# Free Fall

## Equipment

- Computer, PASCO Interface
- Steel Ball
- Stopwatch
- Foam Pad
- PASCO Photogate clamped to a stand, Photogate cable
- "Picket Fence"

## Objectives

- *To compare two different techniques used to determine the acceleration due to gravity, $g$.*

## Introduction

Galileo was the first to describe gravity on Earth's surface correctly. Through experiments, he found that, neglecting air resistance, any object falls with a constant acceleration, $g = 9.8\ \mathrm{m/s^2}$ downward. That means that if the object is dropped from rest, it will travel distance

$$\mathrm{h} = \frac{1}{2}gt^2 \qquad (1)$$

The value of $9.8\ \mathrm{m/s^2}$ implies that any object would travel 4.9 meters in the first second of drop. Such rapid motion makes even a small uncertainty of 0.1 second relatively large unless the object travels a very long distance. For example, in a common laboratory setting where height does not exceed 2 meters, the time of travel won't exceed 0.64 second. Taking in consideration that typical absolute uncertainty due to human reaction ranges between 0.1s and 0.2 s, an experiment in a common laboratory setting yields at least 17% uncertainty. The same absolute uncertainty will produce much smaller relative uncertainty at larger distance of travel. Increasing a height of drop to 5 meters will increase the time of travel to 1 second and reduce the relative uncertainty to 10%. However, if such increase in distance is not possible, a decrease in absolute uncertainty could solve the problem. Due to high sensitivity, electronic sensors produce much smaller absolute uncertainty that aids in avoiding large relative uncertainty in experiments that incorporate small heights. A photogate has an infrared beam between its prongs and each opaque portion of passing picket fence blocks this beam where an electronic sensor measures the time of blockage. Since each opaque portion has exactly same length of 5 cm, a ratio of this distance over the recorded time is the average speed of the picket fence during the beam blockage. If the values of average speed for each opaque segment are graphed against the values of time, the slope of this graph could be interpreted as an acceleration of the picket fence. It is assumed, that the value of the acceleration of a picket fence dropped through the photogate equals g.

In this lab, the value of the acceleration due to gravity will be measured by two different methods. In one method, the timing of fall will be done by a human and, in another method, the timing of fall will be done by an electronic sensor. Experimental values obtained by each method will be compared with the accepted value of $9.8\ \frac{m}{s^2}$.

Experimental results from both methods will be evaluated to rank the methods in terms of accuracy and precision. The % Error between the experimental and accepted values will assess the accuracy of the method and the standard deviation of the experimental values will assess the precision of the method.

## Part #1: Human Timing with a Stopwatch

In this method, the time it takes for a steel ball to fall from a set of known height will be measured by a stop watch.

***1.*** Place a foam pad on the floor and hold a ball so that it is the desired height from the floor. *Assume the uncertainty in the measured distance to be a radius of the ball.*

**2.** Use a stopwatch to record the time of the fall. It's best to have one lab partner drop the ball and another do the timing. *Assume the uncertainty in the timing to be the reaction time of a person working the stopwatch;* the value stays the same unless rotation of partners.

**3.** Repeat the drop for at least 5 trials at each height.

**4.** Repeat the experiment for heights of 0.75, 1.00, 1.25, 1.50, 1.75, and 2.00 meters. (**Do not draw marks on the walls.** Use a Post-It note if you need a visual height indicator.)

For each height of the ball drop, calculate the following:

**5.** The average time and uncertainty $\Delta t$ of the 5 trials.

**6.** Acceleration $a$, from formula (1) in the introduction.

**7.** Percent uncertainty in the acceleration: $(\frac{\Delta h}{h} + \frac{\Delta t}{t} + \frac{\Delta t}{t})100\%$.

| **Height (m)** | | **0.75** | **1.00** | **1.25** | **1.50** | **1.75** | **2.00** |
|---|---|---|---|---|---|---|---|
| **Uncertainty in height (m)** | | | | | | | |
| **Times of Fall (s)** | **Trial 1** | | | | | | |
| | **Trial 2** | | | | | | |
| | **Trial 3** | | | | | | |
| | **Trial 4** | | | | | | |
| | **Trial 5** | | | | | | |
| | **Average** | | | | | | |
| | **Uncertainty, $\Delta t$** | | | | | | |
| **Acceleration (m/s$^2$)** | | | | | | | |
| **% Uncertainty in Acceleration** | | | | | | | |

**Table 1.** Data recorded for ball drops from various heights.

## Part # 2: Electronic Timing with a Picket Fence and Photogate

In this method, the time it takes for a steel ball to fall from a set of known height will be measured by an electronic sensor.

1. Mount the Photogate so that the picket fence can be dropped between the prongs.
2. Plug the Photogate into socket #1 of the PASCO Interface box.
3. Open Capstone File "Free Fall" from the physics lab website.
4. Make sure the foam pad is under the Photogate.
5. Hold the Picket Fence perpendicular to the beam so it is hanging just above the Photogate.
6. Click on "Record" in Capstone. Drop the Picket Fence through the Photogate. It must not bump the table or photogate. Press "Stop".
7. You should see a sloped linear graph that may have a few data points at the beginning or end.
8. Generate the Linear Fit line in Capstone. Look above the graph for the Fit button (a red line surrounded by blue dots), use the pulldown next to it, and pick "Linear: mx+b".
9. Make sure the linear fit visually lines up with the sloped line of points. Use the highlight tool if necessary, to select only points that fall the sloped line.
10. The Slope of the Speed vs. Time graph is the measured acceleration.
11. Repeat 5-10 above for at least 6 trials.

| **Trial** | **1** | **2** | **3** | **4** | **5** | **6** |
|---|---|---|---|---|---|---|
| **Acceleration (m/s$^2$)** | | | | | | |

**Table 2.** Data recorded from Capstone for the Picket Fence drop.

## Part #3: Comparing the Methods

1. Calculate the **average Acceleration** and a Sample Standard Deviation **in acceleration** for each method. To do so, average the values from the row labeled "Acceleration" in Tables 1 and 2; additionally, calculate the standard deviation with =STDEV() for the same set of values.
2. Calculate % Error between the average value determined by each method and the accepted value of g, $9.81\frac{m}{s^2}$ . To calculate % Error use Excel formula "=ABS(value–g)/g" and format the result as %.

| **Description** | **Method 1: Human Timing** | **Method 2: Electronic Sensor** |
|---|---|---|
| **Average Acceleration (m/s$^2$)** | | |
| **Standard Deviation (m/s$^2$)** | | |
| **Accepted *g* (m/s$^2$)** | | |
| **% Error** | | |

**Table 3:** Summary of results.

## Requirements for the Report (also consult the rubric):

Save your Excel files through your Blackboard Group File Exchange

- The **abstract section** must contain the following explanations in paragraph form:
    - How the data was collected in each method including an explanation of the used tools (Note: in the second method, "electronic sensor measured the acceleration" is insufficient. The explanation must include how the computer executes similar steps as humans do in Method 1: as the picket fence falls, the speed of each opaque picket passing through the photogate beam is calculated from the time of the beam's blockage measured by the sensor and the length of the picket; the software presents the data as a graph speed vs. time and the slope of the graph is interpreted as the acceleration of the fall.)
    - How the data was analyzed including the calculation of acceleration in Table 1, and average acceleration, standard deviation, and % error for each method in Table 3.
    - A statement based on Table 3 about the precision and accuracy of each method using % error as a metric to assess the accuracy and a standard deviation to assess the precision.
- The **data section** must include
    - 3 Tables (labeled and captioned)