Physics 1502Q:
6.2 Current and Resistance

Announcements & Reminders

- Complete prelab before the lab
- Next homework is due Monday at 11:59 PM
- Next Reading Assignment is due Sunday at 11:59pm

What was your impression of Exam 1?

A. I thought it was easy
B. I thought it was fair
C. I thought it was difficult because the questions were very different from what was shown in class.
D. I thought it was difficult because I did not prepare adequately.
E. I thought it was difficult because it was too long.

Electric Current, Resistance & Resistors

LEARNING GOALS

By the end of this unit, you should be able to:

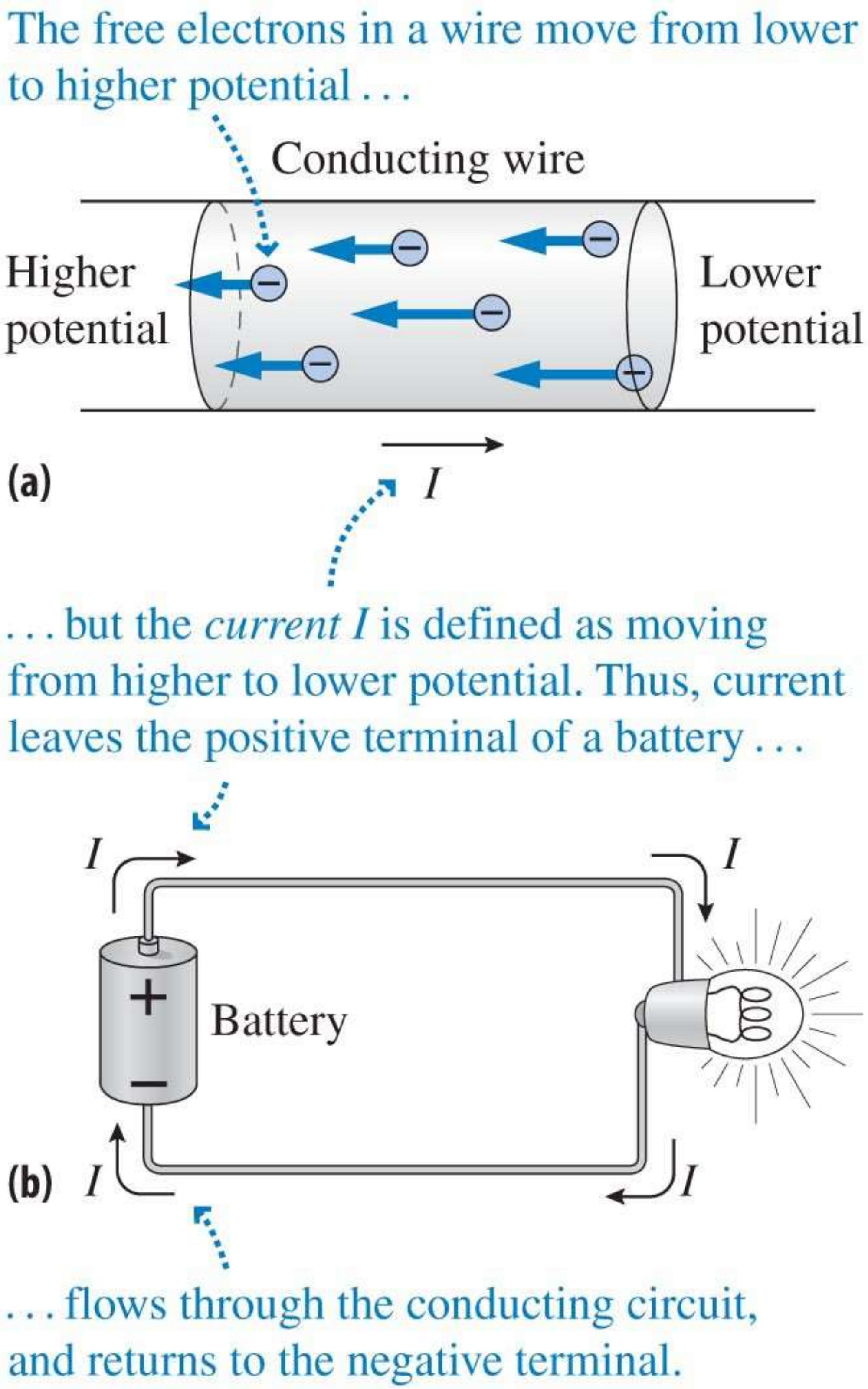
- Explain what an electric current is
- Understand how a current flows inside a conductor
- Understand what resistivity and resistance are
- Explain Ohm’s Law
- Explain the purpose of resistors
- Understand how resistors are combined
- Understand how batteries deliver energy and resistors use energy

Electric Current: Macroscopic View

- Electric Current is a flow of electric charge:

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

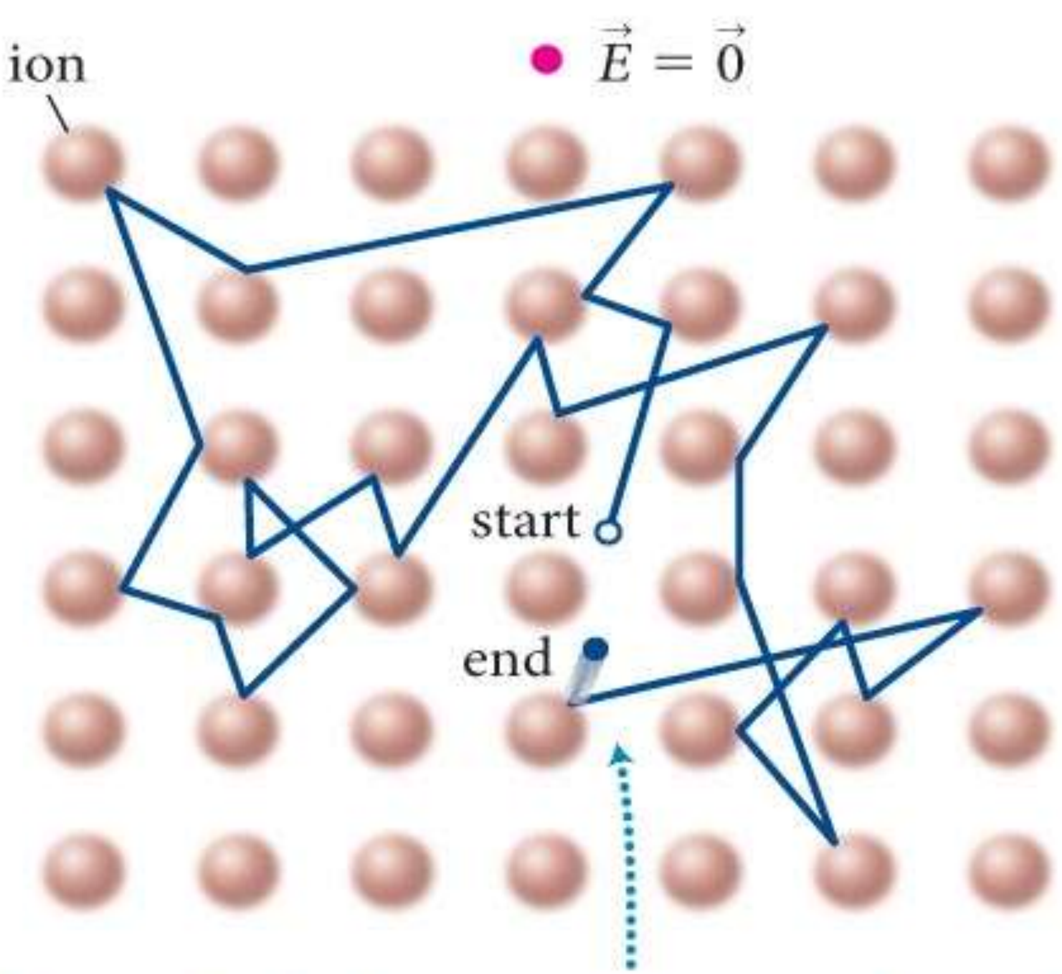
- It is the rate at which charge flows past any point.
- SI units: [C/s] = [A] (ampere)
- By convention, the direction of electric current is taken as the direction in which positive charge carriers would move even though (normally) only conduction electrons can move.



Electrons Flowing in a Conductor

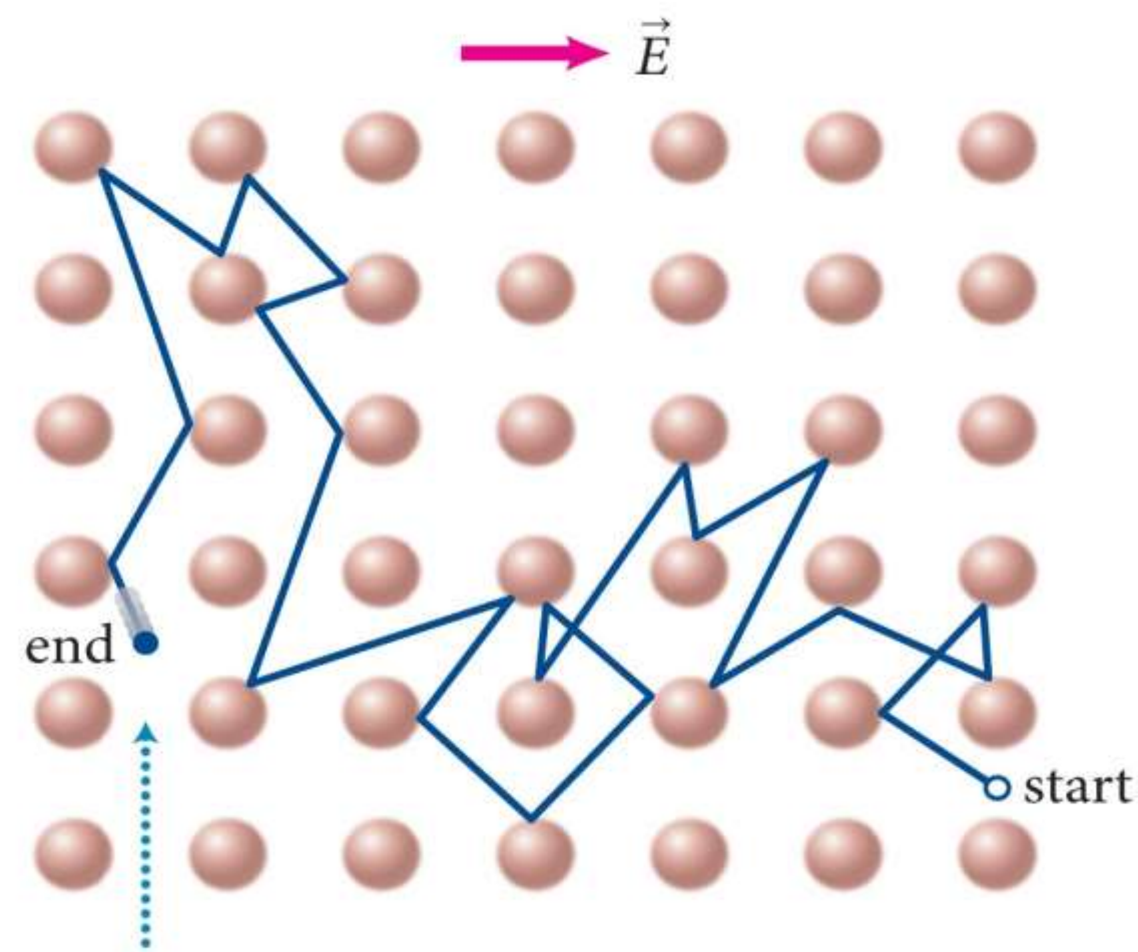
A metal consists of a lattice of positively charged ions through which electrons can move relatively freely

(a) Motion in absence of an electric field



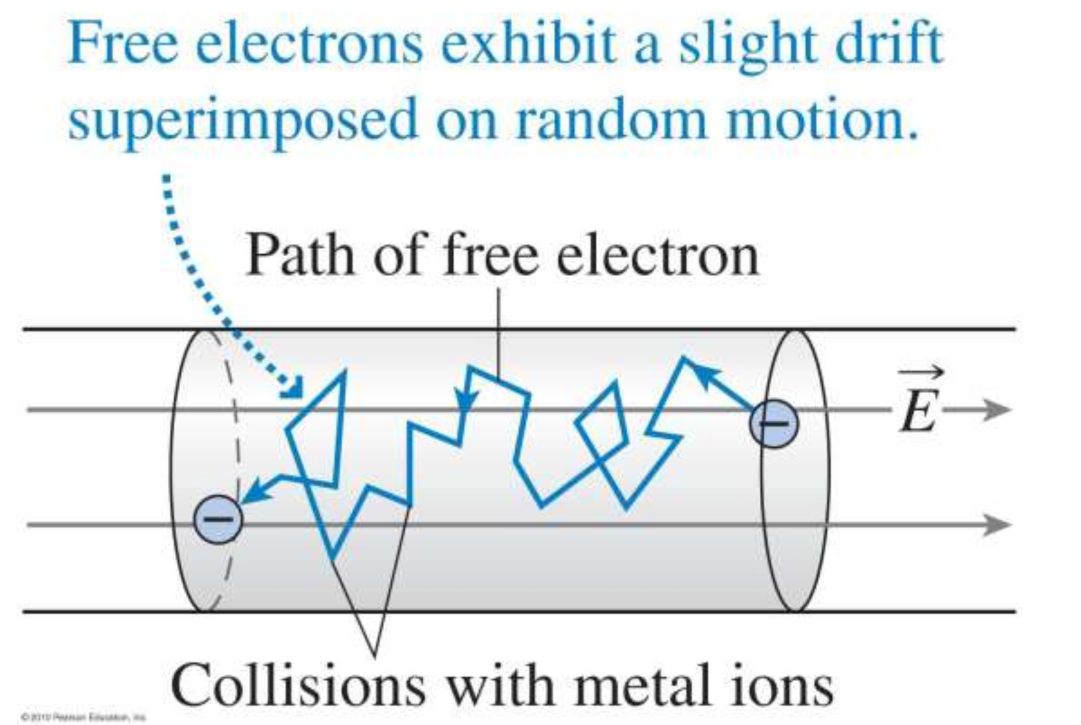
Electron's displacement is zero over long time interval.

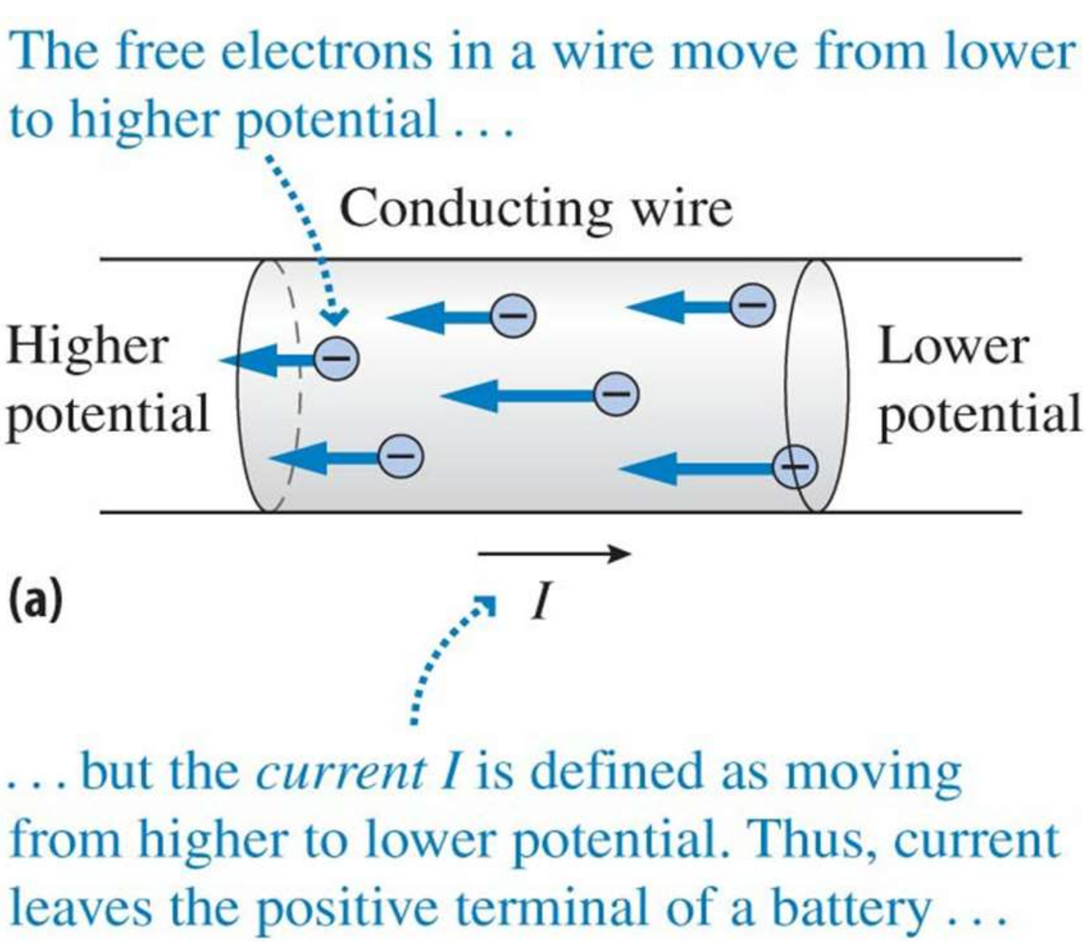
(b) Motion with applied electric field



Electron undergoes displacement in direction opposite to electric field.

Electric Current: Microscopic View





- Must have a conductor for current to flow.
- <u>Free electrons move at random:</u> E-field simply accelerates them in a given direction.
- After a potential difference is applied, the resulting E-field gives conduction electrons an average drift speed v_{drift}.

$$\boxed{I = neAv_{\text{drift}}}$$

- <u>Convention:</u> Direction of current is given by the flow of positive charges, moving from a higher to a lower potential.

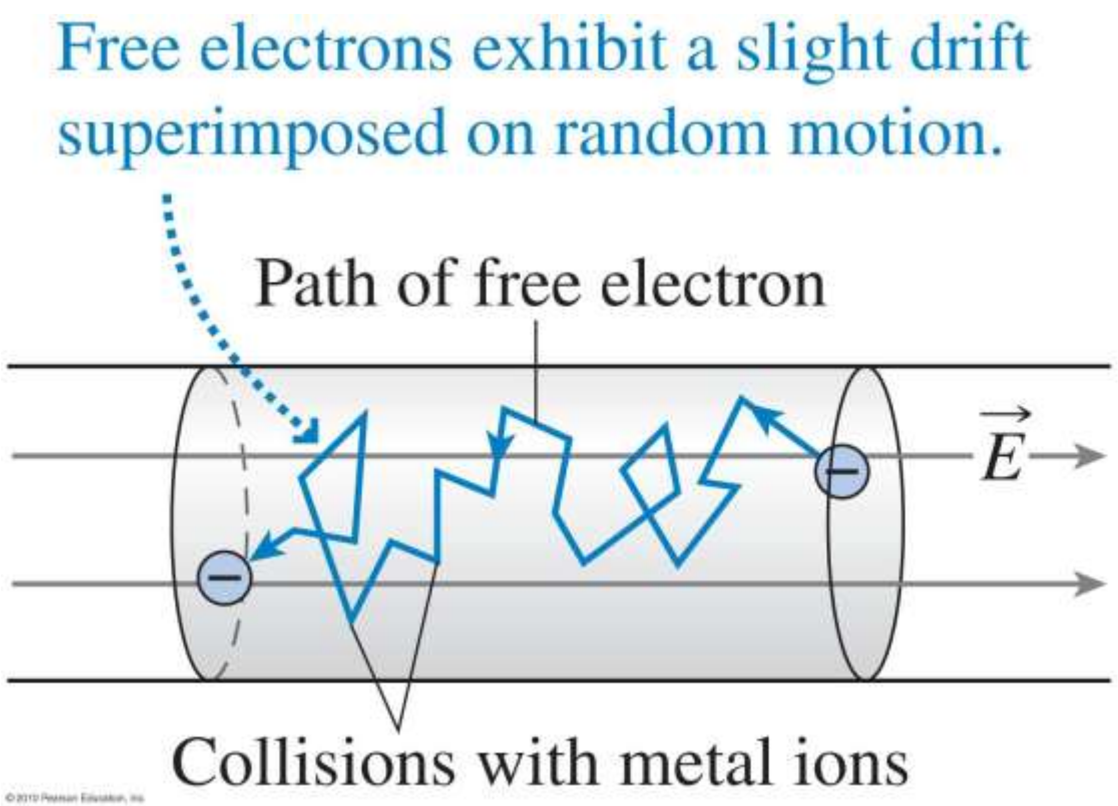
Number Density or Electron Density (*n*)

- In most metals, each atom contributes one valence electron to the sea of electrons that are free to flow as part of the current

- As a result, the number of conduction electrons per cubic meter, also known as the electron density or **number density** n is the same as the number of atoms per cubic meter

Metal	**Electron Density (m^{-3})**
Aluminum	6.0×10^{28}
Copper	8.5×10^{28}
Iron	8.5×10^{28}
Gold	5.9×10^{28}
Silver	5.8×10^{28}

Electrical Resistance: A Microscopic View



resistance of conducting object

length of resistor

$$R = r\,\frac{L}{A}$$

resistivity of material

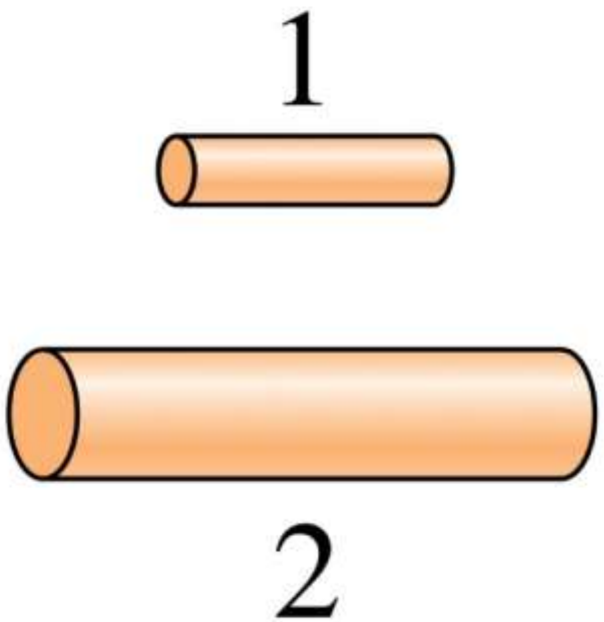
cross-sectional area of resistor

Resistance of a resistor depends on the material it is made of, its length, and its cross-sectional area.

Its SI unit is ohm [Ω].

Question: Resistance

Wire 1 and Wire 2 are made of the same material. Wire 2 is twice the length and twice the radius of wire 1. What is the ratio R_2/R_1 of their resistances?



A. 1/4
B. 1/2
C. 1
D. 2
E. 4

$$R = r\frac{L}{A}$$

Question: Resistance

Wire 1 and Wire 2 are made of the same material. Wire 2 is twice the length and twice the radius of wire 1. What is the ratio R_2/R_1 of their resistances?

A. 1/4

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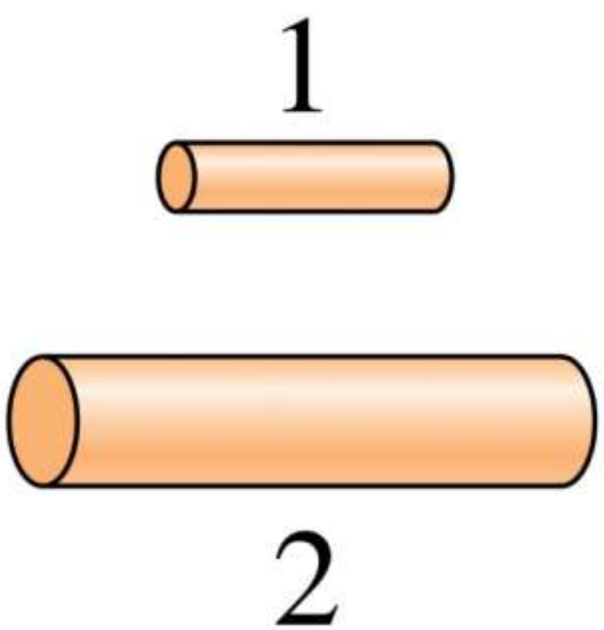


$$\frac{R_2}{R_1} = \frac{\rho L_2}{A_2}\frac{A_1}{\rho L_1} = \frac{\rho L_2}{\pi r_2^2}\frac{\pi r_1^2}{\rho L_1} = \frac{L_2}{r_2^2}\frac{r_1^2}{L_1}$$

$$= \frac{2L_1}{(2r_1)^2}\frac{r_1^2}{L_1} = \frac{1}{2}$$

$$\boxed{R = r\frac{L}{A}}$$

Resistors

- Resistors are devices with specific resistances for use in electrical circuits.

- Color coding indicates the resistance value

- Helps limit and control current.

Example: Lightbulb Filament

The resistance of the filament in a light bulb is 250 Ω. At the operating temperature of the tungsten filament, the resistivity is approximately 5.0x10^{-7} Ωm. If the wire used to make the filament is 0.040 mm in diameter, how long must the filament be?

$$R = r\frac{L}{A} \qquad R = \frac{\rho L}{\frac{\pi d^2}{4}} = \frac{4\rho L}{\pi d^2}$$

$$L = \frac{R\pi d^2}{4\rho} \qquad L = \frac{250\Omega \times \pi \times 4 \times 10^{-5}\mathrm{m}}{4 \times 5 \times 10^{-7}\Omega\mathrm{m}} = 0.63\ \mathrm{m}$$

Resistance and Temperature

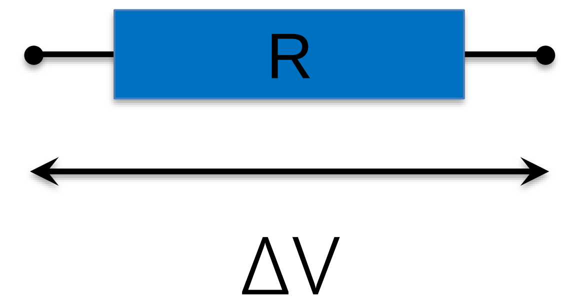
Resistance also varies with Temperature:

$$\boxed{R = R_0\left[1 + \alpha\left(T - T_0\right)\right]}$$

Temperature coefficient
(material dependent)

- R_0 is the initial value of the resistance at a given temperature T_0.
- α is the temperature coefficient of resistance, and is dependent on the material.

Ohm's Law



Voltage
(potential difference across resistor
or combination of resistors)

Resistance

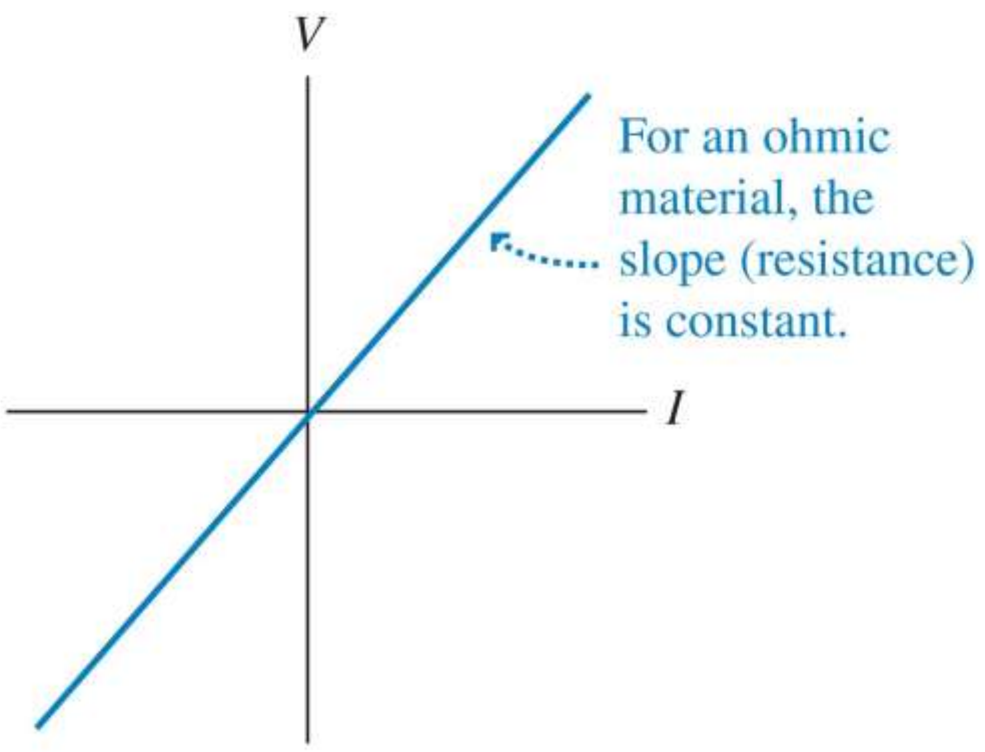
$$\Delta V = IR$$

Current

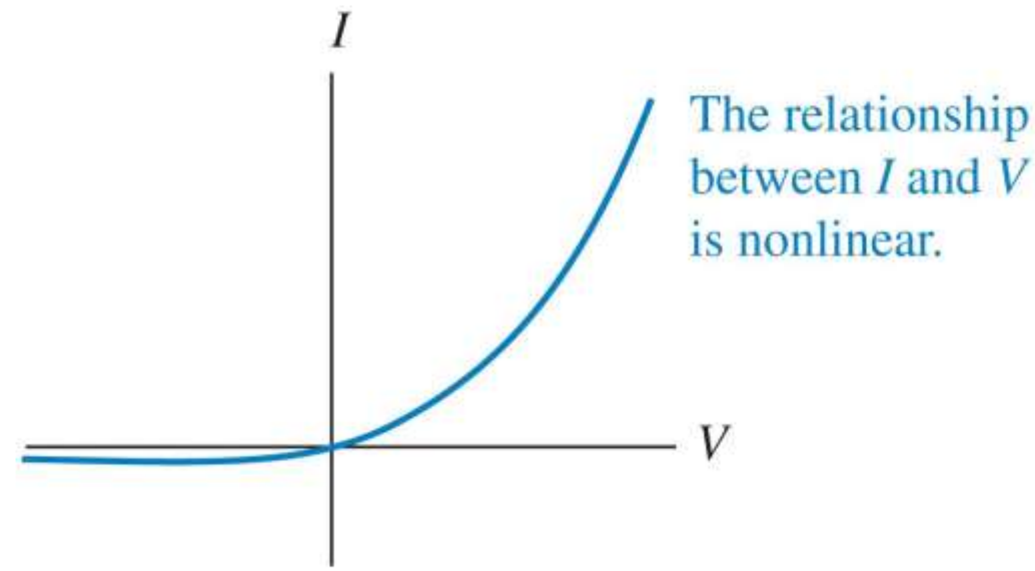
○The potential difference (voltage) always <u>decreases</u> through a resistor.

○ Ohm's Law can be applied to single devices or to combination of devices or even entire circuits.

Ohmic and Non-Ohmic Materials



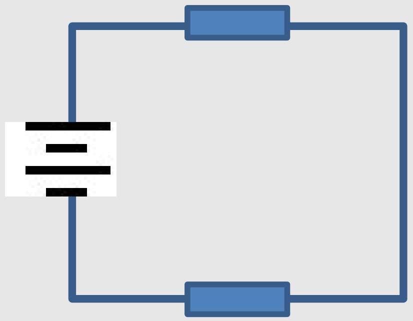
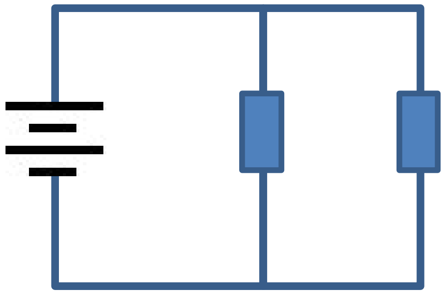
(a) *V* versus *I* for an ohmic material



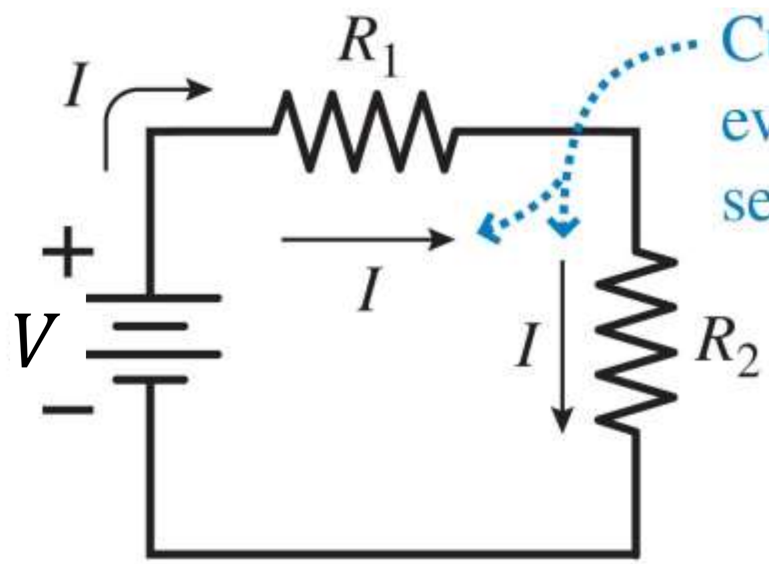
(b) *I* versus *V* for a non-ohmic material, here a semiconductor diode

- Ohmic materials follow Ohm's law
- Non-ohmic materials do not follow Ohm's law

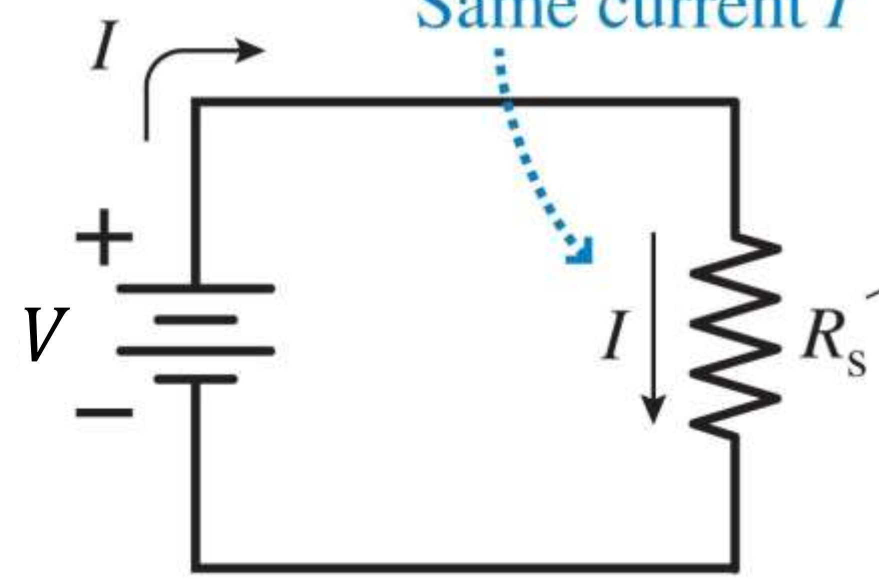
Series and Parallel Circuits

Series		I is the same for all devices $I = I_1 = I_2 = \cdots$	ΔV splits between devices $\Delta V = \Delta V_1 + \Delta V_2 + \cdots$
Parallel		I splits between devices $I = I_1 + I_2 + \cdots$	ΔV is the same for all devices $\Delta V = \Delta V_1 = \Delta V_2 = \cdots$

Resistors in Series



(a) Resistors connected in series



(b) The two resistors are replaced by one of equivalent resistance R_s.

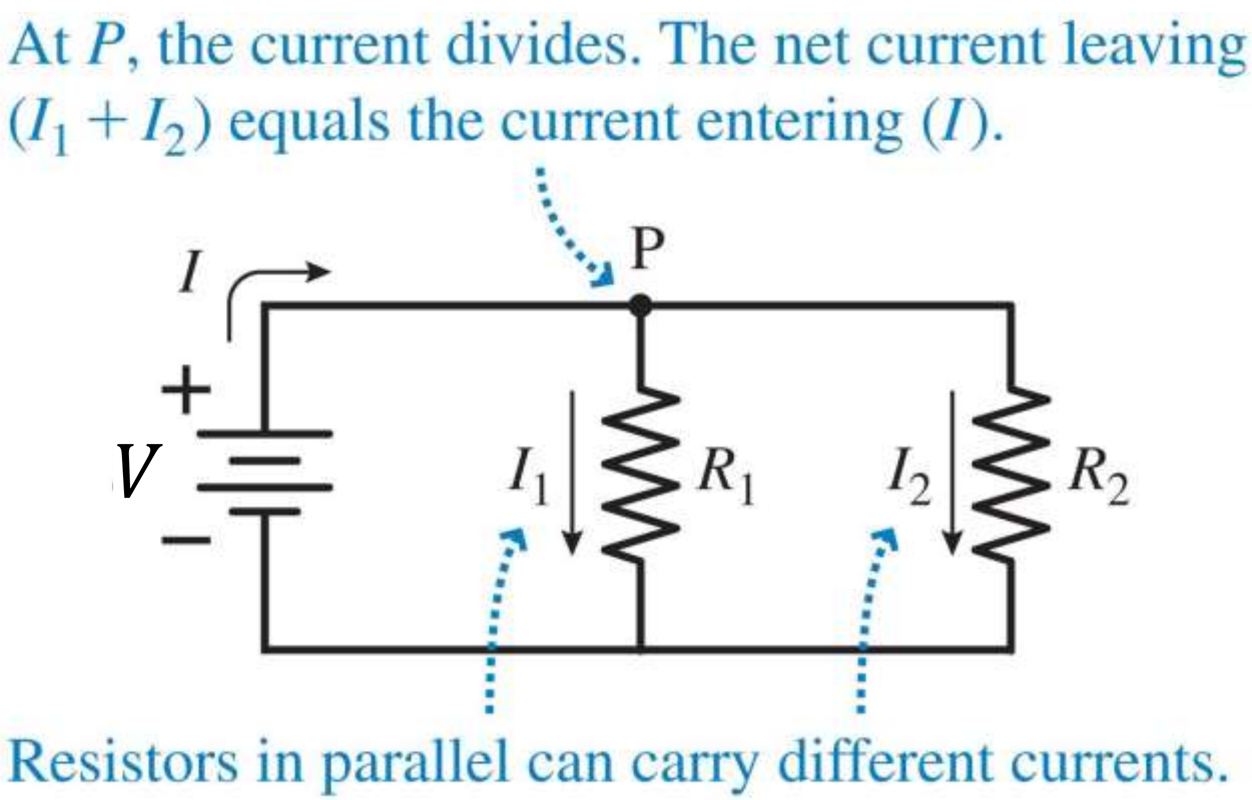
Key point: Current is the same for both resistors

The total potential difference splits:

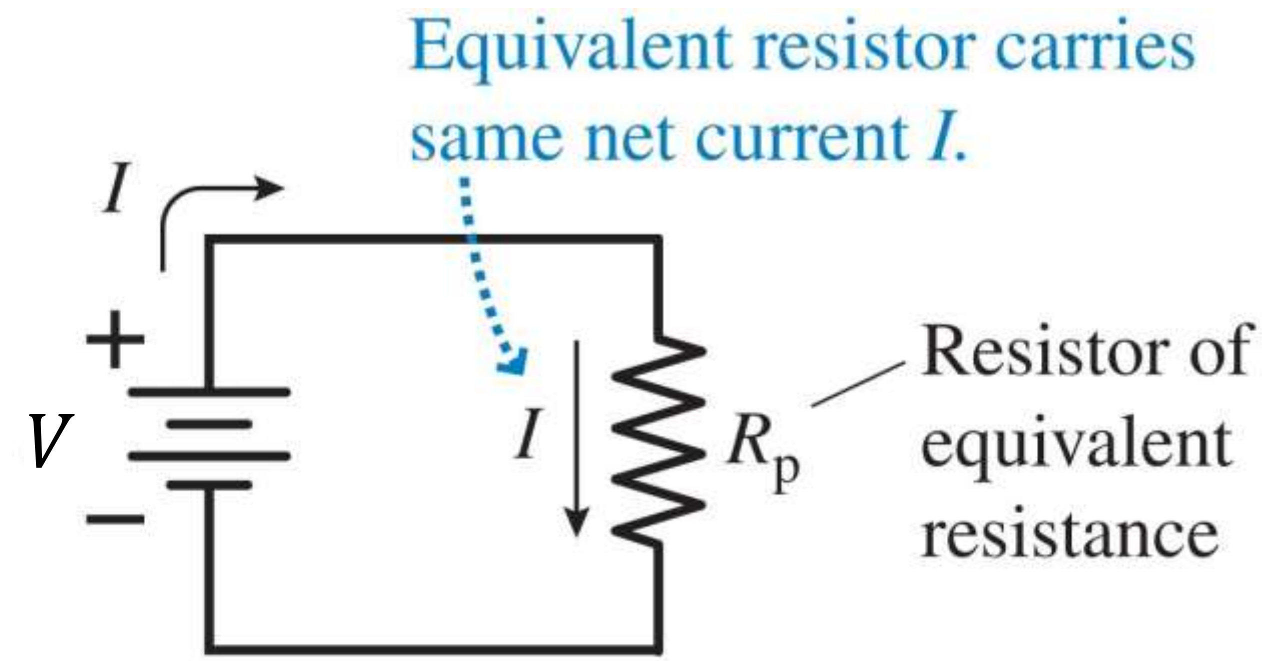
$$V = V_1 + V_2 \longrightarrow V = R_1 I + R_2 I = R_s I$$

or $$\boxed{R_s = R_1 + R_2}$$

Resistors in Parallel



(a) Resistors connected in parallel



(b) The two resistors are replaced by one of equivalent resistance R_p.

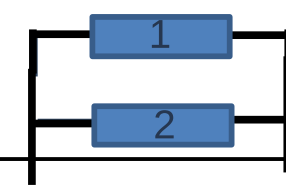
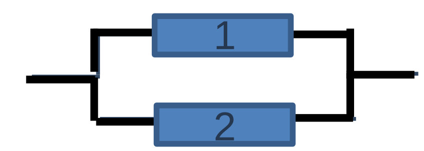
Key point: Potential difference V is the same for both resistors

The total current splits:

$$I = I_1 + I_2 \longrightarrow \frac{V}{R_p} = \frac{V}{R_1} + \frac{V}{R_2}$$

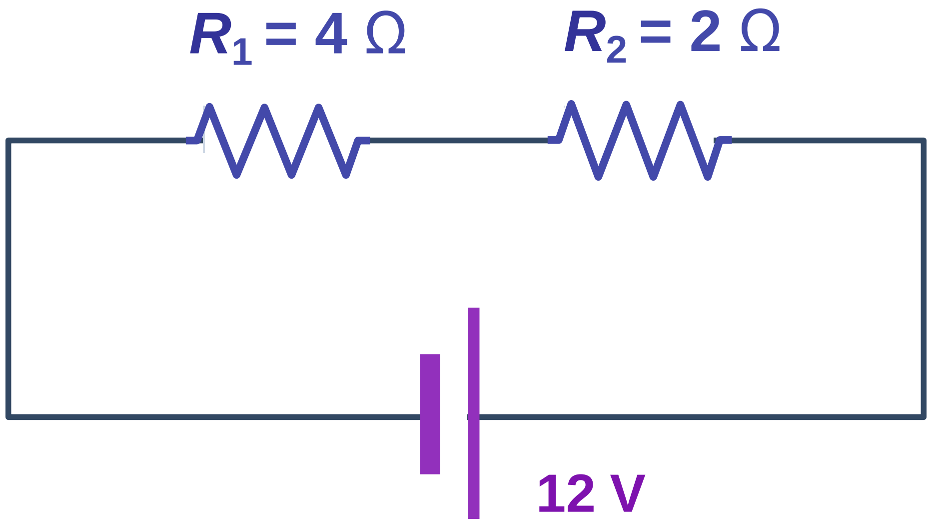
$$\boxed{\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}} \quad \text{or} \quad \boxed{R_p = \frac{R_1 R_2}{R_1 + R_2}}$$

Circuit Summary

	Series 	**Parallel**  
Wiring	Each device on the same wire.	Each device on a different wire.
Voltage	Splits between devices $V_{total} = V_1 + V_2$	Same for each device. $V_{total} = V_1 = V_2$
Current	Same for each device $I_{total} = I_1 = I_2$	Splits between devices $I_{total} = I_1 + I_2$
Resistor	$R_{eq} = R_1 + R_2$	$1/R_{eq} = 1/R_1 + 1/R_2$
Capacitors	$1/C_{eq} = 1/C_1 + 1/C_2$	$C_{eq} = C_1 + C_2$

Question: Series Resistors

In the circuit below, what is the voltage (potential difference) across R_1?



A. 12 V

B. Zero

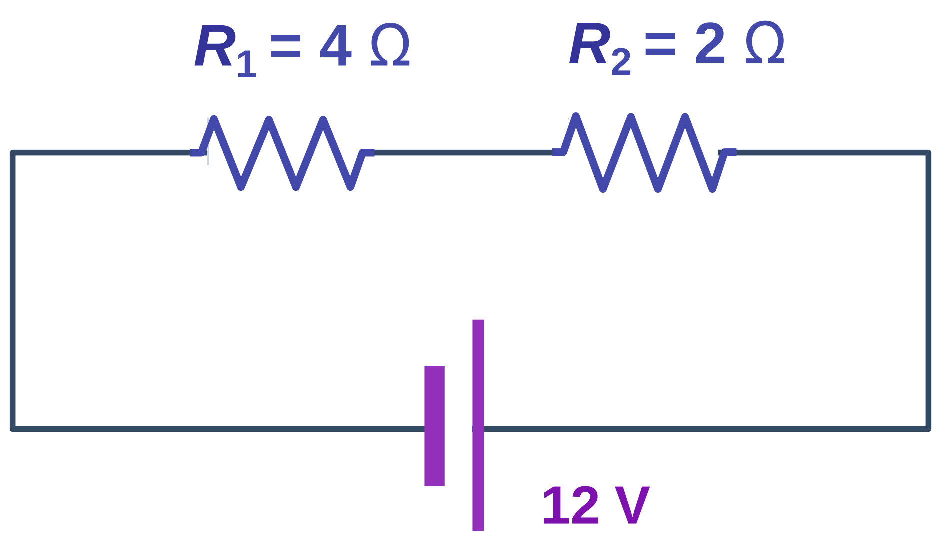
C. 6 V

D. 8 V

E. 4 V

Question: Series Resistors

In the circuit below, what is the voltage (potential difference) across R_1?



A. 12 V

B. Zero

C. 6 V

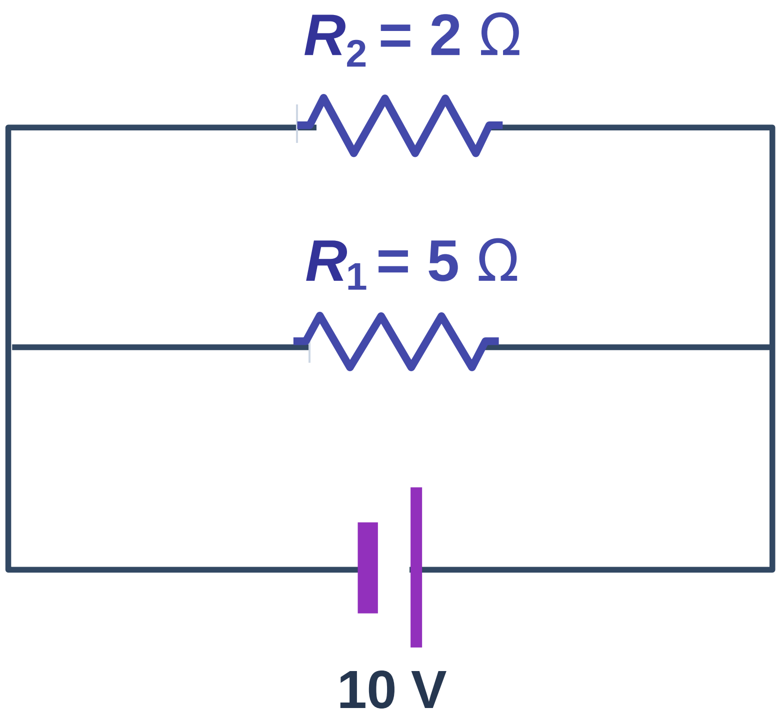
D. 8 V

E. 4 V

The voltage drop across R_1 has to be twice as big as the drop across R_2. This means that $\Delta V_1 = 8$ V and $\Delta V_2 = 4$ V. Or else you could find the current $I = V/R = (12\ \text{V})/(6\ \Omega) = 2$ A, and then use Ohm's law to get the voltages.

Question: Parallel Resistors

In the circuit below, what is the current through R_1?



A. 10 A

B. Zero

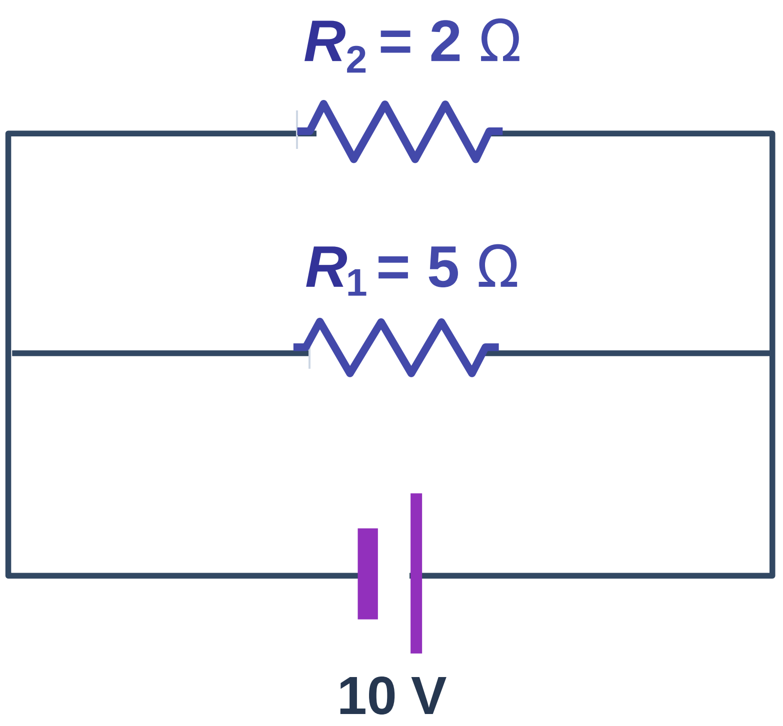
C. 5 A

D. 2 A

E. 7 A

Question: Parallel Resistors

In the circuit below, what is the current through R_1?



A. 10 A

B. Zero

C. 5 A

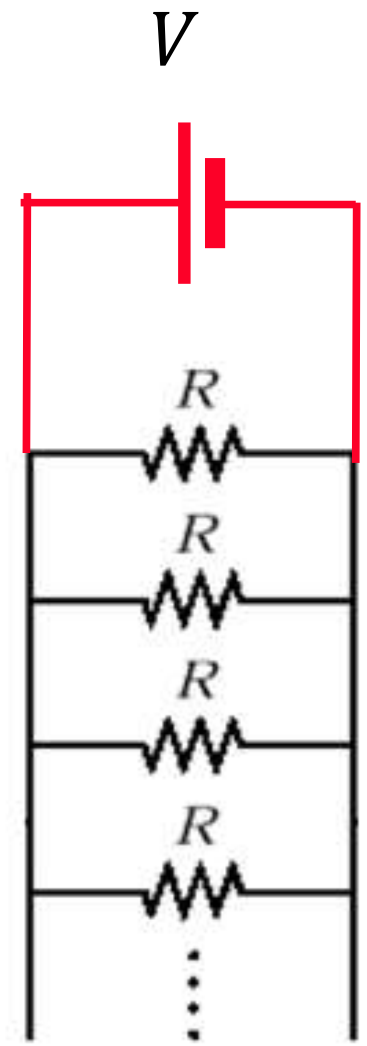
D. 2 A

E. 7 A

The *voltage* is the *same* (10 V) across each resistor because they are in parallel. Thus, we can use Ohm's law, $\Delta V_1 = I_1 R_1$ to find the current $I_1 = 2$ A.

Question: Parallel Resistor II

A parallel circuit is connected to a battery of fixed voltage. As more resistors ***R*** are added to the circuit, what happens to the **total current** in the circuit?



A. Increases

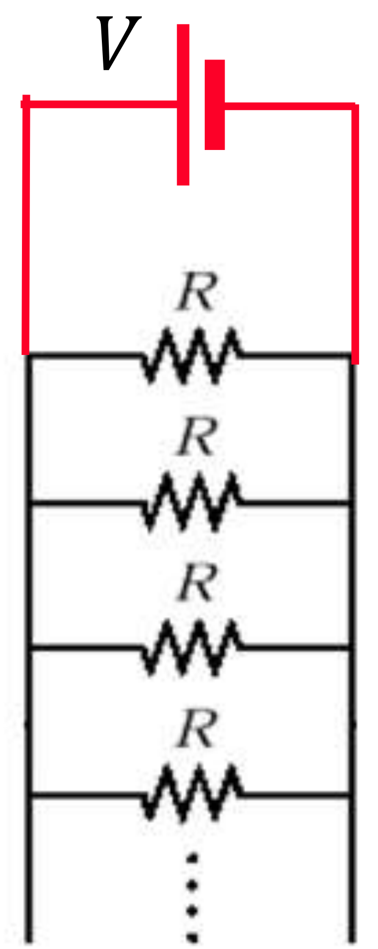
B. Remains the same

C. Decreases

D. Drops to zero

Question: Parallel Resistor II

A parallel circuit is connected to a battery of fixed voltage. As more resistors ***R*** are added to the circuit, what happens to the **total current** in the circuit?



A. Increases
B. Remains the same
C. Decreases
D. Drops to zero

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}$$

As we add parallel resistors, the overall **resistance of the circuit drops**. Since *V* = *IR*, and *V* is held constant by the battery, when **resistance decreases**, the **current must increase**.

Demo: Light Bulbs

Breadboard Activity I

Practice building basic circuits with breadboards

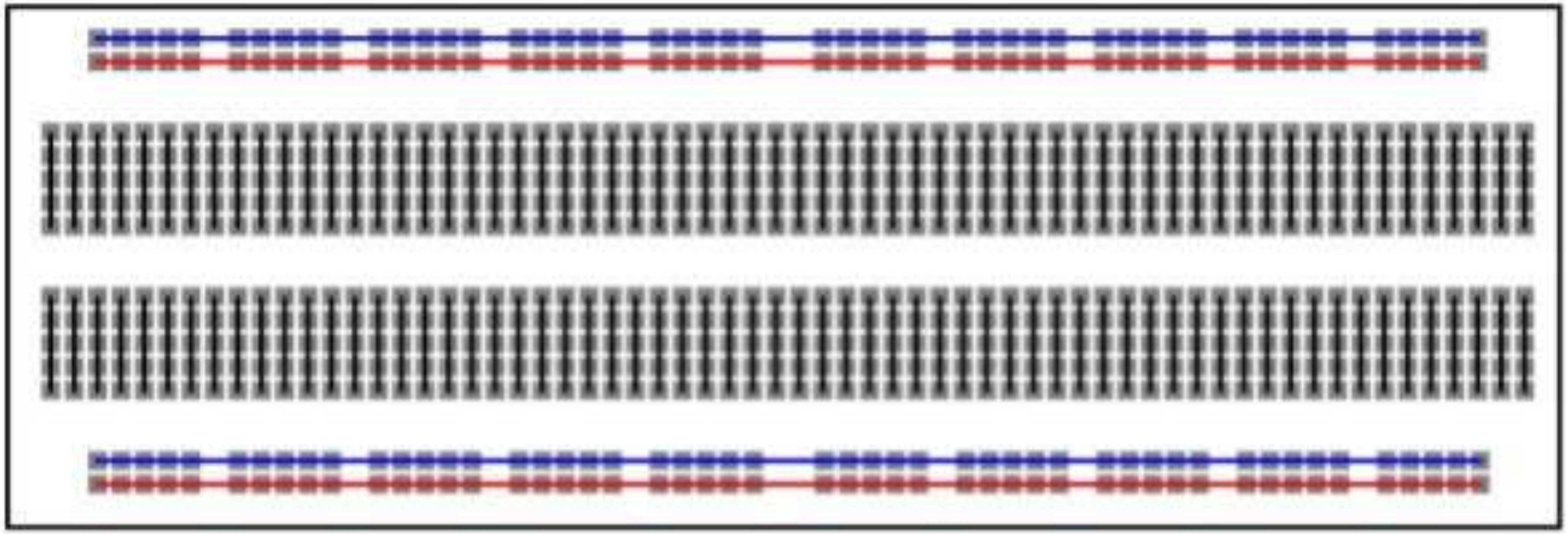


Figure 1: Breadboard layout and connection diagram

Follow the instructions in HuskyCT

Course Contents
>> 6.2 Electric Current; Resistance
>> Breadboard Activity I

PRACTICE PROBLEMS