Question – How can breadboards and simple circuits be used in engineering and science?

Hypothesis – If the energy needed to power specific circuits can be measured, then these individual observations can be used to formulate an idea of the total energy needed to power a home or town.

Materials -

Voltmeter with testing leads	Breadboard
Light Diodes	AC/DC Inverter Set up with connector wires
Ruler	Jumper Wires
1 Capacitor	6 Resistors
Diodes	Oscilloscope

Procedure

Part 1- Set Up

1. The main portion of the module includes a plexiglass baseplate, a hand-operated wheel assembly, a 3D-printed magnet container, a magnet-bearing steel shaft, a voltmeter, an oscilloscope, and an electrical circuit board known as a “breadboard”. The system overview is demonstrated below in Figure 1.

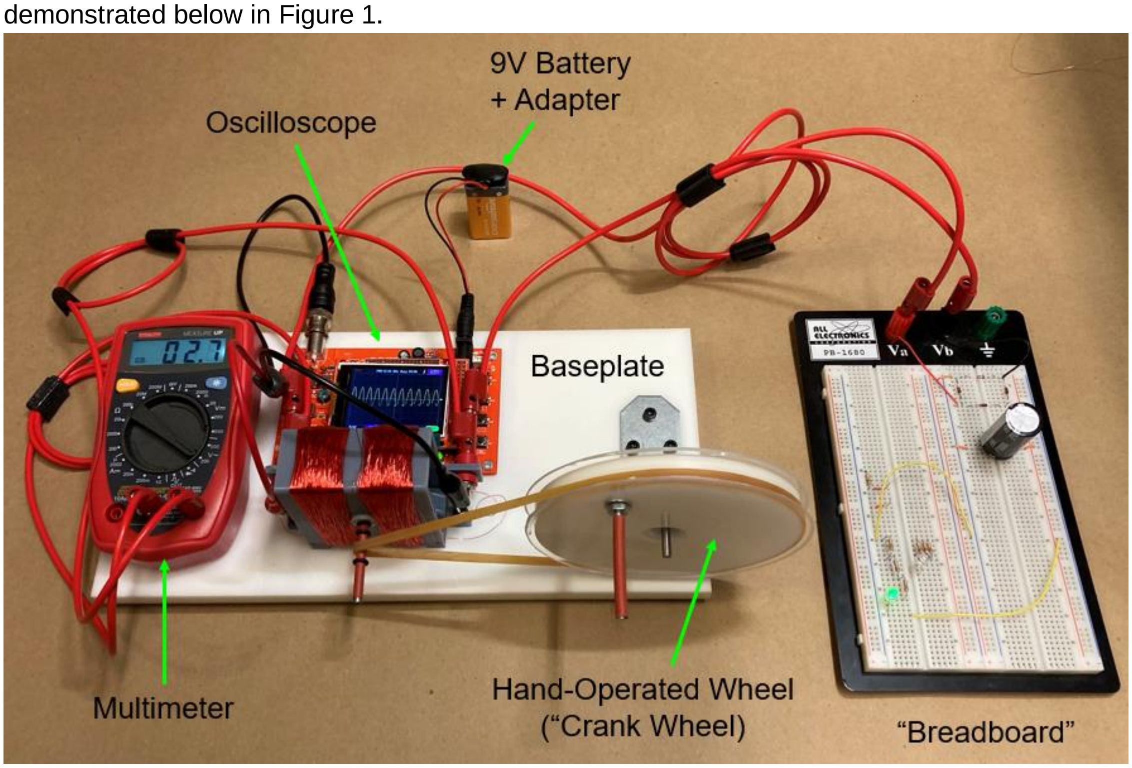

Figure 1. Full system assembly.

2. The oscilloscope should be first plugged into the 9 V battery with the included adapter. The oscilloscope has another plug with two wires. These two clips—the alligator clips—can be clipped onto metal portion of the banana jacks on the magnet container. The oscilloscope is shown below.

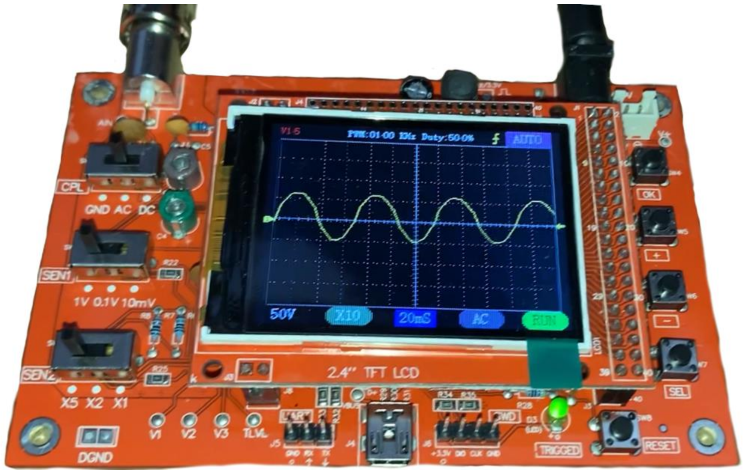

Figure 2. Oscilloscope measuring an alternating current signal.

3. Next the breadboard must be connected. For each of the two wires, plug one end into the port that is opposite of where you clipped to the oscilloscope on the inverter box. The free two ends of the wires can be plugged into the red and black ports of the breadboard. It does not matter which order you choose. The setup should look as shown below.

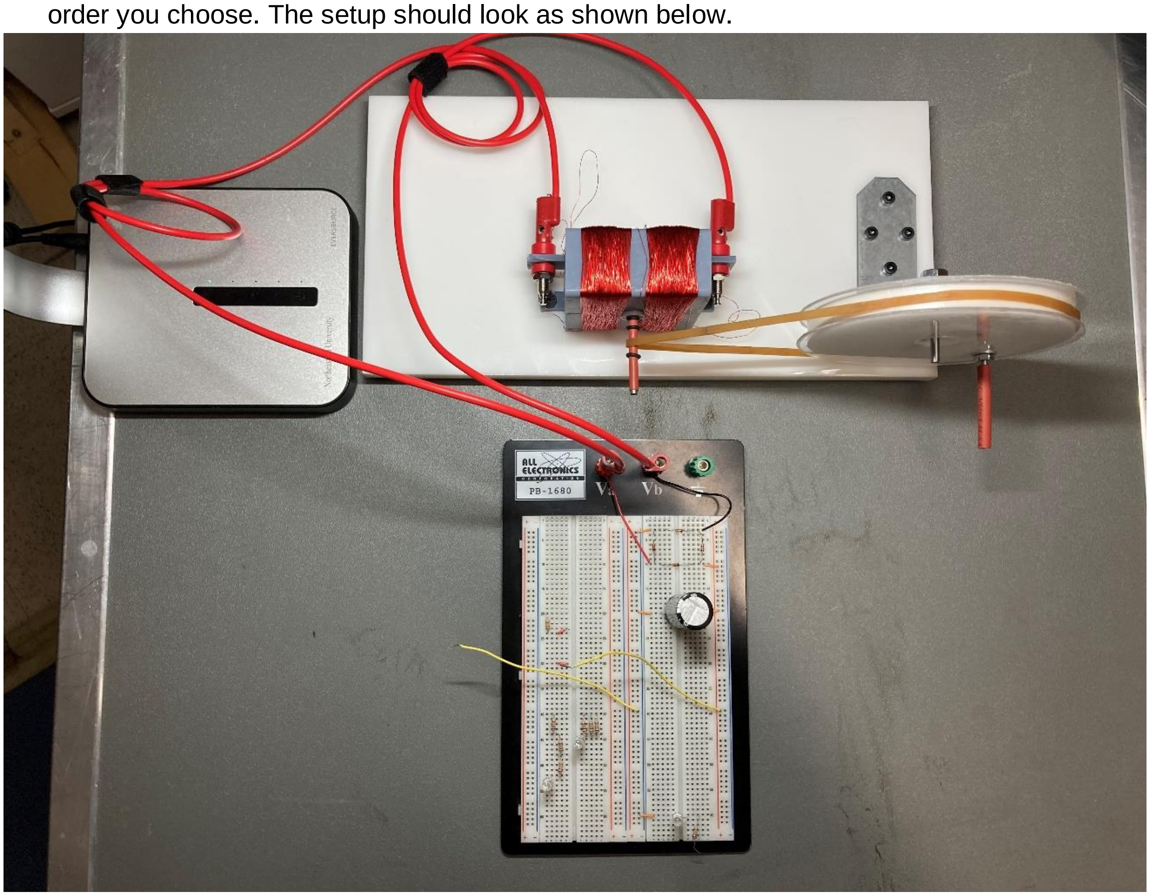

Figure 3. Connection of electrical generator to breadboard.

4. Measure the diameter of the crank wheel. Be sure to measure the diameter of the white inner portion of the wheel rather than the larger clear outer regions. This will act as the “large gear” in this system. Be sure to use consistent units! In other words, stick to using either inches, centimeters, or millimeters for both measurements.

Large gear diameter:____________________

Measure the diameter of the metal shaft protruding from the magnet container. This will serve as the “small gear” in this system.

Small gear diameter:____________________

5. Divide both of the values above by the small gear diameter. Use the resulting value to express the ratio of the large gear diameter to the small gear diameter

Gear ratio:____________________________

6. Wrap a rubber band around large gear and small gear. Spin the large gear to make sure that the small gear is able to rotate freely. Record observations about the relative rotational speeds of the gears. Try counting the number of times the magnets turn for every one turn of the large crank wheel. Similarly, make note of how fast the small gear moves relative to the large gear.

Note: The speed at which the smaller rotating mass—here, the shaft in the magnet container—spins is a direct consequence of the gear ratio. Gear ratio, in turn, results directly from the diameters of the two components that are attached by the driving mechanism, which in our case is the rubber band. Therefore, the larger the diameter of the large wheel (or the smaller the diameter of the small shaft), the greater the number of turns of the smaller rotating mass for every one turn of the larger rotating mass.

7. As you spin the gears, look at the oscilloscope. What shape does the line of the graph take?

Shape of oscilloscope: ________________________________

Note: On the oscilloscope the values at the bottom left and bottom middle. The bottom left shows the increment on the y-axis maximum (we use 5 V per dotted line). The bottom middle value shows you the x-axis total maximum (20 mS). This allows you to measure multiple facets of the system, including amplitude (distance of the line above the x-axis) and frequency.

8. At this time, measure the voltage. This can be done by setting the voltmeter at 200 past the ~V on the dial. This will read AC current. This can be done by plugging in the clips directly into ports the magnetic component.

9. Pick three speeds at which to spin the crank wheel. As a suggestion, aim for approximately ¼ turn per second, ½ turn per second, and 1 turn per second. For each speed, how many complete sine waves are shown on the oscilloscope? The frequency of the sine waves directly reflects the rotational speed of the magnets. Specifically, one sine wave is generated for every half rotation of the magnet system. Also, what do you notice about the amplitude as the frequency increases?

	Approximate rate of large wheel (turns / s)	Number of Sine Waves	Amplitude (V)
<u>Trial I – Slow Spin</u>			
<u>Part II – Medium Spin</u>			
<u>Part III – Fast Spin</u>			

10. You can convert the number of Sine Waves into the rotational speed (revolutions per second) of the magnet pair. The magnet pair will generate two sine waves for every one full revolution. Additionally, the number at the bottom middle of the oscilloscope should be 50 ms by default. This means you are seeing the number of sine waves generated in 0.050 seconds. In order to convert this value to seconds, you need to multiply by (1 second / 50 milliseconds) = 20. Since there are two sine waves for every one full rotation, you also need to divide the number of sine waves by 2. Therefore, the rotational speed (in revolutions per second) of your magnet pair can be calculated as follows:

$$Rotational\ speed\ \left(\frac{rev}{s}\right) = (\#\ of\ sine\ waves\ ) \times 10$$

11. You can use the information you just recorded above to verify how fast you were actually turning the large wheel. Since you know the gear ratio based on the measurements you took previously, you can multiply your rotational rate of the magnet pair by the inverse of the gear ratio to get the *actual* rotational speed of your large wheel:

$$Rotational\ speed\ of\ large\ wheel = (Measured\ rotational\ speed\ of\ magnets\ ) \times \left(\frac{1}{gear\ ratio}\right)$$

12. Now it is time to build a bridge rectifier. A bridge rectifier will convert the mechanical energy from the gear into usable electrical energy. The bridge rectifier consists of 4 diodes in a square shape. These diodes have black stripes on one end, where electricity cannot enter through the black-stripe end.
    Follow the diagram below to build the bridge rectifier exactly as shown. The schematic for a bridge rectifier is also below. Make sure that the opposite sides of the squares match what side the black line is on. (Bonus: map out the pathway of electricity in the schematic below. Use the color-coded arrows as a visual guide)

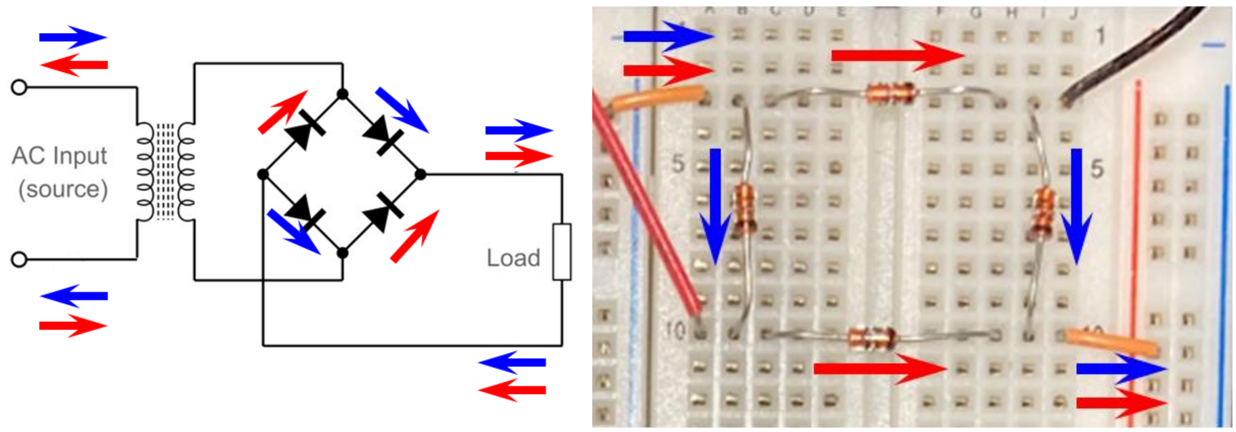

Figure 4: Bridge rectifier with schematic

13. As seen in the figure above, there are the two wires connected from the breadboard ports (red and black). There are also two jumpers. At the bottom of the square, one of the breadboard wires must be plugged in common to the corner of a bridge rectifier, diagonal to the other breadboard wire connected in common to the opposite corner.

14. Match the figure down below (Note: to set up the capacitor, one of the legs will be longer than the other. Bend the longer leg such that it has the same length as the shorter leg. The shorter leg is therefore “flat” while the longer side is bent. A common phrase with electronics is that “flat goes to ground,” so connect the capacitor such that the flat side goes to the ground/negative side of the breadboard terminals).

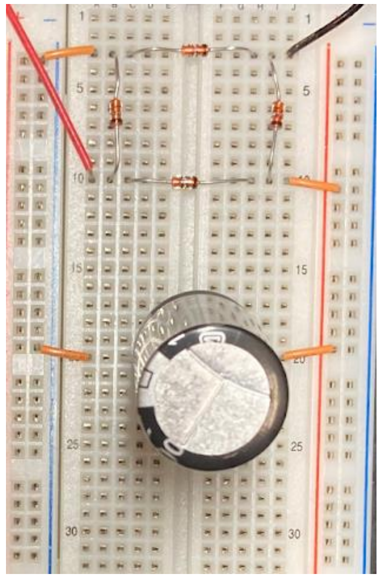

Figure 5: Power source plus bridge rectifier circuitry

15. This is the energy source for your circuits throughout the rest of the lab. Connect the oscilloscope to the capacitor. As you spin the gears, look at the oscilloscope. What shape does the line of the graph take now? Is the shape of the line different from when there was no bridge rectifier involved?

    Shape of oscilloscope: ________________________________

Circuit Analysis Part 1 - Building a series circuit

You will now build your first simple circuit.

1. The two long yellow jumper cables will be used to provide power to your series circuit. Three resistors will be needed for each circuit.
2. Construct the breadboard so that it looks like the image below. There are two circuits on this breadboard. Using the jumpers will allow you to connect to one circuit or another. There is also a zoomed in photo of the series circuit.

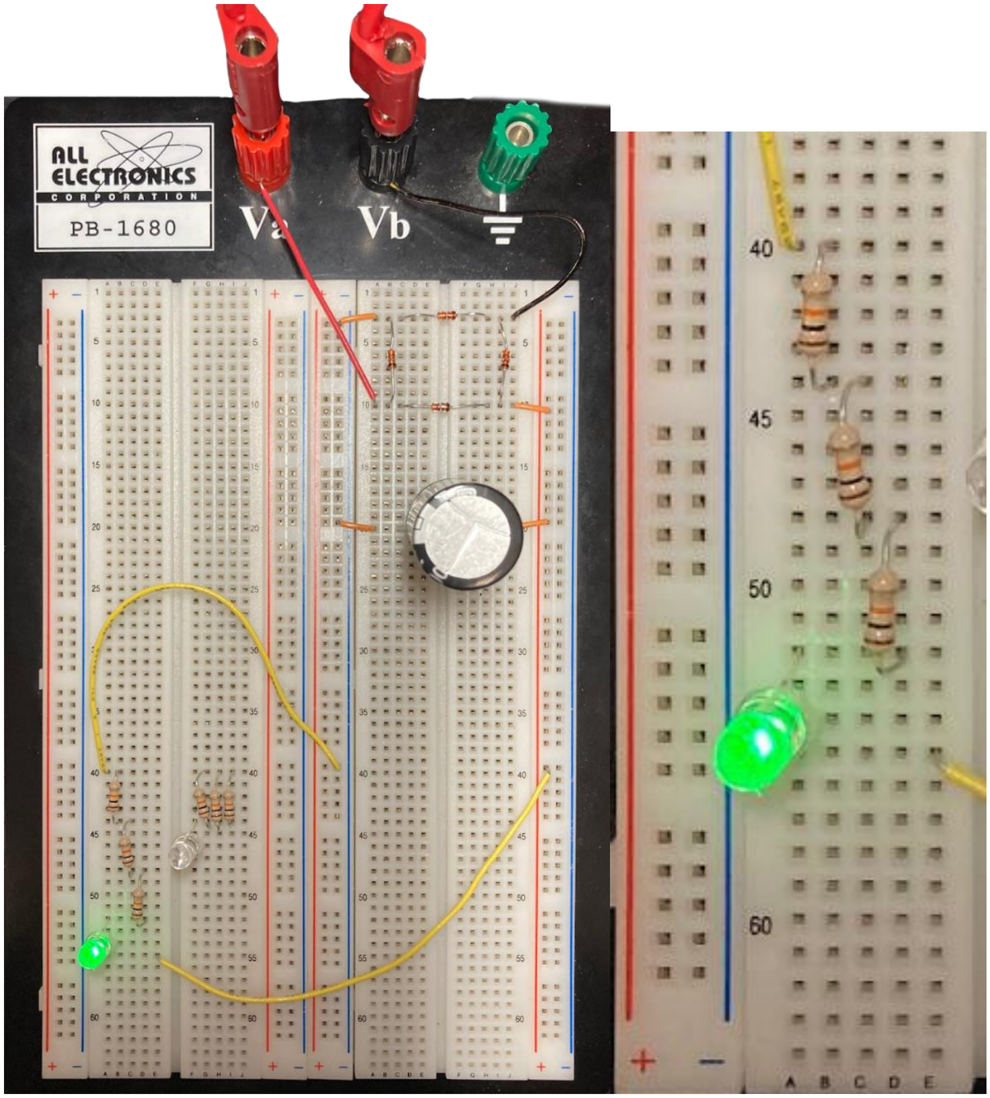

Figure 6: Full breadboard circuitry with zoomed in picture of a series circuit

3. Spin the gear and watch as the LED lights up. Take note as you increase speed of the gear and the brightness of the lights.
4. Use the voltmeter and the end clips, to clip to each of the push-in terminals. Set one push-in terminal at the top of the series circuit (common to the resistor), and the other push-in terminal common to the LED. Set the voltmeter to the 20 after ⎓V. This setting will be kept for the rest of the lab since this setting will measure direct current. Measure the voltage of when the LED lights up. Record values in the proper Results table.
5. Record the speed at which the magnets are spinning right before the diodes light up. You can take a photo of the oscilloscope with your cell phone for this step if you would like. Time how long it takes the LED to stop shining after you have stopped spinning the wheel.

Circuit Analysis Part 2 - Building a Parallel circuit

You will now build a parallel circuit

1. This parallel circuit will be created on the 2nd half of the breadboard nearby the series circuit.

2. Build the breadboard to look like the image below. A zoomed in photo of the parallel circuit is also provided.

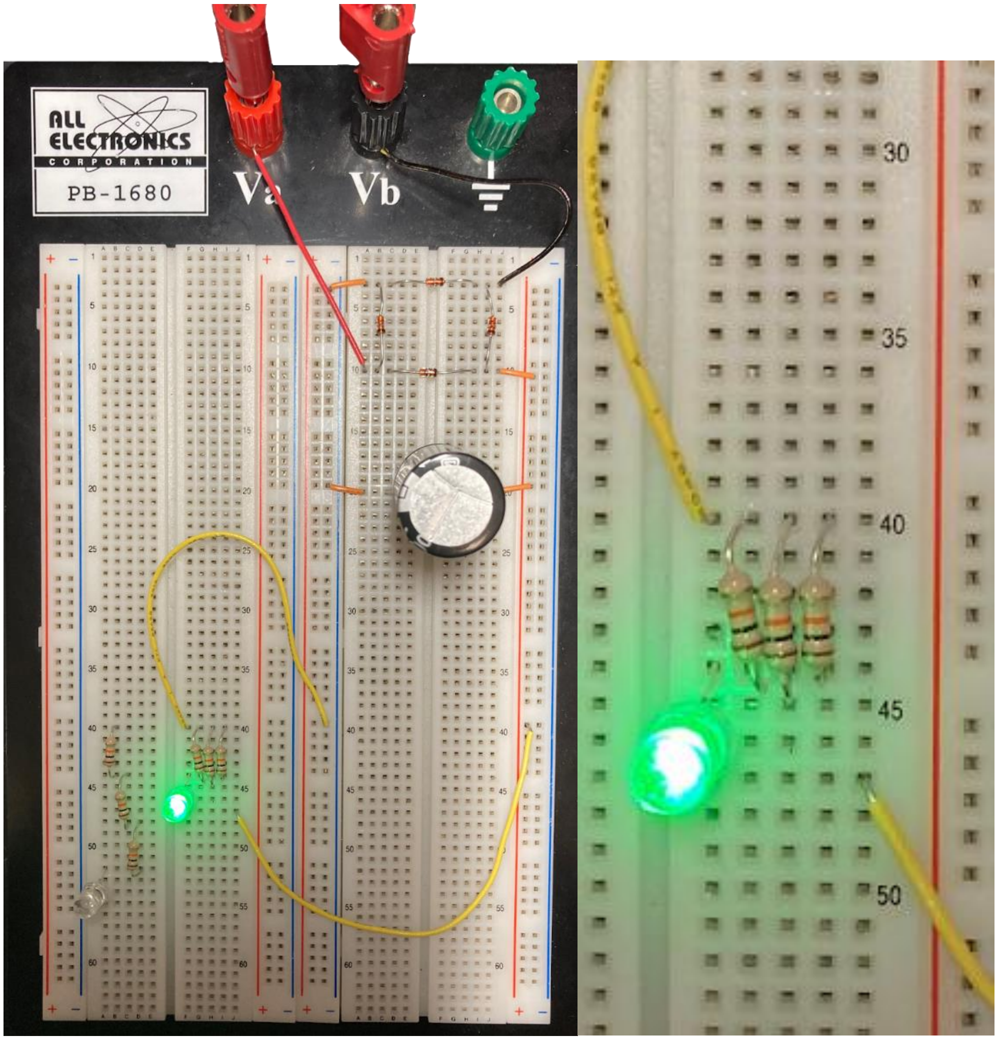

Figure 7: Full breadboard circuitry with zoomed in picture of a parallel circuit

3. Spin the gear and watch as the LED lights up. Take note as you increase speed of the gear and the frequency of the lights.
4. Use the voltmeter and the end clips, to clip to each of the push-in terminals. Set one push-in terminal at the top of the parallel circuit (common to the three resistors), and the other push-in terminal common to the LED. Measure the voltage of when the LED lights up. Record values in the proper Results table.
5. Record the speed at which the gear is spinning right before the diodes light up. Time how long it takes the LED to stop shining after you have stopped spinning the wheel.

Results –

Observational Table I

	Radius (cm)	Speed (revolutions / s)	Volts

Large			
Small			

Energy and Speed Table Analysis Part I – II (all resistors are 10k Ohms)

	Energy Recorded (V)	Speed Recorded (Hz)	Time to dim after spinning stopped (s)
Set-Up Part 1 – AC current			-----------------------
Analysis Part I – Series Resistors			
Analysis Part II – Parallel Resistors			

Conclusion

Throughout this experiment, several observations were made about gear ratios, conversion or energy and circuitry. This experiment was able to prove that smaller gears rotate faster than larger gears when spun at the same time. This experiment also showed the change from mechanical energy into electrical energy that was able to power circuits.

Discussion

How might scientists use these models to plan for real world applications, such as building cities or designing energy systems? How do you think these models could also be used in other energy experiments? What could the LED's represent in the real world?