PHYS 2425
Engineering Physics I

EXPERIMENT 10
ARCHIMEDES' PRINCIPLE

I. INTRODUCTION

The objective of this experiment is to study Archimedes' principle by measuring the weights of various objects in air and in water and measuring the weight of the displaced water to see if the data are in agreement with this principle. Archimedes' principle states that "an object wholly or partially submerged in a fluid experiences a buoyant force upward equal to the weight of the displaced fluid". Algebraically

$$F_B = \rho_{fl} V_{sub} g \tag{1}$$

II. APPARATUS

Triple beam balance, beakers, various objects, supply of water.

III. EXPERIMENTAL PROCEDURE

1. Place the digital balance on a lab jack. Make sure the balance reads zero.
2. Raise the lab jack and hang one of the objects from a hook connected to the bottom of the balance and read the mass of the object and calculate its weight. This is the weight in air. The real weight.
3. Place the beaker with the spout under the object. Fill the beaker with water until the water runs out of the spout. Have a container ready to catch the water.
4. Lower the object into the water while catching the displaced water with a graduated cylinder. This should be done very carefully so as not to spill or splash any water outside. Continue lowering until the object is completely submerged.
5. Take the reading of the digital balance and calculate the (apparent) weight of the object. This is the weight of the object submerged in water.
6. Using the digital scale, measure the mass of the displaced fluid and calculate its weight. Don't forget to subtract the mass of the graduated cylinder.
7. Repeat the above process for the other three objects. Each time dry off the inside of the graduated cylinder.

IV. ANALYSIS

1. Calculate the buoyant force by subtracting the weight of the object under water from the weight of the object in air. Draw a force diagram for the object in air and in water and show that the buoyant force is the difference between the two weights.

2. Calculate the weight of the displaced fluid.

3. Compare these two quantities by calculating the percent difference between them.

4. Write a conclusion summarizing your results. Comment on the success of this experiment. Explain any percent differences which are larger than 10%. Is your result consistent with Archimedes' principle? What do you think are the two most important sources of error?

Experiment (10) Data Table				
Object	Mass m (kg)	Weight in Air $W_1 = mg$ (N)	Apparent Mass (kg)	Weight under Water $W_2 = mg$ (N)
Steel				
Brass				
Aluminum				
Lead				

Object	Buoyant Force $F_B = W_1 - W_2$ (N)	Weight of Displace Water (N)	Percent Difference
Steel			
Brass			
Aluminum			
Lead			

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EXPERIMENT 10
SIMPLE HARMONIC MOTION

I. INTRODUCTION

The objective of this experiment is the study of oscillatory motion. In particular the spring-mass system and the simple pendulum will be studied. For the spring, two quantities will be measured. These are the spring constant and the frequency of oscillation of the spring-mass system. For the pendulum, the frequency of oscillation will be measured and its dependence on several parameters such as length of pendulum string, the mass and the angle will be investigated.

II. APPARATUS

Spring, weights, strings, protracter, meter stick, photogate and a computer.

III. EXPERIMENTAL PROCEDURE

Procedure 1

1. Hang the spring from a support and attach a 50 g hanger. Place a meter stick next to the spring so you can measure the spring stretch. It is better to have the big numbers on the meter stick toward the bottom. Tape the meter stick so it does not move. Record the position of the bottom of the hanger. Call it x_0.

2. Place a 20 g mass on the hanger. The spring will stretch a certain amount. Record the new position of the bottom of the hanger. The difference between this reading and the previous reading, x_0, is the spring stretch.

3. Repeat for masses of 40 g, 60 g, 80 g and 100 g. Each time subtract x_0 from the new position of the bottom of the hanger to get the spring stretch. Enter the positions and the corresponding spring strectches in the data table.

Procedure 2

1. The computer and LabPro should already be on. If they are not, turn them on. Plug the photogate into the LabPro Dig/Sonic 1.

2. Double click on **Logger Pro** and then double click on **Pendulum Timing**.

3. Remove the masses from the spring but leave the hanger. Hang a single 100 g ($= 0.10$ kg) mass on the hanger making the total mass 150 g.

4. Attach (tape) a flag to the mass and set up the photogate such that it is blocked and unblocked by the flag as the mass oscillates up and down. This will allow the computer to measure the period of oscillation of the spring-mass system.

5. Set the spring into oscillation by pulling the mass down 5 cm and releasing. As much as possible the motion of the mass needs to be up and down and not sideways.

6. The computer will display the measured periods of oscillation on the screen. Calculate the average of the first five displayed periods. Call this the measured period of oscillation of the spring-mass system and record it in the appropriate place in the data table.

7. Measure the mass of the spring and record it in the data table.

THE PENDULUM

We would like to establish here that if the pendulum angle is kept small (compared to 1 radian), then the period of the pendulum depends only on the length of the string. Other parameters such as the angle and the mass of the pendulum bob do not affect the period.

Procedure 3

1. Fix the length of the pendulum string from the point of support to the center of the mass to be $l = 1\,\text{m}$. Also fix the mass by using the brass pendulum bob. Place the photogate such that the pendulum bob blocks and unblocks it as it swings back and forth.

2. Pull the pendulum aside until the vertex angle is 5° and release. The computer will display the measured periods of oscillation on the screen. Calculate the average of the first five displayed periods. Call this the measured period of oscillation of the pendulum and record it in the appropriate place in the data table.

3. Repeat above step for vertex angles of 10°, 15° and 20°.

Procedure 4

1. Fix the length of the pendulum string to be 1 m and the angle at 10°.

2. Using the brass pendulum bob, measure the period of oscillation the same way as you have done in the previous procedure and record it in the data table.

3. Repeat the above step for the two other available pendulum bobs which have different masses.

Procedure 5

1. Fix the mass of the pendulum by using the brass pendulum bob and also fix the vertex angle at 10°.

2. With the string length at $l = 1\,\text{m}$, measure the period of oscillation just like you have done in the previous procedures and record it in the data table.

3. Repeat the above step for string lengths of $l = 0.5\,\text{m}$, $l = 0.75\,\text{m}$, $l = 1.25\,\text{m}$ and $l = 1.5\,\text{m}$. Each time record the measured period of oscillation.

IV. ANALYSIS

1. Using the data of procedure 1, plot the force, $F = mg$, (in Newtons) on the vertical axis and the spring stretch (in meters) on the horizontal axis. Draw the best straight line fit for the data which goes through the origin $(0, 0)$. Calculate the slope of this line. The slope of this line represents the spring constant, k. Recall that Hooke's law states that $F = -kx$ where k is the spring constant, x is the spring stretch and F is the force exerted by the spring on the mass hanging on it. In this case the spring force is equal to the weight of the hanging mass, mg.

2. Theoretically, the period of the spring-mass system is given by

$$T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{m}{k}}. \qquad (2)$$

   This equation holds for situations where the entire oscillating mass is concentrated at the end of the spring. It is a good aproximation for problems and experiments where the mass of the spring is very small compared with the hanging mass. If this is not the case for your experiment, then the mass of the spring must be taken into account and the correct expression for the period of the spring-mass system is

$$T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{(m + (m_\text{s}/3))}{k}} \qquad (3)$$

   where m_s is the mass of the spring. Use this expression to calculate the period of the spring-mass system using the value of k claculated in step (1).

3. Calculate the relative uncertainty in the calculated period, $\frac{\delta T}{T}$, and compare it to the relative uncertainty in the measured period as given by the computer.

4. Calculate the percent difference between the theoretical value calculated above and the experimental value measured in precedure (2)

$$\%\,\text{diff.} = \frac{|T_\text{th} - T_\text{exp}|}{\left(\dfrac{T_\text{th} + T_\text{exp}}{2}\right)} \times 100. \qquad (4)$$

5. From the data of procedure (3), what is the dependence of the period of the pendulum on the vertex angle? If the answer is not clear from the data, plot the period on the vertical axis and angle on the horizontal axis to show the dependence more clearly. Remember that there is uncertainty in this measurement. So if the variation in the period is small (under 5 percent), then this variation can be attributed to experimental uncertainty and you must reach the conclusion that the period of the pendulum does not depend on the vertex angle.

6. From the data of procedure (4), what is the dependence of the period of the pendulum on the mass? If the answer is not clear from the data, plot the period on the vertical axis and the mass on the horizontal axis to show the dependence more clearly. Use the same reasoning here you used in the above step to decide whether the period is dependent on the mass.

7. Using the data of procedure (5), plot the square of the measured period of the pendulum on the vertical axis and the length of the string on the horizontal axis. Draw the best straight line fit for the data which goes through the origin. Calculate the slope of this line and compare with the slope predicted by theory by calculating the percent difference. Theoretically, the small-angle approximation for the motion of the pendulum gives the period of the pendulum as

$$T = 2\pi\sqrt{\frac{l}{g}}. \tag{5}$$

   This expression will allow you to calculate the slope of the line as predicted by theory.

8. Write a conclusion summarizing your results. Comment on the success of this experiment. Are your results in agreement with the theory? Explain any percent differences larger than 10%. What do you think are the two most important sources of error?

Experiment (10) Data Table: Procedure (1)			
Hanging Mass m (kg)	Force $F = mg$ (N)	Position x (m)	Spring Stretch $x - x_0$ (m)
Hanger (0.000)	0.000	$x_0 =$	$x - x_0 = 0.0$

Experiment (10) Data Table: Procedure (2)
Oscillating Mass, $m = 0.150\,\text{kg}$
Spring Mass, $m_\text{s} =$
Measured Period, $T_\text{exp} =$
Calculated Period, $T_\text{th} =$
% Difference=

Experiment (10) Data Table: Procedure (3)	
String Length, $L = 1.00\,\mathrm{m}$	
Oscillating Mass, $M =$	
Vertex Angle (deg)	T_{exp} (s)
5°	
10°	
15°	
20°	

Experiment (10) Data Table: Procedure (4)	
String Length, $L = 1.00\,\mathrm{m}$	
Vertex Angle, $\theta = 10^\circ$	
Oscillating Mass (kg)	T_{exp} (s)

Experiment (10) Data Table: Procedure (5)	
Oscillating Mass, $M =$	
Vertex Angle, $\theta = 10^\circ$	
String Length, $L\,(\mathrm{m})$	T_{exp} (s)

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THE PENDULUM

I. INTRODUCTION

The objective of this experiment is to measure the period of the pendulum as we vary the various parameters which could affect it.

II. KEY CONCEPTS

1. The *period* of a pendulum is the time for one oscillation. An oscillation is defined as the motion of the pendulum bob to and fro through one cycle.
2. In its motion, the pendulum is continually falling and rising. It falls, rises, falls again and raises again. This is one cycle. When falling, it is gaining speed and when rising it is losing speed.

III. PREDICTION

With our lab group, predict what are the parameters which affect the period of a pendulum and how do they affect it.
Prediction:

IV. APPARATUS

Weights, hanger, strings, protractor and meter stick.

V. EXPERIMENTAL PROCEDURE

Follow an experimental procedure which will allow you to verify whether your predictions are correct or not. If your predictions prove to be incorrect, you have to modify them to be consistent with your observations.

Procedure 1

1. Fix the length of the pendulum string and the mass of the pendulum bob.
2. Measure the period of the pendulum as you set the vertex angle to 10°, 15°, and 20°. At the outset set an acceptable variation in the measurement which will be attributable to "the limits of accuracy of this experiment". If your measurements of the pendulum period are within these limits, you must say the period is the constant and does not depend on the vertex angle.

Procedure 2

3. Fix the length of the pendulum string and the vertex angle.

4. Measure the period of the pendulum as you set the mass of the bob to 50 g, 100 g and 150 g.

Procedure 3

5. Fix the mass of the pendulum bob and the vertex angle.

6. Measure the period of the pendulum as you set the length of the string to 0.400 m, 0.600 m, 0.800 m and 1.00 m.

IV. ANALYSIS

1. From the data of procedure (1), what is the dependence of the period of the pendulum on the vertex angle? Recall that you have set an acceptable limit to the accuracy of this experiment. So if the variation in the period is small (less than or equal to 5 percent), then this variation can be attributed to experimental uncertainty and you must reach the conclusion that the period of the pendulum does not depend on the vertex angle.

2. From the data of procedure (2), what is the dependence of the period of the pendulum on the mass?

3. Using the data of procedure (3), plot the square of the measured period of the pendulum on the vertical axis and the length of the string on the horizontal axis. Draw the best straight line fit for the data which goes through the origin. Theoretically, the small-angle approximation for the motion of the pendulum gives the period of the pendulum as

$$T = 2\pi\sqrt{\frac{l}{g}}$$

4. With your lab group, try to formulate explanations of your observations. Why does the period of the pendulum depend on some of the parameters and not on others?

5. Write a conclusion summarizing your results. Are your predictions consistent with your experimental results? Do you think this experiment was successful? What do you think are the two most important sources of error?

6. Think of ways to improve this experiment or to modify it to fit your purposes in your class.

Pendulum Data Table: Procedure (1)	
String Length, $L = 1.00\,\text{m}$	
Oscillating Mass, $M =$	
Vertex Angle (deg)	T_{exp} (s)
10°	
15°	
20°	
Pendulum Data Table: Procedure (2)	
String Length, $L = 1.00\,\text{m}$	
Vertex Angle, $\theta = 10^\circ$	
Oscillating Mass (kg)	T_{exp} (s)
Pendulum Data Table: Procedure (3)	
Oscillating Mass, $M =$	
Vertex Angle, $\theta = 10^\circ$	
String Length, $L\,(\text{m})$	T_{exp} (s)