OSCILLATION

Here is another type of question posed in typical first year textbooks. "Bob observes a simple pendulum of length 0.50 metre undergo small amplitude oscillations. What is the period of the pendulum?" It is worthwhile for Bob to study this system. Simple pendula, molecules, currents in electric circuits, and biological systems all can exhibit oscillations. This experiment compares the oscillatory motion of a metal hoop with that of the simple pendulum discussed in your textbook. You will begin to appreciate more complex problems involving oscillations and vibrations in physics, chemistry, and biology.

References

Your course textbook, web based Error Analysis Assignment, sections of the Lab Manual (Commonly Used Instruments, Data Fitting Techniques)

Equipment

Metal hoops, metal clip, support stand, stopwatch, caliper, ruler, tape measure, photogate

Please treat the equipment with care! Please do not mark or bend the metal hoops.

Procedure

A simple pendulum consists of a small object attached to a string of negligible mass. The other end of the string is fixed to a pivot point. For small angle oscillations, the object swings back and forth such that

$$T = 2\pi\sqrt{\frac{L}{g}}, \qquad (1)$$

where L is the length of the string and g is the acceleration due to gravity. The period T is the time required for a complete cycle of motion to occur. We would like to know if a metal hoop that is placed on a pivot rod and allowed to swing back and forth has a period

$$T = 2\pi\sqrt{\frac{D}{g}}, \qquad (2)$$

where D is the mean diameter of the hoop. Note the similarity between these equations.

1. Examine the four hoops. On the largest hoop, note the position of the weld used in its construction and use this as the "top". In your lab notebook, note the serial number of the hoops. This will be useful if you have to find the same hoop at a later time to repeat a measurement. Place a hoop on its pivot rod and allow it to oscillate through as small an angle as possible. Is it accelerating according to your visual observations? Obtain D and T for the four hoops. Each member of your subgroup should perform a measurement of D and T. We suggest that for D you measure the mean diameter.

This can be obtained by measuring from the inside of the thickness of the hoop at one end to the outside of the thickness at the other.

2. Make a graph involving variables related to D and T that can be fit with a straight line relation. To what physical quantities do the coefficients of your fit correspond? Can you extract a value for g? Does obtaining a good quality fit allow you to confirm Eq. (2)?

3. Assuming that you verified Eq. (2), perhaps you can improve your measured value of g. Consider the following quantities.

a. The reading error in the values of D arise because of the uncertainty in reading the position on the tape measure. Since the tape measure is an analogue instrument, this error is somewhat subjective. Your eyesight, your state of mind, the sharpness or otherwise of the edge of the hoop, and so on, will all determine your estimate of this reading error. You should ask yourself how well you can determine the exact readings on the tape measure. If you have measured a value of D=45.62 cm, for example, how well do you know that last figure? If you believe that it could be incorrect by only 0.2 mm, for example, you would quote your error as $\Delta D=0.02$ cm, and $D=(45.62\pm0.02)$ cm. Write down the value that you think best represents this source of uncertainty for your measurement.

b. If you followed the earlier suggestions, you will have taken only one reading of each value of the diameters of the hoops. However, it is probable that some of the hoops are not exactly round. In that case, it would make sense to take several measurements of D at a variety of different positions around the hoop and take an average of these readings.

Start with the largest hoop and make at least six measurements of D. Collect all of your results in a table and then calculate the average mean diameter $\overline{D}$, the standard deviation σ, and the standard error σ_{m}. You can now investigate quantitatively whether the hoop is round. Report a final value of D with its error.

c. Study the second largest hoop. Without writing down any numbers, make a few measurements of $\overline{D}$ at different places around the hoop. Knowing the reading error, make a judgement as to whether or not this hoop needs the more detailed treatment you have given to the largest hoop. Then quote a value of D for this hoop with an associated error.

d. A quick test should convince you that the two smallest hoops are round, to within your reading error. However, the values of D that you have determined for these hoops can be improved by using a more accurate measuring instrument. Use a caliper to measure the outside D_o and inside D_i diameter of these hoops. The average of these values is $D=(D_o+D_i)/2$. Does the resulting value of D agree within errors with your previous measurements using the tape measure?

e. Here are some questions to consider regarding the measurement of T and ΔT.

* What is the reading error of the stop watch?
* Is your reaction time a contributor to ΔT?
* Will a number of repeated measurements of one oscillation of a hoop tell you anything about errors introduced through your reaction time?
* Which gives greater precision, an average of 20 measurements of one oscillation each or one measurement of 20 oscillations?
* The derivation of Eq. (2) is valid for small angles of oscillation for which $\sin\theta \approx \theta$, with θ, the angle of displacement of the pendulum, measured in radians. If the amplitude of the oscillation does not satisfy this condition, the period T depends on the amplitude and is longer than the value given in Eq. (2). Use your calculator to find the largest angle so that $\sin\theta \approx \theta$ holds to within 1%. How large an amplitude of swing can you allow so that this condition holds?
* You may find that it is somewhat difficult to define the precise position of the oscillating hoop corresponding to when you should start and stop the stopwatch when the hoop is oscillating. How did you solve this problem?

4. Suppose a hoop is suspended on its pivot rod. Attach the metal clip to the lowest point Q at the "bottom" of the hoop. During which part of the hoop's swing is the point Q moving fastest? Is this maximum speed v_{max} bigger for a small or large hoop? Make a prediction in your lab notebook and explain your reasoning. Now perform some measurements to determine experimentally how v_{max} depends on the size of the hoop.

Preparatory Question

Find the section on the simple pendulum in your course textbook. Learn about simple harmonic motion or oscillation. Understand how the period of a simple pendulum for small angle oscillation is derived in your text.