PHYSICS

LAB 9

SP211

Simple Harmonic Motion (SHM)

I. Introduction

Simple harmonic motion (SHM) is a phrase that is used for oscillatory motion where the displacement, velocity, and acceleration are sinusoidal.

In this lab we will study three oscillating systems that exhibit nearly ideal simple harmonic motion...Physical Pendulum, a Simple Pendulum, and a Simple Harmonic Oscillator (mass on a spring). In addition, we will study damped oscillator motion by adding a significant amount of air resistance (drag) to one of the systems.

II. Objectives

At the end of this activity, you should:

1. Be able to calculate and observe the period of a Physical Pendulum.

2. Be able to calculate and observe the period of a Simple Pendulum.

3. Be able to calculate and observe the angular frequency and period of a Simple Harmonic Oscillator.

4. Observe the effects of damping on a Oscillator.
III. Needed Equipment

Your instructor will show you the experimental setup, which consists of:

The oscillating systems that we will study are a simple pendulum, a physical pendulum, and a mass on a spring. The simple pendulum consists of a mass hanging from a string. The physical pendulum is a hinged metal meter stick. The simple oscillator will be a mass (rubber stopper) attached to a spring; for the damped oscillator we will attach a paper disk via Velcro to invoke the drag force for damping.

In addition, you will need to connect the motion sensor (MS) to the Lab-Pro and set up Logger-Pro so that we can graph the cosine wave produced in SHM.

IV. Turn in your Pre-lab/homework problem if assigned.

V. Discussion

The paradigm for SHM is a mass \( m \) on a spring with spring constant \( k \). The force the spring exerts on the mass is a linear restoring force: Its magnitude increases linearly with displacement away from equilibrium, and it always points toward the equilibrium position: \( F = -kx \). We’ve seen that SHM can be represented as \( x = A \cos(\omega t + \phi) \), with \( \omega = \sqrt{\frac{k}{m}} \). The amplitude \( A \) and the phase constant \( \phi \) depend on initial conditions.

Another example of SHM is a pendulum swinging with small amplitude: For the pendulum, \( \omega = \sqrt{\frac{mg}{l}} \), where \( m \) is the total mass of the pendulum, \( l \) is its rotational inertia about the pivot point, and \( h \) is the distance from the pivot point to the pendulum’s center of mass. If we measure the angular frequency or period of a pendulum for which we know the mass, rotational inertia and distance from the pivot to the center of mass, we can measure the local value of \( g \).

Your instructor will demonstrate the experimental setup, the required procedures, and how to take data.
VI. Procedure

A. Experiment I: Physical Pendulum Aluminum meter stick

A.1. Preliminary Data: Measure the mass and length of your physical pendulum, and calculate its rotational inertia about its center of mass. Attach the pivot so that the pivot point is about ten percent of the length from one end, and measure carefully the distance from the pivot to the end. Then use the parallel-axis theorem to calculate the physical pendulum’s rotational inertia about its pivot. Don’t forget the uncertainties.

A.2. Using a wristwatch or the clock on the wall in the lab, measure the time for as many oscillations as you can, and calculate the period. Repeat five or six times, calculate the average and the uncertainty.

A.3. Data Analysis:

Use your data to determine the local value for $g$. Does your value for $g$ agree with 9.81 m/s$^2$? Does it agree with the value of 9.80 m/s$^2$ that our textbook uses? Is this measurement sensitive enough to exclude either value?

B. Experiment II: Simple Pendulum

B.1. A “simple” pendulum is a mass at the end of a very light string, so the rotational inertia is very easy to determine.

B.2. Use the same method outlined in part A.2 above to measure the local value of $g$ with a simple pendulum. Don’t forget uncertainties.

B.3. Data Analysis:

Does your value for $g$ agree with 9.81 m/s$^2$? Does it agree with the value of 9.80 m/s$^2$ that our textbook uses? Is this measurement sensitive enough to exclude either value?

C. Experiment III: Simple Harmonic Oscillator

C.1. Preliminary Data: Measure and record the masses $m_{spring}$ of your spring, and $M$, of your black rubber stopper. Don’t forget the uncertainties. You may use the spreadsheet template I sent you by e-mail.
C.2. Measure the Spring Constant: Attach a mass hanger to the end of a spring, and hang the spring from a support so that the mass can oscillate up and down. Measure the spring constant by plotting the coordinate of the bottom of the mass hanger as a function of the weight of the hanger as you add mass to the hanger. Do the plot in Excel, and use LINEST to find the slope and its uncertainty.

C.3. Prediction of the Period: When a mass is oscillating on a real spring, part of the spring oscillates with the mass. We won’t prove the theorem here, but the correct expression for the angular frequency of the oscillation is \( \omega = \sqrt{\frac{k}{M + \frac{1}{3}m_{spring}}} \), that is, you have to add \( \frac{1}{3} \) of the spring’s mass to the mass hanging from the spring.

Predict the angular frequency and period of oscillation for your mass and spring.

C.4. Replace the mass hanger with your black rubber stopper. Set up a motion sensor so that you can measure the motion of the black rubber stopper as it oscillates. (Experiment -> Set Up Sensors; Experiment -> Data Collection; and File -> Settings for Untitled.) Bring the black rubber stopper to rest and then zero the motion detector. Set the rubber stopper into motion, and measure the motion with the motion sensor. Annotate the graph. Using your cursor, measure the time for 7 - 10 complete oscillations (more is better), and from that, find the period and angular frequency, with uncertainties.

Data Analysis:

C.5. Compare your predicted and measured angular frequencies: Do they agree within the experimental uncertainties?

C.6. Using the cursor in Logger Pro, or by examining the data table, find the position and velocity of the black rubber stopper at one instant in time. From these data, find the value of the phase constant, \( \phi \). Use the graph or data table to find the amplitude of the oscillation. Then write equations that describe the position, velocity, and acceleration of the black rubber stopper as functions of time.
D. Experiment IV: Damped Oscillator

Attach the paper disk to the rubber stopper and observe damped oscillations. Notice that the amplitude of oscillations is lowering with each cycle and also notice that there is a definite difference in the frequency of oscillations too. There is nothing to graph or write for this section it is purely observational.

VII. Lab Report to Hand In:

A. The data sheet which shows your measurements and calculations for the Physical Pendulum experiment from Part A. Don’t forget the uncertainties, and remember to add the discussion mentioned in A.3.

B. Data sheet for the Simple Pendulum experiment in Part B. Don’t forget the uncertainties, and remember to add the discussion mentioned in B.3.

C. Graph showing the motion of black rubber stopper form Part C.4. Don’t forget to annotate the graph. Do the calculations in Part C in the spreadsheet template provided. Discuss agreement (Paragraph C.5) and write the equations (C.6) below your calculations.

VIII. Clean-Up

A. End of Lab Checkout: Before leaving the laboratory, please tidy up the equipment at the workstation and quit all running software.

B. The lab station should be in better condition than when you arrived and more importantly, should be of an appearance that you would be PROUD to show to your legal guardians during a “Parents Weekend.”

C. Have your instructor inspect your lab station and receive their permission to leave the Lab Room.

D. You SHALL follow this procedure doing every lab for BOTH SP211 and SP212!

Many thanks to Dr. Huddle for his assistance in producing this Laboratory procedure; specific references can be supplied on request. LCDR Timothy Shivok