

A) Using a simple pendulum to determine the gravitational acceleration ‘g’

<https://www.youtube.com/watch?v=kIasiNg1-fA>

<https://www.youtube.com/watch?v=9VJxrdgjhhk>

1. The formula for the period T , of a simple pendulum as shown on the right, is given by the expression:

$$T = 2\pi \sqrt{\frac{\ell}{g}}, \text{ which only applies for "small angles".}$$

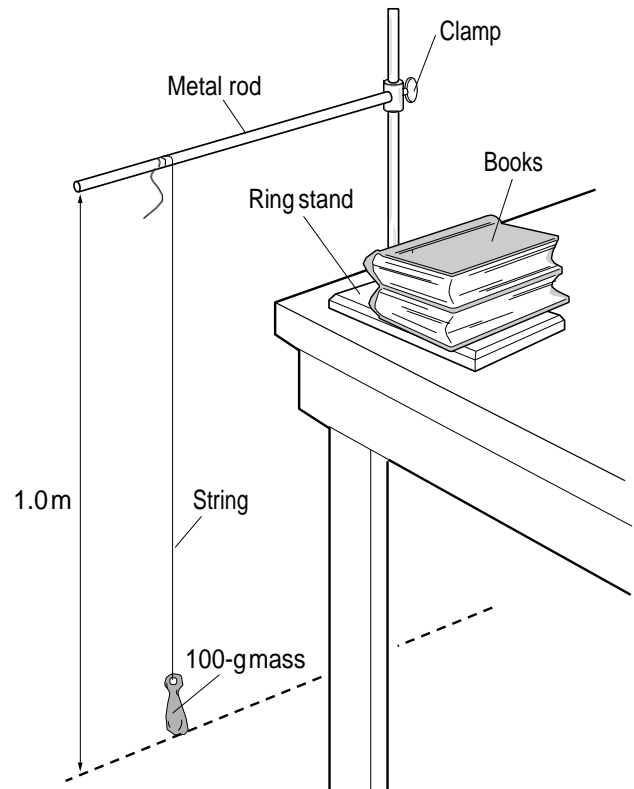
What is meant by “small angles”? (Note: ℓ = length of pendulum)

2. How will the angle from which the pendulum is released, affect the period of the pendulum?
3. How would you measure the length of the pendulum accurately to include the centre of gravity of the mass?
4. What constitutes one period of the pendulum?
5. How many swings would you need to time, before determining the period of the pendulum?
6. To measure ‘g’, all we need to do is to take one measurement of ℓ and T and use:

$$T = 2\pi \sqrt{\frac{\ell}{g}} \rightarrow T^2 = \frac{4\pi^2 \ell}{g} \rightarrow g = \frac{4\pi^2 \ell}{T^2}$$

Why, then, do we repeat the measurement of T , for each value of ℓ ?

7. Why should we need to measure T , for different values of ℓ in the experiment? Why not just one length?
8. State a hypothesis that you could test in an investigation to measure ‘g’ using a simple pendulum by considering the need to vary the length of the pendulum for different sets of measurements.
9. Describe an experiment that you could perform to test your hypothesis. Use the YouTube links above and others, based on your own research.
10. What experimental result would support your hypothesis? What result would contradict your hypothesis?
11. Identify the independent, dependent, and controlled variables in your experiment.
12. Propose or construct one or more tables to record all the needed results in this experiment.
13. Think about how you would plot your independent and dependent variables on a graph to determine ‘g’.



14. Supposing you graphed T^2 against ℓ , and it shows a linear relationship (straight line graph), what does the value of the gradient represent?
15. On such a graph, identify on which axis the independent and dependent variable should be plotted?
16. Why and how can we use the gradient of the line to determine the value of 'g'?
17. Do you expect the graph to pass through the origin? Why or why not?
18. What are systematic and random errors and how does it affect your graph?
19. What safety precautions do we need to consider, for this experiment?
20. Explain the term reliability.
21. Explain the term validity.
22. Explain the term accuracy.
23. Complete the table below to verify your understanding of “small angles” as required for this experiment.

θ (in degrees)	θ (in radians)	$\sin \theta$	Small angle? (y / n)
1	0.0174	0.0174	y
2			
5			
10			
20			
30			
50			

B) Picket Fence Free Fall

YouTube link: https://youtu.be/_4tH0CRh3VM

We say an object is in *free fall* when the only force acting on it is the Earth's gravitational force. No other forces can be acting; in particular, air resistance must be either absent or so small as to be ignored. When the object in free fall is near the surface of the Earth, the gravitational force on it is essentially constant. As a result, an object in free fall accelerates downward at a constant rate. This acceleration is usually represented with the symbol, g .

Physics students measure the acceleration due to gravity using a wide variety of timing methods. In this experiment, you will have the advantage of using a very precise timer and a Photogate. The Photogate has a beam of infrared light that travels from one side to the other. It can detect whenever this beam is blocked. You will drop a piece of clear plastic with evenly spaced black bars on it, called a Picket Fence. As the Picket Fence passes through the Photogate, the photogate measures the time from the leading edge of one bar blocking the beam until the leading edge of the next bar blocks the beam. This timing continues as all eight bars pass through the Photogate. From these measured times, the software calculates and plots the velocities and accelerations for this motion.

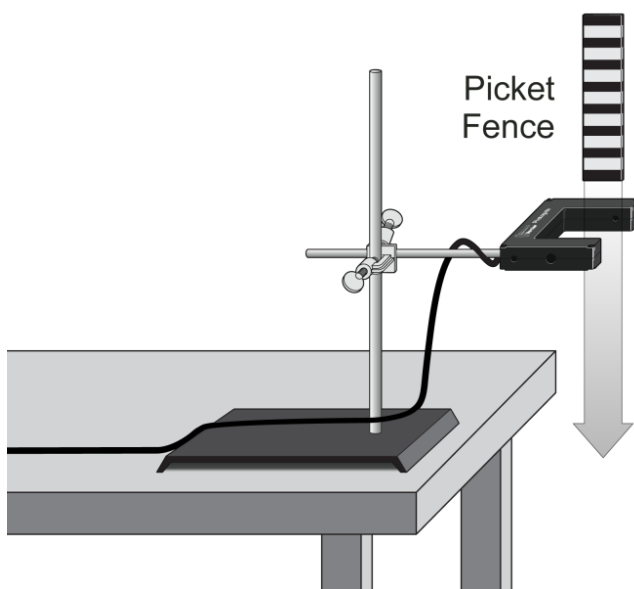


Figure 1

OBJECTIVE

Measure the acceleration of a freely falling body, g , to better than 0.5% precision using a Picket Fence and a Photogate.

MATERIALS

LabQuest
LabQuest App
Photogate
Picket Fence
clamp and ring stand to secure Photogate

PRELIMINARY QUESTIONS

1. Inspect your Picket Fence. You will be dropping it through a Photogate to measure g . The distance, measured from one edge of a black band to the same edge of the next band, is 5.0 cm. What additional information is needed to determine the average speed of the Picket Fence as it moves through the Photogate?
2. If an object is moving with constant acceleration, what is the shape of its velocity vs. time graph?
3. Does the initial velocity of an object have anything to do with its acceleration? For example, compared to dropping an object, if you throw it downward would the acceleration be different after you released it?

PROCEDURE

1. Fasten the Photogate rigidly to a ring stand so the arms extend horizontally, as shown in Figure 1. The entire length of the Picket Fence must be able to fall freely through the Photogate. To avoid damaging the Picket Fence, provide a soft landing surface (such as a carpet).
2. Connect the Photogate to the digital (DIG) port of LabQuest and choose New from the File menu.
3. Observe the reading on the Meter screen. Block the Photogate with your hand; note that the Gate State is shown as Blocked. Remove your hand and the display will change to Unblocked.
4. Start data collection to prepare the Photogate to collect data. **Note:** Data are collected when the gate is blocked for the first time after data collection is started.
5. Hold the top of the Picket Fence between two fingers, allowing the Picket Fence to hang freely just above the center of the Photogate, without blocking the gate. Release the Picket Fence so it leaves your grasp completely before it enters the Photogate. The Picket Fence must remain vertical and should not touch the Photogate as it falls.
6. When the Picket Fence has completely passed through the Photogate, a graph of position vs. time and velocity vs. time appears on the screen.

7. Examine your velocity vs. time graph. The slope of a velocity vs. time graph is a measure of acceleration. If the velocity graph is approximately a straight line of constant slope, the acceleration is constant. If the acceleration of your Picket Fence appears constant, fit a straight line to your data.
 - a. Choose Curve Fit from the Analyze menu.
 - b. Select Linear as the Fit Equation.
 - c. Record the slope of the linear curve fit in the data table.
 - d. Select OK.
8. To establish the reliability of your slope measurement, repeat Steps 4–7 five more times. Do not use drops in which the Picket Fence hits or misses the Photogate. Record the slope values in the data table.

DATA TABLE

Trial	1	2	3	4	5	6
Slope (m/s ²)						

	Minimum	Maximum	Average
Acceleration (m/s ²)			

Acceleration due to gravity, g	\pm	m/s ²
Precision		%

ANALYSIS

1. From your six trials, determine the minimum, maximum, and average values for the acceleration of the Picket Fence. Record them in the data table.
2. Describe in words the shape of the position vs. time graph for the free fall.
3. Describe in words the shape of the velocity vs. time graph. How is this related to the shape of the position vs. time graph?
4. The average acceleration you determined represents a single best value, derived from all your measurements. The minimum and maximum values give an indication of how much the measurements can vary from trial to trial; that is, they indicate the precision of your measurement. One way of stating the precision is to take half of the difference between the minimum and maximum values and use the result as the uncertainty of the measurement. Express your final experimental result as the average value, \pm the uncertainty. Round the uncertainty to just one digit and round the average value to the same decimal place.

For example, if your minimum, average, and maximum values are 9.12, 9.93, and 10.84 m/s², express your result as $g = 9.9 \pm 0.9$ m/s². Record your values in the data table.

Experiment 5

- Express the uncertainty as a percentage of the acceleration. This is the precision of your experiment. Enter the value in your data table. Using the example numbers from the last step, the precision would be

$$\frac{0.9}{9.9} \times 100\% = 9\%$$

- Compare your measurement to the generally accepted value of g (from a textbook or other source). Does the accepted value fall within the range of your values? If so, your experiment agrees with the accepted value.
- Inspect your velocity graph. How would the associated acceleration vs. time graph look? Sketch your prediction on paper. Change the y-axis to acceleration. Comment on any differences between the acceleration graph and your prediction. To examine the data pairs on the displayed graph, tap any data point. As you tap each data point, the acceleration and time values are displayed to the right of the graph. Note that the vertical scale of the graph does not include zero. Is the variation as large as it appears?
- Use the Statistics tool and the acceleration graph to find the average acceleration. How does this compare with the acceleration value for the same drop, determined from the slope of the velocity graph?

EXTENSIONS

- Use the position vs. time data and a quadratic fit to determine g .
- Would dropping the Picket Fence from higher above the Photogate change any of the parameters you measured? Try it.
- Would throwing the Picket Fence downward, but letting go before it enters the Photogate, change any of your measurements? How about throwing the Picket Fence upward? Try performing these experiments.
- How would adding air resistance change the results? Try adding a loop of clear tape to the upper end of the Picket Fence. Drop the modified Picket Fence through the Photogate and compare the results with your original free-fall results.
- Investigate how the value of g varies around the world. For example, how does latitude affect the value of g ? What other factors cause this acceleration to vary at different locations? For example, is g different at high latitudes such as Svalbard, an archipelago north of Norway?
- Collect g measurements for your entire class, and plot the values in a histogram. Is there a most common value? Are the measurements consistent with one another?

C) Using a free fall method and Phyphox's "Acoustic Smartwatch" smartphone app to determine the gravitational acceleration 'g'

YouTube link: https://youtu.be/zRGh9_a1J7s

1. The kinematic formula for the free fall of a ball as shown on the right, is given by the expression: $h = 0.5gt^2$ assuming it is dropped from rest.
2. Refer to the YouTube video above on how to use the "Acoustic Smartwatch" to conduct this experiment.
3. State a hypothesis that you could test in an investigation to measure 'g' using a free fall method by considering the need to vary the length of the pendulum for different sets of measurements.
4. Describe an experiment that you could perform to test your hypothesis. Use the YouTube links above and others, based on your own research.
5. What experimental result would support your hypothesis? What result would contradict your hypothesis?
6. Identify the independent, dependent, and controlled variables in your experiment.
7. Propose or construct one or more tables to record all the needed results in this experiment.
8. Think about how you would plot your independent and dependent variables on a graph to determine 'g'.
9. Supposing you graphed h against t^2 , and it shows a linear relationship (straight line graph), what does the value of the gradient represent?
10. On such a graph, identify on which axis the independent and dependent variable should be plotted?
11. Why and how can we use the gradient of the line to determine the value of 'g'?
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