SIMPLE PENDULUM

What factors affect the period of a simple pendulum? Can the equation for a simple pendulum be determined experimentally?

Objectives

- Experimentally determine the effect of amplitude, mass, and length on the period of a simple pendulum.
- Use the experimental data to develop the theoretical equation for the period of a simple pendulum.
- Practice applying the equation for period on other pendulum systems.

Materials and Equipment

- Data collection system
- PASCO Wireless Smart Gate photogate
- PASCO Photogate Pendulum Set
- PASCO Pendulum Clamp
- Balance, 0.1-g resolution, 2,000-g capacity (1 per class)
- Meter stick
- Table clamp or large base
- Support rod, 60-cm or taller
- Thread
- Scissors

Safety

Follow regular laboratory safety precautions.

Procedure

1. Mount the pendulum clamp near the top of the rod and then cut a length of thread about 75 cm long. Tie a loop on one end of the string.

2. Choose one of the four pendulum bobs from the PASCO Photogate Pendulum Set (all have identical shape but different mass) and put its hook through the loop on the string.

3. Hang the pendulum from the third anchor point on the clamp (farthest from the rod): loosen the anchor's thumbscrew and run the end of the thread under the outer part of the anchor. Tighten the thumbscrew so that the pendulum bob is about 4 cm above the table

4. With the pendulum bob hanging motionless, place the photogate on the lab table with the arms of the photogate pointed upward, directly under the pendulum bob. The pendulum bob should swing freely between the arms on the photogate. See Figure 1.

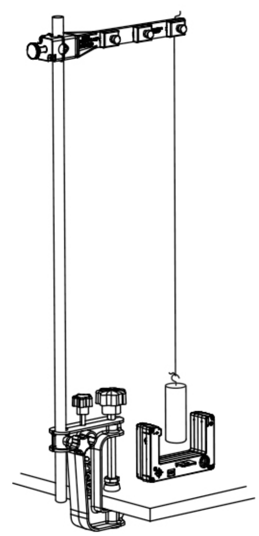


Figure 1

5. Connect the photogate to your data collection system.

6. Configure the data collection system to measure the period of a pendulum using the photogate and then create a table display with the period measurement as one of the columns.

8. Use your hand to pull the pendulum bob back, displacing it a horizontal distance of 3 cm from its equilibrium position. Use the meter stick to measure the horizontal displacement. See Figure 2.

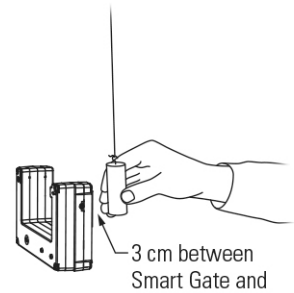


Figure 2

9. Release the pendulum bob so it swings freely through the photogate. Once any wobbling settles down, start recording data.

10. Stop recording data when the data collection system has recorded five period measurements.

11. Use the tools on your data collection system to determine the average of the five period data points. Record this average value as well as the horizontal displacement in Table 1 below.

12. Repeat the same data collection steps three more times, increasing the horizontal displacement by an additional 3 cm each trial. Record your average period and displacement values for each trial in Table 1 below.

Table 1: Period of a pendulum with varying horizontal displacement

Trial	Horizontal Displacement (cm)	Average Period (s)
1		
2		
3		
4		

13. The horizontal displacement can be thought of as the amplitude of a simple pendulum's motion. Study your data. Taking into consideration that the amplitude was doubled, then tripled, then quadrupled, what is the effect, if any, of amplitude on the period of a simple pendulum? Justify your answer using your data below.

14. Remove the pendulum bob currently attached to the thread and then measure the individual mass of all four pendulum bobs. Record the mass in order from smallest to largest in Table 2.

15. Attach the pendulum bob with the smallest mass to the thread.

16. Because we determined that amplitude does not affect the period of a simple pendulum, we can choose any tested amplitude in future trials. Use a 3 cm amplitude for all the remaining experiments, but it is not necessary to measure it precisely.

17. Use your hand to pull the pendulum bob back about 3 cm. Release the pendulum bob so it swings freely through the photogate. Once any wobbling settles down, start recording data.

18. Stop recording data when the data collection system has recorded five period measurements.

19. Use the tools on your data collection system to determine the average of the five period data points. Record this average value in Table 2 below.

20. Repeat the same collect data steps for the remaining three pendulum masses. Record your average period value for each trial into Table 2 below.

Table 2: Period of a pendulum with varying mass

Trial	Bob Mass (g)	Average Period (s)
1		
2		
3		
4		

21. Study your data. Taking into consideration that the mass was almost doubled, then almost tripled, then increased by over eight times from the lowest mass, what is the effect, if any, of mass on the period of a simple pendulum? Justify your answer using your data below.

22. Select any of your pendulum bobs and adjust the length of the string and the pendulum clamp height so it is as long as possible without the pendulum striking the photogate. Measure the distance from the pendulum clamp to the center of the pendulum to within about 1 mm and record it as the pendulum length in meters in Table 3 for Trial 1. It can help measurement accuracy to mark the center of the pendulum with a pencil.

23. Use your hand to pull the pendulum bob back about 3 cm. Release the pendulum bob so it swings freely through the photogate. Once any wobbling settles down, start recording data.

24. Stop recording data when the data collection system has recorded five period measurements.

25. Use the tools on your data collection system to determine the average of the five period data points. Record this average in Table 1 below.

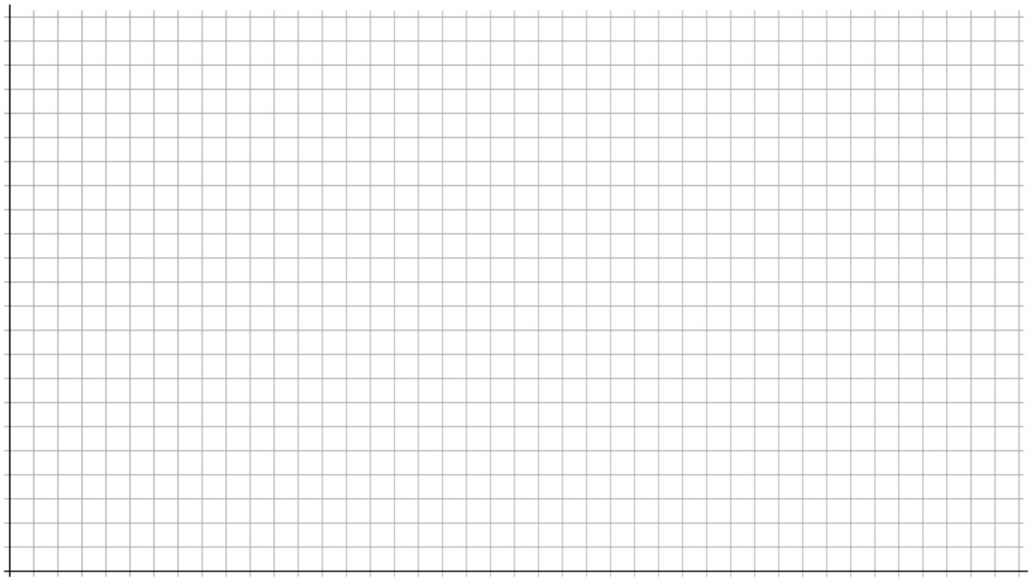
26. Repeat the same collect data steps shortening the pendulum length by about 10 cm in each trial. Measure and record the pendulum length and average of five period data points for each trial.

Table 3: Period of a pendulum with varying length

Trial	Pendulum Length (m)	Period (s)	Period^2 (m^2)
1			
2			
3			
4			
5			
6			

27. Plot a graph of period on the vertical axis versus pendulum length on the horizontal axis in Graph 1. Be sure to label both axes with the correct scale and units.

Graph 1: Period versus pendulum length with constant displacement and mass

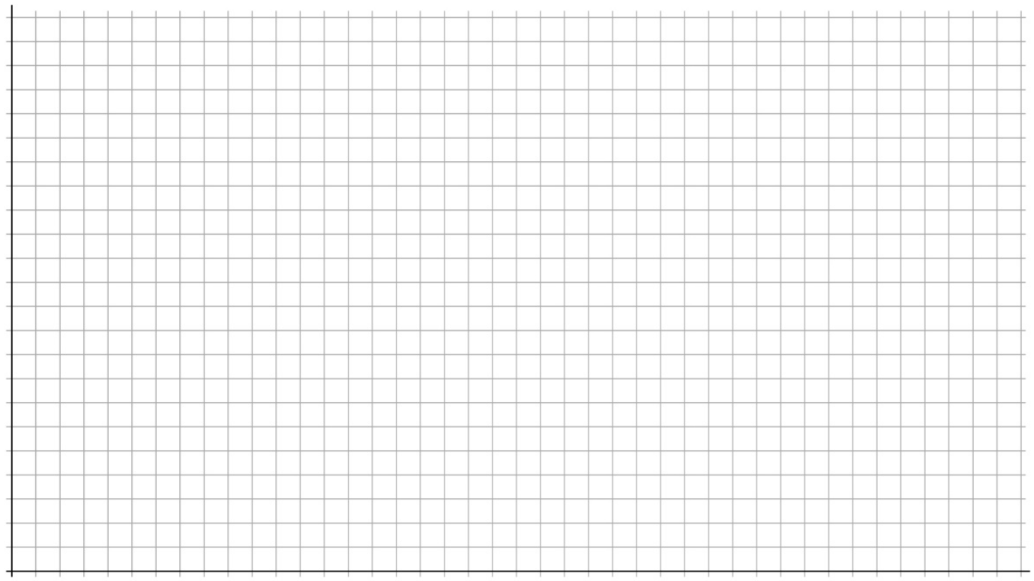


28. Carefully study Graph 1. As the length of the pendulum increases, what happens to the period? Is the relationship between the length of the pendulum and the period linear? Draw a smooth curve through your data points.

29. Graph 1 should show a slight concave down curve. This means the relationship between the length of the pendulum and the period is not linear. A concave down curve can mean a parabola where one of the variables is related to the square of the other. To test this out, complete the last column in Table 3 by squaring each value of the period.

30. Plot a graph of period *squared* on the vertical axis versus pendulum length on the horizontal axis in Graph 2. Be sure to label both axes with the correct scale and units. Draw a line of best fit through your points using a straight edge.

Graph 2: Period squared versus pendulum length with constant displacement and mass



31. The fact that a graph of the period squared versus pendulum length produced a straight line is evidence that Graph 1 was a parabola. Pick two points on your best fit line and calculate the slope. Show all of your work below, don't forget to include units.

32. A very advanced physics student could show that the theoretical slope of Graph 2 should be $4\pi^2/g$ where g is 9.81 m/s^2. Calculate the numerical value of this theoretical slope and compare it to the slope of your graph. Compare the units of the theoretical slope to the units of the slope of your graph. Find the percent error. Show all your work below.

$$\text{Percent error} = \left|\frac{\text{Theoretical} - \text{Measured}}{\text{Theoretical}}\right| \times 100$$

33. The very small percent error found above is strong evidence that the slope is $4\pi^2/g$. We can now find the equation for the period of a pendulum by writing the equation for Graph 2 in $y = mx + b$ form. Replace every term with the corresponding symbol for the variables in Graph 2. The symbol for period is T, substitute T^2 for y, length l for x, and the theoretical slope $4\pi^2/g$ for m. The y-intercept is the value of T^2 when l is zero. This should be zero. Write the equation below and then solve it for T.

34. The equation you found above can be used to predict the period of a pendulum for a given length or in a given gravitational field strength. Use it to predict the period of a 2-m long pendulum on Earth (g = 9.81 m/s^2) and on the Moon (g = 1.62 m/s^2). Show all of your work below.

35. Pendulums can be used to measure the strength of the gravitational field. The gravitational field strength can vary on Earth due to local variations in the topography and density of the surface material. The period of a pendulum with a precisely known length is measured very accurately. This can be used to find g at that location. A 0.800 m pendulum is used for this purpose and measures a period of 1.79795 s. What is the value of g at this location? Show all of your work below.

36. Two students are arguing over whether the mass of the pendulum bob will affect the period. One says it will make the period shorter because gravity will pull harder on the bob, making it move back and forth in less time. The other says it will make the period longer because the bob will have more inertia, making it harder to move and increasing the time for it to move back and forth. Can you settle the argument? Explain the effect of the mass of the bob on the period of a pendulum and why this is so below.