

Picket Fence Free Fall

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 nearly 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 connected to the calculator 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 LabPro or CBL 2 interface will measure 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 program will calculate the velocities and accelerations for this motion and graphs will be plotted.

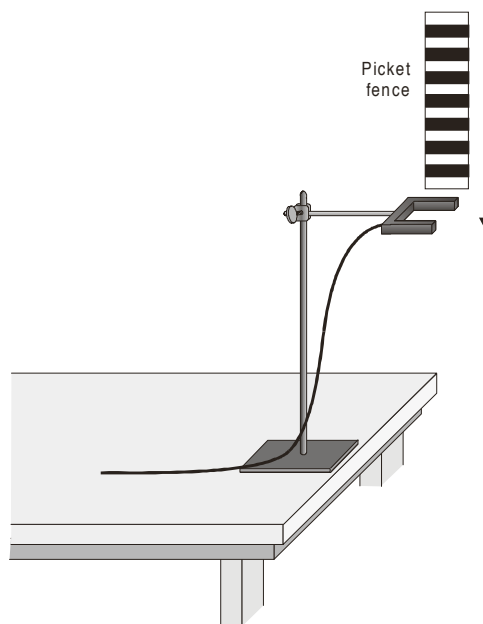


Figure 1

OBJECTIVE

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

MATERIALS

LabPro or CBL 2 interface
TI Graphing Calculator
DataGate program

Vernier Photogate
Picket Fence
clamp or ring stand to secure Photogate

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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 will you need 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, make sure it has a soft landing surface.
2. Connect the Photogate to the DIG/SONIC 1 input of the LabPro or the DIG/SONIC input on the CBL 2. Use the black link cable to connect the interface to the TI Graphing Calculator. Firmly press in the cable ends.
3. Turn on the calculator and start the DATAGATE program. Press **CLEAR** to reset the program.
4. Set up the calculator for motion timing.
 - a. Select SETUP from the main screen.
 - b. Select MOTION from the PHOTOGATE MODES screen.
 - c. Select VERNIER PICKET FENCE from the SELECT DEVICE screen.
 - d. Select OK from the SETTINGS screen.
5. Now collect your free fall data. To do this, select START from the main screen. Wait for the interface to beep.
6. Hold the top of the Picket Fence and drop it through the Photogate, releasing it from your grasp completely before it enters the Photogate. Be careful when releasing the Picket Fence. It must not touch the sides of the Photogate as it falls and it needs to remain vertical.
7. Press **ENTER** to examine your distance $vs.$ time graph. Sketch the graph on paper for later use. Press **ENTER** to return to the SELECT GRAPH menu.
8. Press **▼** to select VELOCITY and press **ENTER**. 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. Press **ENTER**, and select RETURN TO MAIN SCREEN from the SELECT GRAPH screen.
 - b. Select ANALYZE from the main screen.
 - c. Select CURVE FIT from the ANALYZE screen.
 - d. Select LINEAR (VELOCITY VS TIME) from the SELECT CURVE FIT screen.
 - e. Record the slope of the fitted line in the Data Table.

- f. Press **ENTER** to see the fitted line with your data.
 - g. To return to the main screen, press **ENTER**, and then select RETURN TO ANALYZE SCREEN, finally selecting RETURN TO MAIN SCREEN.
9. To establish the reliability of your slope measurement, repeat Steps 6 through 9 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, <i>g</i> | ± | 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 distance *vs.* time graph for the free fall of the picket fence.
3. Describe in words the shape of the velocity *vs.* time graph. How is this related to the shape of the distance *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, ± 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 $g = 9.9 \pm 0.9 \text{ m/s}^2$. Record your values in the Data Table.

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

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

Experiment 5

6. 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.
7. Inspect your velocity graph. How would the associated acceleration *vs.* time graph look? Sketch your prediction on paper. From the main screen, select GRAPHS. Use the cursor keys \blacktriangle and \blacktriangledown to select ACCELERATION and press ENTER . Comment on any differences between the calculator's graph and your prediction. Trace across the acceleration values using your cursor keys. Note that the vertical scale of the graph does not include zero. Is the variation as large as it appears?
8. Find the average acceleration from the trace values. How does this compare with the acceleration value for the same drop, determined from the slope of the velocity graph?

EXTENSIONS

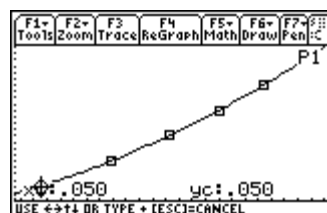
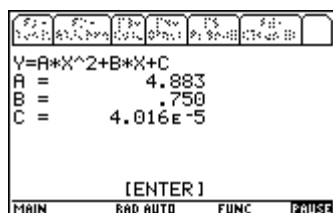
1. Use the distance *vs.* time data and a quadratic fit to determine g .
2. Display the acceleration *vs.* time plot and note the apparent variation in acceleration. Trace across the plot with the \blacktriangleleft and \blacktriangleright cursor keys, and read the acceleration values individually. Is the acceleration varying as much as it first appears?
3. Would dropping the Picket Fence from higher above the Photogate change any of the parameters you measured? Try it.
4. 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.
5. 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.
6. Investigate how the value of g varies around the world. For example, how does altitude affect the value of g ? What other factors cause this acceleration to vary at different locations? How much can g vary at a location in the mountains compared to a location at sea level?

TEACHER INFORMATION

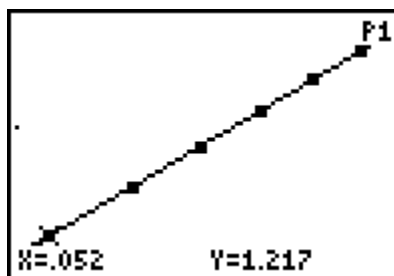
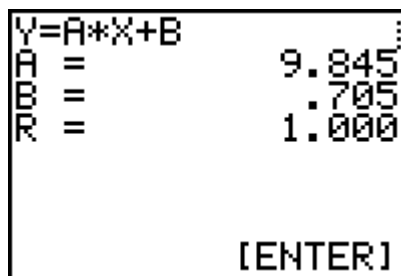
Picket Fence Free Fall

1. Unlike most experiments in this book, this activity uses the DataGate program instead of the DataMate program. DataGate must be loaded onto the calculator from a computer using the TI Graph Link cable and TI Graph Link software. DataGate is provided on the CD accompanying this book. Instructions for loading DataGate to your calculator are in Appendix B.
2. Dirty or scratched Picket Fences may give erratic results.
3. Picket Fences are available from Vernier Software (order code PF \$5.00). You can make your own Picket Fences using clear plastic and black tape, but the tape tends to stretch as it is placed on the plastic. It is difficult to achieve precise results with a handmade fence. The leading edge separation of the bars of tape must be 5.00 cm.
4. It is important that the Picket Fence remain vertical during the fall. If not, the vertical distance between bars gets smaller and the results are off.
5. The Photogate must be rigidly fixed to avoid noise or systematic errors. In particular, do not hold the Photogate in your hand.
6. You may want to have the students drop the Picket Fence onto a rug so that it does not get scratched or damaged.
7. There is a good discussion of variation in the acceleration due to gravity on the earth's surface in the chapter on gravitation in *Fundamentals of Physics* by Halliday, Resnick, and Walker.

SAMPLE RESULTS



Position vs. time fit and graph taken on a TI-89.



Velocity vs. time fit and graph taken on a TI-83.

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Experiment 5

| Trial | 1 | 2 | 3 | 4 | 5 | 6 |
|--------------------------|-------|-------|-------|-------|-------|-------|
| Slope (m/s^2) | 9.784 | 9.797 | 9.791 | 9.810 | 9.810 | 9.819 |

| | Minimum | Maximum | Average |
|---------------------------------|---------|---------|---------|
| Acceleration (m/s^2) | 9.784 | 9.819 | 9.802 |

| | |
|----------------------------------|-------------------------------|
| Acceleration due to gravity, g | $9.80 \pm 0.02 \text{ m/s}^2$ |
| Precision | 0.2 % |

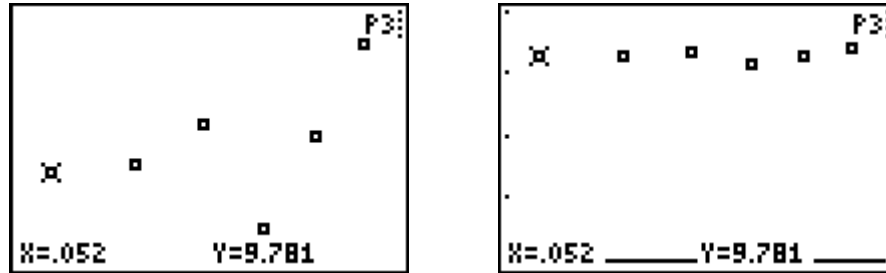
ANSWERS TO PRELIMINARY QUESTIONS

1. Since we know the distance from one edge of a bar to the corresponding edge of the next bar is 5.00 cm, to determine the speed we need to know the length of the time interval (Δt) it took for the Picket Fence to move this far. Then we use the ratio $5.0 \text{ cm}/\Delta t$ to calculate the speed.
2. An object in constant acceleration has a linear velocity *vs.* time graph; that is, the slope of the graph is constant.
3. Initial velocity is independent of the slope of the graph; that is, the acceleration. An object thrown downward still accelerates after release at the same rate as an object that is dropped.

ANSWERS TO ANALYSIS QUESTIONS

1. Values entered in data table.
2. The distance *vs.* time graph is a parabola.
3. The velocity *vs.* time graph is a straight line. The slope of the distance *vs.* time graph at a point is equal to the velocity.
4. Using the example values, the uncertainty is $\frac{1}{2} (9.189 - 9.784) = 0.0175 \rightarrow 0.02 \text{ m/s}^2$. In the last step, the uncertainty has been rounded to two decimal places. **Note:** This is a simple measure of the precision of the acceleration measurements. More advanced physics students may want to use the standard deviation of the measurements for a more rigorous measure.
5. $0.02/9.80 = 0.2\%$.
6. Many physics textbooks use the value of 9.80 m/s^2 for g . Since this value is within the range of the $9.80 \pm 0.02 \text{ m/s}^2$, the experimental result agrees with the textbook value. It is coincidental that the average value, rounded to two decimal places, is the same as the textbook value.

7. Since the velocity graph is linear with a constant slope, the acceleration graph would be a constant function—a horizontal line above the time axis. Note that the data may appear irregular. This is due to small variations in the timing measurement. When the acceleration vs. time graph is selected, it is autoscaled, magnifying these variations. When the origin is included on the vertical axis, the data appear consistent, as in the graph below. The right-hand graph has a y axis running from 0 to 12 m/s^2 . The same point is highlighted in each.



8. The trace values from the acceleration graph are scattered around the value of the slope of the velocity graph.