Physics 1502Q:
7.1 Kirchhoff's Laws

Announcements & Reminders

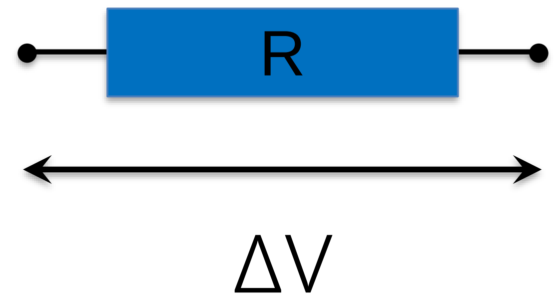
- Homework is due this **Monday at 11:59pm**
- Next Reading Assignment is due next **Sunday at 11:59pm**

Preview of this week and next two weeks

Su	M	T	W	Th	F	Sa
27 Reading Assignment Due 11:59 PM	28 HW Due 11:59 PM	1 Kirchhoff's Laws	2	3 RC Circuits	4 Pre-lab 5 Due before lab	5
6 Reading Assignment Due 11:59 PM	7 HW Due 11:59 PM	8 Intro to Magnetism/ Magnetic Force I	9	10 Magnetic Force II	11 Lab 6: Kirchhoff's Laws Pre-lab 6 Due before lab	12
13	14	15	16	17	18	19

SPRING RECESS

Ohm's Law (Recap)



Voltage
(potential difference across resistor
or combination of resistors)

Resistance

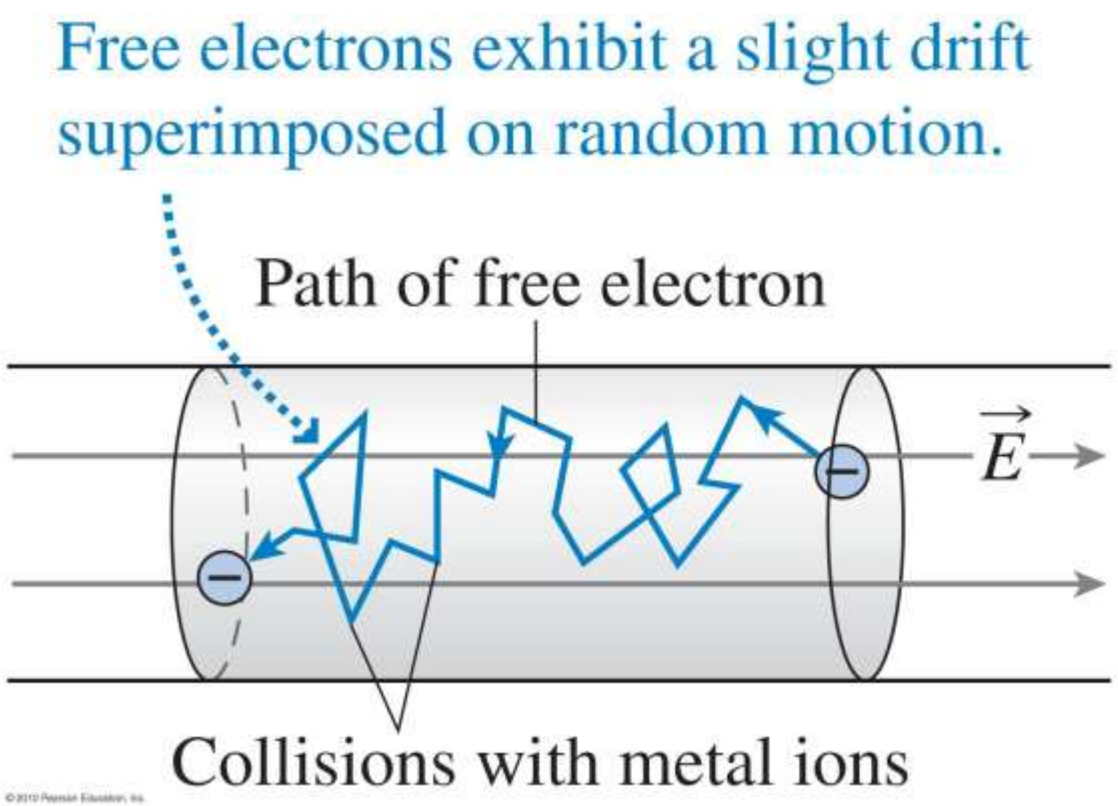
$$\Delta V = IR$$

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.

Electrical Resistance (Recap)



length of
resistor

resistance of
conducting object

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

resistivity of
material

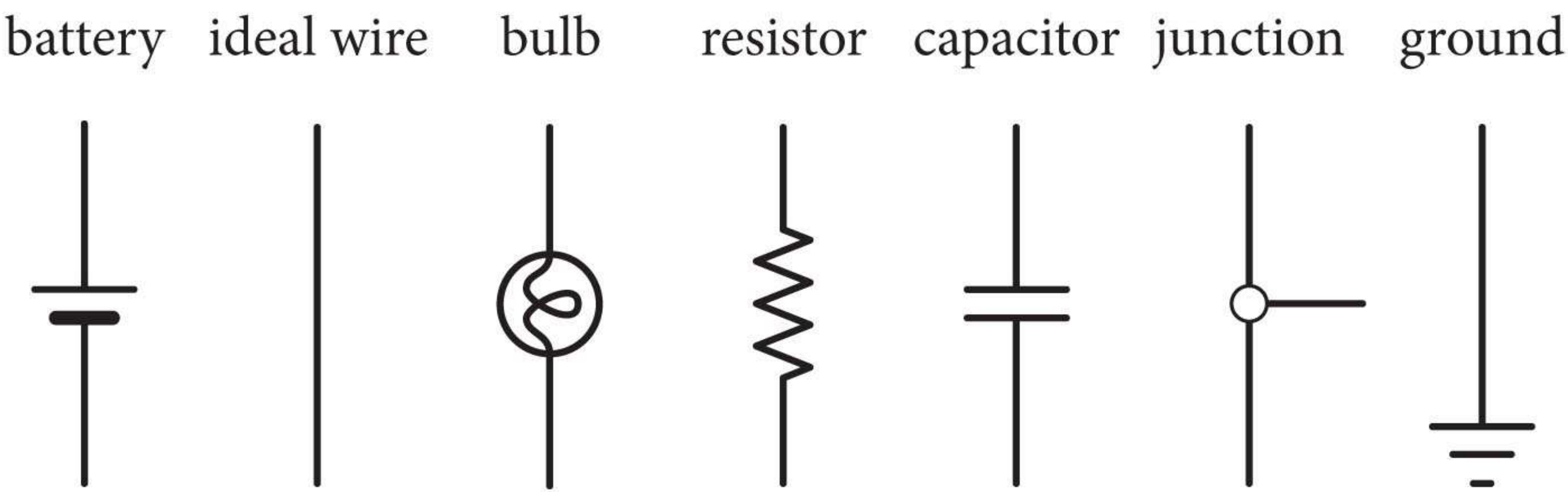
cross-sectional
area of resistor

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

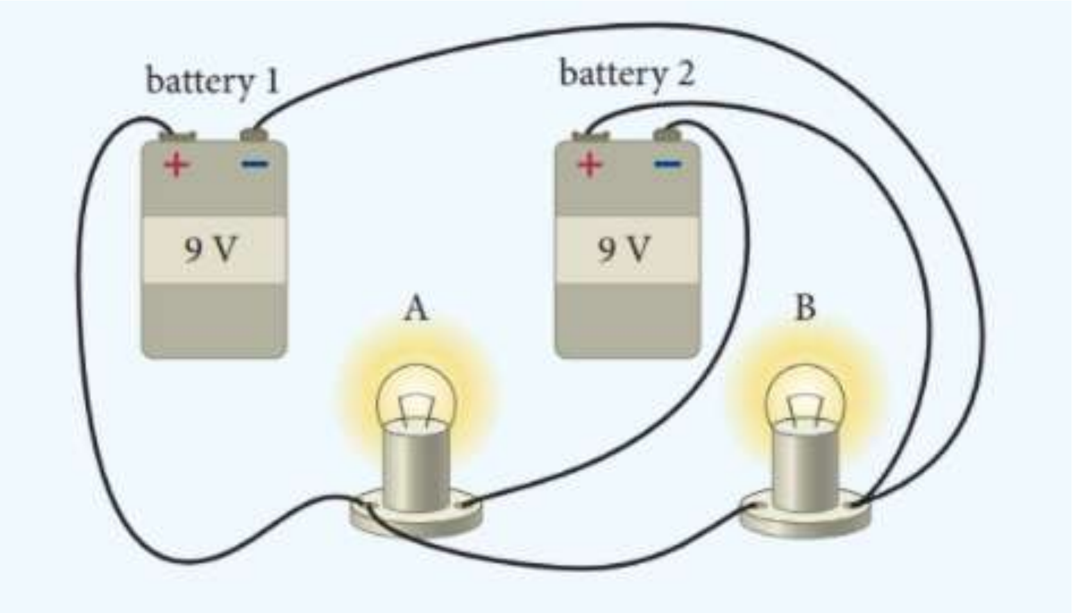
Its SI unit is ohm [Ω].

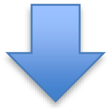
Basic Circuit Elements

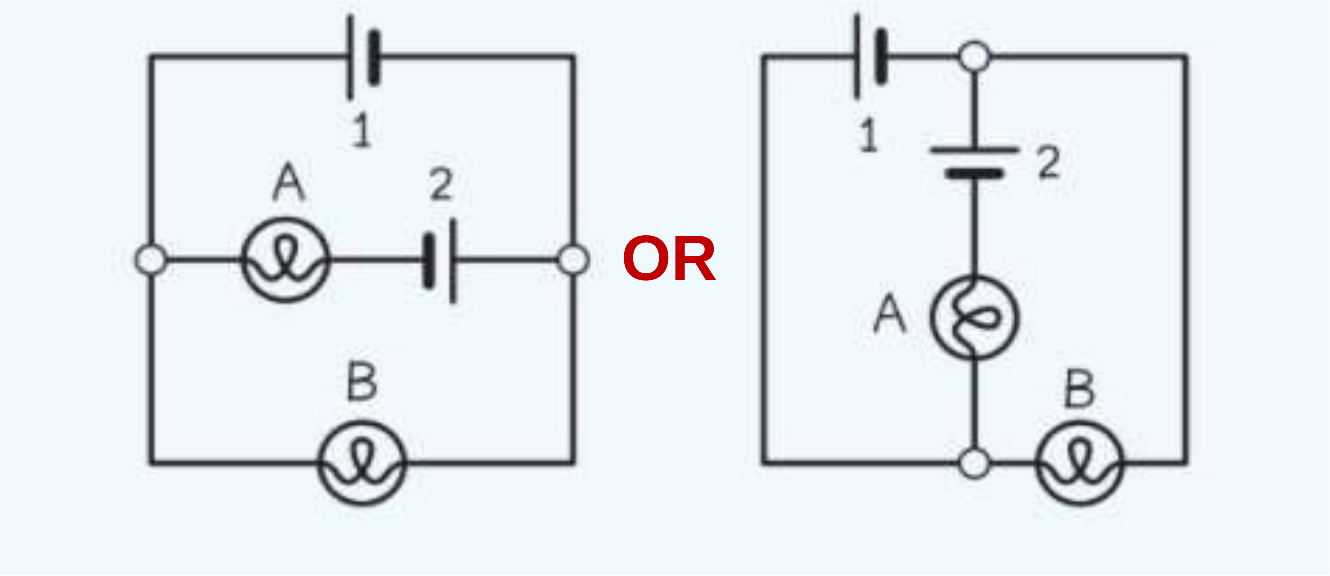
Standard representations of some common circuit elements used in circuit diagrams:

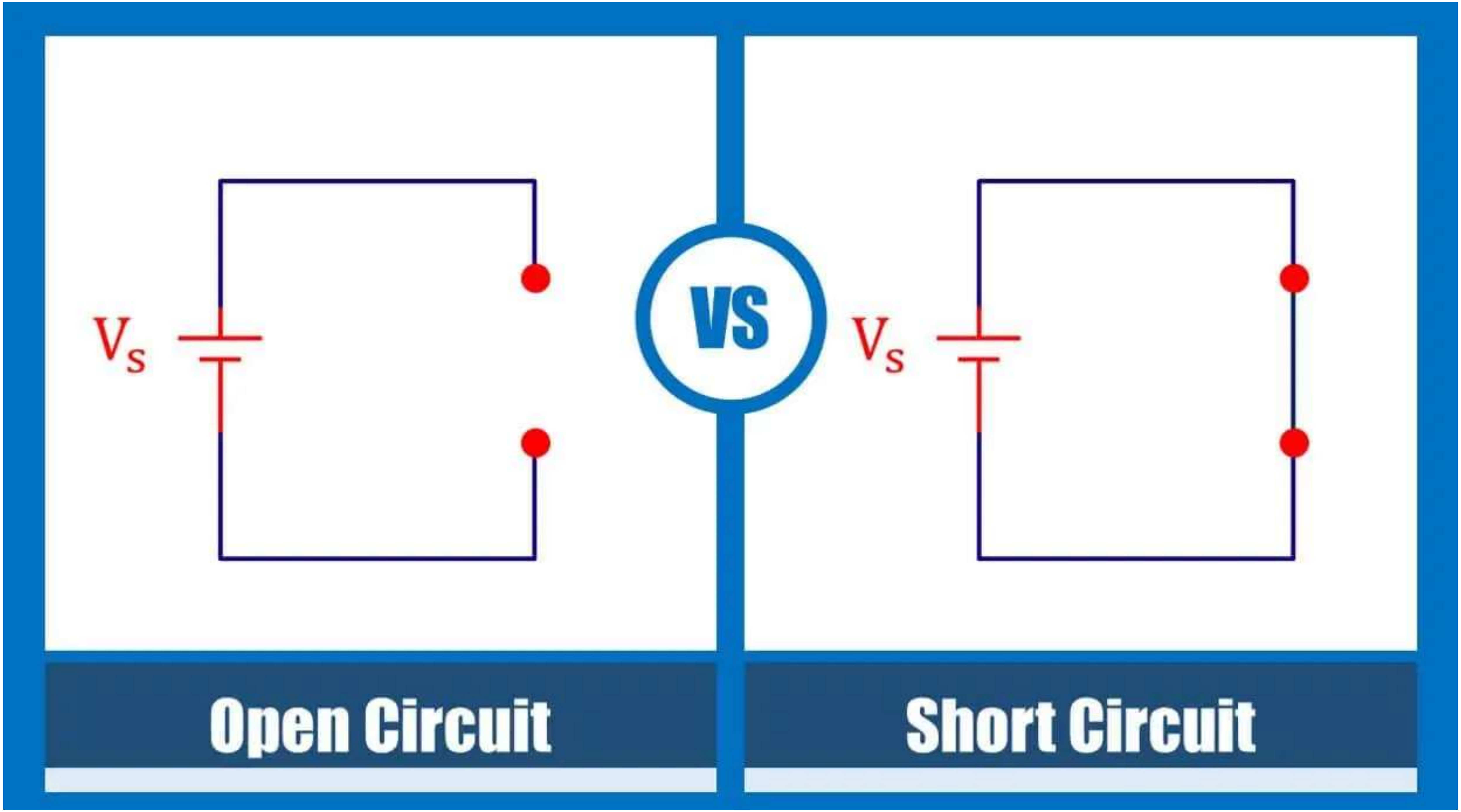


Draw the circuit diagram for the circuit below.









- The circuit is not complete
  - No current will flow
- Circuit resistance is extremely low.
  - Current is very high!

EMF Source (ε)

- Does work on charge carriers
- The term *emf* comes from the outdated phrase *electromotive force,* which was adopted before scientists clearly understood the function of an emf device.
- <u>Example:</u> Battery

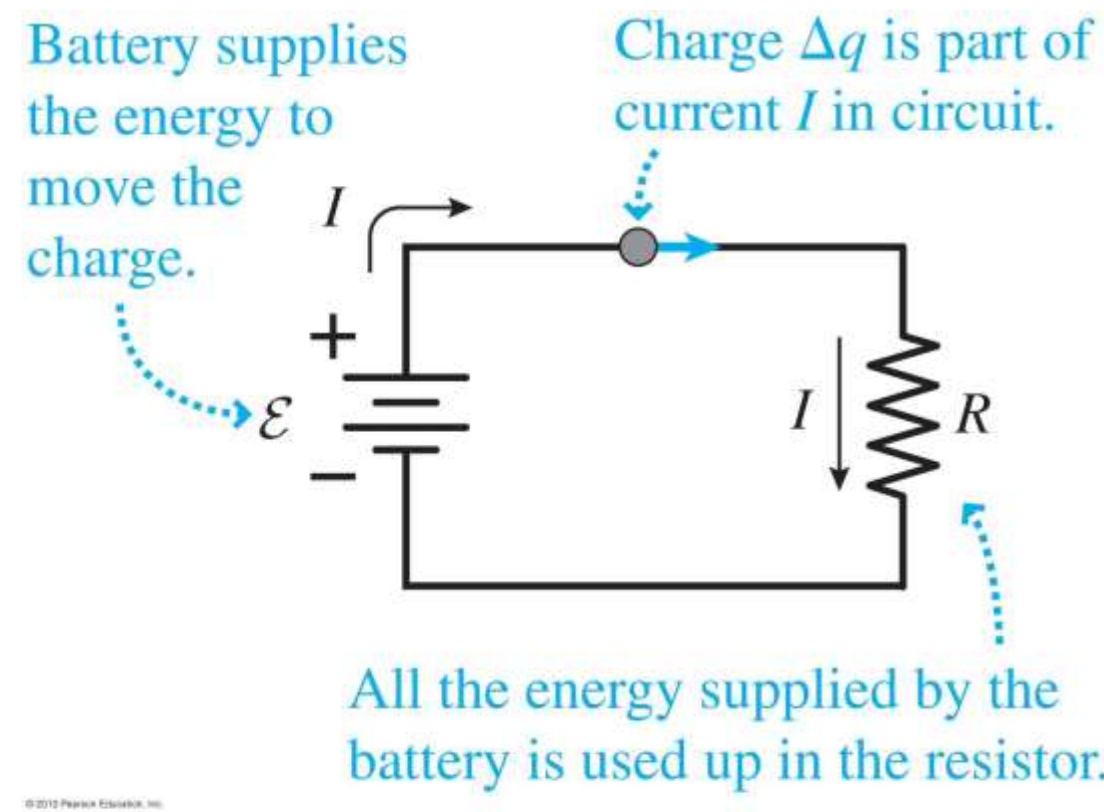
$$\varepsilon = \frac{dW}{dq}$$

Electric Power

If the source is adding energy to the charges, we refer to it as an emf (electromotive force) source (Ɛ). <u>Examples</u>: batteries, generators….

Power Supplied by an emf source:

$$\boxed{P = I\mathcal{E}}$$



Power Dissipated in a Resistor:

$$\boxed{P_R = I_R^2 R = \frac{V_R^2}{R}}$$

SI unit: [P] = W (watts)

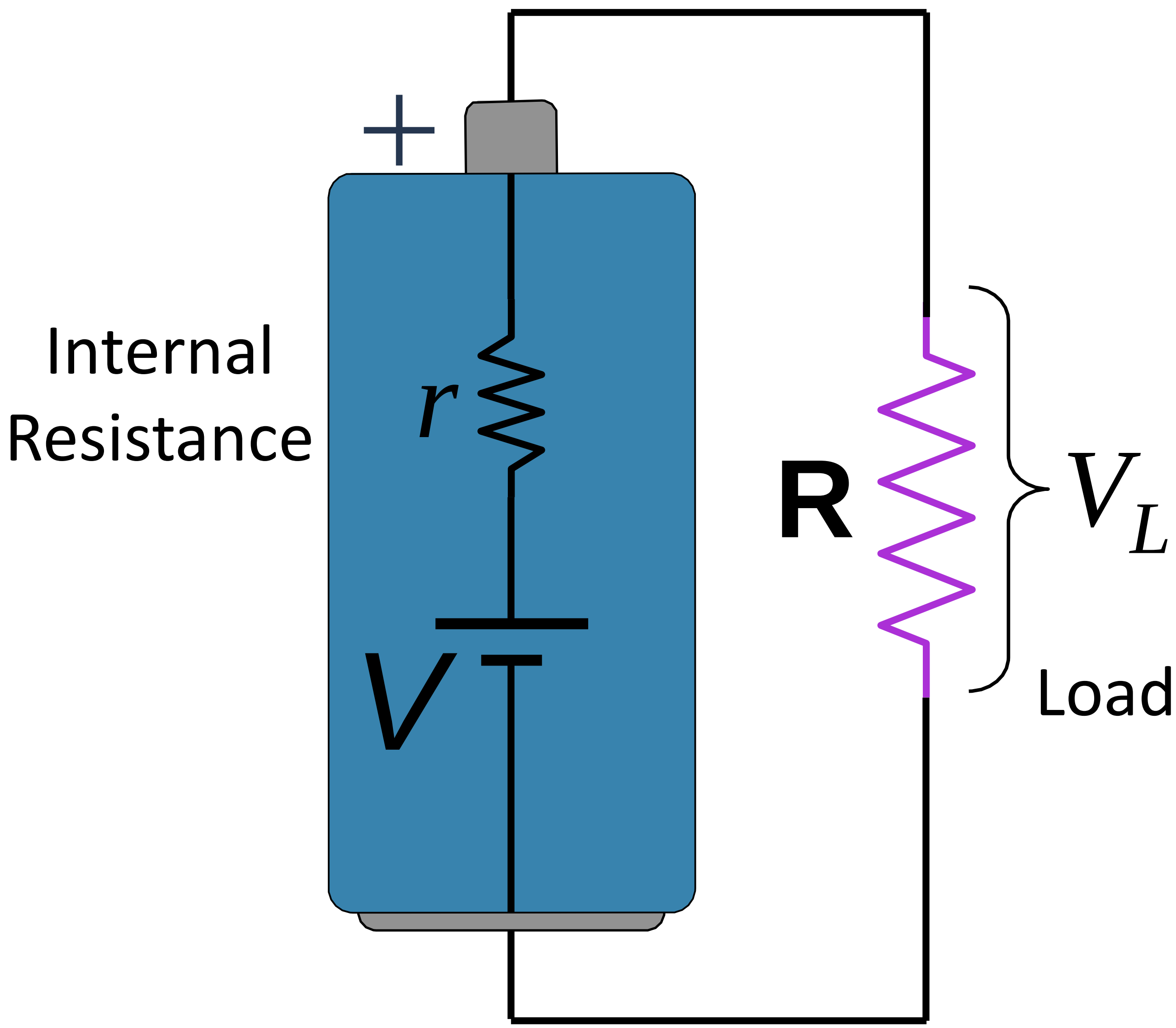
[Ɛ] = V (volts)

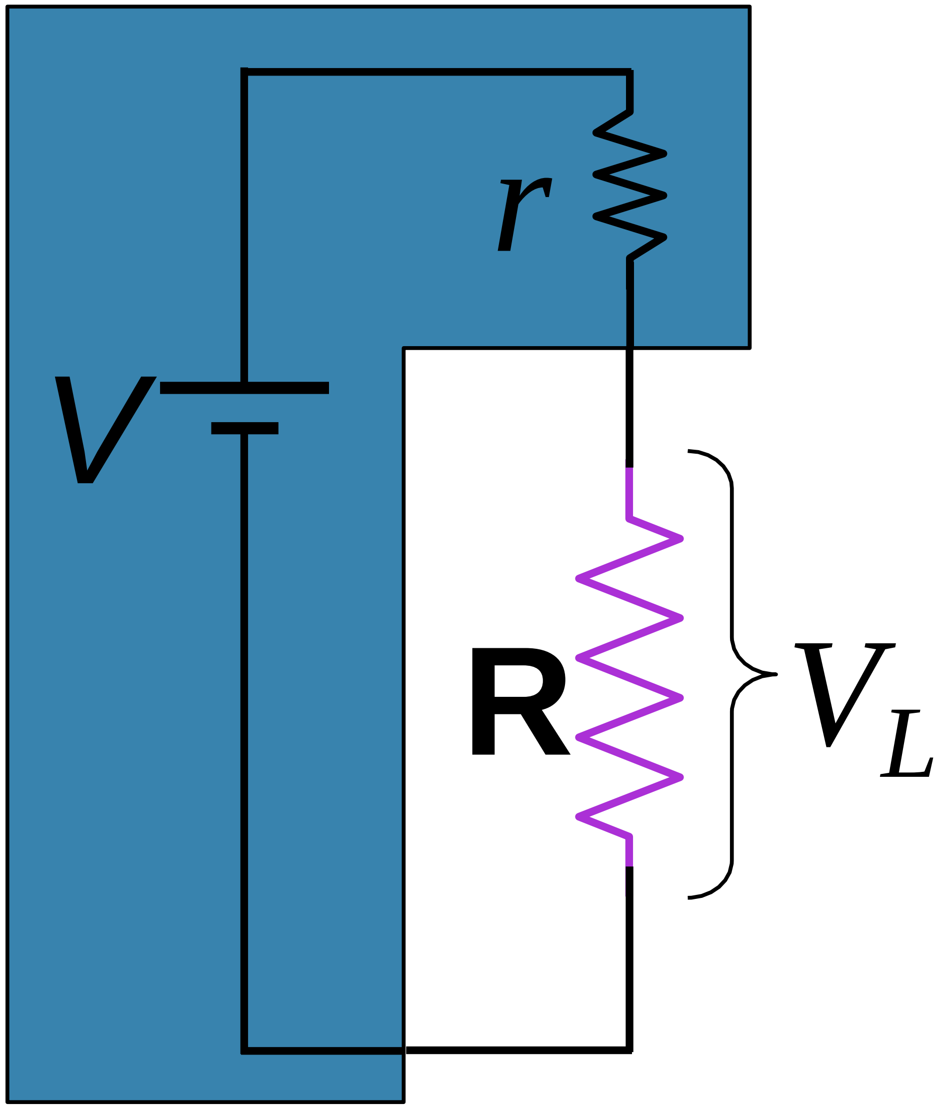
In a resistor, the electrical energy gets converted into thermal energy.

Power Demo

- Lightbulbs

Real Batteries: *Internal Resistance*





$$I = \frac{V}{R + r}$$

Why So Many Battery Sizes?

AAA AA C D

All 1.5V

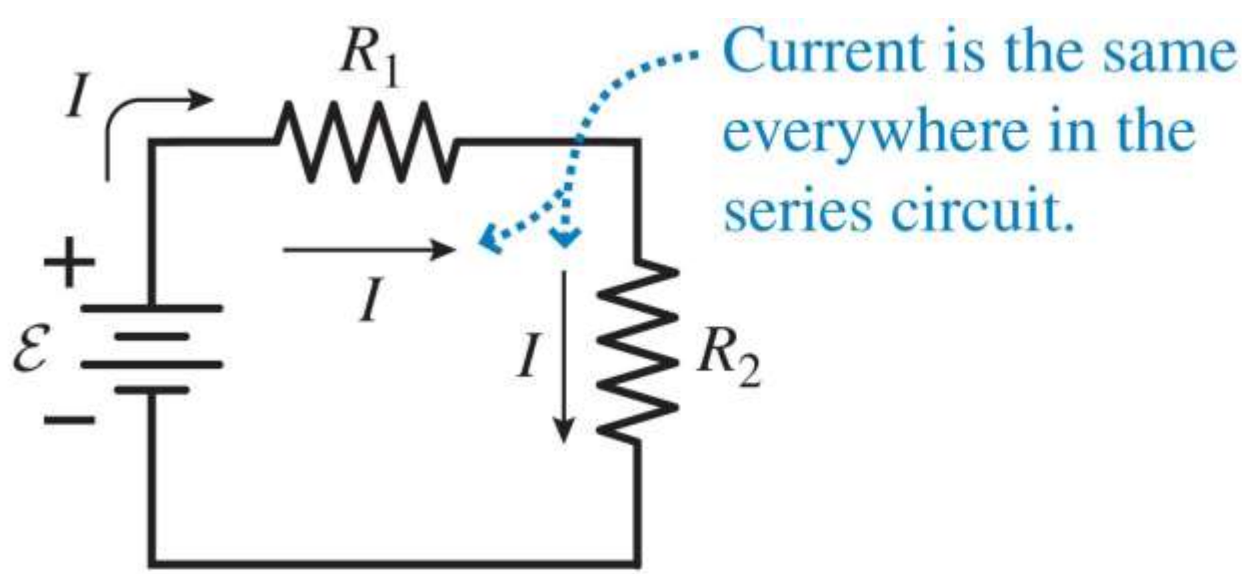
Increasing internal resistance

Larger-sized batteries have a smaller internal resistance

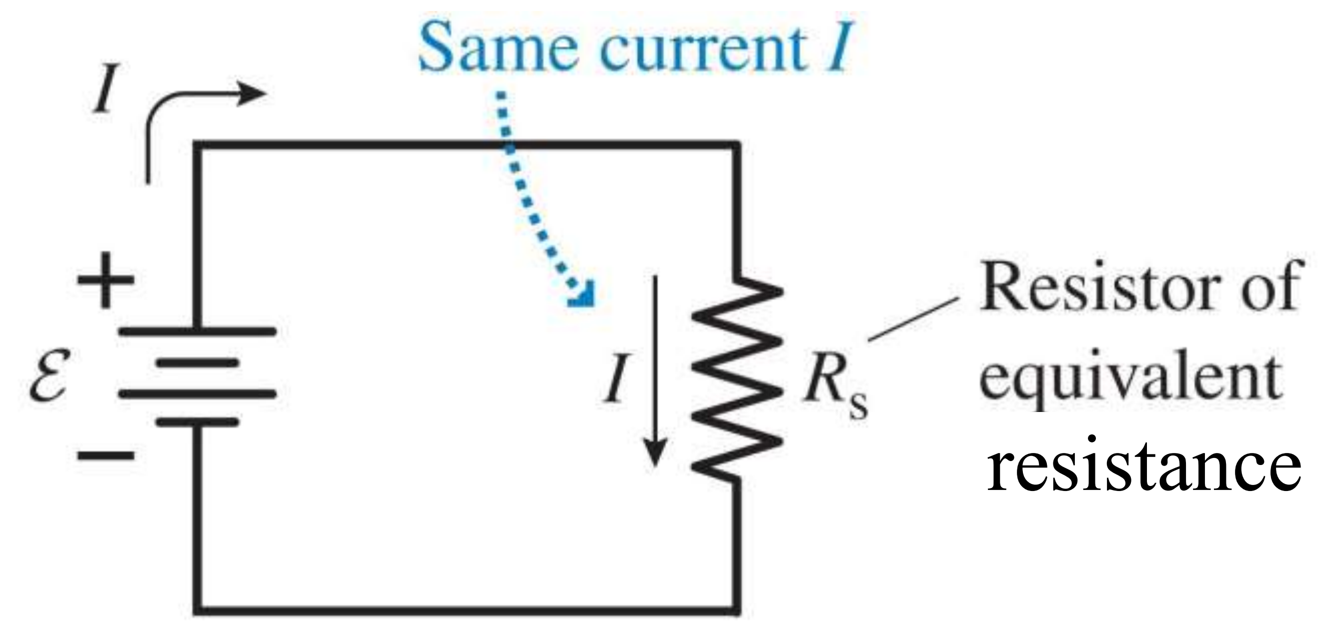
=> larger current output

Single Loop Circuit

- Current makes one continuous loop
- <u>Key point:</u> Current is the same for both resistors
- Resistors are in series



(a) Resistors connected in series

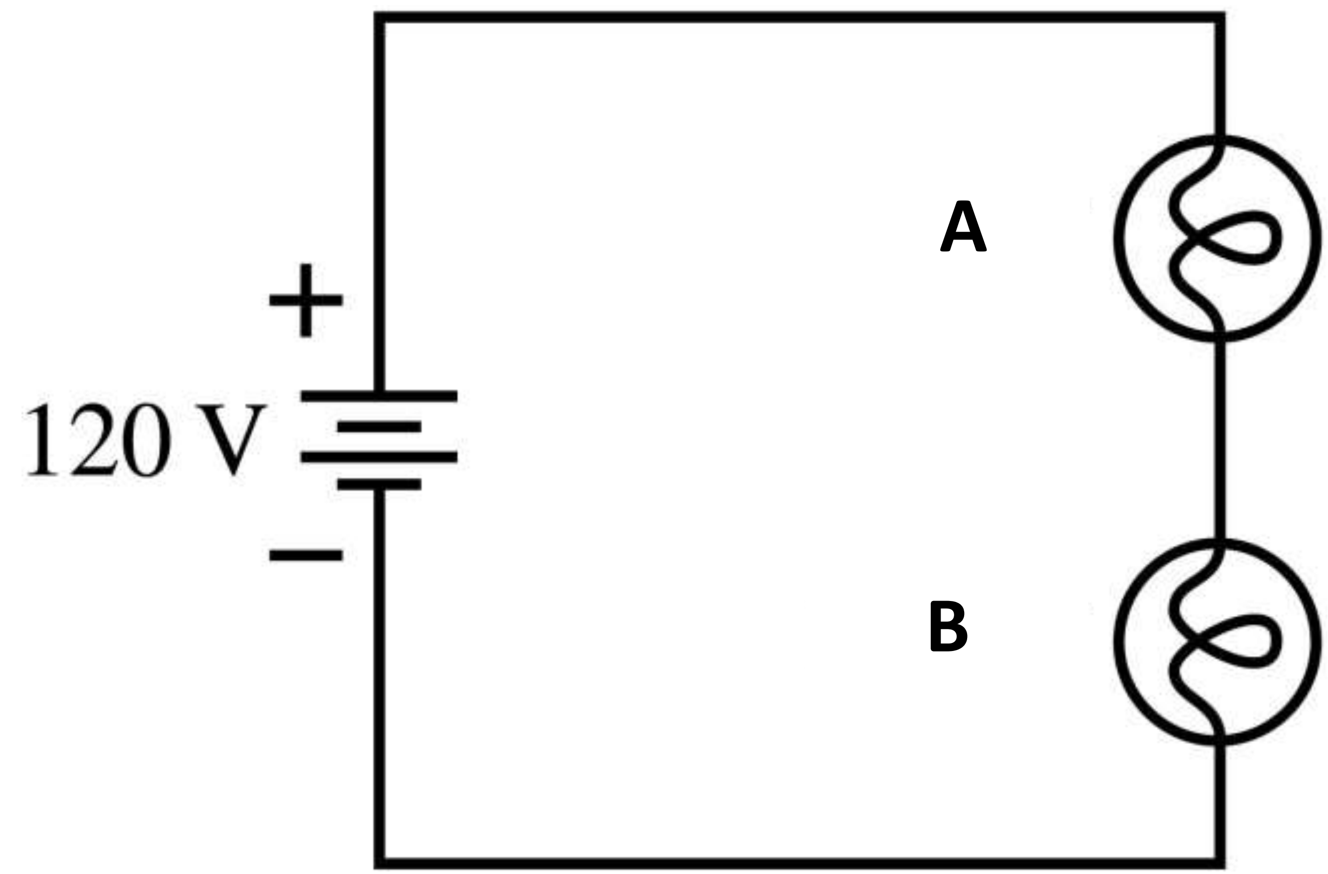


(b) The two resistors are replaced by one of equivalent resistance R_s.

$$e = V_1 + V_2 \qquad e = R_1 I + R_2 I = R_s I \qquad \boxed{R_{eq} = R_1 + R_2}$$

Question: Lightbulbs

Two identical lightbulbs are connected as shown in the figure. Which bulb is brighter?



A. Bulb A

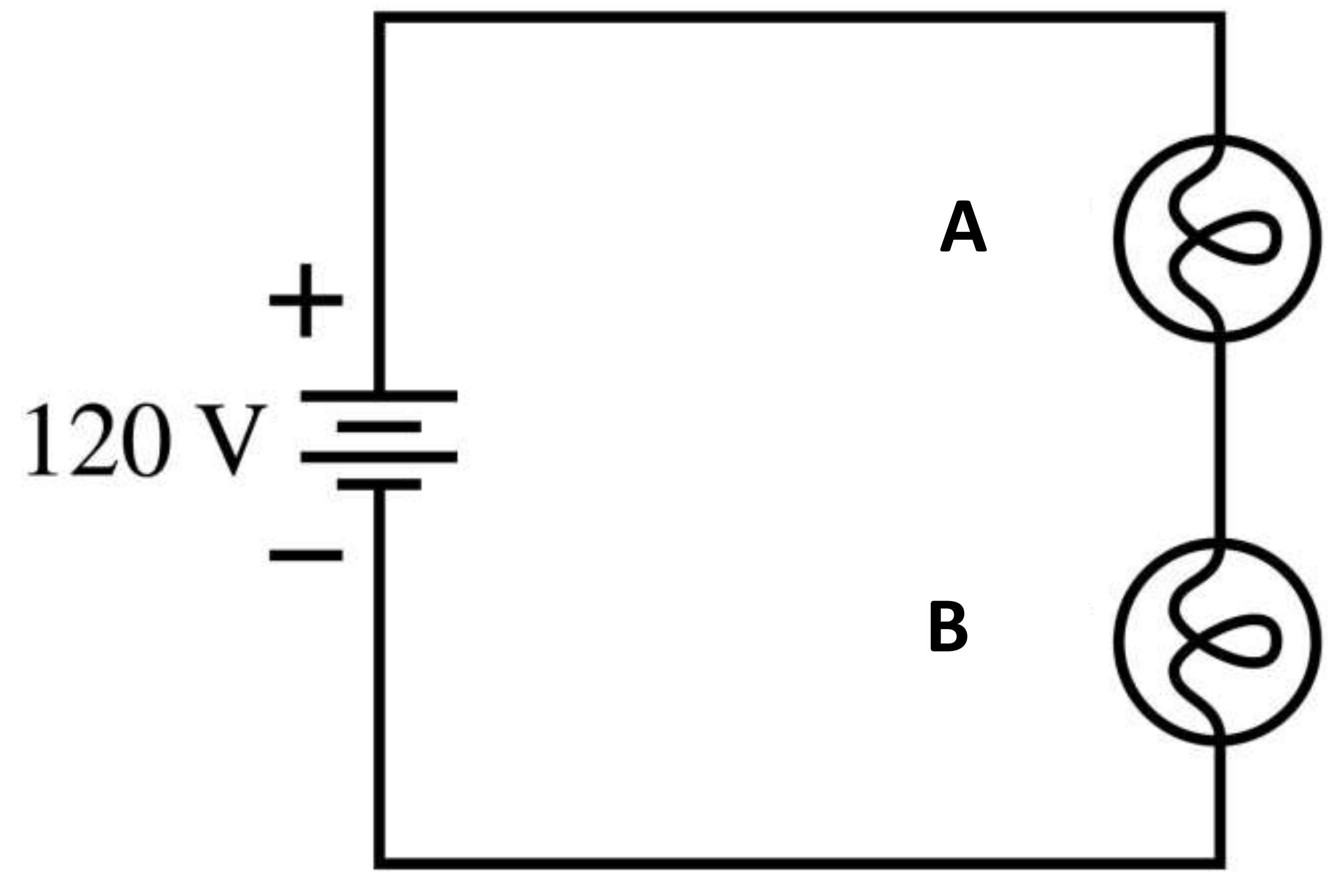
B. Bulb B

C. Both bulbs are equally bright.

D. There's not enough information to tell.

Question: Lightbulbs Answer

Two identical lightbulbs are connected as shown in the figure. Which bulb is brighter?



A. Bulb A

B. Bulb B

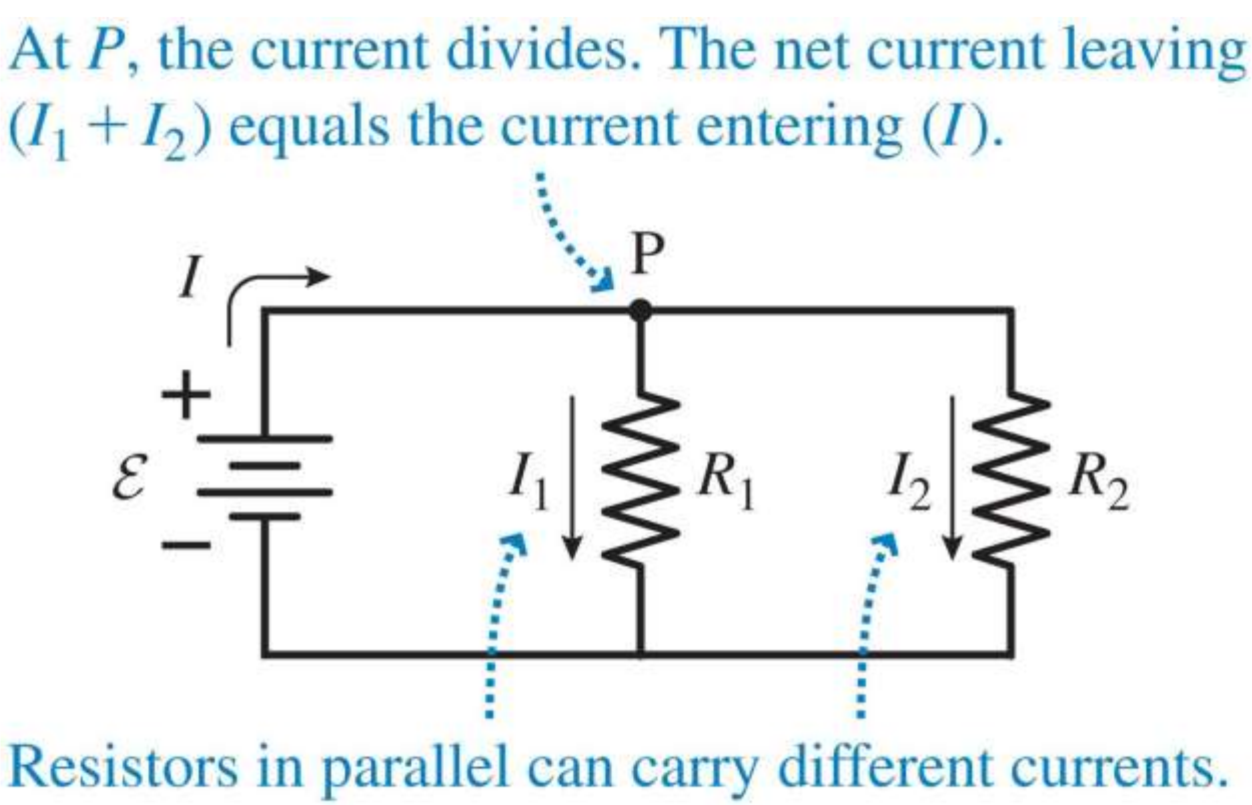
C. Both bulbs are equally bright.

D. There's not enough information to tell.

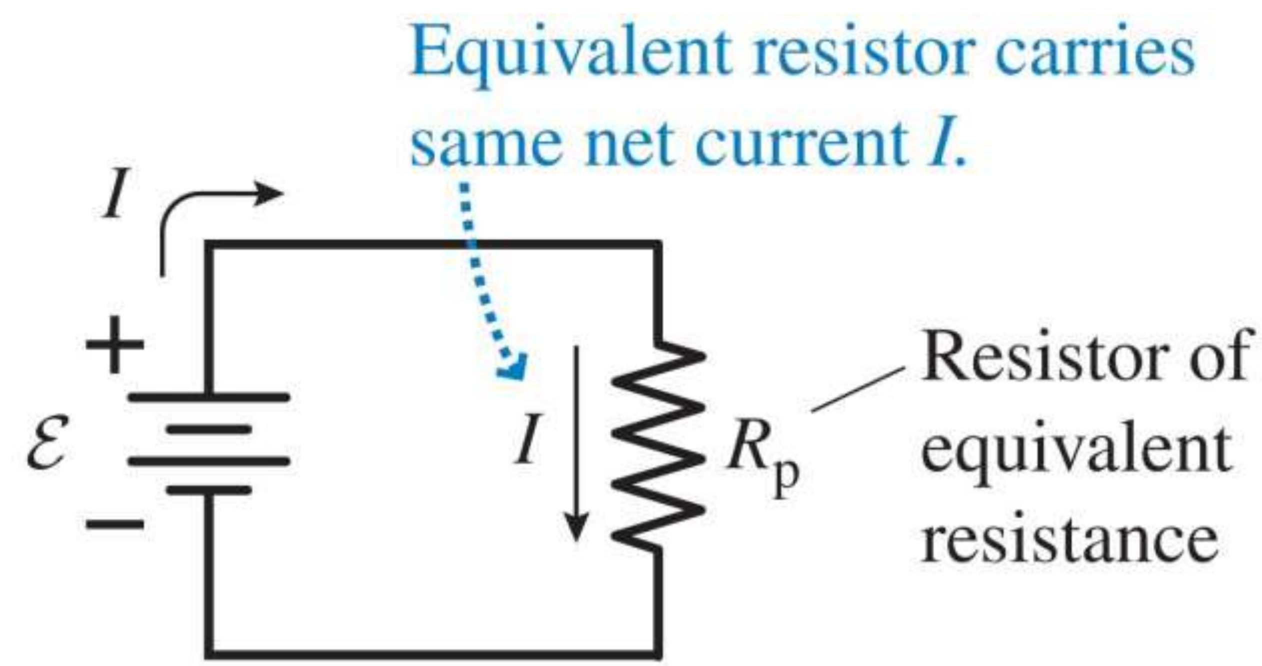
Both bulbs have the same current because they are in series. Since the resistance is same for each bulb, the voltage drop across each is the same ($V = IR$).

Multiloop Circuits

- Current splits to flow through multiple loops
- Key point: Potential difference V is the same for both resistors
- Resistors are in parallel



(a) Resistors connected in parallel

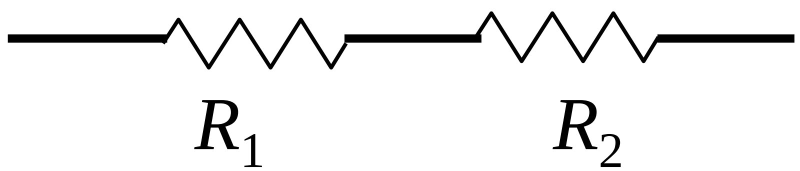
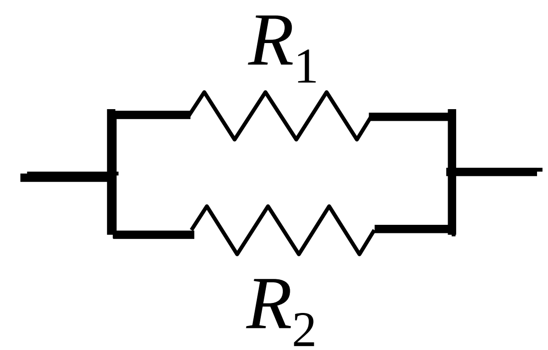


(b) The two resistors are replaced by one of equivalent resistance R_p.

$$e = V_1 = V_2 \qquad e = R_1 I_1 = R_2 I_2 = R_p I$$

$$\boxed{\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}}$$

Resistor Summary

Series Circuit	Parallel Circuit
	
All components are connected with the same wire	There is a junction in the wire separating components
Voltage is <u>different</u> for each resistor. $V_{total} = V_1 + V_2$	Voltage is <u>same</u> for each resistor. $V_{total} = V_1 = V_2$
Current is <u>same</u> for each resistor $I_{total} = I_1 = I_2$	Current is <u>different</u> for each resistor $I_{total} = I_1 + I_2$
$R_{eq} = R_1 + R_2 + \ldots$	$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$

Question: Lightbulbs Again

The three bulbs are identical, and the two batteries are identical. Compare the brightnesses of the bulbs.

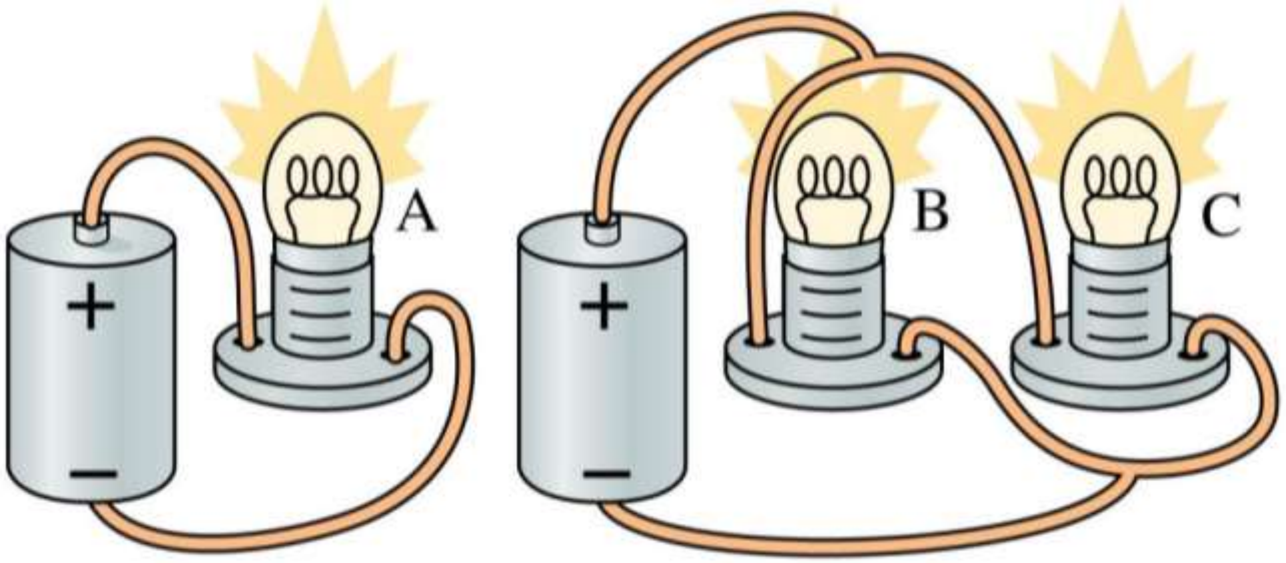
A. $A > B > C$

B. $A > C > B$

C. $A > B = C$

D. $A < B = C$

E. $A = B = C$



Question: Lightbulbs Again Answer

The three bulbs are identical, and the two batteries are identical. Compare the brightnesses of the bulbs.

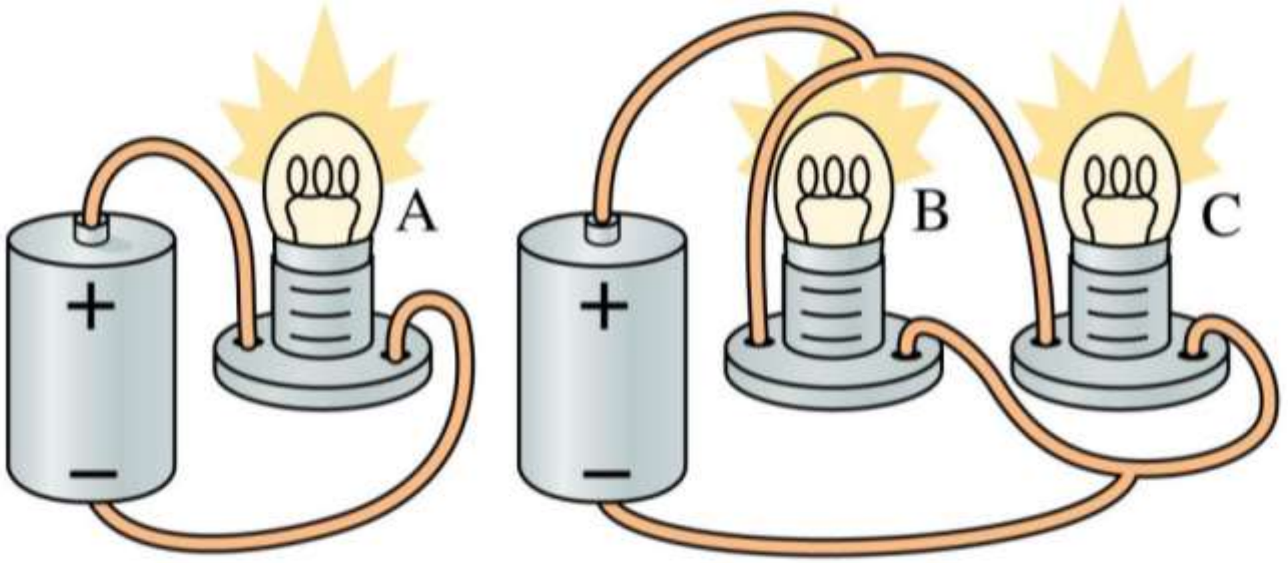
A. A > B > C

B. A > C > B

C. A > B = C

D. A < B = C

E. A = B = C



Voltage is same for all bulbs.
Bulb A is connected directly to the battery.
Bulbs B and C are in parallel with the battery, so they have the same voltage as the battery.

Kirchhoff’s Laws

LEARNING GOALS

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

- Analyze basic circuits using Kirchhoff’s Circuit Laws
- Explain Kirchhoff’s Voltage Law and how it relates to energy conservation
- Explain Kirchhoff’s Current Law and how it relates to charge conservation

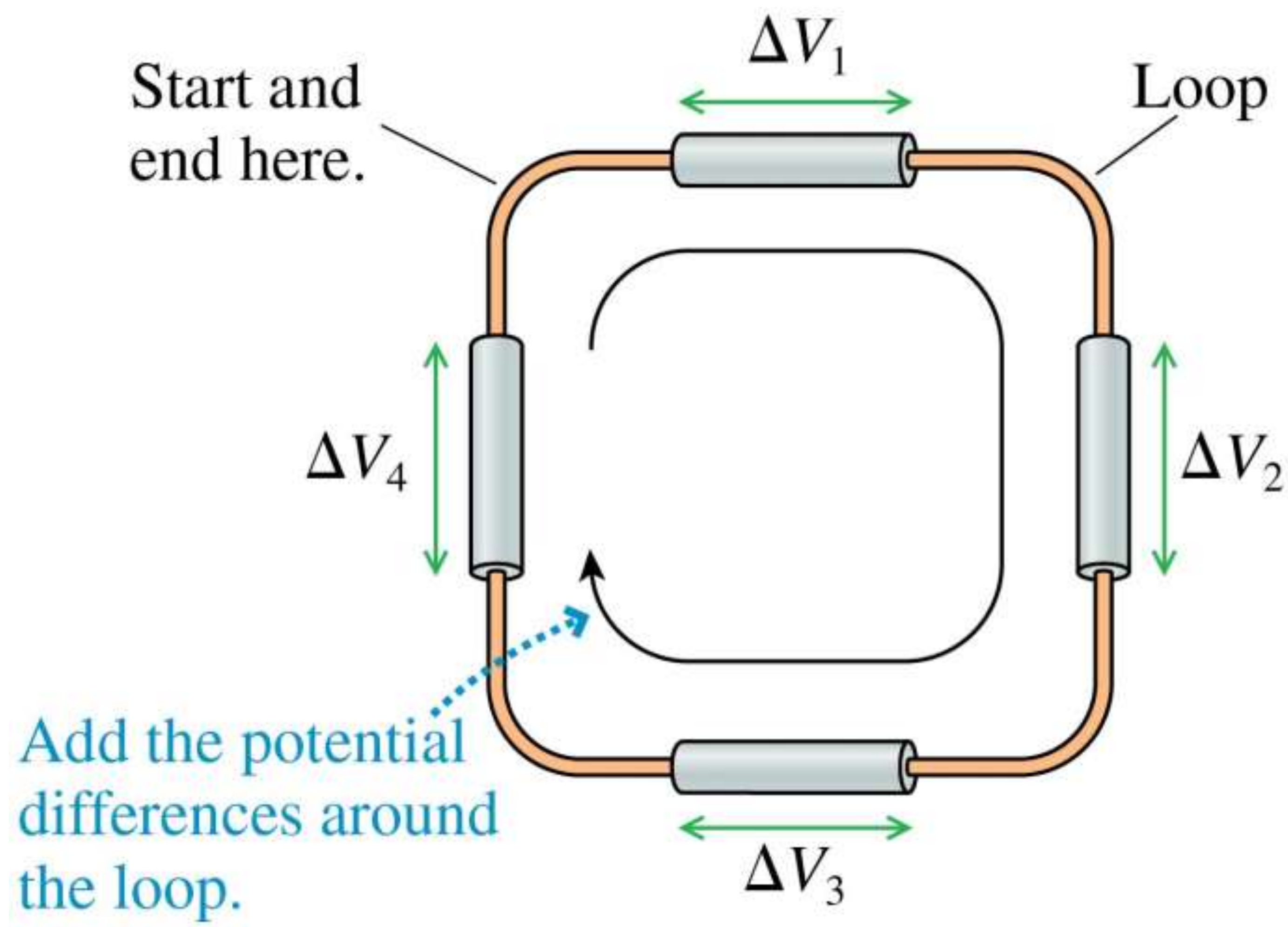
Kirchhoff’s Voltage Law

- For any path that starts and ends at the same point:

$$\Delta V_{\text{loop}} = \sum (\Delta V)_i = 0$$

- The sum of all the potential differences encountered while moving around a loop or closed path is zero.

- Also known as: loop law, KVL, Kirchhoff’s loop rule



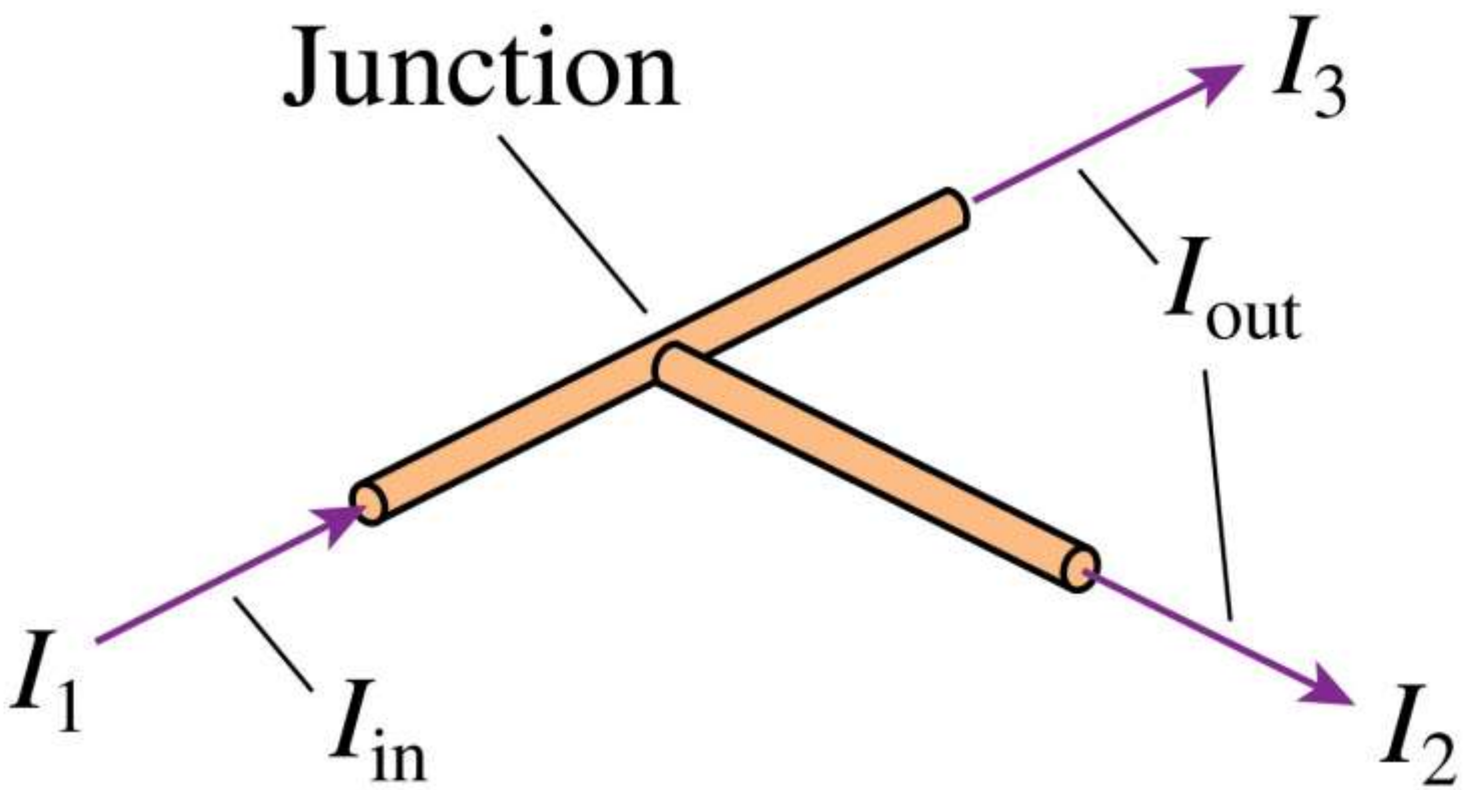
Loop law: $\Delta V_1 + \Delta V_2 + \Delta V_3 + \Delta V_4 = 0$

Kirchhoff's Current Law

- For a *junction*, the law of conservation of current requires that:

$$\sum I_{\text{in}} = \sum I_{\text{out}}$$

- where the Σ symbol means summation
- Also known as:
  - Junction Rule
  - KCL
  - Kirchhoff's junction rule



Junction law: $I_1 = I_2 + I_3$

Question: Branching Current

What is the current in branch P?

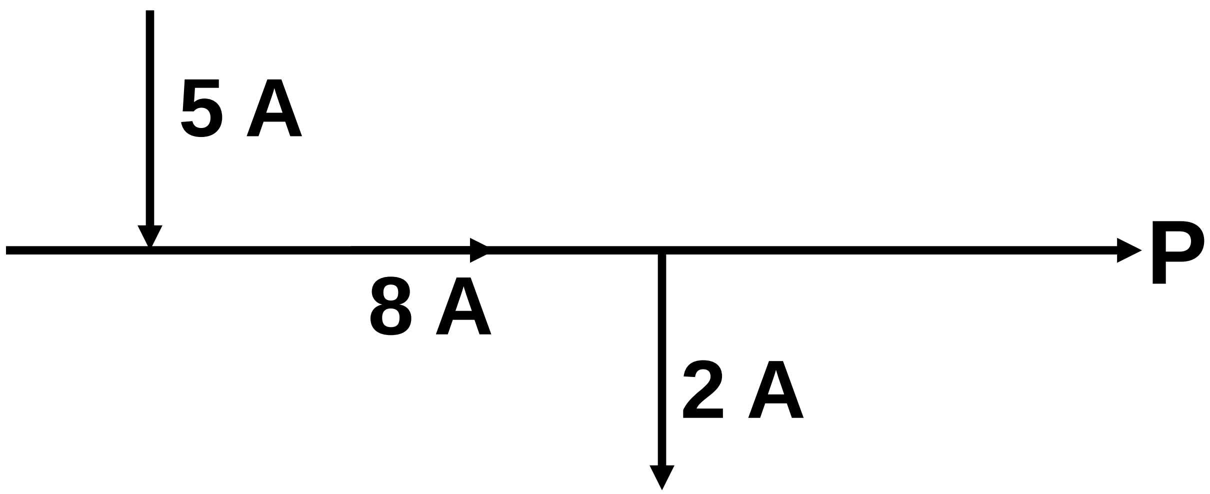
A. 2 A

B. 3 A

C. 5 A

D. 6 A

E. 11 A



Question: Branching Current Answer

What is the current in branch P?

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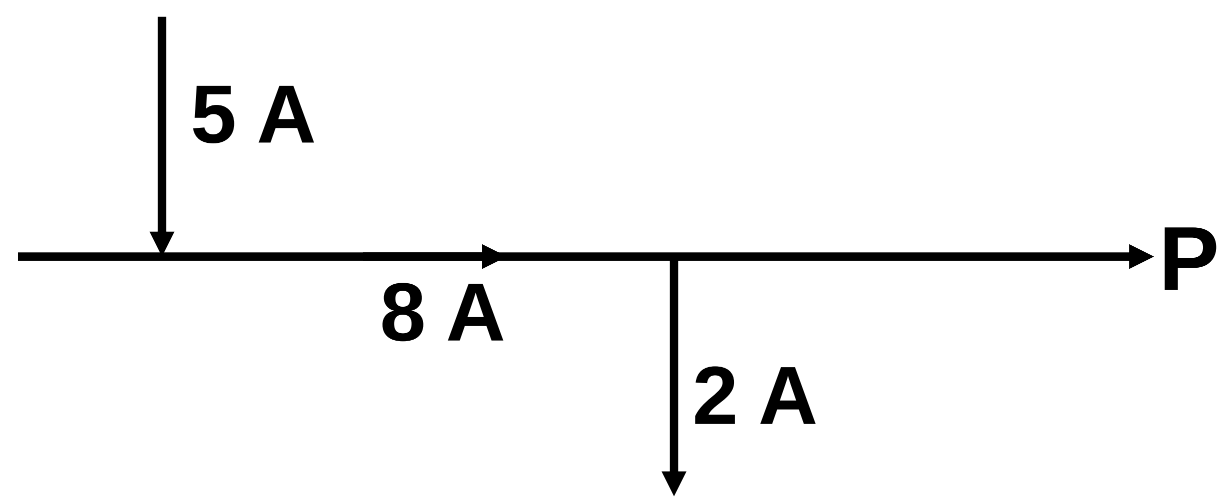
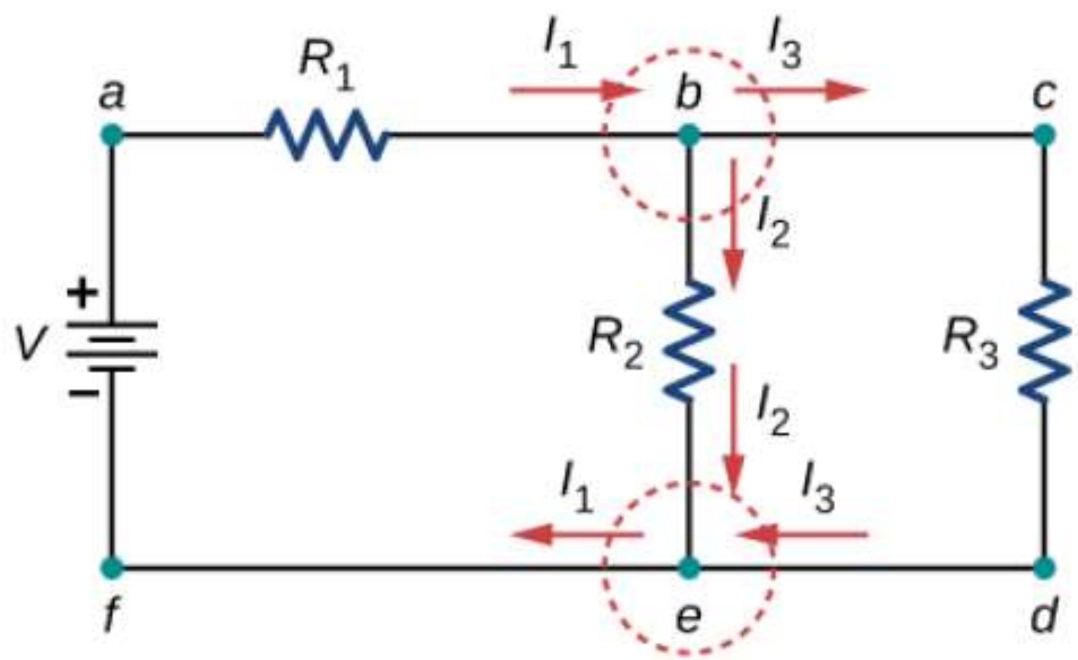
E. 11 A



The current entering the right junction is 8 A, so the current leaving must also be 8 A. One exiting branch has 2 A, so the other branch (at P) must have 6 A.

Kirchhoff’s Laws Strategy



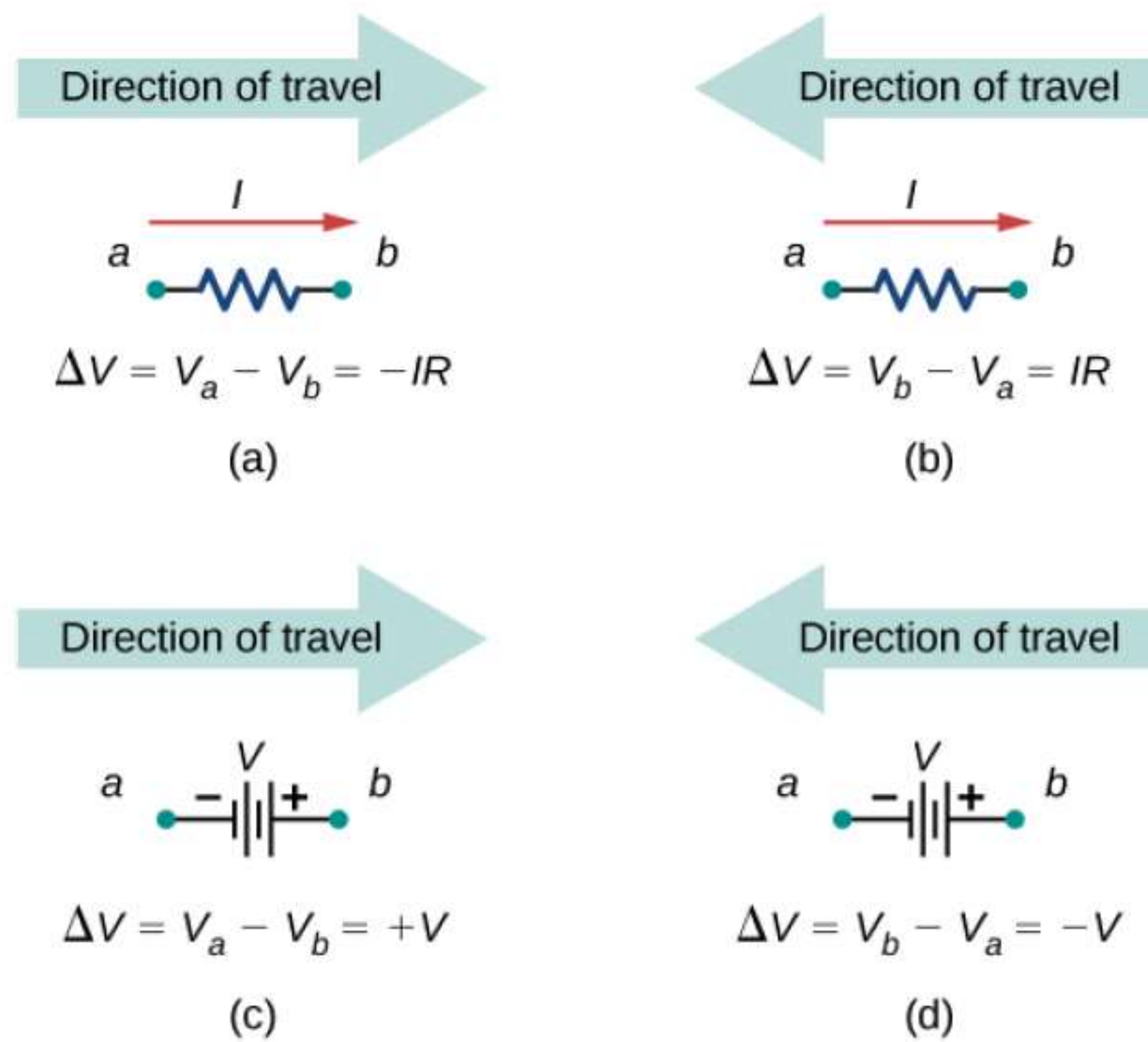
1) Label all currents
    - Choose any direction

2) Choose loops
    - Try to choose the loop direction in

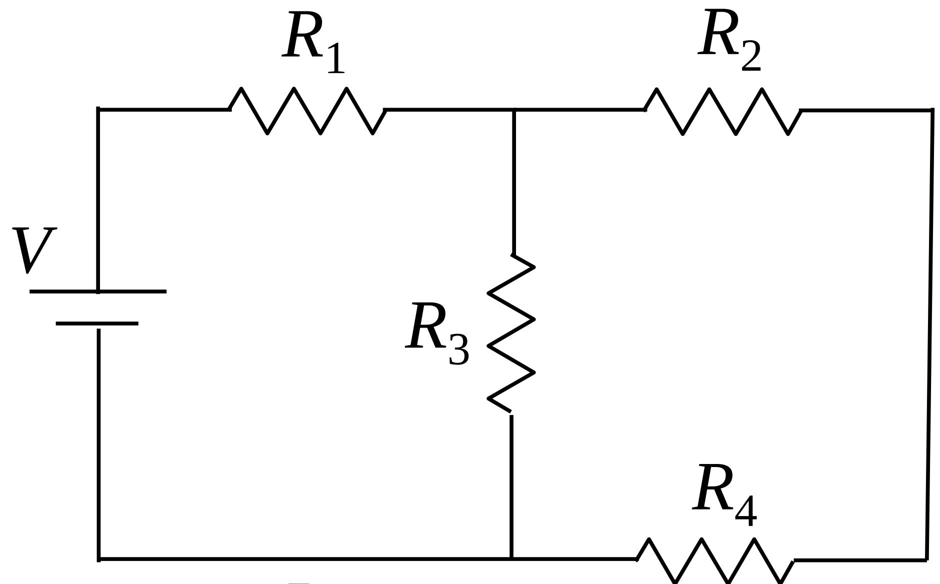
    the same direction as the currents

3) Write down voltage changes as you follow the direction of your loops

4) Write down current equation:
$$I_{\text{in}} = I_{\text{out}}$$

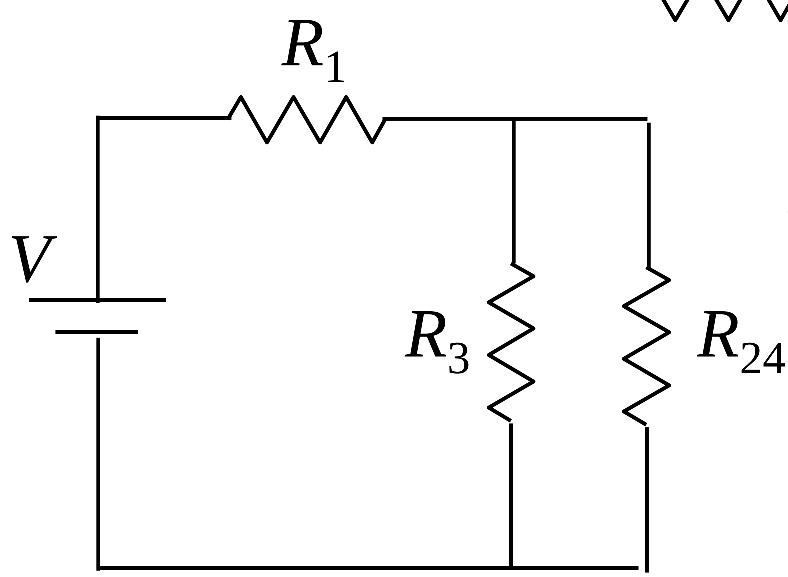


Example: Circuit Currents - 1

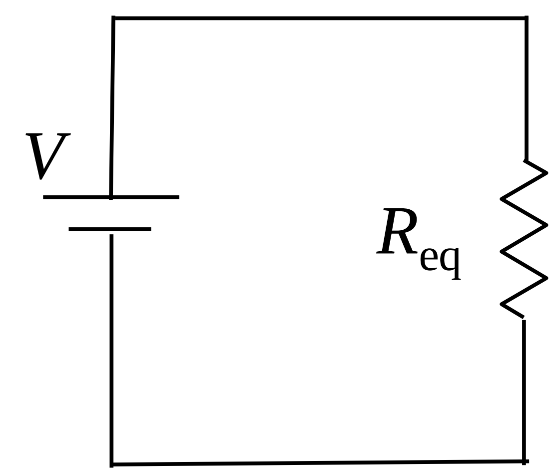


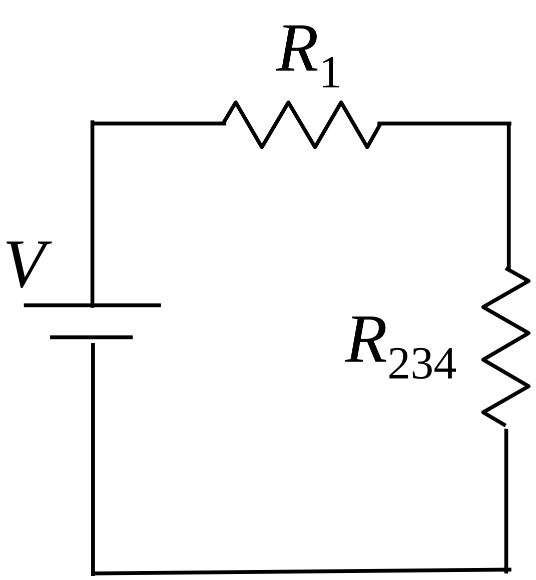
For this circuit, what is the current through each resistor?

Step 1: Find equivalent resistance.



$$R_{24} = R_2 + R_4$$





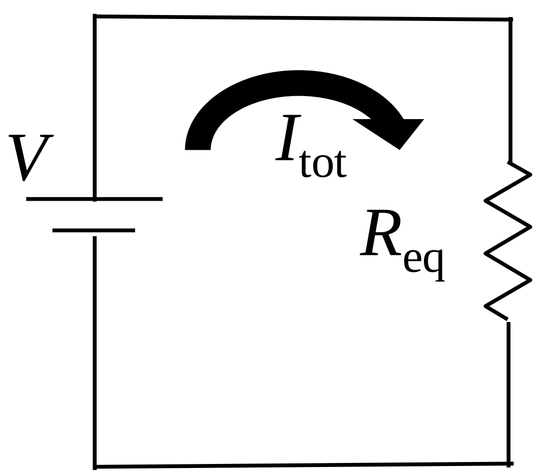
$$R_{234} = \left(\frac{1}{R_3} + \frac{1}{R_{24}}\right)^{-1}$$

$$R_{eq} = R_{234} + R_1$$

$$R_{eq} = \left(\frac{1}{R_3} + \frac{1}{R_2 + R_4}\right)^{-1} + R_1$$

Example: Circuit Currents - 2

Step 2: Find the total current.

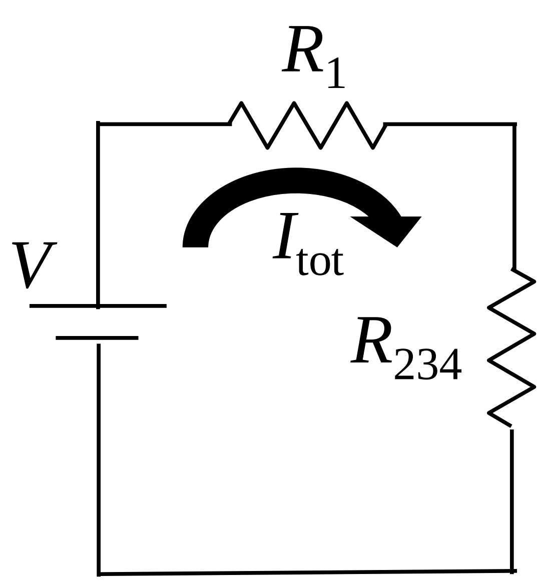


$$V = IR$$

$$V = I_{tot} R_{eq}$$

$$I_{tot} = \frac{V}{R_{eq}}$$

Step 3: Find the current through each resistor by working from simplest to most complex.



KCL:

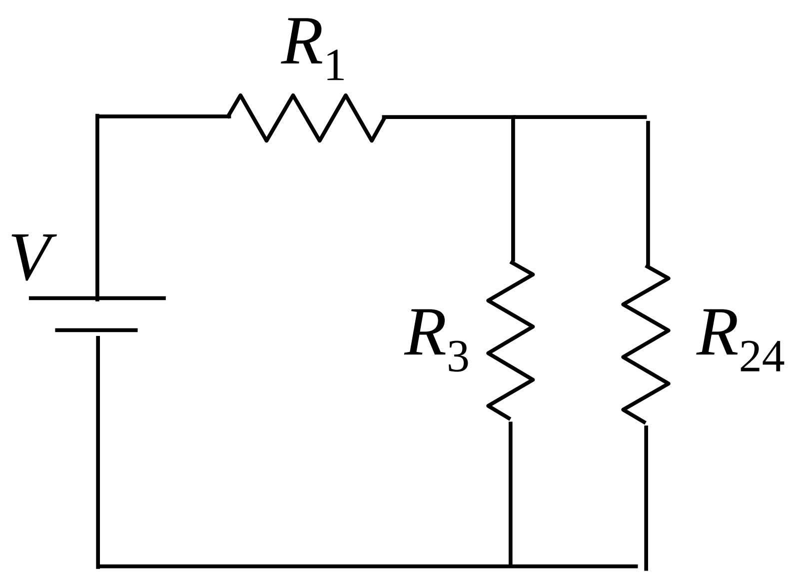
$$I_1 = I_{234} = I_{tot} = \frac{V}{R_{eq}}$$

KVL:

$$V - V_1 - V_{234} = 0$$

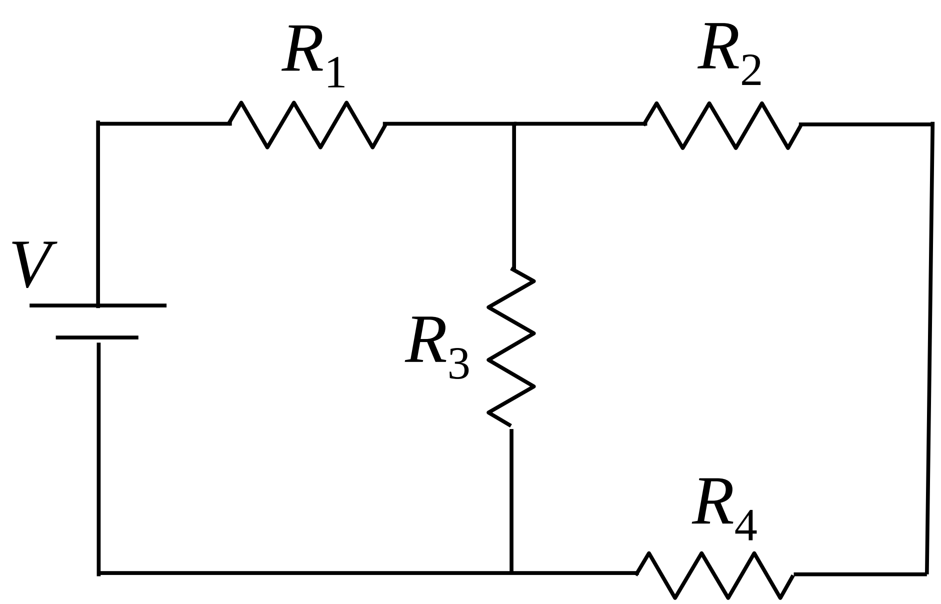
$$V_{234} = V - I_1 R_1$$

Example: Circuit Currents - 3



KVL: $V_3 = V_{24} = V_{234} = V - I_1 R_1$

$$I_3 = \frac{V_3}{R_3} = \frac{V - I_1 R_1}{R_3}$$



KCL: $I_1 = I_3 + I_{24}$

KCL: $I_{24} = I_2 = I_4$

$$I_2 = I_4 = I_1 - I_3$$

Breadboard Activity II (with Measurements)

Practice building basic circuits with breadboards

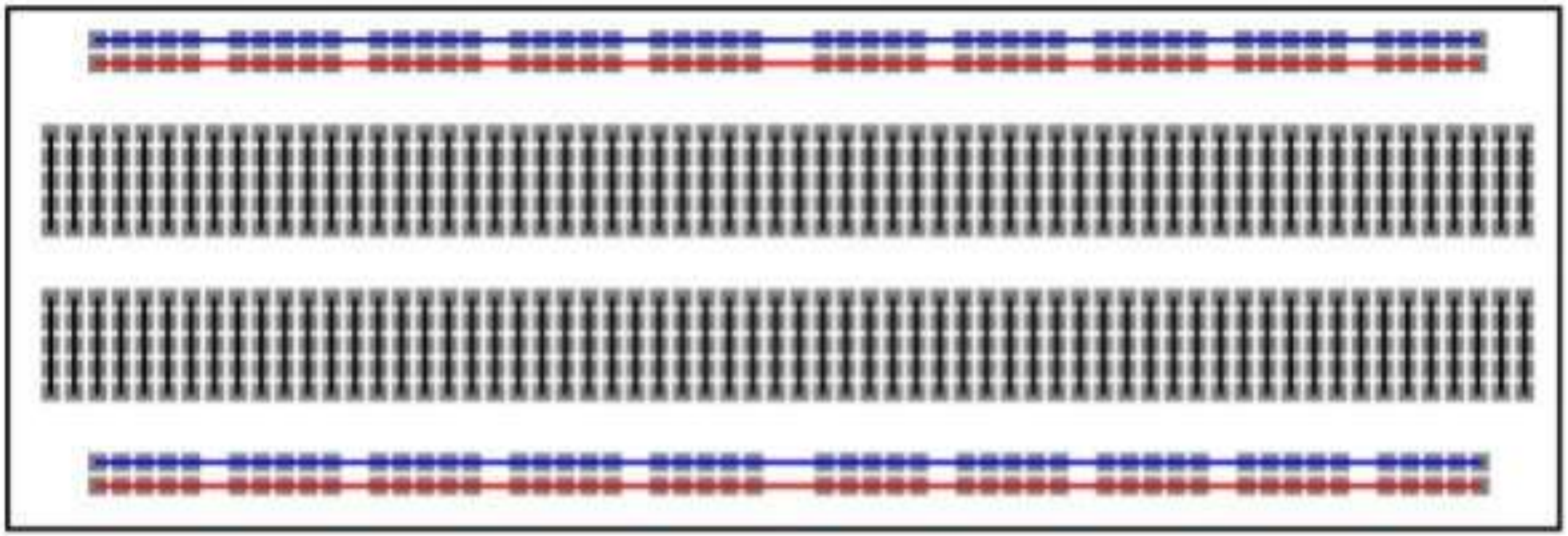


Figure 1: Breadboard layout and connection diagram

Question: Breadboards

Based on the breadboard, this wired circuit is a(n)

A. Open Circuit

B. Short Circuit

C. Parallel Circuit

D. Series Circuit

Question: Breadboards

Based on the breadboard, this wired circuit is a(n)

A. Open Circuit

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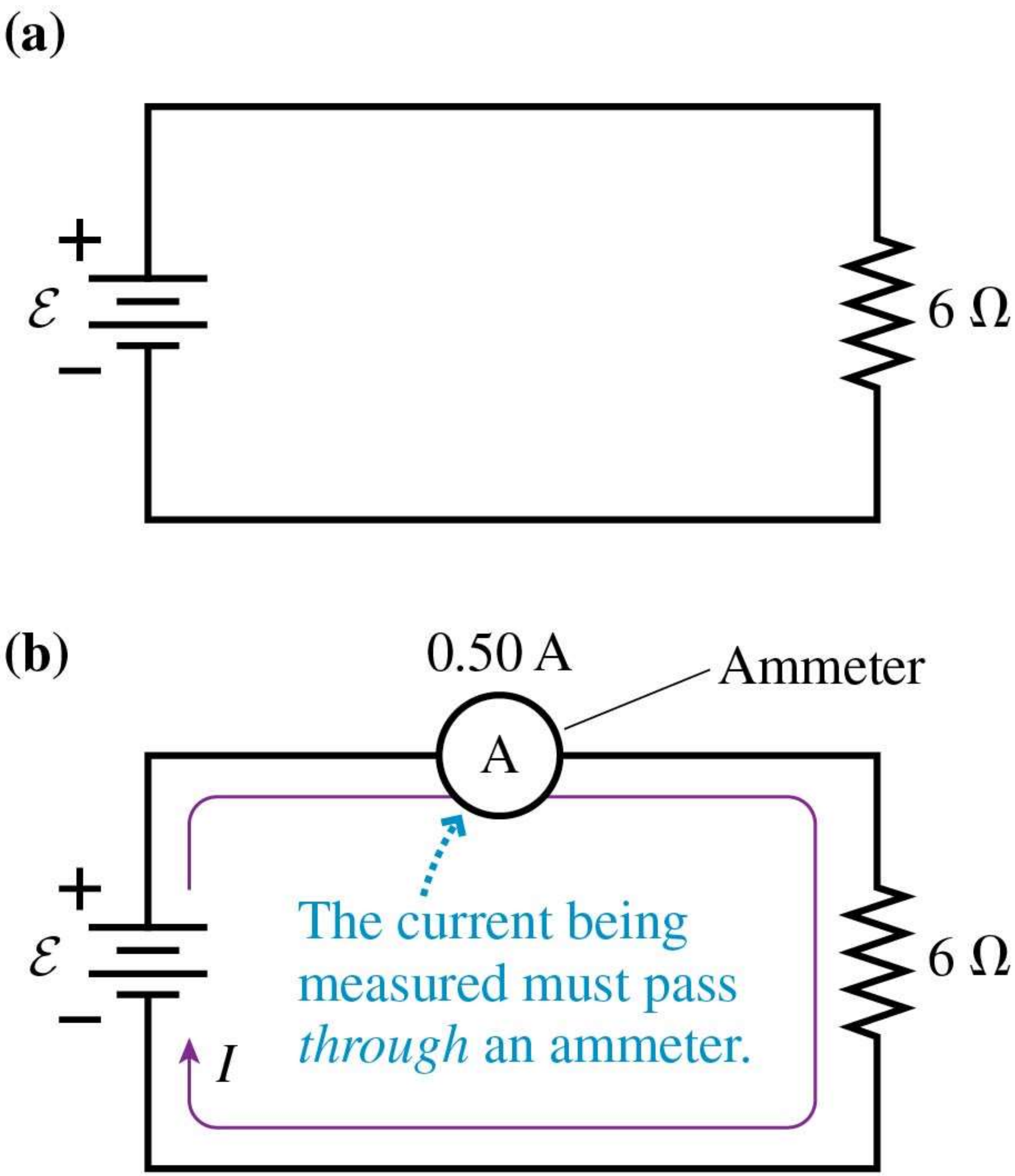
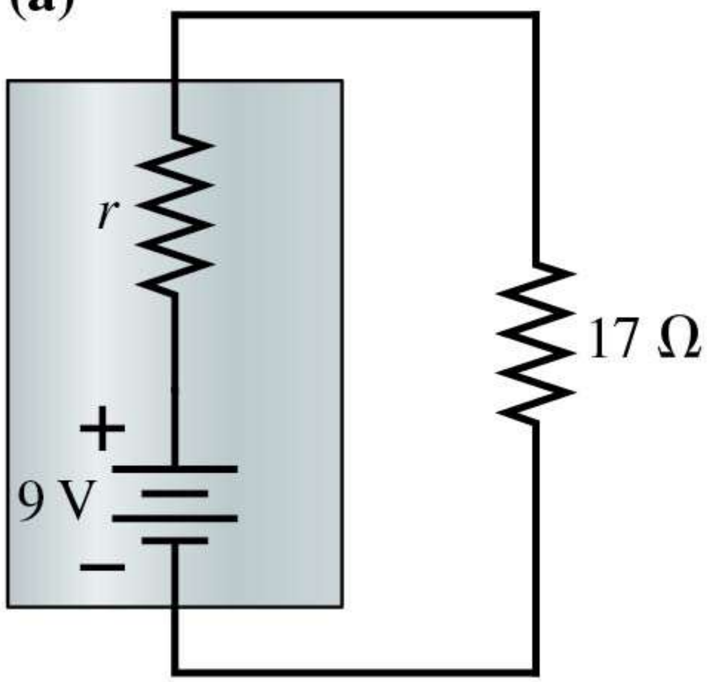
How to Measure Current: Ammeters



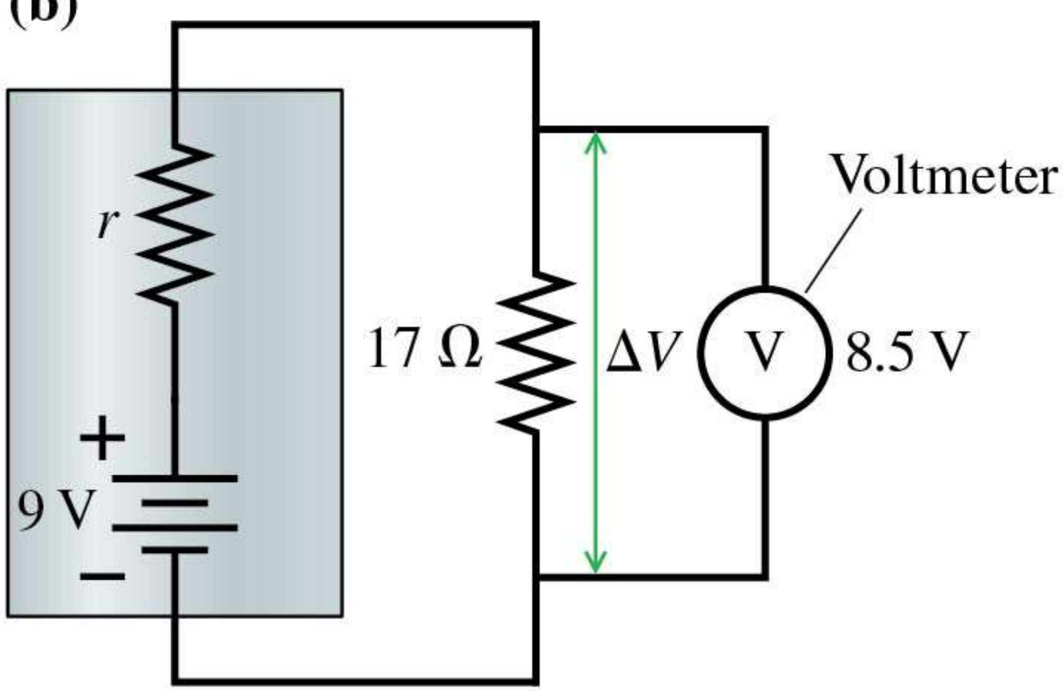
- Figure (a) shows a simple one-resistor circuit.
- We can measure the current by breaking the connection and inserting an ammeter in series.
- The resistance of the ammeter is negligible.
- The potential difference across the resistor must be $\Delta V_R = IR = 3.0$ V.
- So, battery's emf must be 3.0 V.

How to Measure Voltages: Voltmeters

(a)



(b)



- Figure (a) shows a simple circuit with a resistor and a real battery.
- We can measure the potential difference across the resistor by connecting a voltmeter in parallel across the resistor.
- The resistance of the voltmeter must be very high.
- The internal resistance is:

$$r = \frac{\mathcal{E} - \Delta V_R}{\Delta V_R} R = \frac{0.5\ \text{V}}{8.5\ \text{V}}\, 17\ \Omega = 1.0\ \Omega$$

Question: Measuring Circuits 2

- What does the voltmeter read?

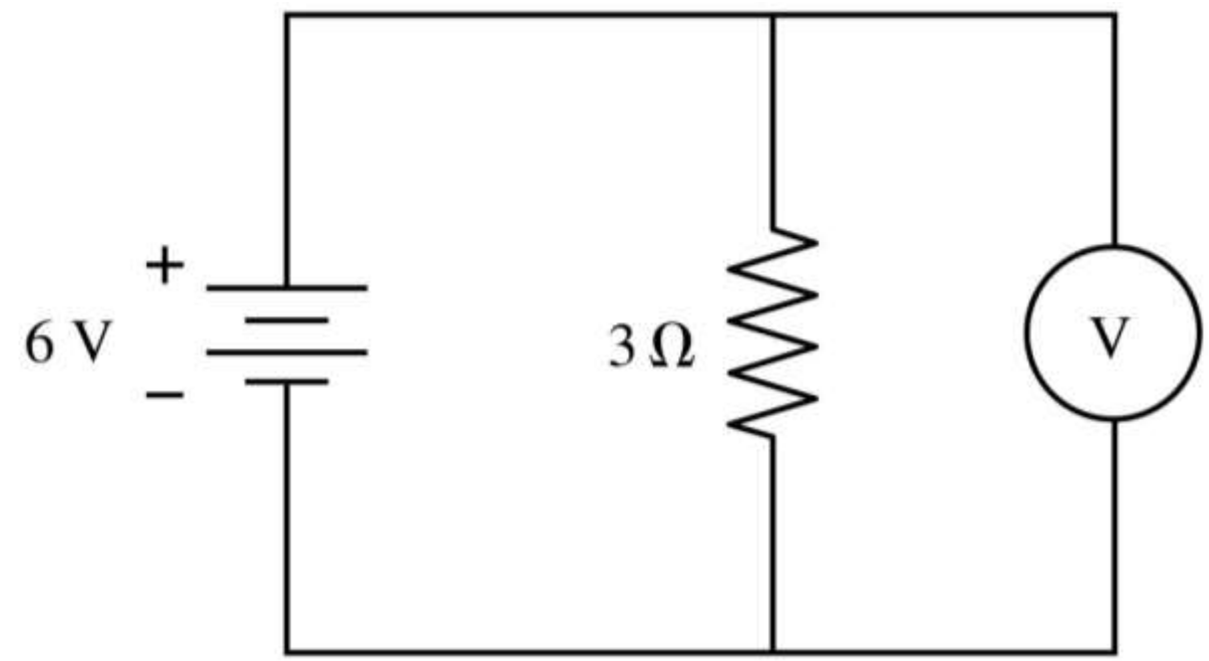
A. 6 V

B. 3 V

C. 2 V

D. Some other value

E. Nothing because this will fry the meter.



Question: Measuring Circuits 2 Answer

- What does the voltmeter read?

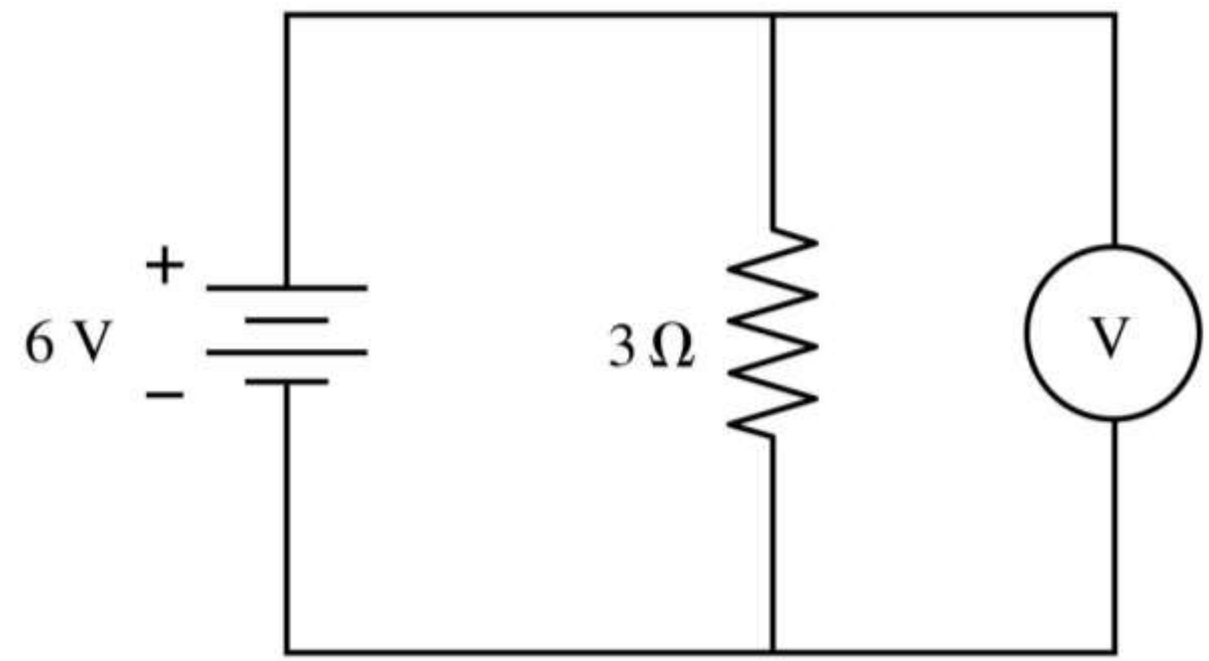
A. 6 V

B. 3 V

C. 2 V

D. Some other value

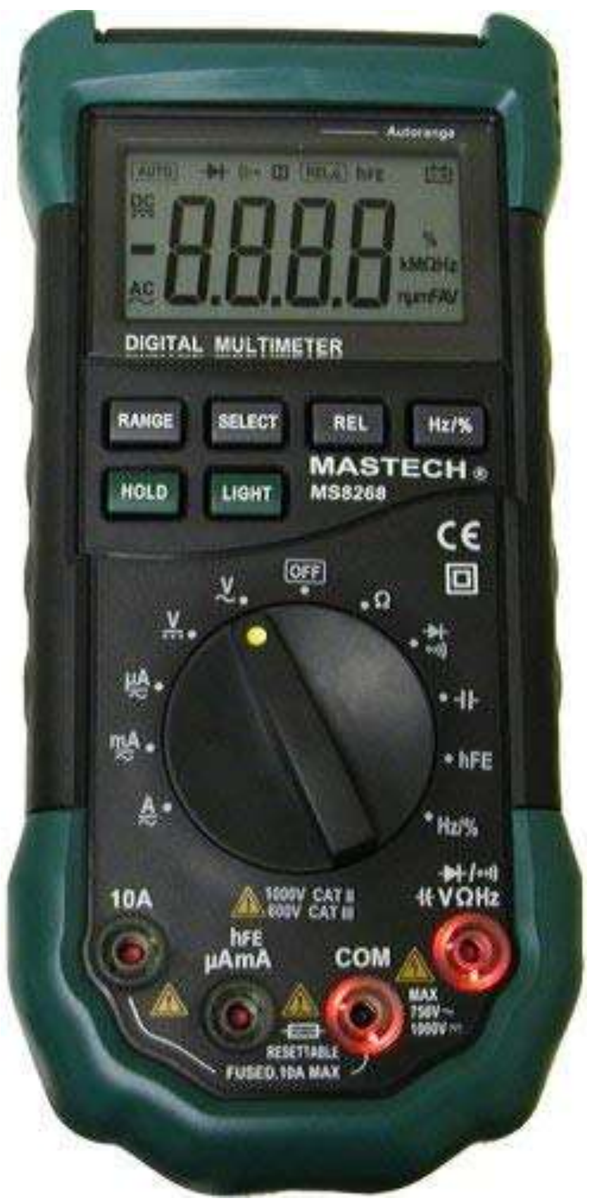
E. Nothing because this will fry the meter.



The voltmeter and the battery are in parallel, so they should have the same potential difference.

Using a Multimeter

When measuring voltage:



Must be measured in parallel!

When measuring current:

Must be measured in series!

Breadboard Activity II (with Measurements)

Practice building basic circuits with breadboards

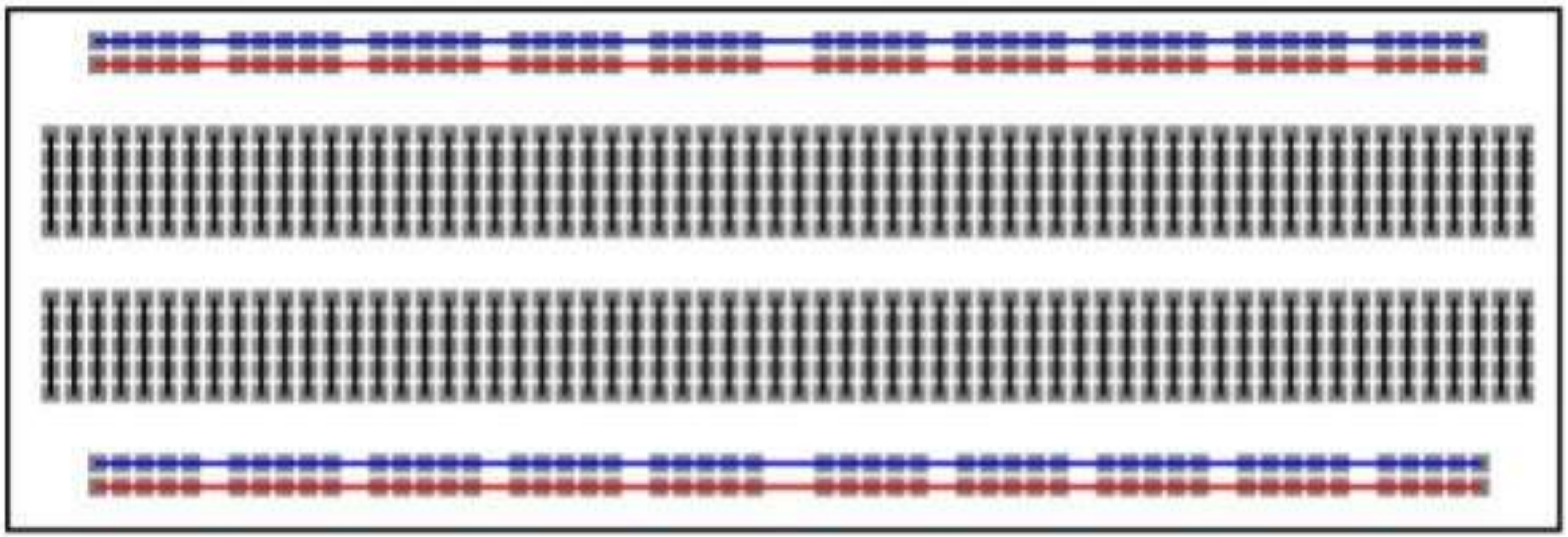


Figure 1: Breadboard layout and connection diagram

Follow the instructions in HuskyCT

Course Contents
>> 7.1 Kirchhoff's Laws
>> Breadboard Activity II

PRACTICE PROBLEMS