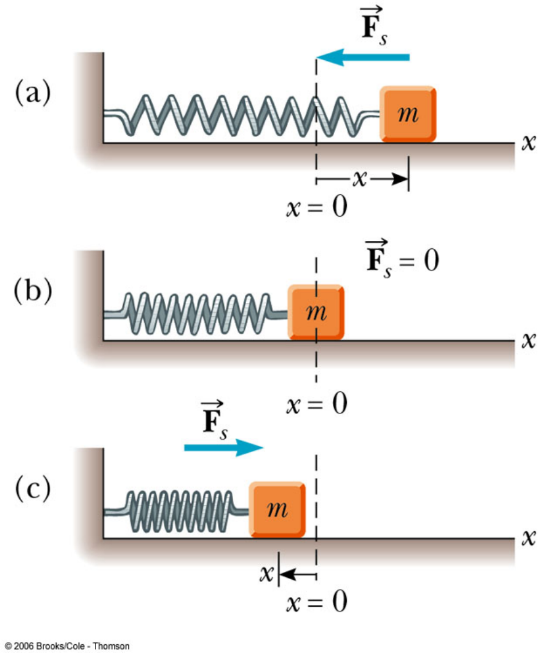
Introduction

The first two labs of Physics 1CL are based on the elastic properties of materials (Hooke's Law) and simple harmonic motion (SHM) as shown by a swinging pendulum and the oscillations of a mass on a spring. Please review Chapter 13 of Serway & Faughn.

For many "stretchy" materials, the amount of stretch is proportional to the stretching force (for fairly small stretches). In the figure, part (b) shows a mass attached to a spring, at and in equilibrium. The spring has its natural length, and is not exerting any force on the mass. In part (a) the spring is stretched by an amount x, and is pulling on the mass with force F_s to the left. As the distance x is increased, the force F_s increases in proportion. This relationship is known as "Hooke's Law", and materials for which this is true are called "linear" materials. In this lab, you will measure the elastic properties of a linear device (a spiral metal spring) and a non-linear device (an elastic band). Some springs (like the one in the figure) also allow for compression. In part (c) of the figure, the force is to the right, but still proportional to x, the amount of the compression.

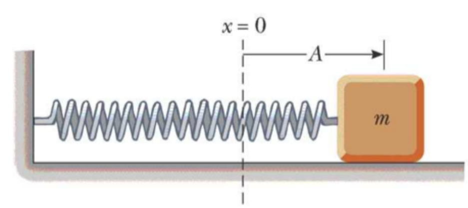


If we hang a mass on a spring, pull it down from its equilibrium position on let go, it will bounce up and down. If the spring obeys Hooke's law (the spring force is linear with displacement), we have a special type of oscillation called simple harmonic motion or SHM. This type of motion is found in many places in nature and is important to understand. We will start to explore some of the properties of this type of periodic motion.

Pre-Lab Questions:

1. *When you apply a 75 N force, a spring extends 20 cm. Assume the spring obeys Hooke's Law. What is the spring constant for this spring?*

2. *As above, when you apply a 75 N force, a spring extends by 20 cm. How much energy was required to stretch the spring assuming you started from its unstretched length? How much energy (in Joules) must you use to stretch is another 10 cm (from 20 cm to 30 cm)?*

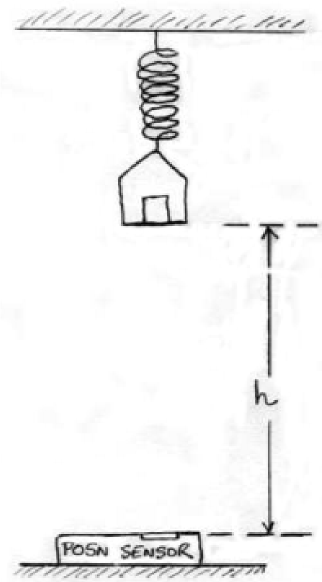


3. *Suppose you have a mass m attached to a spring with constant k. The mass rests on a horizontal frictionless surface. Its equilibrium position is at x = 0. It is pulled aside a distance A and released. What is the speed of the mass as it passes the position x = A/2 (in terms of k, m, and A)? (Hint: Use conservation of energy)*

Group Activity:

A group of students in a physics 1C lab measured the stretch of a spring by adding weights to the holder hanging at the end of the spring. Their goal was to measure the spring constant. They measured height to the base of the holder with a position sensor placed on the floor under the spring as shown in the diagram.
The table shows their data.

Total mass (grams)	Height (meters)
20	1.013
30	0.962
40	0.912
50	0.847



In your lab notebook, draw a graph of height vs. applied force. From the graph determine the "unstretched" height – i.e., what the sensor would read when no weight is attached. On another sheet of graph paper plot the extension of the spring (or amount of stretch from its natural length) vs. the applied force. For this graph, make the horizontal axis the spring extension and the vertical axis the force. Use the graph to find the spring constant. Sketch your graphs and explain your calculations on the group whiteboard for your TA to review, and be prepared to explain your procedures to the other lab groups.

Experiment A: Elastic Properties of a Spring

Attach one end of the spring to the support and the other end to the holder for the masses. Place the position sensor on the floor vertically beneath the holder. Check that the position sensor measures the position of the holder and not the lab table or any other nearby object. Using the position sensor, measure the height to the base of the holder. Add masses in increments of 10 grams, wait 10 sec for the system to settle, and then measure the height after each mass addition. Do not exceed 50 grams.

Remove the masses in increments of 10 grams and measure the height after each mass subtraction. Plot a graph of force vs. height showing all your data. Does the spring have the same behavior as F increases as when F decreases? Is the graph a straight line? Does the spring obey Hooke's Law? Draw the best straight line through your points and using the procedure from the group activity calculate the spring constant. Calculate the energy needed to stretch the spring to the longest value you have plotted. Can this energy be used to do mechanical work when the spring contracts again?

Experiment B: Elastic Properties of a Rubber Band

Repeat Experiment A using a rubber band. However this time instead of starting with 10 grams, start at 50 grams and increase by increments of 10 grams, 10 grams, and then 20 grams. Wait 10 seconds for the system to settle after adding or removing masses. Again, measure as you increase the mass, and as you decrease the mass back to the starting value. Does the rubber band have the same behavior when F increases as it does when F decreases?

As in Experiment A, make a plot of force vs. length. Show where you are increasing the stretch and where you are decreasing the stretch. Calculate the average spring constant. Comment on the differences between your graphs for the rubber band and the spring. Calculate the amount of energy needed to stretch the rubber band to the longest value you have plotted and the energy you get back as the rubber band contracts again. Do you get back the same energy that you put in? If not explain where the energy went, or the extra energy comes from.

Experiment C: Investigating the "Restoring Force" on a Pendulum Bob

1) Introduction:

When you have a mass on a string (like prelab question 3) and pull it aside and then let go, the mass swings back and forth in an arc. If frictional forces are low and the amplitude of the swing is not too large, the motion is typical of a very special and frequently found type of oscillatory motion called "Simple Harmonic Motion" or SHM. In SHM, the "harmonic" part refers to the fact that the displacement of the mass as a function of time (measured from its center position) is proportional to a sine or a cosine wave. A cosine wave changes value smoothly from +1, to zero, to –1, back to zero, and so on indefinitely. The pendulum bob swings from its max positive position to zero, to its max negative position, back to zero etc., over and over again. Therefore, the position as a function of time is given by:

$$\text{position} = \text{amplitude} * \text{cosine}(\text{constant} * \text{time})$$

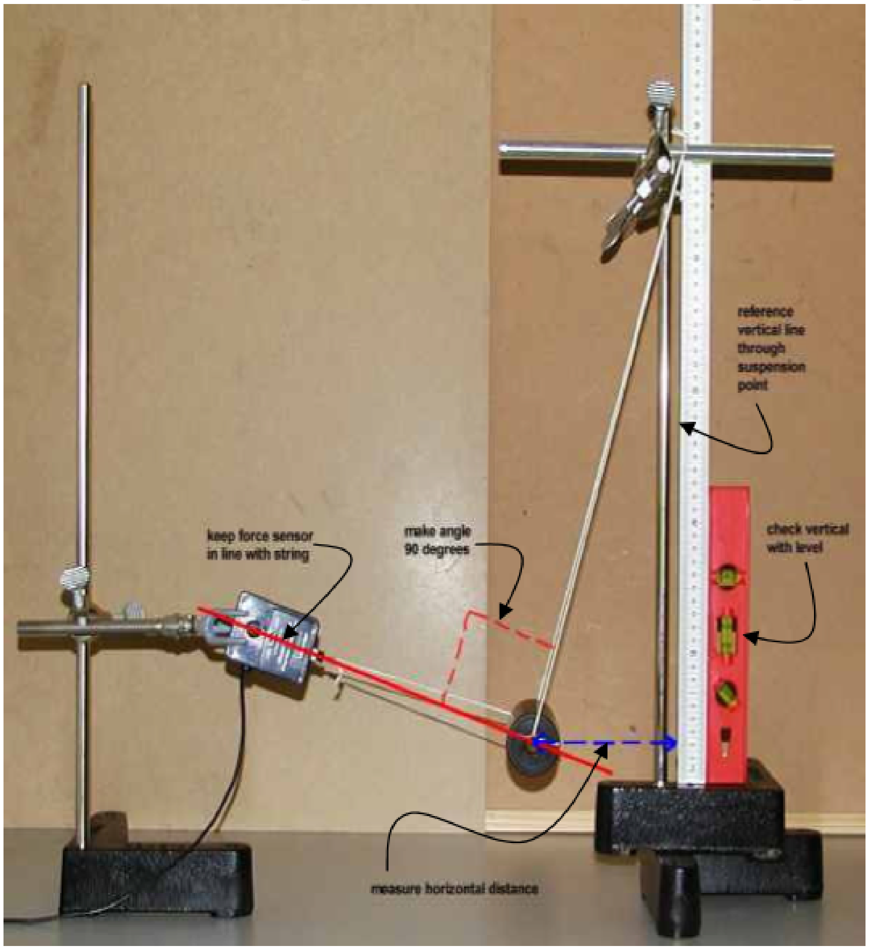
This is usually written as:

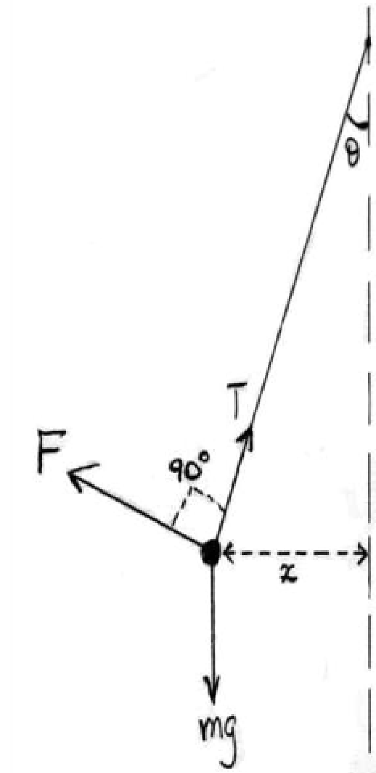
$$x = A\cos(2\pi f t)$$

where A = amplitude and f = linear frequency. You should refer to section 13.5 of the text for mathematical details of the motion.

In order for motion to be an oscillation about a central position there needs to be a net force that tends to make the object move back to the center. On each oscillation the object overshoots, comes to a stop, returns, and overshoots again. This net force is called a ***restoring force***, as it always tries to restore the object to its equilibrium position. If the oscillation has the exact mathematical form of SHM, then the magnitude of the restoring force is proportional to the object's displacement from its equilibrium position. This experiment will allow you to measure how the restoring force on a pendulum bob changes with the pendulum angle from the vertical. From this, you should be able to determine if the motion of the pendulum should be SHM.

We will hold the pendulum bob aside with a force *F* perpendicular to the pendulum's support string. The force *F* does not change the value of the tension, and balances the restoring force so the system is in equilibrium.





2) Force Diagram Analysis:

In the diagram above, assume the string has length L.

- Draw a force diagram for the mass.
- Express the angle θ in terms of x and L.
- Express the tension T, and the force F in terms of the mass and angle.
- Finally express F in terms of x.

3) Procedure:

- Set up the apparatus as shown in the photograph. Hang the mass by a string from the support bar. Measure the string length from the support to the center of the hanging mass.
- Using the level, establish a vertical reference line (the white ruler) through the point where the string is fastened to the support at the top. Pull the mass away from vertical with the cord attached to the force sensor.

- Adjust the angle of the force sensor and its cord to be in line with each other and at right angles to the string supporting the mass.
- Measure the horizontal distance from the center of the mass to the vertical reference line with a ruler.
- Manually support the mass so that the cord to the force sensor is slack, then set the zero point on the force sensor. Gently let the mass hand on the string again and measure the force in the cord to the force sensor. You now have a pair of values, force and distance.
- Repeat each of these steps for four different distance values.
- On graph paper make a plot of force vs. position, x. Draw the graph to scale, label the axes. Do the data points make a straight line? Do you expect a straight line?
- Compare the slope to the expected value and explain any discrepancies.

Conclusion:

1. *Please do a write-up for the section of the lab that your TAs specified. You can download an example off the class website.*