A Pendulum and a Pulse

Pre-Lab: Galileo, Springs, Pulses

A Bit of History

Though you may not appreciate it, a ball on a string's an incredible thing. Until the 1930's, the pendulum clock was the most accurate timepiece ever created. Léon Foucault used a very long pendulum to demonstrate the rotation of the earth. And Newton used a pendulum to test the Equivalence Principle, which would become one of the postulates of Einstein's theory of general relativity a couple centuries later. These are just three examples of the greatness of this seemingly simple apparatus.

Before all of these came Galileo, the first person to do rigorous scientific studies on the pendulum. Most of the properties of pendulums that introductory students discuss in the 21st century were fleshed out by Galileo at the beginning of the 17th century. His student and biographer Vincenzio Viviani wrote of how Galileo first became interested in the pendulum. Roger G. Newton recounts the tale in his book *Galileo's Pendulum*:

> He was seventeen and bored listening to the Mass being celebrated in the cathedral of Pisa. Looking for some object to arrest his attention, the young medical student began to focus on a chandelier high above his head, hanging from a long, thin chain, swinging gently to and fro in the spring breeze. How long does it take for the oscillations to repeat themselves, he wondered, timing them with his pulse. To his astonishment, he found that the lamp took as many pulse beats to complete a swing when hardly moving at all as when the wind made it sway more widely.

While this basic story is easy to find in the literature, it is almost always accompanied by the disclaimer that it is not true.

Springs

This lab is about the pendulum, but your Pre-Lab exercises will concern a mass-spring system. It turns out that for small oscillations, both pendulums and mass-spring systems undergo simple harmonic motion. What that means for the pendulum is that if you plot the angle as a function of time, you get a sinusoidal wave. For the mass-spring system, if you plot the position of the mass as a function of time you will see a sinusoid.

The oscillations of a mass-spring system can be described using just a few variables:

- m, the mass of the mass
- k, the force constant of the spring
- A, the amplitude of the oscillation
- T, the period of oscillation
- f, the frequency of oscillation (or ω, the angular frequency of oscillation)

What follows is a little virtual experiment where you will briefly explore the relationships among some of these quantities.

Do This: Go to the Pre-Lab links page on the lab website to find the PhET Masses & Springs simulation. Get the applet up and running on your computer.

Do This: In the top right corner of the applet window is a slider that controls friction. To make things easier, turn the friction all the way down to "none".

Do This: In the bottom right corner of the window there is a checkbox next to the word "Stopwatch". Check that checkbox.

Do This: Connect the 250-g mass to Spring 2 using your mouse. Get the mass oscillating.

PL1. What is the period of the oscillation? Explain your procedure.

PL2. Using your response to PL1, what is the frequency of the oscillation? Show your work.

PL3. Using your answer to PL1 or PL2, what is the angular frequency of the oscillation? Show your work.

PL4. Using your answer to PL1, PL2, or PL3, what is the force constant of Spring 2? Show your work.

PL5. Why don't the directions above instruct you to use the ruler to make sure the oscillations have a specific amplitude?

Read This: This particular applet can help you learn a lot more about springs. For example, you could explore Hooke's law or the beautiful ballet of energy transformations that take place as the mass oscillates. We won't force you to do any of that, but don't forget that this resource is out there.

Pulses

We now move from springs to hearts. It turns out these two topics are not as unrelated as they may seem at first glance. Though we won't discuss it here, a beating heart can be modeled as a mass on a spring with some damping. In this lab, it will be highly important for you to know how to check your pulse. In case you don't know how to perform this important life task, never fear! We are here to help you out!

Do This: Read the article found on the Pre-Lab Links page. Then answer the following questions.

PL6. When is your heart rate slowest? Fastest?

PL7. Which finger should you NOT use to check your pulse? Why?

PL8. According to the National Institutes of Health, USA, what is the typical pulse rate for your age group?

Read This: Now it's time to check your pulse!

PL9. Check your pulse at your wrist over a period of *30 seconds* according to the instructions given in the article. Record your heart rate.

PL10. Now check your pulse at your wrist over a period of *60 seconds* according to the instructions given in the article. Record your heart rate.

PL11. Try to find your pulse in another location and record your heart rate for a 30- and 60-second period. Make sure to record the location you use as well.

PL12. Do the four rates fall in the same general vicinity? If not, why might this be the case?

Read This: In addition to traditional heart rate monitors, new technology is also emerging which makes monitoring your heart rate extremely easy. A particularly fascinating development is an app that can use a webcam to check your heart rate! If you're interested, there are optional links on the Pre-Lab Links page that will direct you to information about this app.

Part I: Your Pendulum and Your Pulse

The Story

Apocryphal stories like Galileo's chandeliers are not uncommon in the history of science (think Newton's apple). Even though we know this particular story isn't true, it's interesting to ask ourselves if it *could* be true. Can a pulse actually be used as a timer to discover the properties of the pendulum?

Equipment

- **6 Pendulum bobs (wood, white plastic, black plastic, aluminum, steel, brass)**
- **Thread**
- **Scissors**
- **Protractor**
- **Meter stick**
- **Digital scale**
- **Support stand**
- **Tape**

1. Your Experiments

1.1. Devise, execute, and analyze an experiment to answer the question "How does varying _____ affect the period or frequency of a pendulum?" But there's a twist: you may only use your pulse to keep time. That is, **your heart is your only clock**. **You may in no way refer to any other clocks as you do your experiment.** (That means you **may not** act like you know your pulse rate from the Pre-Lab because you used a clock to find that.) Remember that your TA needs to be able to clearly follow your procedure, analysis, and conclusions. With that in mind, a good answer should contain the following:

a) A clear statement of what relationship is being studied.
b) A clear statement of your hypothesis.
c) A clear description of your procedure.
d) Diagrams that show your setup and give an indication of what any variables mean.
e) Data tables that organize your measurements in a clear way. The independent variable should span as wide a range of values as is reasonable given the available equipment.
Plot
f) A plot that makes your data easy to understand. Curve fits could be nice.
g) A conclusion in several sentences of English. Don't forget to answer the question posed at the end of The Story by referring to your results.

Your answer should be clear and complete. It does not necessarily need to be long.

Plot
1.2. Repeat Step 1.1, but choose a different property to modify. You are still answering the question "How does varying _____ affect the period or frequency of a pendulum?" but you are filling in the blank with a different word.

1.3. In this lab you used a timepiece with a large uncertainty. How did you design your procedure to reduce the uncertainty in your results? Explain.

Head-Scratchers

Don’t forget to complete the following problems. They should be at the end of your lab report. If you want to work on them during lab, start a new page in your lab notebook.

- 1.3