7. Pendulums and Springs

This week the laboratory procedure will be different compared to what we normally do. Instead of all the class doing the same experiment we shall spread our effort and look at two different but somewhat similar experiments. Half of the class will study motion of the simple pendulum, while the other half will be looking at the behavior of springs. As you work through your experiment today, keep in mind that next time you will present your work to the people from the other half of the class, who have not done this experiment and will not be familiar with your results. So, think about the best way you can present your findings to make them accessible to your fellow students.

The following are the descriptions of both experiments. Before coming to the lab read through both and think which of the two experiments you will be interested in doing.

I. A Simple Pendulum

A pendulum is an object suspended from a point in such a manner that it can swing in an arc of a circle. A simple pendulum is one in which all of the mass is concentrated in a point at the end of a massless cord. Obviously, simple pendulums do not exist. However, we may make a real pendulum that approximates the ideal simple pendulum by using a very light string with a (relatively) large mass at the end.

1. Do all pendulums swing at the same rate? If so, can you find the guiding principle which determines this rate? If not, what variable(s) determine the rate? Come up with your own list of variables before coming to the lab and be ready to test it when you are there.

2. The motion of a pendulum is an example of periodic motion. Another example of periodic motion, which we have already discussed, is rotation. Recall what physical quantity is called period and what physical quantity is called frequency. What is the frequency of a grandfather clock’s pendulum? The period? Are you sure?
Investigate the behavior of a simple pendulum and the factors which govern the period of its oscillations (see Sec. A.6). In order to measure the period, set up the motion sensor in such a way that it either registers the position of the pendulum bob all the time or catches the position of the bob as it crosses the sensor’s field of view.

Three factors that we might expect to have an effect on the period are the amplitude of the swing, the mass of the pendulum’s bob, and the length of the pendulum. Using the guidelines below, investigate the amplitude, the mass, and the length independently --- vary one while holding the other two constant. Before carrying out the experiments, write down your predictions of which variable(s) will affect the period and why they will have an effect.

3. How will you measure the amplitude of the swing? At first, focus your attention on small and medium amplitudes, then try to do one very large amplitude. Does it look like that there is a difference between the case when all the amplitudes are small and when you have the large amplitude? If so, try to find the boarder line between the “small” and the “large” amplitudes. Use the small amplitudes for the rest of the experiment.

4. Be sure to record the value of all three variables while varying any one of them.

5. Measure the period a few times for each configuration according to Sec. A.6.

6. Note that the length is measured from the pivot point at the top to the center of mass of the bob.

7. Vary each parameter over several (more than four) values. If you suspect that the period does not depend on a variable, use a few widely spaced values. If you then find that the period does depend on that value, take more data points in between these values. Be organized and present your data in order of the values not in the order taken.
8. On all graphs, place $T$ on the horizontal in units of seconds per radian rather than seconds per oscillation.

9. Except for the large amplitude trial, do you observe any relationship between the amplitude and the period of the oscillations? Plot a graph if necessary.

10. Do you observe any relationship between the mass and the period? Plot a graph if necessary.

11. Do you observe any relationship between the length and the period? Plot a graph if necessary.

You should have one graph for each parameter that affects the period of oscillation.

12. What shape is each graph drawn? Write the equation (with coefficients from the trendline) which best fits your graph. Figure out the units of each coefficient.

13. What would a vertical line indicate?

14. One of the coefficients in your trendline equation should be a familiar quantity. What quantity is it? What value do you find?

Hint: What causes a pendulum to swing?

Solve the equation that contains the familiar quantity for the period in units of seconds per oscillation (not seconds per radian). You have just derived the equation for the period of a simple pendulum.

If you have time left, design a pendulum for each period of 0.25 sec, 1 sec, and 1 min. Design a pendulum which has the same frequency as your pulse. Test your designs.
II. The Behavior of Springs

All springs stretch when pulled. The amount of stretch (the extension) is clearly related to the amount of force exerted to stretch (or compress) the spring. We are going to discover the specifics of this property.

Hooke's Law describes the relationship between the extension of a spring, \( x \), and the force required to cause the extension, \( F \). We can set up the force sensor and the motion sensor so that we can find the relationship between \( F \) and \( x \). Think about the best way to do this.

Aside: We have not used the force sensor until this point. You can set it up by plugging it in to GLX in the same way as you usually do with the motion sensor. Make sure to zero out the force sensor before taking any measurements. The sensor gives positive readings of force if you push on it and negative readings of force if you pull on it. All the readings are given in newtons (N).

Take several readings of force for various extensions of the spring. You can measure extension either with the motion sensor or with a regular meter-stick/ruler. Plot the force versus the extension. Repeat your experiment with two other springs. Label each graph according to the color of the spring.

1. What do the graphs look like?

2. Use Excel to find the equation of the best trendline; this relationship (equation) is known as Hooke's Law. What are the coefficients in Hooke's Law? If you think it should be linear, then find the uncertainty on the slope and intercept (Recall Excel-Lab). Otherwise, simply note the equation and the shape of the trendline.

You have just experimentally derived Hooke's law for your springs. Each spring has characteristic coefficients. In the equation of the trendline, the coefficient of the linear
term is denoted \( k \) and is known as "the spring constant." \( k \) is a measure of the stiffness of the spring.

3. What are the units of the spring constant?

Measure the spring constant from the graph for each of your springs. Be sure to match the values of the spring constants to the springs of the correct colors.

When a mass bounces on a spring, it oscillates in periodic manner. Another example of periodic motion, which we have already discussed, is rotation. Recall what physical quantity is called period and what physical quantity is called frequency.

Investigate the behavior of a spring pendulum and the factors which govern the period of its oscillations (see Sec. A.6). In order to measure the period, set up the motion sensor in such a way that it either registers the position of the mass on the spring all the time or catches the position of this mass as it crosses the sensor’s field of view.

Think about what factors may affect the period of oscillations of a mass on a spring and how you can design an experiment to test your predictions.

Two factors that we might expect to have an effect on the period are the stiffness of the spring \( k \), and the mass \( m \) attached to the spring.

Using the guidelines below, investigate how the mass may affect the period.

Measure the oscillation period \( T \), associated with several small amounts of mass (on the order of 200 grams or so). **Note:** the oscillating mass should be displaced only slightly from the equilibrium position. A large initial displacement can change the attention of the lab from periodic motion to projectile motion… which would be bad.
Plot $m$ versus $T$, where $T$ is measured in units of seconds per radian, not seconds per oscillation.

4. What shape is your graph? Write the equation (with coefficients from the trendline) which best fits your graph. Figure out the units of each coefficient.

5. One of the coefficients in your trendline equation should look familiar. What value does it remind you of? To check your hypothesis, repeat your experiment with two other springs. Are your results consistent?

Aside: Solve this equation for the period in units of seconds per oscillation (not seconds per radian). You have just derived the equation for the period of a spring.