

## Variable-g Pendulum

### Equipment

1	Rotary Motion Sensor	PS-2120A
1	Rotational Accessory	CI-6691
1	Acceleration Sensor	PS-2118
1	90 cm Rod	ME-8738
1	45 cm Rod	ME-8736
1	Large Rod Base	ME-8735
1	Multi-Clamp	ME-9507
Required but not included:		
1	Level	SE-8729
1	Meter Stick	SE-8827

### Introduction

The black rod shown in Figure 1 acts as a pendulum, and is constrained to oscillate in a plane tilted at an angle from the vertical. This effectively reduces the acceleration due to gravity because the restoring force is decreased. The Acceleration Sensor is fastened to the Rotary Motion Sensor, and directly measures the effective "g" for the pendulum.

### Theory

A physical pendulum consists of a rod of length,  $L$ , pivoted about one end. The angular frequency,  $\omega$ , of the oscillation (for small amplitudes) is

$$\omega = \sqrt{3g/2L} \quad (1)$$

The angular frequency is related to the period of oscillation,  $T$ , by

$$T = \frac{2\pi}{\omega} \quad (2)$$

In this lab, you will change the effective "g" by changing the plane of oscillation of the pendulum, and measure the resulting angular frequency.

## Setup

1. Connect the 90 cm rod to the base as shown in Figure 1. Use the multi-clamp to support the 45 cm rod horizontally.
2. Slide the Rotary Motion Sensor onto the horizontal rod as shown in Figure 2. Connect the sensor to port P2.
3. Fasten the metal bracket to the side of the Rotary Motion Sensor using the thumbscrew. The bracket needs to be parallel to the case as shown.
4. Attach the Acceleration Sensor to the bracket as shown in Figure 3. Connect the sensor to port P1.
5. In PASCO Capstone, set the sample rate of the Rotary Motion Sensor to 50 Hz and the sample rate of the Acceleration Sensor to 20 Hz.
6. Create a graph of Angle (in degrees) vs. Time.
7. Attach the black tube from the Rotational Accessory as shown in Figure 1.



Figure 1: The effective "g" for the pendulum is varied by changing the angle of the plane of oscillation.

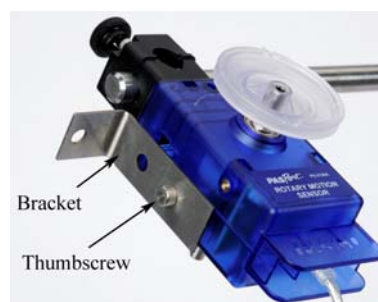


Fig. 2: Acceleration Sensor Bracket

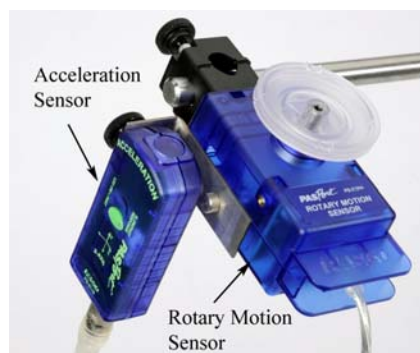


Figure 3: Acceleration Sensor

8. In the Capstone calculator, create the following calculations for the effective  $g$  ( $g_{\text{eff}}$ ) and the period:

$$g_{\text{eff}} = \text{smooth}(11, \text{abs}(9.8 - [\text{Acceleration-x, Ch P2 (m/s}^2)]) \text{ with units of m/s}^2$$

$$\text{Period} = 6.28/[\omega \text{ (rad/s)}] \text{ with units of s}$$

9. Create a table as shown below. Create User-Entered Data sets called “ $g$ ” with units of  $\text{m/s}^2$  and “ $\omega$ ” with units of  $\text{rad/s}$ . Fill the first column with the suggested values. The third column has the calculation “Period”.

Table I: Vary “ $g$ ”

$g$ ( $\text{m/s}^2$ )	$\omega$ ( $\text{rad/s}$ )	Period (s)
9.8		
9.0		
8.0		
7.0		
6.0		
5.0		
4.0		
3.0		
2.0		
1.0		

10. Create a Digits display and select the calculation “ $g_{\text{eff}}$ ”.

## Procedure

- Adjust the plane of oscillation so that the pendulum is vertical. Use a level to get the case of the Rotary Motion Sensor as close to vertical as possible.
- Zero the Acceleration Sensor.
- Click on Record, and observe the effective “ $g$ ” in the display. It should be close to  $9.8 \text{ m/s}^2$ , but record the actual value in row 1. Click on Stop.
- Allow the pendulum to oscillate at small angles, and take 5 to 10 periods worth of data. Make sure the amplitude is less than  $20^\circ$ .
- Use a Damped Sine Wave curve fit, and record the angular frequency,  $\omega$ , in row 1 of the table.
- Click on Record, and adjust the plane of oscillation of the pendulum until the effective “ $g$ ” in the display is about  $9.0 \text{ m/s}^2$ . Record the actual value in row 2 of the table, and click on Stop.

7. Take a run of data as before and record the angular frequency in the table.
8. Repeat for all the other listed values of "g". In each case, replace the suggested value with your actual value for "g" from the display.

### Analysis

9. Create a graph of  $\omega$  vs. "g". Is it linear? Should it be?
10. Try a QuickCalc on the vertical axis. Does graphing  $\omega^2$  give a linear relationship?
11. What is the physical significance of the slope? Hint: Look at Equation (1).
12. Using this, what is the theoretical length of the pendulum?
13. What is the actual length of the rod, measured from the end to the pivot point? How does it compare?
14. Why is "L" not the total length of the rod?

### Period

15. In Table I, use Equation (2) to verify the calculation for the first row of the third column.
16. Create a graph of T vs. g. Is it linear?
17. In general, how does the period depend on gravity? Try various QuickCalcs on both axes to linearize the data.