26.5 Home wiring and power distribution systems

A simple circuit

- The kitchen is one of many circuits in the home.
- Let's assume your kitchen has three devices:

Toaster

Microwave

Kettle

Power ratings

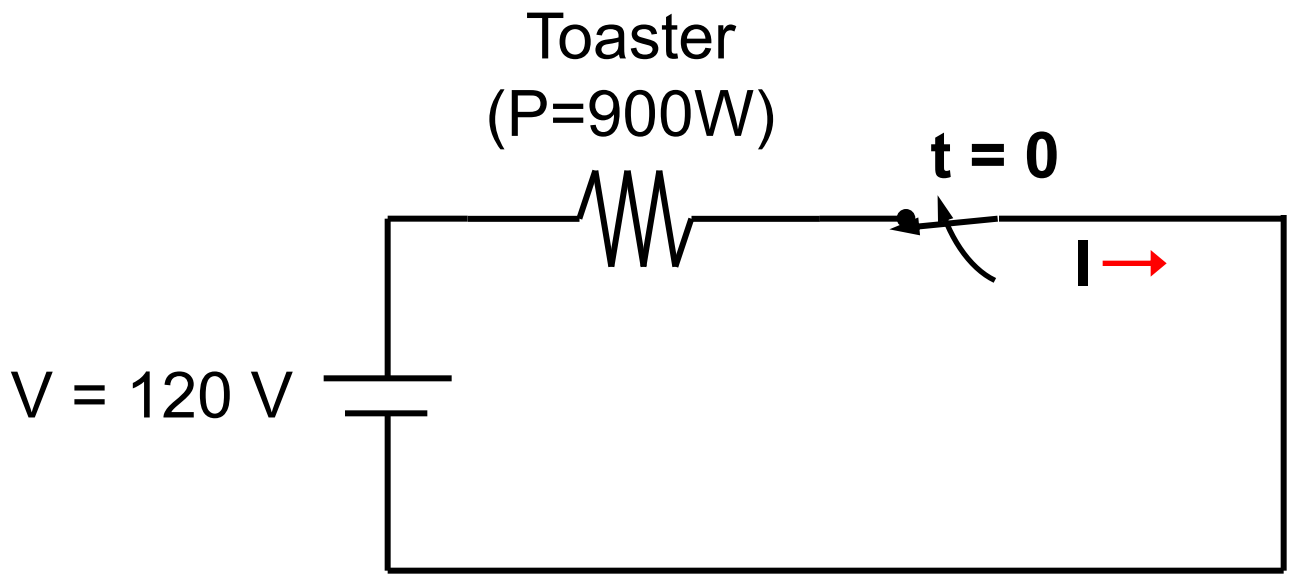
- Devices have a “power rating” inscribed on them
- This toaster’s power rating is 900 W
- We also see that it is meant to be used in North America (where outlets provide 120 V)

Activity in your groups (on paper)

Question

$P=VI$ $P=I^2R$ $P=V^2/R$

- Based on the power used by the toaster and the 120 V it uses, calculate the current when it is being used (the switch is closed).

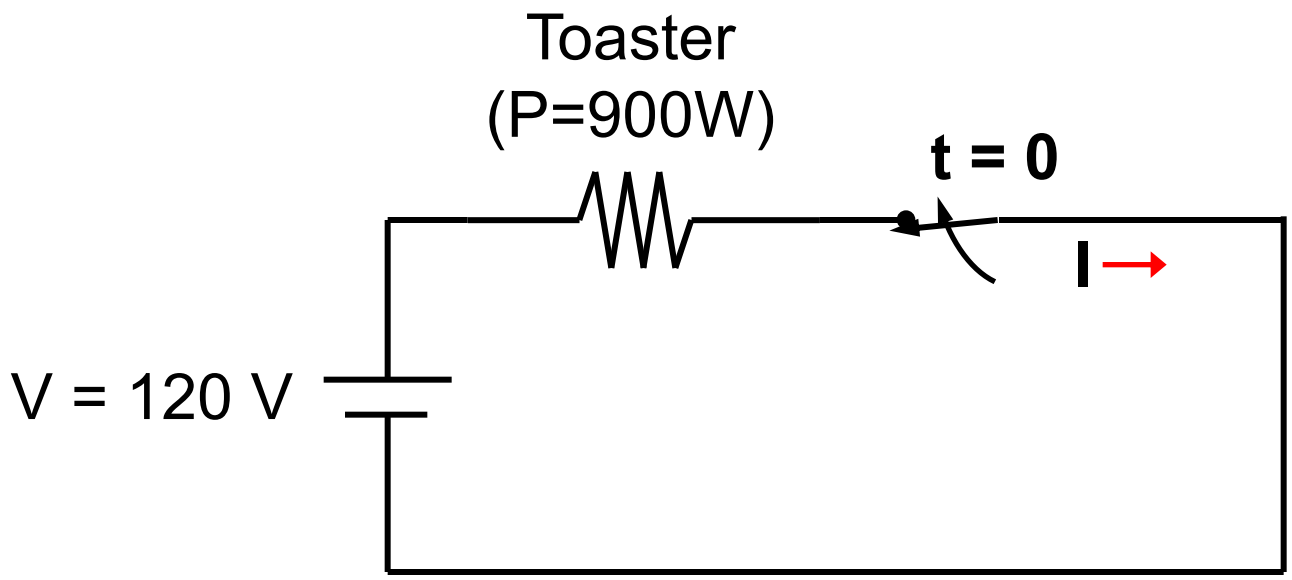


Answer

$P=VI$ $P=I^2R$ $P=V^2/R$

- It uses up energy at a rate of P=900W when 120 V are applied to it, so rearrange P = VI to find:

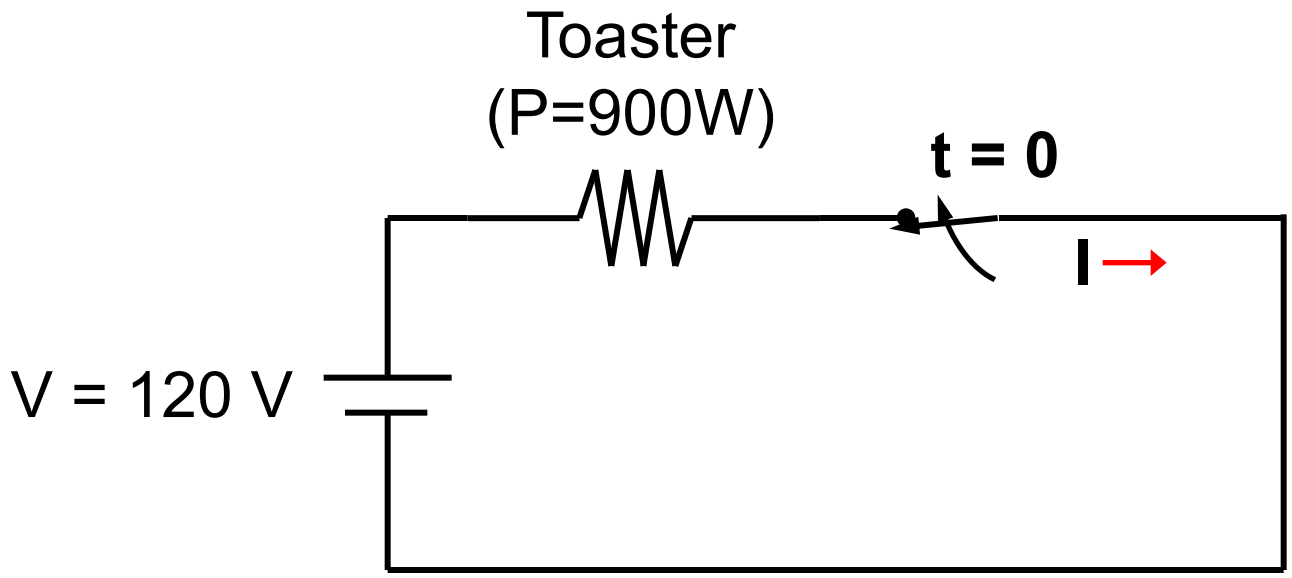
$$I = P/V$$
$$I = 900/120 = 7.5\ A$$



Question

$P=VI$ $P=I^2R$ $P=V^2/R$

- Based on the power used by the toaster and the 120 V it uses, calculate the resistance it causes in the circuit.

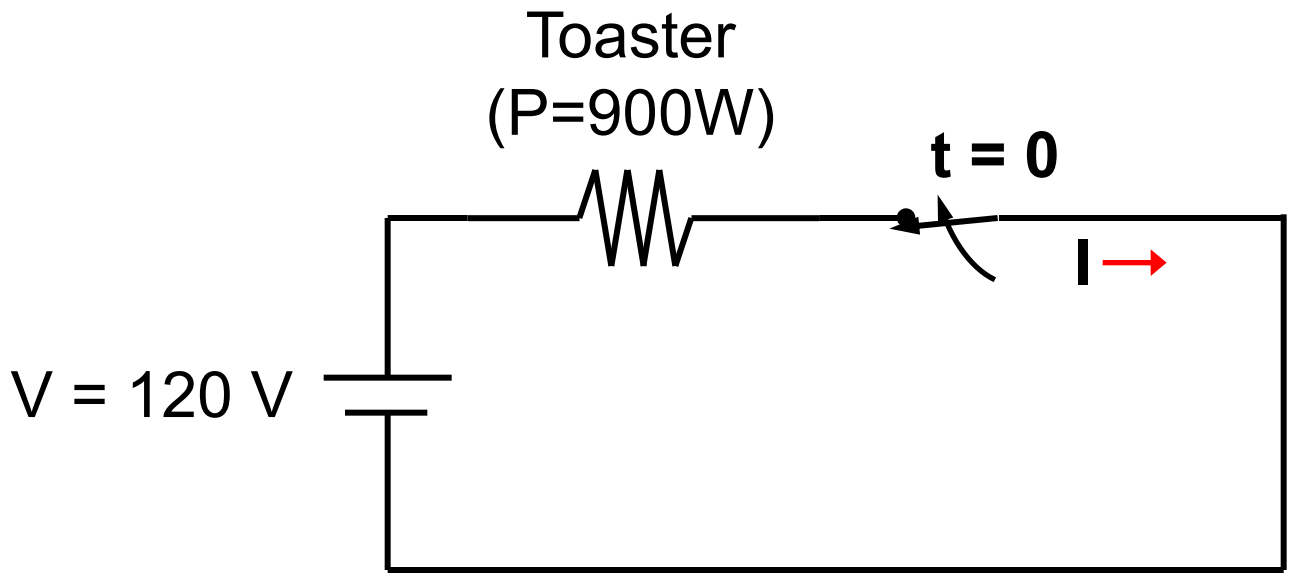


Answer

$P=VI$ $P=I^2R$ $P=V^2/R$

- It uses up energy at a rate of P=900W when 120 V are applied to it, so rearrange $P=V^2/R$ to find:

$$P=V^2/R$$
$$R = 120^2/900 = 16\ \Omega$$



Question

$P=VI$ $P=I^2R$ $P=V^2/R$

- Find the current used and the resistance caused by the other two devices if <u>alone</u> in a 120V circuit:

Toaster (900 W)

$I_{toaster}$ =

$R_{toaster}$ =

Microwave (1050 W)

$I_{microwave}$ =

$R_{microwave}$ =

Kettle (600 W)

I_{kettle} =

R_{kettle} =

Answer

$P=VI$ $P=I^2R$ $P=V^2/R$

- Find the current used and the resistance caused by the other two devices if <u>alone</u> in a 120V circuit:

Toaster (900 W)

$I_{toaster} = 900/120$
$= 7.5$ A

$R_{toaster} = 120\text{^}2/900$
$= 16.0\ \Omega$

Microwave (1050 W)

$I_{microwave} = 1050/120$
$= 8.75$ A

$R_{microwave} = 120\text{^}2/1050$
$= 13.7\ \Omega$

Kettle (600 W)

$I_{kettle} = 600/120$
$= 5$ A

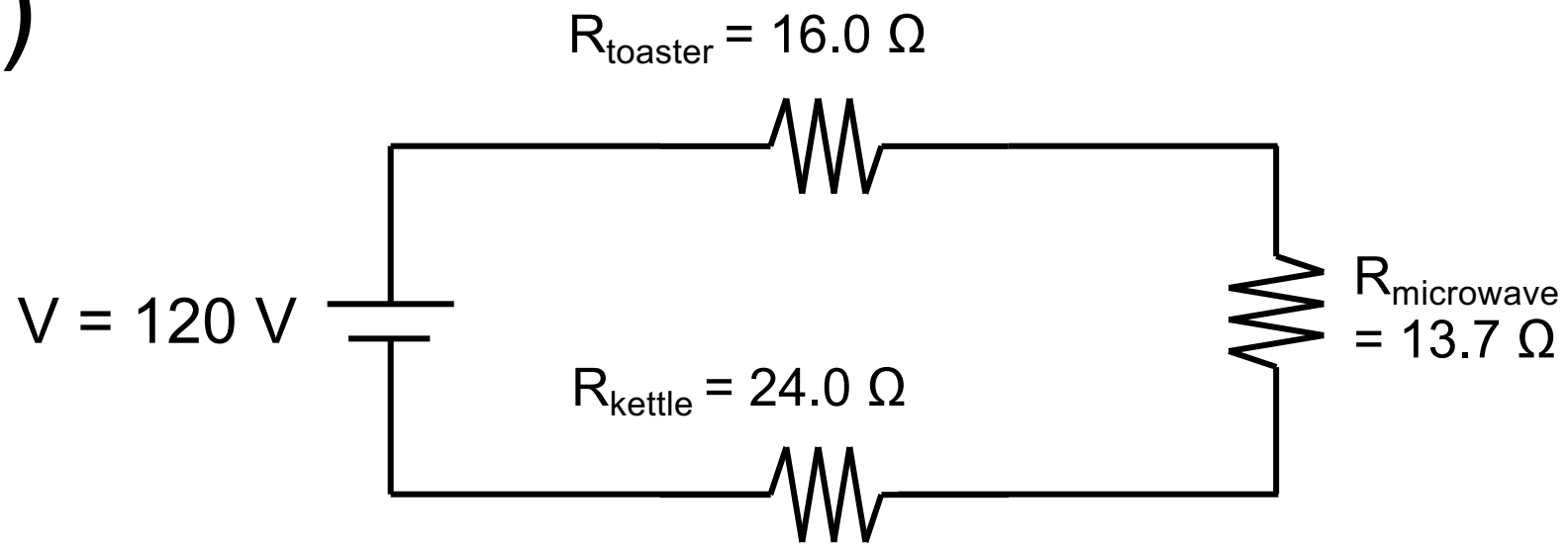
$R_{kettle} = 120\text{^}2/600$
$= 24.0\ \Omega$

Question

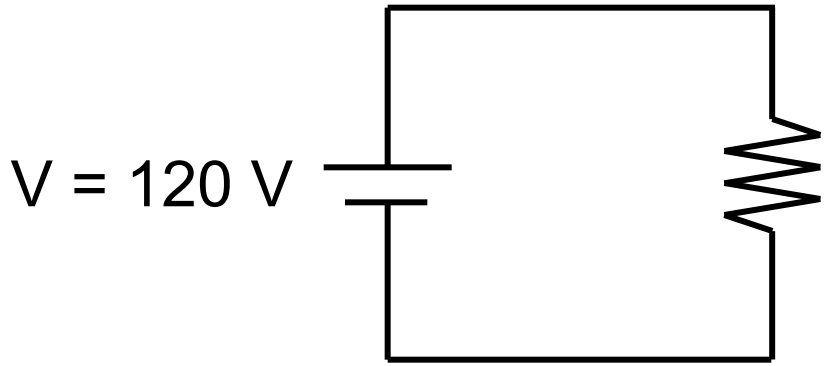
$R_{toaster} = 16.0\ \Omega$
$R_{microwave} = 13.7\ \Omega$
$R_{kettle} = 24.0\ \Omega$

- Draw a circuit where all three devices are connected in **series** to 120 V. Assume each one causes the same resistance found previously.
  1. What is the equivalent resistance of the circuit?
  2. What is the total current in the circuit?
  3. What is the current through each device?
  4. What is the potential difference across each device?
  5. How do these results compare to the requirements the device manufacturer gives?

(1)



Equivalent circuit:



$R_{equiv} = R_{toaster} + R_{microwave} + R_{kettle}$

$R_{equiv} = 16.0 + 13.7 + 24$

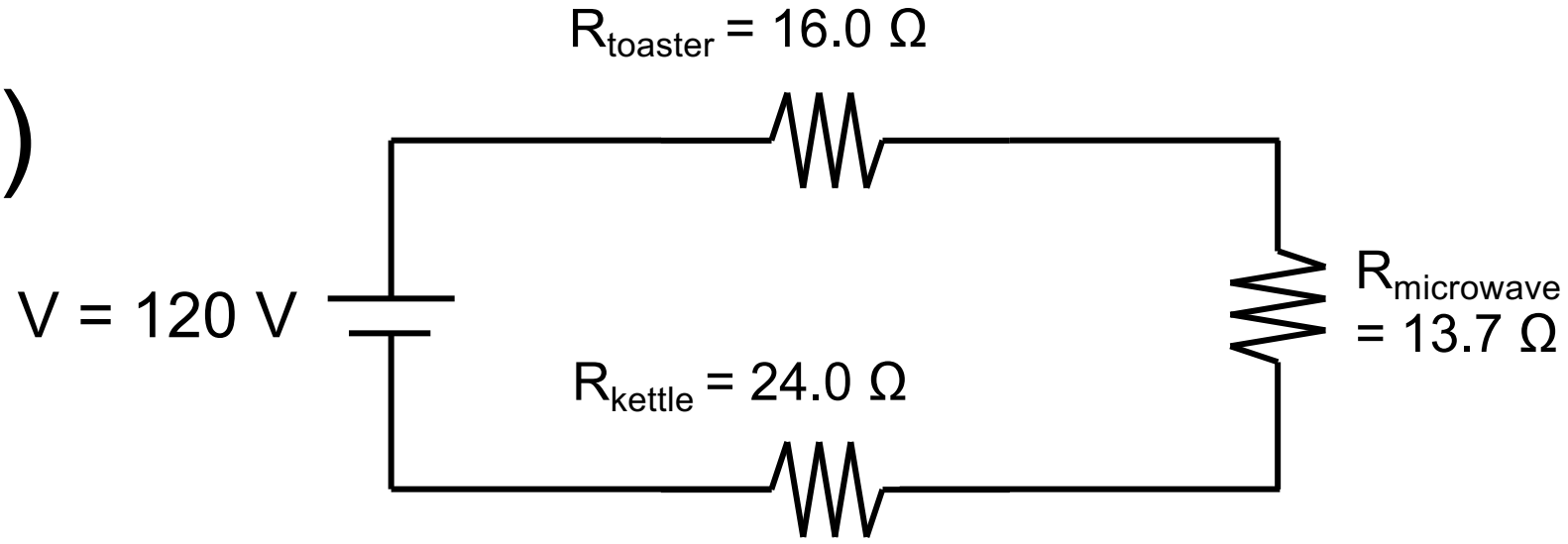
$R_{equiv} = 53.7\ \Omega$

Question

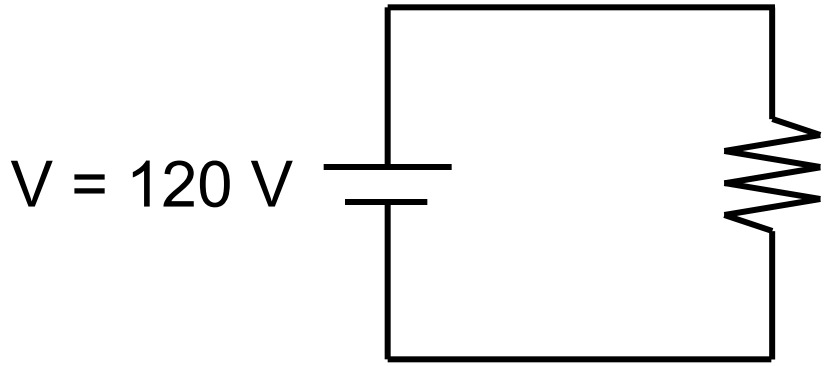
$R_{toaster} = 16.0\ \Omega$
$R_{microwave} = 13.7\ \Omega$
$R_{kettle} = 24.0\ \Omega$

- Draw a circuit where all three devices are connected in **series** to 120 V. Assume each one causes the same resistance found previously.
  1. What is the equivalent resistance of the circuit?
  2. **What is the total current in the circuit?**
  3. What is the current through each device?
  4. What is the potential difference across each device?
  5. How do these results compare to the requirements the device manufacturer gives?

(2)



Equivalent circuit:



$R_{equiv} = R_{toaster} + R_{microwave} + R_{kettle}$

$R_{equiv} = 16.0 + 13.7 + 24$

$R_{equiv} = 53.7\ \Omega$

Loop rule (potential gains minus drops equals zero): $120 - 53.7I = 0$

$I = 120/53.7$

$I = 2.23$ A

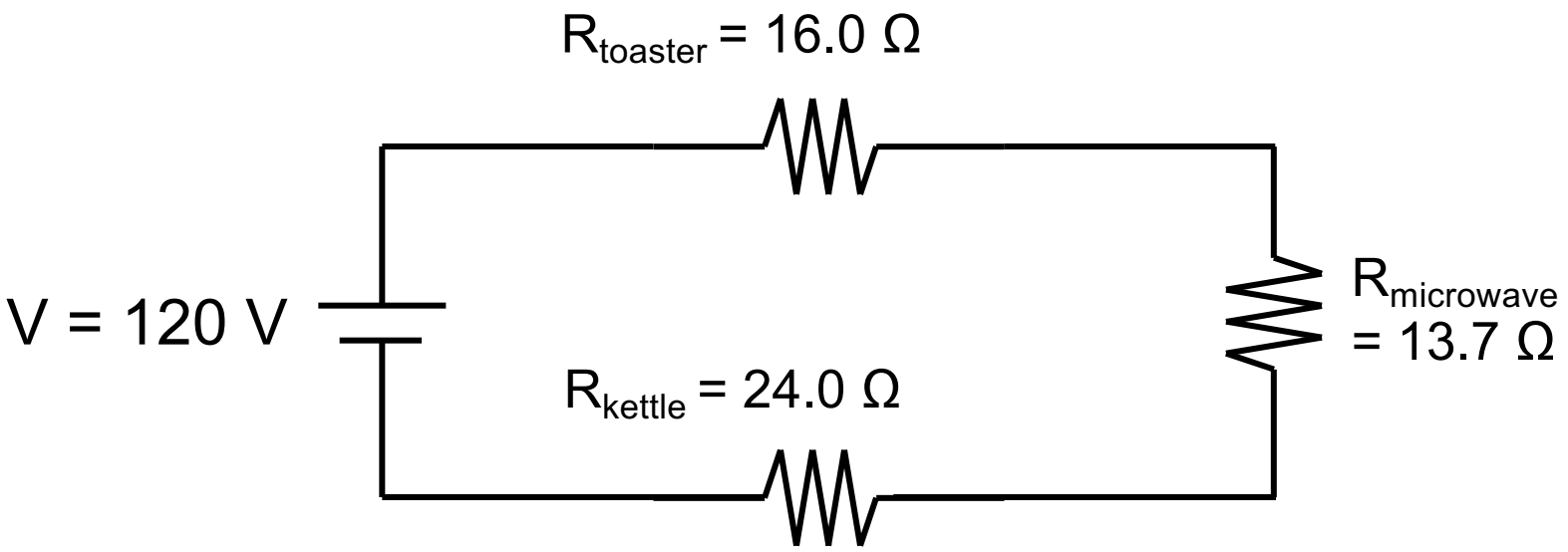
Question

$R_{toaster}$ = 16.0 Ω
$R_{microwave}$ = 13.7 Ω
R_{kettle} = 24.0 Ω

- Draw a circuit where all three devices are connected in **series** to 120 V. Assume each one causes the same resistance found previously.
  1. What is the equivalent resistance of the circuit?
  2. What is the total current in the circuit?
  3. **What is the current through each device?**
  4. What is the potential difference across each device?
  5. How do these results compare to the requirements the device manufacturer gives?

(3)

Each device gets the **same 2.23 A** since they are **in series**



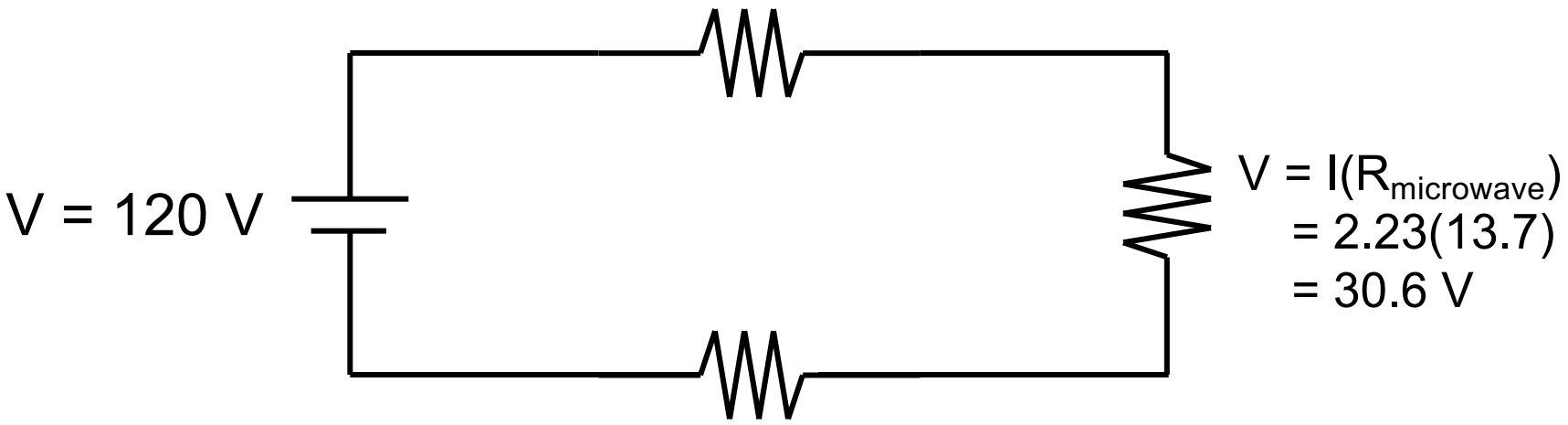
Question

$R_{toaster} = 16.0\ \Omega$
$R_{microwave} = 13.7\ \Omega$
$R_{kettle} = 24.0\ \Omega$

- Draw a circuit where all three devices are connected in **series** to 120 V. Assume each one causes the same resistance found previously.
  1. What is the equivalent resistance of the circuit?
  2. What is the total current in the circuit?
  3. What is the current through each device?
  4. **What is the potential difference across each device?**
  5. How do these results compare to the requirements the device manufacturer gives?

(4)

$V = I(R_{toaster})$
$= 2.23(16.0)$
$= 35.7\ V$



Check your work using loop rule (potential gains minus drops equals zero):

$$120 - 35.7 - 30.6 - 53.5 = 0.2 \approx 0$$

Question

$R_{toaster} = 16.0\ \Omega$
$R_{microwave} = 13.7\ \Omega$
$R_{kettle} = 24.0\ \Omega$

- Draw a circuit where all three devices are connected in **series** to 120 V. Assume each one causes the same resistance found previously.
  1. What is the equivalent resistance of the circuit?
  2. What is the total current in the circuit?
  3. What is the current through each device?
  4. What is the potential difference across each device?
  5. **How do these results compare to the requirements the device manufacturer gives?**

(5)

Toaster (900 W)

$V_{required}$ = 120 V
$I_{required}$ = 7.5 A

$V_{received}$ = 35.7 V
$I_{received}$ = 2.23 A

Microwave (1050 W)

$V_{required}$ = 120 V
$I_{required}$ = 8.75 A

$V_{received}$ = 30.6 V
$I_{received}$ = 2.23 A

Kettle (600 W)

$V_{required}$ = 120 V
$I_{required}$ = 5 A

$V_{received}$ = 53.5 V
$I_{received}$ = 2.23 A

(5)

- These results do not satisfy the manufacturer's requirements. The devices are designed to receive about 120 V of potential difference and draw the required current.
- Too high a voltage can damage a device.
- Too low a voltage, the device just won't run, or it may try to draw more current (to get the require power, P=VI) in which case the wires can overheat or cause a fire.

Question

- Based on your answer, what are some problems with connecting these devices in series?

Answer

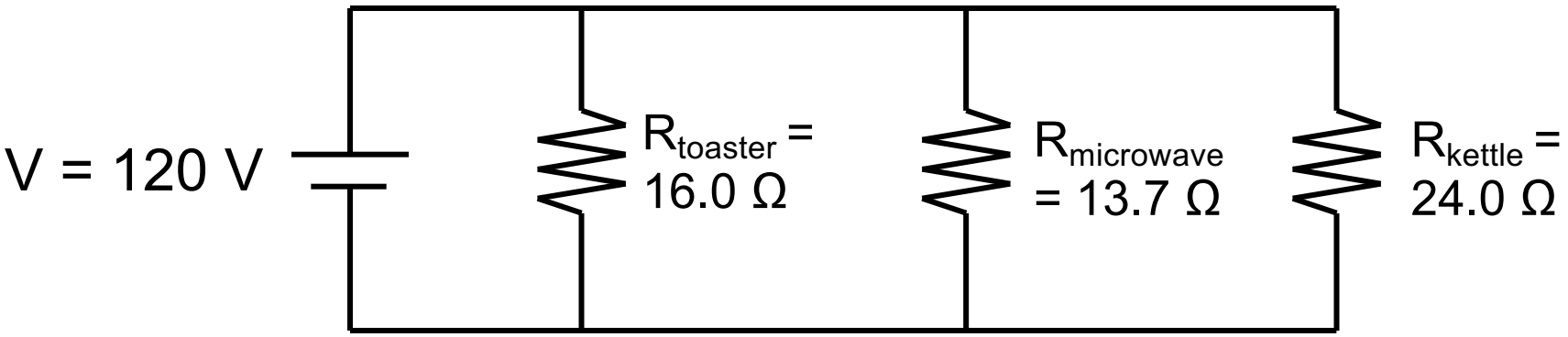
- If any outlet was not used, the circuit would be open, so no current would flow (nothing would work).
- Every device sold in stores would need to be designed to use the same current (since current is the same in series).
- The initial 120 V would get reduced by each device (loop rule), so devices would get less than the required voltage
  - If the device has a motor, it may not be able to develop enough torque to turn, so would just get hotter and possibly cause a fire.
  - The devices might draw more current to compensate for the lower voltage to get the required power (P=VI), but the higher than intended current can overheat the wires and possibly cause a fire.
- If a device fails, they all go out. Hard to diagnose.

Question

- What would be the best way to ensure that your devices would always get the required voltage and power outlined by the manufacturer?

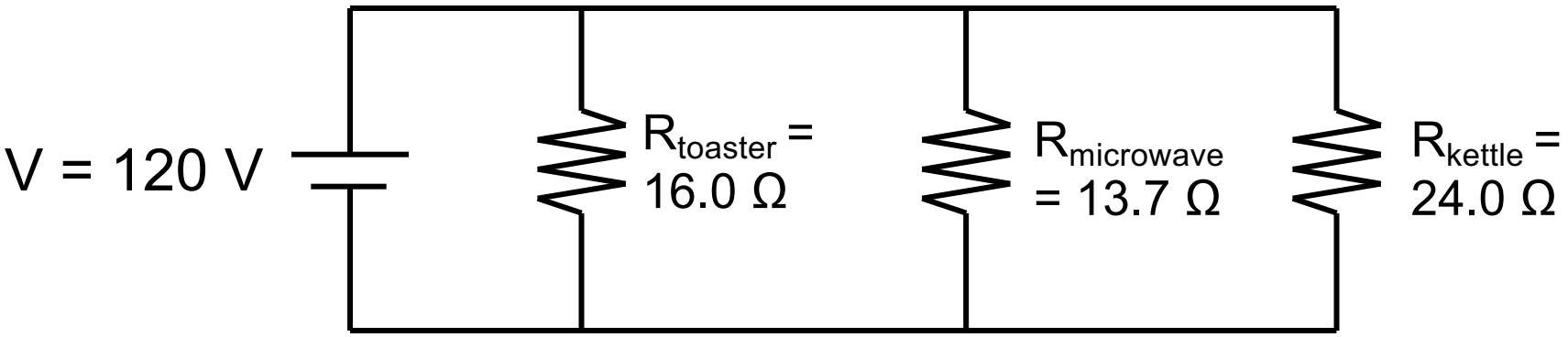
Answer

- Connect them in parallel!



Question

- Based on your answer, what are some benefits of connecting these devices in parallel?

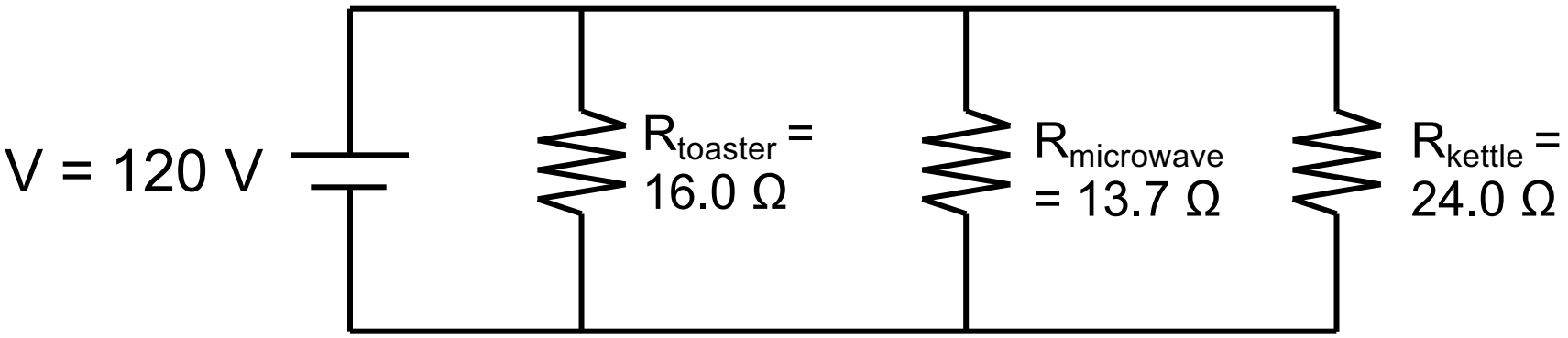


Answer

- All devices get the same voltage.
- The manufacturer can know what this voltage is and design the device accordingly.
- The power required by the device will generate a pre-determined current when plugged into 120 V, therefore ensuring it can be safe for household wiring.

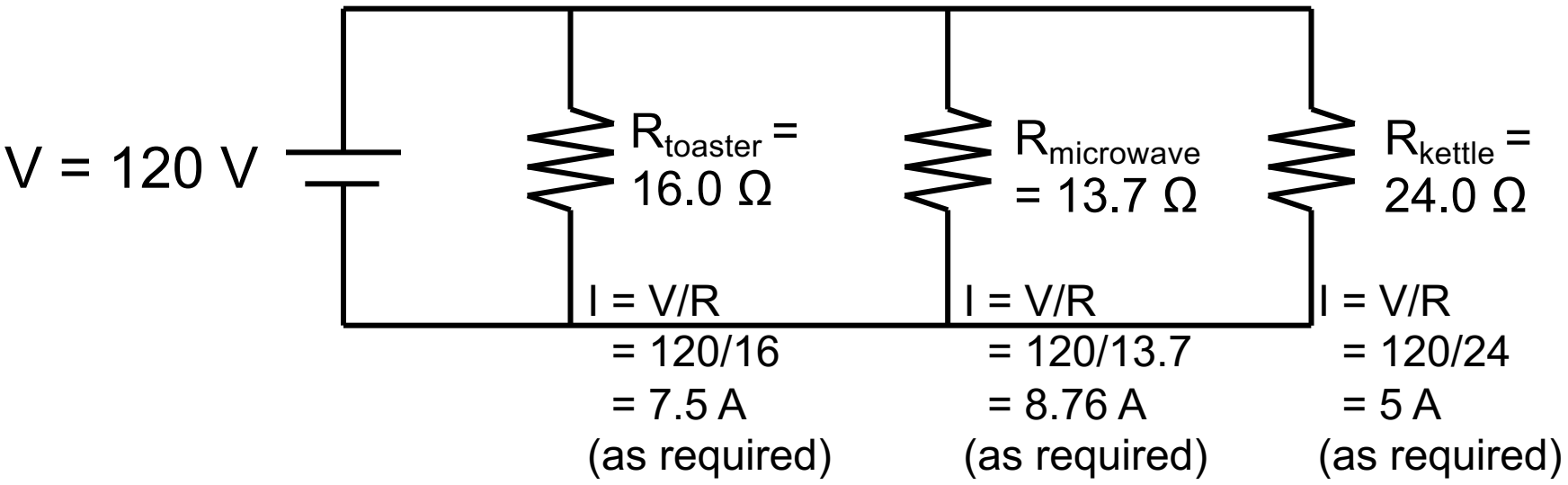
Question

- Calculate the current drawn by each device.



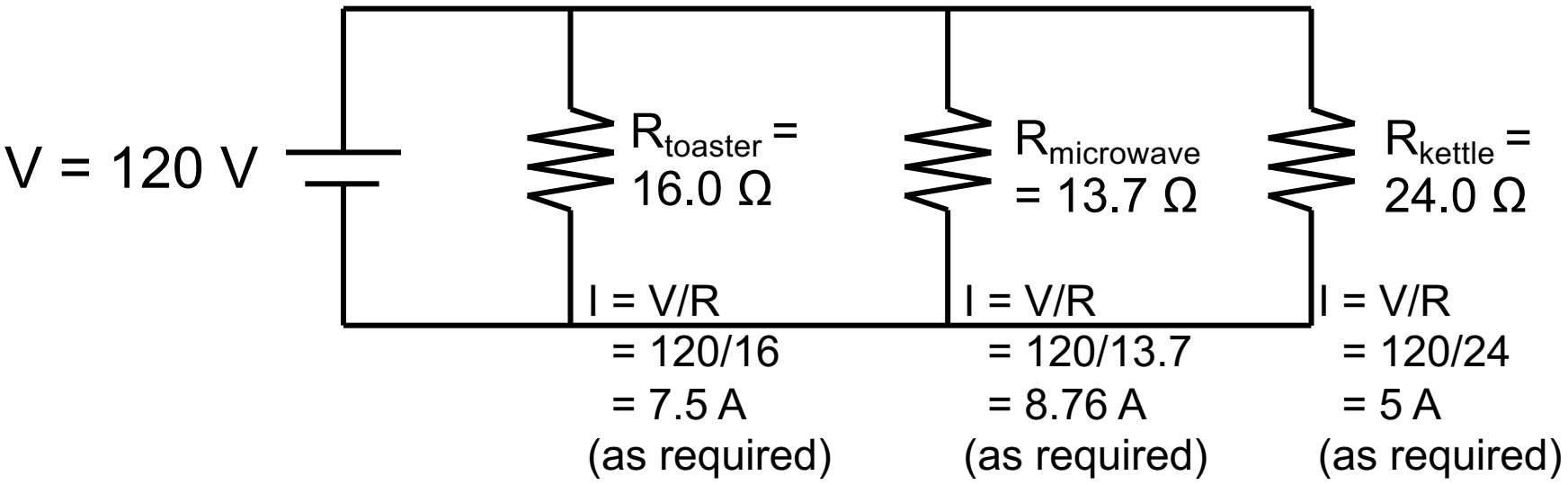
Answer

- Calculate the current drawn by each device.



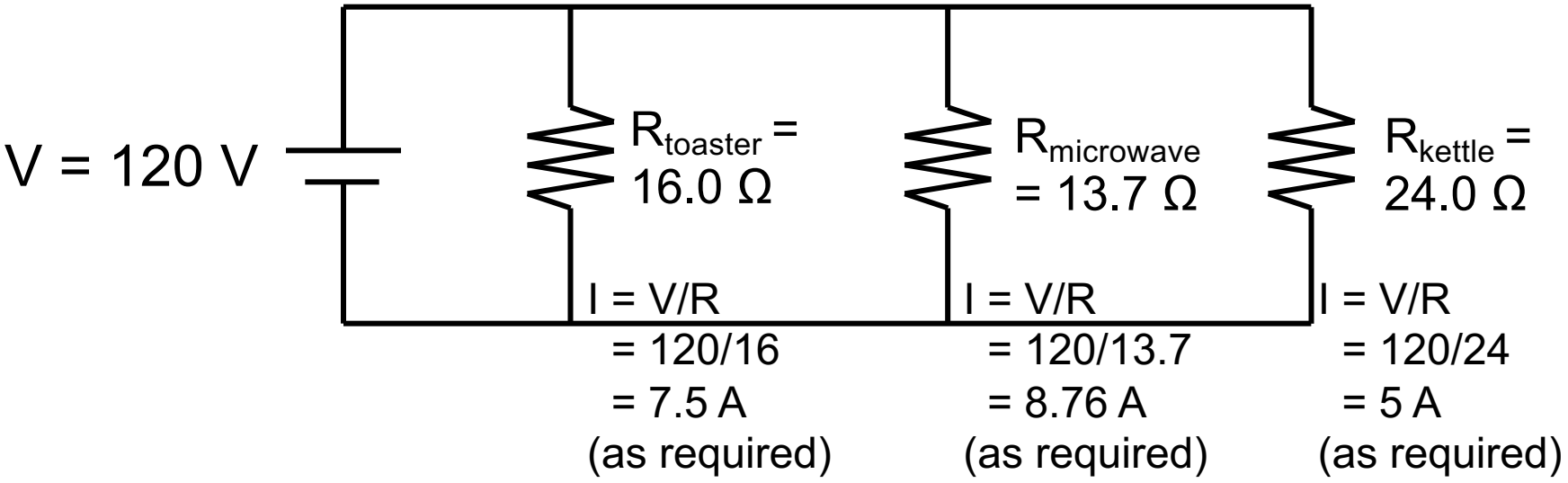
Question

- Calculate the **total current** drawn by the circuit.



Answer

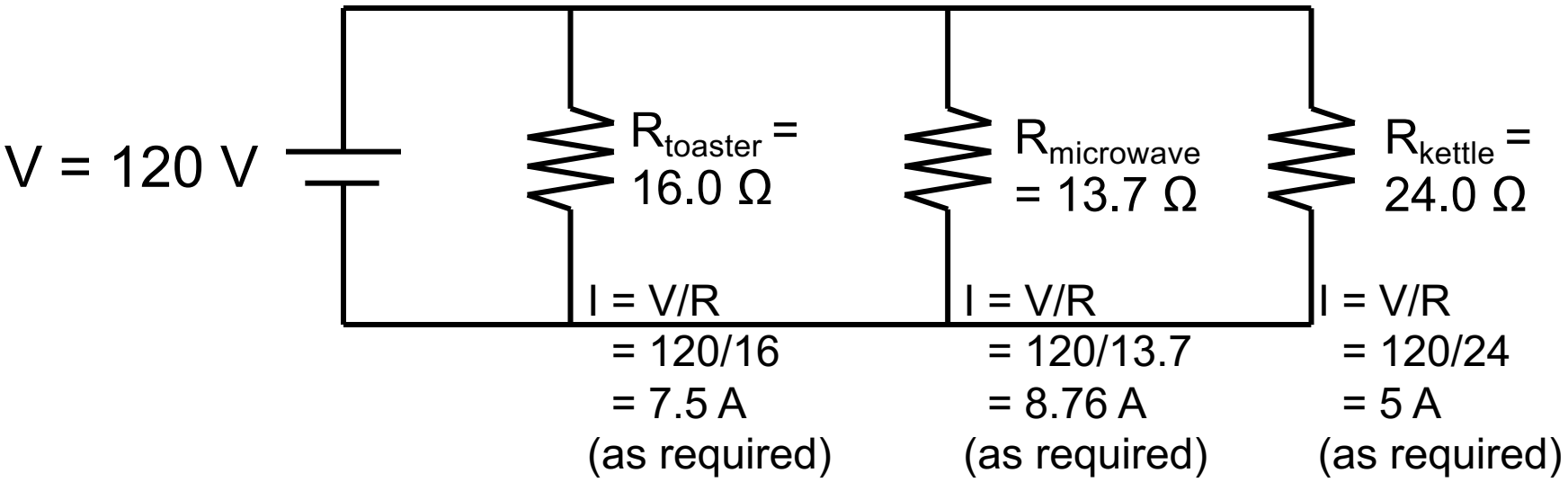
- Since the circuit is in parallel, the total current drawn is equal to the sum of the currents in each branch: I = 7.5 + 8.76 + 5 = 21.26 A



Question

$I = 7.5 + 8.76 + 5 = 21.26\ A$

- Typically, a home circuit's maximum allowed current is 20 A, so these three devices run together not be allowed (the circuit breaker would open the circuit)



Activity in your groups (smartamp.com)

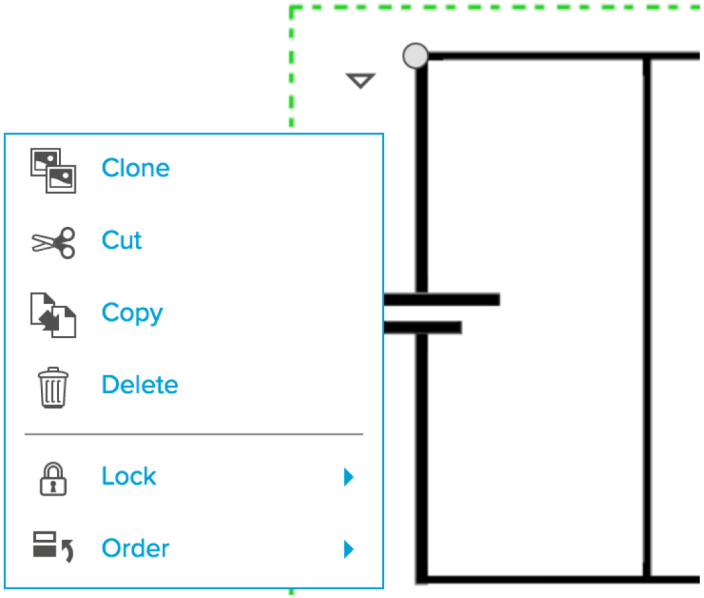
Lakeside View Global Vision
CEGEP JOHN ABBOTT COLLEGE

Demonstration of SMART amp

- Before you begin, I will go over the instructions and provide a demonstration

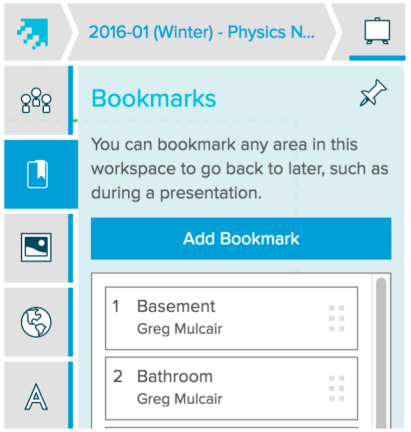
SMART amp interface

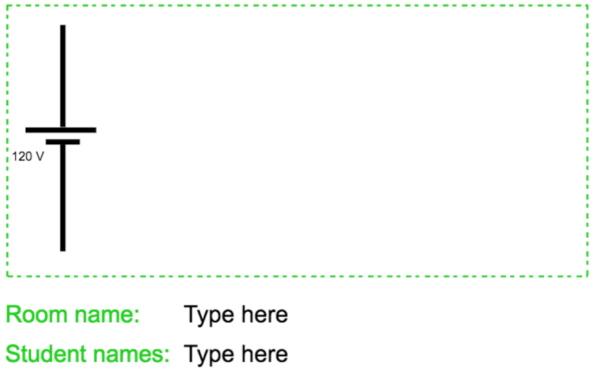
- In the menu bar at the top, you can use the:
  - Arrow to move items
  - Hand to move the page
  - Pencil to draw
  - Eraser to erase
  - Magnifying glass to zoom
  - Garbage to delete an item
- When you select an item, the dropdown menu allows you to easily clone or delete it.



Activity

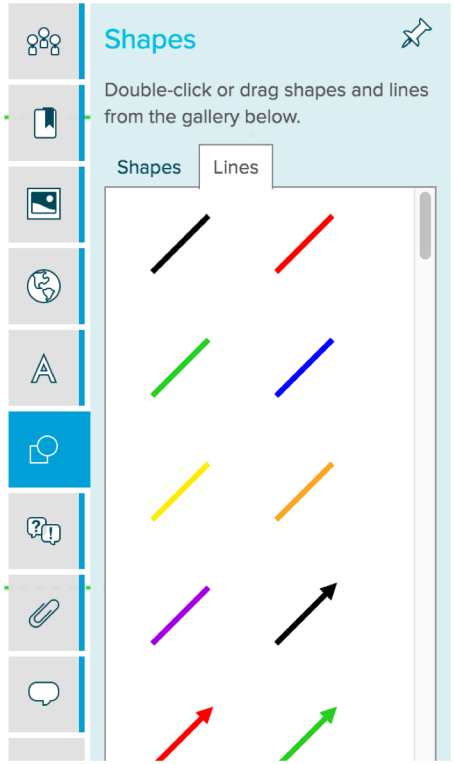
- Log into SMART amp (www.smartamp.com)
- Open the workspace for our class:
  - “Home circuit – Morning class” or
  - “Home circuit – Afternoon class”
- Click the Bookmark icon and click the bookmark with your room name:
- This will zoom you into your room’s circuit. Type the room name and the first names of the students in your group

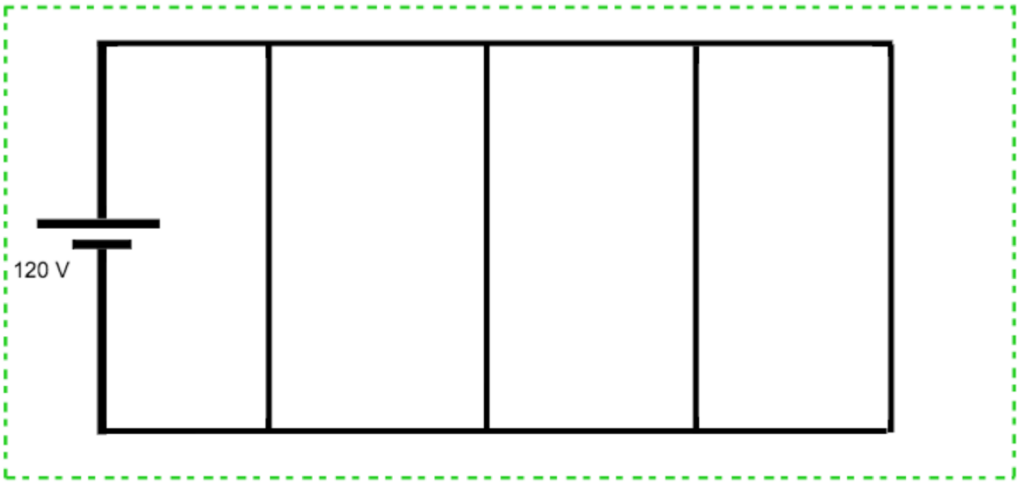




Draw lines of circuit

- Start your circuit using **Lines** in “Shapes” 



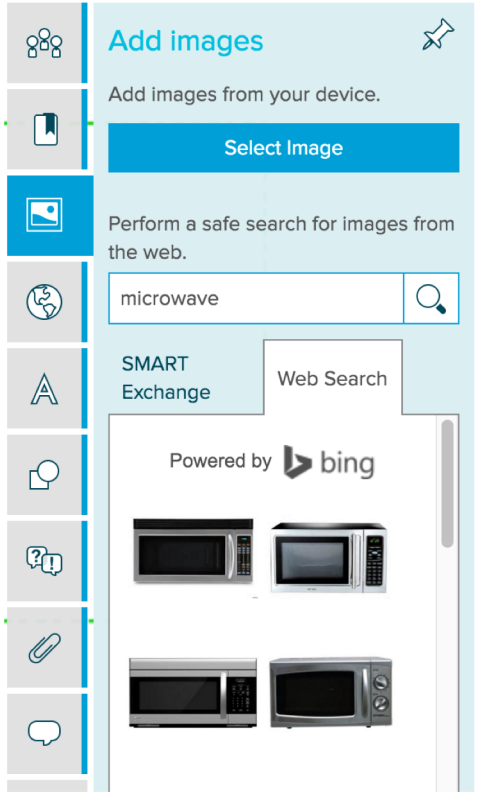


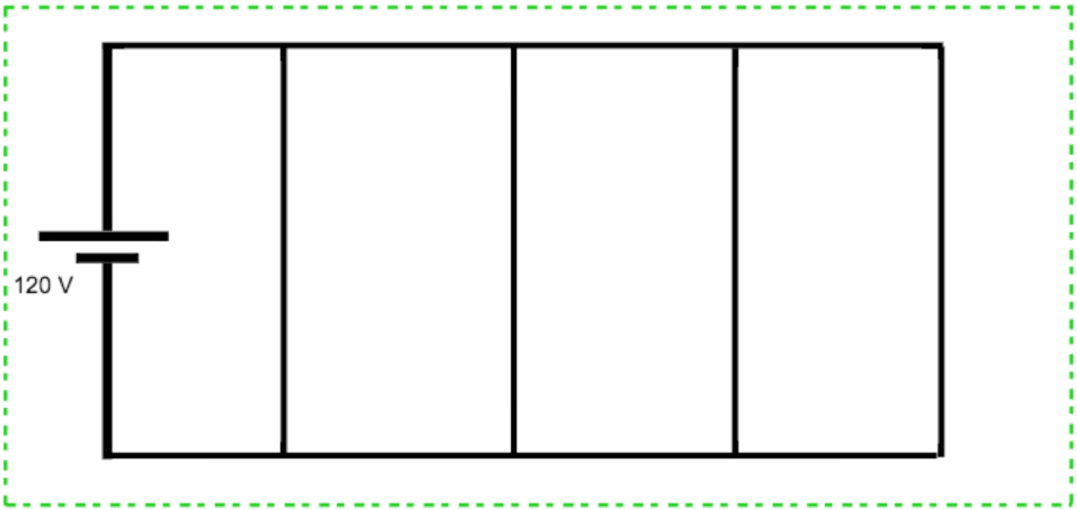
Room name: Greg's sample room

Student names: Greg

Add devices

- Find the device from a **Web Search** in "Images"



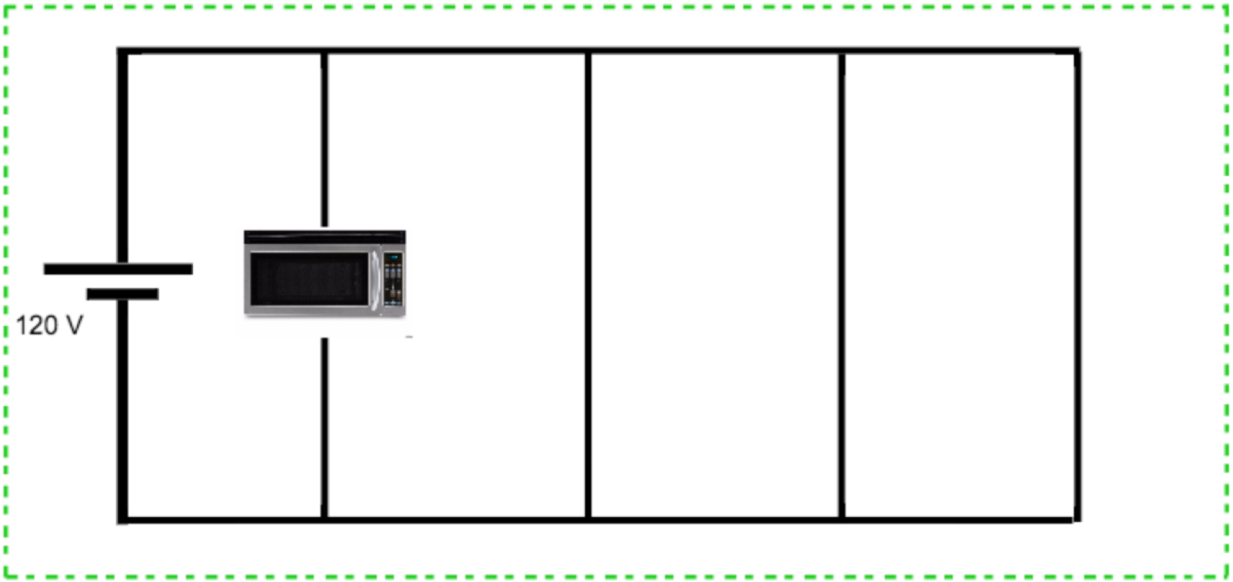


Room name: Greg's sample room

Student names: Greg

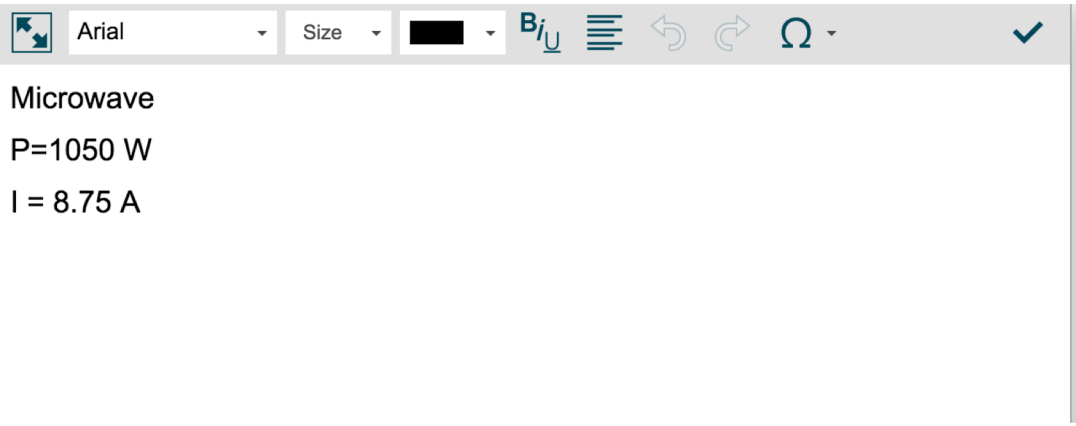
Add the image to the circuit

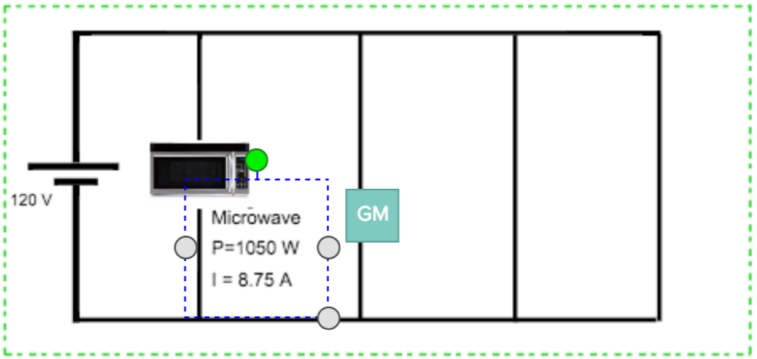
- Drag the found image into the circuit and resize



Add device name, power, current

- Calculate the current used by the device.
- Drag a text block into the circuit from “Text” 
- Double-click it to enter the text edit mode.
- Change font size to 18pt.
- Type the name, power and current for the device.



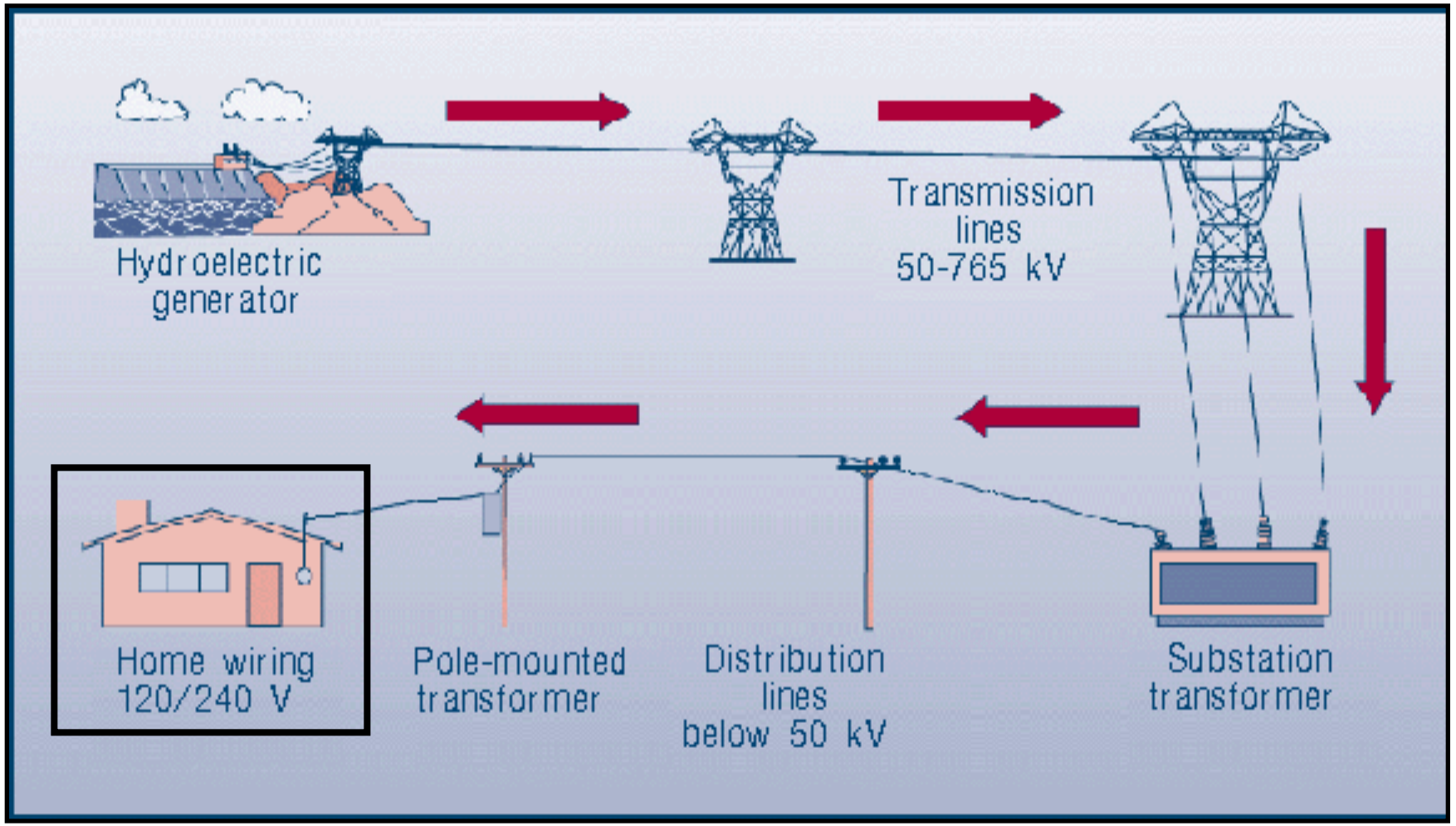


Find total current

- Repeat for all other devices (add image and type their respective names, powers and currents)
- Calculate the total current drawn by your circuit and type it in the space provided below your circuit
- If the total current is above 20 A, “turn off” enough devices (put a line through them) so that the current is below 20 A. Find the new total current.

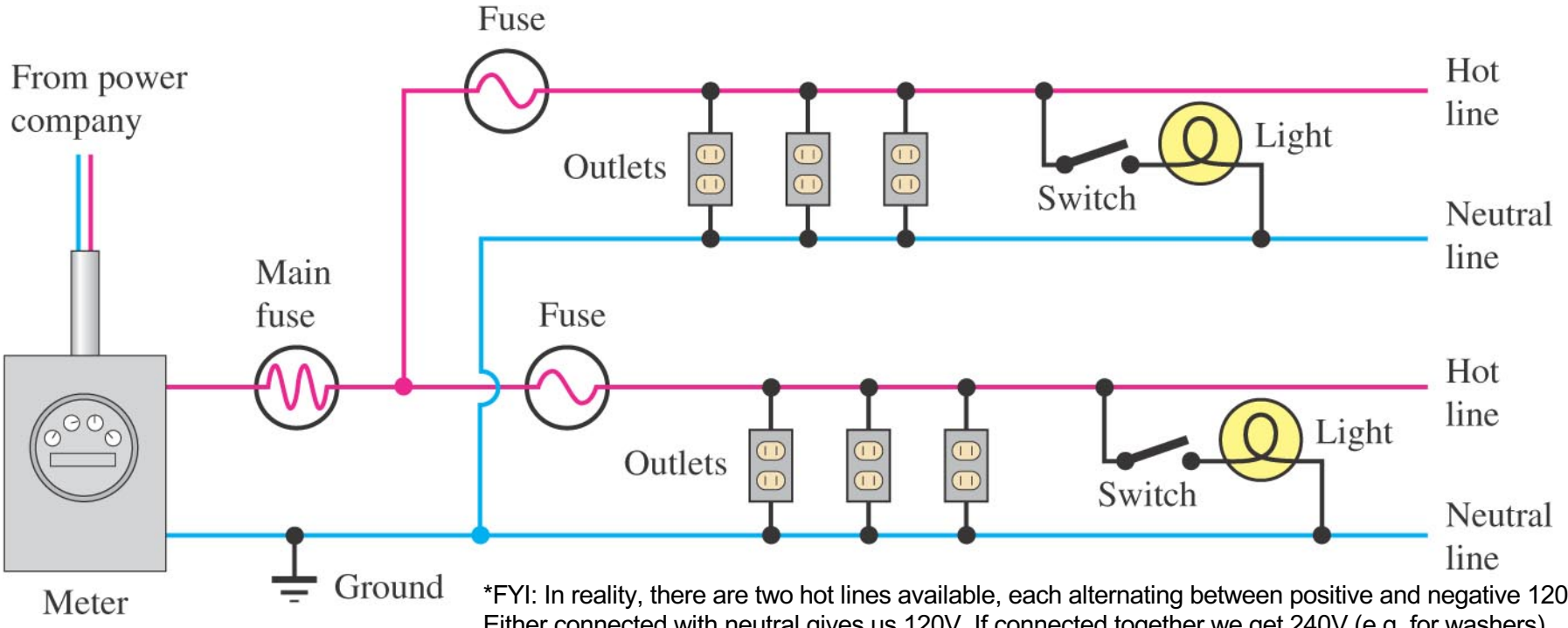
Power distribution systems

Power distribution systems



Power distribution systems

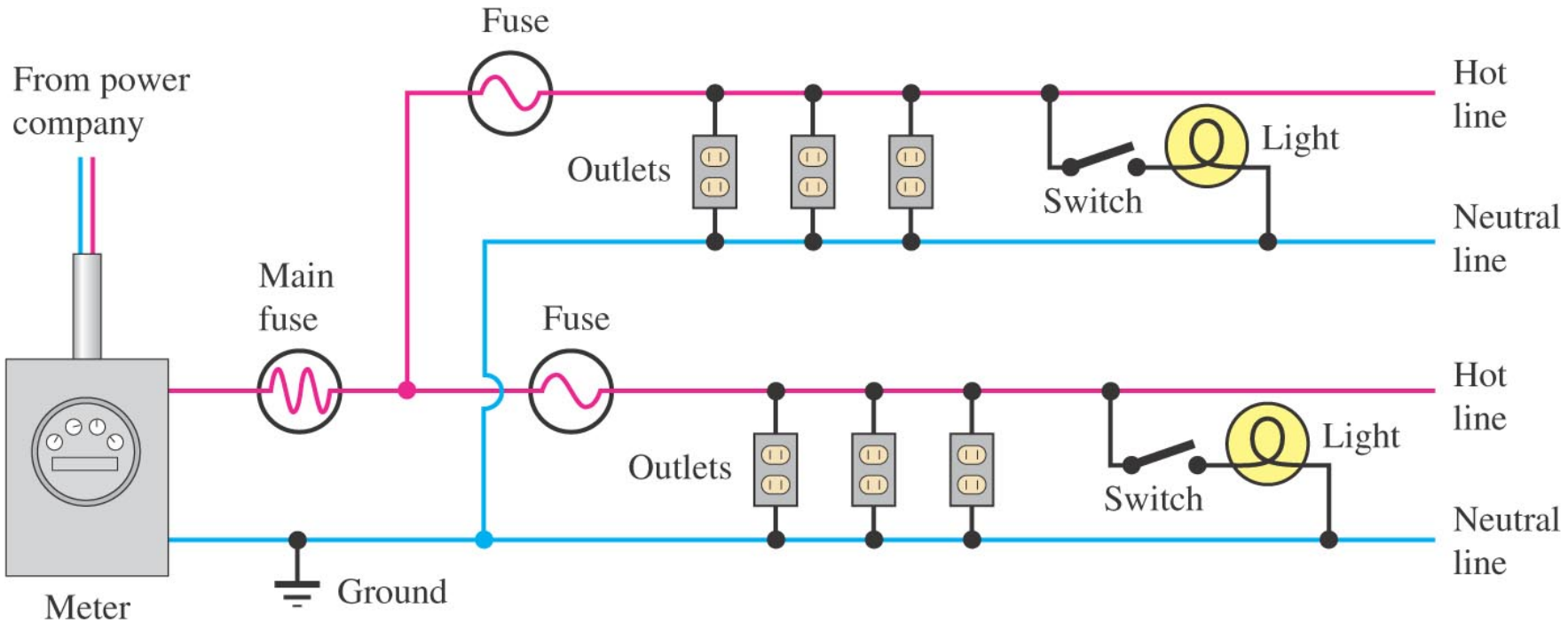
- The utility company distributes electric power to individual homes by a pair of wires: the *neutral* line and the *hot* line*
- Each house is connected in parallel with these wires
- A meter is connected in series with the live wire entering the house



*FYI: In reality, there are two hot lines available, each alternating between positive and negative 120V. Either connected with neutral gives us 120V. If connected together we get 240V (e.g. for washers).

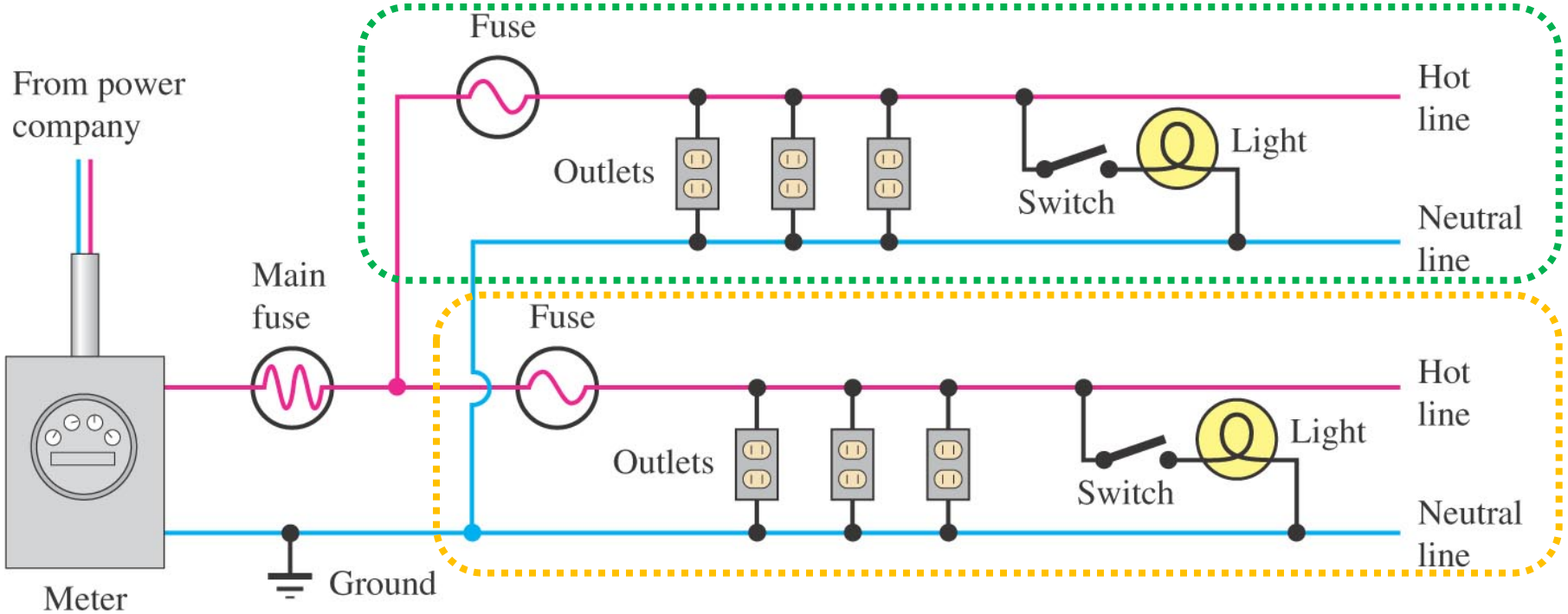
Power distribution systems

- The neutral line's potential is zero
- The hot line's potential is 120V
- So the potential difference between them is 120 V
- So everything that is plugged in gets 120V of potential difference



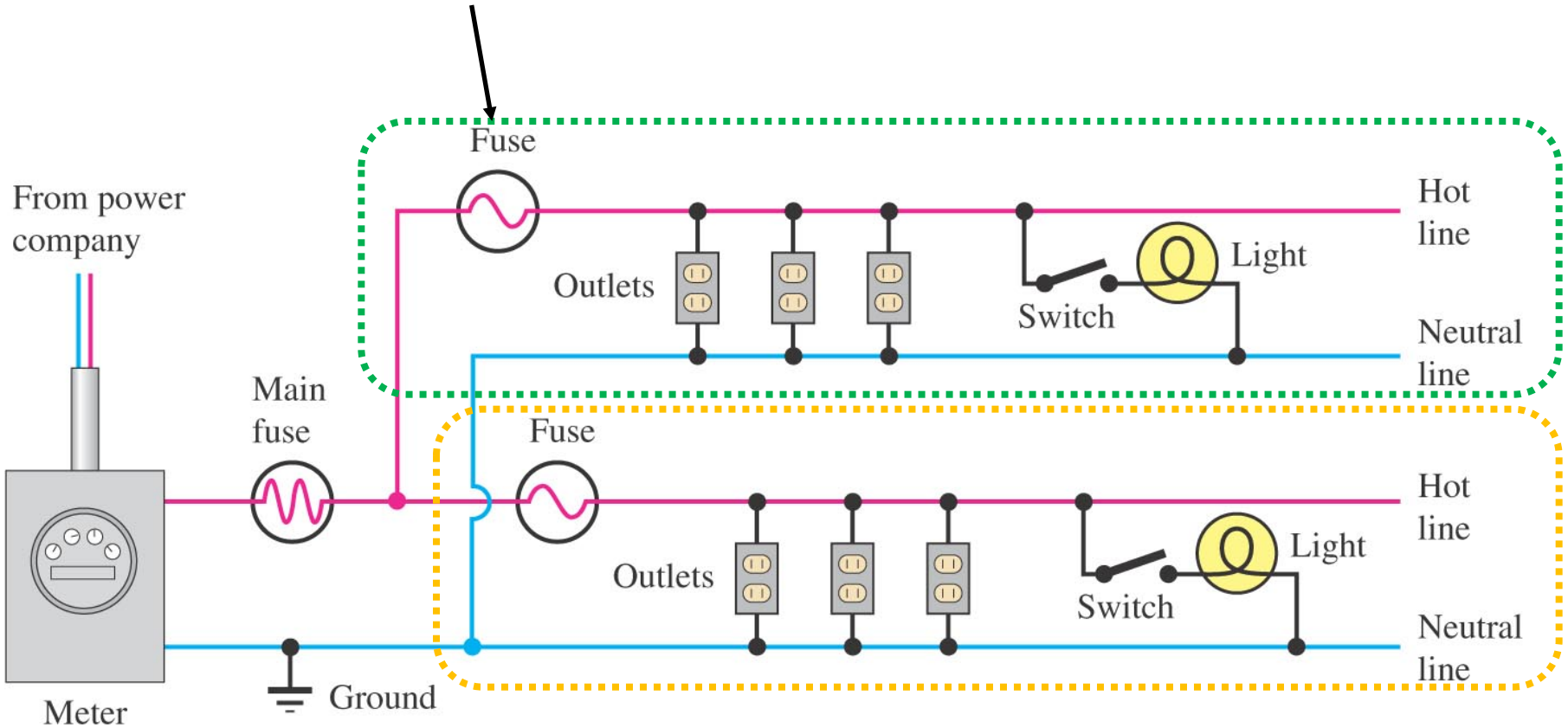
Household Wiring

- A home has several of these circuits. For example:
  - The **green circuit** might be for part of the kitchen
  - The **orange circuit** might be for the office
  - Etc...



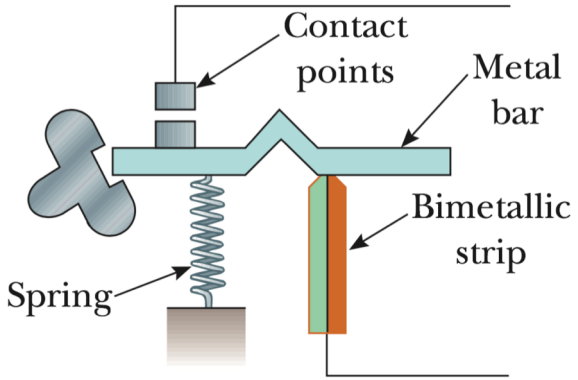
Household Wiring

- The wires are usually able to handle up to 20 A of current maximum
  - Larger currents can overheat wires, damage insulation and possibly cause a fire.
  - A circuit breaker (fuse) would open the circuit to stop this dangerous current.



For the curious…

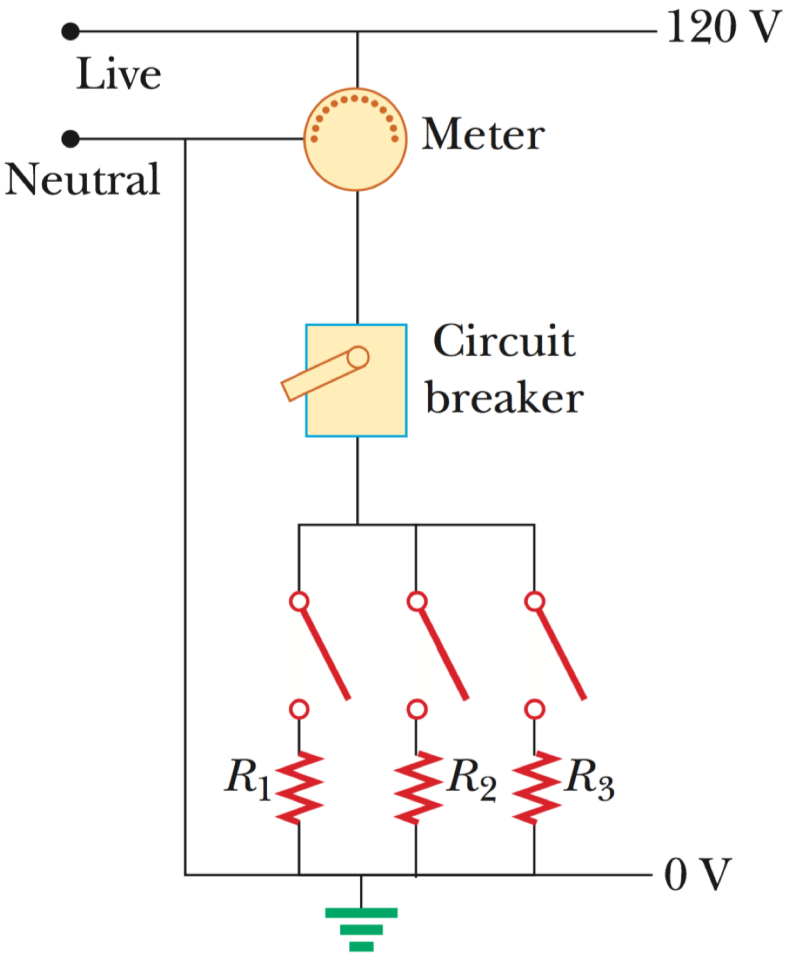
Source: University Physics, Serway



- In most homes, when the current in a circuit exceeds 15 - 20 A, the circuit breaker acts as a switch and opens the circuit.
  - Current passes through a bimetallic strip, the top of which bends to the left when excessive current heats it. If the strip bends far enough to the left, it settles into a groove in the spring-loaded metal bar. When this occurs, the bar drops enough to open the circuit at the contact point.
- The bar also flips a switch which indicates that the circuit breaker is not operational. So, once you turn off the device that overloaded the circuit, you can flip the switch back and your circuit will work again.
- This design has the disadvantage that some time is required for the heating of the strip, so this delay can cause damage since the switch doesn't open in time.
- Because of this, many circuit breakers are now designed to use electromagnets

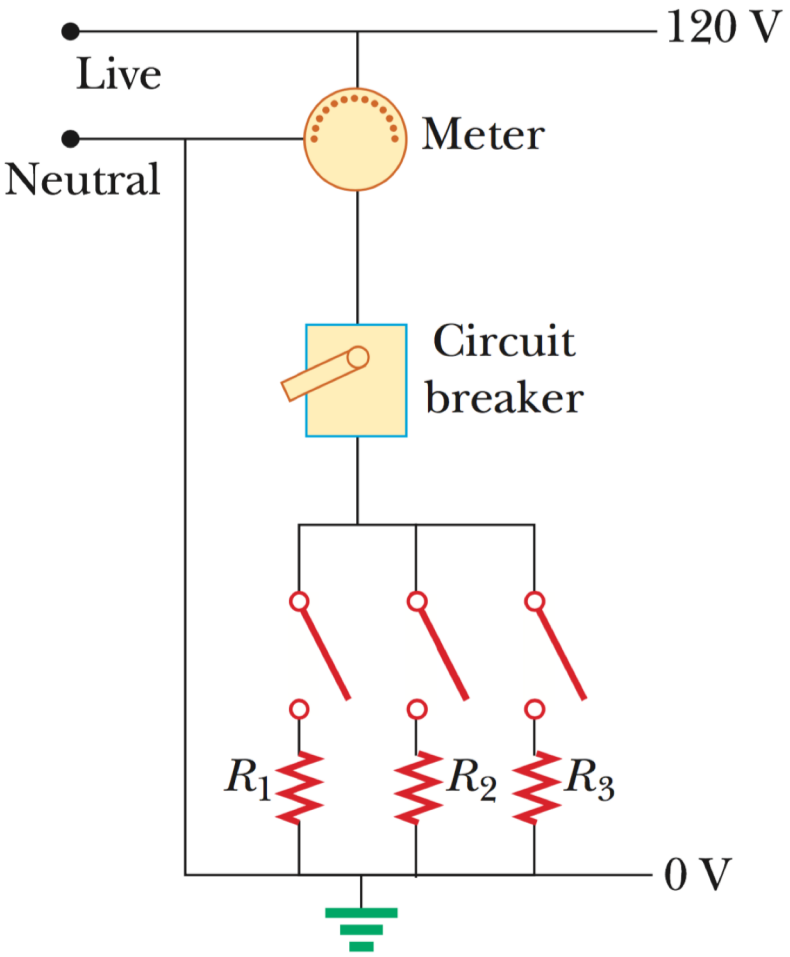
Example kitchen circuit

- One of the many circuits in the home would be in the kitchen.
- Here is how it would look with our same three devices:
  1. Toaster (900 W)
  2. Microwave (1050 W)
  3. Kettle (600 W)



Current drawn by each

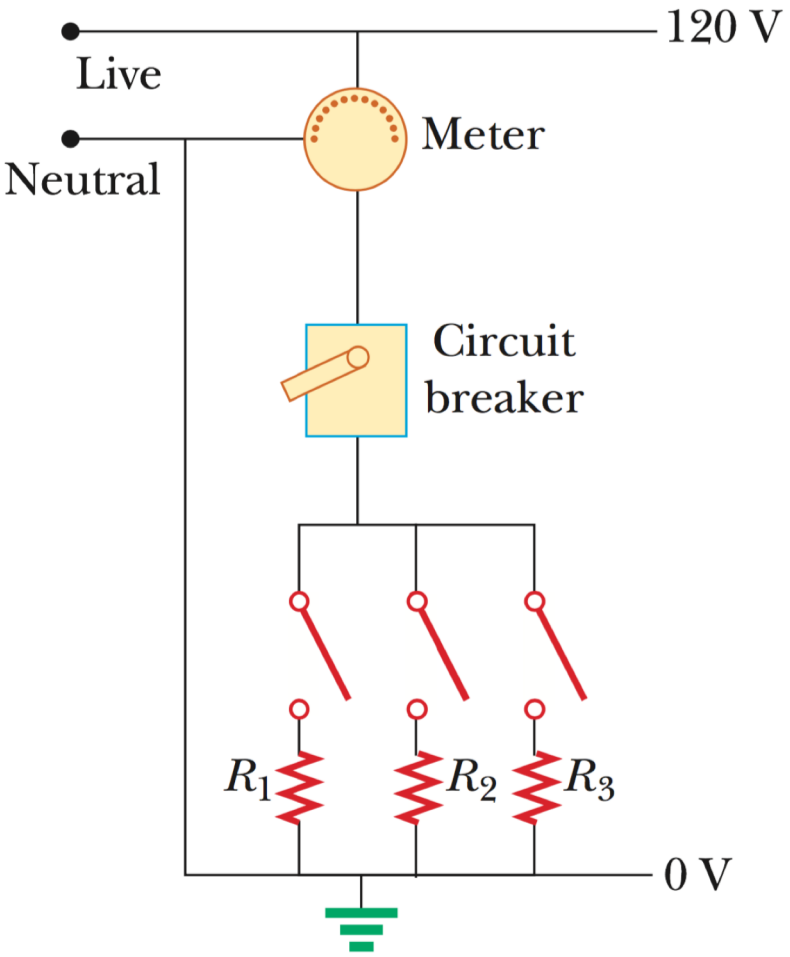
- They each get 120 V
- As we found before, if we rearrange P = VI we can find the current I = P/V drawn by each:
  1. $I_{toaster}$=900/120=7.5 A
  2. $I_{microwave}$=1050/120=8.75 A
  3. I_{kettle}=600/120=5 A



Source: College Physics | Serway | 7th Edition

Question

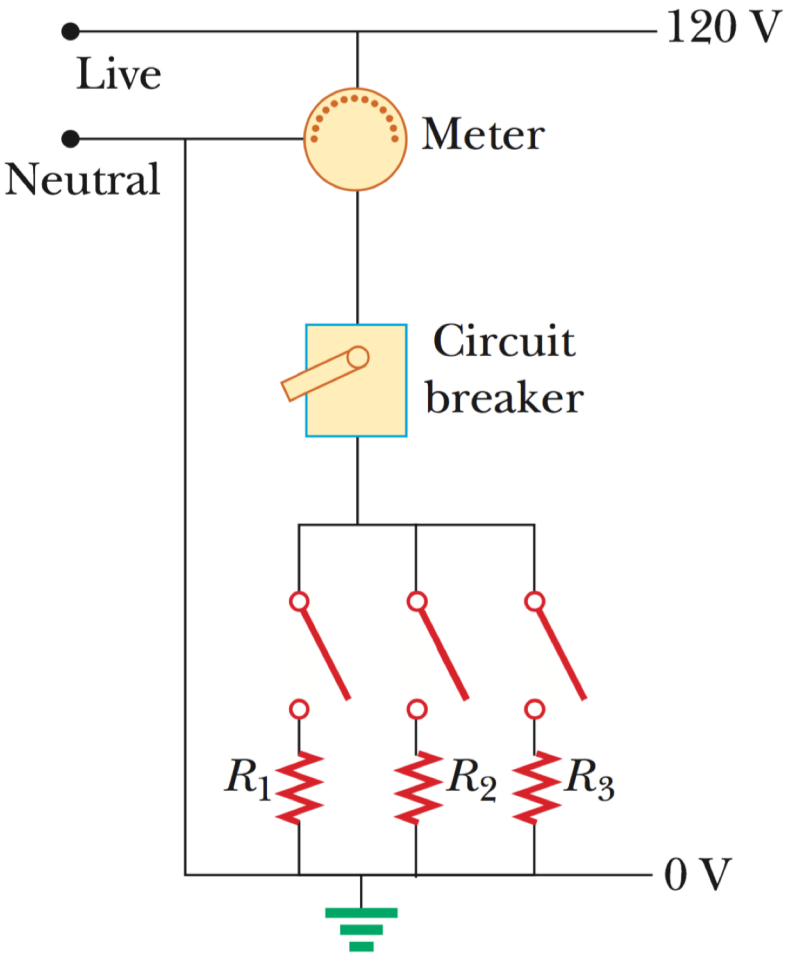
- Knowing the currents they each draw:
  1. $I_{toaster}$=900/120=7.5 A
  2. $I_{microwave}$=1050/120=8.75 A
  3. I_{kettle}=600/120=5 A
- We found the total current drawn.
- Will the breaker open?



Source: College Physics | Serway | 7th Edition

Answer

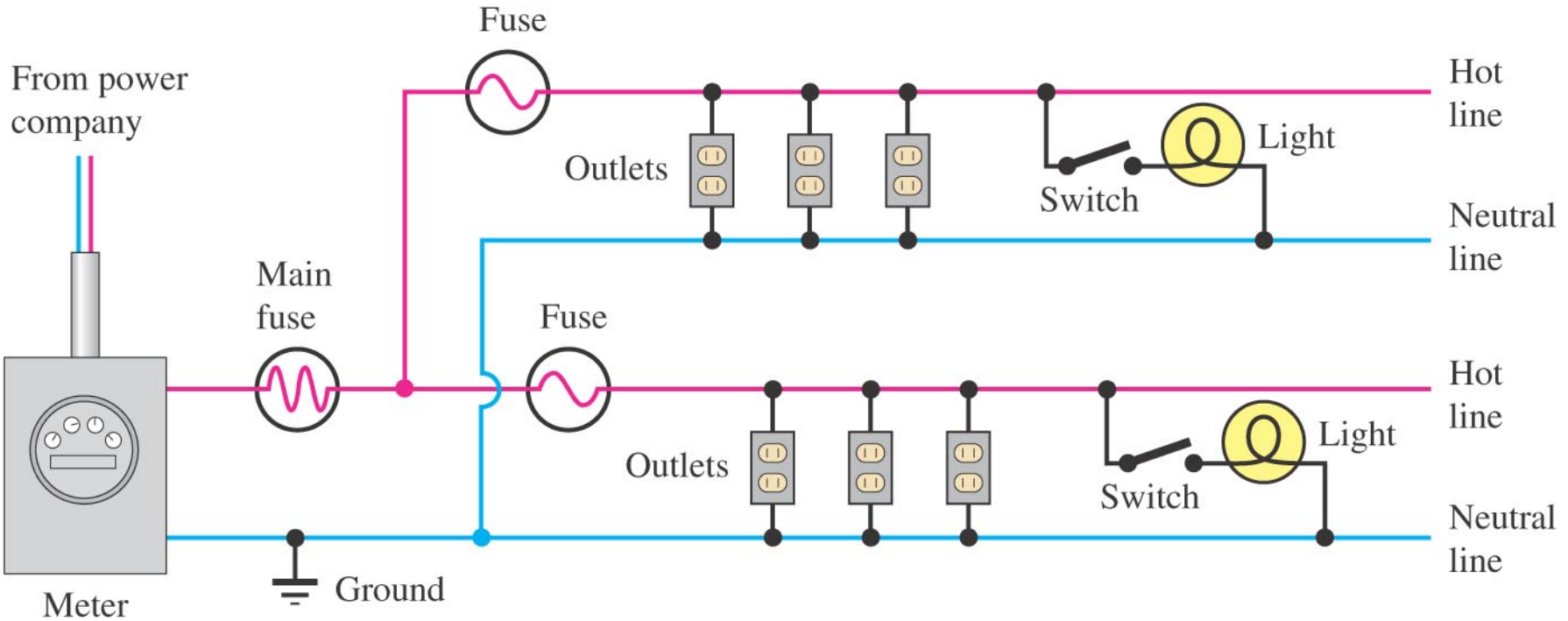
- The total current is the sum (junction rule):
- 7.5+8.75+5 = 21.25 A
- Since the circuit breaker is designed to allow a maximum of 20 A, **yes** the circuit breaker will open.



Source: College Physics | Serway | 7th Edition

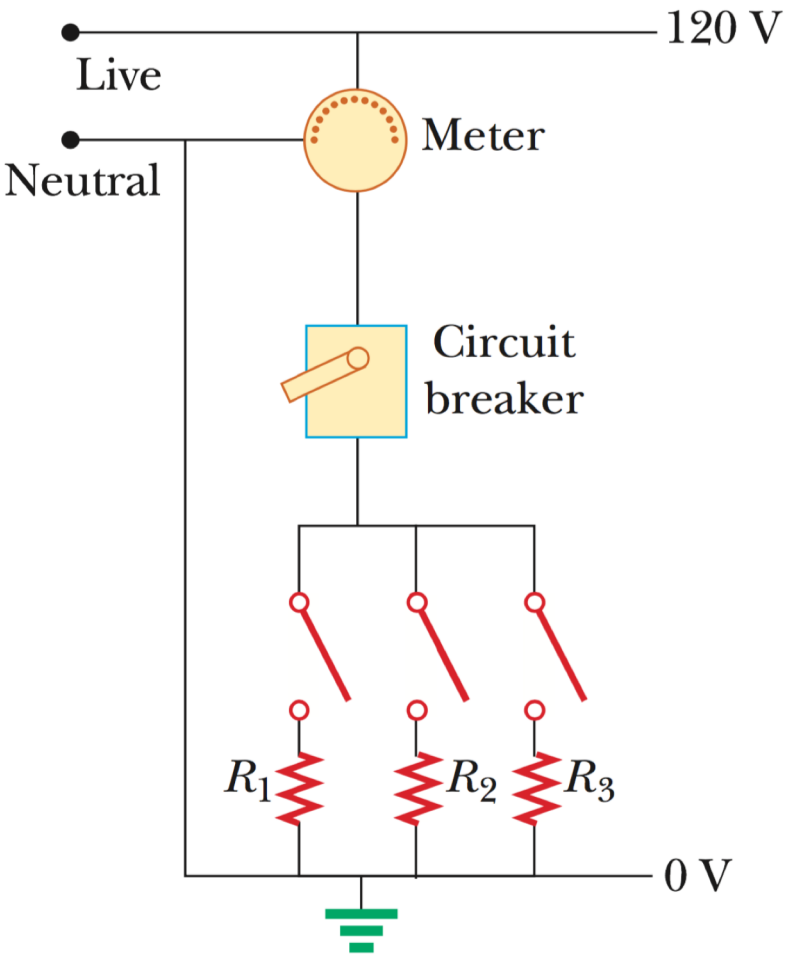
Household Wiring

- After the meter, the wire splits so that multiple parallel circuits can be distributed throughout the house
- Each circuit has its own fuse or circuit breaker
  - For devices needing 240 V, a third wire is maintained at -120 V



Household Wiring

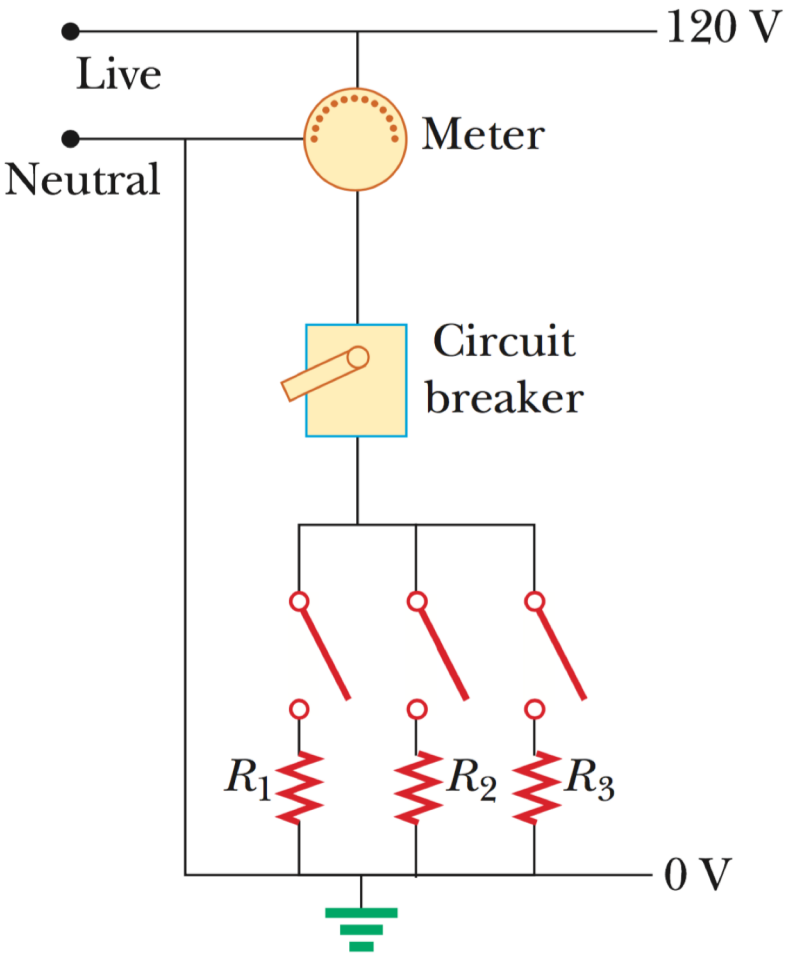
- Notice that the more you connect, the more you reduce the equivalent resistance of the combined load (recall how resistors add in parallel).



Household Wiring

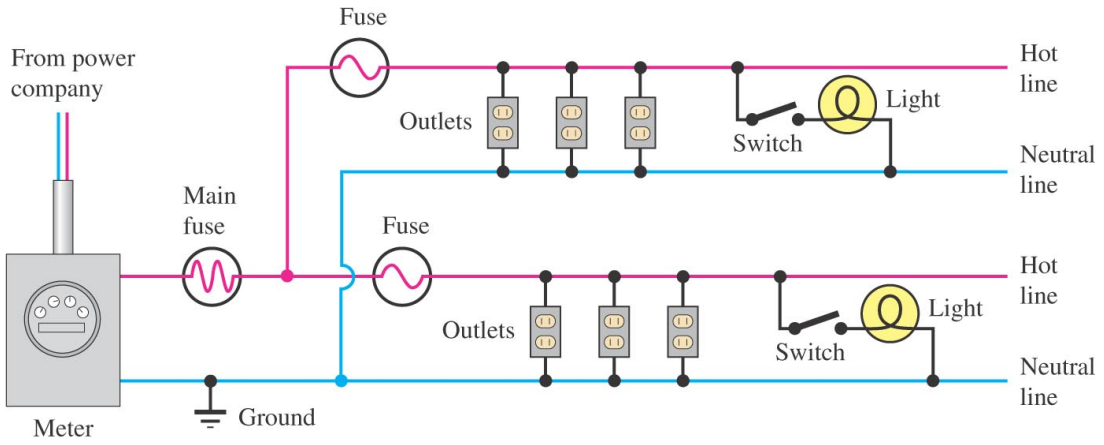
- And so, the more devices you connect in your circuit, the more current you draw:

$$
\begin{aligned}
I_{\text{outlet}} &= I_1 + I_2 + I_3 + \cdots \\
&= \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} + \cdots \\
&= V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \cdots\right) \\
&= \frac{V}{R_{\text{parallel}}}
\end{aligned}
$$



Household Wiring

- But remember that our homes are made up of several circuits (each controlled by a circuit breaker).
  - Kitchen circuit
  - Office circuit
  - Etc…



- So we are allowed to use all the appliances in our home as long as they are connected in circuits which don't exceed 20 A.

Home consumption

Home consumption

- This will be the last part of the project (instructions will be posted after the test).

Electrical Safety

Electrical Safety

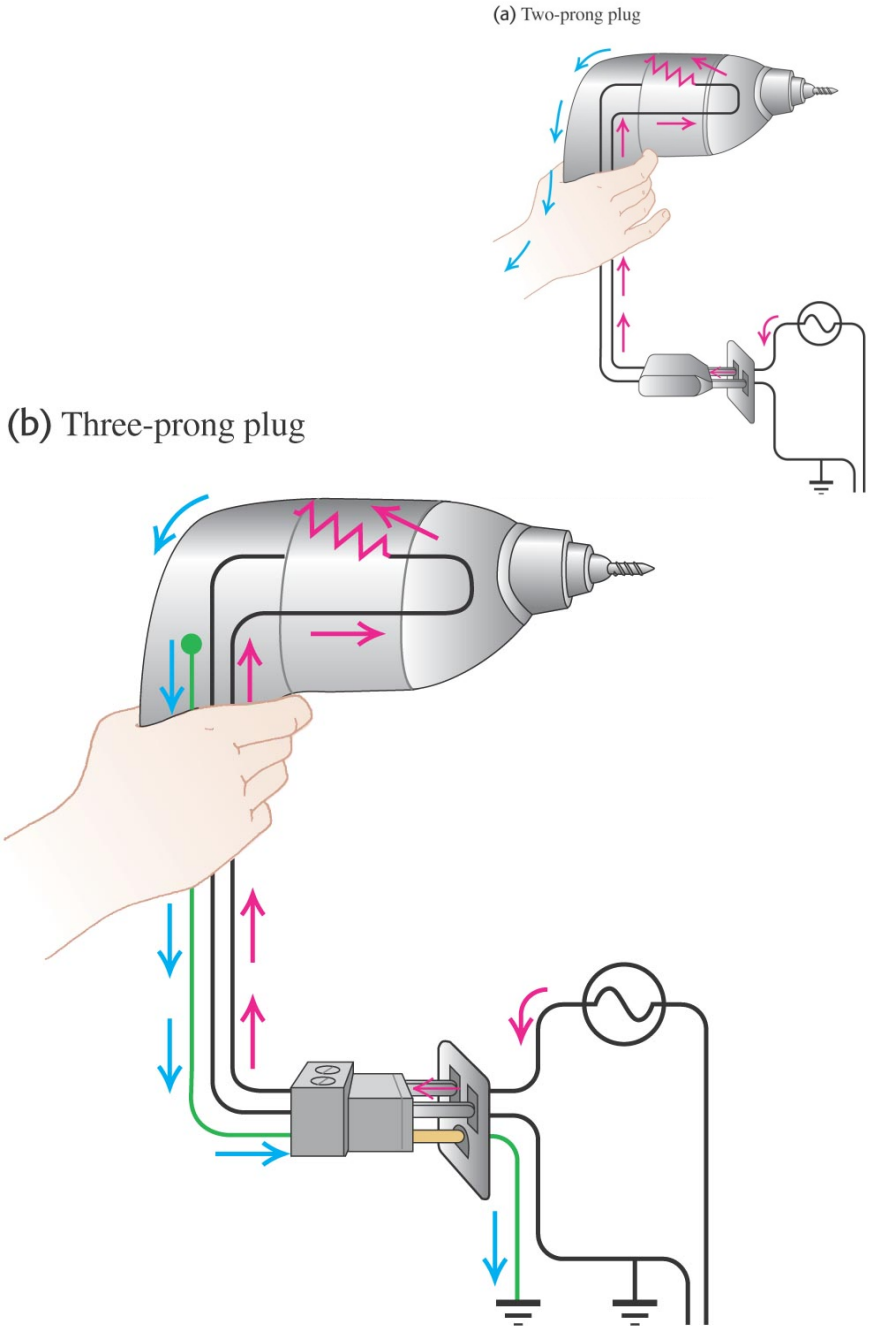
- A person in contact with ground can be electrocuted by touching the live wire
- Electric shock can result in fatal burns
- Electric shock can cause the muscles of vital organs (such as the heart) to malfunction
- The degree of damage depends on:
  - the magnitude of the current
  - the length of time it acts
  - the part of the body touching the live wire
  - the part of the body in which the current exists

Electric current effects on the body

- Stimulation of muscles and nerves
  - We've all felt that buzzing or tingling sensation without experiencing injury. A current as low as 0.25 milliamperes (mA) can cause this feeling.
  - Starting at 10 mA, most people cannot let go of the shock source because their muscles contract.
  - Above 50 mA, an electric current can trigger cardiac arrest if it passes through the heart.
- Electric burns to tissue and organs
  - Above 100 mA, electrical marks appear on the body at the points of contact.
  - Above 10,000 mA (10 amperes), burns are very severe

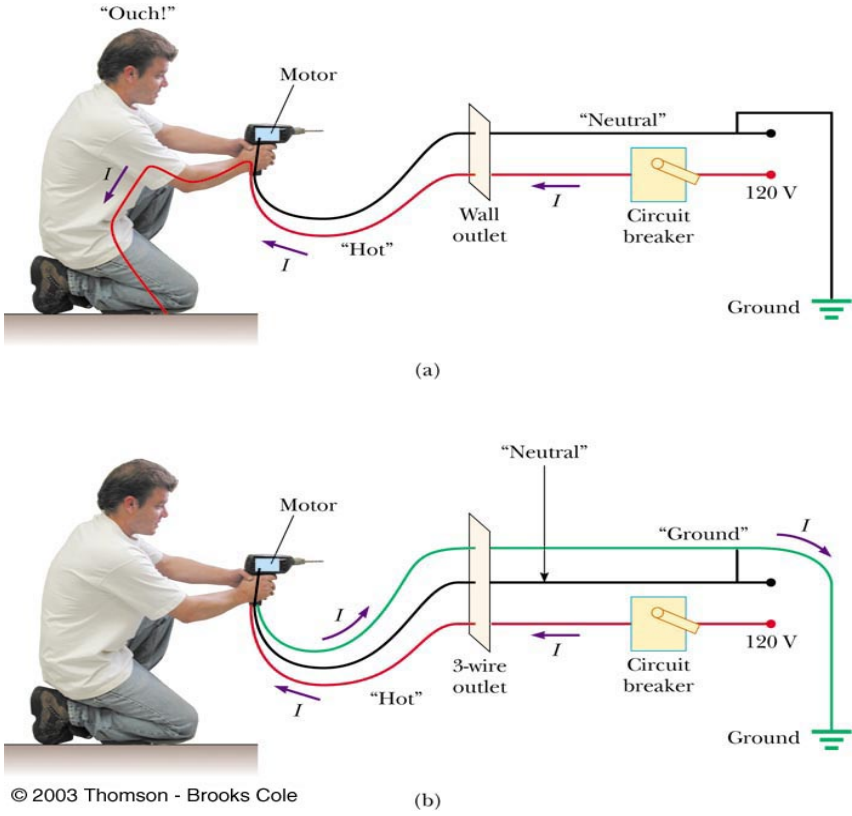
Ground wire

- Electrical equipment manufacturers use electrical cords that have a third wire, called a ground
- This safety ground normally carries no current and is both grounded and connected to the appliance



Ground Wire

- If the live wire is accidentally shorted to the casing, most of the current takes the low-resistance path through the appliance to the ground
- If it was not properly grounded, anyone in contact with the appliance could be shocked because the body produces a low-resistance path to ground



Typical home wiring