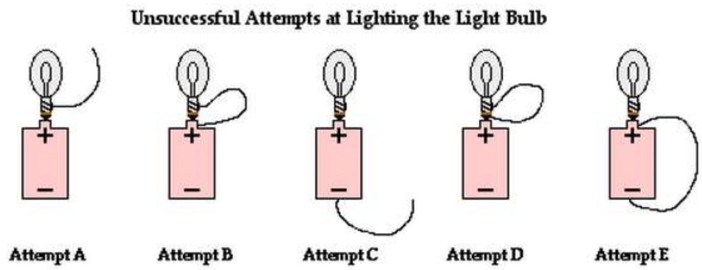
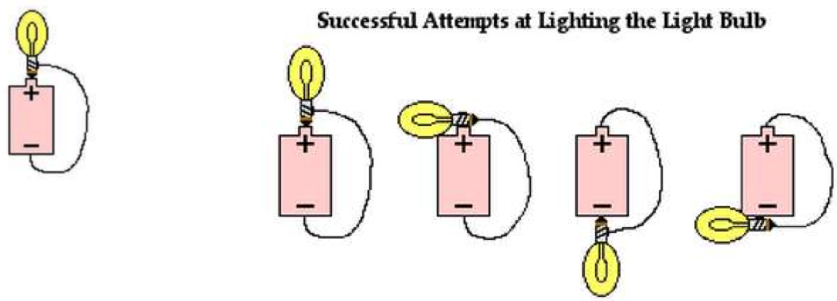
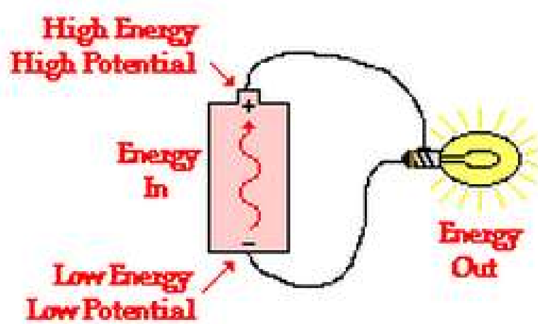
CURRENT ELECTRICITY

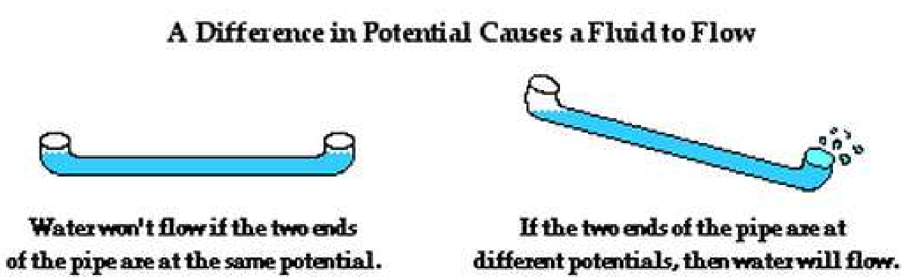
- **Current** → flow of charge within a circuit.





- A circuit must be *closed* for there to be a current.
- **More current means a brighter bulb.**
- Just like an object in a gravitational field will naturally move from high to low potential (think a dropped ball), the same will happen to a charge in an electrical field
  - This is why charge flows through a circuit.





- This **potential difference** creates the electric field that drives the current in the wire.
    - Aka: **voltage**, **electric potential**
    - Units: Volts (V)

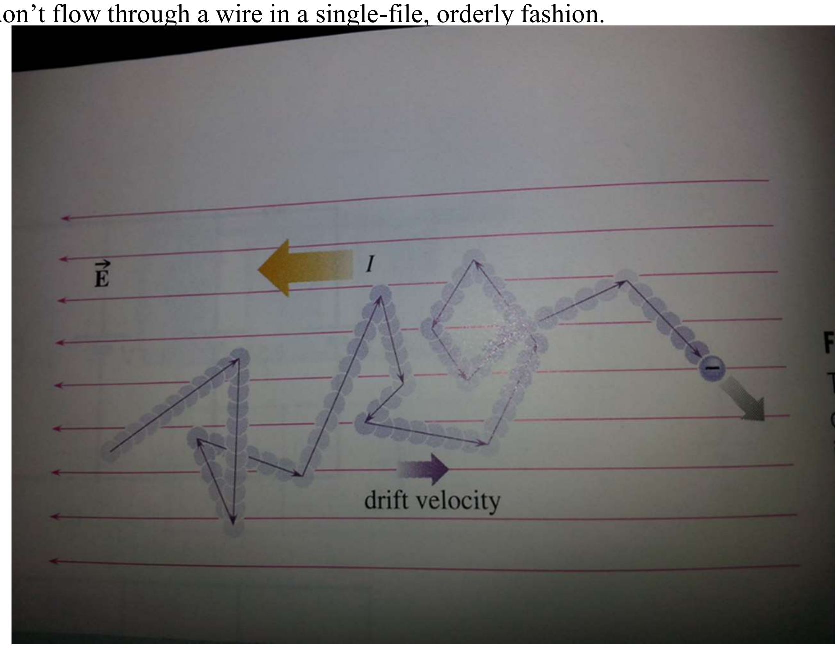
$$I = \frac{q}{t}$$

- I → current
    - Units: Amperes (A)
    - 1 A = 1 C/s

EXAMPLE 22.2 **Charge flow in a lightbulb**

A 100 W lightbulb carries a current of 0.83 A. How much charge flows through the bulb in 1 minute?

- Charges don't flow through a wire in a single-file, orderly fashion.



- **Conservation of Current** → the current entering the load is the same as the current leaving the load.
    - **Load** → what is hooked up to the circuit. It takes energy carried by the charge and transforms it into another type of energy.
    - Ex: a light bulb transforms electric energy into light and thermal energy (heat)
    - Ex: a motor transforms electric energy into mechanical energy (spins the motor)
    - Having no load connected to a circuit leads to a **short circuit**.
- **Law of Conservation of Current** → the total current is the same at all points in a current-carrying wire.

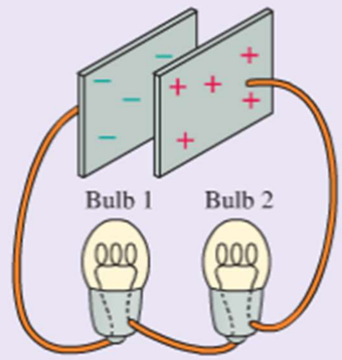
CONCEPTUAL EXAMPLE 22.1 **Which bulb is brighter?**

The discharge of a capacitor lights two identical bulbs, as shown in FIGURE 22.8. Compare the brightness of the two bulbs.

REASON Current is conserved, so any current that goes through bulb 1 must go through bulb 2 as well—the currents in the two bulbs are equal. We've noted that the brightness of a bulb is proportional to the current it carries. Identical bulbs carrying equal currents must have the same brightness.

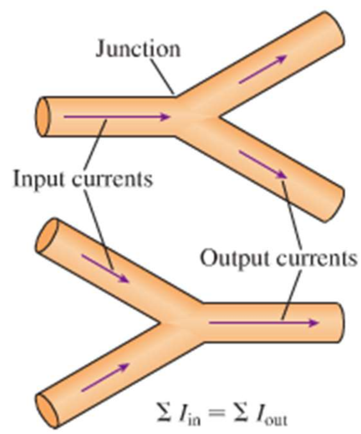
ASSESS This result makes sense in terms

FIGURE 22.8 Two bulbs lit by the current discharging a capacitor.



- **Junction** → a point where a wire branches.
  - ➢ Current must still be conserved.
- **Kirchoff's Junction Law** → The rate at which charges flow into a junction must match the rate at which they flow out.
  - ➢ A result of the Law of Conservation of Charge.

$$\Sigma I_{in} = \Sigma I_{out}$$

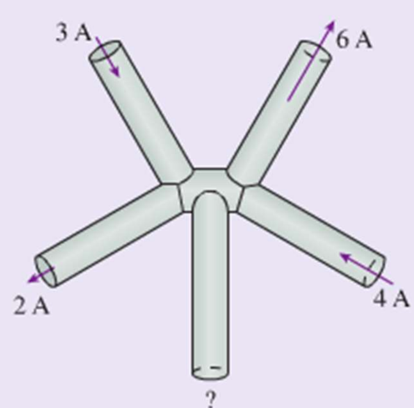


EXAMPLE 22.3 **Currents in a junction**

Four wires have currents as noted in FIGURE 22.12. What are the direction and the magnitude of the current in the fifth wire?

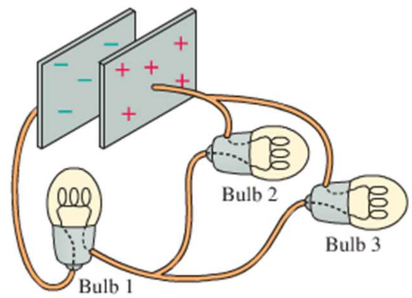
PREPARE This is a conservation of current problem. We compute the sum of the currents coming into the junction and the sum of the currents going out of the junction, and then compare these two sums. The unknown current is whatever

FIGURE 22.12 The junction of five wires.



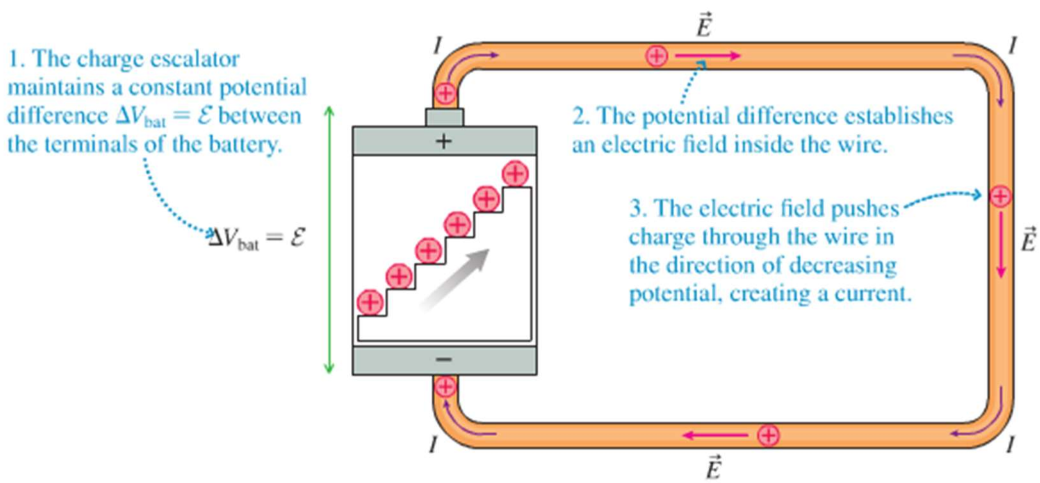
STOP TO THINK 22.1 The discharge of a capacitor lights three bulbs. Comparing the current in bulbs 1 and 2, we can say that

A. The current in bulb 1 is greater than the current in bulb 2.
B. The current in bulb 1 is less than the current in bulb 2.
C. The current in bulb 1 is equal to the current in bulb 2.



- **A battery is a source of potential difference.**

FIGURE 22.16 The electric field and the current inside the wire.



STOP TO THINK 22.3 In Figure 22.16 the wire is changed to a new one, leading to an increased current in the wire. Compared to the original wire, the potential difference across the ends of this new wire is

A. Larger. B. Smaller. C. The same.

-
- **Resistance** → how hard it is to push a charges through a wire.
- Factors that increase resistance:
  - Length of the wires
  - Cross-section of the wires
  - Resistivity of the material

Material	Resistivity (ohm•meter)
Silver	1.59×10^{-8}
Copper	1.7×10^{-8}
Gold	2.4×10^{-8}
Aluminum	2.8×10^{-8}

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

- R → resistance
  - Units: Ohms (Ω)
- ρ → resistivity (Ω·m)
- L → length of wire
- A → cross-sectional area of wire

EXAMPLE 22.6 The length of a lightbulb filament

We calculated in Example 22.5 that a 60 W lightbulb has a resistance of 240 Ω. At the operating temperature of the tungsten filament, the resistivity is approximately $5.0 \times 10^{-7}\ \Omega \cdot \text{m}$. If the wire used to make the filament is 0.040 mm in diameter (a typical value), how long must the filament be?

- **Ohm's Law**

$$\Delta V = IR$$

EXAMPLE 22.7 Making a heater

An amateur astronomer uses a heater to warm her telescope eyepiece so moisture does not collect on it. The heater is a 20-cm-long, 0.50-mm-diameter nichrome wire that wraps around the eyepiece. When the wire is connected to a 1.5 V battery, what is the current in the wire?

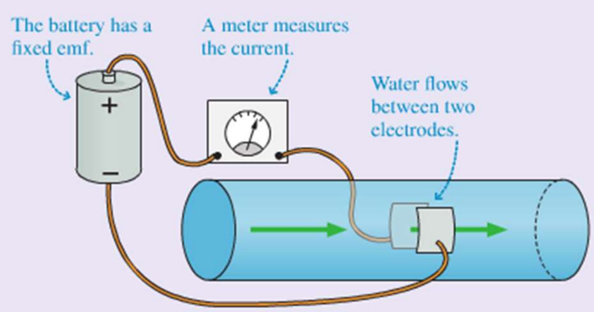
CONCEPTUAL EXAMPLE 22.8 Testing drinking water

A house gets its drinking water from a well that has an intermittent problem with salinity. Before the water is pumped into the house, it passes between two electrodes in the circuit shown in FIGURE 22.18. The current passing through the water is measured with a meter. Which corresponds to increased salinity—an increased current or a decreased current?

REASON Increased salinity causes the water's resistivity to decrease. This decrease causes a decrease in resistance between the electrodes. Current is inversely proportional to resistance, so this leads to an increase in current.

ASSESS Increasing salinity means more ions in solution and thus more charge carriers, so an increase in current is expected. Electrical systems similar to this can therefore provide a quick check of water purity.

FIGURE 22.18 A water-testing circuit.



STOP TO THINK 22.4 A wire connected between the terminals of a battery carries a current. The wire is removed and stretched, decreasing its cross-section area and increasing its length. When the wire is reconnected to the battery, the new current is

A. Larger than the original current.
B. The same as the original current.
C. Smaller than the original current.

$$P = VI$$

$$P = I^2R$$

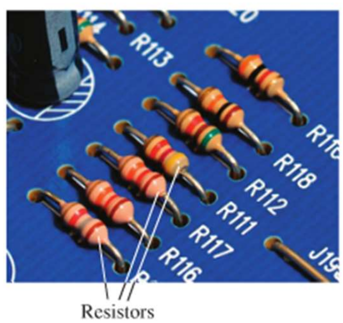
$$P = \frac{V^2}{R}$$

- Ohm's Law *does not* apply to all instances.
  - Limited to materials where the resistance remains constant.
  - **Ohmic** → materials to which Ohm's law applies. Ex: wires or lightbulb filaments.
  - **Nonohmic** → Ohm's law does not apply. Ex: the internal workings of batteries and capacitors.
- **Resistors** → circuit elements designed to *create* resistance to control current.
  - Not all resistance is bad.

Examples of resistors

Heating elements

As charges move through a resistive wire, their electric energy is transformed into thermal energy, heating the wire. Wires in a toaster, a stove burner, or the rear window defroster of a car are practical examples of this electric heating.



Circuit elements

Inside many electronic devices is a circuit board with many small cylinders. These cylinders are resistors that help control currents and voltages in the circuit. The colored bands on the resistors indicate their resistance values.

Sensor elements

A resistor whose resistance changes in response to changing circumstances can be used as a sensor. The resistance of this night-light sensor changes when daylight strikes it. A circuit detects this change and turns off the light during the day.

CONCEPTUAL EXAMPLE 22.9 The changing current in a toaster

When you press the lever on a toaster, a switch connects the heating wires to 120 V. The wires are initially cool, but the current in the wires raises the temperature until they are hot enough to glow. As the wire heats up, how does the current in the toaster change?

REASON As the wire heats up, its resistivity increases, as noted above, so the resistance of the wires increases. Because the potential difference stays the same, an increasing resistance causes the current to decrease. The current through a toaster is largest when the toaster is first turned on.

ASSESS This result makes sense. As the wire's temperature increases, the current decreases. This makes the system stable. If, instead, the current increased as the temperature increased, higher temperature could lead to more current, leading to even higher temperatures, and the toaster could overheat.

EXAMPLE 22.10 Analyzing a single-resistor circuit

A 15 Ω resistor is connected to the terminals of a 1.5 V battery.

a. Draw a graph showing the potential as a function of distance traveled through the circuit, starting from $V = 0$ V at the negative terminal of the battery.
b. What is the current in the circuit?

PREPARE To help us visualize the change in potential as charges move through the circuit, we begin with the sketch of the circuit in FIGURE 22.24. The zero point of potential is noted. We have drawn our sketch so that "up" corresponds to higher potential, which will help us make sense of the circuit. Charges are raised to higher potential in the battery, then travel "downhill" from the positive terminal through the resistor and back to the negative terminal. We assume ideal wires.

FIGURE 22.24 A single-resistor circuit.

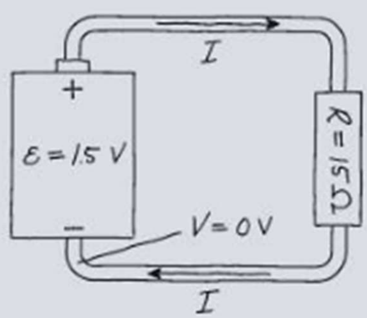
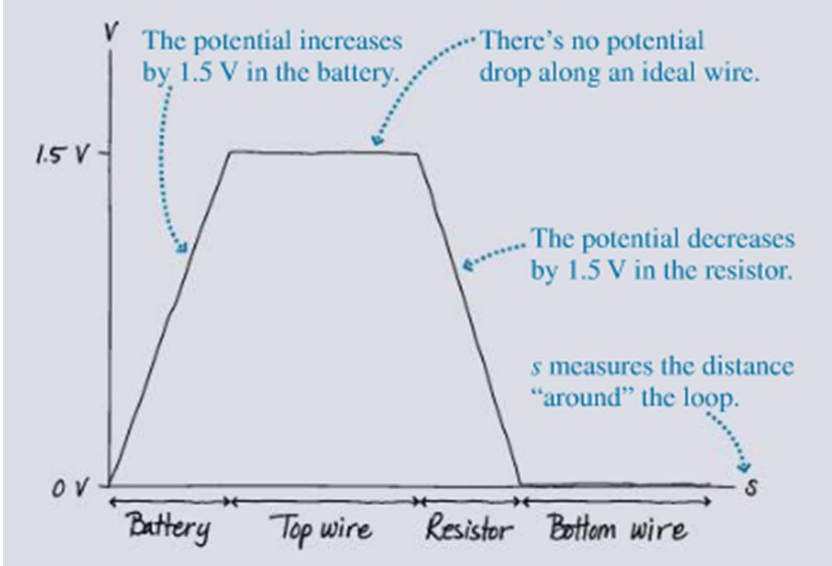
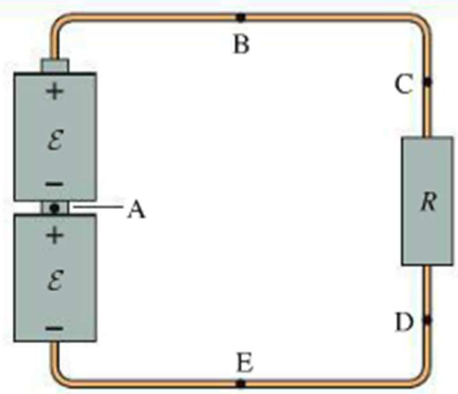


FIGURE 22.25 Potential-versus-position graph.

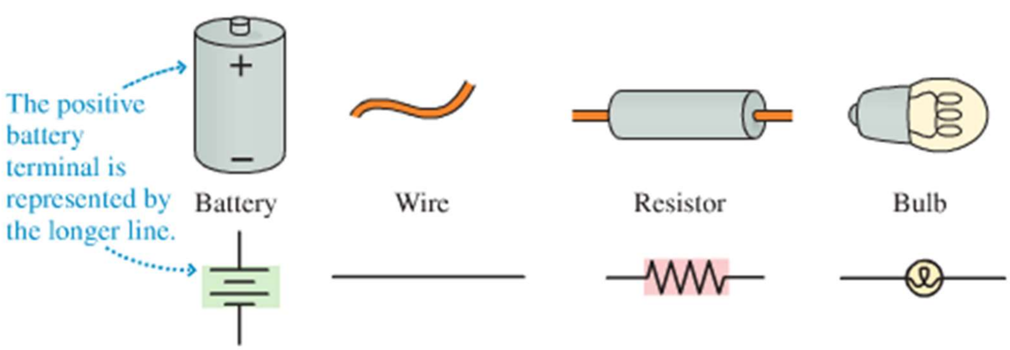


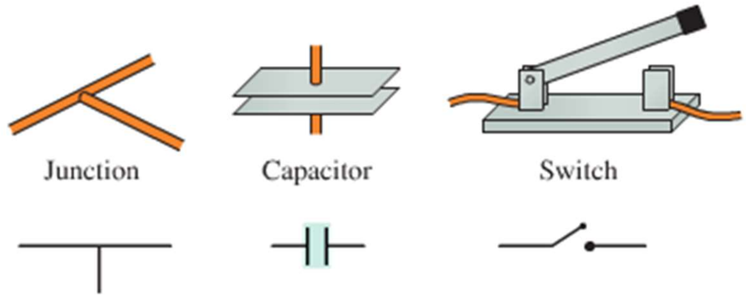
STOP TO THINK 22.5 Two identical batteries are connected in series in a circuit with a single resistor. $V = 0$ V at the negative terminal of the lower battery. Rank in order, from highest to lowest, the potentials V_A to V_E at the labeled points, noting any ties. Assume the wires are ideal.



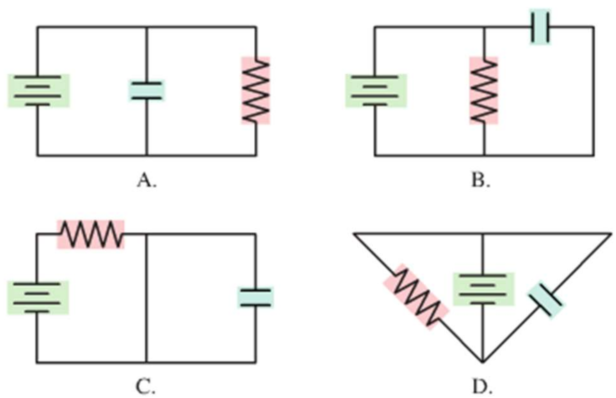
- **Circuit Diagrams**

FIGURE 23.2 A library of basic symbols used for electric circuit drawings.





STOP TO THINK 23.1 Which of these diagrams represent the same circuit?



- **The net change in potential difference around a closed loop (when connected to a load/loads) must be zero.**
  - Just like dropping a ball results in gravitational U being zero, a charge reaches the negative terminal with zero electric U.
- **Kirchoff's Loop Law**

$$\Delta V_{loop} = \Sigma \Delta V = 0$$

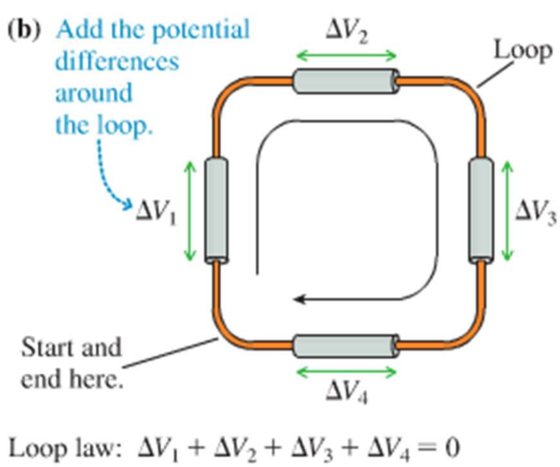
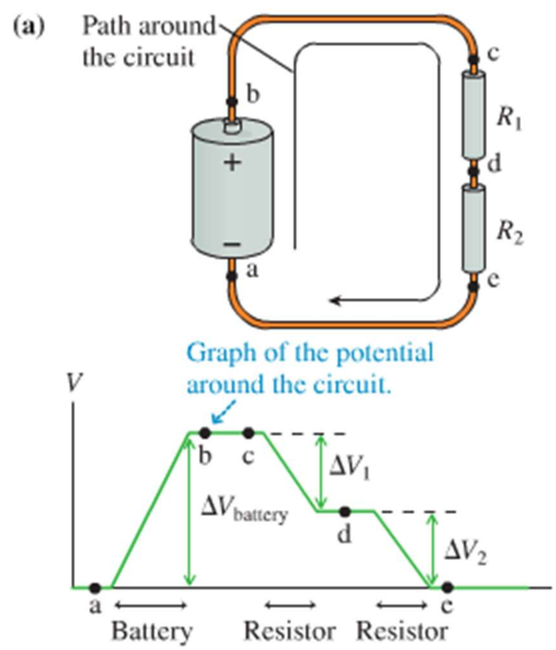


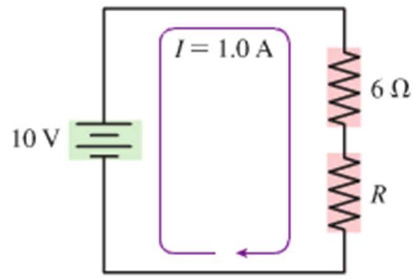
FIGURE 23.5 Kirchhoff's loop law.



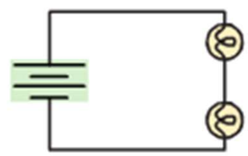
- Electric potential drops as it moves through a resistor.

STOP TO THINK 23.2 What is the potential difference across resistor R?

A. −3.0 V B. −4.0 V
C. −5.0 V D. −6.0 V
E. −10 V



Series Circuits



Series

- A circuit with no junctions.
- Current has only one path to flow through.
- All bulbs will have the same brightness.
- As you connect more bulbs, all the lights become more dim.

- **Equivalent resistance** → the sum of all resistances in a circuit.

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

- Current is the same everywhere across a series circuit.
  - $I_1 = I_2 = I_3 \ldots$
- The sum of your voltage drops is the voltage of your battery. (Kirchoff's Loop Law)

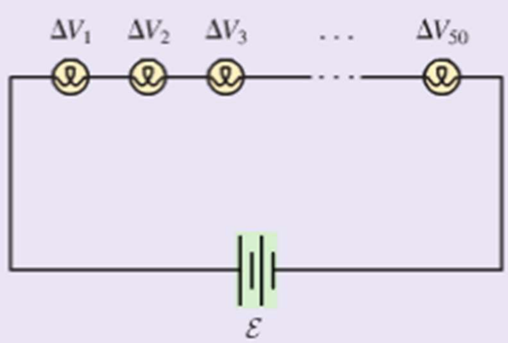
EXAMPLE 23.3 Potential difference of Christmas-tree minilights

A string of Christmas-tree minilights consists of 50 bulbs wired in series. What is the potential difference across each bulb when the string is plugged into a 120 V outlet?

PREPARE FIGURE 23.14 shows the minilight circuit, which has 50 bulbs in series. The current in each of the bulbs is the same because they are in series.

SOLVE Applying Kirchhoff's loop law around the circuit, we find

FIGURE 23.14 50 bulbs connected in series.



- Downside of series circuits: If one bulb goes out, they all do, since there no longer is a closed circuit.
- Remember, a battery is a source of *potential difference*, not a source of current.
  - The amount of current depends on both the potential difference supplied by the battery and the resistance in the circuit.

Parallel Circuits

- A circuit with junction.
  - ➢ Charges have multiple paths through with to flow.
- The sum of the current branches is the same as the current outside of the battery.
  - ➢ Kirchoff's Law of Junctions

$$I_{total} = I_1 + I_2 + I_3 \ldots$$

Diagram A

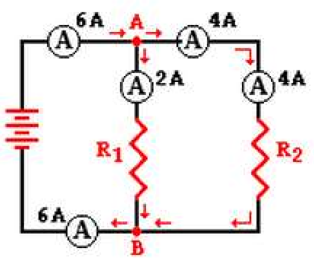
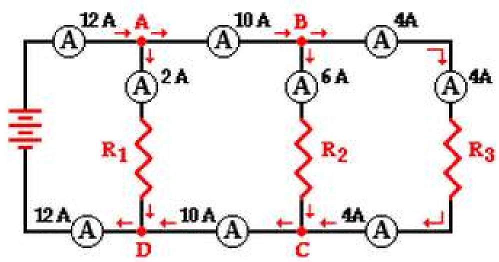
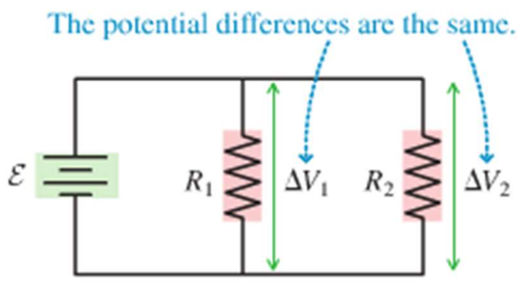


Diagram B



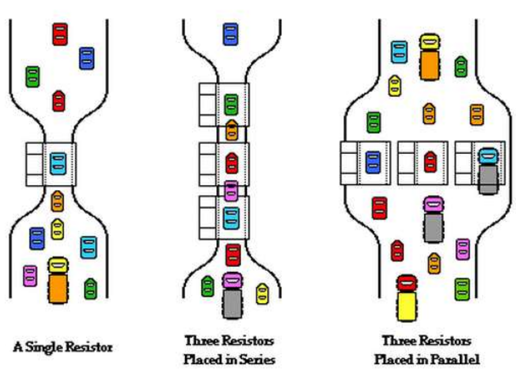
- $\Delta V_{battery} = \Delta V_1 = \Delta V_2 = \Delta V_3 \ldots.$

(a) Two resistors in parallel



$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots$$

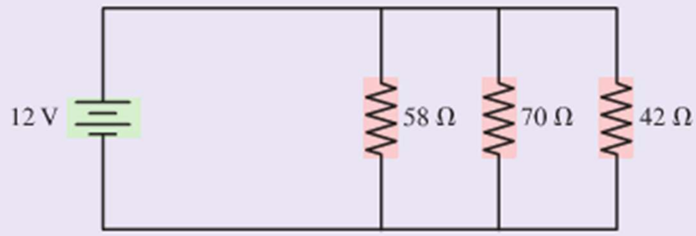
Influencing the Flow Rate on a Tollway



EXAMPLE 23.6 **Current in a parallel resistor circuit**

The three resistors of FIGURE 23.22 are connected to a 12 V battery. What current is provided by the battery?

FIGURE 23.22 A parallel resistor circuit.



PREPARE The three resistors are in parallel, so we can reduce them to a single equivalent resistor, as in FIGURE 23.23.

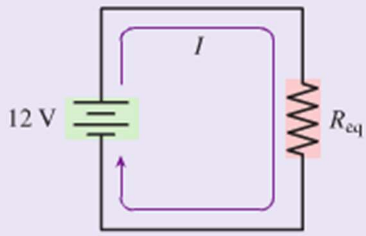
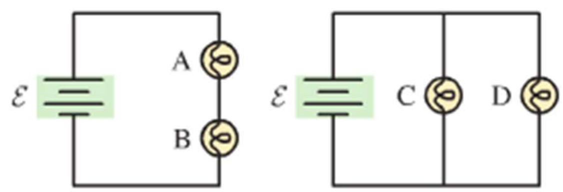
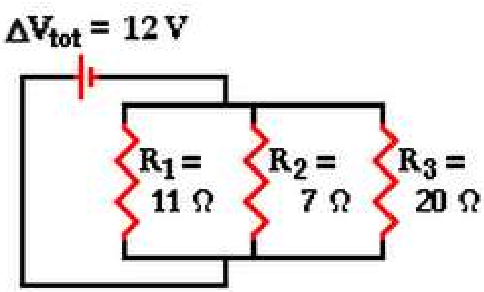


FIGURE 23.23 Analyzing a circuit with parallel resistors.

- **The equivalent resistance of several resistors in parallel is always *less* than any single resistor in the group.**

STOP TO THINK 23.3 Rank in order, from brightest to dimmest, the identical bulbs A to D.





R_{eq} = ____ Ω I_{tot} = ____ A

I_1 = ____ A ΔV_1 = ____ V

I_2 = ____ A ΔV_2 = ____ V

I_3 = ____ A ΔV_3 = ____ V

- **Ammeter** → measures current in a circuit.
  - Ideal ammeter has no resistance.
- **Voltmeter** → measures potential differences in a circuit.
  - Ideal voltmeter has infinite resistance to avoid drawing any current. (They're actually pretty close to that ideal).

STOP TO THINK 23.4 Which is the right way to connect the meters to measure the potential difference across and the current through the resistor?