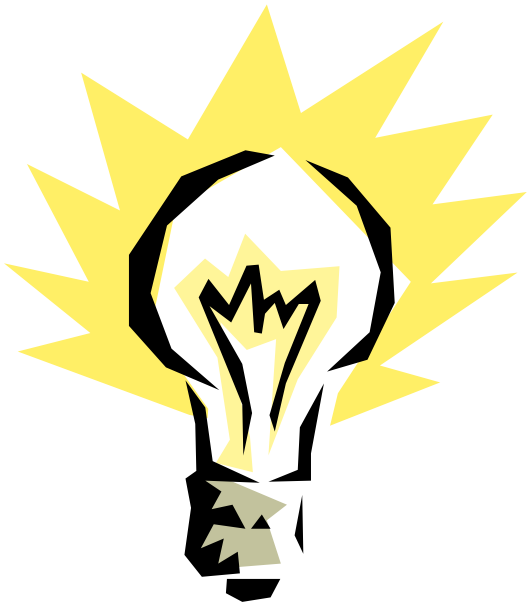
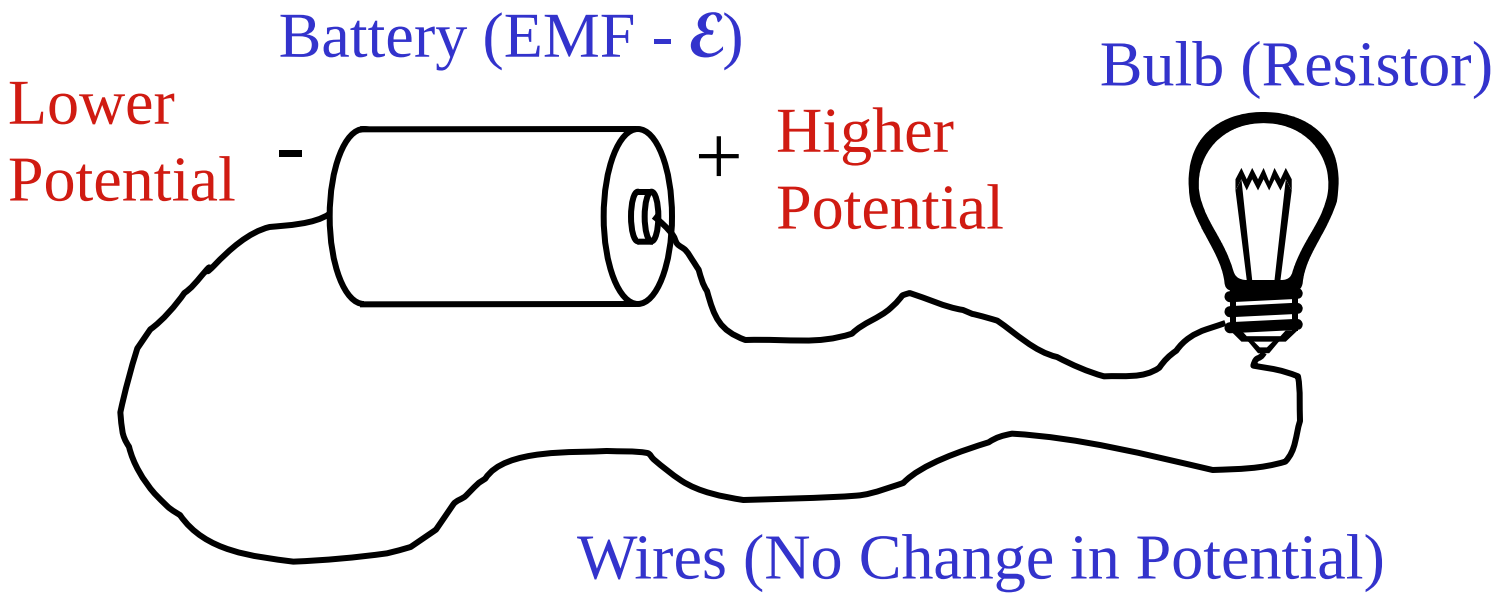
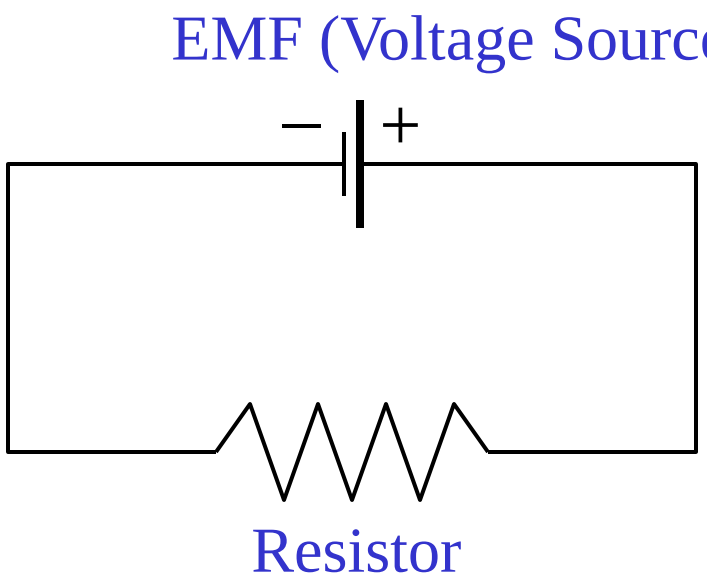
Chapter 13

Electric Circuits




Battery (EMF - $\mathcal{E}$)
Bulb (Resistor)
Lower Potential
-
+
Higher Potential
Wires (No Change in Potential)


EMF (Voltage Source)
−
+
Resistor

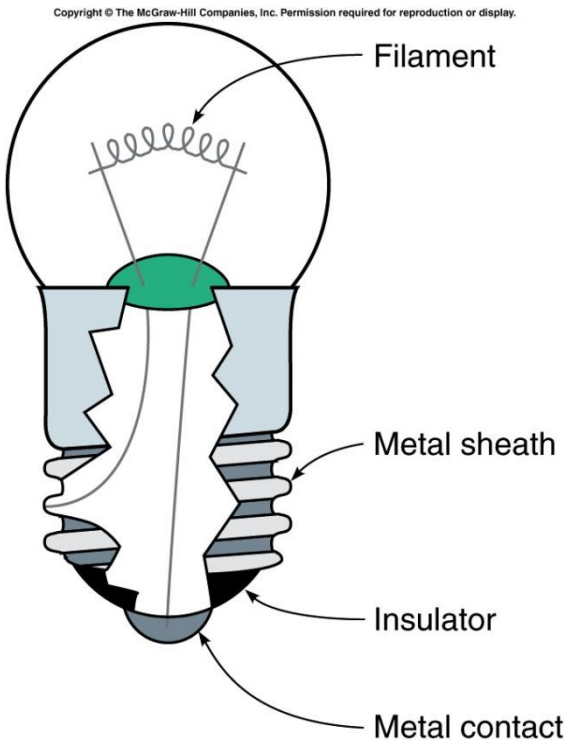
Working Circuits

For a circuit to work, it needs:

- A source of potential difference.
  - A battery or an ac source (like a socket)
- A complete conducting path loop.
- A resistor (like a light bulb) inserted in the path.

- Turns chemical energy into electrical energy.
- Positive charges on one end and negative charges on the other create a potential difference ($\mathcal{E}$).
- Direct current (dc)

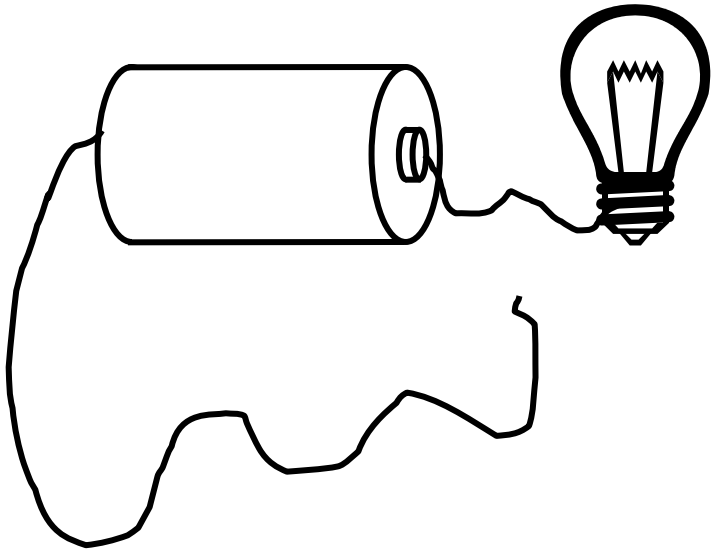
- Energy converted to electrical energy at power plant and transmitted.
- Potential difference exists across leads ($\mathcal{E}$).
- Alternating current (ac)

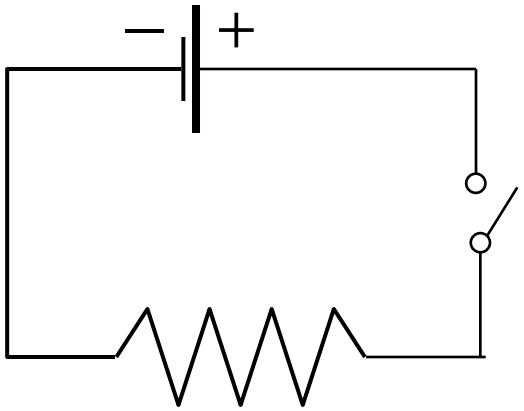


- Thin filament impedes current (a resistor), gets hot and glows.
- Must be placed in circuit path.

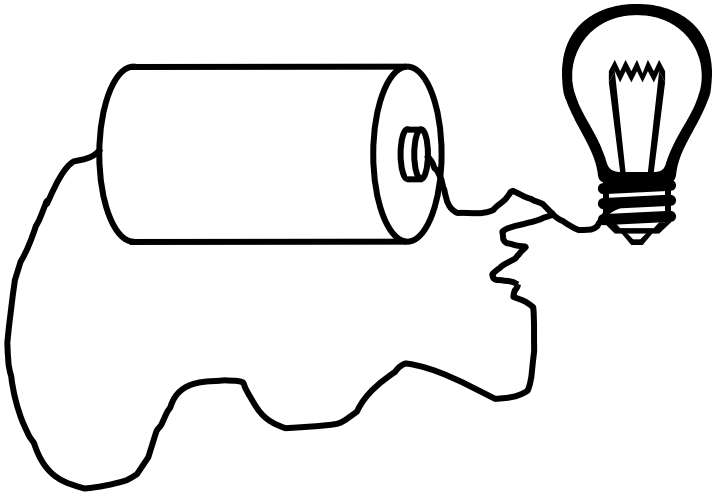
Circuits that won't work

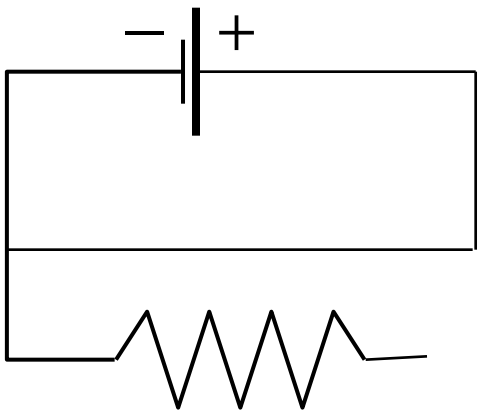
Not closed





Bulb not in circuit



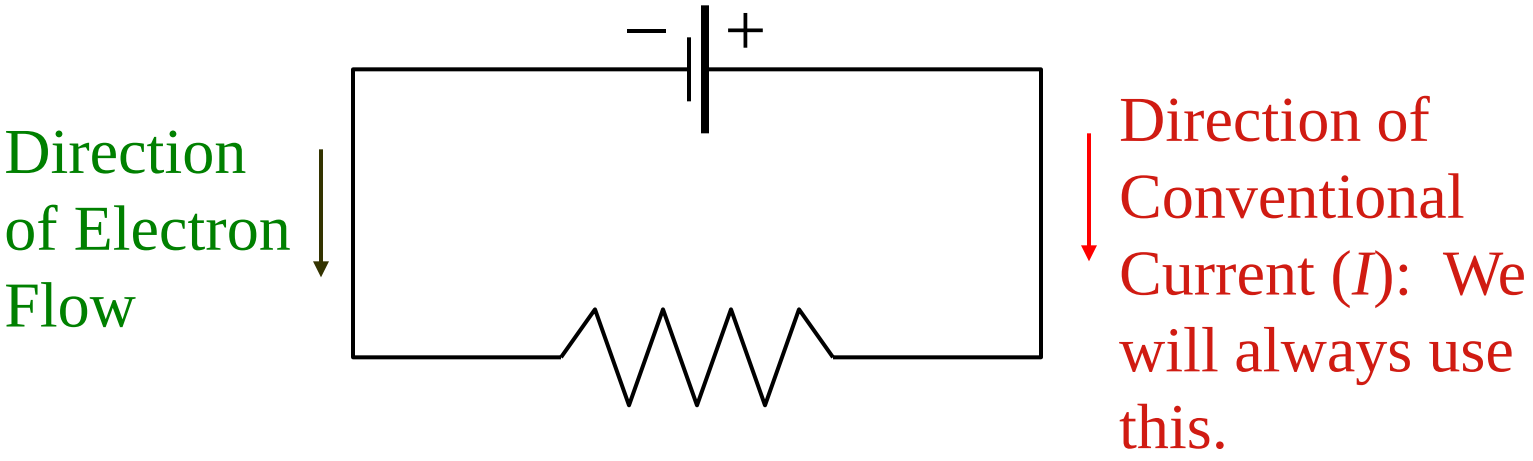


Current

$$I = q/t$$

Current is charge per time

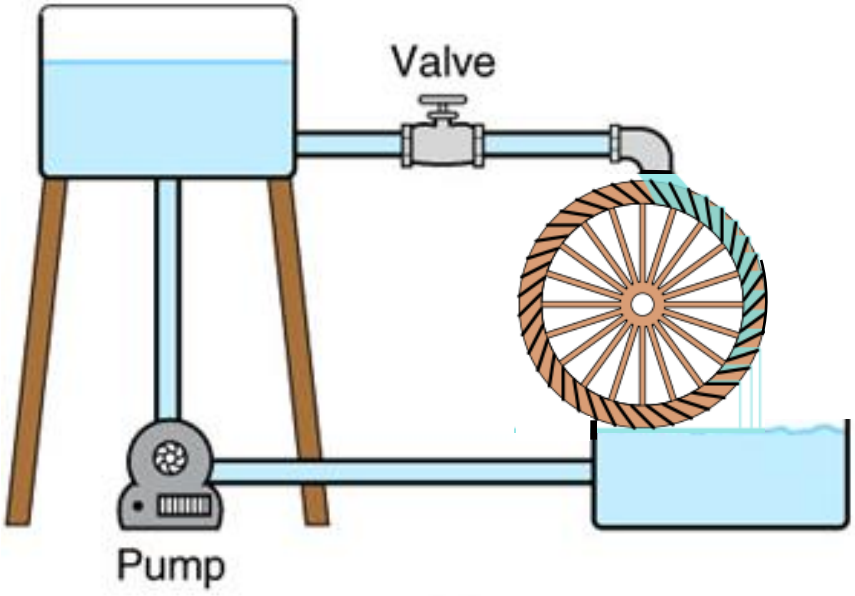
SI Units: Coulombs/Second = Amps

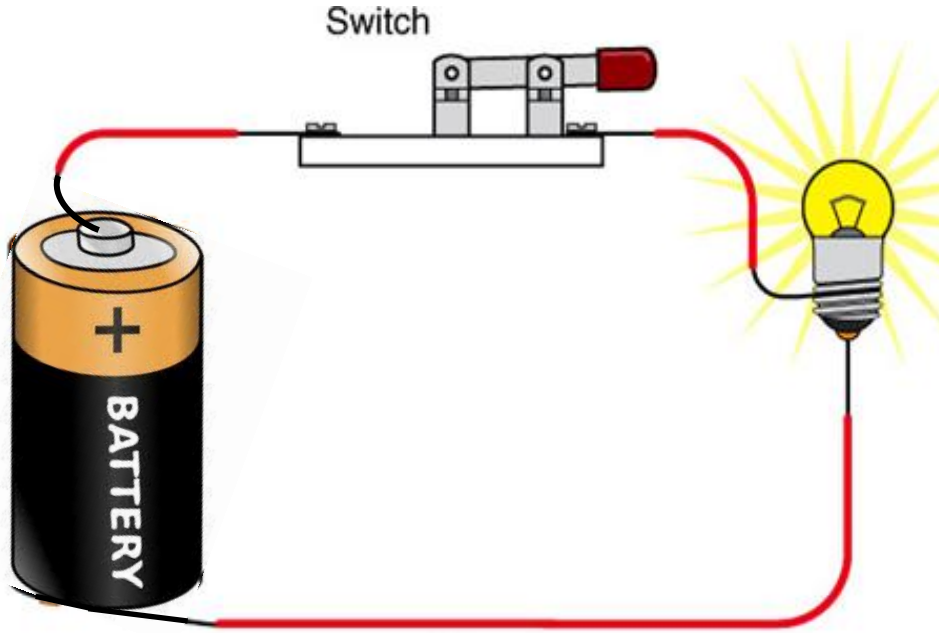


Problem: Suppose one trillion electrons flow past a point in one half second. What is the current?

Water/Electric Analogy

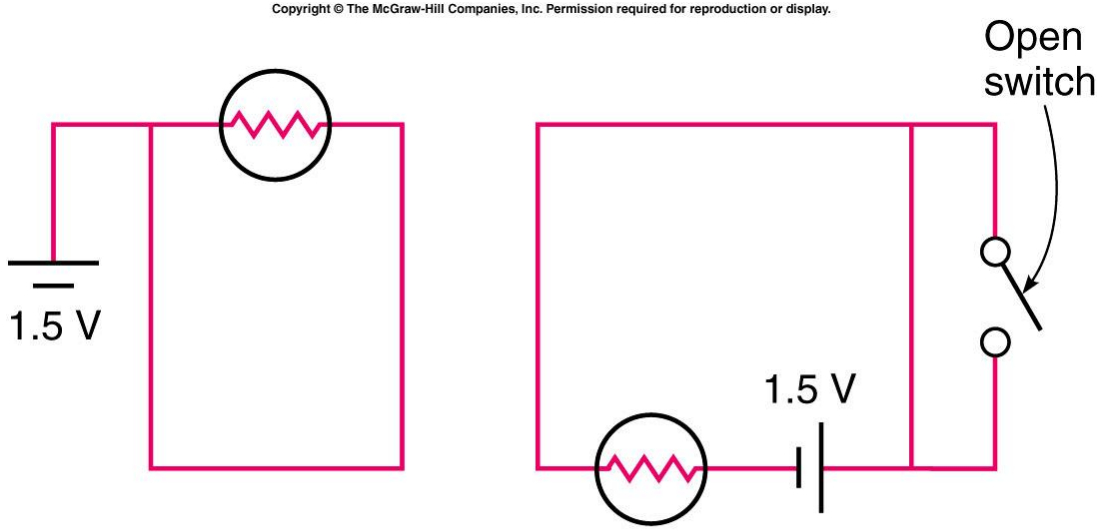
– The battery is like the pump.
– Electric charge is like water.
– Connecting wires are like pipe.
– The light bulb is like a water wheel.
– The switch is like the valve.
– Gravitational potential energy is like electric potential





Interactive Question

Will the light bulb in either circuit go on?



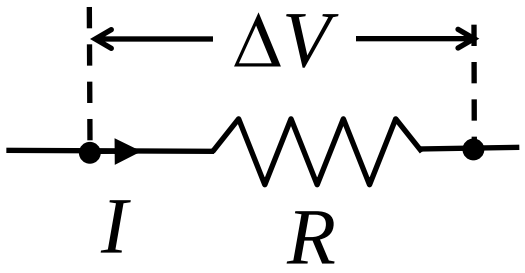
(A) (B)

A) Yes, circuit A only
B) Yes, circuit B only
C) Yes, both circuits
D) No, neither circuit

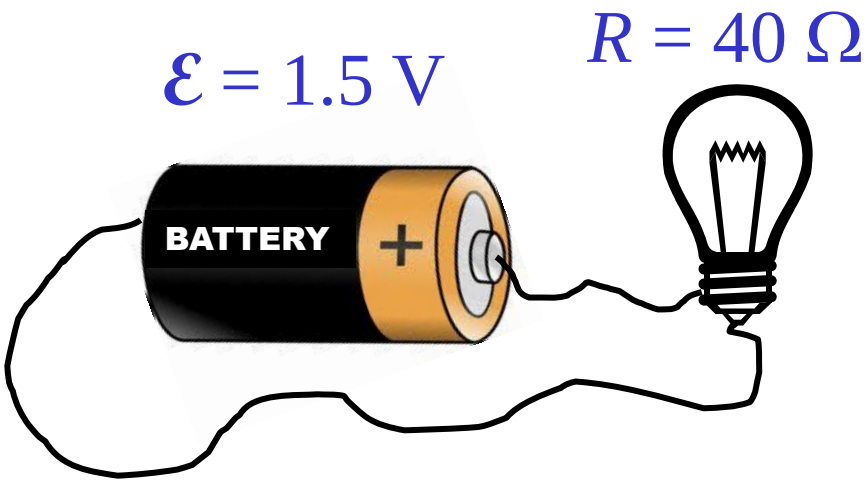
Ohm's Law

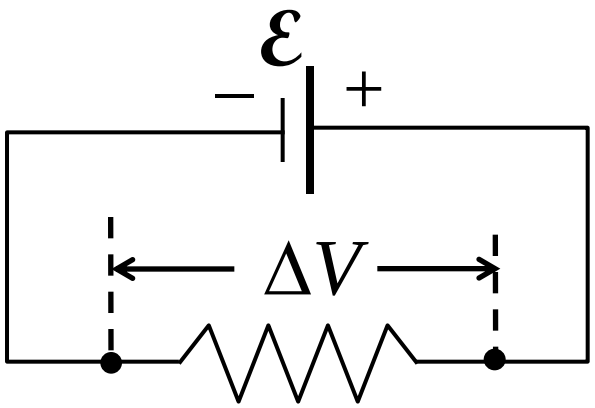
The voltage drop across a resistor is a directly proportional to the resistance of the resistor, and the current in the resistor

$$\Delta V = IR$$



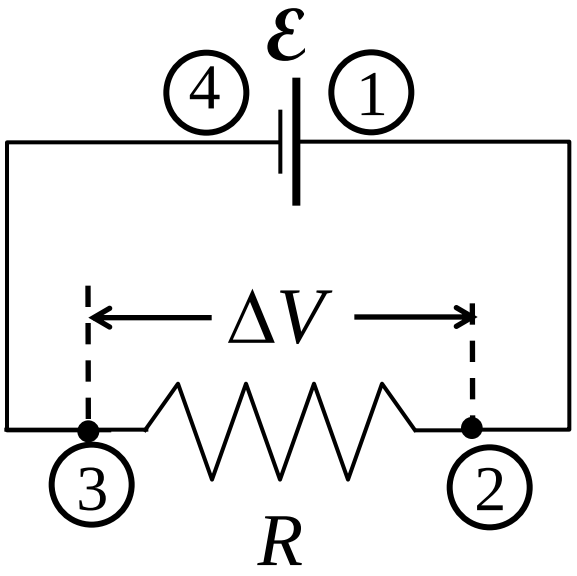
- SI Unit of resistance is Ohms (Ω)
- Resistance depends on the properties of the substance
- An approximate relationship for many metals

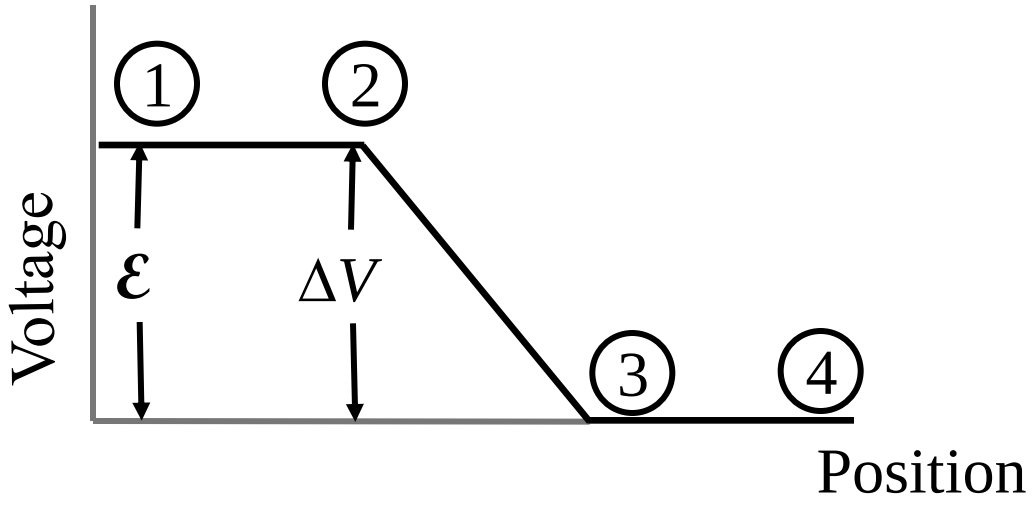




- The loop rule: Around any closed loop, the sum of the voltage rises is equal to the sum of the voltage drops.
  - Compare the gravitational analogy
- The battery raises the voltage 1.5 V and the voltage drop across the light bulb is then ΔV=1.5

Gravitational Analogy





- The battery raises the electric potential by $\mathcal{E}$.
- Wires don't change the electric potential.
- Across the resistor, the electric potential drops by ΔV.

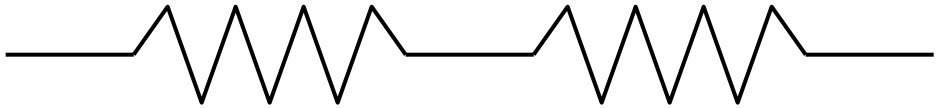
Problem: One twelve volt battery is connected to a 80 Ω resistor. What is the current through the resistor?

Problem: A hair dryer draws 13 A when plugged into a 120 V line. What is the resistance of the hair dryer?

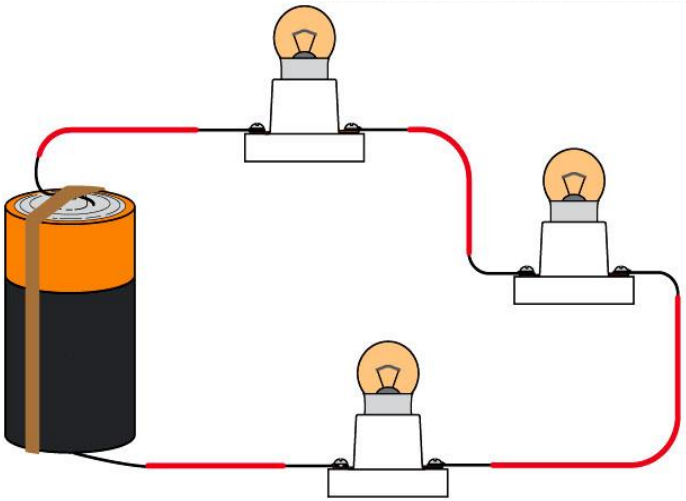
Series Connections

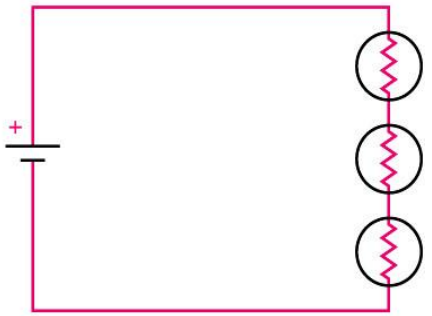
Electric elements can be connected in series or parallel:

- In series, there are no point in the circuit where the current can branch into secondary loops.
- All the elements line up with no junctions between them.
- Components connected in series have the same current flowing through them.



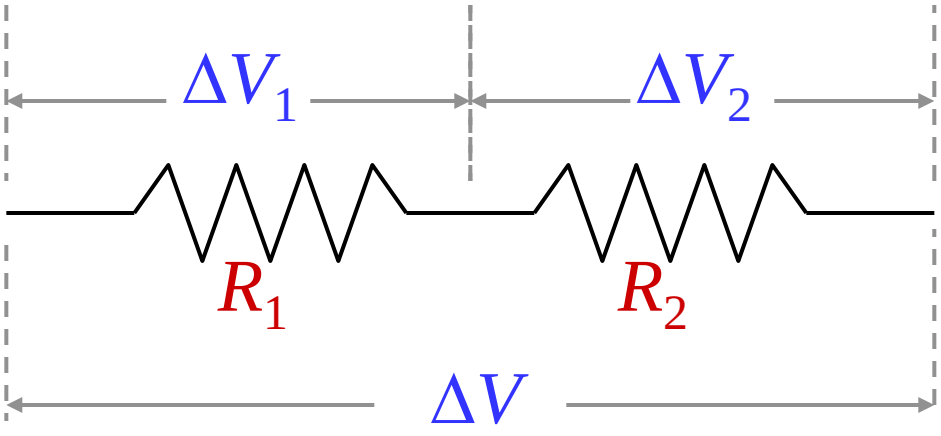
Here is a circuit where all four elements are connected in series.

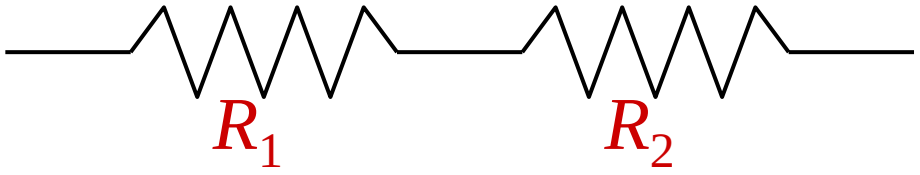




Resistors in Series

- Current doesn't get reduced by a resistor
  $I_1 = I_2 = I$
- The total resistance is the sum of each resistor
  $R_S = R_1 + R_2$
- The voltage drops across each resistor using Ohm's law so that $\Delta V_1 = IR_1$ and $\Delta V_2 = IR_2$
- The total voltage difference across the combination is the sum of the individual changes. $\Delta V = \Delta V_1 + \Delta V_2$





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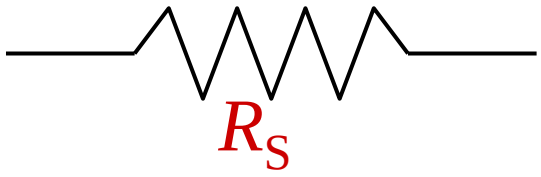
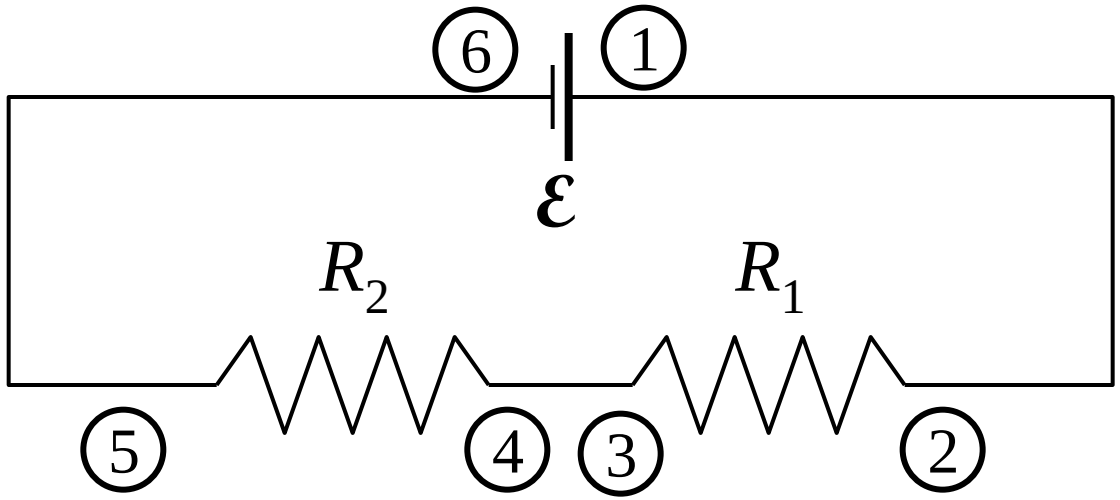


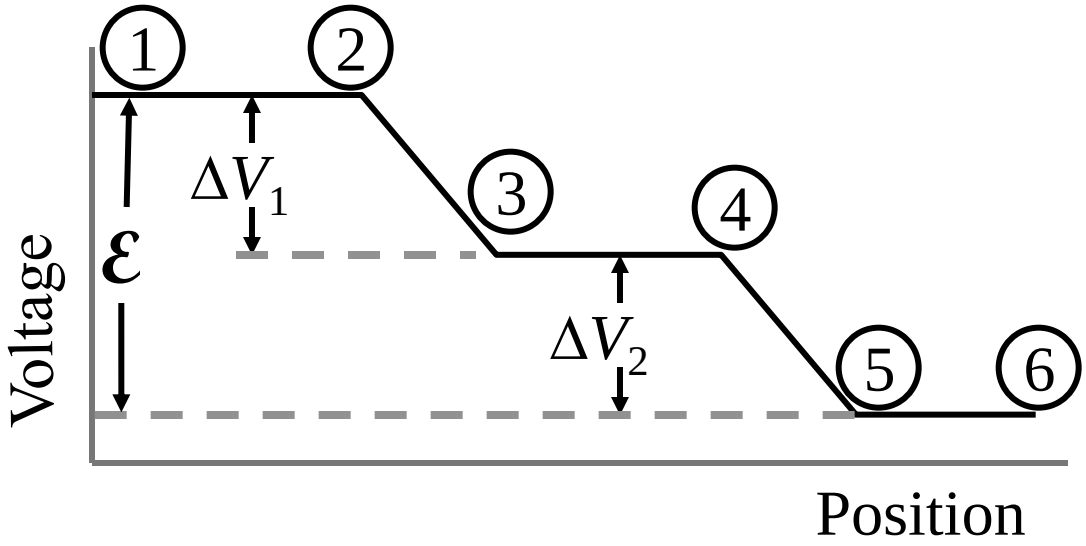
In general,
$R_S = R_1 + R_2 + R_3 + \ldots$

Series Gravitational Analogy



$$\mathcal{E} = IR_S$$

$$\Delta V_1 = IR_1$$
$$\Delta V_2 = IR_2$$



Problem: A 3Ω, a 6Ω, and a 9Ω resistor are placed in series and connected to a 12 V battery?

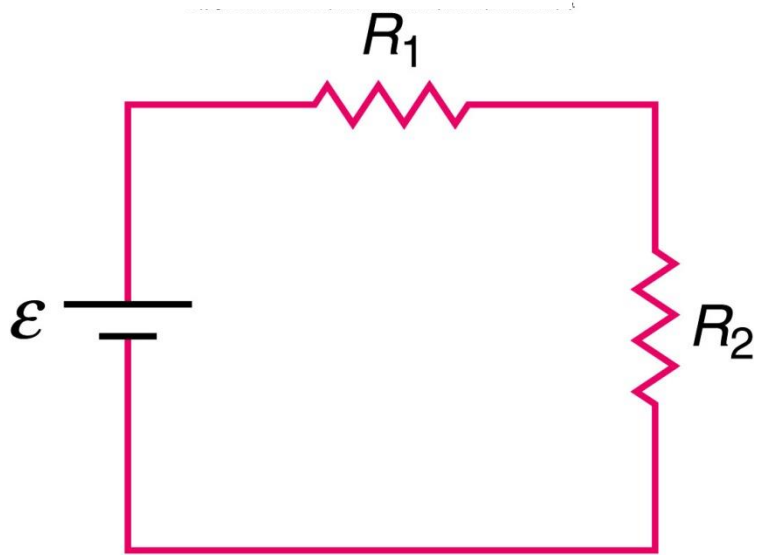
(a) What is the current flowing through each resistor?

Problem: A 3Ω, a 6Ω, and a 9Ω resistor are placed in series and connected to a 12 V battery?

(b) What is the voltage drop across each resistor?

Interactive Question

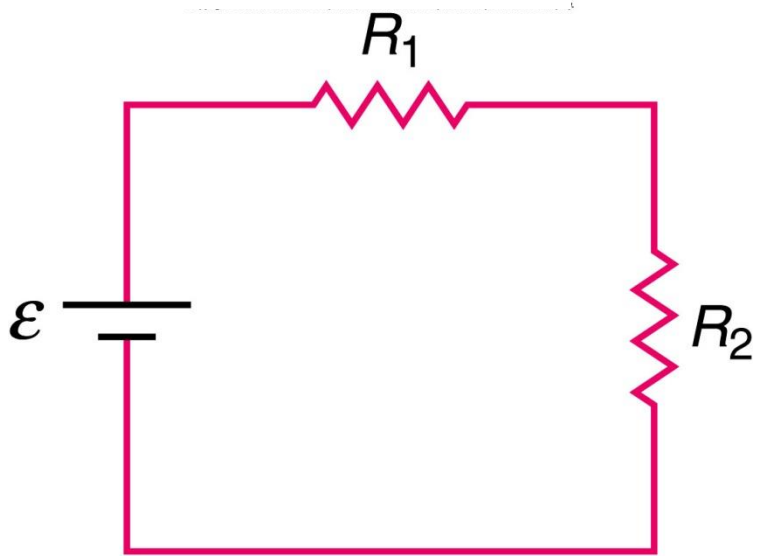
Two resistors are connected in series with a battery as shown. R_1 is less than R_2. Which of the two resistors has the greater current flowing through it?



A) R_1
B) R_2
C) They have the same current
D) More information is needed

Interactive Question

Two resistors are connected in series with a battery as shown. R_1 is less than R_2. Which of the two resistors has the greatest voltage difference across it?

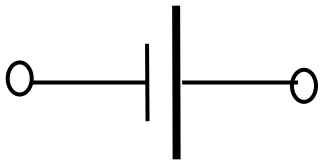


A) R_1
B) R_2
C) They have the same voltage difference
D) More information is needed

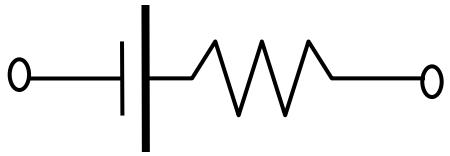
Batteries, Internal Resistance, and Terminal Voltage

- Real batteries and real wires have a little resistance
- As the battery ages the resistance increases
- The internal battery resistance can be modeled simply as another resistor in series.
- The terminal voltage is the voltage measured across the terminals of the battery. When the battery is in use, the terminal voltage is less than the ideal voltage.

An ideal battery:



A more realistic battery:

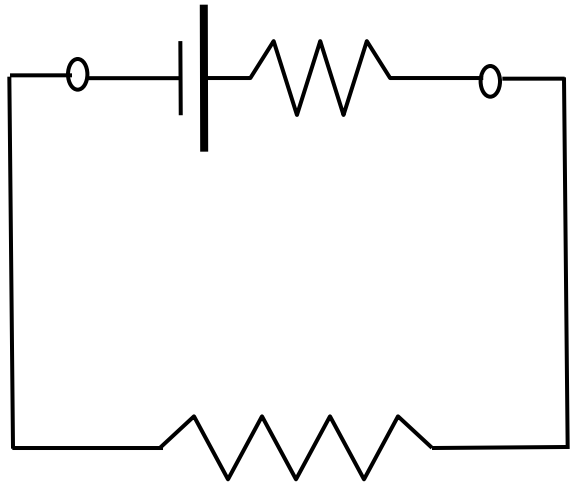


Internal Resistance

Problem: An ideal battery has a voltage of 9.0 volts and is attached to a 20 Ω external resistor. The battery has an internal resistance of 1 Ω.

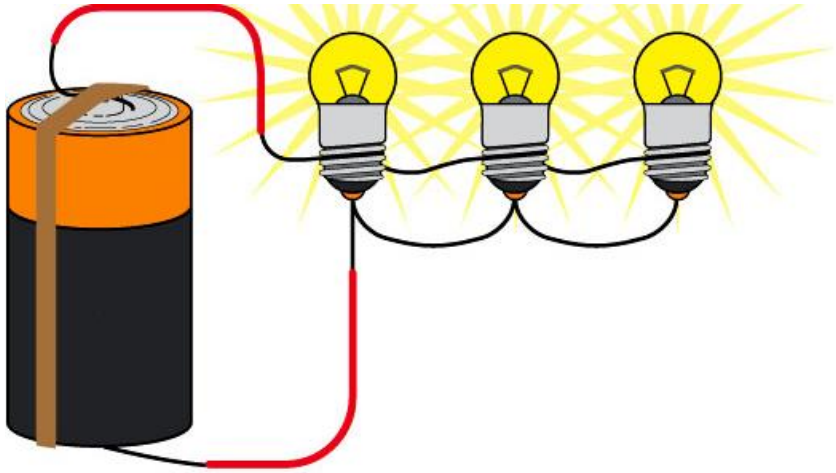
A) What current is flowing through the circuit?

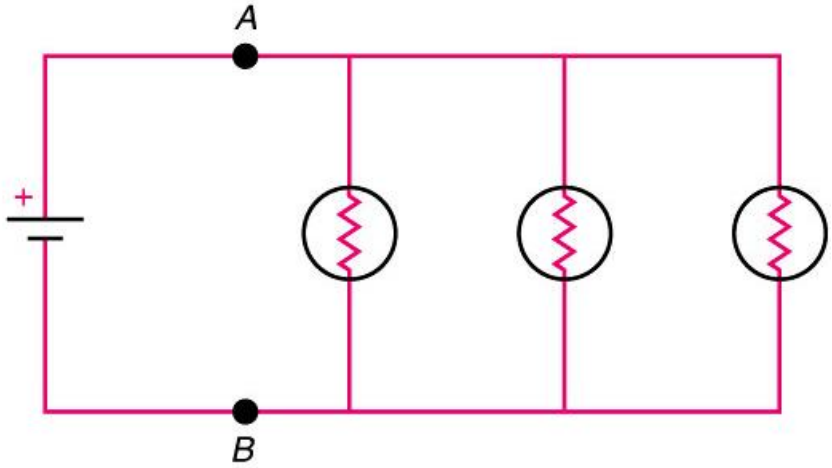
B) What is the terminal voltage of the battery?



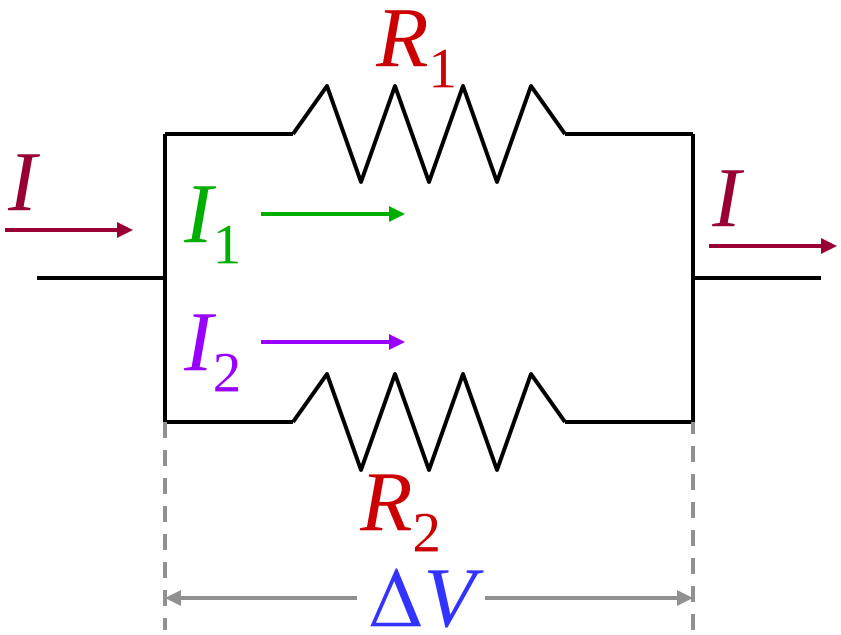
Parallel Connections

- In a parallel circuit, there are points at which the current can branch or split up into different paths.
  - The flow divides and later rejoins.
  - A portion of the total current flows through each branch.
  - The currents can be different, since they divide: they add to give the total current through the combination.
- The voltage difference across each branch is the same, since they are connected between the same two points





Resistors in Parallel

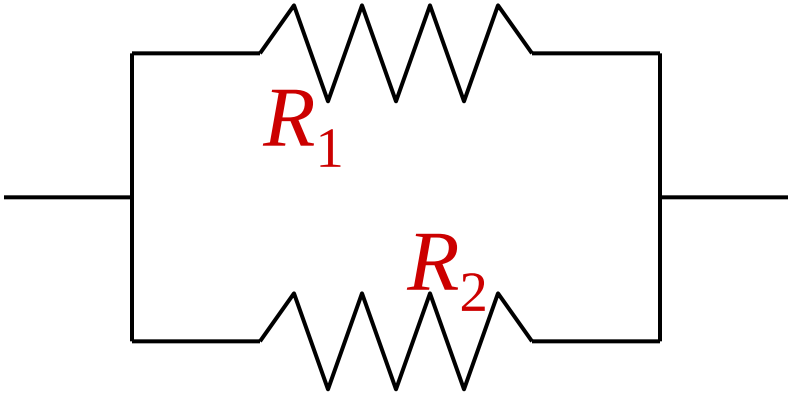


$$\Delta V_1 = \Delta V_2 = \Delta V$$

$$I = I_1 + I_2$$

There are more paths for the current to go through so the total resistance decreases.

$$1/R_P = 1/R_1 + 1/R_2$$



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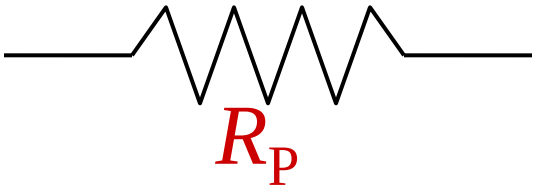
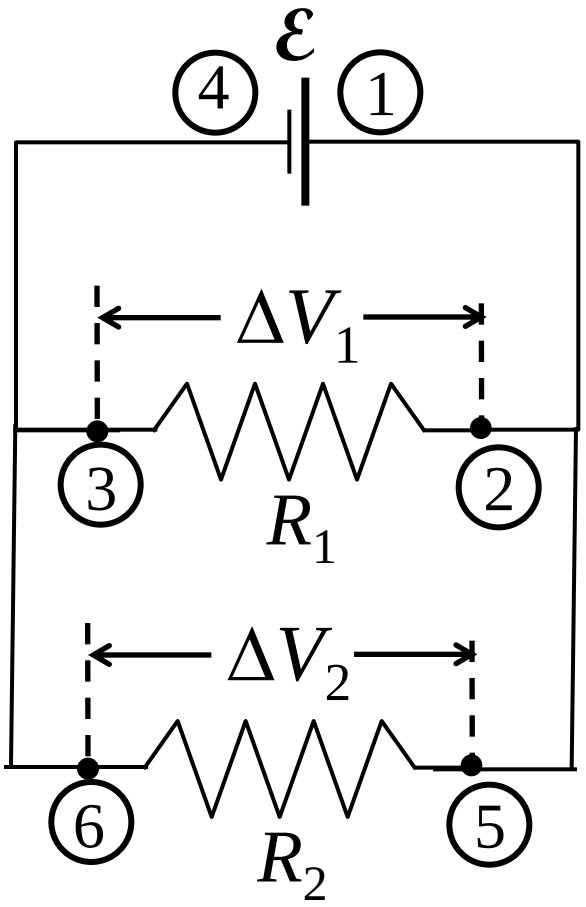
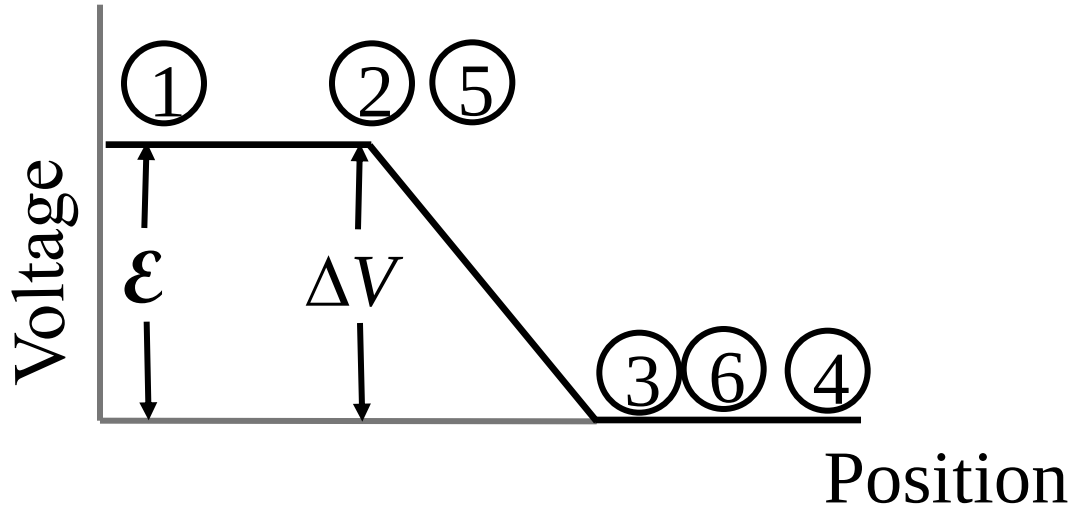


In general, $1/R_P = 1/R_1 + 1/R_2 + 1/R_3 + \ldots$

Gravitational Analogy

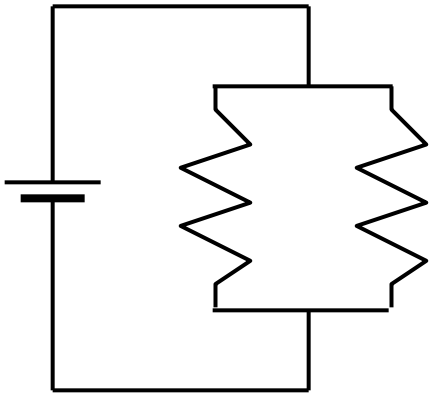




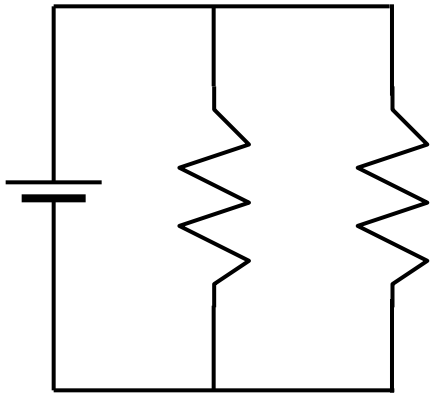
- $\mathcal{E} = \Delta V_1 = \Delta V_2$
- The total current coming out of the battery is split into the two branches, then comes back together.

Interactive Question

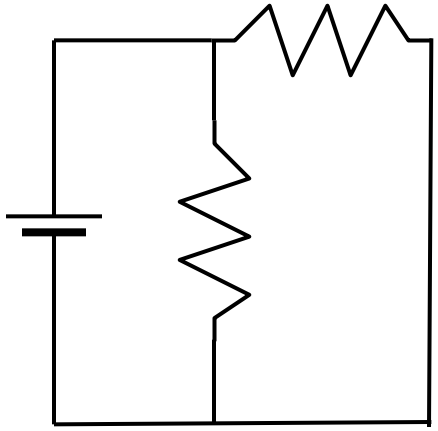
Which of the following circuits are identical?



(A)



(B)



(C)

A) (A) and (B) only
B) (B) and (C) only
C) (A) and (C) only
D) (A), (B), and (C)
E) None of the above

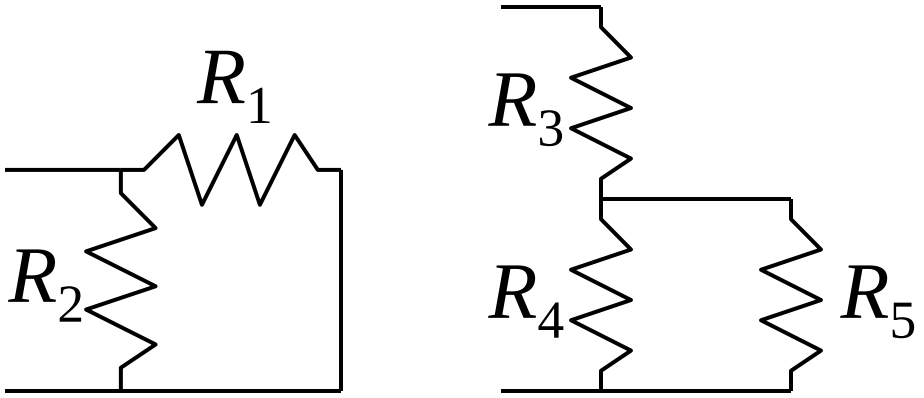
Problem: A 3 Ω, a 6 Ω, and a 9 Ω resistor are placed in parallel and connected to a 12 V battery?

(a) What is the total current flowing through the system?

Problem: A 3 Ω, a 6 Ω, and a 9 Ω resistor are placed in parallel and connected to a 12 V battery?
(b) What is the current in each resistor? ?

Interactive Question

Consider the two circuits on the right. Which of the following statements is true?

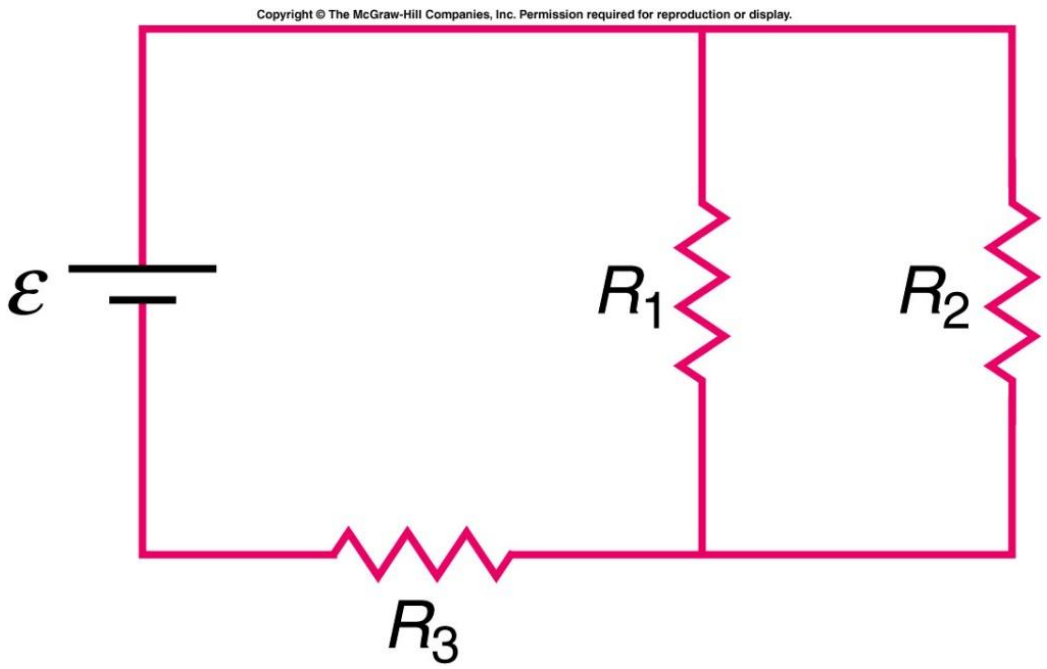


A) R_1 and R_2 are in parallel. R_3 and R_4 are in series.
B) R_4 and R_5 are in parallel. R_3 and R_4 are in series.
C) R_1 and R_2 are in series. R_3 and R_4 are in series.
D) R_1 and R_2 are in parallel. R_4 and R_5 are in parallel.
E) R_1 and R_2 are in series. R_4 and R_5 are in parallel.

Interactive Question

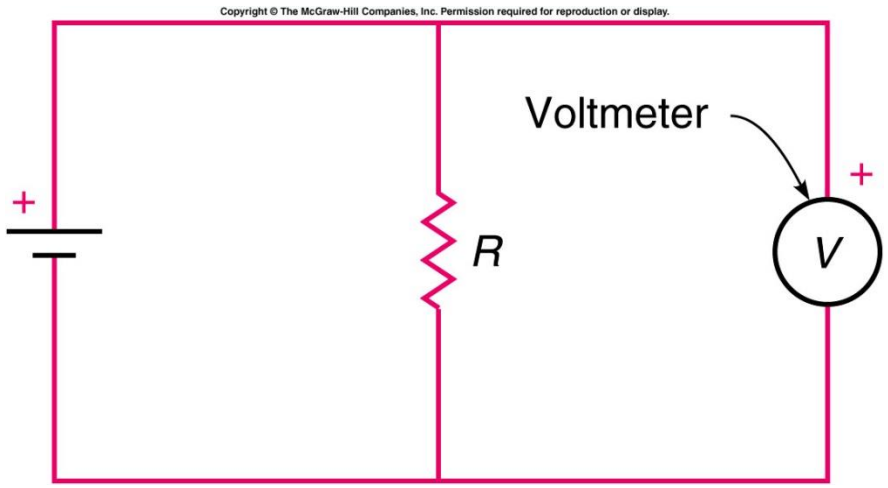
In the circuit shown, R_3 is greater than R_2, and R_2 is greater than R_1. $\mathcal{E}$ is the electromotive force of the battery whose internal resistance is negligible. Which of the three resistors has the greatest current flowing through it?

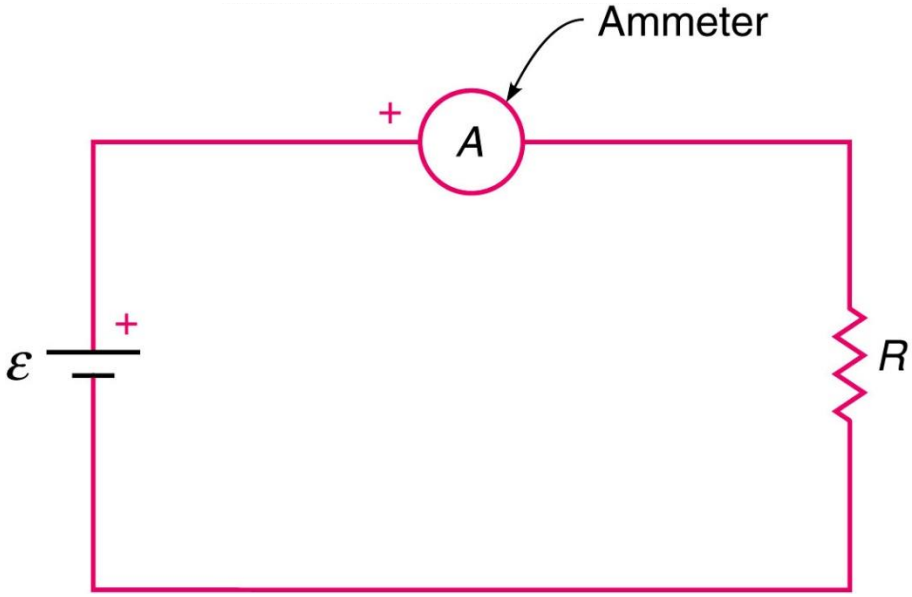
A) R_1
B) R_2
C) R_3
D) R_1 and R_2 are equal, and greater than R_3
E) They are all equal



Voltmeters and Ammeters

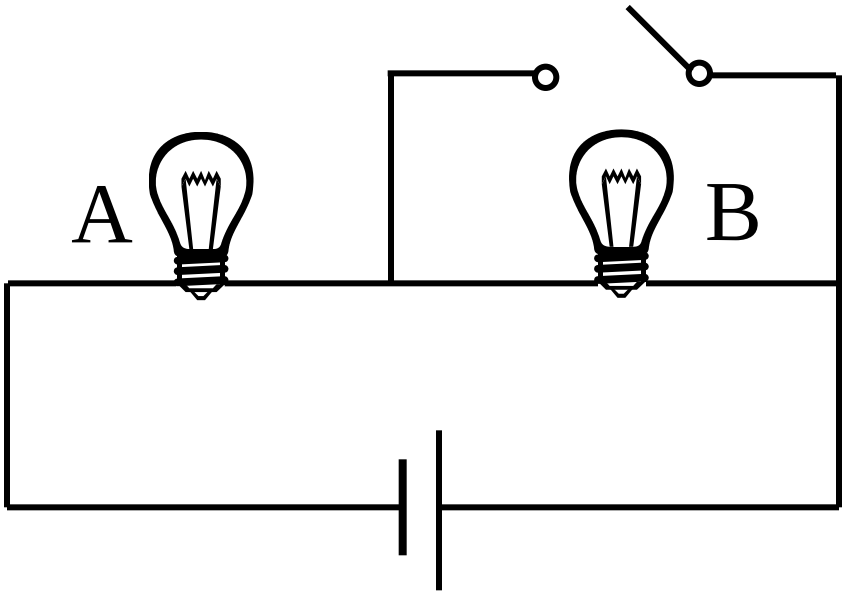
- A voltmeter measures the voltage difference between two points in a circuit.
  - It is inserted in parallel with the element whose voltage is being measured.
  - It has a large resistance, so little current flows through it.
- An ammeter measures the electric current flowing through a point in a circuit.
  - It is inserted in series into the circuit.
  - It has a small resistance, so its effect on the current is small.





Interactive Question

The circuit below consists of two identical light bulbs burning with equal brightness and a single 12 V battery. When the switch is closed, the brightness of bulb A



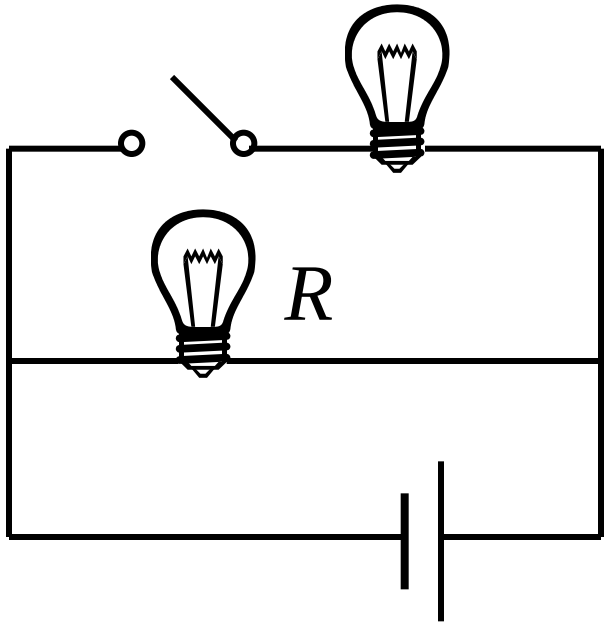
A) increases

B) decreases

C) remains unchanged

Interactive Question

A simple series circuit contains a resistance R and an ideal battery. If a second resistor is connected in parallel with R by closing the switch,

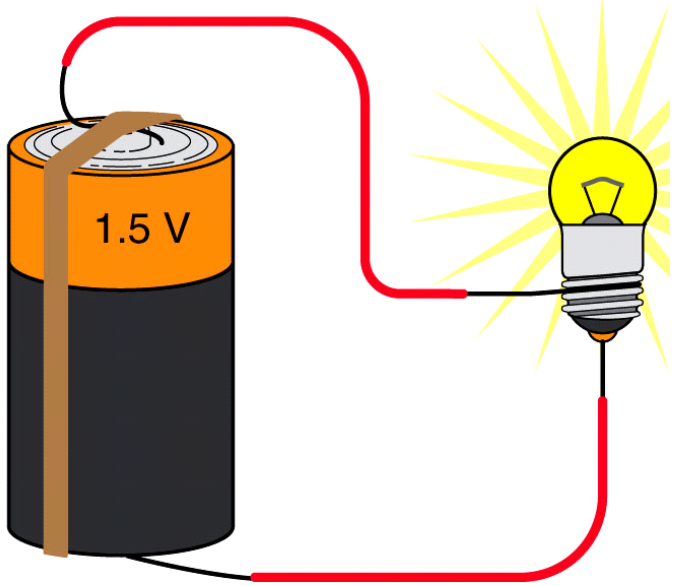


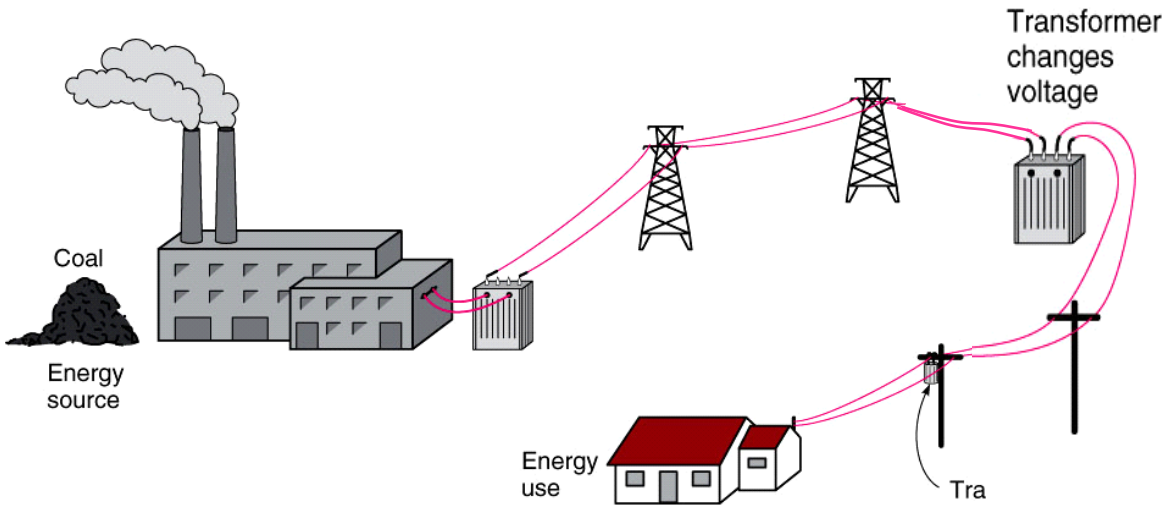
A) the voltage across R will decrease.
B) the voltage across R will increase.
C) the total current in the circuit will increase.
D) the equivalent resistance of the circuit will increase.

Electric Power and Energy

- Energy is conserved. (Power = Energy/Time)
- For a battery, chemical energy is converted to electrical energy, then, with a light bulb, to heat and light.
- For a generator, many kinds of energy can be converted to electrical energy.

$P = \mathcal{E}I$ $P = I^2R$





Electric Energy and Power

Electric energy (not power) is actually purchased from the electric company:

Energy = Power × Time = kilowatt·hour (kWh)

- 1 kilowatt equals 1000 watts
- 1 hour = 3600 seconds
- 1 kilowatt-hour equals 3.6 million joules

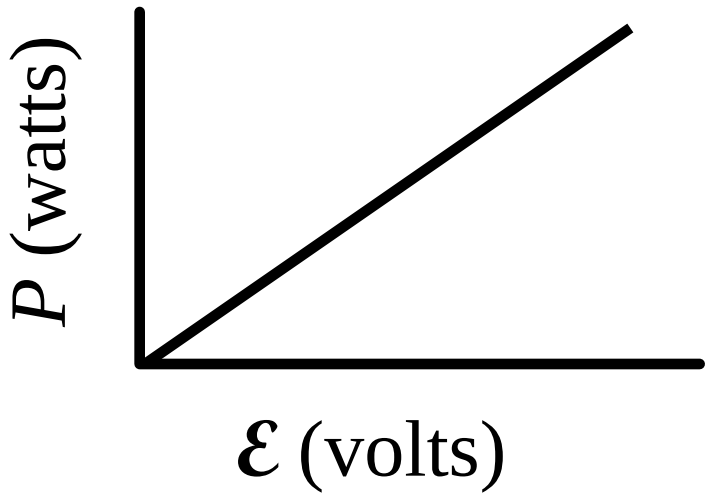
Power in Oklahoma costs about $0.10 per kWh

Problem: How much does it cost to run a 1200 W hair dryer for 10 minutes?

Problem: A light bulb with a resistance of 10 Ω is placed in series with two 12 V batteries. How much power is dissipated by the bulb?

Interactive Question

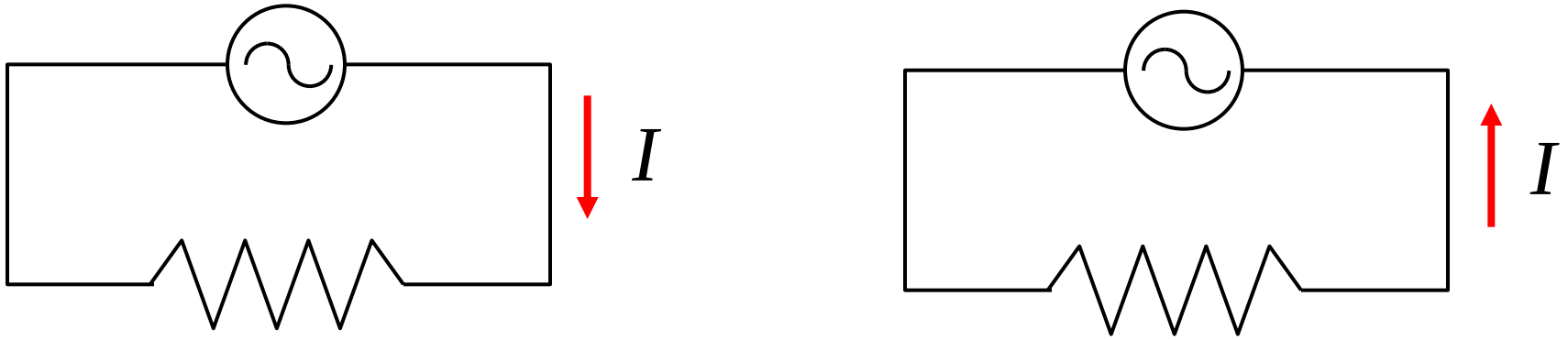
In the graph shown, what physical quantity does the slope represent?



A) Current
B) Energy
C) Voltage
D) Resistance
E) Power

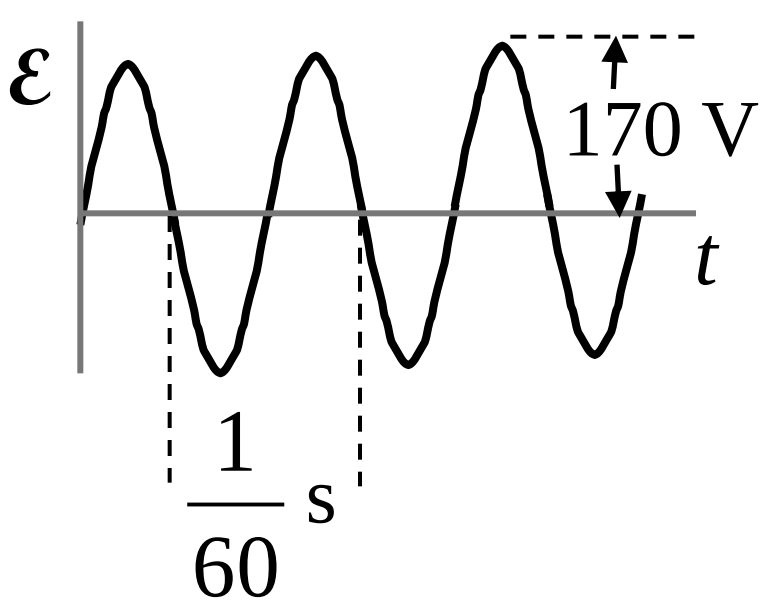
Problem: A 4 amp current is maintained in a simple circuit with a total resistance of 2 Ω. How much heat is generated in 3 seconds?

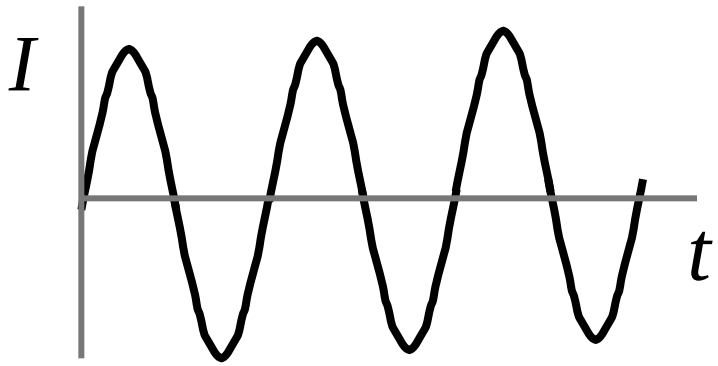
Alternating Current and Household Current



The current from a wall outlet is alternating current (ac) rather than direct current (dc).

- Direct current flows in a single direction from the positive terminal of a battery to the negative terminal
- Alternating current continually reverses its direction moving in one direction, then the other, then back again.
- In North America the ac goes through 60 cycles each second (60 Hz).





- Current and voltage follow a sinusoidal pattern.
- The important variable is the effective voltage or current which is 0.707 times the maximum.
  - In the U.S. the effective voltage (or RMS voltage) is 120 V so the maximum is 170 V.
  - The current depends on the resistance of the appliance.

The formulas we have learned for dc currents work for ac currents if the effective current and voltages are used.

$$V_{\text{RMS}} = I_{\text{RMS}} R$$

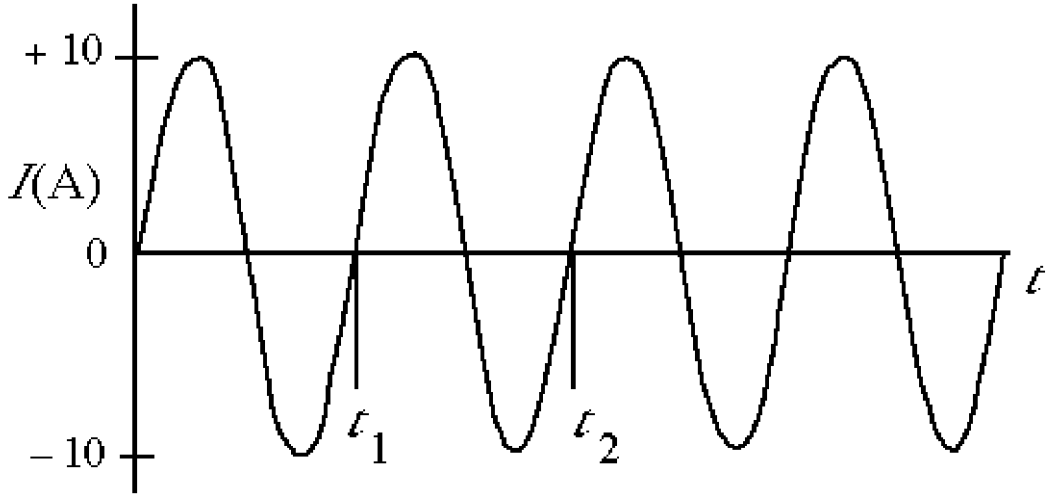
$$P = I^2_{\text{RMS}} R$$

Problem: A 100 W light bulb is designed to operate at 120 V ac.

A) What is the effective current in the light bulb?

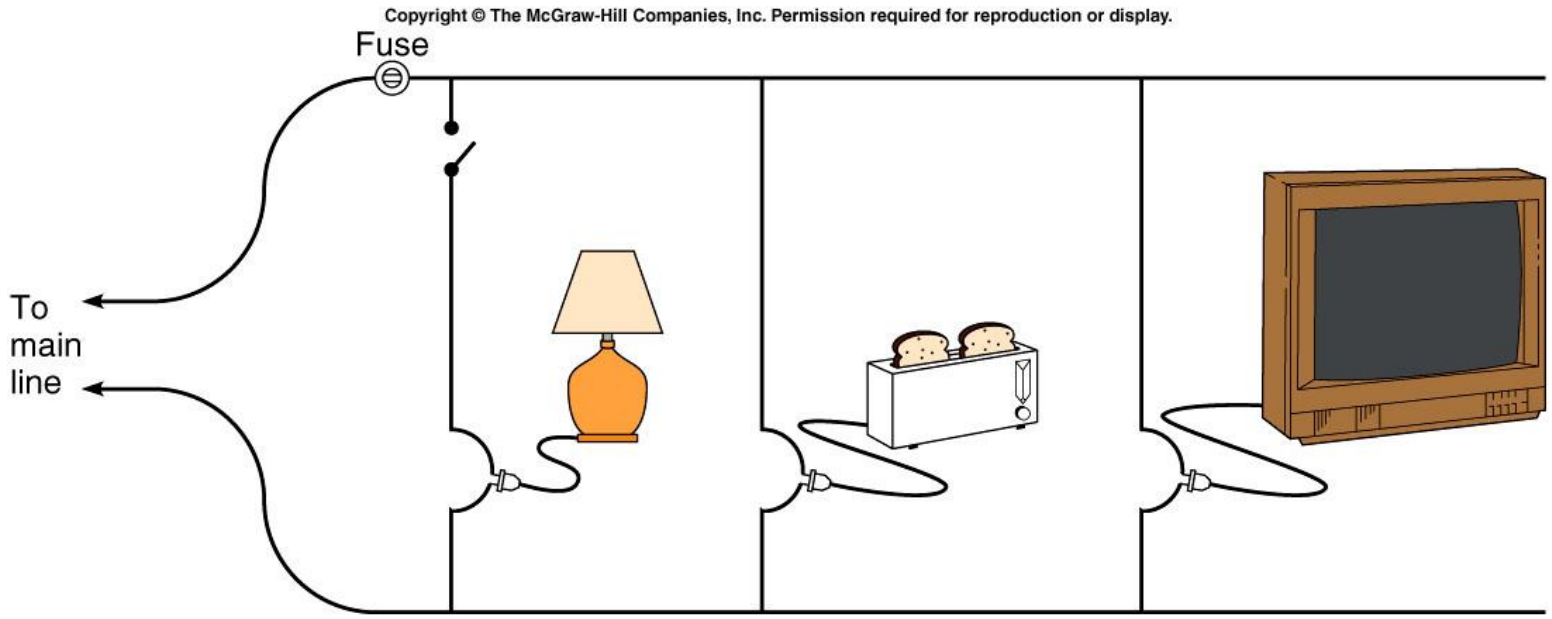
B) What is the resistance of the bulb?

Problem: The figure below shows the time variation of the current through the heating element of an iron when it is plugged into a standard 120 V, 60 Hz outlet. What is the (A) rms current and (B) resistance of the iron?

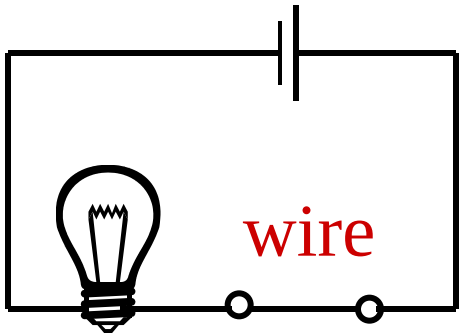


Household circuits are wired in parallel so that appliances can be added to the circuit without affecting the voltage.

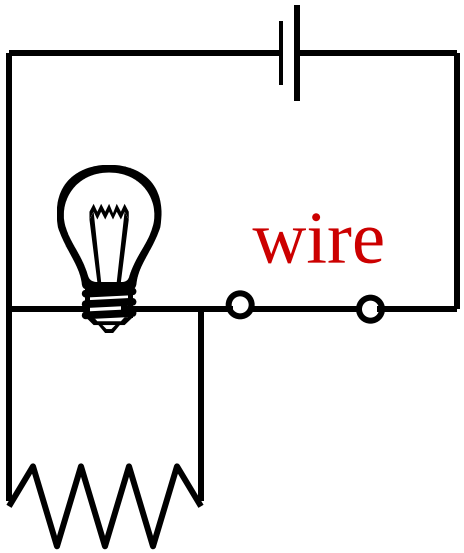
- As appliances are added, the total resistance decreases and more current flows through the circuit.
- A fuse or circuit breaker in series with one branch disrupts the circuit if the current gets too large to avoid overheating.
- Appliances with larger power requirements (stoves, clothes dryers, etc) are usually connected to a separate 220-V line.



Problem: How many amps run through a tungsten wire when it is hooked up in series to a 100 watt light bulb and plugged into a 120 V electrical outlet? The light bulb has a resistance of 144 Ω.

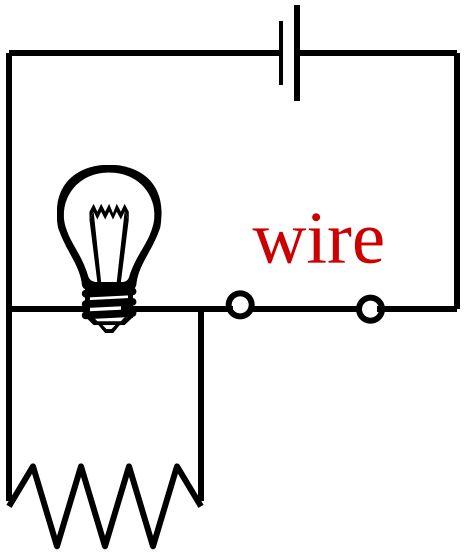


Problem: How many amps run through a tungsten wire when it is hooked up in series to a 100 watt light bulb that is in parallel with a 600 W heater and plugged into a 120 V electric outlet?



The heater has a resistance of 24 Ω (which we can determine using $P=\mathcal{E}I$, and $\mathcal{E}=I^2R$ with $\mathcal{E}$=120 V.) We already know the light bulb has a resistance of 144 Ω.

Problem: What if 600 W heater is replaced with a 740 W heater with a resistance of 19.5 Ω?



Interactive Question

At 120 V, which has a larger resistance, a 100 W light bulb or a 60 W light bulb?

A) 100 W
B) 60 W
C) They both have the same resistance

Interactive Question

If a 100 W light bulb is placed in series with a 60 W light bulb (instead of in parallel as they were designed for), which will burn brighter?

A) 60 W
B) 100 W
C) The same
D) It depends on the order of the bulbs