1001 INSTRUCTOR GUIDE
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Lab 1
Velocity and Acceleration

Purpose:

- To identify motion with a constant velocity and with a constant acceleration.

Energy & Environment Context:

- A firm notion of acceleration is needed to understand force and thus, energy.

Teaching Tips:

1. This exercise does not introduce forces yet. ***Do not talk about forces,*** and discourage your students from using the word because they will not use it correctly yet. *This exercise, as far as the students are concerned, only involves velocity and acceleration, not force.*

2. *First students should obtain some value for the speed of the motorized toy car without using equipment. They could use an arm for distance measurement and " count" to obtain values for time. (See the student lab manual.)*

3. Before students try using the computer for making measurements they should follow the directions and obtain values for velocity by using a meter stick and stop watch. It can be useful to have the groups put results on the board at this point so they can compare results.

4. Using a meter stick and stop watch to find the distance traveled for various times when a cart is on an incline can be difficult. Students will have to start the car from the top part of the track several times. Don't let them spend too much time on this.

5. Encourage the students to work together to make the predictions: making rough plots of velocity-versus-time for constant velocity, increasing velocity, decreasing velocity, and so on. Do not let them sit quietly at the same table and work individually.

6. The accelerations should be determined by finding the slopes of the velocity vs. time graphs obtained with the computer

7. It is important for students to understand before lab is over that the slope is rise over run, and rise over run on a velocity vs. time graph is change in velocity divided by change in time, so the slope of a velocity vs. time graph is the acceleration.

8. When students start using the computer be certain they explore and experiment with the setup before taking data they will actually use. All the students in the group should have an opportunity to work with the computer, and associated software (refer them to the instructions in the appendix of their manual.) You might ask for three data sets, if you have time, so that all students will get a chance to operate the equipment.

For all the labs which involve the usage of LoggerPro it should be stated that students are responsible for properly setting the range on the graph axis. For example, if they want to prove that the cart is moving with constant velocity, they should use a range that includes the cart's full motion.

Indicate the time interval along the horizontal axis which describes the desired process. Choose such a range for the vertical axis, so that they can see the features they are interested in.

From the very beginning they can be taught how to copy data to excel file (it's extremely simple, literally copy & paste the column), to be able to make a good graph at home in case if they have wrong one in the pdf export.

PART 1: Level Track, Battery Car
(constant velocity motion)

Purpose:

- To introduce students briefly to the need for experimental technique, by analyzing motion in one dimension.
- To get familiar with the computer and LoggerPro software and to show its features and reliability.
- To solidify the relationship between position, velocity, and acceleration for constant velocity.
- To get the students thinking about experimental uncertainty.

***Expe*riment Setup:**

Teaching Tips:

Every group must do this problem. It will take longer than you think. Give them at least 40 minutes to work with the equipment.

Many students have difficulty connecting graphs with physical equations, or connecting graphs with genuine motion. Make sure that everyone knows how to graph the simplest possible motion before moving on to more difficult cases.

PART 2: Inclined Track, Cart
(constant acceleration)

Purpose:

- To reveal the constant, nonzero acceleration of a cart down an incline.
- To distinguish between the concepts of velocity and acceleration, and identify graphs of each.

Experimental Setup:

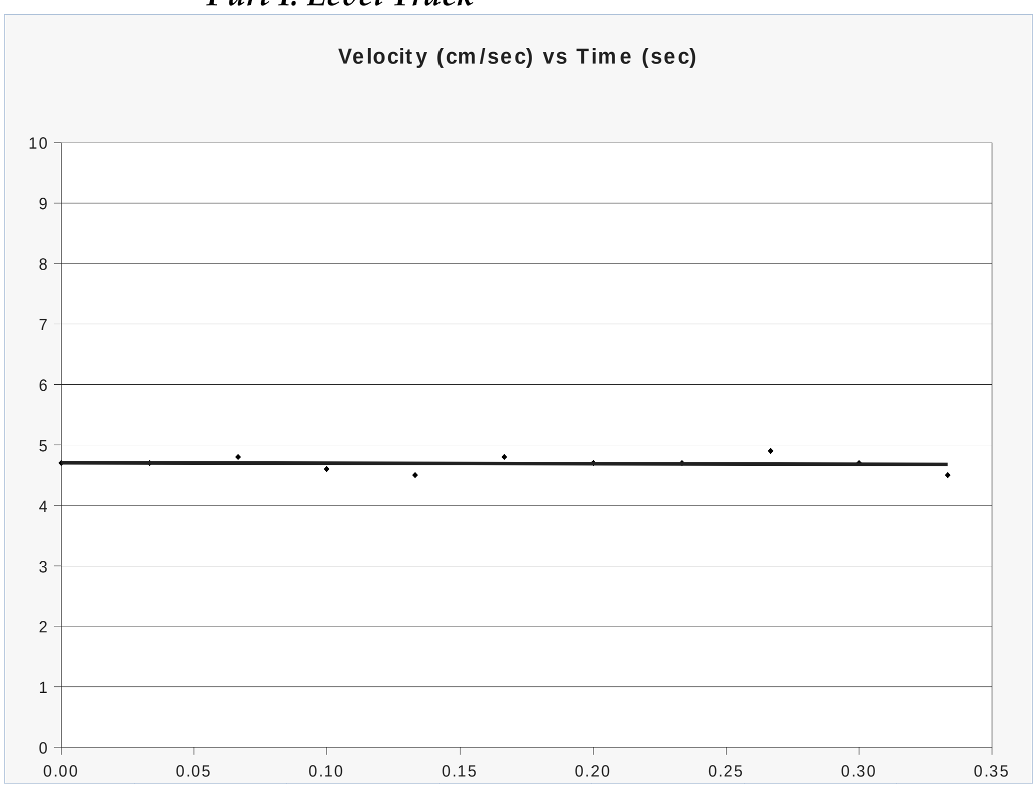
Teaching Tips:

The idea of constant acceleration is problematic. The students will be tempted to say "increasing acceleration" when they mean to say "increasing velocity," so it may take a short discussion (not a lecture) on acceleration to help clarify this.

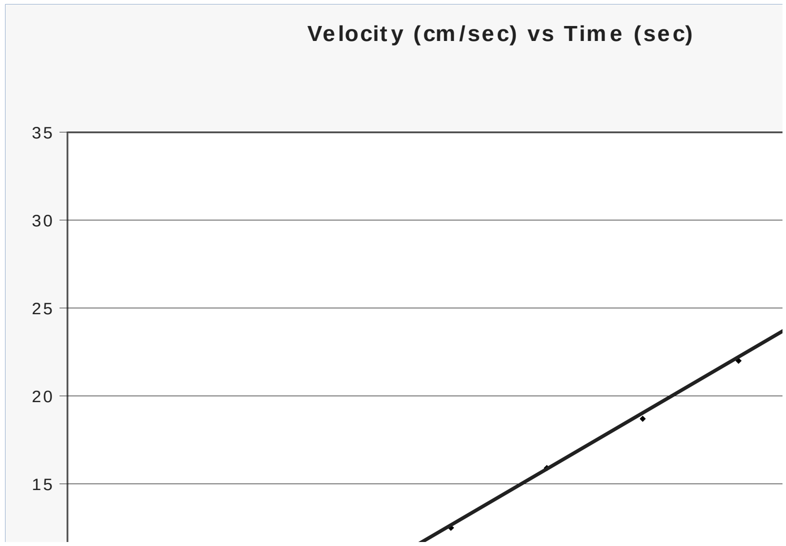
You can tell students that our bodies are acceleration detectors. We can feel acceleration, but cannot necessarily feel constant velocity motion. Get students to use the vernacular as much as possible. If they practice saying these terms they will understand test questions better.

Sample Results:

Part I: Level Track



Part II: Inclined Track



Acceleration: 0.95 m/s^2

Conclusions:

In the conclusions, the students are asked: *Did either the battery car or the cart have a constant velocity? If so, which one(s)? Did either object have a constant acceleration? If so, which one(s)?*

Hopefully they will determine that the battery car in part I moved with a constant velocity (same speed the entire time) whereas the cart on the incline in Part II had a steadily increasing velocity, meaning there was a constant acceleration. Be sure that you watch out for references to an "increasing acceleration" in Part II.

The conclusion also asks about the graphs of velocity and acceleration versus time for each motion, and emphasizes being able to identify the graphs for each. The students should be able to describe motion with constant velocity and with constant acceleration. They may describe this motion in terms of displacement, velocity, acceleration, or simply what they did and saw. Again, this exercise does not introduce forces, and the students should be discouraged from mentioning force in this answer as they will likely use them incorrectly.

Lab 2
Velocity, Acceleration, and Newton's Second Law

Part I: Inclined Track, Cart
Part II: Tension and Level Track

Purposes:

- To investigate Newton's second law and acceleration due to gravity.
- To consider the relationships between position, velocity, and acceleration. (qualitatively and graphically)
- To convince students that acceleration of a cart down an incline is independent of the mass of the cart.
- To see equations as mathematical relationships, not just "answer machines."

Energy & Environment Context:

- A firm conception of force is needed to understand work and, thus, energy.

Teaching Tips:

1. Students should get approximate values for average velocity using a meterstick and a stop watch. You can discuss with students how this compares with values they obtain using the video equipment.

2. Students should just obtain approximate masses of the cart and added weights. *This is a qualitative/semi-quantitative exercise, not a quantitative exercise! Be careful so students don't worry about measuring masses and forget to "think" about Newton's second law.*

   If there is too much mass placed on the carts, they do not work well because of the limitations of the bearings and friction. A careful exploration is required to determine what range of mass can be used.

3. Be certain each student has the opportunity to use all aspects of the equipment and computer data acquisition.

4. Accelerations should be determined by finding the slopes of the velocity vs. time graphs.

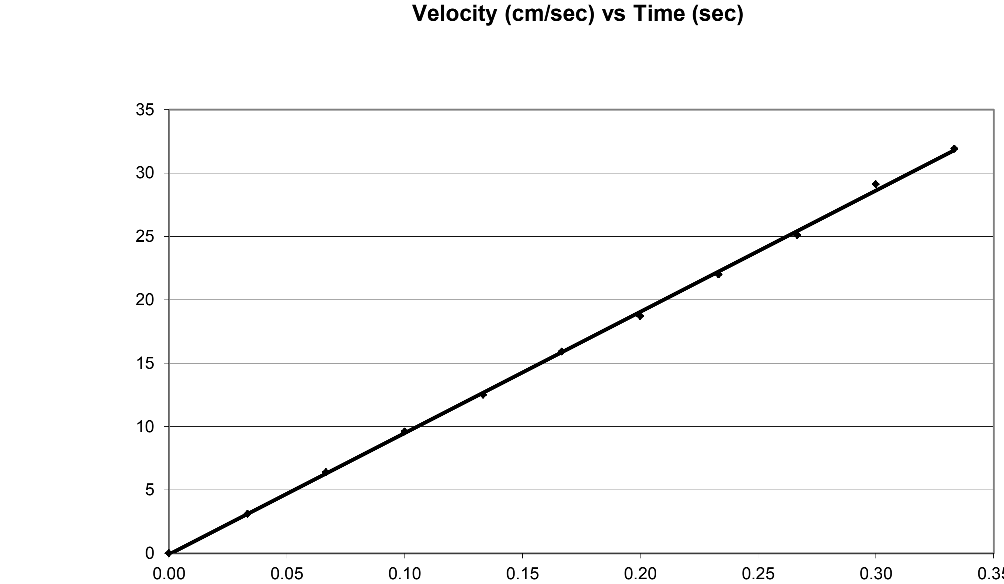
Difficulties and Alternative Conceptions:

Students have difficulty distinguishing between acceleration of the cart due to the gravitational force on it (down the incline) and acceleration of the cart due to tension of the string -- the difference between these is very subtle to the students.

There is also a very common alternative conception that heavier things accelerate faster than lighter things. Allow the students themselves to explore this idea with their own experiments (cart on the incline). You must review the results with them and remind them what it means.

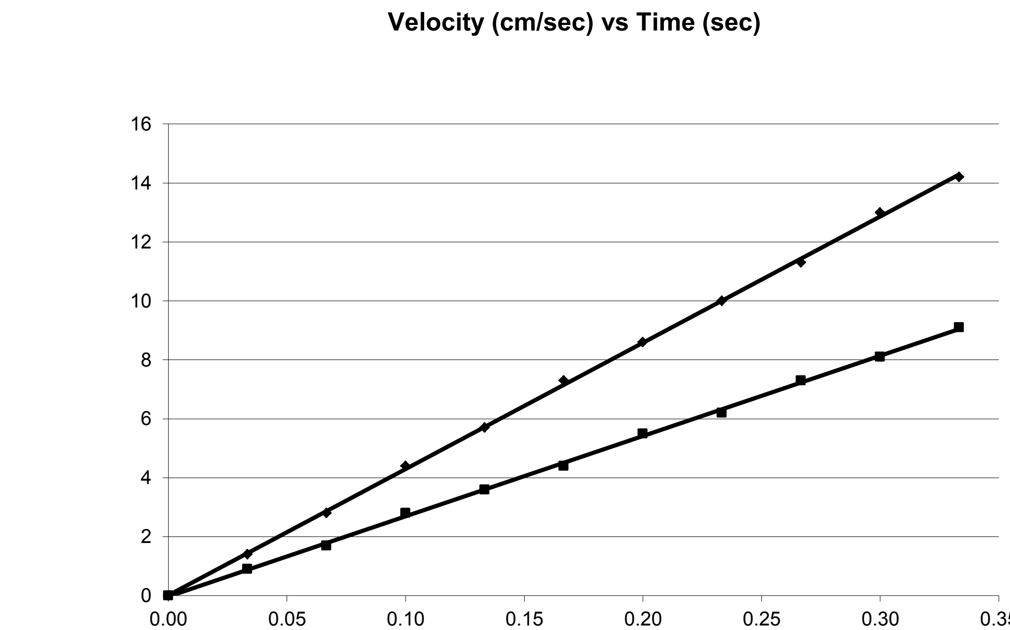
Sample Results:

Part I: Inclined Track



Acceleration (unweighted): 0.93 m/s^2 Acceleration (weighted): 0.96 m/s^2

Part II: Tension and Level Track



Acceleration (unweighted): 0.43 m/s^2 Acceleration (weighted): 0.27 m/s^2

Conclusions:

Your students should be able to distinguish between what happens when the aluminum track is inclined and when a hanging mass accelerates the cart. The best way to discuss this is to illustrate it using proportions with Newton's second law:

For the inclined track:

Unweighted:

$$\sum F = m\ a$$

Weighted:

$$\sum F = m\ a$$

For the cart accelerated by a hanging mass:

Unweighted:

$$\sum F = m\ a$$

Weighted:

$$\sum F = m\ a$$

Be careful with the notation for Newton's Second law when clarifying it with students – always refer to the "net force" or sum of the forces, not just an ambiguous "F".

Lab 3
Work and the Conservation of Energy

Purpose:

- To investigate the concept of work, KE, PE, and the conservation of energy.

Energy & Environment Context:

- This is the first of several exercises involving the conservation of energy. In this exercise, it is just kinetic and potential energy -- later it will be electrical, thermal, and light energy, which are important in energy usage issues.

Teaching Tips:

1. When the students want to find the velocity of the cart just before the hanging weight hits the floor, it should be easier to use the motion detector with the cart on the horizontal track instead of the falling weight.

2. Better results are obtained when the weight falls from the highest point possible.

Difficulties and Alternative Conceptions:

Some students will get these new concepts and their units confused: force and Newtons, energy and Joules, and work and Joules.

Students may have difficulty distinguishing between the concepts of "work" and "energy". They might determine that the initial gravitational potential energy of the hanging weight is converted to kinetic energy (motion) of the hanging object, but it is not clear how "work" is also equivalent to these values. One relationship stated in their manual is that when you do *work* on an object, you transfer *energy* to that object. Avoid references to the "work-energy theorem" which is really just a special case of energy conservation.

Sample Results:

$$KE_{exp} = \frac{1}{2}mv^2 = \frac{1}{2}(153\text{ gm} + 50\text{ gm})(13.7\,{}^{m}\!/\!_{s})^2 = 19.1\text{J}$$

$$PE = mgh = (153\text{ gm} + 50\text{ gm}) \bullet g \bullet 97.5\text{ cm} = 19.4\text{ J}$$

$$\text{work} = \text{force} \bullet \text{distance} = mgh = (153\text{ gm} + 50\text{ gm}) \bullet g \bullet 97.5\text{ cm} = 19.4\text{ J}$$

Conclusions:

In the conclusions, the students are asked:

Comment on your values for the total change in kinetic energy of the cart and the hanging mass, the change in potential energy of the hanging mass, and the work done on the hanging mass. Do your values support the conservation of energy? Explain. How can you account for any discrepancies between these values?

The largest source of discrepancies could well be due to the way the students locate the cursor when collecting data.. The pulley is, of course, not frictionless, and some tracks are 'more frictionless' than others. Most students will cite air resistance. Students should also recognize that, if the gravitational energy is converted to kinetic energy, there should be less kinetic energy if the discrepancies are due to friction and air resistance. If the kinetic energy is greater, there must be measurement error.

A physics instructor demonstrates the conservation of energy with a bowling ball attached to the ceiling with a string. . . will this instructor get smacked in the nose by the bowling ball? Will it touch his nose? What if he gave the bowling ball a slight push when he let go?

This is simply a question about conservation of energy with loss due to air resistance, and the students should have little problems with it. It also makes for a good demo in the lecture or the lab -- just be sure NOT to give it that little push!

Lab 4
Energy Transfer Through Work

Part 1: Transfer of Chemical Energy to Gravitational Potential Energy Through Work

Purpose:

- To find the work done and the power output of the students when climbing a flight and four flights of stairs

Energy & Environment Context:

- Students will gain a conception of how much power a watt is and how much energy a Joule is, two of the units that they will be using most in this course.

Teaching Tips:

1. Make sure that the students do not hurt themselves or others on the stairs. Each group should have a "lookout" on the stairs to avoid runing into anyone.
2. Remind students of the safety warning in their lab manual and tell them to notify you of health concerns before they begin: *This exercise requires physical activity. If you are unable to participate due to an injury or asthma, tell your instructor.*

Difficulties and Alternative Conceptions:

Some of the students will have difficulty distinguishing between energy, work, and power as well as the respective units. Some students will also have difficulties with their weight in pounds, their mass in kilograms, and their weight in Newtons.

Sample Results:

One flight: $PE = mgh = (65 \text{ kg}) \bullet g \bullet (12 \text{ steps} \bullet 15.3 \text{ cm}) = 1170 \text{ J}$

$$\text{power} = \frac{\text{work}}{\text{time}} = \frac{1170 \text{ J}}{1.66 \text{ sec}} = 705 \text{ Watts} = 0.95 \text{ hp}$$

Four flights: $PE = mgh = (65 \text{ kg}) \bullet g \bullet (48 \text{ steps} \bullet 15.3 \text{ cm}) = 4680 \text{ J}$

$$\text{power} = \frac{\text{work}}{\text{time}} = \frac{4680 \text{ J}}{7.11 \text{ sec}} = 658 \text{ Watts} = 0.88 \text{ hp}$$

Conclusions:

In the conclusions, the students are asked:

How does your power for a single flight compare to that for four flights of stairs?

Most students will have a power output between 500 and 800 watts.

Read the article about the Annual Empire State Building Run-Up. Consider the record-holders and the 88-year-old orchestra conductor… Calculate their work and power. Compare to your work and power, and explain the differences. Also consider long distance runners and sprinters.

Paul's work:: 240,000 Joules
Chico's work: 240,000 Joules
Belinda's work: 180,000 Joules

Paul's power: 390 watts
Chico's power: 116 watts
Belinda's power: 243 watts

Most students will have a power output of 5 to 10 watts/kilogram body weight.

As you climb the stairs, you convert food to kinetic energy… Based on your leg power and the efficiency of converting food energy into work, how long would it take you, climbing stairs, to burn off a Big Mac (570 kilocal) and a Double Whopper with cheese (1010 kilocal)?

For a Big Mac, it should take about 12.5 minutes at 800 watts and about 20 minutes at 500 watts. For a Double Whopper with cheese, it would take about 22 minutes at 800 watts, and it would take about 35 minutes at 500 watts..

PART 2. Transfer of Mechanical to Thermal Energy Through Work

Purpose:
- To investigate the conservation of energy with mechanical and heat energy.

E & E Context:

- Waste heat is a product of electricity production. In this exercise, students examine the equivalent of heat in terms of mechanical energy.

Teaching Tips:

1. In this lab one should hold one of end of the rope in their hand . Students should rotate the mechanism with the maximum possible speed (but keeping the mass at the same height - ideally, there should not be any pressure in the hand holding another end of the rope). The rope is typically wrapped around the cylinder 1-2 times.

2. Thermal energy should be referred to as "heat energy" as the book does so.

3. Have the students do their theoretical calculations before allowing them to actually conduct their experimental trial -- it is tempting to start before the math is done.

4. The measured resistance is not actually the resistance of the aluminum drum itself; it is actually the resistance of the thermistor within the apparatus.

5. Remind students of the safety warning – the weight on the nylon rope is heavy enough to injure (and possibly break) unprotected toes!

Difficulties and Alternative Conceptions:

The distinction between "heat" and "temperature" is often a difficult one for students, and the students often use the term "heat" in the vernacular sense, when they actually mean what you and I would call thermal or internal energy.

Sample Results:

temperature change = 12º C
mass of weight = 8.4 kg
mass of drum = 0.2022 kg
work put in = 2493 Joules
predicted number of turns = 200
actual number of turns = 209

Conclusions:

In the conclusions, they are also asked:

What was the amount of heat transferred to the aluminum drum?
This depends on the temperature change on which the students decide.

Compare the number of actual drum turns needed to add this amount of heat to the drum to the number predicted by your calculations. Did you have to turn the crank more times or less?
They should, of course, find it took more.

Explain any difference between your numbers. Are there assumptions in your prediction that account for any difference? What could you and your lab partners change to increase the accuracy of the theoretical number of turns?
Heat transfer to the air in the room would be one factor. Additionally, the students should point out that the squeakiness of the apparatus indicates energy is lost as sound too. Keeping the temperature of the drum need room temperature is one way to improve accuracy of this exercise -- less energy will be lost as heat to the room air.

What would you expect if you performed your trials outside instead of indoors?
It would be less accuracy outside if it is cooler than room temperature. Wind and solar energy would also contribute to inaccuracies when performed outdoors.

Using what you know of heat flow and thermodynamics, discuss how the specific heat capacities of aluminum and copper affect the use of these metals in flat-plate solar collectors.

An aluminum module with the copper core would have the metal with the high specific heat capacity on the outside and the low specific heat on the inside. It takes more heat to raise the temperature of aluminum than it does copper. The better heat conductor can still be used at the center to heat the fluid in the tubes, and a material that can store a lot of heat energy without loss to the environment can be used on the exterior of the collector.

Lab 5
Heat and Insulation

Purpose:

- To explore the thermal resistance of four different insulators in an endeavor to determine the characteristics of an effective insulator.

Energy & Environment Context:

- Heating and cooling use between 50% and 70% of the energy used in homes because most houses in the United States are not well insulated.

Teaching Tips:

1. Be sure each group uses cans with the same amount of water, about 300 gm.

2. In this lab students can easily cover the pop cans not only from the sides, but from the top and bottom as well. In the prelab questions they should be asked to derive the formula for the total surface area of the cylinder, given its radius and height.

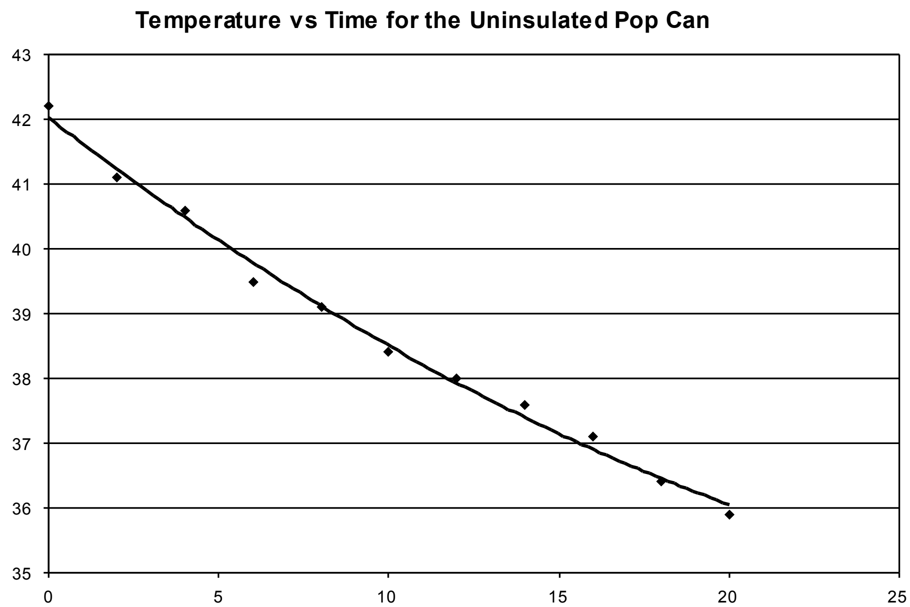
3. The temperature changes rather slowly. If possible, use LoggerPro's temperature sensor instead of a thermometer.

4. This exercise is semi-quantitative as students are not measuring the thermal conductivity of the insulators; instead, they are simply finding a semi-quantitative measure of their thermal resistance.

Difficulties and Alternative Conceptions:

The relative thermal resistances of the materials might not fit the students' expectations.

Sample Results:



Conclusions:

In the conclusions, the students are asked:

What materials was the best insulator? The second best? The worst? The second worst?

The bubble wrap and foam "can cozzy" should be the best insulators while the sheet of rubber should be the worst insulator of the four.

Based on your results, what do you think makes for a good insulator?

The students should observe that air pockets make for a good insulator: both the bubble wrap and foam "can cozzy" consist mostly of air pockets.

Why do most houses in Minnesota have double- or triple-pane windows? Is it the glass that is an efficient insulator, or is something else involved?

Glass is not an efficient insulator; it is the air between the glass that is important.

How can igloos of the Inuit (sometimes known as Eskimos) be constructed of snow and still remain warm inside? Why do animals burrow into snow to find shelter from the winter cold?

Snow is mostly air: 10 cm of fresh snow is equivalent to as little as 0.1 cm of rain.

The following materials (at the stated thicknesses) have the same thermal resistances: 13 cm of polyurethane foam, 58 cm of white pine, 5.5 meters of window glass, and 2.25 km of silver. How does this fit with your results in this exercise?

Students can use this formation to answer the earlier question about double- and triple-pane windows. In addition, the students should realize that polyurethane foam, like the "can cozzy" and bubble wrap, is mostly air.

Consider the insulation with which we who live in Minnesota are terribly familiar: winter clothes. What do people usually wear in winter? What about these winter clothes makes them better insulators than our summer clothes? Relate your answers to this exercise.

We wear cotton and wool sweaters, knit hats, down feather jackets, and so forth. All of these contain air pockets and, therefore, act as efficient insulators.

What heat transfer mechanism or mechanisms were involved in this exercise? Radiation? Conduction? Convection? Draw an illustration to help explain your answer.

There is negligible radiation in this exercise due to the use of the aluminum pop can. Tape over the hole in the can minimizes convection, except from the outer surface of the can to the air. Conduction between the water, can surface, and the various insulators is the principle heat transfer mechanism.

1001 Lab 5 – Heat and Insulation

Lab 6
Heat, the Solar Input, and Earth's Available Energy

Purpose:

- To calculate the solar input and, thus, Earth's available energy from the Sun.
- To make an estimation of how many people the Earth can support.

Energy & Environment Context:

- Almost all of the Earth's available energy comes from the sun. Fossil fuels are a result of ancient photosynthesis. Renewable biomass fuel, as well as our food supply, is products of photosynthesis as well. Wind and waves are driven by heat from the sun, and, of course, solar panels directly collect the radiant energy. Consequently, the planet's available energy and our food supply are both constrained by the amount of energy received from the sun. For our food, humans still depend on the plant kingdom, which is completely dependent on solar radiation.

Teaching Tips:

1. This exercise requires 20 minutes of sunshine, and the apparatus needs to be shielded from the wind if there is any (without shielding it from sunshine).

2. If the lab is performed outside (it works well even in the cold weather), it should be stressed that there are two opposite processes - solar heating and cooling due to the interaction with air (which we assume to be much slower – less efficient). However, as students leave the building, they should let the plates cool down for a few minutes first. Otherwise, they will see that the plates are cooling in the sun (due to the interaction with air) and the result will not make any sense.

3. There should be a conversion chart in the boxes the plates come in that converts resistance into temperature. If there is no chart, request one using labhelp.

4. The notation of 'calories' and 'Calories' (kilocalories) is a little tricky, students may be off by three orders of magnitude.

Difficulties and Alternative Conceptions:

The students may need reminders about finding power from energy and time. The cross-sectional areas of the Earth may cause some conceptual difficulties for the students.

Sample Results:

The value for the solar input is about 1000 watt/ m^2. Expect a lot of variability in the answers, but the results should be on the order of 1000 watt/ m^2, most likely lower.

Conclusions:

- The total solar power received by Earth is about 1×10^{17} watts.
- The amount of solar energy received by Earth in one day is about 1×10^{22} J.
- The amount of solar energy used in photosynthesis is about 8×10^{18} Joules in one day, and the solar power used in photosynthesis is about 8×10^{13} watts.
- About 8×10^{12} watts of the solar power is available to humans as food.

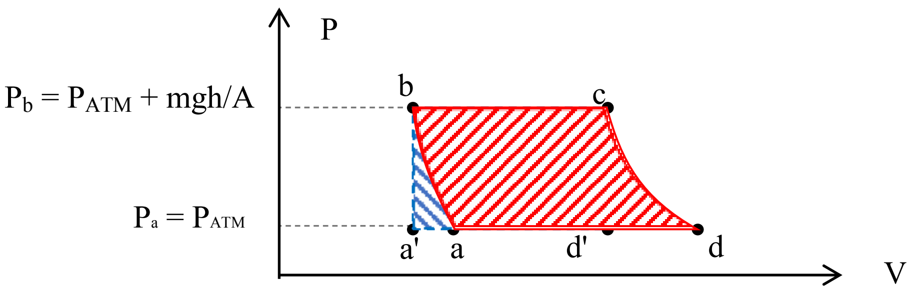
1001 Lab 6 – Heat, The Solar Input, and Earth's Available Energy

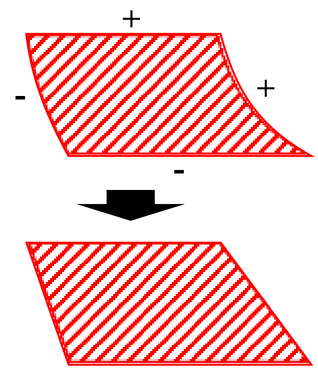
- About 1.7 x 10^{14} calories of food are produced on Earth in one day.
- Assuming humans are omnivorous, the maximum population is about 16 billion. If the population doubles every 40 years, this theoretical maximum population will be reached in about 50 years.
- Assuming all humans are vegetarian, the maximum population is about 55 billion. If the population doubles every 40 years, this theoretical maximum population will be reached in a little more than 120 years.

Lab 7
Mechanical from Thermal Energy – Heat Engine

Purpose:

- To observe the main stages of the typical engine's cycle.
- To calculate the efficiency of the thermal engine and to see that it is less than 1.
- Compare the calculated efficiency with the maximum thermodynamic (Carnot) efficiency $1 - T_c / T_h$.





$T_{ab} \equiv T_{cold}$, $T_{cd} \equiv T_{hot}$.

Red – thermodynamic work; students approximate the area between two isobars and two isotherms by a parallelogram abcda.
Blue – mechanical work (mgh).

+ — system adsorbs heat.
– — system produces heat.

Mechanical work:
$W_M = mgh = (P_b - P_a)(V_c - V_b)$

Thermodynamic work (parallelogram approximation):
$W_T = (P_b - P_a)(V_c - V_b)$ or $W_T = (P_b - P_a)(V_d - V_a)$
This is a very rough approximation. The result can be same as for the Mechanical work.

Thermodynamic work (trapezoid approximation):
$W_T = (P_b - P_a)(V_c - V_b + V_d - V_a) / 2$

Thermodynamic work (exact answer):
$W_T = P_b (V_c - V_b) + \nu R T_{hot} \ln(V_d / V_c) - P_a (V_d - V_a) - \nu R T_{cold} \ln(V_a / V_b) =$
$P_b (V_c - V_b) + P_b V_c \ln(V_d / V_c) - P_a (V_d - V_a) - P_b V_b \ln(V_a / V_b)$

Heat input (that's how the code works, no need to explain to students):
$Q_{bc} = 7/2\ P_b (V_c - V_b) = 7/2\ \nu R (T_{hot} - T_{cold})$
$Q_{cd} = \nu R T_{hot} \ln(V_d / V_c) = \nu R T_{hot} \ln(P_b / P_a) = P_b V_c \ln(P_b / P_a)$
$Q = Q_{bc} + Q_{cd}$

Energy & Environment Context:

A typical example of the thermal engine is considered. It resembles all main features of the real engines used in the industry.

Teaching Tips:

1. When calculating the volume of the system, students should take into account the volume of the cylinder. This will not affect the Work (the cycle will just shift on the PV diagram), but will change the Heat, and so the efficiency.

2. Warn students that the tubes can be easily damaged by the heater.

3. For the code to work properly, all the units have to be entered in SI: Pascals, m^3, Kelvins.

4. The scale on the piston is given in millimeters, the radius is indicated on its side.

5. A good initial height of the piston – 2-3cm.

6. Make sure the piston is not fixed by a screw on the top.

Difficulties and Alternative Conceptions:

It is highly nontrivial to explain to students the difference between the mechanical and thermodynamic work. One way to do is as follows.

Mechanical work

We use the engine to lift the weight and change its potential energy by

$$E = mgh = \frac{mg}{A} Ah = (P_b - P_a)(V_c - V_b)$$

Thermodynamic work

In this case we start from the definition of the mechanical work (first equality):

$$\Delta W = F\,\Delta r = \frac{F}{A} A\,\Delta r = P\,\Delta V$$

Which tells us that work is the area on the PV graph (just like for the coordinate the travelled distance is the area on the Vt graph).

Over different stages of the cycle, the work performed by the system can be either positive (bc, cd) or negative (da, ab). Which altogether gives us an area inside the loop for the whole cycle.

How can they not be equal?

Strictly speaking, it is not true that we are lifting the weight from the height corresponding to the volume V_b to the height corresponding to V_c. Our PV diagram indicates that we gradually add mass (ab) before lifting it and then gradually remove it afterwards (cd). Effectively, the initial and final heights are different from those we use to find h. Furthermore, these two corrections are not equal to each other (aa'd and dd'c), since these operations are performed at different temperatures.
The difference between these two effects, aa'b and dd'c, is responsible for the difference between mechanical and thermodynamic work.

Sample Results:

	A	**b**	**C**	**d**
Pressure, Pa	1.00×10^5	1.02×10^5	1.02×10^5	1.00×10^5
Volume, m^3	4.66×10^{-5}	4.56×10^{-5}	5.43×10^{-5}	5.54×10^{-5}
Temperature, K	280	280	333	333

$v = 2.00 \times 10^{-3}$ moles

Mechanical work:
$W_M = 1.72 \times 10^{-2}$ J

Thermodynamic work:
$W_T = 1.75 \times 10^{-2}$ J

Heat:
Q = 3.19 J

Useful efficiency:
$\eta_{useful} = 0.54\%$

Maximum thermodynamic efficiency:
$\eta_{max} = 15.9\%$

Conclusions:

- The Mechanical and Thermodynamic works are very close.
- The efficiency of the real engine is much lower than the maximum efficiency.

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Lab 8
Green House Effect

Purpose:
- To observe the Green House effect.
- To figure out its relative strength comparing to the change of the surface color.

Energy & Environment Context:

The goal of the lab is to understand whether the human activities, which increase the amount of CO_2 in the atmosphere, can cause global warming.

Teaching Tips:

1. Many factors have greater impact on the temperature other than the type of gas in the tank: the position of the lamp relative to the tank, isolation of the sensor, etc.

2. Once the students set up an experiment, they should keep everything unchanged for all 4 measurements. If a group decides to use a cover, for consistency it should be on the tank during all 4 experiments.

3. First ask students to run trials without CO_2, then with CO_2. Otherwise, they will have to move the tank to clean it after the CO_2 trial.

4. Make sure that the initial temperature is same for all 4 experiments. Then collect data using LoggerPro during same time intervals.

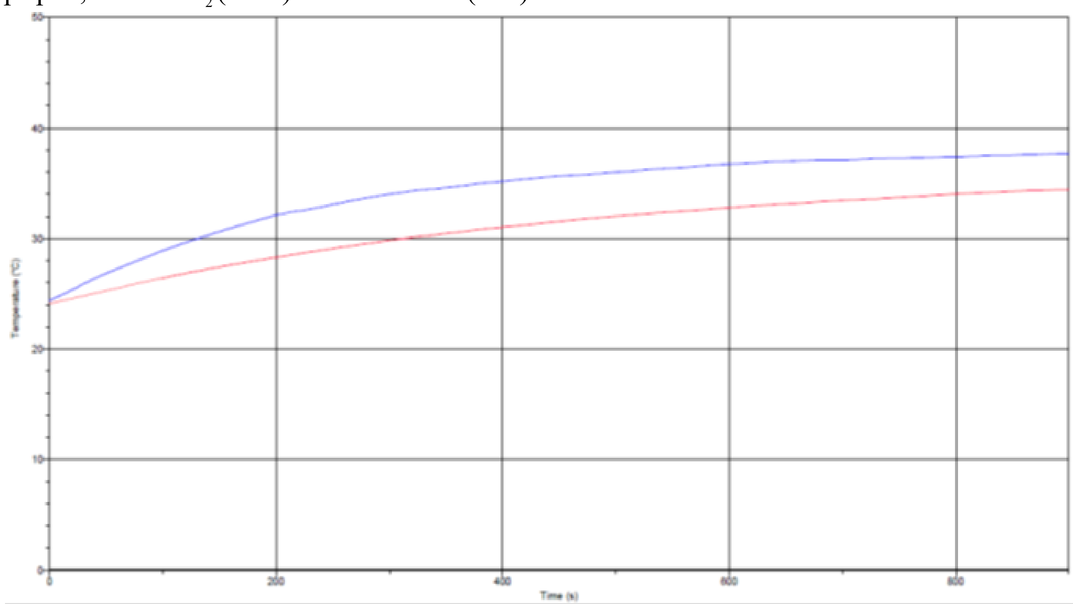
Use tape and plastic glasses to hide the wire and the sensor from the light and to fix the tank on the table.

Difficulties and Alternative Conceptions:

Probably, a few groups will have poor results. Still, it is important to treat the obtained results properly. Students should explain whether the experiment proves something, or it has to be repeated after having fixed the issues, which lead to such a result.

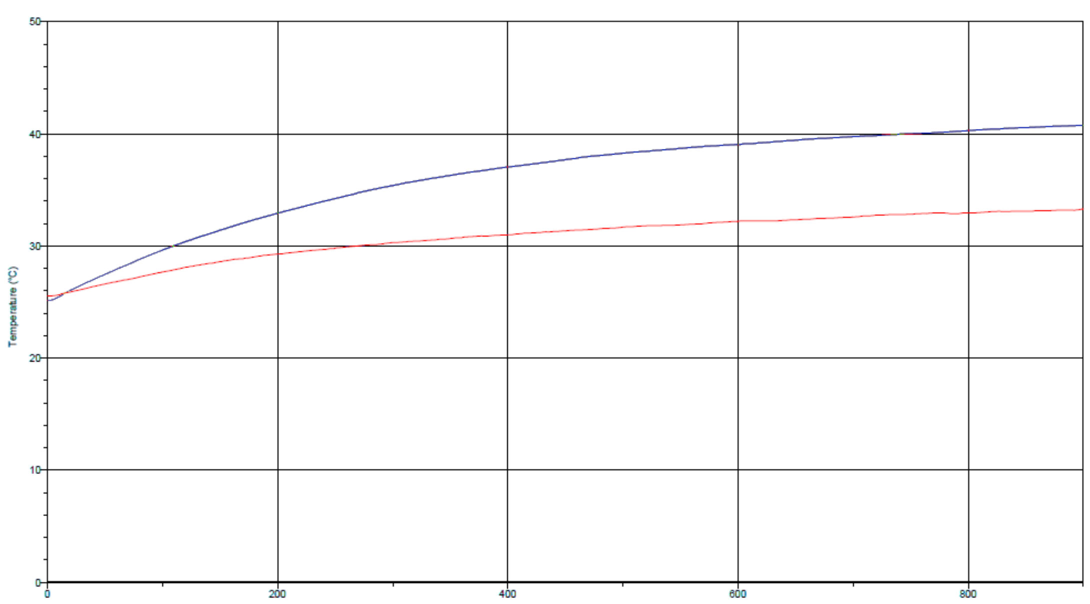
Sample Results:

White paper, with CO_2 (blue) and without (red):



Time interval: 15 min.
Initial temperature: 24.2 C.
Final temperature: 34.4 C without CO2, 37.7 with CO2.

Black paper CO_2 (blue) and without (red):



1001 Lab 8 – Greenhouse Effect

Time interval: 15 min.
Initial temperature: 25.2 C.
Final temperature: 33.3 C without CO_2, 40.8 with CO_2.
The experiment was performed without a lid on the tank.

Conclusions:

CO_2 has a significant effect on the atmospheric temperature.

The effect is of same order as changing the color of the surface.

Lab 9
Electrical Circuits

Purpose:

- To discuss the concepts of current, voltage and resistance.
- To explore circuits and to investigate Ohm's Law in a simple series circuit.
- To become familiar with constructing circuits and connecting the digital multimeter.

Energy and the Environment Context:

- Electricity is at the center of energy use in the modern world. This exercise is the first step in investigating electrical energy and power.

Teaching Tips:

1. When talking about V, I and R a good analogy can be comparing electrons in a circuit to water in a tube.
   V: height difference between the ends of the tube.
   I: the flow of the water.
   R: hydropower stations, taking energy from the water.

2. You can use two DMMs setup to read Amps and Voltage connected to the circuit simultaneously.

3. The first thing the students can be asked to explain is why the resistance of resistors is same when measured with a single DMM measuring Ω in the circuit, or with two DMMs measuring voltage and current, but the results are very different for the light bulb.

4. In the second part, students can be given the formula for the parallel and series connection of resistors (without derivation). They will be able to measure the individual resistances and compare their predictions with measurements.

Difficulties and Alternative Conceptions:

The subject of circuits is fraught with misconceptions and difficulties. One main difficulty students have is connecting the multimeter correctly and selecting the correct settings to measure current, voltage and resistance respectively. (Refer them to **Appendix I – The Digital Multimeter** if they have trouble with this.) Translating their circuit diagrams into actual circuits is also a common difficulty. Remind students to connect their circuits in as simple a way as possible so that it is easy to look at the circuits and tell what is connected and in what way the parts of the circuit are connected. Keep the wires short and don't let them cross unless it is essential for connecting the circuit.

This is also an introduction to the often bewildering concepts of current, voltage, and resistance -- expect that a discussion of these concepts will be necessary.

Sample Results:

$R_1 = 998$ Ohms
$R_2 = 24$ Ohms
$I_{total} = 0.0055$ A
$V_{exp} = 5.68$ V $V_{th} = 5.65$ V
$V_{R1exp} = 5.52$ V $V_{R1th} = 5.55$ V
$V_{R2exp} = 0.13$ V $V_{R2th} = 0.13$ V

$R_1 = 998$ Ohms $R_2 = 24$ Ohms

Series Circuit:
$I_{total} = 0.0055$ A
$V_{exp} = 5.68$ V $V_{th} = 5.65$ V
$V_{R1exp} = 5.52$ V $V_{R1th} = 5.55$ V
$V_{R2exp} = 0.13$ V $V_{R2th} = 0.13$ V
Power = 0.031 Watts

Parallel Circuit:
$V_{exp} = 5.30$ V $V_{th} = 5.15$ V
$V_{batt} = 5.34$ V $V_{R1 + R2} = 5.30$ V
$I_{R1exp} = 0.0052$ A $I_{R1th} = 0.0053$ A
$I_{R2exp} = 0.22$ A $I_{R2th} = 0.22$ A
Power = 1.17 Watts

Conclusions:

In the conclusions, the students are asked:

Superconductors are materials which, when cooled sufficiently, offer almost no resistance to electrical current. The copper wires in your circuits do, however, add to the total resistance. What if the wires used in the circuit with the light bulb were replaced with superconducting wires and the resistance became almost nothing? Would the current in the circuit change, or the does voltage, or both? What would happen to the bulb? Explain your answer with Ohm's Law.

Since the voltage would remain the same (because the battery has not changed) and the resistance decreased, the current would increase. Remember that the brightness of a light bulb is approximately related to the power dissipated by it, which is $P = I^2R$, so the bulb's brightness will increase in the current increases.

Parallel circuits use more power, by an order of magnitude or two, than series circuits.

Lab 10
Magnets and Moving Charges

Part 1. The effect of a magnetic field on a moving charge

Purpose:

- To investigate how magnetic fields exert a force on moving charges.
- To observe an alternating current (AC).
- To see the effect of Earth's magnetic field.

Energy and Environment Context:

- The ability of a magnetic field to exert a force on moving charges is central to how generators produce electricity and how motors produce motion.

Teaching Tips:

1. Find out ahead of time the voltage rating of the cathode ray tube. Also find out ahead of time the ideal accelerating voltage with which to start.

2. Both magnets and compasses can be broken (showing opposite direction). Actually, the electron beam is the only available in the lab thing which can be used to determine whether the magnet is fine or not (some smartphones also have a compass tool). Magnets can be fixed with the use of magnetizer.

3. The students will work with equipment that produces large voltages, and improper use can cause injury. To avoid danger, the power should be off, and students should use shielded banana cables for the high voltage hookups between the CRT and power supply.

4. NOTE that students are not using the deflecting plates in this lab; they should only connect the CRT to the power supply to accelerate the electrons. The magnetic field of the magnets is the only force causing a substantial deflection of the beam.

Difficulties and Alternative Conceptions:

Some students will assume that, if the electrons are moving faster, the electrons will have a smaller deflection than slower electrons do. (This is only in reference to a Conclusions question; the lab does not ask students to try different accelerating voltages to compare the deflection.)

Sample Results:

This is a qualitative exercise, not a quantitative one -- the students do not need to do any calculations, just observe what happens and record their observations. The beam should deflect downward when the north end of the magnet is brought near the side of the CRT screen, and upward when the south end is brought near.

Conclusions:

In the conclusions, the students are asked if the deflection depends on the electrons' speed. You and I -- but not your students -- know from Lorentz Law that the force on a charged particle is $F = qE + q (v \times B)$. So, when the velocity of the electron is greater, the force on it is greater, and thus its deflection is greater. However, this is not the case for this setup. The effect of moving through the magnetic field faster overcomes that of the greater force ($a \sim F \sim v$, $t \sim 1/v$, $y \sim a t^2 \sim 1/v$). So students may be confused if they use different accelerating voltages.

They are also asked to discuss what effects a higher electron velocity in the wires of a generator and a motor would have. A higher electron velocity would have essentially the same effect as a higher current -- a stronger magnetic field would be produced. A small generator could thus produce more electricity, and a small motor could produce as much mechanical energy as a larger motor.

Part 2. The effect of a changing magnetic field on the voltage in a coil

Purpose:

- To investigate the electric fields induced by changing magnetic fields.
- To construct a simple electric generator using coils and small magnets.

Energy and Environment Context:

- The induction of electric fields by changing magnetic fields is important to how generators produce electricity. The students will also construct a rudimentary electric generator in order to understand how they work.

Teaching Tips:

1. The small neodymium magnets should be affixed with tape to a pencil or dowel to allow students to plunge the magnets through and around the coils.

2. To check which end of a compass is the N pole students should hold the compass level at a location away from anything iron or steel such as chairs with metal parts or parts of the lab tables that have metal bolts on the underside. The end of the compass that points in the general direction of geographic north is the N pole. Bar magnets can change polarity if quickly placed in a strong magnetic field or dropped, so they should be checked. (The N pole marked on a bar magnet might actually be a S pole.)

3. The currents in this lab are too low to be detected by the ampermeter, You should use the voltage probe with LoggerPro. It will show the alternating current.

Difficulties and Alternative Conceptions:

The principal difficulty is that students need assistance with the proper setting, scale, and connections for LoggerPro to display the induced current.

Sample Results:

This is a qualitative exercise, not a quantitative one -- the students do not need to do any calculations just observe what happens and record what they observe.

Conclusions:

In the conclusions, the students are asked:
What factors affect the induced current? In this exercise, you and your lab partners used a magnetic field to induce a current. In the previous exercise, you and your partners used a current to produce a magnetic field. How do the factors that affected the magnetic field in the previous exercise compare to the factors in this exercise? The students should find the same relationships as in the previous exercise: distance vs. induced current and magnetic field strength vs. induced current.

Based on what you know… how could you convert your generator in this exercise into a motor?

It would be fairly easy to convert a generator into a motor; the students should describe the loop having a current run through it and being free to rotate in the magnetic field of the bar magnet or, even better, a u-shaped magnet.

Lab 11
Wind, Water and Energy

Purpose:
- Observe the transition of energy into work and vice versa.
- See how the main types of generators work.
- Discuss the concept of power.
- Keep discussing the alternating current (AC).
- Calculate the efficiency in different ways.

Energy & Environment Context:
Hydropower and wind power as energy sources are becoming more and more popular in society. Utilizing the energy of falling mass has been done for a long time. The Trebuchet is an early example of humans using gravitational potential energy.

The AC currents generated in this lab are common. AC is used in most electronic devices, and for transferring electricity.

Teaching Tips:

1. The measurements need to be made with the use of LoggerPro, a voltage probe and DAQ interface. The multimeters are not able to accurately measure the AC currents for this lab.

2. The current from wind power is the most stable, it's a good idea to perform this part first to allow students to get confidence.

3. For the hanging mass and water turbine, the largest possible height difference should be used. It's also recommended to use a good amount of water in the carboy tank.

4. You can make a good demonstration for students by releasing the mass without the LED light plugged. Then, in the middle of the fall, plug it in and the mass will immediately slow down, or even stop.

5. For the wind power, make sure that students measure the wind speed next to the generator's propeller.

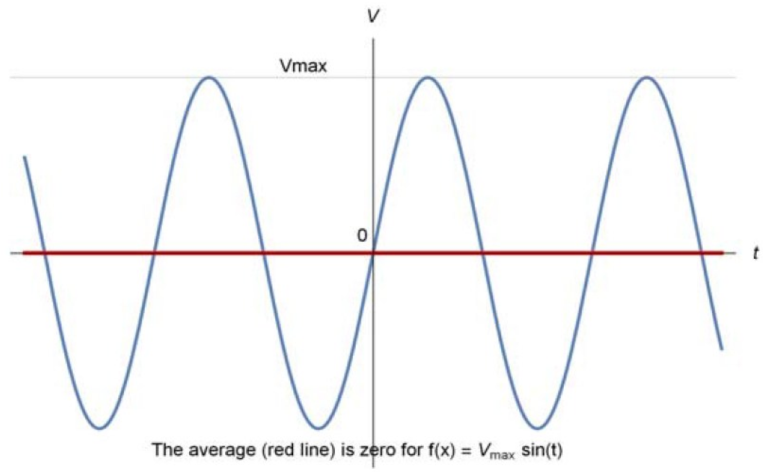
By the beginning of this lab the students are supposed to be familiar with the Ohm's law and the electric definition of power (worth reminding!):

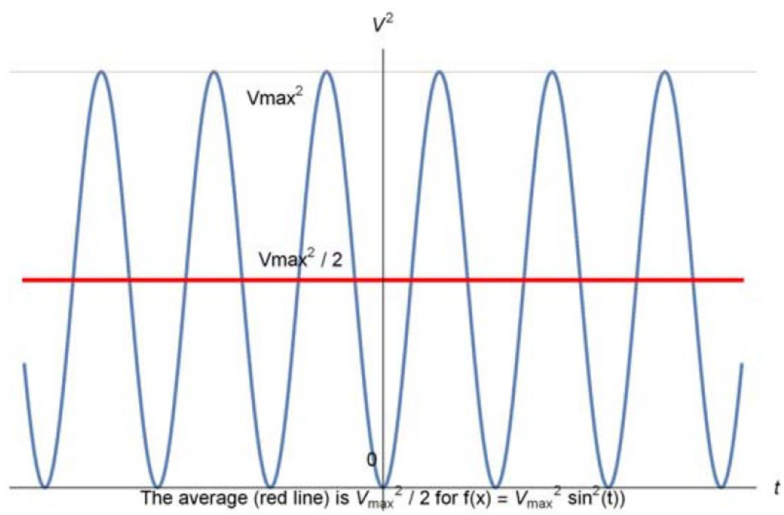
$$V = IR$$
$$P = I^2R = VI = \frac{V^2}{R}$$

You can explain the basic idea of the AC – electrons moving back and forth in the circuit, and also draw a sine wave.

It is surprisingly easy to explain the factor of two, which appears in the calculation of the power in the AC circuit. Since LoggerPro shows the voltage, we are going to employ the formula $P = V^2/R$.

The first important idea: the average value of the sine function, which goes between –V and V is zero (first graph). Second idea: after squaring we again get a sine function (here students have to believe, but it is a reasonable guess) which goes between zero and V^2. The average value in this case is $V^2/2$ (second graph).





Thus, one gets:

$$Average(V^2) = \frac{V_{max}^2}{2}$$

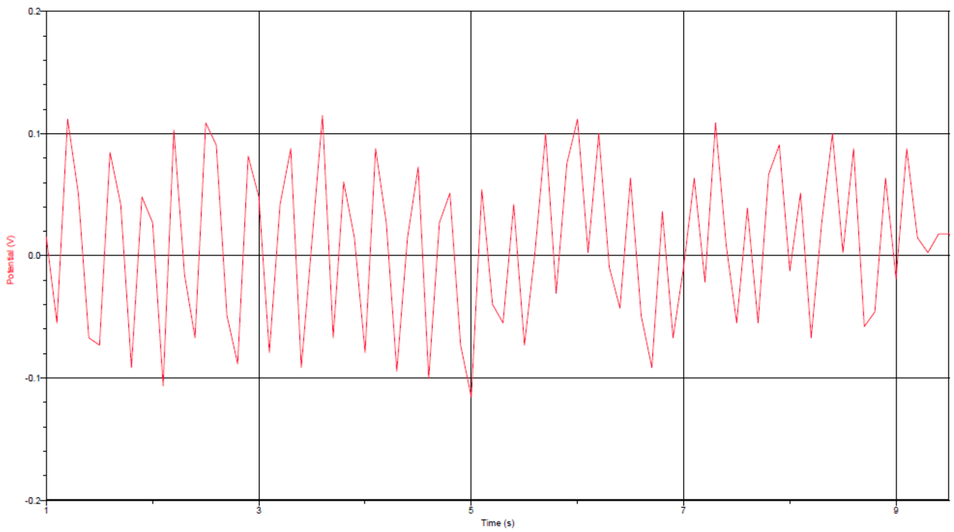
$$Average(P) = \frac{Average(V^2)}{R} = \frac{V_{max}^2}{2R}$$

Difficulties and Alternative Conceptions:

It may take some time to find the optimal mass for the first experiment.
The efficiency will be very low.

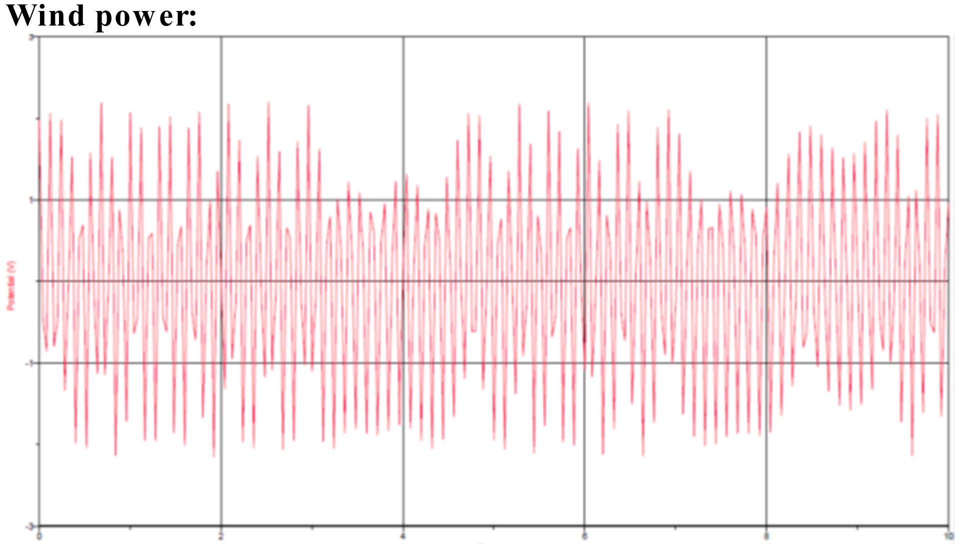
Sample Results:

Hanging mass:



Mass: 55g.
Height: 1.3m.
V_{max}: 0.08 V.
Resistance: 100 Ohm.
Time: 9.5 s.
E = mgh = 0.7 J
W = 3.2×10^{-5} J
Efficiency: $\eta = 4.6 \times 10^{-5}$

Wind power:



V_{max}: 1.5 V.
Resistance: 100 Ohm.
Wind speed: 4.5 m/ s.

Power input: 0.05 W
Electric power: 0.011 W
Efficiency: $\eta = 0.23$

Conclusions:

- Considered engines produce alternating current.
- The efficiencies vary a lot. Even though we could expect the wind power to be inefficient, due to the poor construction of the generators, it turns out to be highest.

Lab 12
Energy and Atomic Spectra

Purpose:

- To observe that atoms emit light only on the certain frequencies.

Energy & Environment Context:

Spectroscopy is widely used in different fields of science and engineering.

The energy levels of the electrons inside the atom are quantized. Einstein was the one who discovered the relation between the energy of the photon and its frequency.

$$\Delta E = E_f - E_i = h\nu = \frac{hc}{\lambda}$$

Teaching Tips:

1. When preparing the lab, find gases with the brightest lines to start with.
2. If possible, close the shades in the room.
3. The polarizer on the eyepeice has to be rotated to align the spectrum with the device. A piece of tape can be used to keep the polarizer in place once it has been aligned.
4. First, let students use the spectrometer with the light bulbs in the room. They should be able to see 3-4 distinct lines.
5. Then, use the sunlight to observe the continuous spectrum.
6. Include a molecule (carbon dioxide or water vapor) to see that the spectrum is more complex (nearly continuous). The carbon dioxide spectrum tends to be brighter than water vapor.
7. Turn on every bulb for 5-10 minutes to let everyone use it, then ask students to compare the results.
8. Ask students to google spectrum charts to check the experimental data. A program called The Elements Spectra should also be installed that can display theoretical spectra.

Difficulties and Alternative Conceptions:

It can take some time to find out how the spectrometers work.

Sample Results:

Conclusions:

Individual elements have different, discrete spectraWe can identify elements based on their spectra.
More complicated things *tend* to have more complicated spectra (but not uniformly, etc).

Lab 13
Half Lives

Purpose:

- Observe the process of gamma decay of Barium in excited state, obtained through radioactive decay of Cesium.
- To fit the experimental data by the theoretical curve and calculate the half-life time for the gamma decay.

Energy & Environment Context:

Teaching Tips:

1. A good idea is to show students how to export data to excel and then fit it with the exponential curve (this can also be done in logger pro)
2. Setting your sampling rate can be important if you want good looking data. This can be changed in Data > Data Collection... A good sampling rate will depend will the quality of your sample.

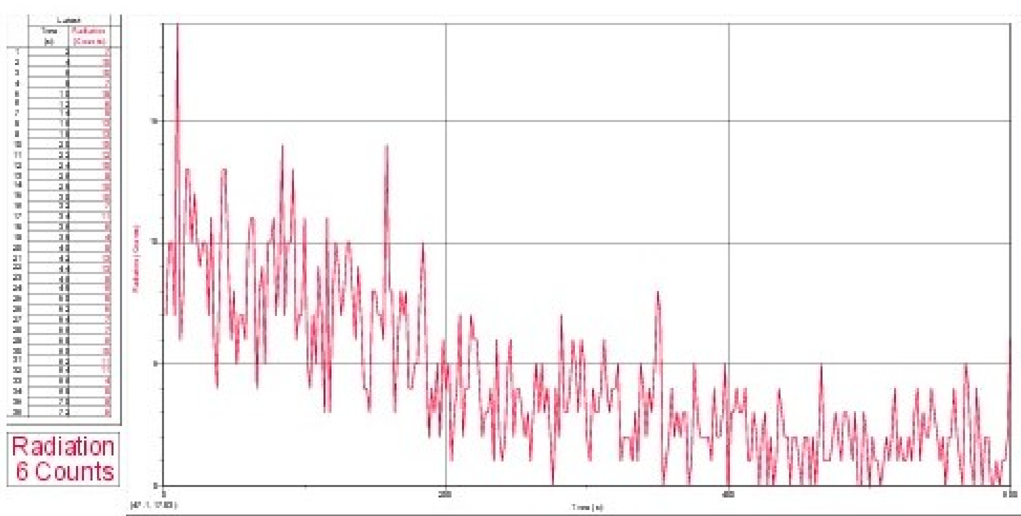
Difficulties and Alternative Conceptions:

Students may say that the material with shorter half-life time is safer, since it will decay shortly and then will stay safe.

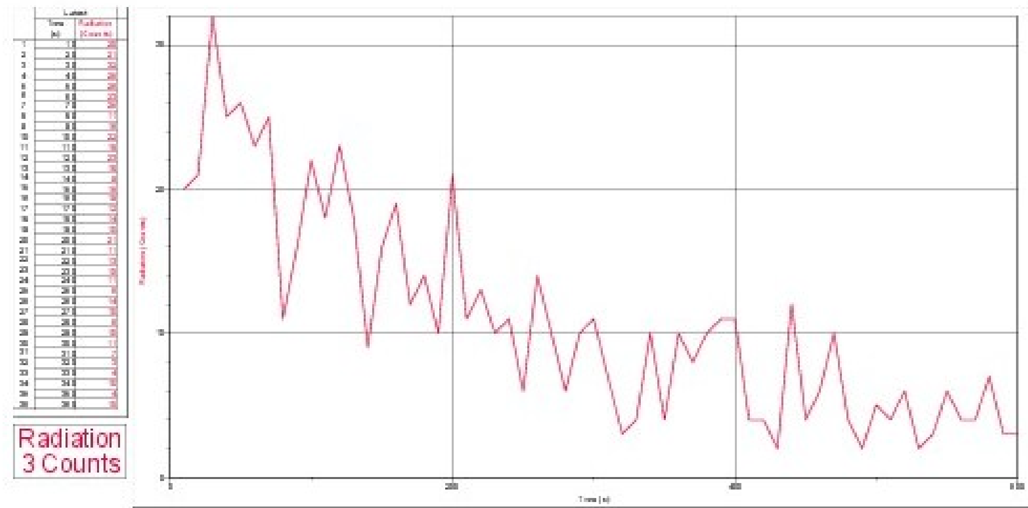
Sample Results:

$$N = N_0 e^{-kt} = N_0 \left(\frac{1}{2}\right)^{\frac{t}{\tau}}$$

$$\tau = \frac{log2}{k} = 173s$$



using 3 second binning



using 10 second binning

Conclusions:

- The decay follows an exponential decay but is random over short times
- We can measure the decay and fit it to determine the half-life