Experiment 11: Simple Harmonic Motion

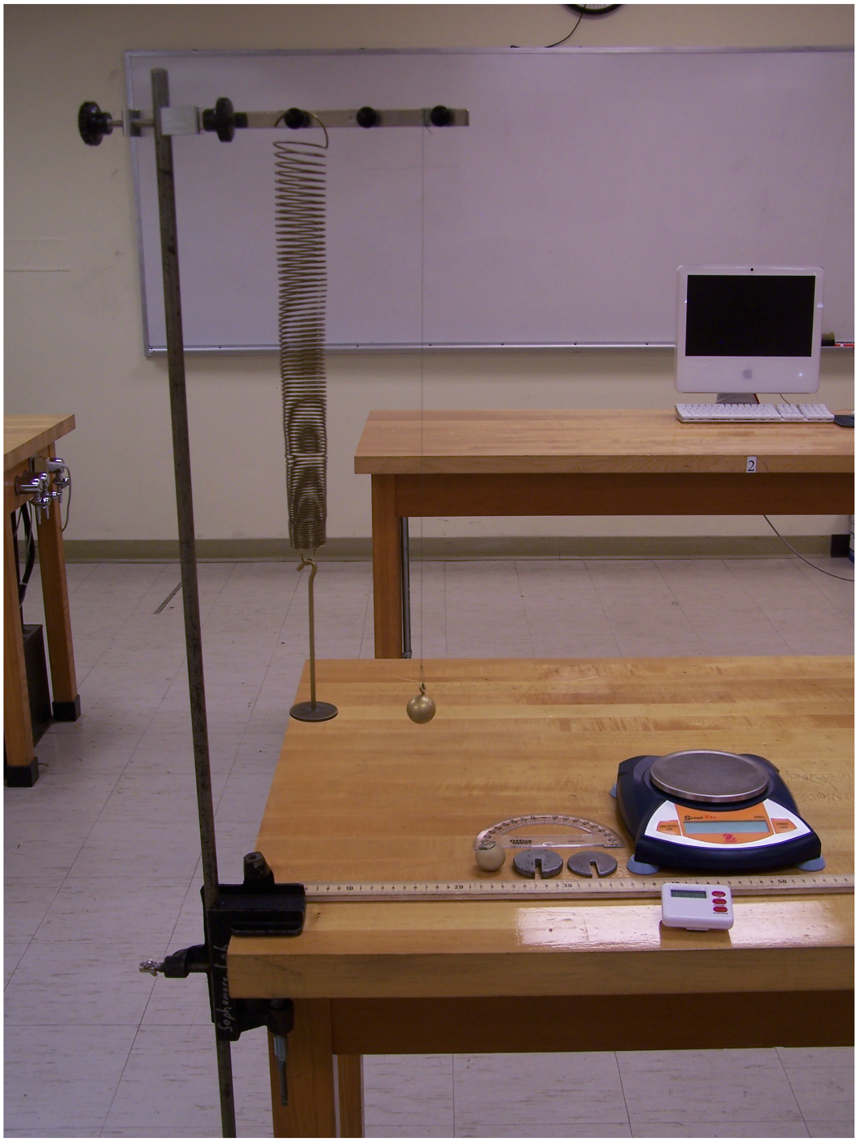

Figure 11.1

EQUIPMENT

Spring
Metal Ball
Wood Ball
(*Note: sharp hooks*)
Meter Stick
Digital Balance
Stopwatch
Pendulum Clamp and Rod
String
Masses: (2) 100g, (1) 50g
Mass Hanger
Table Clamp
Protractor

Advance Reading

Text: Simple harmonic motion, oscillations, wavelength, frequency, period, Hooke's Law.

Lab Manual: Appendix B

Objective

To investigate simple harmonic motion using a simple pendulum and an oscillating spring; to determine the spring constant of a spring.

Theory

Periodic motion is "motion of an object that regularly returns to a given position after a fixed time interval." *Simple harmonic motion* is a special kind of periodic motion in which the object oscillates sinusoidally, smoothly. Simple harmonic motion arises whenever an object is returned to the equilibrium position by a *restorative force* proportional to the object's displacement.

$$F = -kx \tag{11.1}$$

The illustrative example above is *Hooke's Law*, which describes the restorative force of an oscillating spring of stiffness k (spring constant).

For an ideal, massless spring that obeys Hooke's Law, the time required to complete an oscillation (period, T, seconds) depends on the spring constant and the mass, m, of an object suspended at one end:

$$T = 2\pi\sqrt{\frac{m}{k}} \tag{11.2}$$

The inverse of period is the frequency of oscillation. Recall that frequency, f, is the number of oscillations completed by a system every second. The standard unit for frequency is hertz, Hz (inverse second, s^{-1}).

The period of oscillation of an ideal, simple pendulum depends on the length, L, of the pendulum and the acceleration due to gravity, g:

$$T = 2\pi\sqrt{\frac{L}{g}} \tag{11.3}$$

When setting the pendulum in motion, small displacements are required to ensure simple harmonic motion. Large displacements exhibit more complex, sometimes chaotic, motion. Simple harmonic motion governs where the *small angle approximation* is valid:

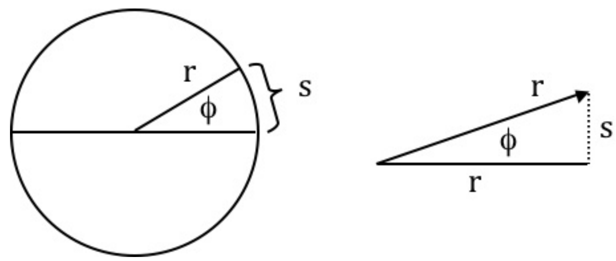

Figure 11.2: Small Angle Approximation

The arc length, s, of a circle of radius r is:

$$s = r\phi \tag{11.4}$$

When ϕ is small, the arc length is approximately equal to a straight line segment that joins the two points. Therefore, the following approximations are valid:

$$\phi \approx \sin\phi \approx \tan\phi \tag{11.5}$$

Name: ____

1. Define simple harmonic motion. What conditions must be met? (20 pts)

2. What physical phenomenon does the relationship $T = 2\pi\sqrt{\frac{m}{k}}$ describe? (20 pts)

3. What physical phenomenon does the relationship $T = 2\pi\sqrt{\frac{L}{g}}$ describe? (20 pts)

4. The following data were collected for *Part 1* of the lab procedure. Complete the table. The force is due to the gravitational force. All distances are measured from the *bottom of the hanger to the top of the stool.* You should ignore the initial weight of the hanger. *Note* that Δx is the change from initial position, $x_f - x_0$, not the change from the previous position, $x_2 - x_1$. (40 pts)

Mass (g)	**Height (cm)**	Δx **(m)**	**Force (N)**
0	**57.5**	**0**	**0**
100	**46.5**		
200	**36.5**		
300	**25.5**		
400	**15.5**		
500	**4.5**		

PROCEDURE

PART 1: Spring Constant - Hooke's Law

1. Hang the spring from the pendulum clamp and hang the mass hanger from the spring. Place a stool under the hanger and measure the initial height x_0 above the stool.

2. Add 50 g to the mass hanger and determine the change in position caused by this added weight.

3. Add 50 g masses incrementally until 250 g has been added to the mass hanger. Determine the total displacement and the total added weight with each addition.

4. Generate a graph of F *vs.* Δx using *Graphical Analysis*. Analyze the graph with a linear fit; print a copy for each partner.

PART 2: Spring Constant - Oscillation

5. Measure the mass of the spring, mass hanger, and 100 g mass.

> *Note:* The spring used for this experiment is not ideal; its mass affects the period of oscillation. Account for this by adding 1/3 the mass of the spring to the value of suspended mass, m, in your calculations.

6. Hang the spring from the pendulum clamp. Hang the mass hanger + 100 g from the spring (refer to Fig. 11.1).

7. Pull the mass hanger down slightly and release it to create small oscillations. Measure the time required for 20 oscillations. (This is like measuring one period twenty times over.)

8. Calculate the period for the oscillating spring.

9. Calculate the spring constant of the spring using your knowledge of the object's mass and period of oscillation.

PART 3: Simple Pendulum

10. Measure the mass of the metal ball.

11. Construct a simple pendulum 100.0 cm in length using the metal ball and some string. (L is measured from the center of mass of the ball.)

12. Move the pendulum from equilibrium (about 10°-20°) and release it. Measure the time required for 20 oscillations.

13. Determine the period. Record it in the table provided.

$$T = \frac{\text{time required}}{20\ cycles} \tag{11.6}$$

14. Shorten L in increments of 20.0 cm and measure T for each length.

15. Repeat the procedure using the wood ball.

16. Produce graphs of T^2 *vs.* L for each ball. Apply a linear fit; print a copy for each partner.

QUESTIONS

1. Solve Eq. 11.3 for g.

2. Does the period of a simple pendulum depend on the mass?

3. How long must a simple pendulum be to have a period of 1.5 s?

4. Assume you are safely located on the moon and have access to a simple pendulum, stopwatch, and meter stick. Is it possible to determine the acceleration due to gravity of the moon, g_{moon}, using only these three items? (*Hint:* $g_{moon} \neq 0$ m/s^2)

5. Consider your T^2 *vs.* L graph. What are the slope values? Show that the slope should be equal to $4\pi^2/g$. Compare each graph value to the accepted value.