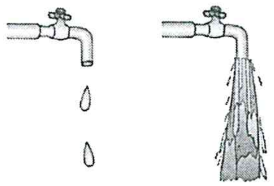
Name: ____________________

Period: ____________________

Current

Current Flows

Current is the amount of charge flowing per second, just like gallons per second. More current means more coulombs per second. Current is NOT about the speed of the electrons. All current travels at the same speed. This *drift velocity* of electrons is actually very slow. It takes over an hour for an electron to travel one meter in a wire.



Less current. *More current.*

Electrical Current

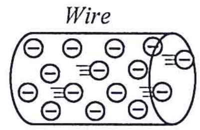
$$I = \frac{Q}{t}$$

Current (*in Amperes [Amps]*) → I; Charge (*in Coulombs [C]*) → Q; Time (*in sec*) → t

Ex. A device draws 300 mA. How much charge does it use in 5 seconds?

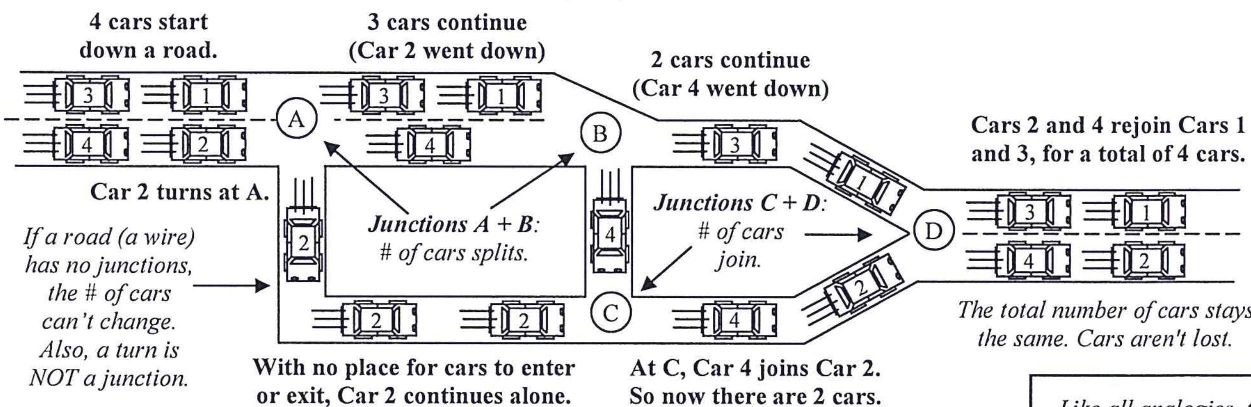
I = 0.3 A t = 5 sec Q = ?	$I = \frac{Q}{t}$ *so* $Q = I(t)$ $= 0.3(5) = 1.5C$

Current tells us how much charge passes thru a wire's "cross sectional area", which would be the area cut perpendicularly thru a solid (like a wire). The cross sectional area of a cylinder is a circle.



Current in Circuits

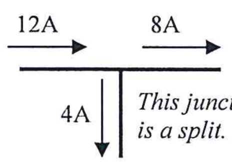
Current flows thru wires, much like water flows thru pipes. The following diagram uses four cars to show how current splits, joins, or remains constant in circuits.

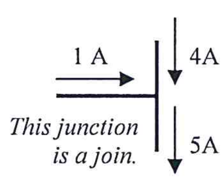


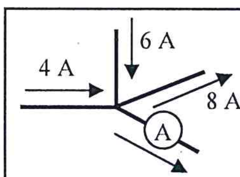
Cars driving on roads combine and split just like current flowing thru wires in circuits.

- The amount of current cannot change in a wire (*like Car 2, bottom left*), only at junctions.
- At a junction the current can split (*like A or B*) or join (*like C or D*). A turn is not a junction.
- ***"The amount of current flowing into a junction must equal the amount of current flowing out of the junction."*** This is known as **Kirchhoff's Junction Law:** $\Sigma I_{in} = \Sigma I_{out}$. This is just another statement of Conservation of Mass: # e's in = # e's out.

Like all analogies, this one has limitations. Cars are self-propelled: electrons are moved by electric fields from batteries. Also, roads are empty to begin with. ***Wires already have electrons in them.***







Ex. What does the ammeter read?

Kirchhoff's Junction Law: $\Sigma I_{in} = \Sigma I_{out}$

$$4 + 6 = 8 + I$$
$$10 = 8 + I$$
$$I = 2 \text{ Amps}$$

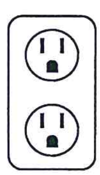
Types of Current

You use two kinds of current every day: direct current (DC) and alternating current (AC).

DC

Direct Current (DC) flows in only one direction. Batteries provide direct current from chemicals and different metals.

Alternating Current (AC) flows one way and then reverses. The power in your house is AC, alternating 60 times a second.



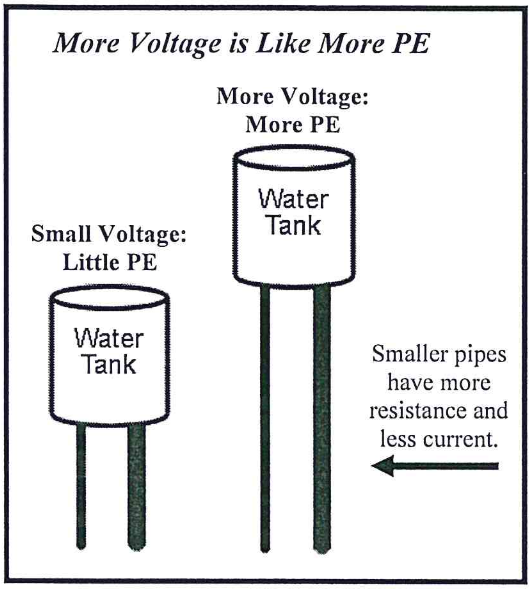
AC

Converting between AC and DC:

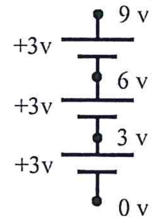
Devices are designed for either AC or DC and cannot run off the other. To plug a battery powered devices into the wall requires an AC adaptor, which has a rectifier circuit in it. Car's produce only direct current. Using a house-hold AC device in a car requires an in-

Voltage in Circuits

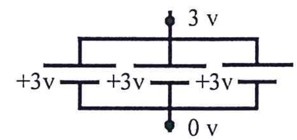
Batteries add voltage: as you move over a battery you gain voltage. The voltage at the bottom of the first battery is always 0 volts. *Think of batteries as lifting water up: adding electrical potential energy.*



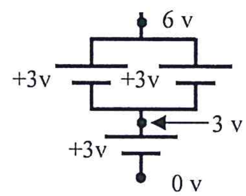
Batteries in series add voltage (raising electrical potential energy).



Batteries in parallel share the same voltage. (They just last longer.)

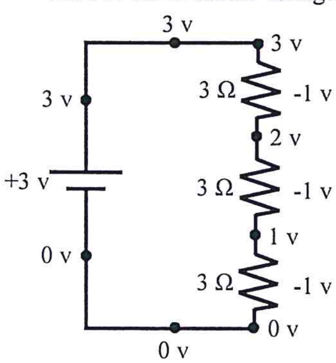


Remember: there can never be a change of voltage on a wire.

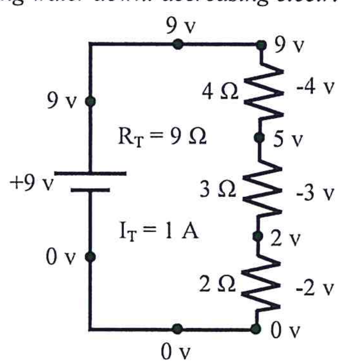


Notice here that the two batteries in parallel add only 3 volts, giving 6 volts total.

Resistors use (subtract) voltage: Every resistor in a circuit uses voltage. Think of it as a negative voltage: subtract the voltage it uses from the voltage at the top of the resistor. Resistors in series SHARE voltage, with bigger resistors using more of the available voltage. *Think of resistors as lowering water down: decreasing electrical potential energy.*



In this circuit we don't need to calculate the voltage drops. Since there are three resistors of equal resistance, each will use one-third the available voltage.



To find the voltage drops, we must first find the total current.

$$I_T = \frac{V_T}{R_T} = \frac{9v}{9\Omega} = 1A$$

$V_{4\Omega} = IR = 1(4) = 4v$

$V_{3\Omega} = 3v$

$V_{2\Omega} = 2\ v$

Notice that the biggest resistor used the most voltage.

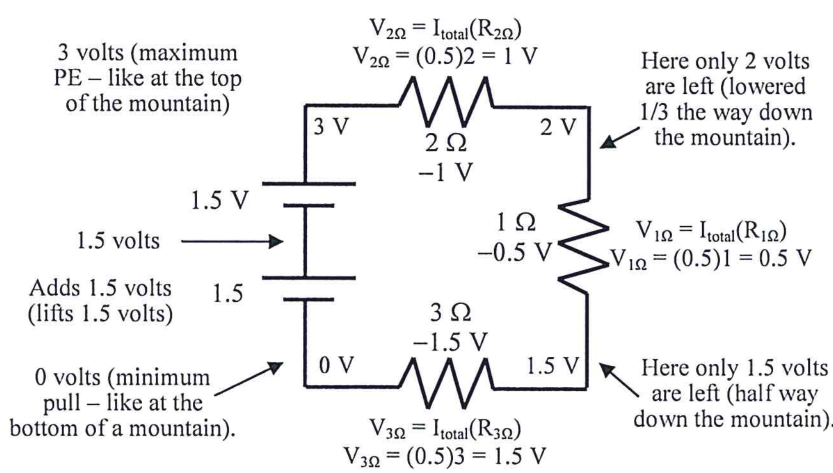
Each battery raises voltage (the electrical potential energy) and each resistor uses part of the voltage (lowering the electrical potential). Since the three resistors are in series, they have the same current (since there is only one path for the current).

$V = IR$, so $I = V/R$

$R_{total} = 6\ \Omega$ and $V_{total} = 3$ v

So, $I = 3v/6\Omega = 0.5$ amps.

Then use V = IR for each resistor to find how much voltage it uses.

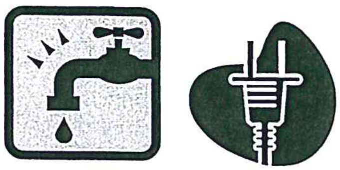


Name: ____________________

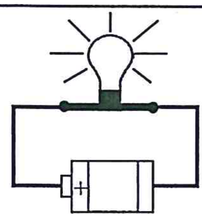
Period: ____________________

Circuits and Symbols

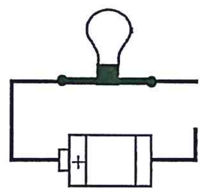
Electricity works a lot like water. Often imagining how water would work in an circuit will tell you how electricity will work as well.



***Electricity flows through circuits:** paths of conductors (usually wires). Any break in the circuit will cause the circuit to fail, just like a break in a pipe lets water leak out of a water system.*



A *closed circuit* has no breaks: the light lights up.



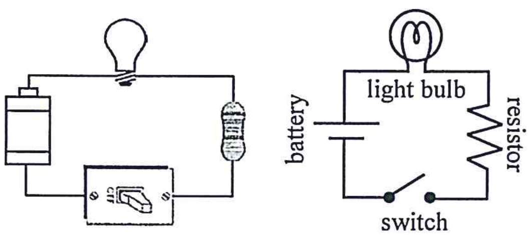
An *open circuit* has a break in it: the light will not light up.

A break in a circuit is any spot where an insulator is in the way of the electricity's flow. Paper, plastic, or even an air gap can keep electricity from flowing.

Circuit diagrams

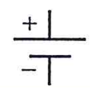
Circuit diagrams are a short-cut method of drawing circuits. They don't need to be perfectly draw, but they can be drawn wrong.

These components *look* similar, but are very different and have different functions.



The diagram on the right is a faster way of drawing the circuit on the left. (Notice the direction of the battery, which is important)

Electrical Symbols

Electrical Device	Symbol	Function	Water Equivalents
wire	———	paths for electricity to flow.	pipes
battery		pushes electricity through circuit.	pump
light bulb		lights up; resists electricity.	no equivalent
switch		turns electricity on and off	valve
resistor		resists flow of electricity.	restriction in a pipe

3 Quantities of a Circuit

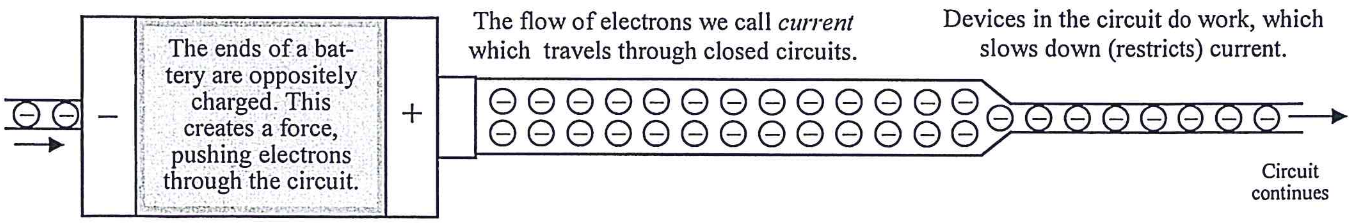
Voltage *Pushes Electrons*

Current *Flows Through Circuits*

The flow of electrons we call *current* which travels through closed circuits.

Resistance *Resists Current Flow*

Devices in the circuit do work, which slows down (restricts) current.



Voltage is measured in ***Volts***.

Current is measured in ***Amps***.

Resistance is measured in ***Ohms.***

These three quantities are linked in any circuit.
Change one of them and one or both of the others will change.

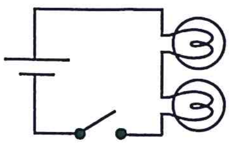
Name: ____________________

Period: ____________________

Types of Circuits and Ohm's Law

Types of Circuits

Series circuits have all only one path for the electricity to flow.

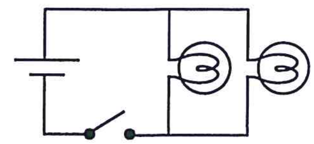


Two lightbulbs in series. Each light is dependent on the other.

If any part of a series circuit is broken, the circuit fails. If either light is unscrewed both lights will turn off.

The branches (paths) of a parallel circuit are independent. If either light is unscrewed, the other will remain on.

Parallel circuits have multiple paths for the electricity to flow.



Two lightbulbs in parallel. Each light is independent of each other.

Your house is wired in parallel, so that each light and appliance can be turned on and off independently.

Ohm's Law

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

Current (in *amps*) → I; V ← Voltage (in *volts*); R ← Resistance (in *ohms*)

Current equals the voltage divided by the resistance.

Also, V = IR and R = V/I

Abbreviations:

A - Amps - current
v - volts - voltage
Ω - ohms - resistance

Increasing voltage increases current.

Increasing resistance decreases current.

Decreasing voltage decreases current.

Decreasing resistance increases current.

Ex. How much current does a 12 v battery push through a 3 Ω resistor?	
V = 12 v R = 3 Ω I = ?	$I = \frac{V}{R} = \frac{12\ v}{3\ \Omega} =$ (4A)

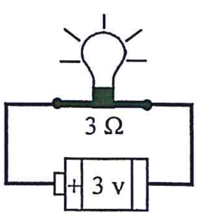
Ex. How strong a battery produces 2 A through a 3 Ω resistor?		
V = ? v R = 3 Ω I = 2 A	$I = \frac{V}{R}$	So, V = IR = (2A)(3Ω) = (6 v)

Current

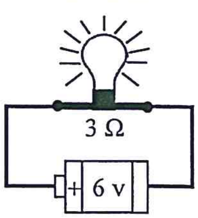
Current is moving electrons, moving charge.

Increasing current causes more electricity to move through a device.

Increasing electricity through a device causes it to work faster (in a motor) or be brighter (in a lightbulb).



Using Ohm's Law: I = V/R
I = 3v/3Ω
I = (1 A)



Using Ohm's Law: I = V/R
I = 6v/3Ω
I = (2 A)

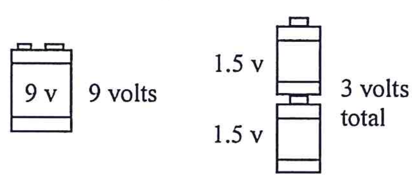
More current = brighter light.

Voltage

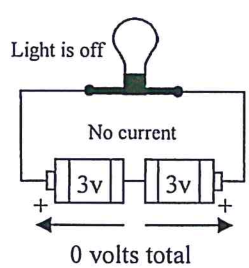
Voltage is electrical potential: how much work a battery can do.

Voltage is linked to energy:
1 volt of voltage = 1 joule of energy per coulomb of charge

To increase voltage you could use a stronger battery OR add batteries.



More voltage is like a stronger pump, giving more force and more current.

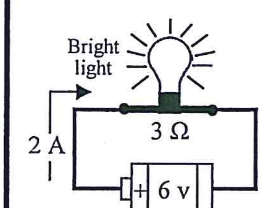


The lightbulb doesn't light here, because the two batteries are pushing *opposite directions*. To add together, batteries must be facing the same direction.

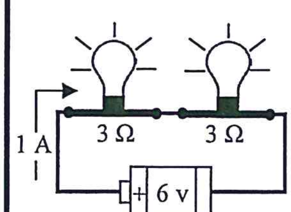
Resistance

Resistance slows down current. Think of resistance like a dam holding back water.

Adding devices in a circuit increases resistance.



I = V/R
= 6v/3Ω = 2 A
The light is bright because the 6 volts only have one light to run.



I = V/R
= 6v/6Ω = 1 A
Both lights are dimmer because the 6 volts have two lights to run.

More resistance = less current
Less current = less light

Name: ____________________

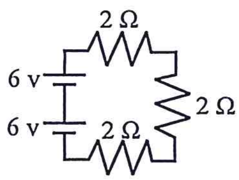
Period: ____________________

V, R, and I in Series Circuits

Total Voltage (V_T)

If the batteries are in series (in a line) then *add them together* to find the total voltage (V_T).

$V_T = V_1 + V_2 + V_3 + ...$

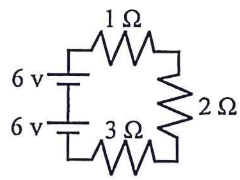


$V_T = 6\ v + 6\ v = 12\ v$

Total Resistance (R_T)

If the resistors are in series then *add them together* to find the total resistance (R_T).

$R_T = R_1 + R_2 + R_3 + ...$

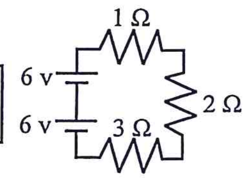


$R_T = 1\ \Omega + 2\ \Omega + 3\ \Omega = 6\ \Omega$

Total Current (I_T)

Use Ohm's Law to calculate the total current from V_T and R_T.

$V_T =$ 12 v

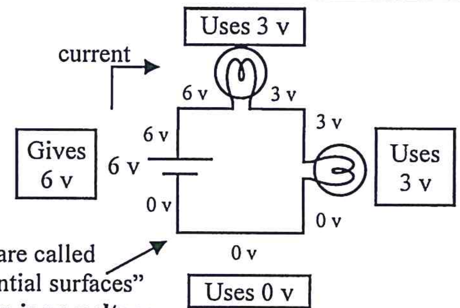


$R_T =$ 6 Ω

$I = \frac{V}{R} = \frac{12\ v}{6\ \Omega} = 2A$

Voltage Drop

Each resistor in a series circuit "uses" part of the energy of the circuit, reducing the voltage. Eventually the voltage is back to zero at the negative side of the battery. Then the battery energizes the electrons again.



Wires are called "equal potential surfaces" because **there is no voltage drop across a wire** (R = 0, so V = 0).

A circuit uses up all the voltage given by the batteries. Batteries give voltage: circuits use voltage. The voltage at the negative end of the batteries is always zero!

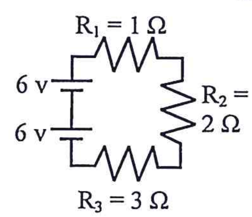
Voltage Across a Resistor

Calculating Voltage over a particular resistor:
1) find the total current;
2) use Ohm's Law for that resistor.

$V_{RX} = I_T R_X$, where R_X is a particular resistor.

$V_T = 12\ v$
$R_T = 6\ \Omega$
$I_T = 2\ A$

$V_1 = I_T R_1 = (2A)(1\Omega) = 2\ v$



$V_3 = I_T R_3 = (2A)(2\Omega) = 4\ v$

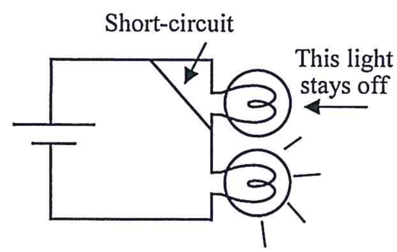
$V_3 = I_T R_3 = (2A)(3\Omega) = 6\ v$

Notice that each resistor uses up part of the voltage and that all of the individual voltage drops equal V_T.

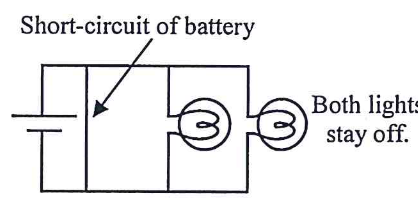
Short Circuits

A short-circuit is when a wire by-passes a device in a circuit.

Electricity always chooses the path of least resistance. Since wires have virtually no resistance, electricity will go thru a wire instead of a device or circuit. This causes a short-circuit.



Short-circuiting a device just by-passes it: it stays off. It is easier for the current to go thru the wire than the light bulb.



Short-circuiting a battery can be dangerous: it will drain the battery quickly and can lead to a melted wire or even a fire!

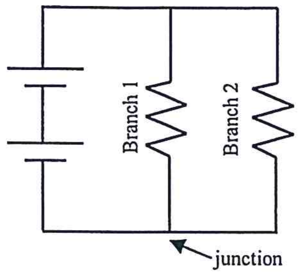
Name: ____________________

Period: ____________________

V, R, and I in Parallel Circuits

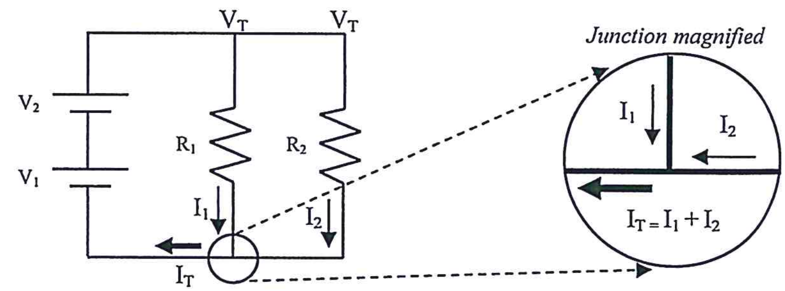
Parallel Circuits Basics

Parallel circuits have independent paths. We call these independent paths "branches".



Since wires use no voltage, we know that both branches have the same voltage.

Also, we know that all the current coming into a junction must go out.



I_T in a Parallel Circuit

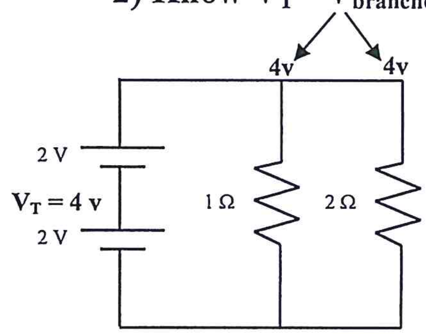
Follow these steps to find Total Current (I_T)

1) Find V_T

These batteries are in series, so you add them together. →

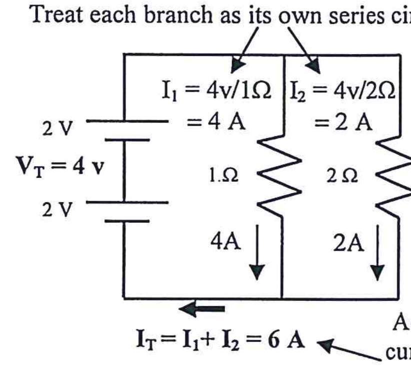
$V_T = V_1 + V_2 = 4V$

2) Know $V_T = V_{branches}$



3) Find I in each branch:

Treat each branch as its own series circuit.



Use Ohm's Law: $I = V/R$

$I_T = I_1 + I_2 = 6$ A ← Add the branch currents together to get the total current.

4) Find Total Current (I_T)

> *Going farther* **5) Finding Total Resistance (R_T)**
>
> Once you know V_T and I_T, you can find R_T by Ohm's Law:
> If $V = IR$, then $R = V/I$. $R = 4v/6A = 2/3\ \Omega = 0.67\ \Omega$.

Electrical Power

Electrical Power:

Power (in *watts*) → $P = VI$ ← Voltage (in *volts*), Current (in *amps*)

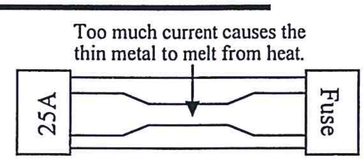
Power equals the voltage times the current.

This equation gives us the same *watts* as P = W/t. How? First you have to know that V = Joules/Coulomb and I = Coulombs/Second. Canceling out units gives us:

$$P = VI = \frac{\text{Joules}}{\text{Coulombs}} \times \frac{\text{Coulombs}}{\text{Second}}$$

$$= \frac{\text{Joules}}{\text{Second}} = \frac{W}{T} = \textit{Power}$$

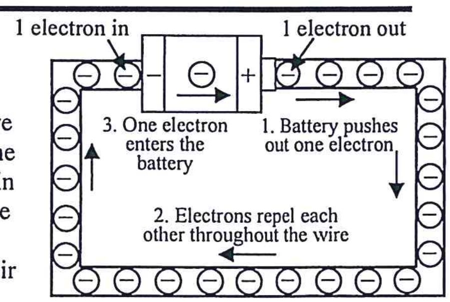
Fuses



Electricity cause heat. *Fuses melt* (or break) when too much current passes through it, protecting expensive electronic equipment. Circuit breakers protect against too much current like fuses, but can be reset.

Electrons

The electrons that move to make electricity come mostly from the wires in the circuit, not from the battery. Metals are conductors because their electrons can move.



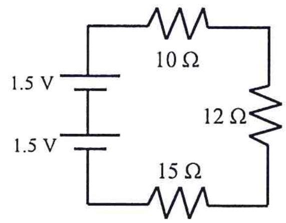
Extra Practice

Equivalent Resistance

Resistors in Series

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

As you add resistors in series, you increase resistance. Simply add the amounts together.

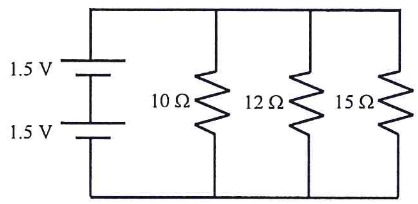


Example: *Calculate the total resistance of this circuit.*

$R_T = R_1 + R_2 + R_3 \ldots$
$R_T = 10 + 12 + 15$
$R_T = 37\Omega$

Resistors in Parallel

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



Example: *Calculate the total resistance of this circuit.*

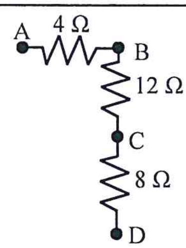
$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$$

$$\frac{1}{R_T} = \frac{1}{10} + \frac{1}{12} + \frac{1}{15} = .1 + .083 + .067$$

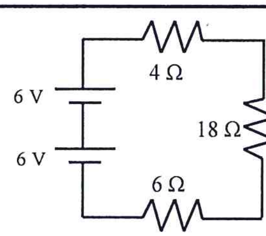
$$\frac{1}{R_T} = .25 \qquad R_T = \frac{1}{.25} = 4\Omega$$

As you add resistors in parallel, you open more paths for the electricity to flow, increasing total current, and decreasing total resistance. For resistors in parallel, the total resistance is always less than the smallest resistor.

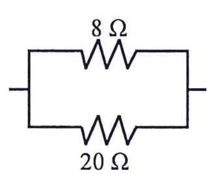
1. These resistors are in:
2. What is R_{total} from A to C?
3. What is R_{total} from B to D?
4. What is R_{total} from A to D?



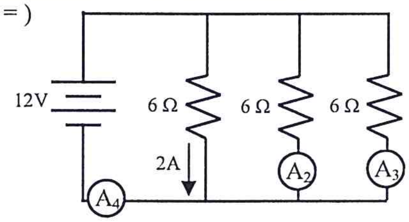
5. Calculate the total resistance.
6. Calculate total voltage.
7. Calculate total current.



8. Calculate the total resistance.
9. How does R_{total} compare with the individual resistors?
10. Why?



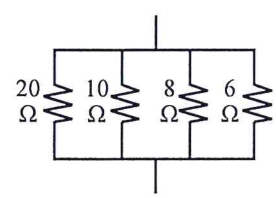
11. A_2 reads (current 2 =)
12. A_3 =
13. A_4 =
14. Since V = IR and R = V/I, R_{total} =



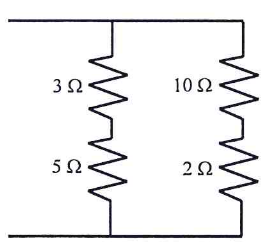
15. If one of the resistors is removed, R_{total} =

16. You are given four 100 Ω resistors.
    A. If in series R_{total} =
    B. If in parallel R_{total} =

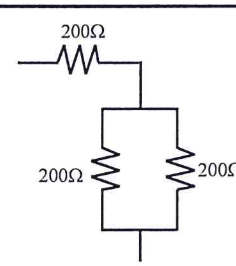
17. Without calculating, you know that R_{total} must be less than:
18. Calculate R_{total}.



19. Calculate and label the total resistance for each pair of resistors in series.
20. Calculate the total resistance for the two parallel branches.



21. What is the equivalent resistance of the parallel resistors?
22. Calculate R_{total} for all three resistors.



Name: ____________________

Period: ____________________

Extra Practice

Electrical Power

1. A 400Ω resistor has 0.5A flowing thru it. If P = VI, how much power does it dissipate (release into its surroundings)?

2. A 12V battery has 3 amperes flowing thru it. If P = W/t, how much time is necessary for it to produce 60J of energy?

3. Substitute V = IR into P = VI and create a new equation for power that does not have voltage in it.

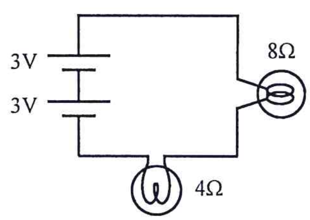
4. In V = IR, solve for I and substitute that into P = VI to create an equation for power that does not have current in it.

5. Given $P = VI = I^2R = V^2/R$, how does the power change if:
   A. The voltage is doubled. (*Something else will change, too, so use the equation where only V changes*).
   B. The current is doubled and the resistance is doubled.
   C. The voltage is doubled and the resistance is halved.

6. A 4Ω resistor has 300mA flowing thru it. How much power does it use?

7. A 12kΩ (12,000Ω) resistor uses 1.5V. How much power does it dissipate?

Let's discover how power works in circuits.



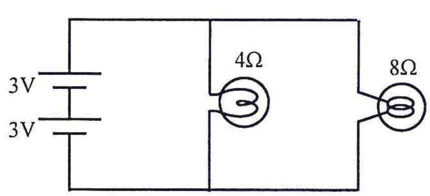
8. Two light bulbs are in the circuit shown.
   A. Are the bulbs in parallel or series?
   B. Calculate the current flowing thru each bulb.
   C. Calculate the voltage used by each bulb.
   D. Which light bulb has the most current?
   E. Calculate the power used by each.

F. Brightness is about power. So which bulb is brighter?

In series, the resistors have the same current, but the bigger resistor uses more voltage and more power.

G. Calculate the power generated (created) by the batteries.

Notice that the power generated by the battery equals the power used by the resistors.



9. The circuit is then reconfigured as shown.
   A. Are the bulbs in parallel or series?
   B. What is the voltage across each bulb?
   C. Which light bulb has the most current?
   D. Calculate the power used by each bulb.

E. Brightness is about power. So which bulb is brighter?

In parallel, the resistors have the same voltage, but the smaller resistor has more current and more power.

F. Calculate the power generated by the batteries.

So, the power generated by the battery equals the power used by the resistors in both parallel and series.

10. Three light bulbs of equal resistance are configured as shown. Which one is brightest and why? (*Think voltages and currents.*)