Prerequisite Assumptions
Before beginning the lesson students should understand;

- how to operate their calculator, (Verify all students have a calculator. There is a tub of extra calculators)
- dimensional analysis,
- percentages,
- ratios and fractions and
- engineering notation.

COURSE COMPETENCIES

- Apply correct terminology and symbols for electrical schematics
    - You correctly sketch a model of a resistive DC circuit.
    - You describe a resistive DC circuit model, given in a schematic, using descriptive English words.
    - You solve linear equations with one unknown
    - You solve linear equations for one dependent variable
    - You manipulate linear equations to isolate selected variables.
    - You translate real problems into mathematical equations.
    - You apply the mathematics to determine the components, quantities, and properties of DC resistive electrical circuits.
    - Calculate power in DC resistive circuits

BACKGROUND
This lesson applies simple mathematics for complicated situations. Simple circuit terminology is introduced. It is important for each student to be able to clearly sketch, label and explain simple DC resistive circuits. Sketching a circuit is a good engineering practice and if done well, communicates concepts and ideas effectively.

Based on each group's performance adjust groups.

EXPLICIT CONNECTIONS
It is important that each person understands the data that is communicated in an accurate sketch of a circuit.

The vocabulary is new to most of the students – write the words frequently, quantity, symbol, unit, and unit symbol and have the students do the same. The students need to understand that while these problems are complex, simple mathematics is used to solve them.

NOTES TO SELF

- Assess the group dynamics and adjust groups if needed.
- Encourage each individual to sketch accurately the circuits (practice makes perfect).
- Have groups sketch and defend their circuit diagrams on the white board, encouraging good labeling.
- Strongly encourage students to make predictions and then back them up with calculations so they continue to build their confidence.

Duration Minutes	Lesson	Suggested Structure
20	Review linear equations & solve equations	Cohort
15	Lecture: Introduction to circuit modeling	Cohort
10	Lecture: Series / Parallel voltage sources	Group
10	Problem Set 2.1: Introduction to circuits	Group
10	Problem Set 2.2: Series voltage sources	Group
10	Problem Set 2.3: Parallel voltage sources	Group
15	Lecture: Introduction of Ohm's Law	Cohort
20	Problem Set 2.4: Ohm's Law	Group
20	Blackboard: Practice Set 1 - Ohm's Law	Individual
20	Problem Set 2.5: Linear Equations	Group
20	Blackboard: Practice Set 2 - Linear Equations	Individual
20	Blackboard: Practice Set 3 - Fractions and Ratios	Individual
20	Lecture: Power Rule and Manipulating Linear Equations	Cohort
20	Problem Set 2.6: Manipulating Linear Equations	Group
20	Blackboard: Practice Set 4 - Power Rule	Individual
20	Blackboard: Practice Set 5 - Ohm's Wheel	Individual
30	Quiz	Cohort

Lesson	*Objectives*	*Material*
2.1	Introduction to circuits	Modeling Circuits
2.2	Series voltage sources	Flashlight batteries
2.3	Parallel voltage sources	Door Lock batteries
2.4	Ohm's Law	Ohm's Law
2.5	Linear Equations	Popcorn
2.6	Power Rule and Ohm's Wheel	Power Rule

Prerequisite Assumptions
Before beginning the lesson, students should understand

- how to operate their calculator,
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- percentages,
- ratios and fractions and
- engineering notation.

Specific Objectives
<u>*By the end of this lesson, you should understand;*</u>

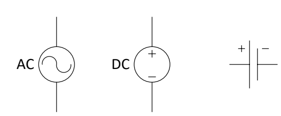
- ✓ Simple electrical circuits using a source, resistance (load) and circuit path
- ✓ Voltage sources in series and in parallel
- ✓ Circuit analysis using Ohm's Law
- ✓ Circuit analysis using the Power Rule

<u>*By the end of this lesson, you should be able to;*</u>

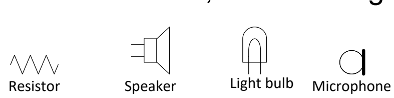
- ✓ Apply Ohm's Law to analyze simple circuits
- ✓ Manipulate linear equations that represent circuits
- ✓ Solve linear equations to understand circuit behavior
- ✓ Calculate series and parallel voltages across components in circuits

Modeling notes:
We model circuits in a schematic, which is simply a sketch of the circuit. Think of a schematic as a "recipe" for building the circuit.
A circuit must have;

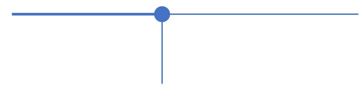
- A **source**, most often a **voltage source** that pushes the electrons along. Think of the voltage source as the pump that forces water (current) through a pipe. The unit for Voltage is *volts (V)* and the unit for current is *amperes* or *amps (A)*. Throughout this program, you will use <u>conventional</u> flow of current, which means that the current is always pushed out the positive terminal of the voltage source and into the positive terminal of devices. It is important that the direction of the current flow be indicated on your schematic.
    - ⇒ On a schematic, voltage is represented with these symbols



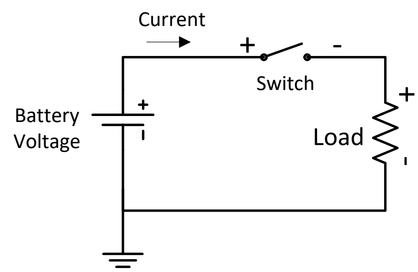
- The **load** consumes power and impedes or resists the flow of electrons. To function, a load will need voltage and current. The unit for a resistance is *Ohms (Ω)*.
    - ⇒ On a schematic, the following symbols are frequently used.



- **Ground** is most often used as a reference voltage and is always at zero voltage (0 V) or zero potential. Ground (or some other reference) is required for a circuit to operate. When the ground symbol is not explicitly shown on a schematic, assume that it is on the negative side of the voltage source.
  - ⇒ On a schematic, the ground is represented with the following symbol 

- A **closed conductive path** connected from the voltage source through the load to ground. This path depicts the conductive wire that connects all the components within the circuit.
  - ⇒ Represented with a line (or lines) on a schematic 

The figure to the right is a schematic of a simple electronic circuit. This circuit consists of



- a battery voltage source which pushes the current along
- an arrow that indicates the direction of the current, note that conventional flow of current leaves the source from the positive terminal and enters components at the positive terminal.
- a switch to complete the electrical path
- a load, which provides resistance to the current, consumes energy, and produces work. So if the load is a light bulb, the light will illuminate when the flow of electrons starts.
- a ground, which is required for a circuit to operate.

The natural physical laws are responsible for the responses within the circuit and we use simple mathematics to predict how the circuit will behave.

Battery

Batteries are a common source of power. In a battery, a chemical reaction causes electrons to flow.

Battery ratings include the **capacity** in *amp-hours (amp-hour* or *A-hr)*. A battery rated at 1 amp-hour should be able to supply a current of 1 amp to a load for exactly 1 hour, or 2 amps for 1/2 hour, or 1/3 amp for 3 hours, etc., before becoming completely discharged. In an **ideal battery**, current and voltage are stable forever. Often engineers use ideal components like a battery to do analysis and simulation.

The following chart from Duracell shows some typical characteristics of their batteries.

Alkaline Manganese Dioxide Performance Characteristics (Source: Duracell)

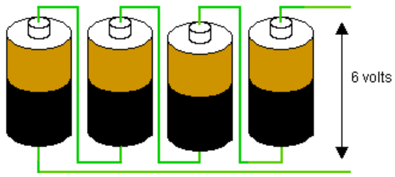
PRODUCT NUMBER	SIZE	NOMINAL VOLTAGE (volts)	RATED CAPACITY (ampere-hours)
MN1300	D	1.5	15.000
MN1400	C	1.5	7.800
MN1500	AA	1.5	2.850
MN2400	AAA	1.5	1.150

As shown above, AA, AAA, C, and D batteries, each produce1.5V but have different capacities.

Batteries strung together in **series** increases the *voltage*. Batteries strung together in **parallel** increases the *current*.

The *voltages* of batteries connected in series *increase*. Batteries in series have the positive terminal connected to the negative terminal of the next battery. This configuration is called **series aiding**.

Four 1.5V AA batteries placed in **series** give a total voltage of,
1.5V + 1.5V +1.5V +1.5V = 6 volts.

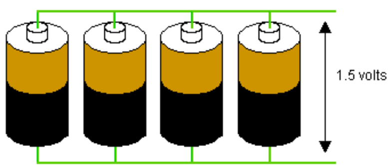


https://forum.sparkfun.com/viewtopic.php 1https://forum.sparkfun.com/viewtopic.php?f=14&t=35921

What would be the expected maximum current out of this circuit? 2.85A

The *current* of batteries in connected in parallel *increases*. Batteries in parallel have their negative terminals connected and their positive terminals connected. This configuration is called **parallel aiding**.

Four AA batteries placed in **parallel** give a total current of,
2.85A + 2.85A +2.85A +2.85A = 11.4 A.



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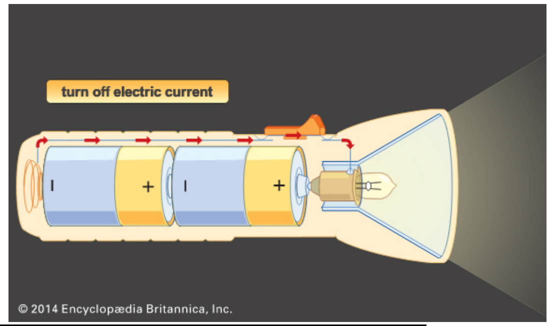
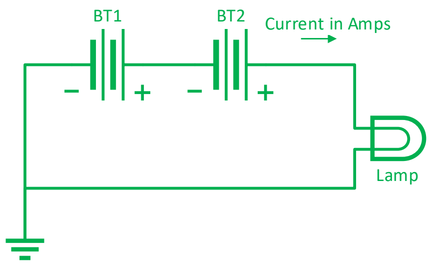
What would be the expected voltage at the two terminals? *1.5V*

Problem Situation 2.1 – Modeling Circuits

1) Sketch the schematic for the flashlight shown on the right.



Each group should be able to sketch their circuit on the white board. It is important to understand how the circuit is connected. The students need to understand that ground, indicated or not, is at zero potential, traces must connect all circuit components, conventional current direction and how to connect series and parallel components.



2) Are the batteries in series or parallel?

The batteries are connected in a daisy chain. This is a series configuration.

3) Are they aiding or opposing?

The batteries are connected in a series configuration and are placed with the same polarity, negative to positive. These are in series aiding.

4) If they are standard C batteries, how much voltage will be delivered to make this flashlight produce light?

Each of the batteries are 1.5 volts and they are in a series configuration. The voltages are added together so the total is 1.5 V + 1.5 V = 3 V.

5) On your sketch, indicate the direction of the current (conventional flow).

6) If one battery were reversed, would the flashlight operate? Explain.

Reversing one of the batteries, reverses the polarities. Series Voltage sources are added with respect to their polarity. 1.5 V – 1.5 V = 0 V

7) Identify on the flashlight where the voltage potential is at zero volts?

Problem Situation 2.2 – Designing a big flashlight

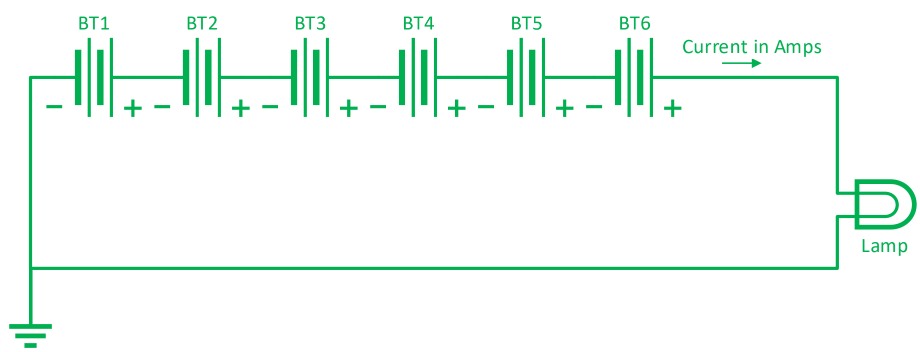
1) You want a flashlight that produces a lot of light. The largest practical bulb requires 9 volts (max). How many D batteries would be required to provide the 9 Volts?

The voltages of batteries in series with the polarity all being negative to positive are added together. Each battery is 1.5 V. $1.5V * number\ of\ batteries = 9V \rightarrow$ $number\ of\ batteries = \frac{9V}{1.5V} = 6\ batteries$

2) Should these batteries be in series or parallel? Would these batteries be aiding or opposing?

Voltage sources in parallel increase the current and voltage sources in series increase the voltage. Therefore, these batteries must be in series.

3) Sketch the schematic for this flashlight. On the schematic;
   a. label the positive and negative (+, -) terminals of the battery components
   b. indicate with an arrow the direction of the conventional current flow



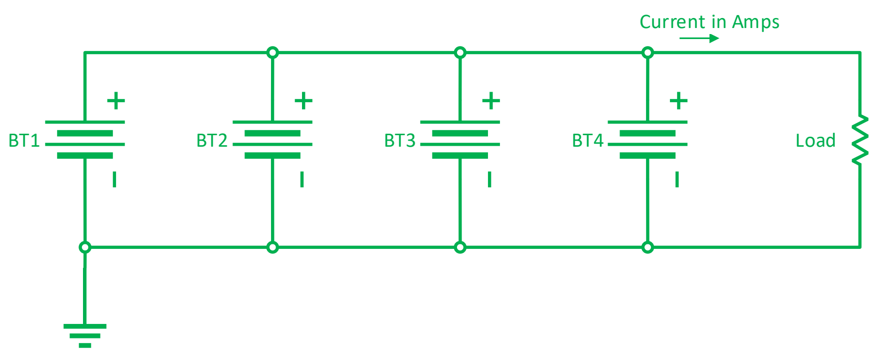
Problem Situation 2.3 – Door lock batteries

You acquired a battery-operated dead-bolt lock for your front door. It seems like a great solution for you. To move the deadbolt, it requires a significant amount of power. This lock requires 1.5 Volts at 2 Amps to move the deadbolt. A correct code opens a switch completing the circuit to withdraw the dead bolt.

1) How many AA batteries would be required to provide the 1.5 Volts at 2 Amps? AA batteries are rated at 2.85 amp hours and the maximum current each battery can produce is 0.600 A. Should these batteries be in series or parallel?

> Voltage sources in parallel increase the current and voltage sources in series increase the voltage. This lock needs more current at 1.5 V. Therefore, these batteries must be in parallel.
>
> Each battery provides 0.6 amps = 600 mA. This lock requires 2 amps $\frac{2\ amps}{lock} * \frac{1\ battery}{0.6\ amps} = 3.33\ batteries\ per\ lock$. Since we cannot use a partial battery, this lock needs 4 batteries.

2) Sketch the schematic for this door lock. On the schematic;
   a. label the positive and negative (+, -) terminals of the battery components
   b. indicate with an arrow the direction of the conventional current flow



Problem Situation 2.4 – Ohm's Law

> Spend time talking about the units and the linear relationship of the circuit behavior. This is where the students learn how powerful simple mathematics are used to predict and design electronic circuits. Encourage using the units correctly.

We know that in a circuit there is a minimum of voltage, current and resistance. The following table defines the units.

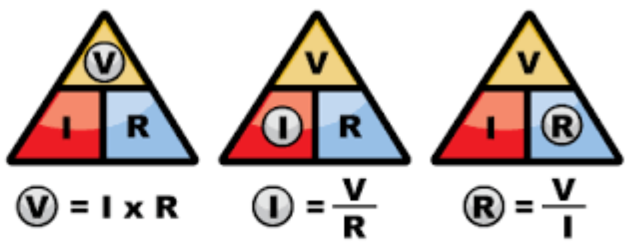
Quantity	Unit Name	Unit Symbol
Electric current (I)	Ampere (amp)	A
Voltage (V) or Electromotive force (E)	Volt	V, E
Resistance (R)	Ohm	Ω
Electric power (P)	Watt	W

The German physicist *Georg Ohm* discovered and quantified the relationship between voltage, current and resistance in an electrical circuit.

Ohm's law states that the current through a conductor between two points is directly proportional to the voltage across the two points.

$Voltage = Current * Resistance$	(Quantities)
$Volts = Amperes * Ohms$	(Unit Names)
$V = IR$	(Unit Symbols)

By knowing any two values of the Voltage, Current or Resistance quantities we can use Ohms Law to find the third missing value. Ohms Law is foundational to most circuit analysis. Ohm's triangle, shown below is a good memory tool.



Ohm's Law is a **linear** equation. A linear equation is an equation for a straight line when plotted on a graph. Each term is a first degree constant or variable.

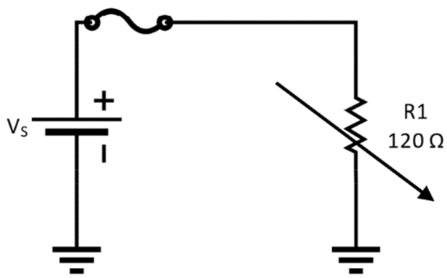
1) Suppose you have a speaker that you want to install in your car. This 3Ω speaker draws power from the 12 V car battery. How much current will this speaker draw? Sketch the circuit.

I need to determine the current this speaker will draw. Ohms Law states that V = IR. V = 12V and the load is the speaker so, R = 3Ω. $12V = I * 3\Omega \rightarrow I = \frac{12V}{3\Omega} = 4A$

2) Based on Ohm's Law if you were to use a 5 V source with the same speaker, what would change and how much would it change?

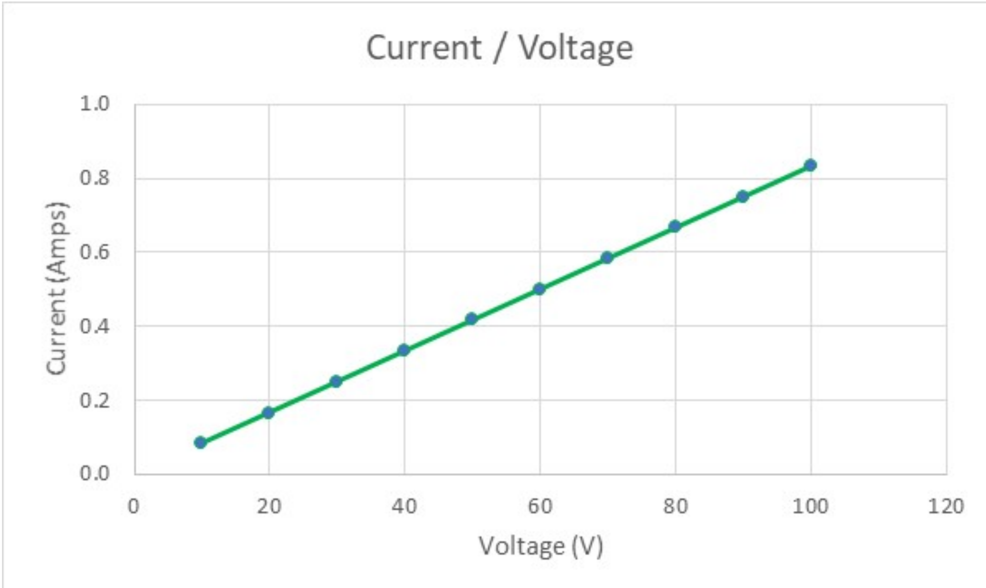
I need to determine the current this speaker will draw. Ohms Law states that V = IR. V = 5V and the load is the speaker, R = 3Ω. $5V = I * 3\Omega \rightarrow I = \frac{5V}{3\Omega} = 1.67A$

3) For the following circuit; hold the resistance constant at 120 Ω; calculate the current as the voltage changes as indicated in the chart. Use no more than three significant digits.



Voltage (V)	Current (mA)	Resistance (Ω)
10	0.0833	120
20	0.167	120
30	0.250	120
40	0.333	120
50	0.417	120
60	0.500	120
70	0.583	120
80	0.667	120
90	0.750	120
100	0.833	120

4) Graph the current and resistance on the following chart. Notice the axis units.



5) What is the shape of the graph? Can you recognize a relationship between voltage and current?

It is a straight line. As voltage goes up, current goes up (Ohm's law);
Current / Voltage = 1 / Resistance

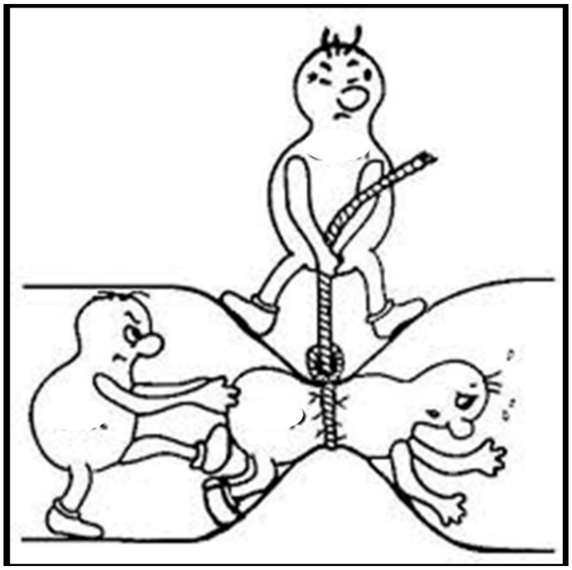
6) Looking at the graph, predict what the current would be if the voltage is 25 V and the resistance was the same at 120Ω. Then calculate the current, see how close your prediction was to the calculation, and verify that the graph is helpful.

I need to predict the voltage at 25 V from the graph. Graphically it looks like about 0.2V. To calculate I will use Ohm's Law; $I = \frac{V}{R} = \frac{25V}{120\Omega} = 0.208\ A = 208\ mA$

7) Can you predict the voltage required if you changed the load to 80 Ω that required 1.2 Amps? What equation would you use? Can you calculate the voltage?

I need to determine the voltage required to operate a load of 80 Ω at 1.2 Amps. I would guess that I would need xxx volts. I will use Ohm's Law; V = IR = 80Ω * 1.2 A = 96V.

8) Can you label which each character depicts; Voltage in volts, Current in Amps and Resistance in Ohms.



Problem Situation 2.5 – Popcorn

This is just practice for linear equations and to build confidence and have fun.

1) Watch the following short clip. [Act 1 (https://youtu.be/BVh9Dt33bLQ).](https://youtu.be/BVh9Dt33bLQ)

2) What do you observe about this video?

Make sure everyone makes a prediction. For a successful electronics career these students need to build confidence in their knowledge from the beginning.

3) Which configuration holds more popcorn?

4) [Act 3 (https://youtu.be/BVh9Dt33bLQ).](https://youtu.be/BVh9Dt33bLQ)

Problem Situation 2.6 – Power Rule

Every electrical component consumes **power**. The letter P represents power in *Watts (W)*. Components such as a resistor convert electrical energy into heat. Electrical components are physically limited to the amount of power they can consume without burning up. Overloading electrical components destroys the components and can cause fires.

Power Rule

$Power = Current * Voltage$ (Quantities)

$Watts = Amperes * Volts$ (Unit Names)

$P = IV$ (Unit Symbols)

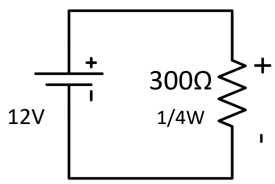
1) What equation would you use if you wanted to calculate the current and knew the power and the voltage?

I am being asked to determine the equation to calculate the current if I know the power and the voltage. I will use the power rule; $P = IV \rightarrow I = \frac{P}{V}$

2) What equation would you use if you wanted to calculate the voltage and had the power and the current?

I am being asked to determine the equation to calculate the voltage if I know the power and the current. I will use the power rule; $P = IV \rightarrow V = \frac{P}{I}$

3) In the following circuit, the load has a resistance of 300Ω and can handle ¼ Watt of power without sustaining damage.
   a. What current does the load draw?



I am asked to determine the current. The data I have is R = 300Ω and V = 12V and the maximum power is P = 0.25W.
I use Ohm's to calculate the current. $I = \frac{V}{R} = \frac{12V}{300\Omega} = 0.04A = 40mA$

   b. Will this component fail? First, take a guess and then calculate.

I need to determine if the component consumes more than 250mW. I predict xx.
I will use the Power Rule. $P = 0.04A * 12V = 0.48W$.

   c. What would you recommend changing about this circuit or components?

Since this resistor will fail with this much power. I would recommend changing this circuit, maybe with a component that is rated for at least ½ Watt.

4) A ¼ Watt 220 Ω resistor has 7.35 V measured across it. Will this resistor burn up? First, take a guess and then calculate the answer.

I am being asked to determine if the power applied to this component will be above what it is rated 250mW. Prediction is xxxx. I know the voltage, V and the resistance, R. I will use Ohm's Wheel to calculate P in terms of V and R. $P = \frac{V^2}{R} = \frac{7.35V^2}{220\Omega} = 0.246W = 246mW$

5) This same resistor used in the previous question has 10.3 mA through it. Can you predict the voltage potential across the resistor and the power consumed? Take a guess and then calculate the answer.

I am being asked to determine if the power applied to this component will be above what it is rated. Prediction is xxxx. I know the current, I and the resistance, R. Voltage = 10.3 mA *220 Ω = 2.27V. I will use Ohm's Wheel to calculate P in terms of I and R. $P = I^2R = 0.0103A^2 * 220\Omega = 0.0233W = 23.3mW$

6) The following chart lists some common household appliances and devices. You need to determine the missing information.

Device	Voltage (V)	Resistance (Ω)	Current (A)	Power (W)
Refrigerator	120	12	10	1200
Heater	120	9.6	12.5	1500
TV	120	48	2.5	300
Hair Dryer	120	9	13.3	1600
Phone Charger	120	960	0.13	15
Light bulb	120	120	1	120