previous iClicker questions, unexpected answers!

Which has a larger resistance, a 60 W or a 100 W lightbulb?

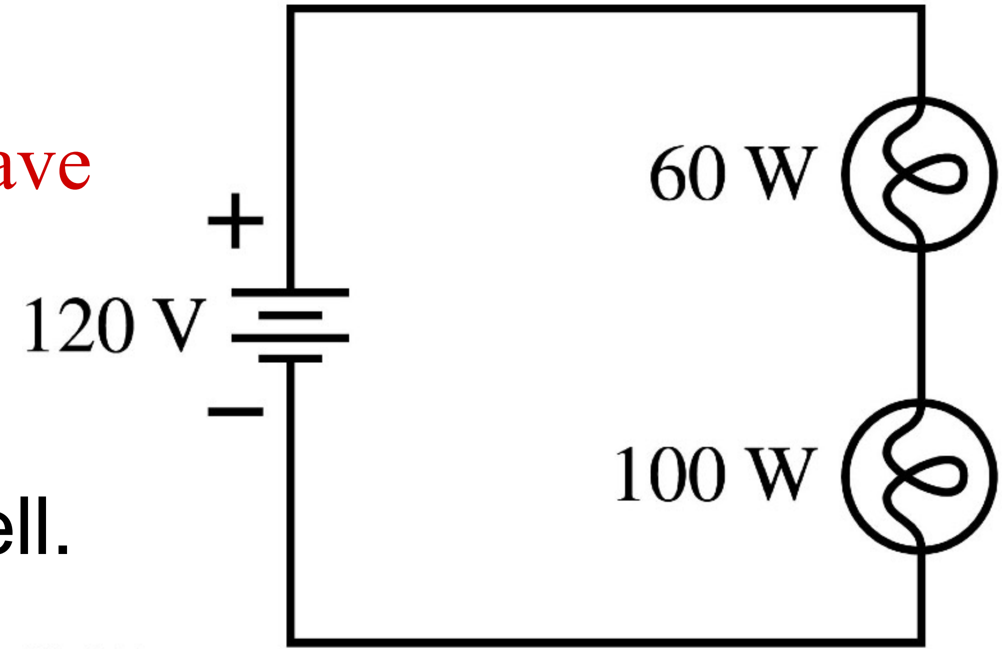
✔ **A. The 60 W bulb**
B. The 100 W bulb
C. Their resistances are the same.
D. There's not enough information to tell.

$P = \frac{(\Delta V)^2}{R}$ with both used at $\Delta V = 120$ V

Which bulb is brighter?

✔ **A. The 60 W bulb**
B. The 100 W bulb
C. Their brightnesses are the same.
D. There's not enough information to tell.

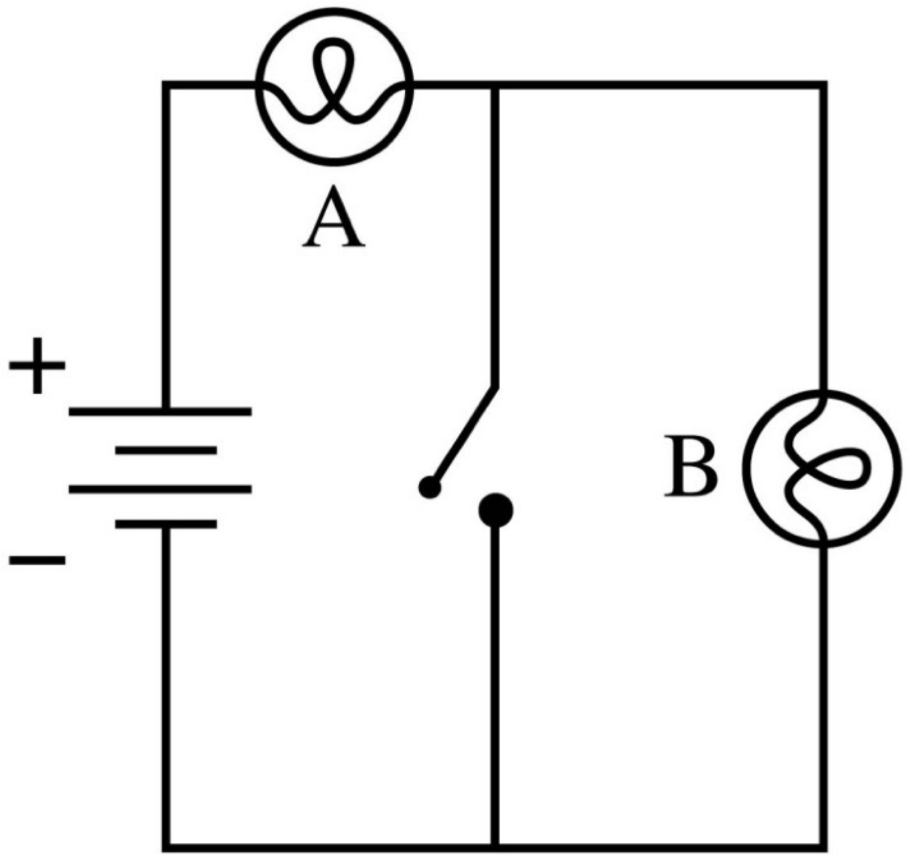
$P = I^2R$ and both have the same current.



iClicker question 12-1

The lightbulbs are identical. Initially both bulbs are glowing. What happens when the switch is closed?

A. Nothing
B. A stays the same; B gets dimmer.
C. A gets brighter; B stays the same.
D. Both get dimmer.
E. A gets brighter; B goes out.



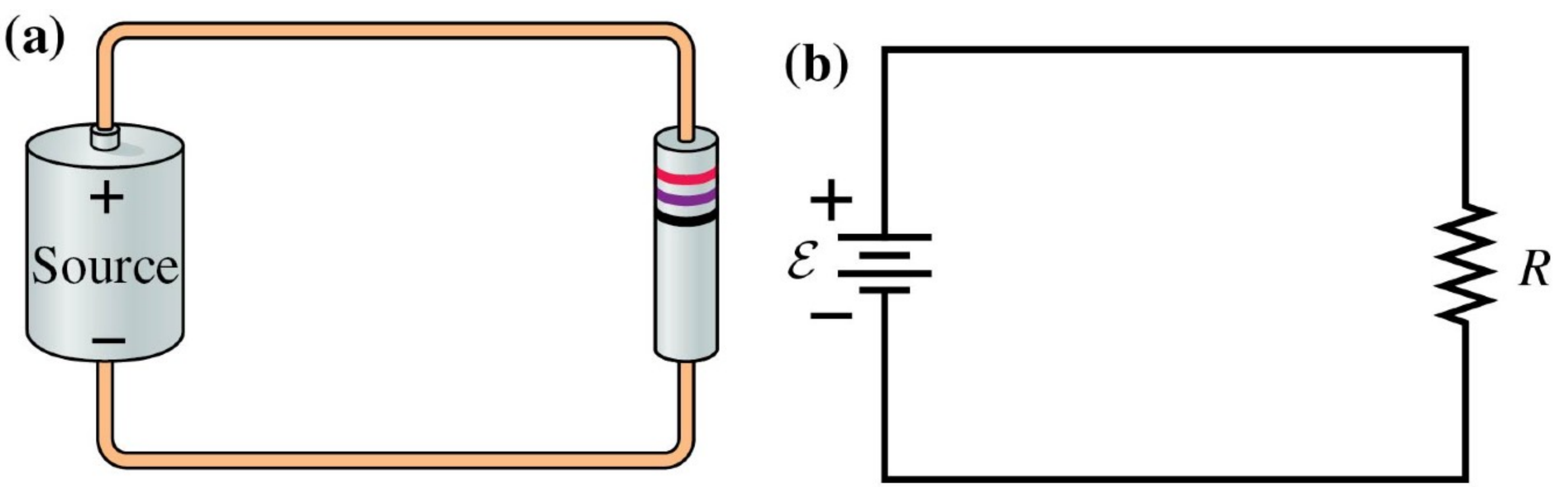
Tactics: Using Kirchhoff's Loop Law, simple circuit

TACTICS BOX 28.1

Using Kirchhoff's loop law

❶ **Draw a circuit diagram.** Label all known and unknown quantities.

- For example:
  The most basic electric circuit is a single resistor connected to the two terminals of a battery.



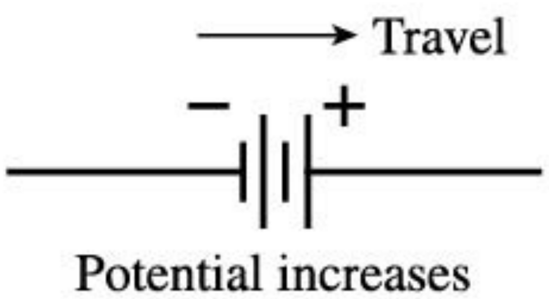
TACTICS BOX 28.1

Using Kirchhoff’s loop law

❸ **“Travel” around the loop.** Start at any point in the circuit, then go all the way around the loop in the direction you assigned to the current in step 2. As you go through each circuit element, ΔV is interpreted to mean $\Delta V = V_{\text{downstream}} - V_{\text{upstream}}$.

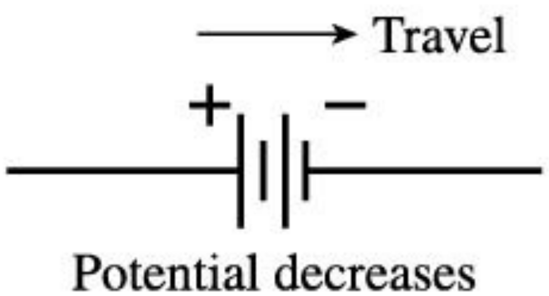
- For an ideal battery in the negative-to-positive direction:

$$\Delta V_{\text{bat}} = +\mathcal{E}$$

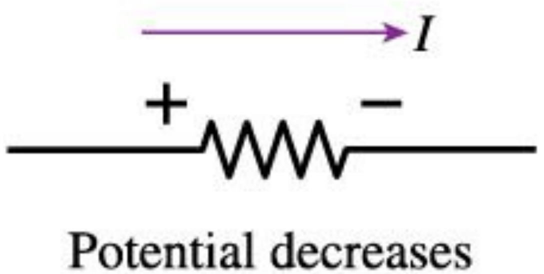


- For an ideal battery in the positive-to-negative direction:

$$\Delta V_{\text{bat}} = -\mathcal{E}$$



- For a resistor: $\Delta V_{\text{res}} = -\Delta V_{\text{R}} = -IR$



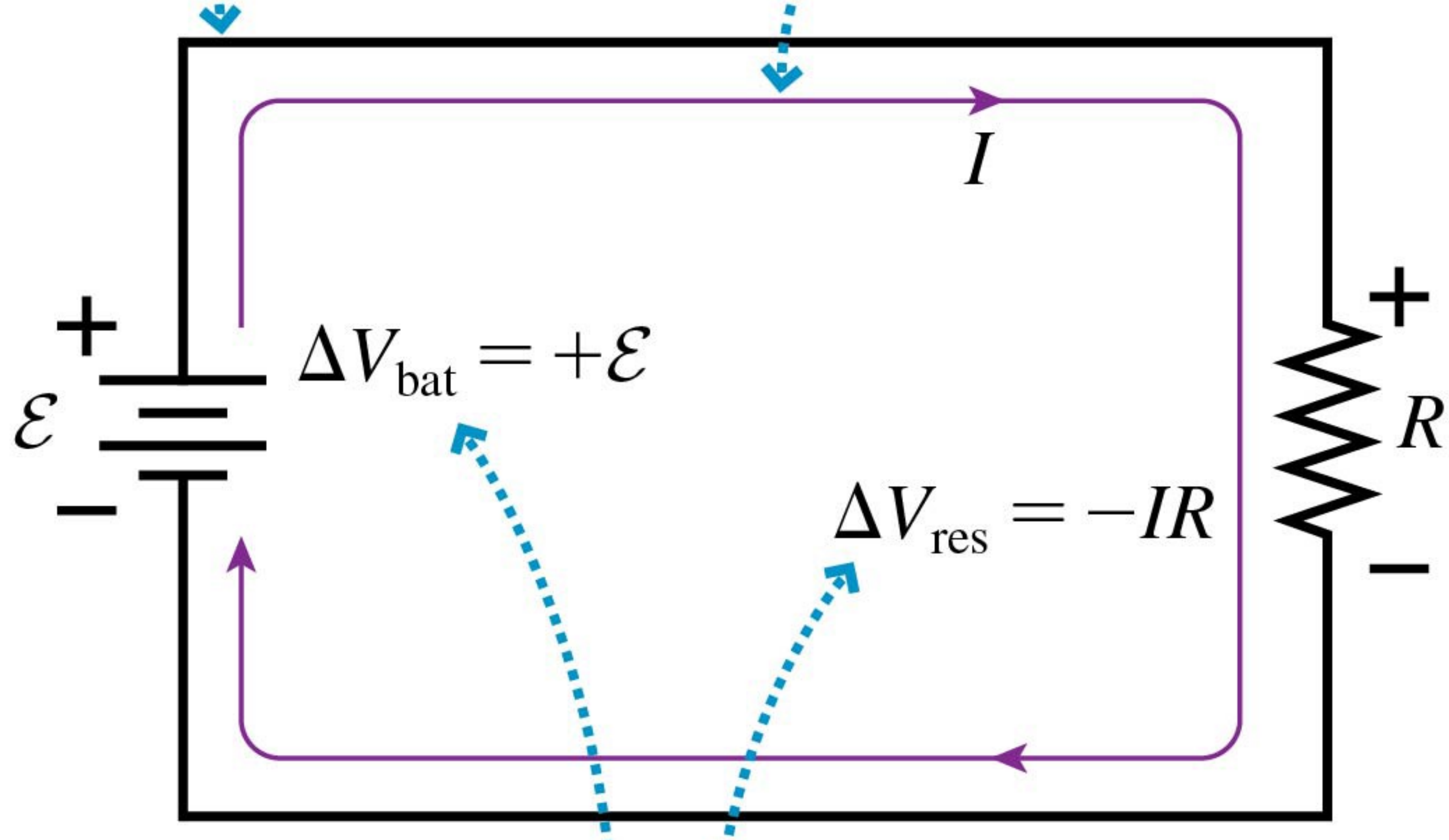
❹ **Apply the loop law:** $\sum (\Delta V)_i = 0$

Exercises 4–7

Analyzing the Basic Circuit

❶ Draw a circuit diagram.

❷ The orientation of the battery indicates a clockwise current, so assign a clockwise direction to I.



❸ Determine ΔV for each circuit element.

❹ **Apply the loop law:** $\sum(\Delta V)_i = 0$

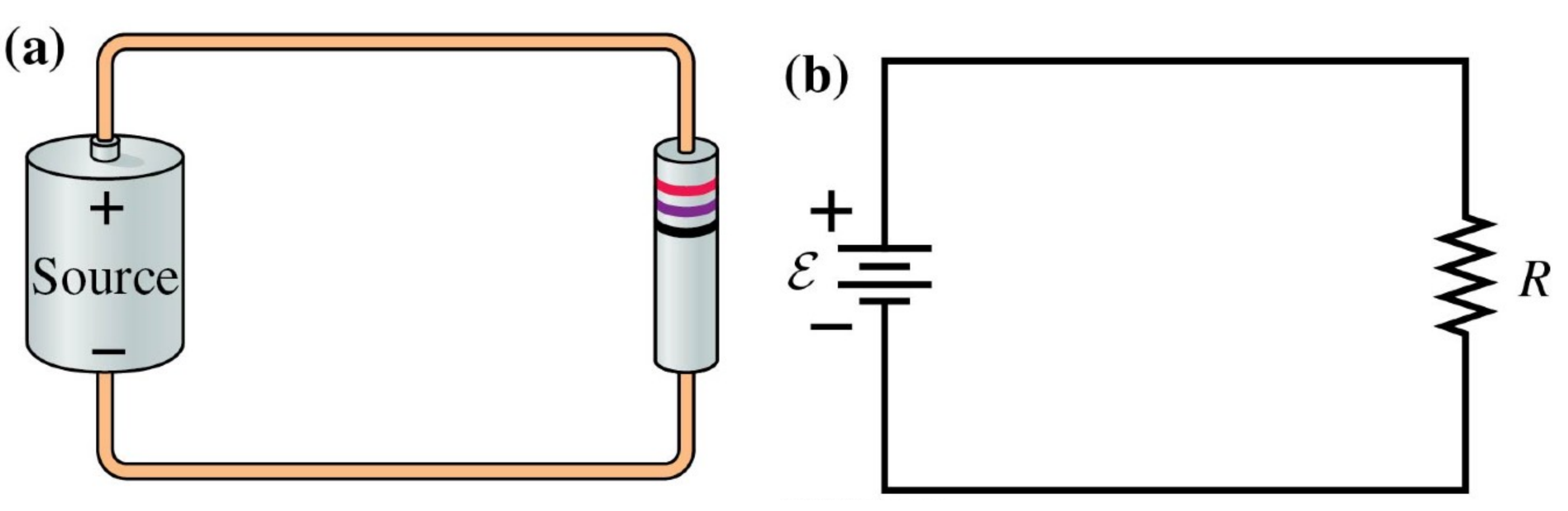
Review. Tactics: Using Kirchhoff's Loop Law

TACTICS BOX 28.1 MP

Using Kirchhoff's loop law

1. **Draw a circuit diagram.** Label all known and unknown quantities.
2. **Assign a direction to the current.** Draw and label a current arrow *I* to show your choice.
   - If you know the actual current direction, choose that direction.
   - If you don't know the actual current direction, make an arbitrary choice. All that will happen if you choose wrong is that your value for *I* will end up negative.

- For example:
  The most basic electric circuit is a single resistor connected to the two terminals of a battery.



Review. Tactics: Using Kirchhoff's Loop Law

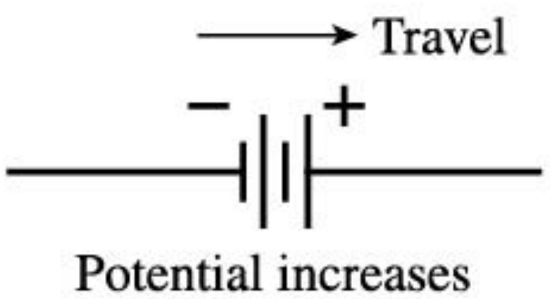
TACTICS BOX 28.1

Using Kirchhoff's loop law

❸ **"Travel" around the loop.** Start at any point in the circuit, then go all the way around the loop in the direction you assigned to the current in step 2. As you go through each circuit element, ΔV is interpreted to mean $\Delta V = V_{\text{downstream}} - V_{\text{upstream}}$.

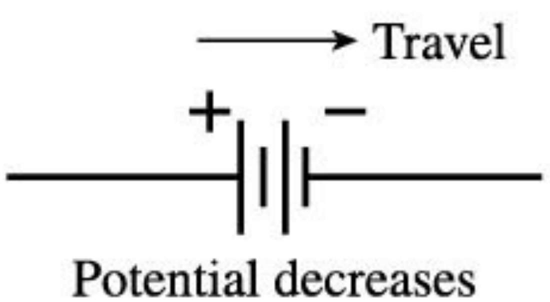
- For an ideal battery in the negative-to-positive direction:

$$\Delta V_{\text{bat}} = +\mathcal{E}$$

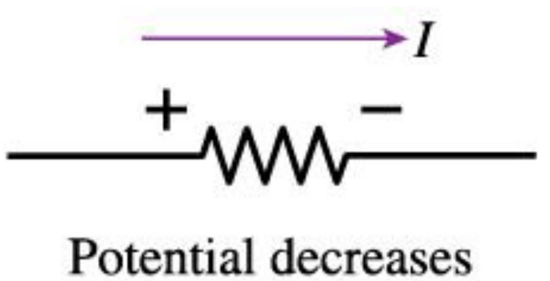


- For an ideal battery in the positive-to-negative direction:

$$\Delta V_{\text{bat}} = -\mathcal{E}$$



- For a resistor: $\Delta V_{\text{res}} = -\Delta V_{\text{R}} = -IR$



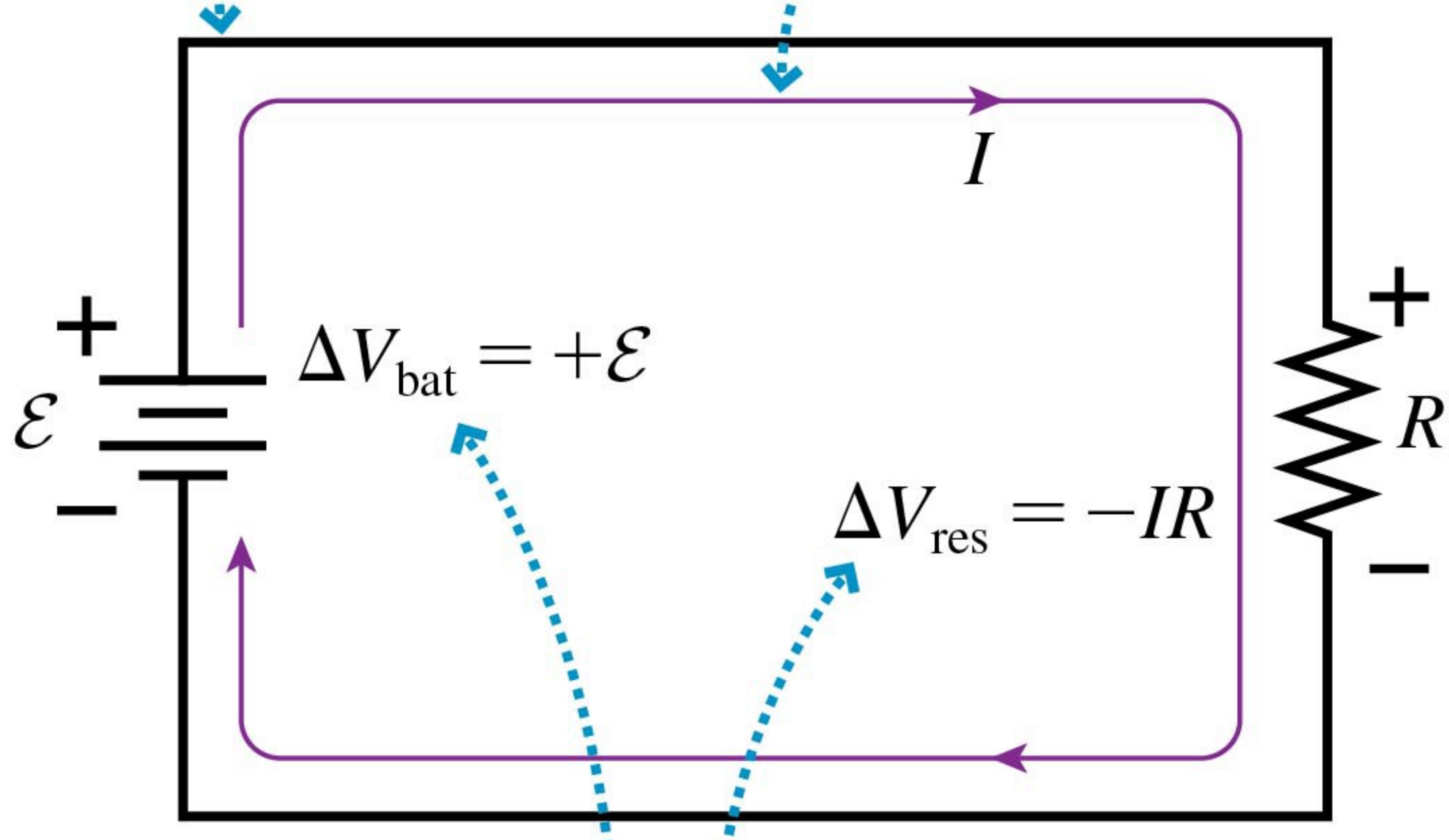
❹ **Apply the loop law:** $\sum (\Delta V)_i = 0$

Exercises 4–7

Review. Analyzing the Basic Circuit

❶ Draw a circuit diagram.

❷ The orientation of the battery indicates a clockwise current, so assign a clockwise direction to I.

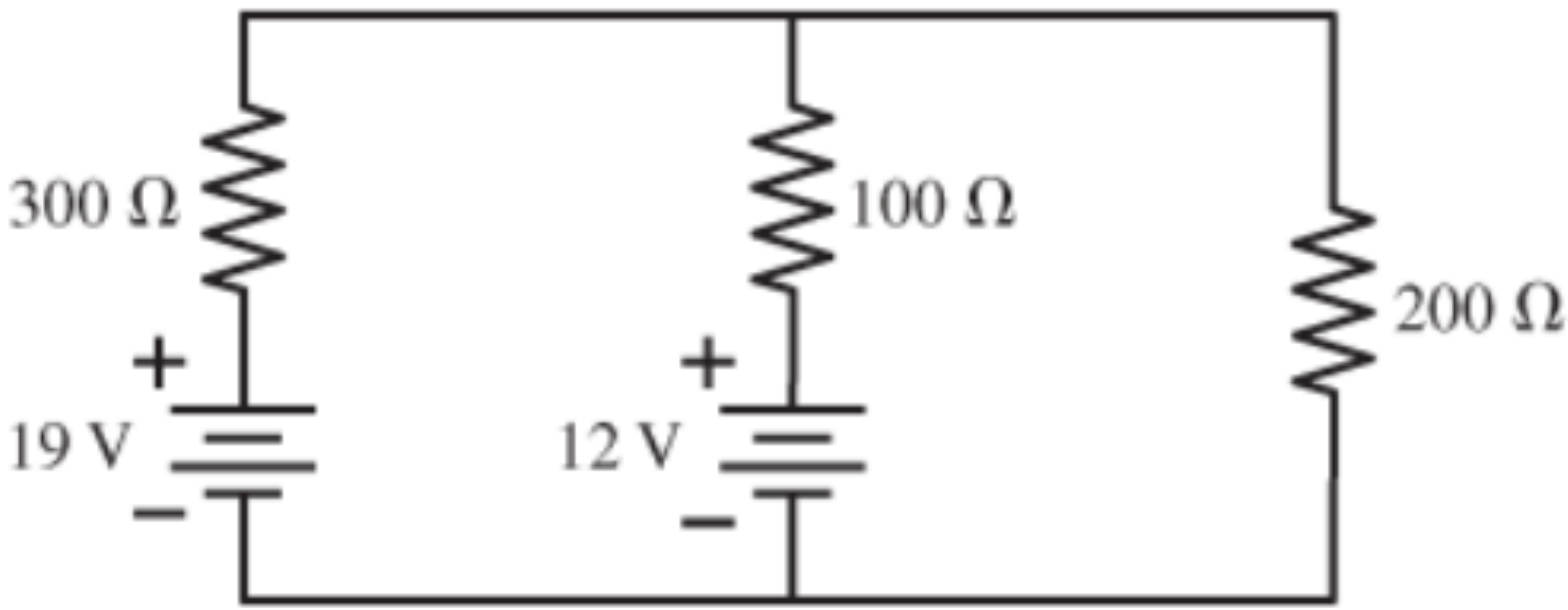


❸ Determine ΔV for each circuit element.

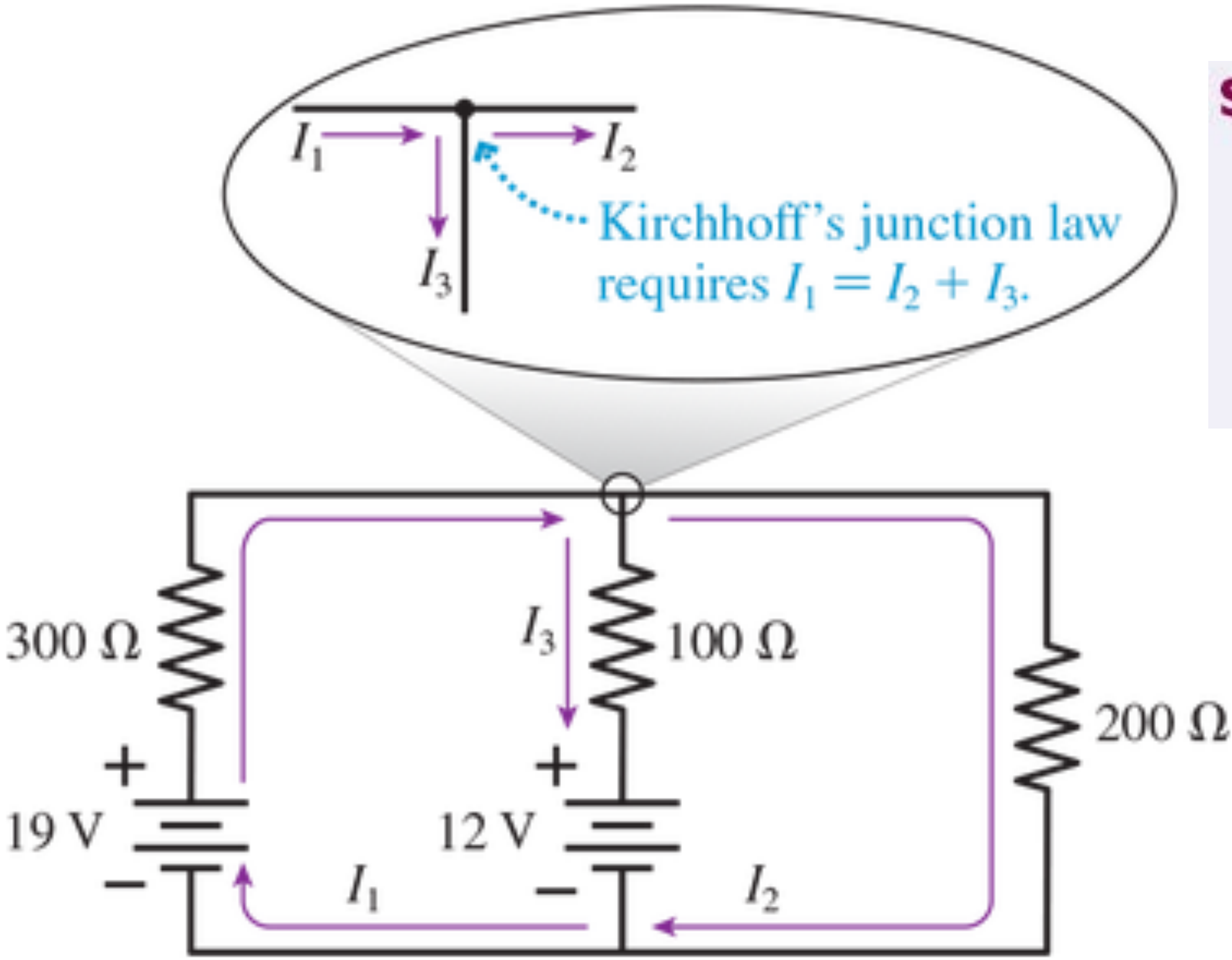
❹ **Apply the loop law:** $\sum (\Delta V)_i = 0$

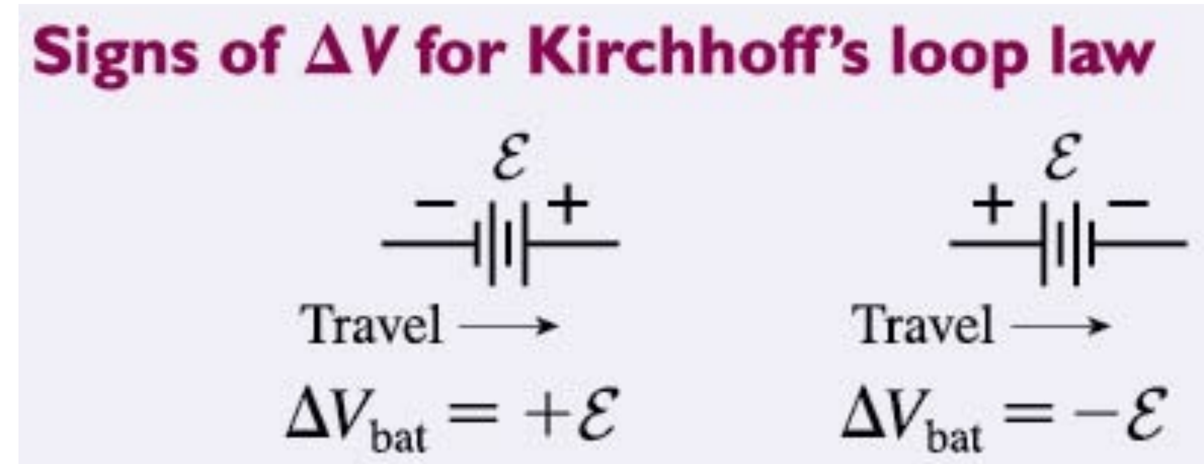
Example 28.10 Analyzing a two-loop circuit

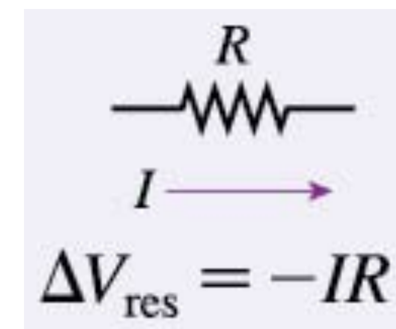
A two-loop circuit.



Example 28.10 Analyzing a two-loop circuit







$$I_3 = I_1 - I_2$$

$$\sum(\Delta V)_i = 19\text{ V} - (300\,\Omega)\,I_1 - (100\,\Omega)\,I_3 - 12\text{ V} = 0$$

$$\sum(\Delta V)_i = 12\text{ V} + (100\,\Omega)\,I_3 - (200\,\Omega)\,I_2 = 0$$

Current opposite to direction of travel!

Getting Grounded

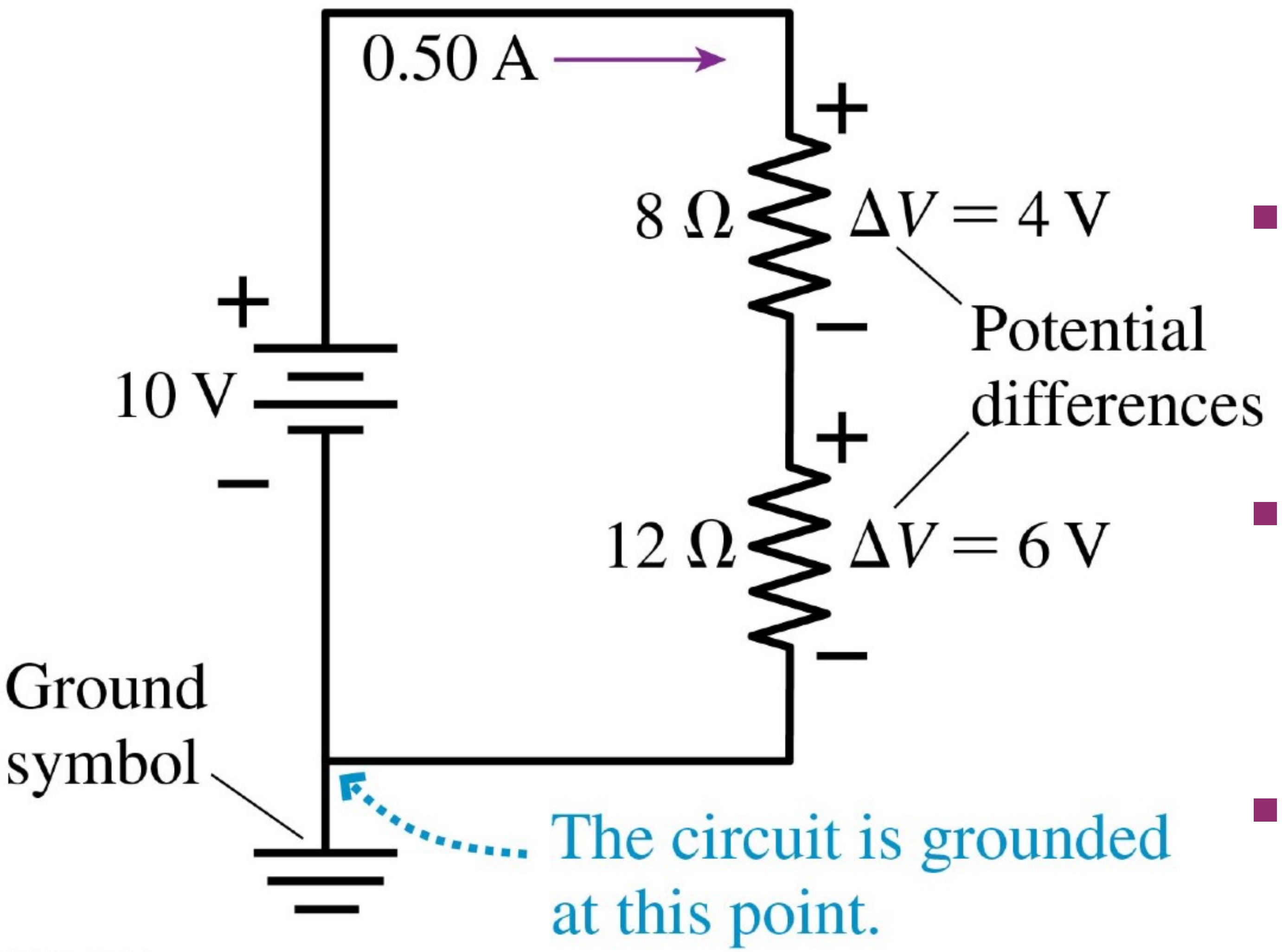
- The earth itself is a conductor.
- If we connect one point of a circuit to the earth by an ideal wire, we can can agree to call the potential of this point to be that of the earth:

$$V_{\text{earth}} = 0\ \text{V}$$

- The wire connecting the circuit to the earth is not part of a complete circuit, so there is no current in this wire!

- A circuit connected to the earth in this way is said to be **grounded**, and the wire is called the *ground wire*.
- The circular prong of a three-prong plug is a connection to ground.

A Circuit That Is Grounded

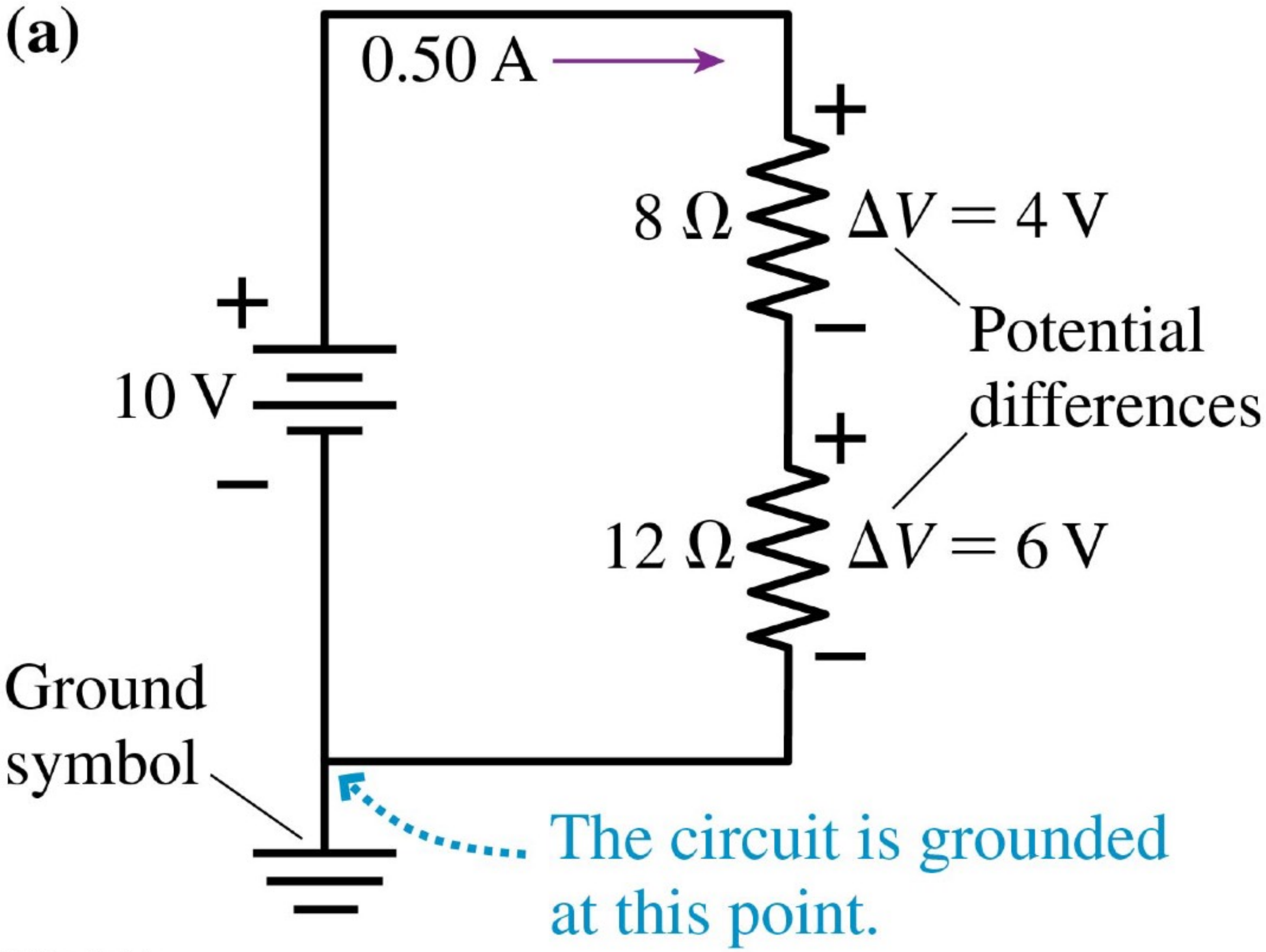


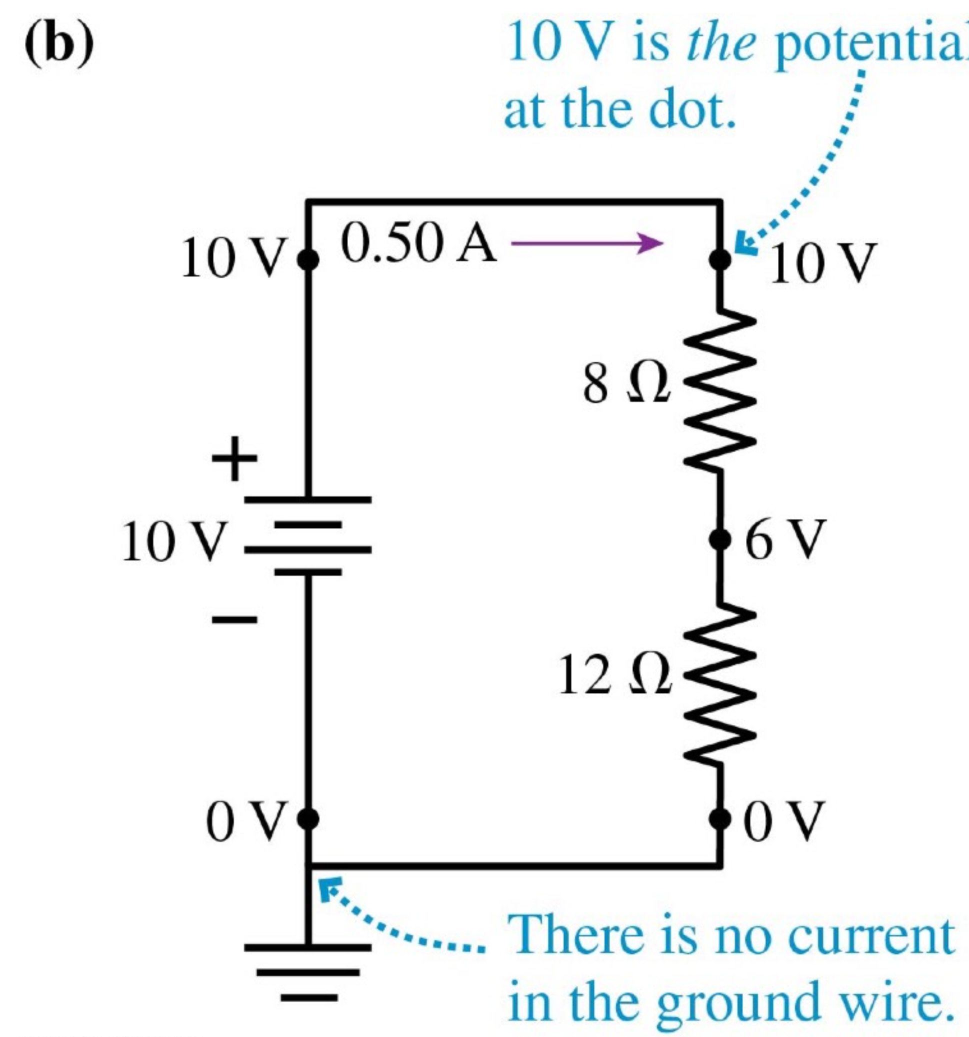
- The figure shows a circuit with a 10 V battery and two resistors in series.
- The symbol beneath the circuit is the ground symbol.
- **The potential at the ground is $V = 0$.**
- Grounding the circuit allows us to have *specific values* for potential at each point in the circuit, rather than just potential differences.

Example 28.11 A Grounded Circuit

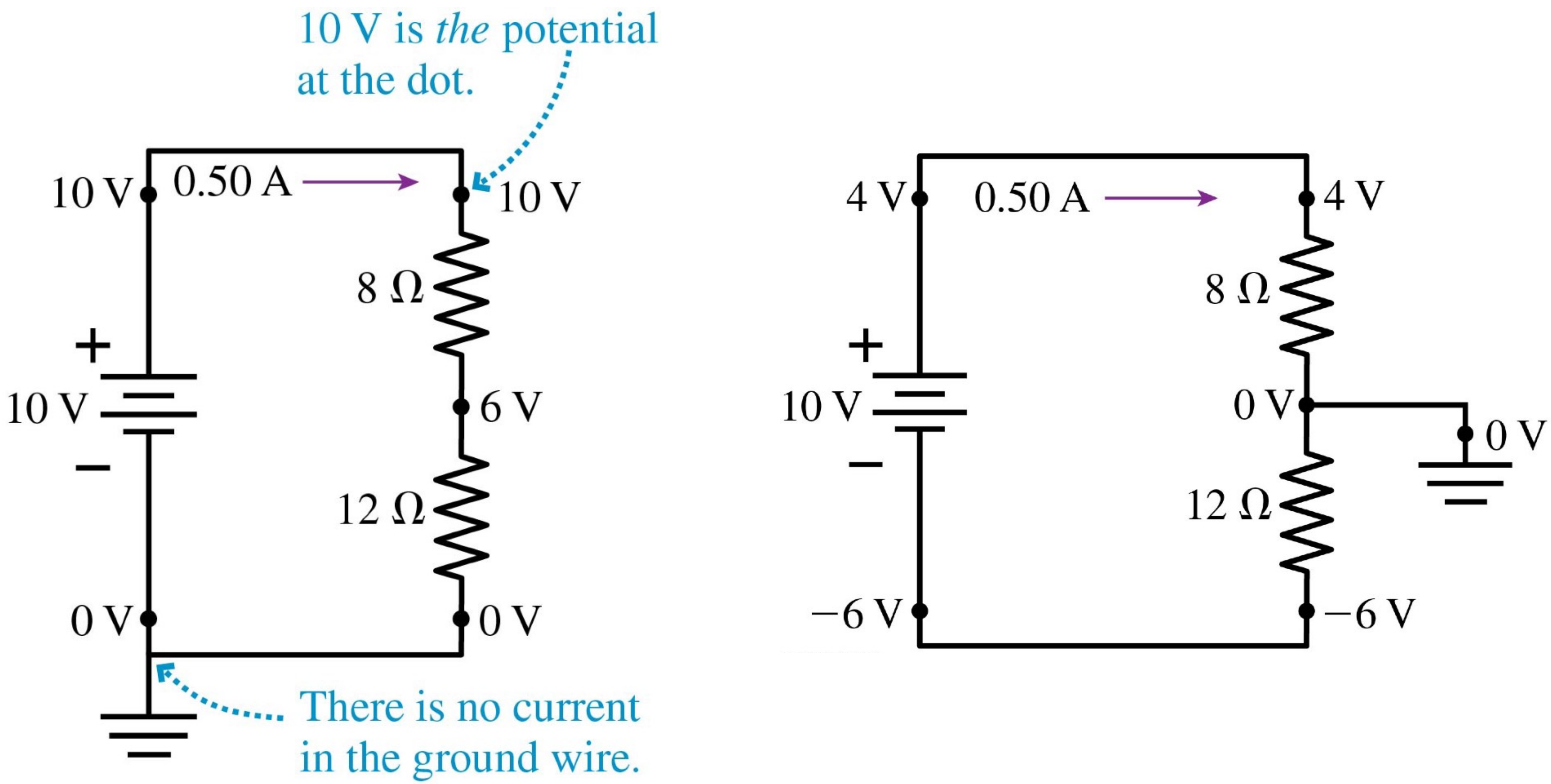
EXAMPLE 28.11 **A grounded circuit**

Suppose the circuit of Figure 28.32 were grounded at the junction between the two resistors instead of at the bottom. Find the potential at each corner of the circuit.



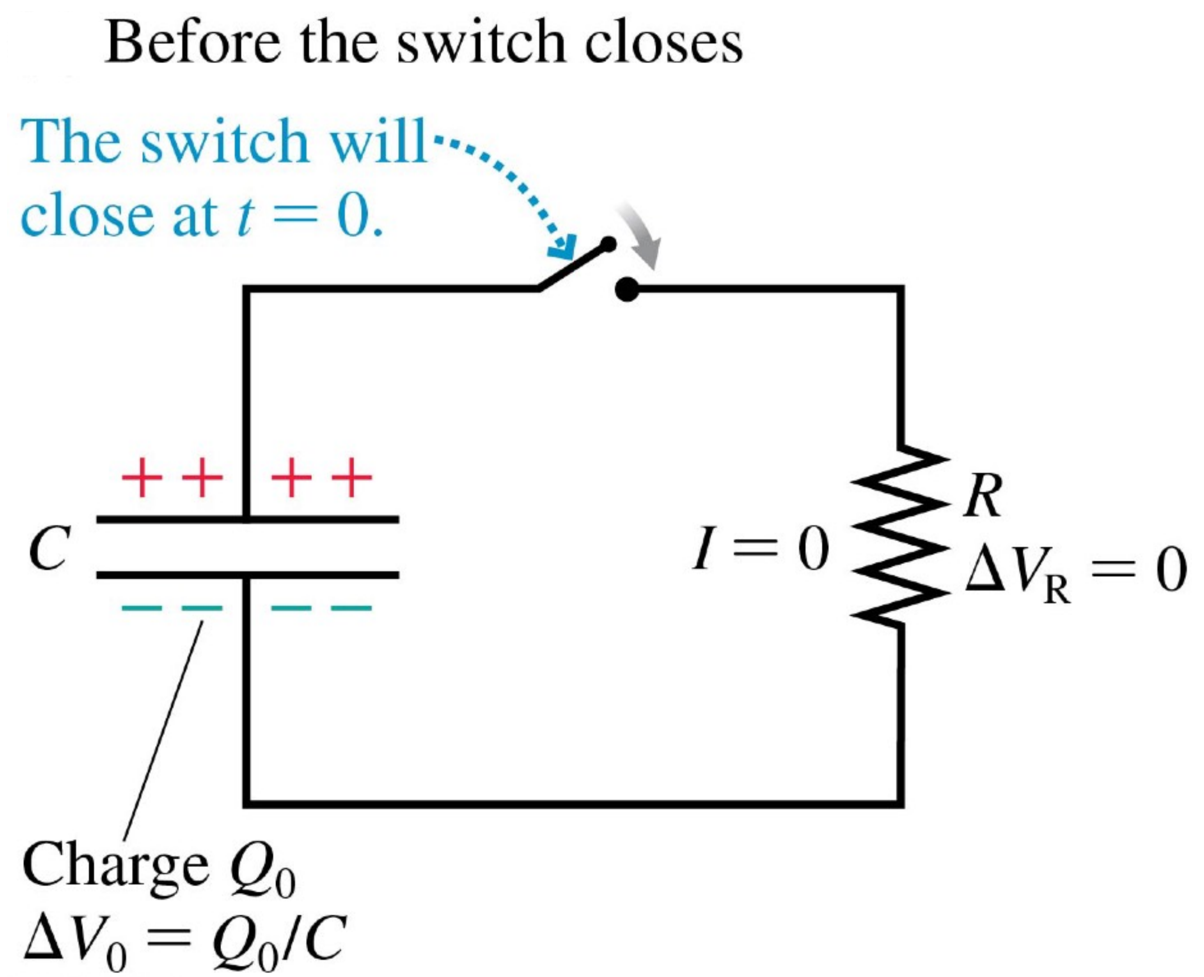


Compare a circuit with two distinct ground points:



RC Circuits

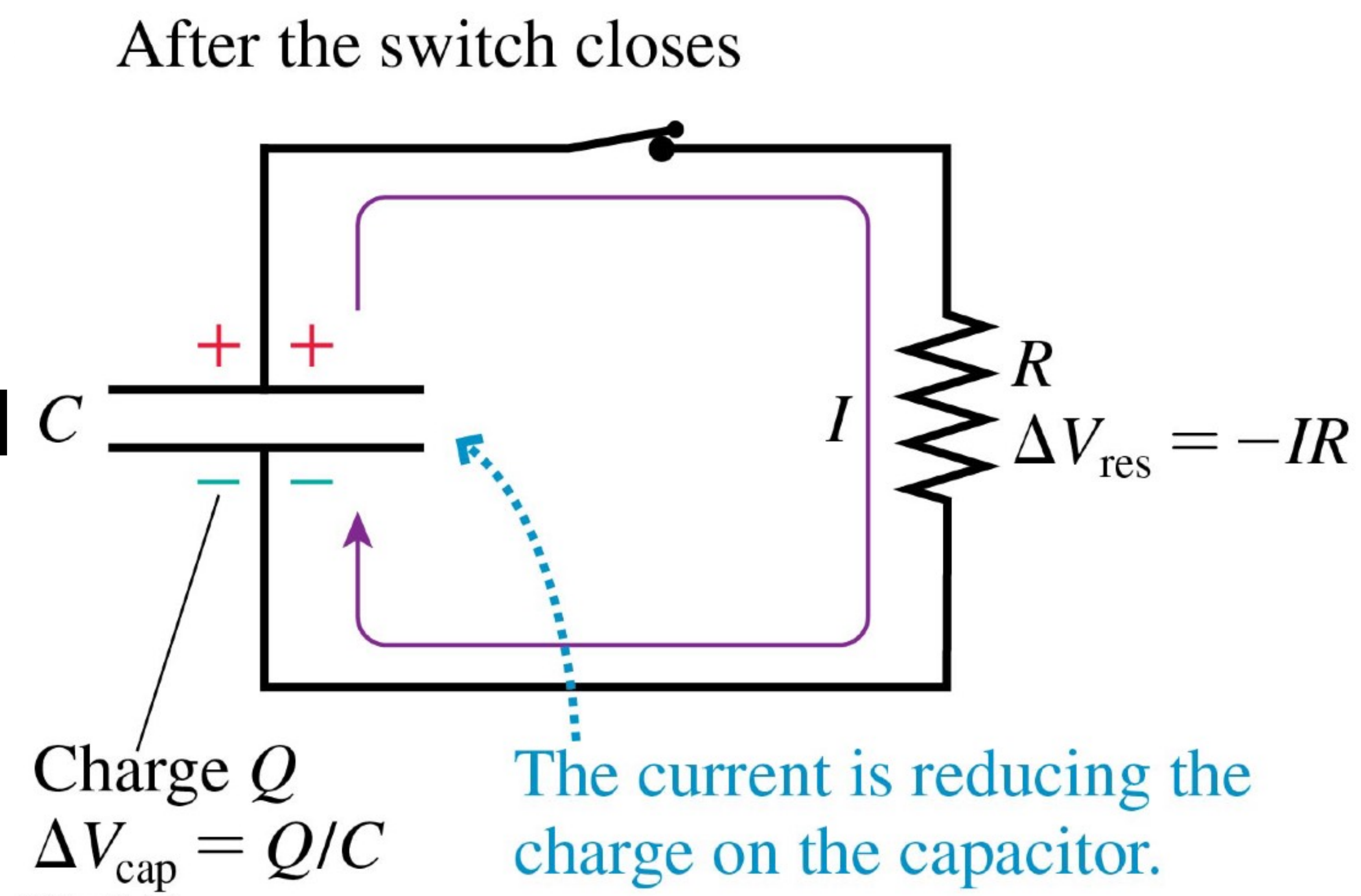
- The figure shows a charged capacitor, a switch, and a resistor.
- At $t = 0$, the switch closes and the capacitor begins to discharge through the resistor.



- A circuit such as this, with resistors and capacitors, is called an ***RC* circuit**.
- We wish to determine how the current through the resistor will vary as a function of time after the switch is closed.

RC Circuits

- The figure shows an *RC* circuit, some time after the switch was closed.
- Kirchhoff's loop law applied to this circuit clockwise is



$$\Delta V_{\text{cap}} + \Delta V_{\text{res}} = \frac{Q}{C} - IR = 0$$

- Q and I in this equation are the instantaneous values of the capacitor charge and the resistor current.
- The resistor current is the rate at which charge is *removed* from the capacitor:

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

RC Circuits

- Knowing that $I = -dQ/dt$, the loop law for a simple closed RC circuit is

$$\frac{dQ}{dt} + \frac{Q}{RC} = 0$$

- Rearranging and integrating:

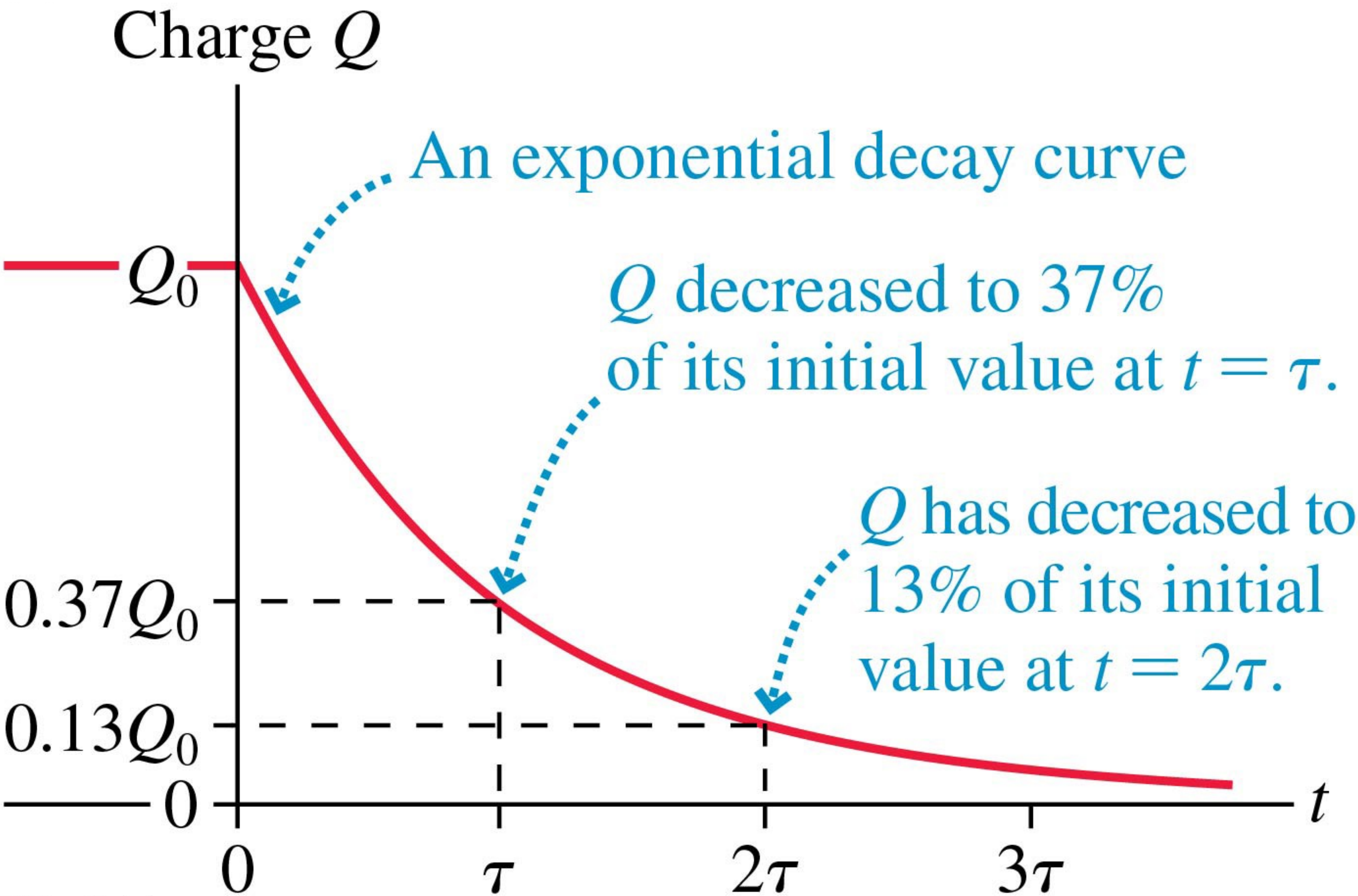
$$\int_{Q_0}^{Q} \frac{dQ}{Q} = -\frac{1}{RC}\int_0^t dt$$

$$Q = Q_0 e^{-t/\tau}$$

where the **time constant** $\boldsymbol{\tau}$ is

$$\tau = RC$$

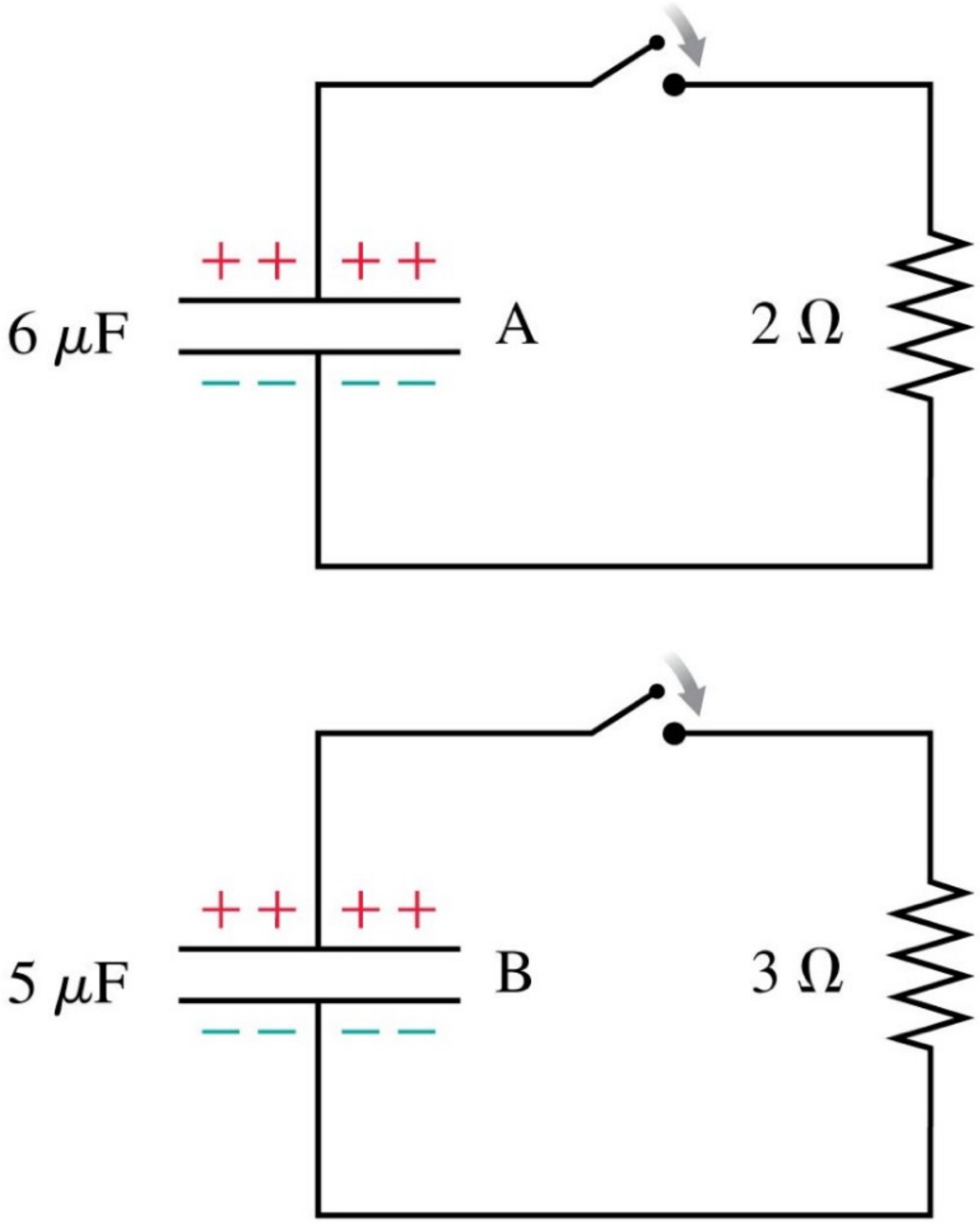
RC Circuits


Charge Q
An exponential decay curve
Q decreased to 37% of its initial value at $t = \tau$.
Q has decreased to 13% of its initial value at $t = 2\tau$.
Q_0
$0.37Q_0$
$0.13Q_0$
0
t
0
τ
2τ
3τ

iClicker question #12-2

Which capacitor discharges more quickly after the switch is closed?

A. Capacitor A
B. Capacitor B
C. They discharge at the same rate.
D. Can't say without knowing the initial amount of charge.



RC Circuits

- The charge on the capacitor of an RC circuit is

$$Q = Q_0 e^{-t/\tau}$$

  where Q_0 is the charge at $t = 0$, and $\tau = RC$ is the time constant.

- The capacitor voltage is directly proportional to the charge, so

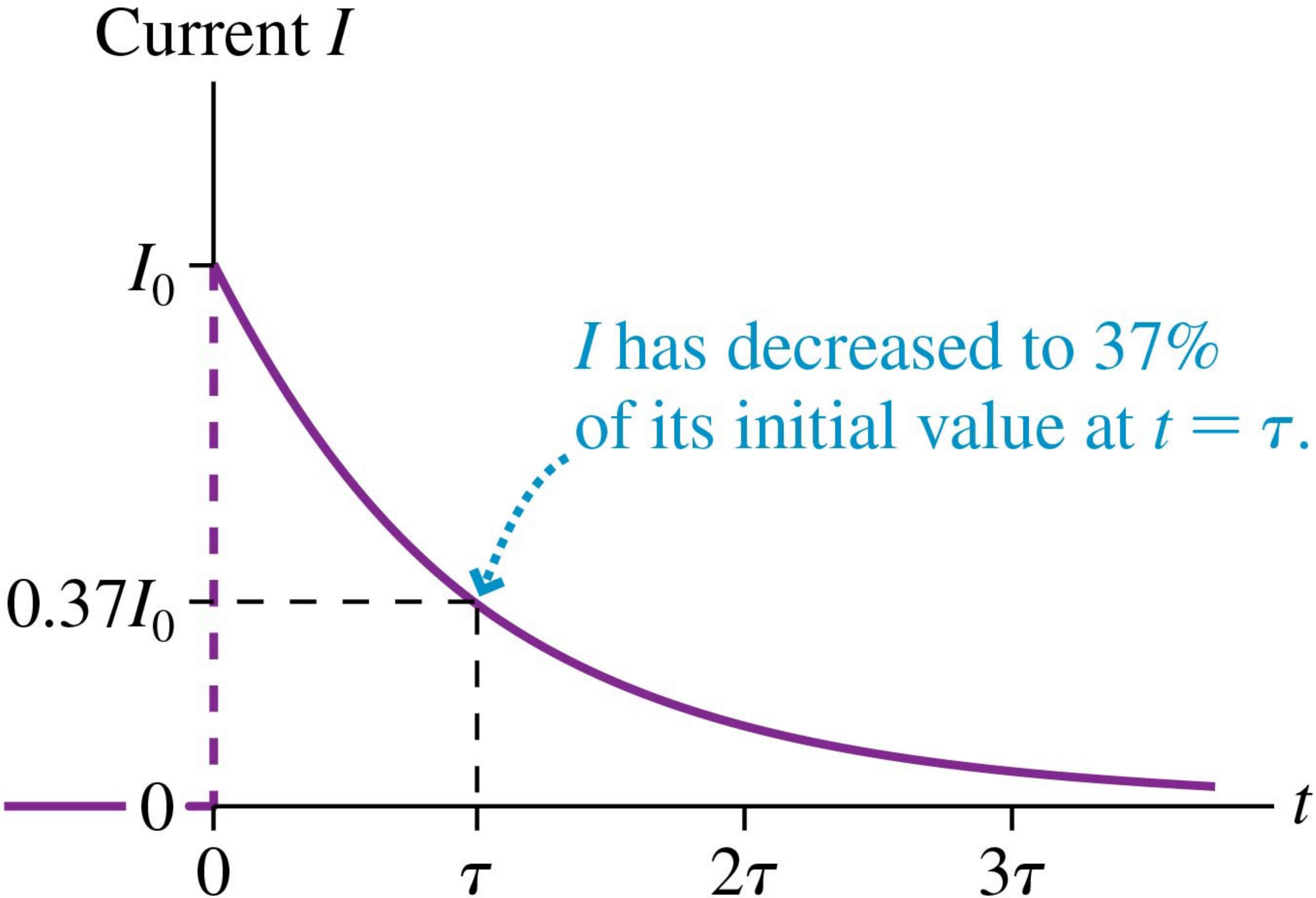
$$\Delta V_C = \Delta V_0 e^{-t/\tau}$$

  where ΔV_0 is the voltage at $t = 0$.

- The current also can be found to decay exponentially:

$$I = -\frac{dQ}{dt} = \frac{Q_0}{\tau} e^{-t/\tau} = \frac{Q_0}{RC} e^{-t/\tau} = \frac{\Delta V_0}{R} e^{-t/\tau} = I_0 e^{-t/\tau}$$

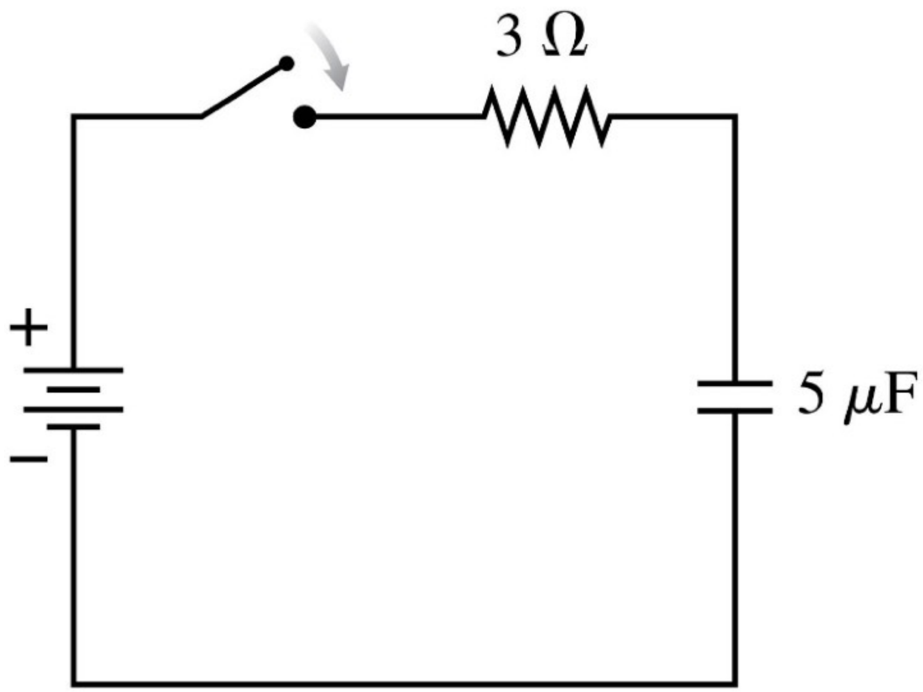
RC Circuits



Current I
I_0
$0.37I_0$
0
I has decreased to 37% of its initial value at $t = \tau$.
t
0
τ
2τ
3τ

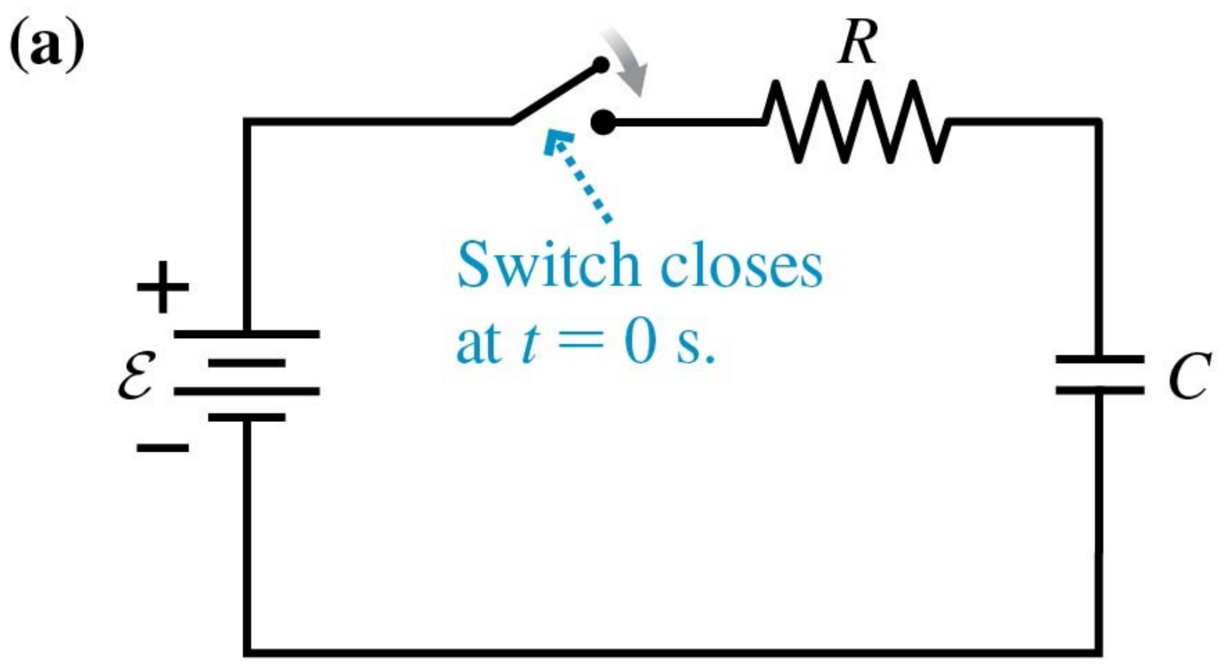
iClicker question #12-5

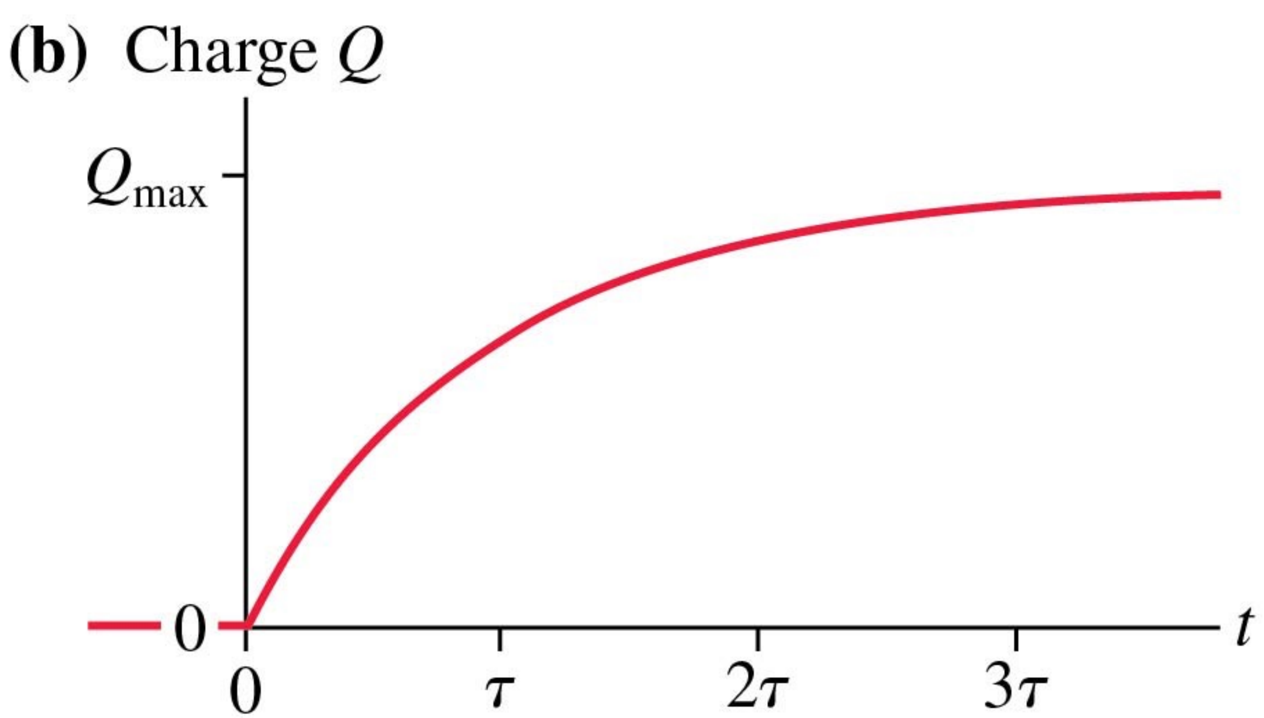
The capacitor is initially unchanged. Immediately after the switch closes, the capacitor voltage is



A. 0 V
B. Somewhere between 0 V and 6 V
C. 6 V
D. Undefined.

Charging a Capacitor





- Figure (a) shows a circuit that charges a capacitor.
- The capacitor charge and the circuit current at time t are

$$Q = Q_0(1 - e^{-t/\tau})$$

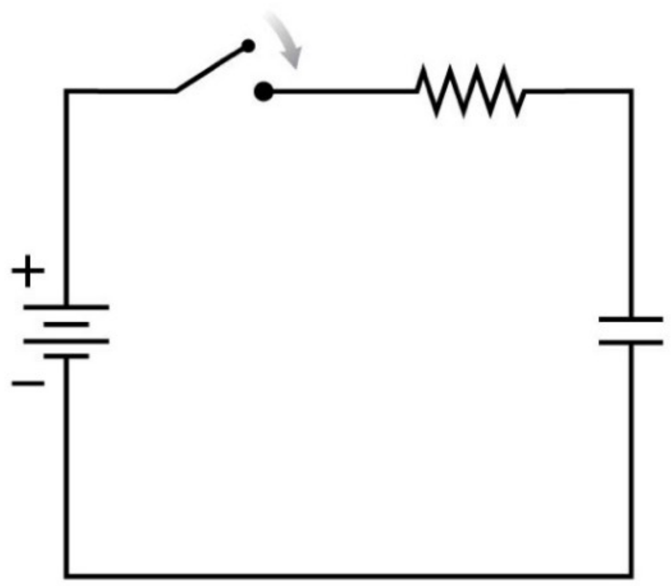
$$I = I_0 e^{-t/\tau}$$

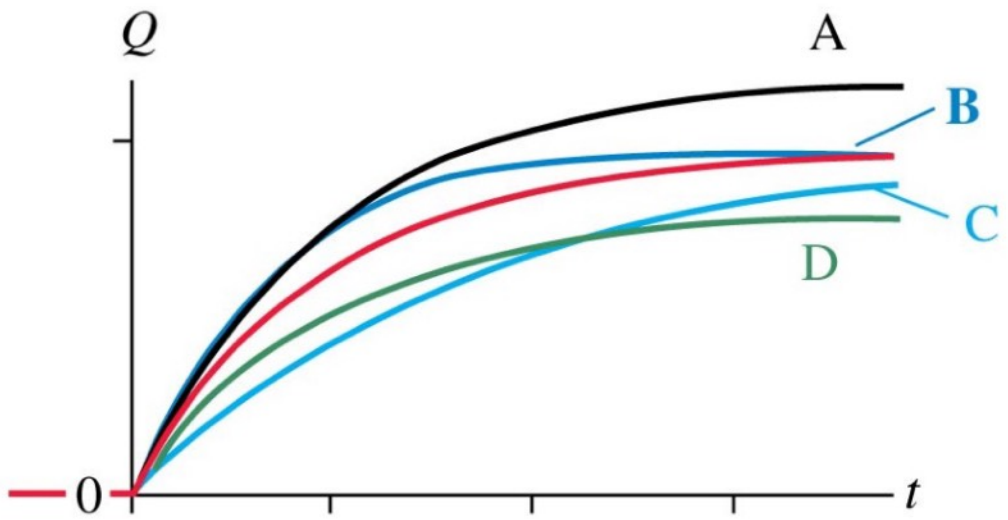
where $I_0 = \mathcal{E}/R$ and $\tau = RC$.

- This “upside-down decay” is shown in figure (b).

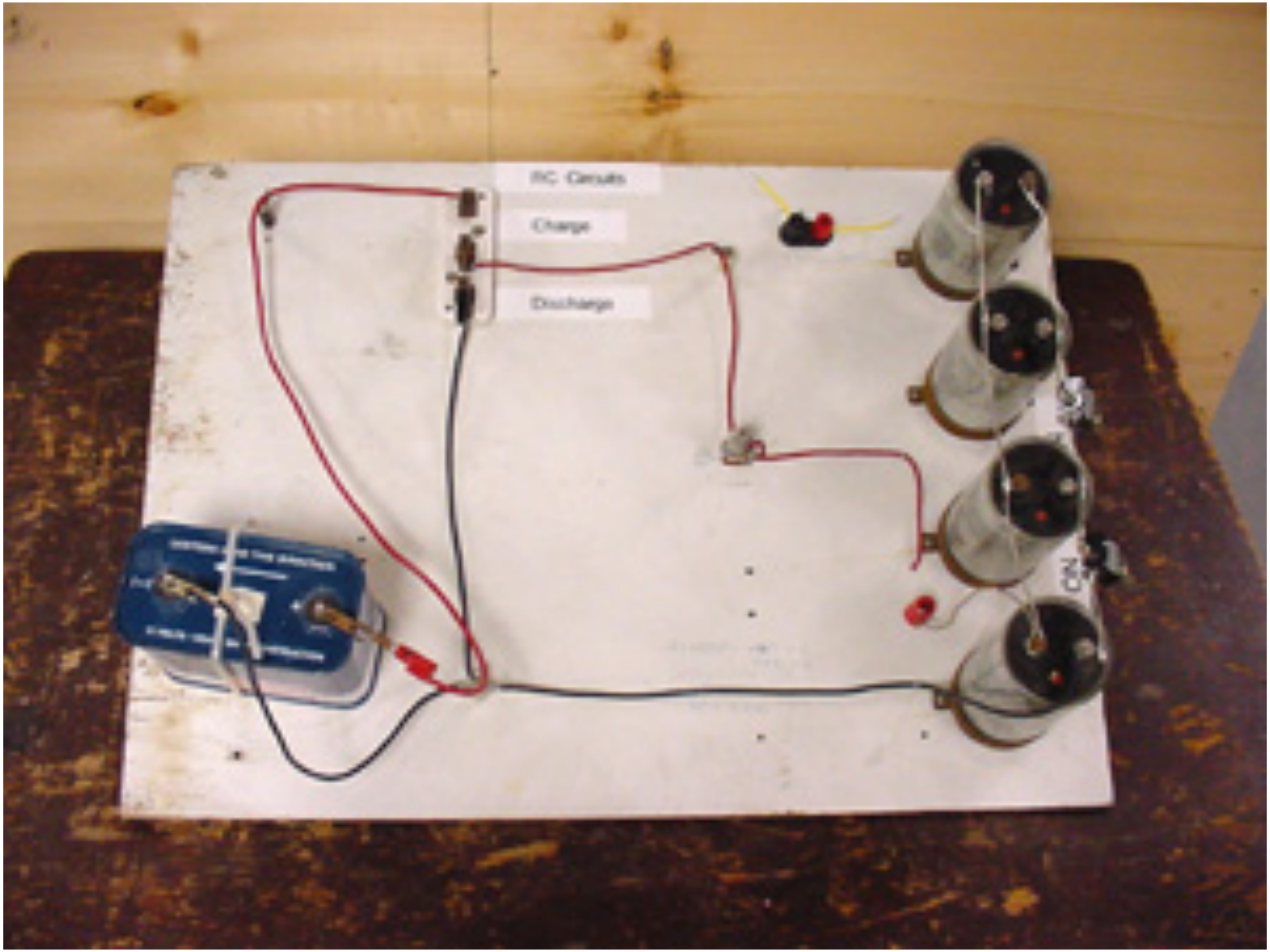
iClicker question #12-3

The red curve shows how the capacitor charges after the switch is closed at $t = 0$. Which curve shows the capacitor charging if the value of the resistor is reduced?





RC time constant demo



Ch 28 Review: General Strategy

Solving Circuit Problems

MODEL Assume that wires and, where appropriate, batteries are ideal.

VISUALIZE Draw a circuit diagram. Label all quantities.

SOLVE Base the solution on Kirchhoff's laws.

- Reduce the circuit to the smallest possible number of equivalent resistors.
- Write one loop equation for each independent loop.
- Find the current and the potential difference.
- Rebuild the circuit to find I and ΔV for each resistor.

ASSESS Verify that

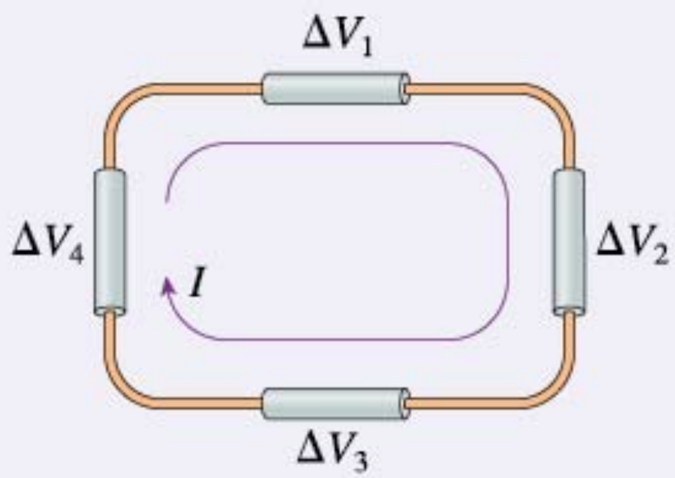
- The sum of potential differences across series resistors matches ΔV for the equivalent resistor.
- The sum of the currents through parallel resistors matches I for the equivalent resistor.

Ch 28 Review: General Strategy

Kirchhoff's loop law

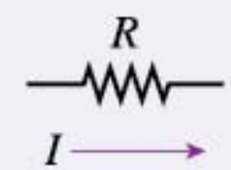
For a closed loop:

- Assign a direction to the current I.
- $\sum(\Delta V)_i = 0$



Signs of ΔV for Kirchhoff's loop law

$\Delta V_{\text{bat}} = +\mathcal{E}$ $\qquad$ $\Delta V_{\text{bat}} = -\mathcal{E}$

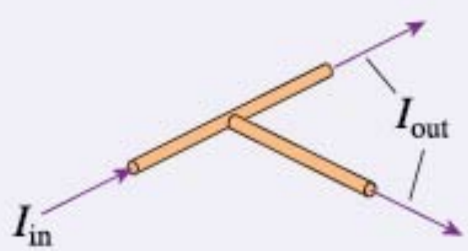


$\Delta V_{\text{res}} = -IR$

Kirchhoff's junction law

For a junction:

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



Ohm's Law

A potential difference ΔV between the ends of a conductor with resistance R creates a current

$$I = \frac{\Delta V}{R}$$

Ch 28 Review: Important Concepts

The **energy used by a circuit** is supplied by the emf $\mathcal{E}$ of the battery through the energy transformations

$$E_{\text{chem}} \rightarrow U \rightarrow K \rightarrow E_{\text{th}}$$

The battery *supplies* energy at the rate

$$P_{\text{bat}} = I\mathcal{E}$$

The resistors *dissipate* energy at the rate

$$P_{\text{R}} = I\,\Delta V_{\text{R}} = I^2 R = \frac{(\Delta V_{\text{R}})^2}{R}$$

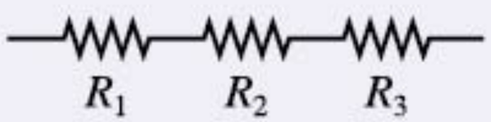
Ch 28 Review: Applications

Equivalent resistance

Groups of resistors can often be reduced to one equivalent resistor.

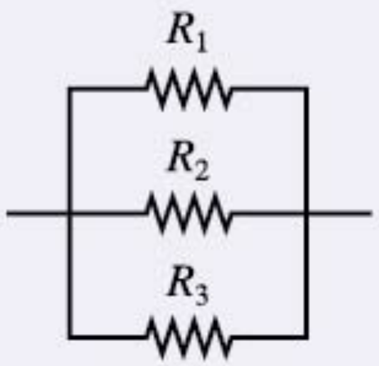
Series resistors

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



Parallel resistors

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



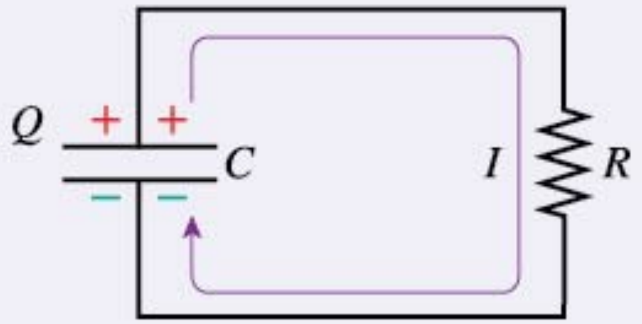
RC circuits

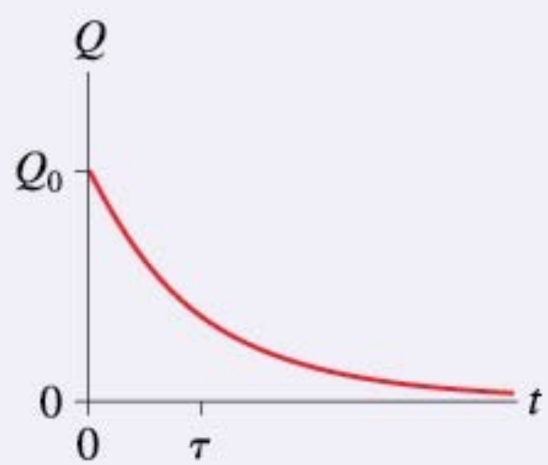
The charge on and current through a discharging capacitor are

$$Q = Q_0 e^{-t/\tau}$$

$$I = -\frac{dQ}{dt} = \frac{Q_0}{\tau} e^{-t/\tau} = I_0 e^{-t/\tau}$$

where $\tau = RC$ is the **time constant.**

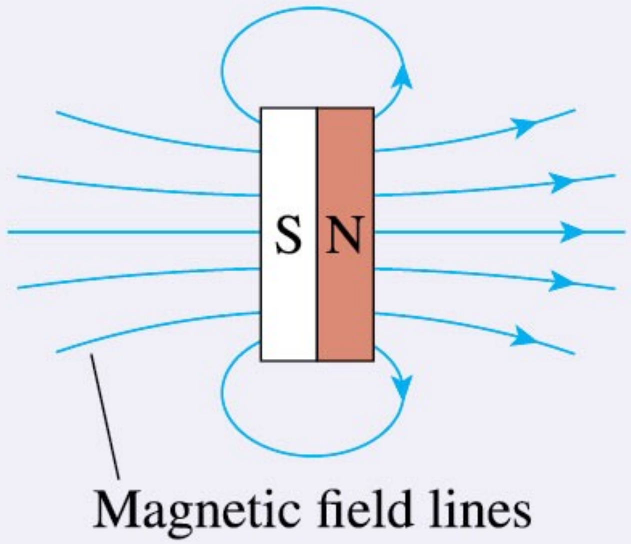




What is magnetism?

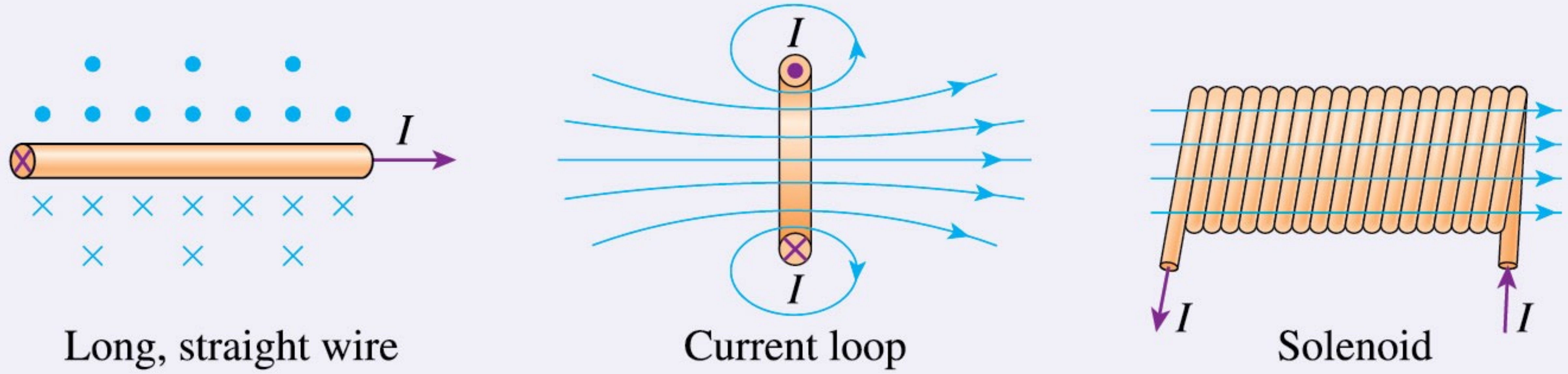
Magnetism is an interaction between *moving* charges.

- Magnetic forces, similar to electric forces, are due to the action of magnetic fields.
- A magnetic field $\vec{B}$ is created by a moving charge.
- Magnetic interactions are understood in terms of magnetic poles: north and south.
- Magnetic poles never occur in isolation. All magnets are dipoles, with two poles.
- Practical magnetic fields are created by currents—collections of moving charges.
- Magnetic materials, such as iron, occur because electrons have an inherent magnetic dipole called electron spin.



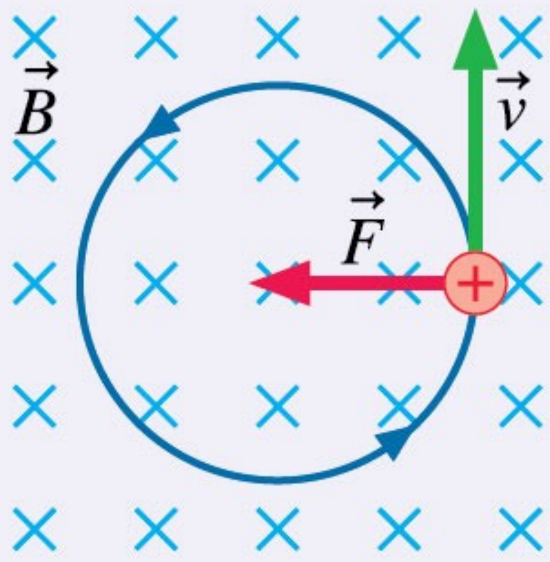
What fields are especially important?

We will develop and use three important **magnetic field models**.



How do charges respond to magnetic fields?

A charged particle *moving* in a magnetic field experiences a force perpendicular to both $\vec{B}$ and $\vec{v}$. The perpendicular force causes charged particles to move in circular orbits in a uniform magnetic field. This cyclotron motion has many important applications.



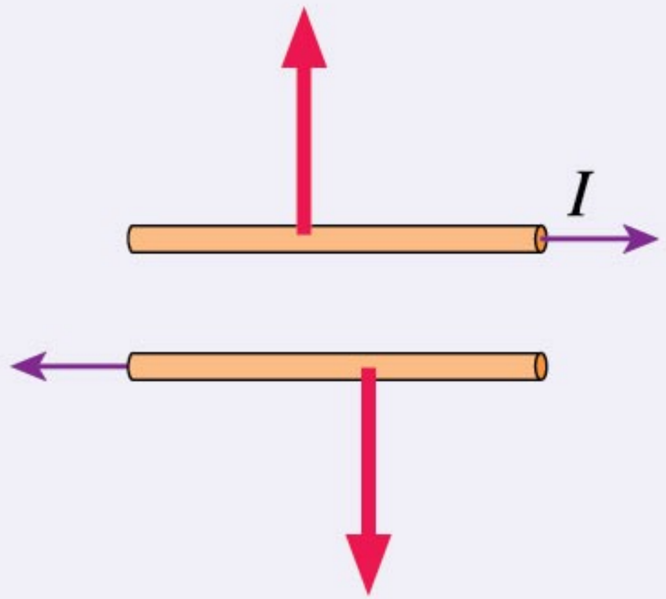
« LOOKING BACK Sections 8.2–8.3 Circular motion

« LOOKING BACK Section 12.10 The cross product

How do currents respond to magnetic fields?

Currents are moving charged particles, so:

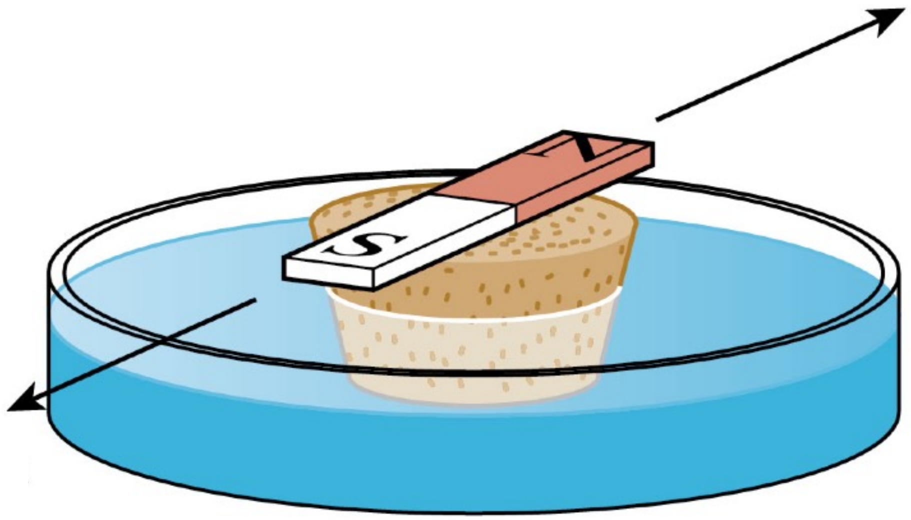
- There's a force on a current-carrying wire in a magnetic field.
- Two parallel current-carrying wires attract or repel each other.
- There's a torque on a current loop in a magnetic field. This is how motors work.

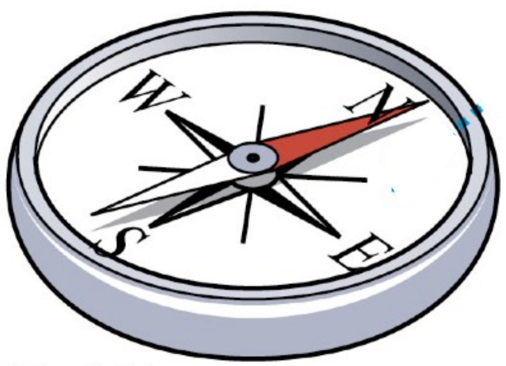


Why is magnetism important?

Magnetism is much more important than a way to hold a shopping list on the refrigerator door. Motors and generators are based on magnetic forces. Many forms of data storage, from hard disks to the stripe on your credit card, are magnetic. Magnetic resonance imaging (MRI) is essential to modern medicine. Magnetic levitation trains are being built around the world. And the earth's magnetic field keeps the solar wind from sterilizing the surface. There would be no life and no modern technology without magnetism.

Discovering Magnetism: Experiment 1



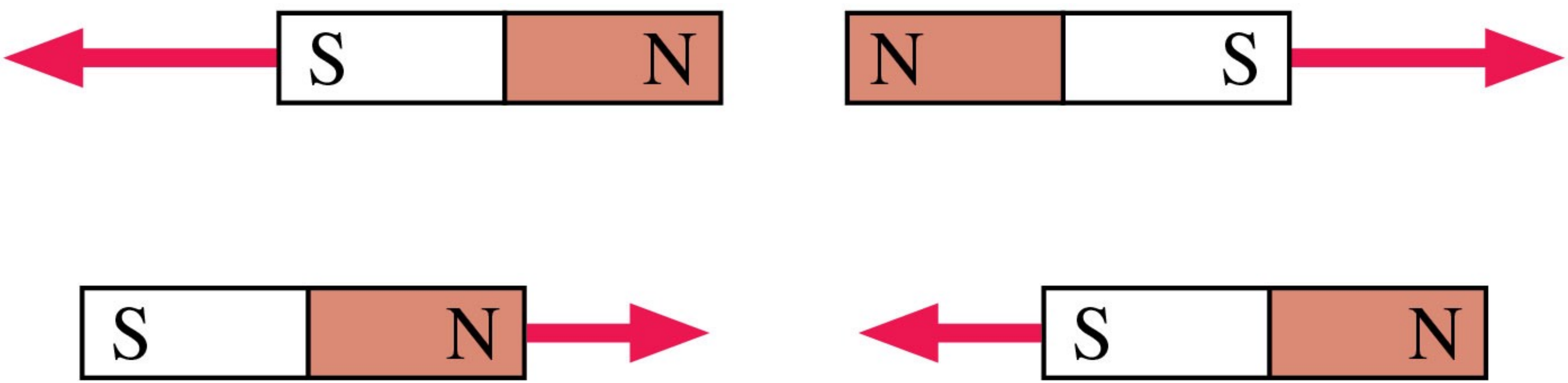


- Tape a bar magnet to a piece of cork and allow it to float in a dish of water.
- It always turns to align itself in an approximate north-south direction.

- The end of a magnet that points north is called the *north-seeking pole*, or simply the **north pole**.
- The end of a magnet that points south is called the **south pole**.

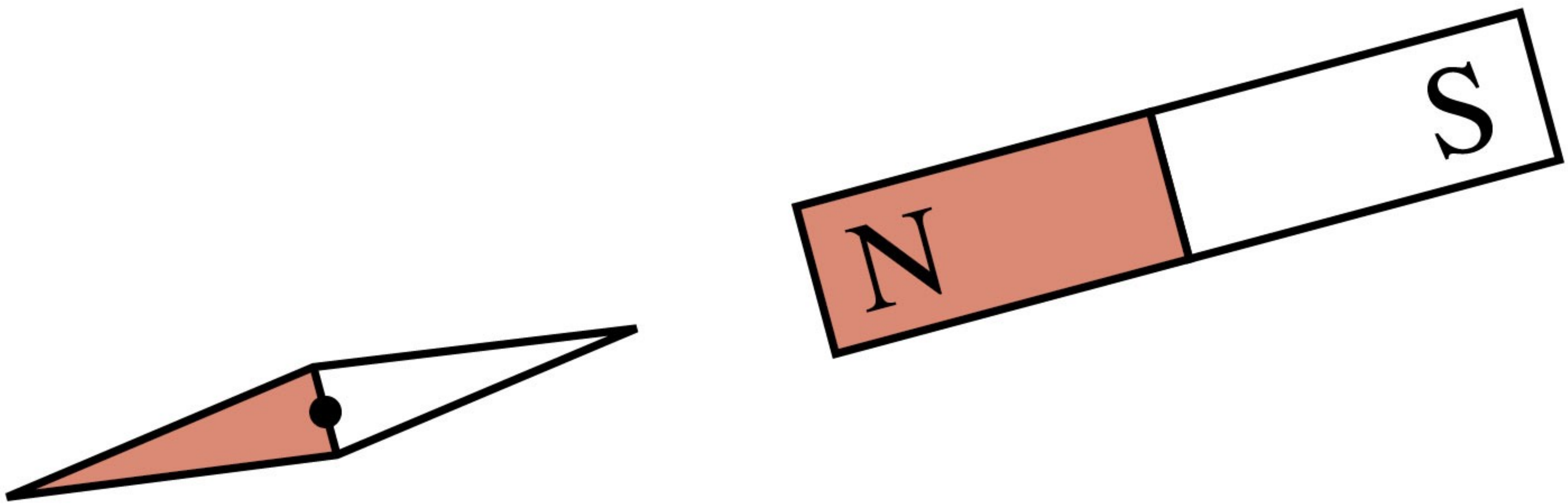
Discovering Magnetism: Experiment 2

- If the north pole of one magnet is brought near the north pole of another magnet, they repel each other.
- Two south poles also repel each other, but the north pole of one magnet exerts an attractive force on the south pole of another magnet.



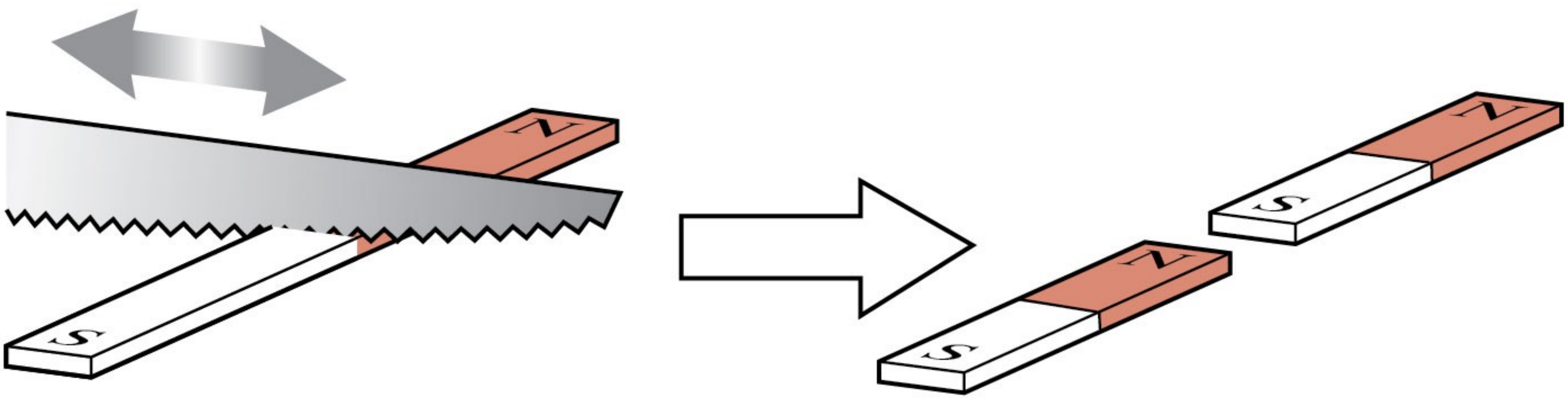
Discovering Magnetism: Experiment 3

- The north pole of a bar magnet attracts one end of a compass needle and repels the other.
- Apparently the compass needle itself is a little bar magnet with a north pole and a south pole.

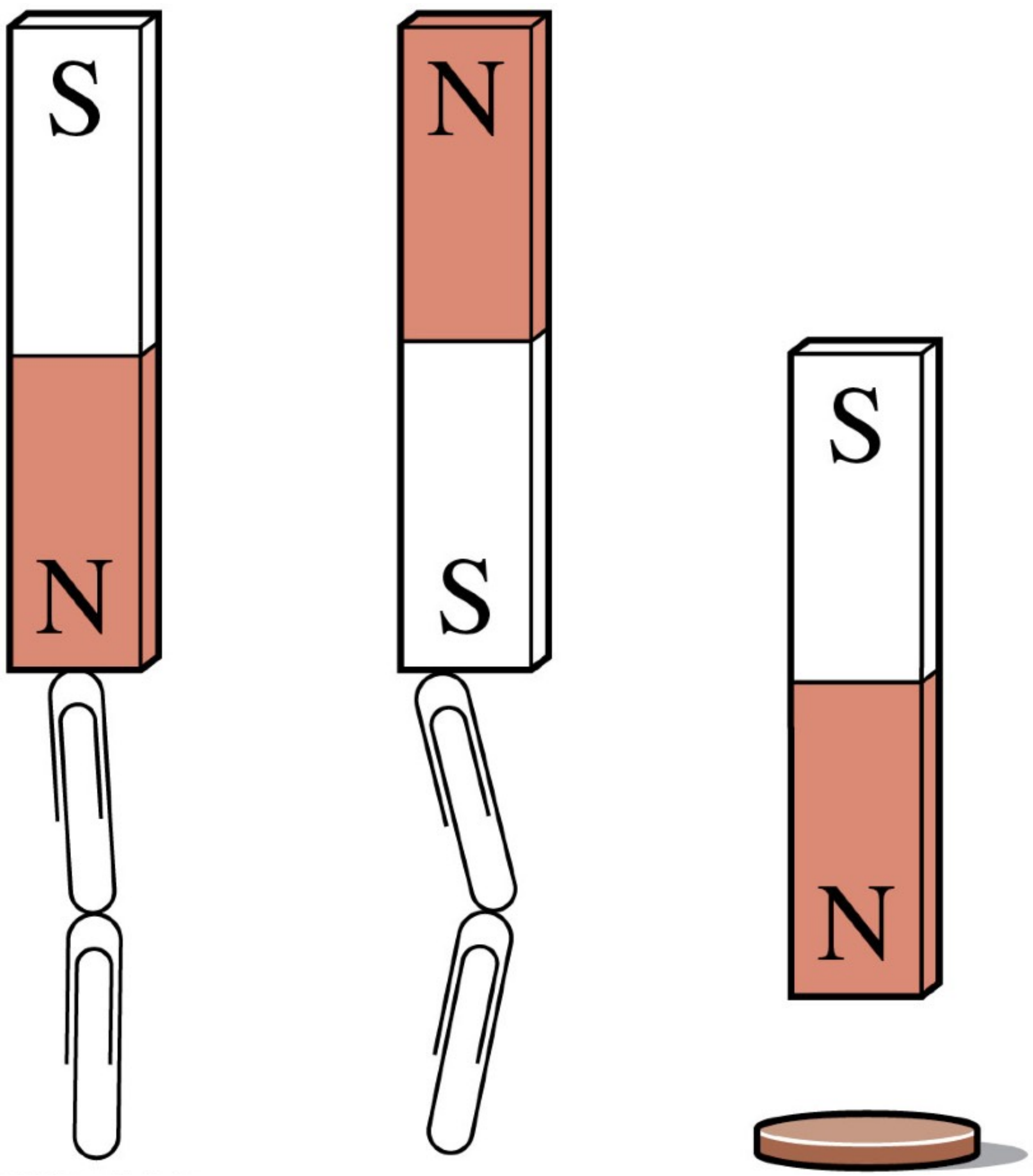


Discovering Magnetism: Experiment 4

- Cutting a bar magnet in half produces two weaker but still complete magnets, each with a north pole and a south pole.
- No matter how small the magnets are cut, even down to microscopic sizes, each piece remains a complete magnet with two poles.

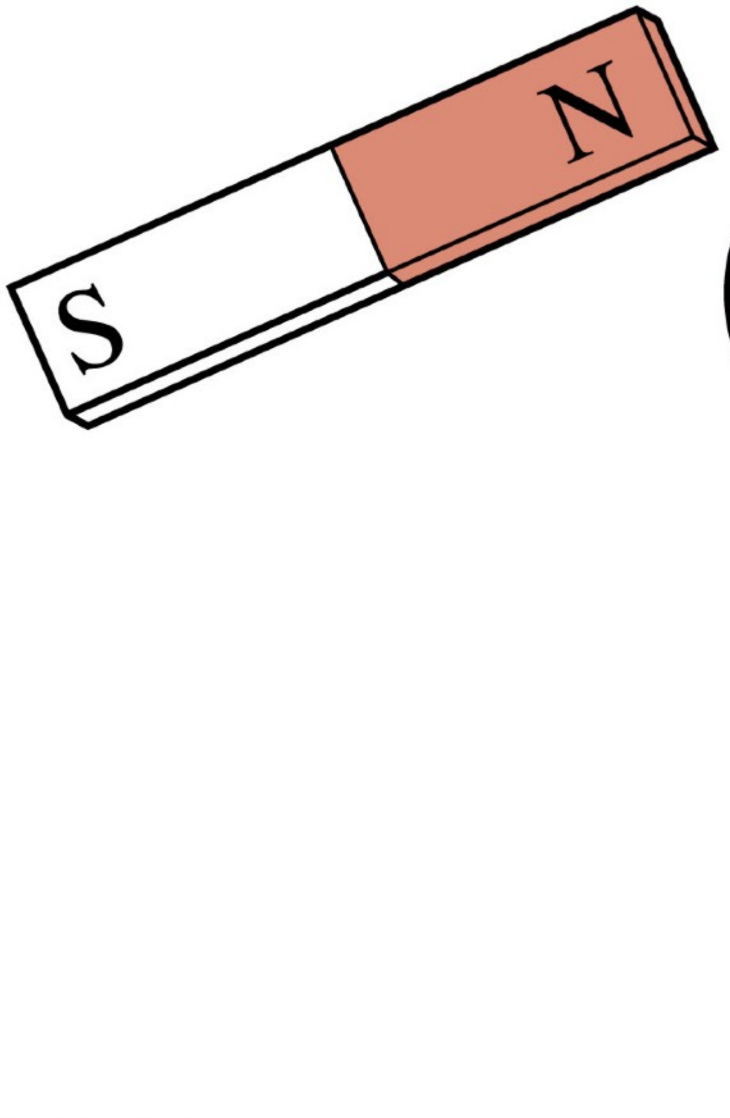


Discovering Magnetism: Experiment 5



- Magnets can pick up some objects, such as paper clips, but not all.
- If an object is attracted to one end of a magnet, it is also attracted to the other end.
- Most materials, including copper (a penny), aluminum, glass, and plastic, experience no force from a magnet.

Discovering Magnetism: Experiment 6



- A magnet does not affect an electroscope.
- A charged rod exerts a weak *attractive* force on *both* ends of a magnet.
- However, the force is the same as the force on a metal bar that isn't a magnet, so it is simply a polarization force like the ones we studied in Chapter 22.

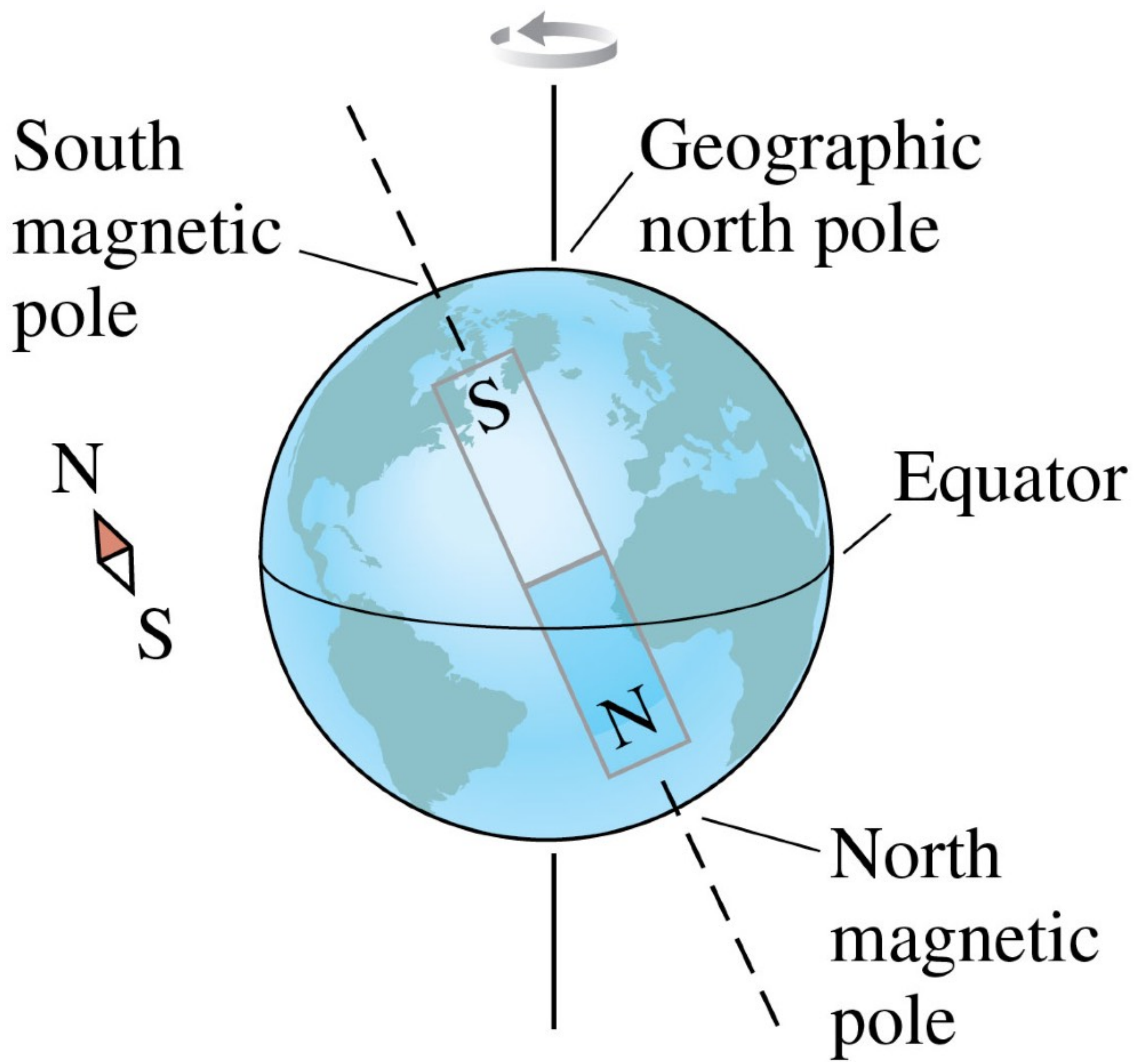
- Other than polarization forces, charges have *no effects* on magnets.

What Do These Experiments Tell Us?

1. Magnetism is *not* the same as electricity.
2. Magnetism is a <u>long range force</u>.
3. All magnets have <u>two poles</u>, called north and south poles. Two like poles exert repulsive forces on each other; two opposite poles attract.
4. The poles of a bar magnet can be identified by using it as a compass. The north pole tends to rotate to point approximately north.
5. Materials that are attracted to a magnet are called **magnetic materials**. The most common magnetic material is iron.

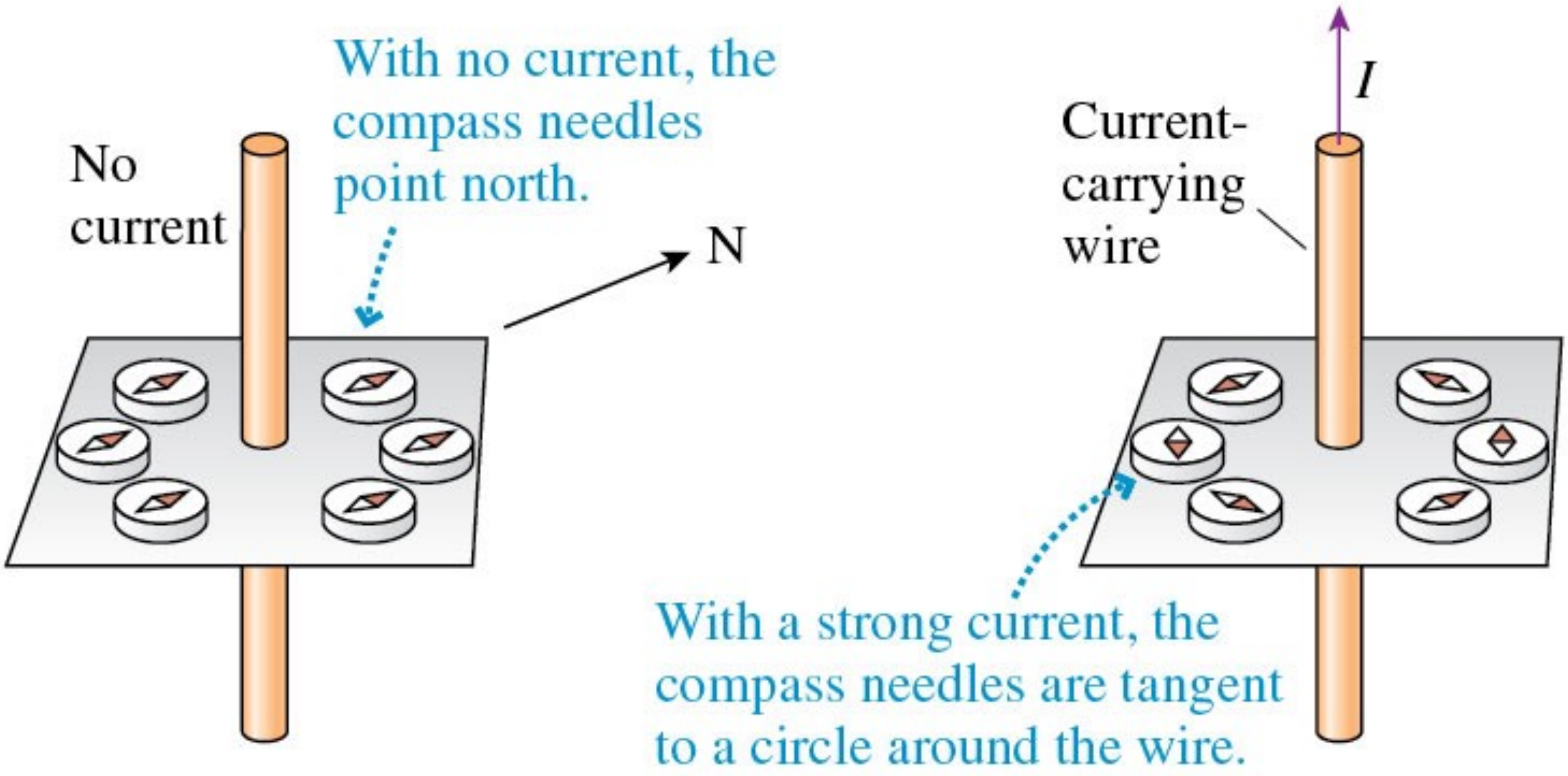
Compasses and Geomagnetism

- Due to currents in the molten iron core, the earth itself acts as a large magnet.
- The poles are slightly offset from the poles of the rotation axis.
- The geographic north pole is actually a *south* magnetic pole!



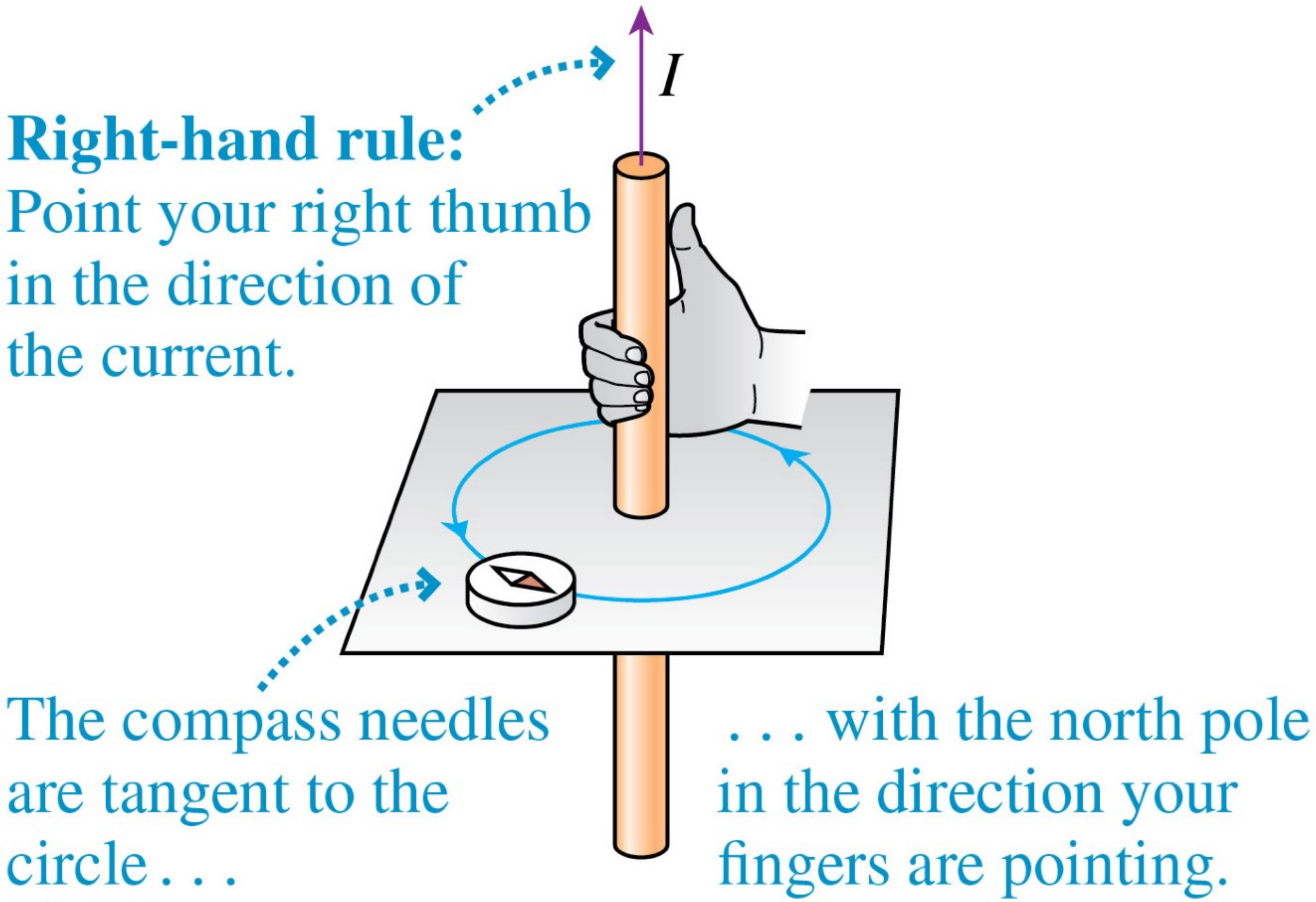
Electric Current Causes a Magnetic Field

- In 1819 Hans Christian Oersted discovered that an electric current in a wire causes a compass to turn.



Electric Current Causes a Magnetic Field

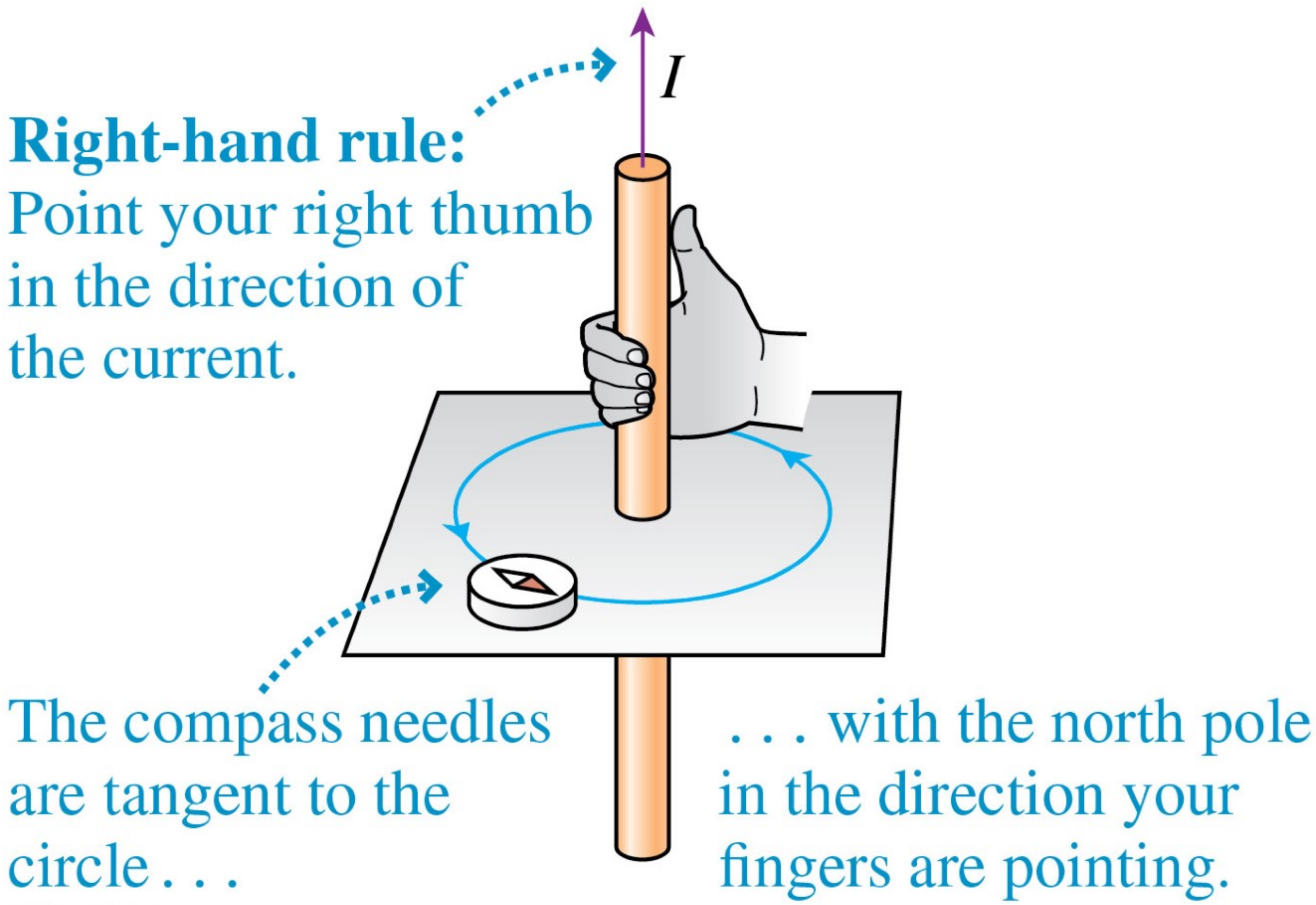
- The **right-hand rule** determines the orientation of the compass needles to the direction of the current.



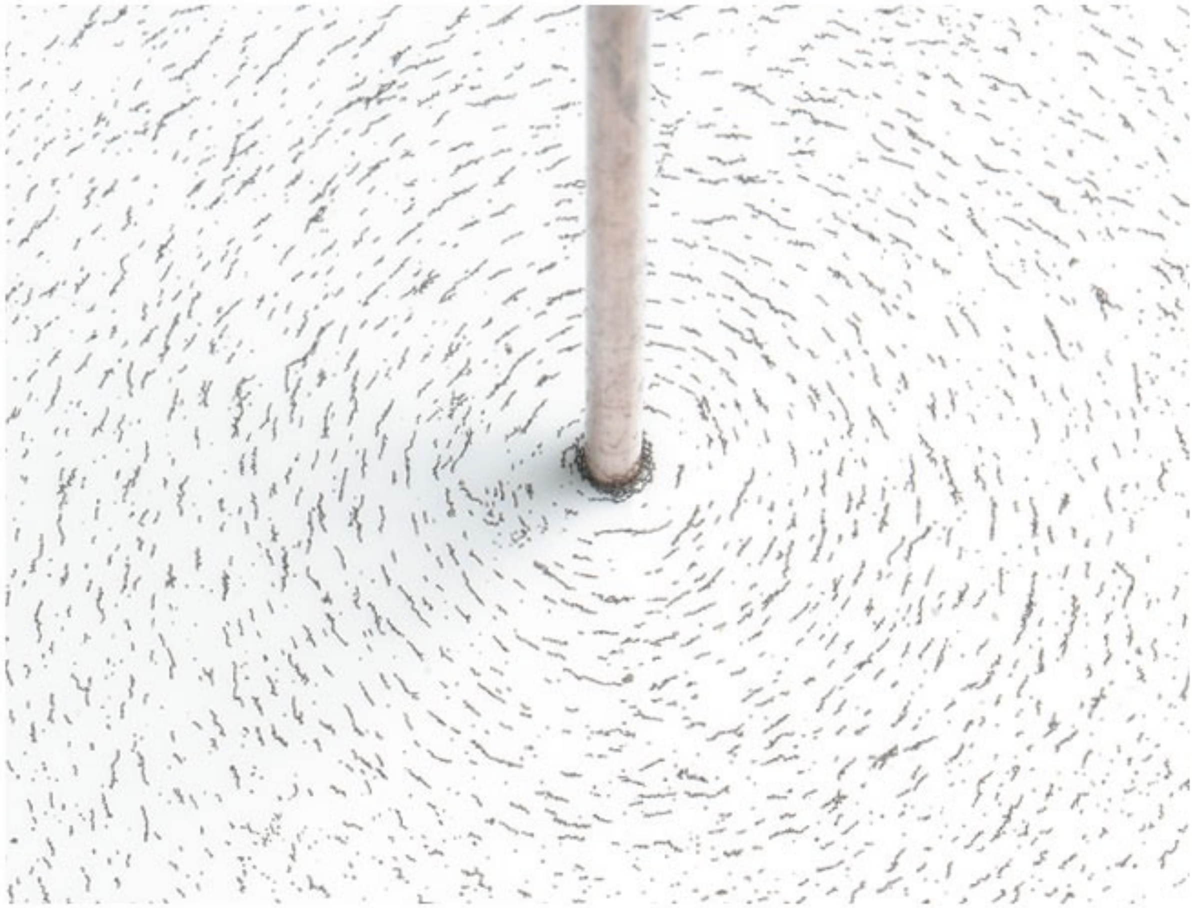
iClicker survey #12-4: Did you know this?

A. YES
B. NO
C. I don't care
D. Where am I?
E. Who am I?

- The **right-hand rule** determines the orientation of the compass needles to the direction of the current.



Electric Current Causes a Magnetic Field



- The magnetic field is revealed by the pattern of iron filings around a current-carrying wire.