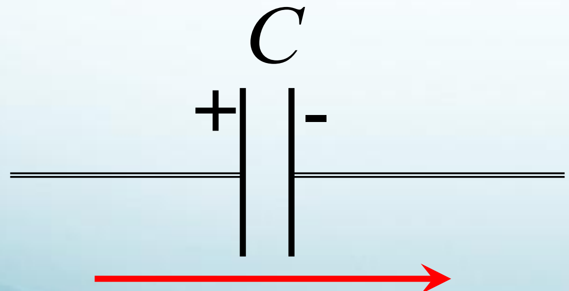
Lower to higher V: $\Delta V = +IR$



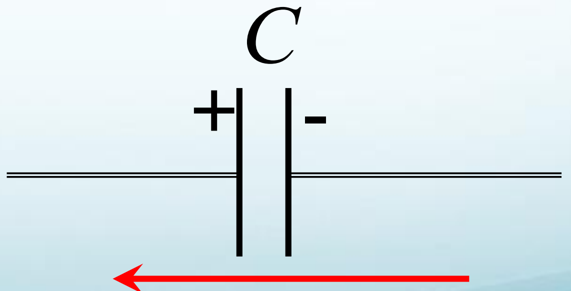
Lower to higher V: $\Delta V = +e$



Higher to lower V: $\Delta V = -e$



Higher to lower V: $\Delta V = -\frac{Q}{C}$



Lower to higher V: $\Delta V = +\frac{Q}{C}$

Resistors in Series

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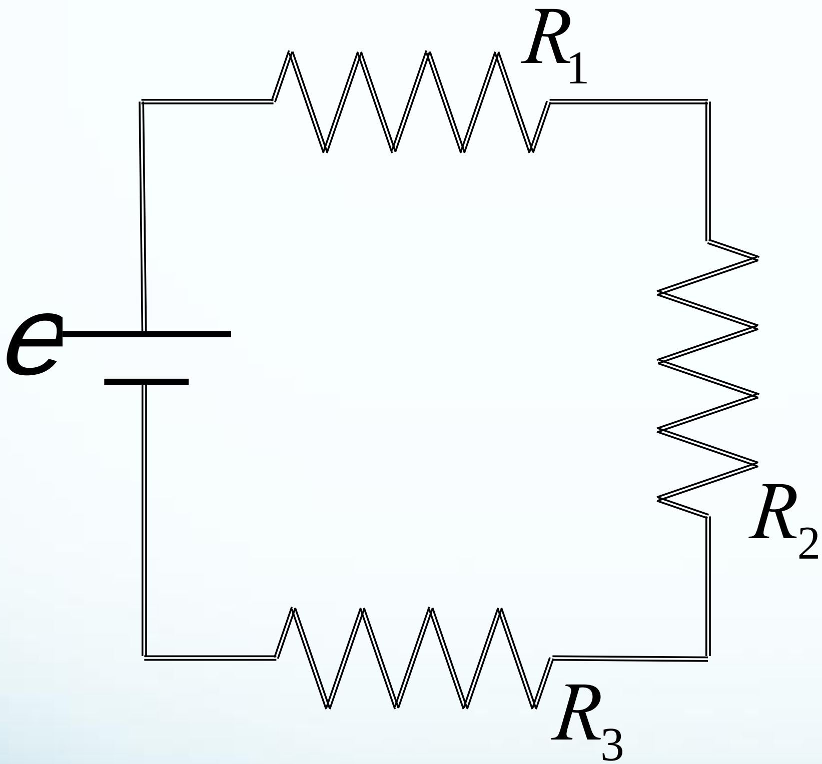
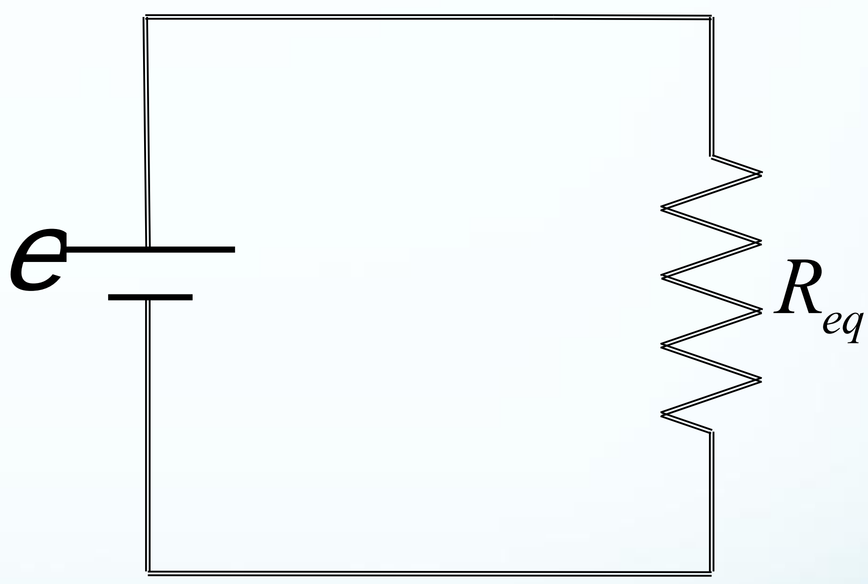
Resistors in Series



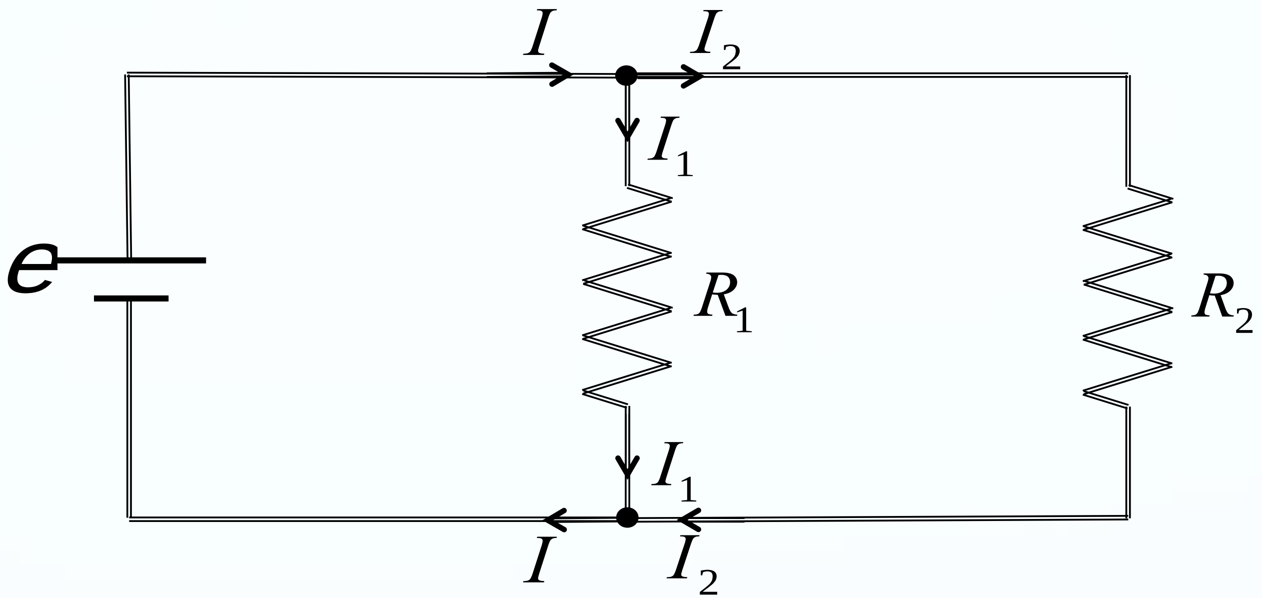


Resistors in series act like a single equivalent resistor:

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

Resistors in Parallel

Resistors in Parallel and Kirchhoff's junction rule



$$R_{eq} = \left(\frac{1}{R_1} + \frac{1}{R_2}\right)^{-1}$$

Current is the flow of charges. Charge has to be conserved.

Current into junction = current out of junction

$$I = I_1 + I_2$$

Summary of Resistors

Ohm's Law

$$\Delta V_R = IR$$

Resistors in Series: have the same current running through them

$$R_{eq} = R_1 + R_2 + \ldots + R_N$$

Resistors in Parallel: have the same voltage across them

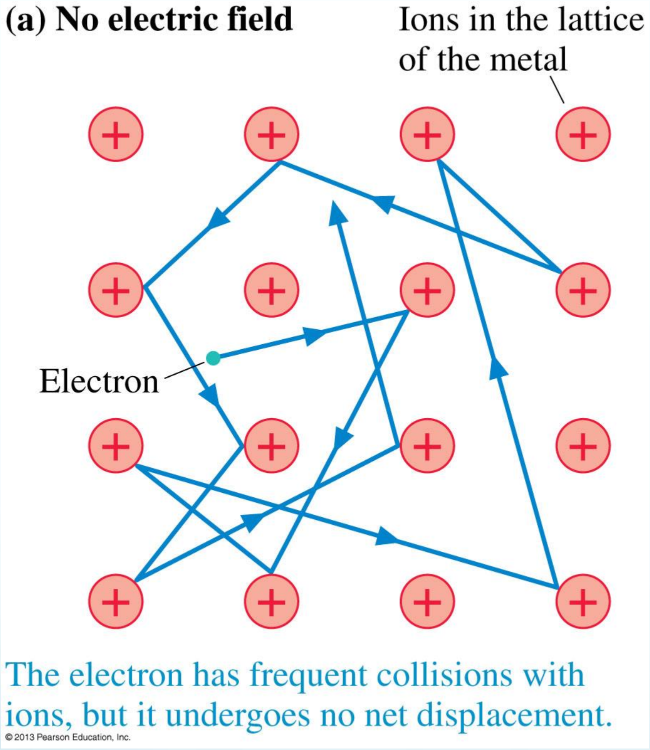
$$R_{eq} = \left(\frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_N} \right)^{-1}$$

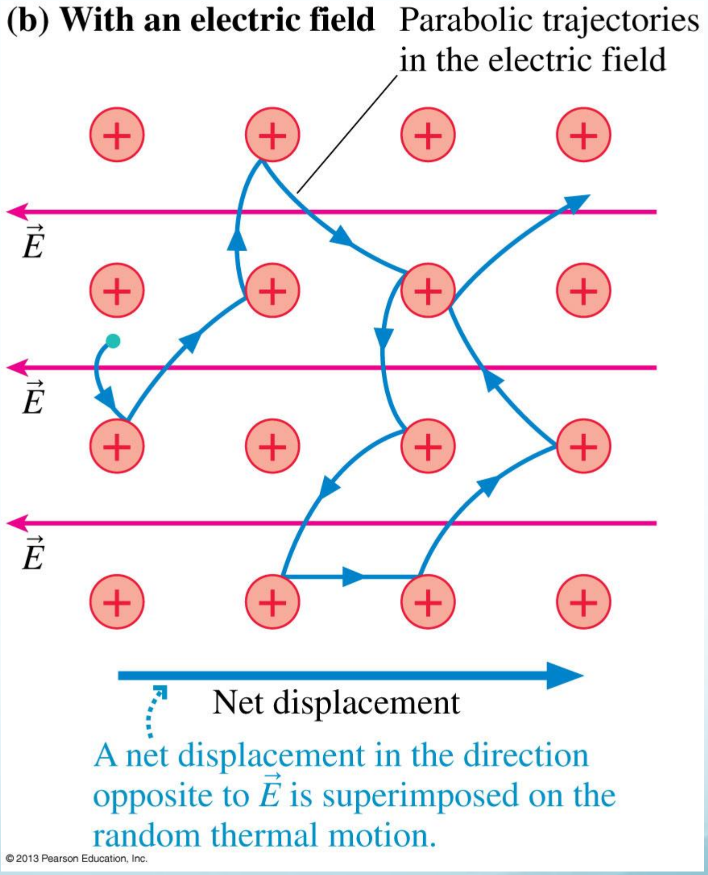
This section we talked about:

Chapters 26 and 27

See you on Wednesday

Inside a conductor





Net result: electrons move at an average net “drift speed” v_d