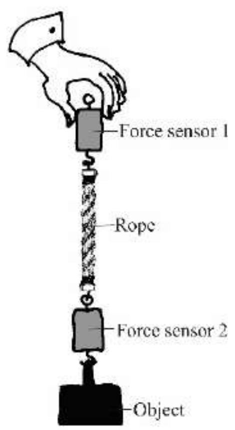
Appendix

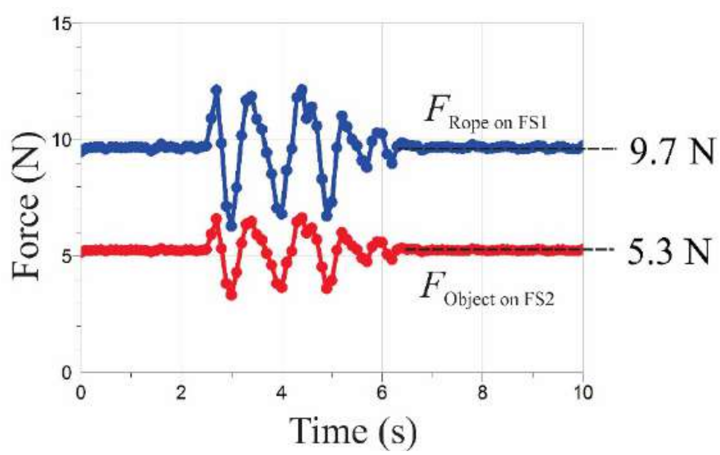
A.1. Represent, analyze and explain

Class: *Equipment:* two force sensors, a thick rope, a string, a heavy object; or no equipment if you use the graphs below.

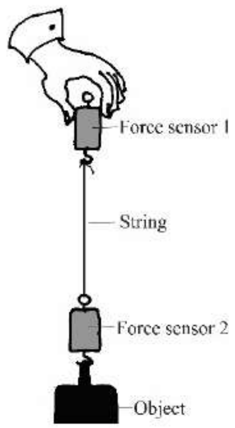
Experiment 1: The figure below shows the set-up for the experiment. Use two force sensors, a thick rope and a heavy object. The top sensor measures the force that the rope exerts on it and the second sensor measures the force that the object exerts on it.

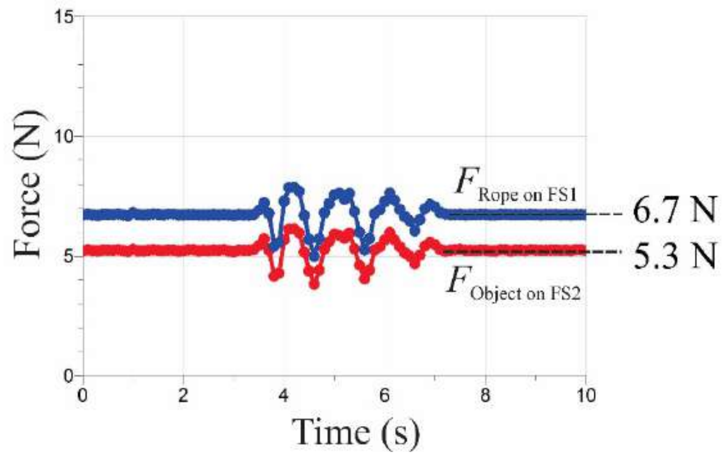
First, hold the set-up at rest, and then move the whole set-up up and down a few times, and then stop moving it. The force sensors measure vertical components of forces. The force-versus-time readings of both sensors are shown in the graph below. The average force sensor readings when the set-up is at rest are given on the right side of the graph. Positive readings mean the forces point downward.





Experiment 2: Replace the thick rope in Experiment 1 with a light string (see the figure below) and repeat the experiment as described above. The corresponding force-versus-time readings of both sensors are shown in the graph below. The average force sensor readings when the set-up is at rest are given on the right side of the graph.



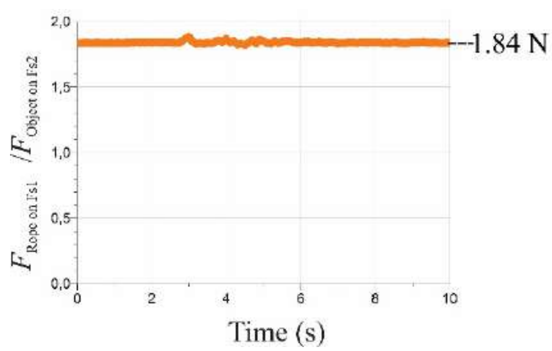


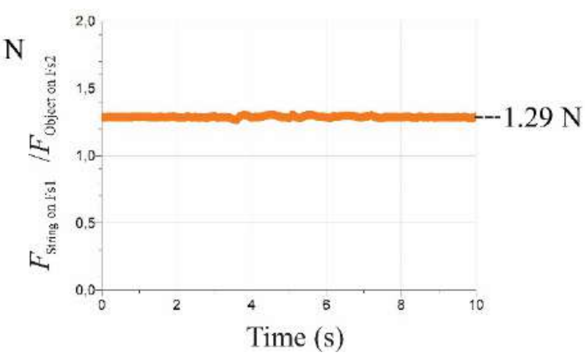
a. Work with your group to explain the outcomes of both experiments using force diagrams and Newton's laws.

b. Make a list of relevant physical quantities that you can determine using the data from the graphs and determine their values.

c. Determine for both experiments in which direction you moved the set-up from rest (up or down). Explain.

Using your measurements, construct two new graphs showing the *ratio* of the force-sensor-readings-versus-time (see the graphs below). The left graph corresponds to Experiment 1 and the right one to Experiment 2.





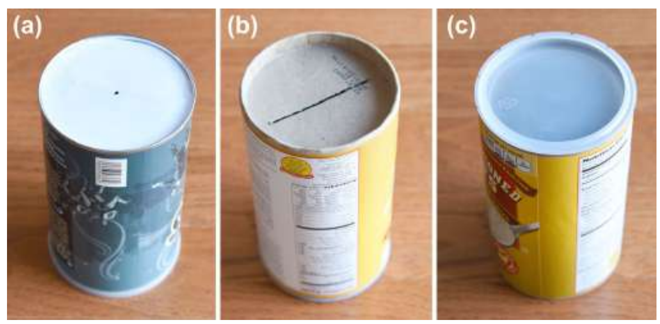
d. Evaluate the new graphs. Are they qualitatively in agreement with what you expect, based on the previous graphs?

e. Derive the equation for the ratio of forces measured by two sensors for both experiments. Explain why the ratio of the forces stays practically constant although the forces are changing.

f. Using the values of the physical quantities that you determined in part **b.** and the equation that you derived in part **e.**, predict the ratio of the forces in both cases and compare the values with those shown in the graphs. Indicate any assumptions that you made. Discuss whether the predicted and experimental values agree.

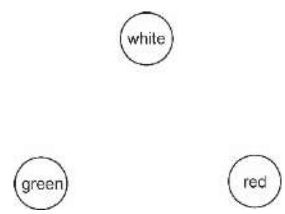
A.2. Apply

Class: *Equipment per group:* two round cardboard boxes (such as boxes for oatmeal or coffee with a plastic transparent cover – see photos on the right), three bulbs (two colored with permanent markers), a power supply to light the bulbs, a fluorescent lamp and a computer with a monitor.



Experiment 1: Make a pinhole camera by making a small hole in the bottom of the box (photo (a) above) and using a transparent cover on the opposite side (photo (c)) as a screen.

a. Work with your group to predict what you will see (in a dark room) on the screen of the pinhole camera if you aim the camera toward white, red, and green lightbulbs arranged as shown in the figure on the right. Predict how the image on the screen will change if you come closer to or go further away from the lightbulbs. Then perform the experiments and compare your predictions with the outcomes.



Experiment 2: Make a "line-hole" camera by cutting a straight narrow aperture in the bottom of the cardboard box (see the photo (b) above) and using a transparent cover on the opposite side as a screen.

b. Based on your knowledge about the pinhole camera, discuss with your group members and predict what you will see if you place one **small lightbulb** in front of the line-hole camera. Explain in detail how the pinhole camera model helped you to make the prediction. Use ray diagrams to support your prediction.

c. Take a line-hole camera and perform the experiment described in part **b**. Compare your prediction with the outcome of the experiment and reconcile any discrepancies.

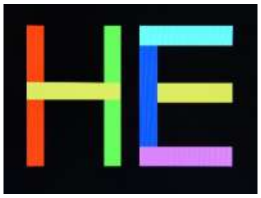
d. Predict what you will see on the screen of the line-hole camera if you aim it toward the **three colored lightbulbs** that you used in the part **a**. In addition, predict how the image on the screen will change if you rotate the camera around the "principal axis". Then perform the experiment, compare your predictions with the outcomes of the experiments and reconcile any discrepancies.

e. Place a **vertical linear light source** (such as a fluorescent tube) in front of the line-hole camera and observe the image on the camera screen. Also observe what happens when you rotate the camera around the principal axis. Explain any patterns that you identified.

f. Based on the explanations that you devised in part **e**., predict what you will see on the screen of the line-hole camera if you aim it toward a computer monitor which is showing a slide with big white letters **HE** on a black background (you can make the slide suing Power point; use Arial font type). Also predict how the image will change if you rotate the camera around the principal axis. Adjust your distance to the monitor to get the whole image on the screen of the camera.

g. Perform the experiments described in part **f.**, compare your predictions to the outcomes and reconcile any discrepancies. Compare the object and the image and try to find out which features of the image does the line-hole camera bring up ("amplify"). Test your idea by making and observing your own slides.

h. Aim a line-hole camera toward the computer monitor which is showing a slide with colored letters **HE** (such as shown on the right). Observe the image on the camera screen as you rotate the camera around the principal axis. Explain any patterns that you identified.

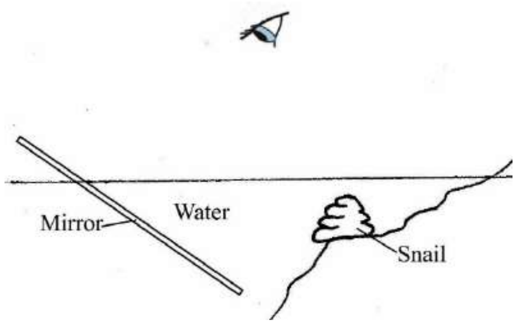


i. Design your own slides. Observe them using a line-hole camera and try to explain the patterns.

A.3. Explain/Apply

Class: *Equipment per group:* whiteboard and markers.

Observe the photo on the right. The photographer was holding a mirror half immersed in the water, as shown in the sketch below (in the upper part of the mirror you can see the person who is taking the photo of the experiment).



There is a snail near the mirror (you can see the snail in the lower part of the photo). In addition, you see two more images of the snail in the mirror. Work with your group to explain qualitatively how these two images form using ray diagrams. Make sure your diagrams also account for the orientation of the images (note that the snail in the upper image is upside down with respect to the snail in the image below it). *Hint*: one of the images is the result of total internal reflection.

A.4 Represent, analyze and explain

Class: *Equipment per group:* whiteboard and markers.

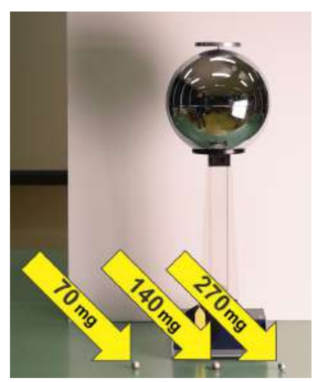
This activity is based on two experiments that you can watch in the video [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-a-4].

Experiment 1: Connect one terminal of a voltmeter to a Van de Graaff generator's dome and the other one to the ground. You can assume that the floor, the table, and the room around the Van de Graaff dome are all at the same potential as the ground. Then slowly turn the crank of the generator and observe the reading of the voltmeter.

a. Watch Experiment 1 in the video. Work with your group to draw a graph of potential difference between the dome and the ground against the number of turns of the crank.

b. What can you say about the charge on the dome as a function of the number of turns in this experiment? Explain. (*Hint*: The dome can be seen as one plate of a capacitor and the surroundings as the other plate).

Experiment 2: Fix a flat metal plate on top of the dome. You also have three equal-size small spheres made of aluminum foil. The masses of the spheres are 70 mg, 140 mg, and 270 mg (see the figure on the right). Perform the following experiment with each sphere (watch the video). Put the sphere on the discharged plate on the dome. Then slowly turn the crank until the sphere flies off the plate.



c. Work with your group to explain qualitatively why the aluminum sphere flies off the plate when you turn the crank a certain number of times. Draw a force diagram for the sphere for the moment when it takes off.

d. Choose the system and represent the process using energy bar charts. Take the moment when the sphere just took off as the initial state and the moment when the sphere is at its highest point as the final state.

e. From the video, estimate the number of turns needed to make each sphere fly off the plate (N_{fly}). Represent your results as a table, with the N_{fly} values in the first column and the corresponding masses of the spheres in the second column.

f. Your friends Isabel and Josh have two different hypotheses. Josh says that N_{fly} is directly proportional to the mass of the sphere *m* and Isabel says that it is directly proportional to $\sqrt{m}$. Which hypothesis is better supported by the data that you obtained in part **b.**? Explain.

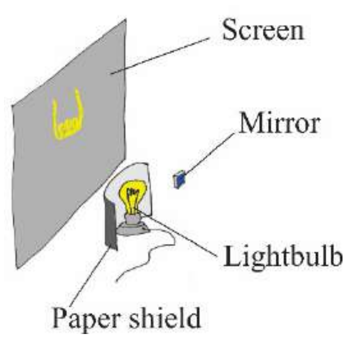
g. Try to derive the relationship between N_{fly} and *m*. Assume that the charged plate creates a uniform $\vec{E}$ field which is directly proportional to the charge on the plate, and that the aluminum sphere is very small compared to the plate. Which hypothesis from part **f.** is in agreement with the expression that you derived?

A.5 Evaluate

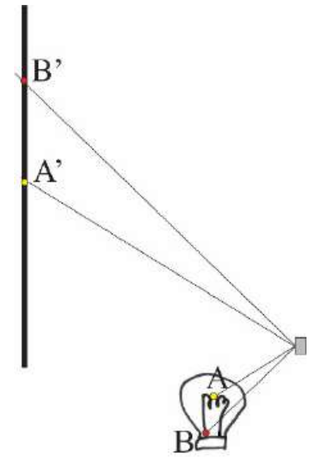
Class or lab: *Equipment:* a clear incandescent lightbulb, a power supply, a tiny mirror (5 mm x 5 mm) a screen for the bulb and a larger screen to view the image

After learning how a plane mirror produces an image, students observed the outcome of the following experiment.

Place the tiny mirror, a clear incandescent lightbulb and a screen as shown in the figure below. Also put a paper shield between the lightbulb and the screen to prevent light from the lightbulb shining directly on the screen. Observe a magnified, upside down image of the lightbulb filament on the screen (as shown in the figure).



Students discussed the observation in groups and proposed different explanations. One group proposed the following explanation:



"If the mirror is much smaller than the object (which is true in our case) then there is too little space on the mirror to produce the image of an object behind the mirror. However, because the mirror is very small, the rays that emerge from a point on the object and reflect from the mirror remain together; they do not spread, as they do with a large mirror. This means that each point on the object (see points A and B on our diagram) produces a bright spot on the screen (points A' and B') and all these spots together form the image of the object on the screen. It is clear from our diagram that the image is upside-down and that the farther away we place the screen, the larger the image – exactly as observed in our experiment. We think this experiment clearly shows that very small mirrors produce real and inverted images in front of the mirror while, as we know, large mirrors produce virtual and upright images behind the mirror."

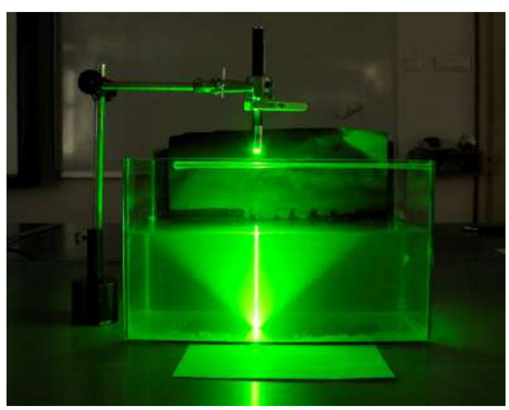
a. Discuss with your group members the students' explanation. Explain which parts of the explanation you agree with and which you disagree with and why.

b. Propose an improved explanation.

c. Suggest one or more testing experiments that you could use to disprove those parts of the student's explanation with which you disagree. For each testing experiment, make predictions about the outcomes of the experiments based on your and on their explanation.

A.6 Propose different explanations and test them

Lab: *Equipment:* aquarium made of flat transparent walls and bottom, green laser pointer, lab stand, few drops of milk (added to water in the aquarium to make the effect more visible), white paper. Additional materials are available upon request.



Direct a green laser beam vertically downward into a partially filled glass aquarium tank that is sitting on top of a flat surface, with a piece of white paper inserted between the table and outer-bottom of the tank. You notice a clearly visible cone with an apex at the bottom of the aquarium (see the photo on the right).

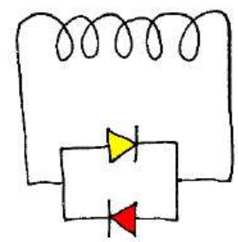
a. Work with your group to devise explanations for the observed light cone.

b. Come up with the ways to test proposed explanations. What equipment do you need?

c. Design testing experiments, make predictions based on your explanations, conduct the experiments, compare the outcomes to the predictions and decide how to proceed. You might need to repeat this process multiple times.

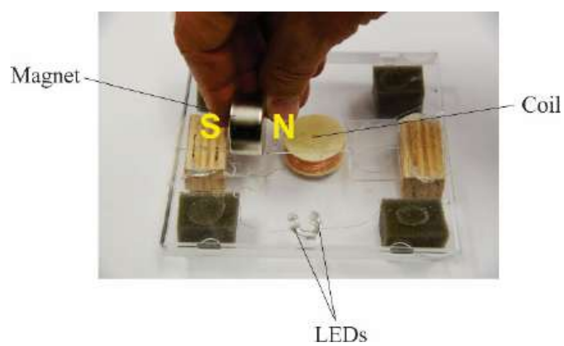
A.7 Represent, reason, apply

Class: *Equipment per group:* whiteboard and markers.



You have a red and yellow LED (red $\Delta V_{\text{open R}} = 1.5\ \text{V}$, yellow $\Delta V_{\text{open Y}} = 1.6\ \text{V}$), a small coil with many turns of insulated copper wire (data for our coil: outer diameter 30 mm, inner diameter10 mm, height 13 mm, 900 turns, made of 0.2-mm thick insulated copper wire) and a strong neodymium disk magnet. Glue the coil at the centre of a plastic CD cover and connect LEDs and a coil as shown on the circuit diagram on the right. Perform the following experiment and record its outcome with a high-speed camera.

Experiment: Hold the magnet so that its axis is parallel to the CD cover (see the figure on the right). The magnet is initially resting near one side of the coil. Then quickly move the magnet across the coil.



a. Observe the high-speed video of the experiment [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-a-7]. The video is recorded at 400 frames per second. Use the arrow keys to play the video frame-by-frame. Identify and describe the patterns.

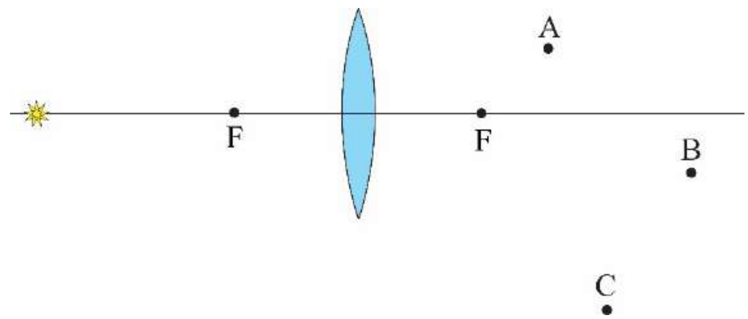
b. Work with your group members to explain the outcome of the experiment based on your knowledge of electromagnetic induction, magnets, and LEDs. Make sure your explanation accounts for each step of the experiment, contains sketches of magnetic field lines, and is consistent with the circuit diagram shown above. Predict what you will see if you move the magnet (same orientation of poles as above) from right to left.

c. What other information about the experiment or about the set-up can you determine based on the video and data given in the activity? List as many as you can, and determine or estimate their values. Indictae any assumptions that you made.

A.8 Decide

Class or lab: *Equipment per group:* whiteboard and markers, a lens, and a light source (if available).

The figure below shows a convex lens and a point-like light source on the principal axis of the lens. The figure shows the relative size of the lens.



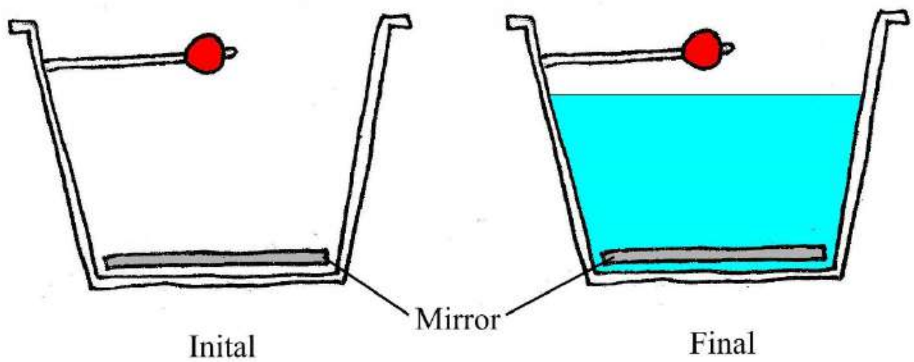
a. Using ray diagrams, determine what each observer in locations A, B and C sees (a point-like light source, its image, none of these,…).

b. Is there a location from which the observer can see the point-like light source and its image at the same time? If you think there is, draw a point at that location. If you think that such a location does not exist, explain why.

A.9 Experiment

Lab: *Equipment:* a water tank, a small ball (such as a float), a straw, a glue gun, a mirror at the bottom of the tank.

Using the straw and glue gun, fix a small ball on the side of a plastic tank as shown in the figure below. Put a mirror on the bottom of the tank as shown in the figure and observe the image of the ball that appears in the mirror. Then pour water into the tank and observe what happens to the image of the ball.



a. Work with your group members to predict how the location of the image of the ball changes as you add water to the tank. Your prediction should include ray diagrams.

b. Obtain the equipment and perform the experiment (in order to compare outcomes, you may need to take photos using a camera on a tripod, and compare them).

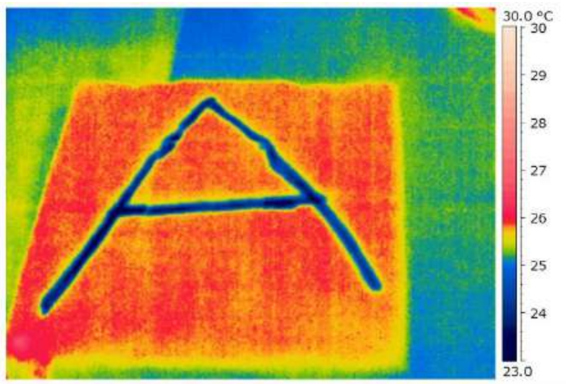
A.10 Reason

Class: *Equipment per group:* whiteboard and markers.

You have a Styrofoam square board, an alcohol-based black marker, a regular digital camera and an infrared (thermal) imaging camera. On a sunny summer day you perform the following experiments:

Experiment 1: The Styrofoam board and the marker have been in the same room for several hours. Put the Styrofoam board on the floor and draw the letter "A" on the board. Immediately after that, your friend takes two photos of the board, one with a regular digital camera (Figure 1) and one with a thermal camera (Figure 2). Two minutes later she takes another thermal image (Figure 3).

Figure 1



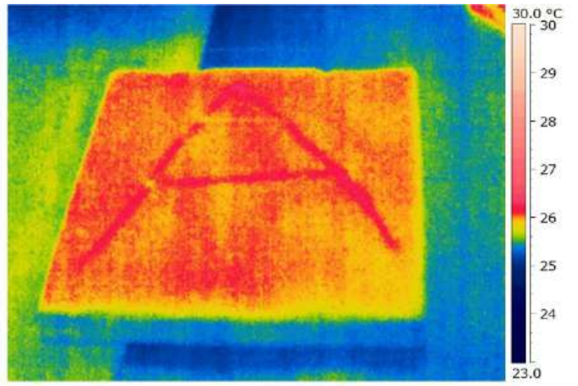


Figure 2 **Figure 3**

<u>Experiment 2</u>: (performed immediately after Experiment 1) Take the board out on the terrace and put it on the floor. Make sure the Sun is shining on the board. Two minutes later, your friend takes another thermal image (Figure 4).

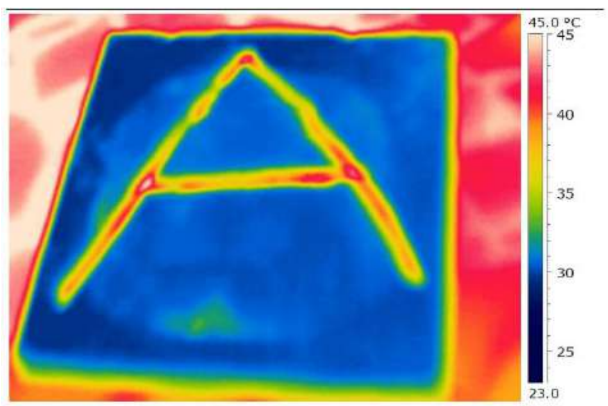


Figure 4

a. Estimate the average temperature of the Styrofoam board (on the parts with no ink), of the tiles and the carpet in the room, and of the terrace floor.

b. Based on Figure 2, describe how and where the temperature of the board changed right after it was painted with the black marker. Propose an explanation for the changes (note that the marker had been in the room for several hours before it was used).

c. Based on Figure 3, describe how and where the temperature of the board changed compared to the situation in Figure 2. Propose an explanation for the changes.

d. Based on Figure 4, describe how and where the temperature of the board changed compared to the situation in Figure 3. Propose an explanation for the changes.

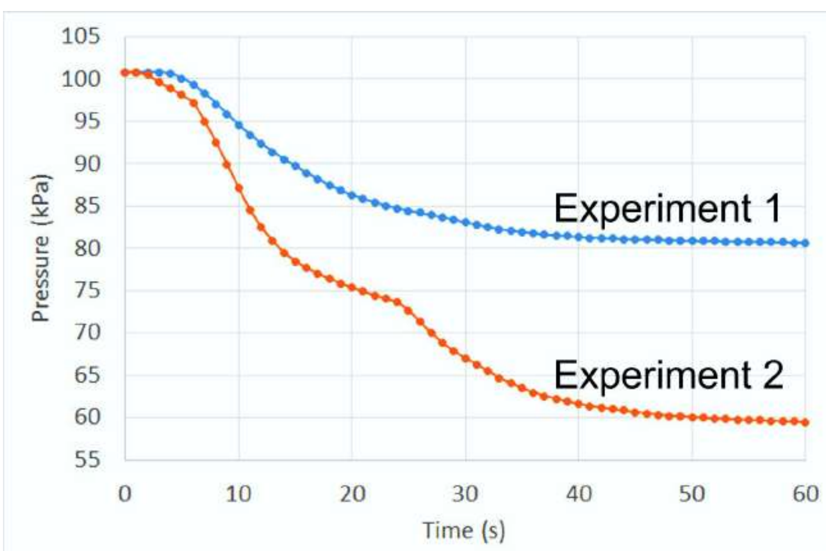
A.11 Reason, tell all…

Lab: *Equipment:* small glass bottle (in our case the total volume of the bottle is 370 ml), two bowls, teapot, gas pressure sensor with data acquisition device (see the photo on the right). Alternatively – no equipment, use the data in the problem.

Experiment 1: Put an open, empty, dry bottle in water that was just boiling for several minutes so that the bottle and the air inside the bottle reach the temperature of the water (hold the bottle in vertical position and make sure no water enters the bottle). Take the bottle out of the hot water, close the bottle with a cap that is connected to the gas pressure sensor and dip the bottle in a large bowl filled with water at $24\ ^\circ\mathrm{C}$. At the same time, start recording the pressure.

Experiment 2: Put an open bottle in water that was just boiling for several minutes so that the bottle and the air inside the bottle reach the temperature of the water. Then pour a little bit of the boiling water into the bottle. After a minute, take the bottle out of the hot water, pour out any water that was in the bottle, close the bottle with the cap that is connected to the gas pressure sensor and dip the bottle in the bowl filled with water at $24\ ^\circ\mathrm{C}$. At the same time, start recording the pressure.

Pressure-versus-time curves for both experiments are shown in the same graph below:



a. Discuss with your group members whether the gas inside the bottle in any of the two experiments can be modeled as an ideal gas undergoing an isochoric process. Support your judgment with calculations using the data that you can get from the graph. For the experiment(s) in which the process occurring to the gas cannot be described as an isochoric process, propose one or more explanations for why that is so. Propose also testing experiments that could reject one or more of your explanations and predict their outcomes based on the explanations under test.

The system is the gas inside the bottle. The initial state is when you close the bottle with the cap (t = 0) and the final state is when the gas pressure in the bottle reaches the final value (t = 60 s).

b. Compare the work done on the gas in both experiments. Explain.

c. Compare the change in internal energy in both experiments. Explain.

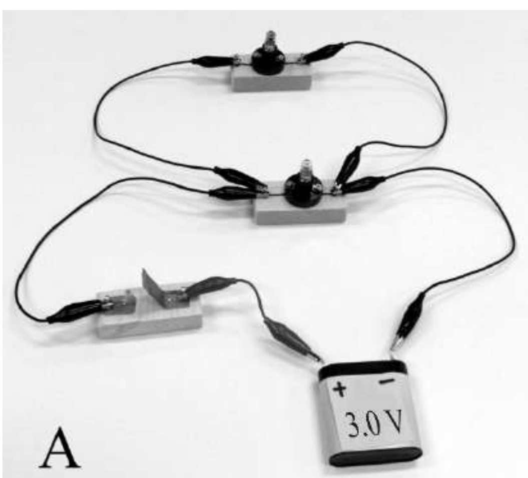
d. Compare heating provided to the gas by the environment in both experiments. Explain.

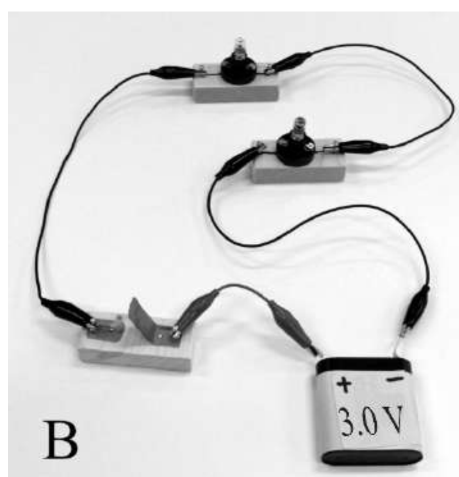
e. Represent both processes with energy bar charts.

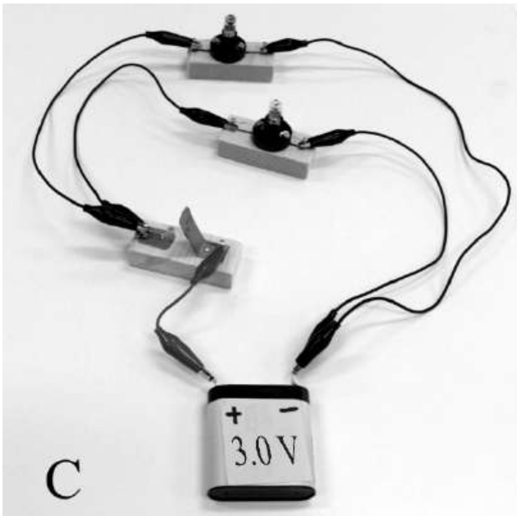
A.12 Represent

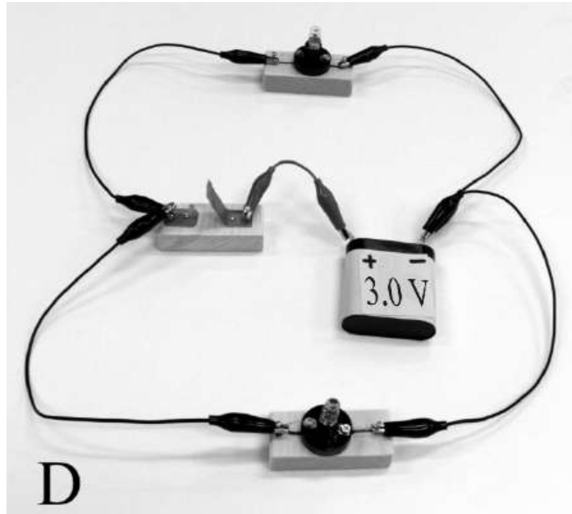
Class: *Equipment per group:* whiteboard and markers.

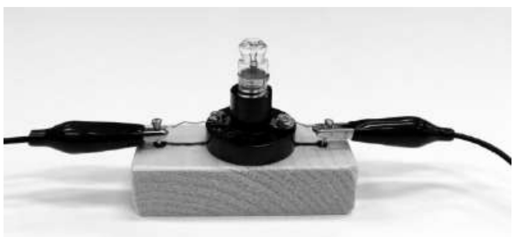
The photos below show four circuits. Every circuit has two identical bulbs, a switch and a battery with an emf of 3.0 V. The two photos at the bottom show a close-up view of the bulb holder and the switch.











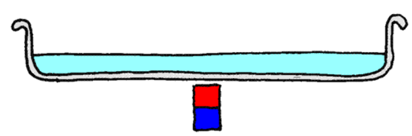
a. Identify which circuits are equivalent and draw a circuit diagram that represents them.

b. Draw a circuit diagram(s) for the remaining circuit(s).

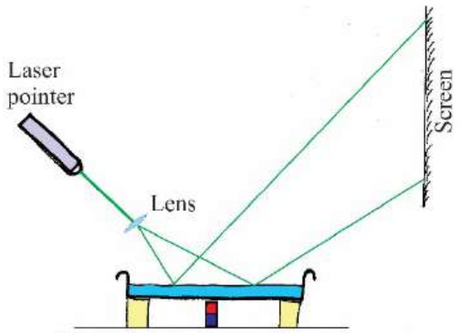
A.13 Represent, reason and explain

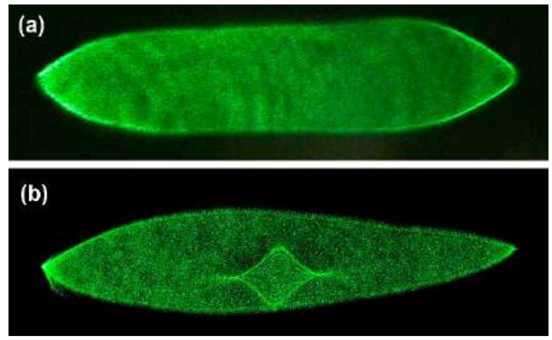
Class or lab:

Your friends are tasked to investigate whether the magnetic field of a bar magnet has any effect on the shape of the surface of water. They designed the following experiment.



They poured a small amount of water into a thin-walled plastic tray to make a shallow layer of water. They placed a small neodymium bar magnet under the center of the tray, as shown in the figure above. They decided to examine the shape of the water surface in the following way. They aimed a laser pointer at the water surface but they placed a small convex lens between the laser pointer and the tray to make the light beam divergent (see the figure on the left below). The photo on the right shows the pattern on the screen formed by the light that reflected from the water surface ((a) is without the magnet and (b) is with the magnet).





a. What can you deduce about the shape of the water surface based on the photos of the patterns that appeared on the screen? Discuss the answer with your group members and come to a consensus. Make a sketch of the proposed shape of the water surface and explain how the pattern on the screen is formed. Include ray diagrams in your explanation.

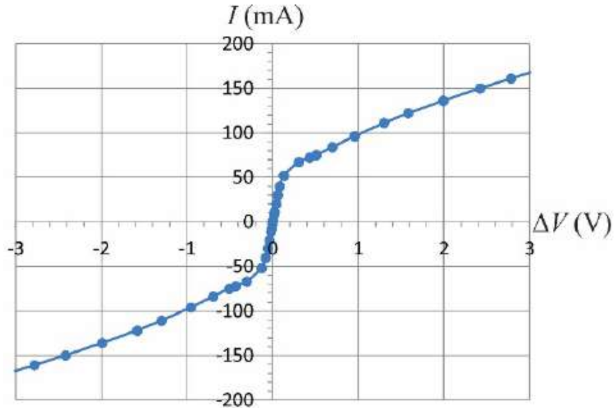
b. Is this finding consistent with the fact that water is a diamagnetic liquid? Explain.

c. Based on what you have learned about diamagnetic materials, predict what will happen to the pattern on the screen if you flip the magnet under the tray (so that the magnetic poles exchange places).

A.14 Apply

Class: *Equipment per group:* whiteboard and markers.

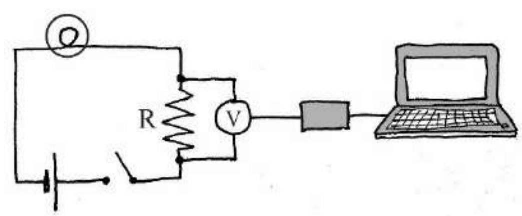
The figure on the right shows a I-versus-ΔV graph for an incandescent lightbulb that is used in battery-powered flashlights.



a. Compare and contrast the shape of the graph in the figure with a I-versus-ΔV graph for a commercial resistor. Give a qualitative explanation for the shape of the I-versus-ΔV graph in the figure.

b. Determine the resistance of the lightbulb filament when the current through the filament is 50 mA and when the current is 150 mA. Determine also the power output of the lightbulb at these two currents.

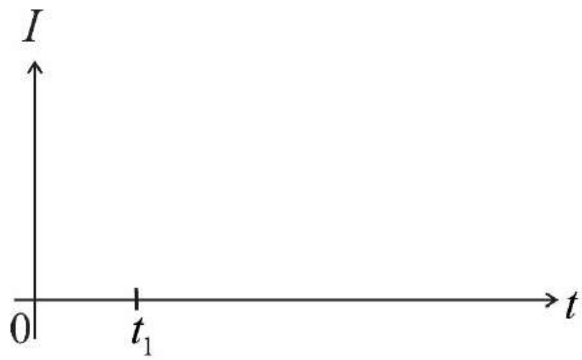
You connect the lightbulb, a 1.0 Ω resistor, a switch, and a battery as shown in the figure on the right. The switch is initially opened. You measure the time dependence of the potential difference across the resistor $\Delta V(t)$ using an interface and a computer.



You start measuring the potential difference at $t = 0$. At t_1 you close the switch.

c. Explain how you can use the $\Delta V(t)$ measurements to determine the time dependence of the current through the lightbulb $I(t)$. Your explanation should include a mathematical expression that allows you to determine the current at a particular time. Indicate any assumptions that you made.

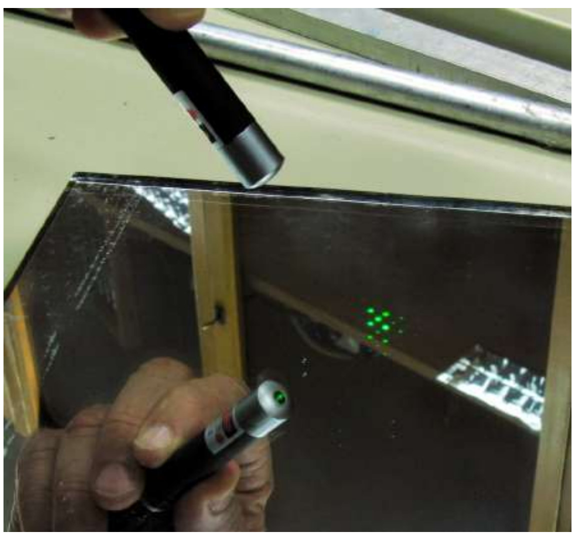
d. Predict: On the figure below, draw a qualitative graph of $I(t)$ that shows how the current through the lightbulb changes with time. Assume that the time interval between successive measurements of the current is sufficiently short so that even the fastest variations of the current are recorded in the graph. Remember that the filament of the lightbulb is cold before you close the switch and very hot when the lightbulb has been glowing for some time.

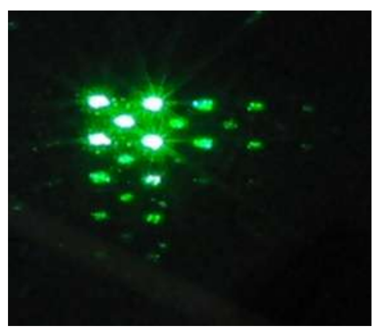


A15. Propose different explanations and test them

Lab: *Equipment:* green laser, plane mirror, and other equipment available on request.

If you shine a laser pointer on a regular plane mirror (ours was 5 mm thick) you will observe the pattern shown in the photos below (the photo on the right shows the magnified pattern).





a. How would you explain this observation? Discuss with your group members and make a list of possible explanations of the observed phenomenon.

b. Come up with ways to test the proposed explanations. What equipment do you need?

c. Design testing experiments, make predictions based on your explanations, conduct the experiments, compare the outcomes to the predictions, and decide how to proceed. You might need to repeat this process multiple times.