Springs and Energy

In this lab you will predict and measure the dependence of the elastic force on an object's stretch in two types of elastic systems: a metal spring and a rubber band. Then you will show that energy is conserved as a hanging mass attached to a spring oscillates up and down.

The Experiment:

Materials - poles and clamp, PASCO Dynamics System spring and Equal Length colored spring set (with different colors for different groups), rubber band, electronic balance, 10 and 20 g cylindrical masses, 50 g hanger, S-hook, two-meter stick, string, tape, calibration mass, rotary motion sensor, force sensor, motion detector, LabQuest interface and cables

<u>Part A: Measuring a spring constant</u>

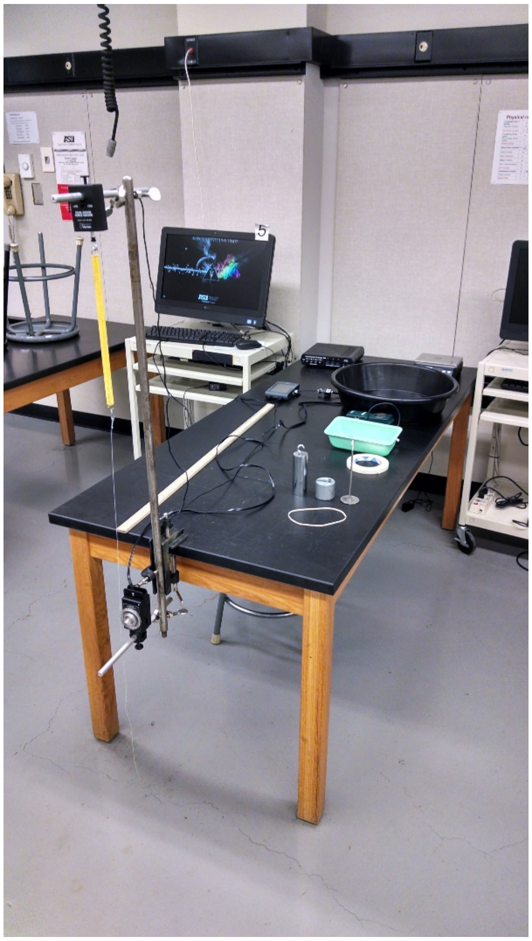


Figure 1 - The setup for Part A of the experiment.

<u>1)</u> Clamp the long pole to the edge of the table and clamp two shorter poles facing outward over the edge of the table as shown in Figure 1: one near the top of the long pole and the other near the bottom (beneath the clamp). Don't attach the sensors to the poles yet.

<u>2)</u> You should have two different springs as part of your setup, a short unpainted one and a long painted one. Let's call the short spring "Spring A" and the long spring "Spring B". Use the prediction sheet to draw two graphs for the relationship that you expect to see between the elastic force and stretch: one for both Spring A and Spring B (draw two curves on the same graph) and the other for the rubber band. You can hang these objects from the top bar and stretch them by hand to get an intuitive feel for how they differ, but ***do not stretch them too far*** or you will permanently deform them! Stretching them most of the distance between the top and bottom pole should be okay.

<u>3)</u> Hang Spring A from the top bar and place the 50 g hanger on the end of it. Although the spring is already stretched, let's consider this the initial equilibrium (or "zero") point. Measure and record the position of the bottom of the hanger. Now add small amounts of additional mass to the hanger (in increments of 10 or 20g) and record the position the hanger falls to each time. When you are satisfied with your data, open a new file in Logger Pro and plot the applied force on the spring (measured relative to the applied force at the initial equilibrium) versus the stretch of the spring (also measured relative to the initial equilibrium position). Fit a relationship to your data. Is it linear? What do your fitting coefficients physically mean?

4) Assume Spring A obeys Hooke's Law. Establish a simple expression for the spring constant k in terms of the stretch x, the hanging mass m, and the gravitational acceleration g. Find Δk, the measurement error in k, by applying error propagation techniques to your formula. Assume a measurement error in both m and x from the precision of the electronic balance and the meter stick. Choose a particular value of m and x that you measured to evaluate the measurement error in k. (Note: You can do this step later when you are writing your lab report).

5) We have taken a small set of discrete measurements for the force and stretch, but it would be more useful to have a continuous measurement of these quantities. To do this we can use the force sensor and the rotary motion sensor. As shown in Figure 1, place the force sensor on the top pole with the hook facing down, and the rotary motion sensor on the bottom pole with the wheel facing away from the table. Make sure they are aligned on top of each other.

6) Attach the rotary motion sensor and the motion detector to digital ports 1 and 2 of the LabQuest interface and the force sensor to analog port 1. Save your previous graphs and open the premade Logger Pro file on the Lab Share drive titled "Springs and Energy" in the "Physics > Majors > PHY 150" folder (it may be under a subdirectory). All three sensors should be recognized by Logger Pro in this file.

7) Make sure the force sensor switch is on the 10 N setting and calibrate it. As a reminder, right-click on the force sensor on the LabQuest configuration window and hit "Calibrate". Under the "Calibrate" tab, hit the "Calibrate Now" button. Make sure nothing is hanging from the sensor's hook and then add "0" as the first value and click "Keep". Now hang the known calibration mass on the hook and enter the corresponding number of Newtons being applied in the second box. After clicking "Keep" your sensor should be calibrated. Now check the rotary motion sensor calibration by making sure on the "Equation" tab of the sensor's calibration options you have selected "Rotary Motion Position <Computer>" and have set the diameter to 48 mm (the diameter of the larger wheel). Make sure to click "Apply" and then "Done".

8) Attach a long piece of string to the end of the spring and hang it from the force sensor. The string must be long enough to wrap around the largest wheel of the sensor below. Now "zero" both the force sensor and the rotary motion sensor when the spring is unstretched. To take data, hit "Collect" and pull on the string so it wraps around the bottom of the large wheel and up the other side (do this so that the wheel turns counterclockwise as seen from the front while you are pulling). As you pull, the spring will stretch and the wheel will turn simultaneously. Pull until the spring has stretched most of the way to the sensor, and then slowly loosen the pull so that you also record data as the spring relaxes to its unstretched position.

9) Plot the force on the force sensor versus the position of the wheel (which measures the stretch of the spring). For any part of your graph that looks linear, select that part of the data and fit a line. Physically interpret the slope and intercept of your fit(s). Does it differ at all from what you found in step 3?

10) Change the switch on the force sensor to the 50 N setting and repeat steps 8 and 9 with both Spring B and the rubber band. Fit lines to any part of your data that is linear. Does the graph for your rubber band differ from the graphs for Spring A and Spring B? Using the slope(s) of your fit(s) as a guide, describe what's happening to the stiffness during each part of the motion for all three objects. Why do you think the rubber band behaves the way it does?
11) In your lab report, use a %-difference to compare Spring A's spring constant to the 3.4 N/m value given by the manufacturer's specification. Estimate the measurement error in your value of the spring constant by using the error propagation formula.
12) Different groups have different colored springs for Spring B. Do these all have the same spring constant? Compare your spring constant for Spring B with that of other groups and see if the class can come to a consensus on what the stiffness of each colored spring is. Do this as part of your whiteboard session at the end of class.

Part B: Conservation of energy

1) Now remove the rotary motion sensor and the pole it is on. You will no longer need them. Turn the upper pole so that it is over the table and remove the force sensor. Place the motion detector facing upward on the table beneath the pole. Put the S-hook on the pole and hang Spring A from the S-hook. Add the 50 g hanger to the end of the spring. Your setup should now look like Figure 2, except using the smaller spring and without any extra mass on the hanger. You can calibrate the motion detector using the room temperature.

2) Use the prediction sheet to draw how the system's different forms of energy—gravitational, elastic, and kinetic—change as a function of height as the hanger falls from its highest point to its lowest point. Draw and label separate curves for gravitational, elastic, kinetic, and total energy.

2) Now hold the hanger on the spring up so that the spring is at its *unstretched* length and "zero" the motion detector. This will place the zero position at the bottom of the hanger when the spring has zero stretch. Now begin recording and release the hanger. The detector will record the position and velocity oscillations of the system for ten seconds.

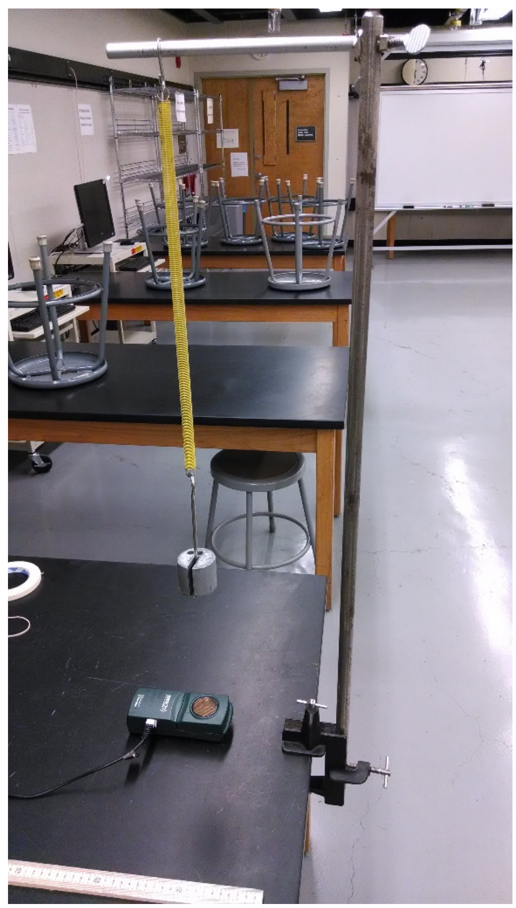


Figure 2 - The general setup for Part B with the spring and hanger over the motion detector lying on the table.

3) Show that the total mechanical energy in the system is conserved during this motion. Create calculated columns for the kinetic energy, elastic potential energy, and gravitational potential energy. Then create a column that calculates the total energy.

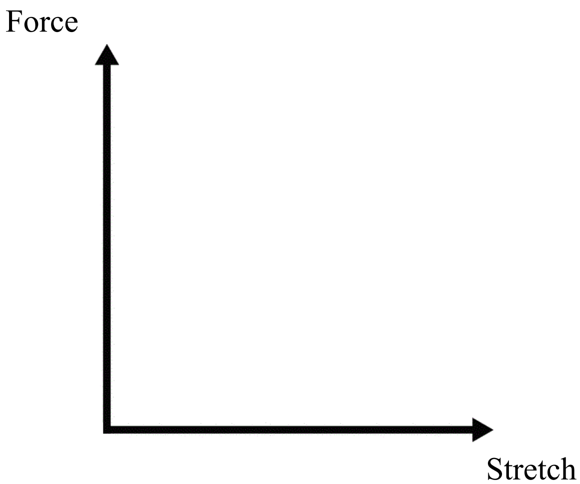
Plot all of these columns versus time on the same graph. Do a linear fit to the total energy. Is your slope zero? If not, can you explain why? Also, calculate the mean energy in your system over the whole time interval and quote this value in your report.

4) You can select your energy data and position data from a single oscillation where the system is going from its smallest stretch to largest stretch and make a plot of energy versus position to compare to your prediction graph. Depending on where you defined zero gravitational potential energy to be, your plot may differ from your predictions a bit.

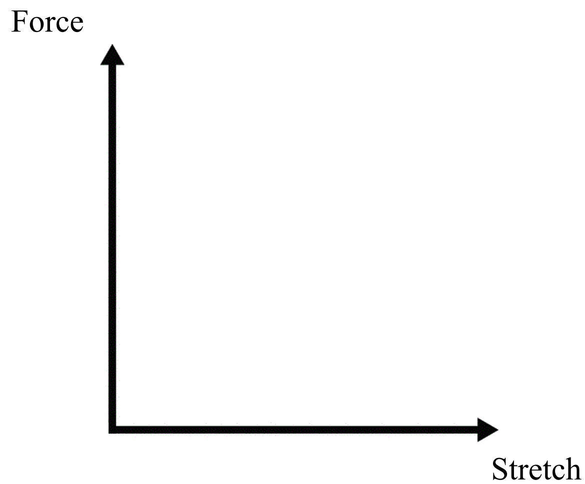
5) Report your group's results from today's lab on a whiteboard as part of a class discussion.

Predictions

For the two springs, extending and contracting



For the rubber band, extending and contracting



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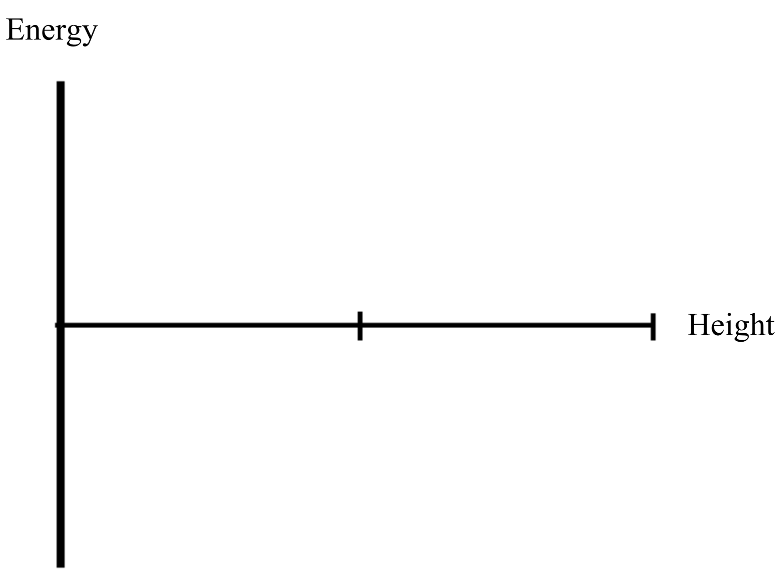
Gravitational, elastic, kinetic, and total energy vs. height below drop point for the system (assume height = 0 is highest point, the middle notch is the equilibrium point and the right notch is the lowest point in the motion)



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