*Question: How do you measure the acceleration of a falling object?*

In this Investigation, you will:

1. Make graphs of the motion of a marble in free fall.
2. Learn to determine the acceleration of the marble.
3. Make a theory that can predict the speed of the falling marble.

The gravity drop is designed so you can study how gravity affects the motion of falling objects. In this Investigation, you will measure the speed of the marble at points in its path as it falls. You will use the data you collect to make a graph of the marble's motion. Using this graph, you will be able to make predictions about the marble's motion.

## 1 Creating a hypothesis

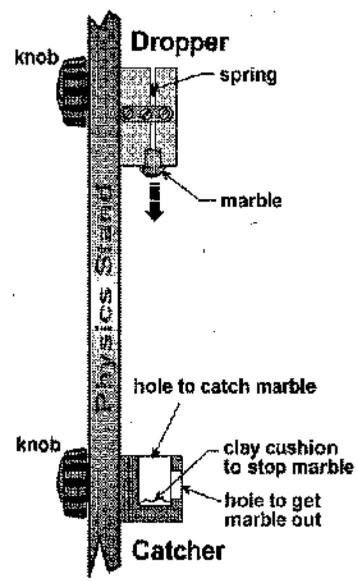
**a.** In this Investigation, you will be measuring the speed of a steel marble at certain places in its fall. Do you think the speed of the marble will increase, decrease, or stay the same as it falls? Your answer to this question will be your hypothesis for the Investigation.

**b.** Write a short paragraph to justify the hypothesis you created in the previous question.

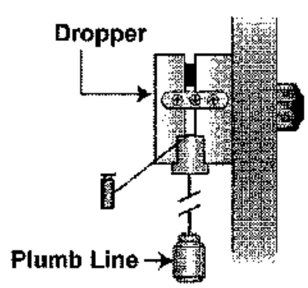
## 2 Setting up the experiment

1 Starting at the base of the physics stand, attach the catcher at the first hole, the dropper at the nineteenth hole, photogate A at the seventeenth hole, and photogate B at the sixteenth hole. The photogates should fit tightly against the physics stand. What is the distance between the photogates?

2 Use the plumb line to level the physics stand. Clip the silver cylinder in the dropper. Make sure the string moves freely through the cylinder. Adjust the length of the string with the stopper so that the brass plumb bob falls just inside the catcher. If the brass plumb bob fits into the catcher without touching the sides, the physics stand is level. If the stand is not level, adjust it by raising or lowering the feet on the underside of the stand. Remember: "Right raises, left lowers."




3 Practice dropping a steel marble from the dropper. Use your thumb to *gently* push the dropper. Wrap your middle fingers around the pole to brace the physics stand. If the physics stand is perfectly level, the marble drops into the catcher without hitting the sides. You will hear a "thunk" as the marble hits the clay in the catcher after a good drop.



## B Doing the experiment

1. Connect photogates A and B to the timer with the cords provided. One cord should connect photogate A to the slot above the A button on the timer. The other cord should connect photogate B to the slot for the B button. Set the timer to interval mode.
2. Drop the steel marble until you get a good drop, and record the distance between the photogates (0.05 m) and all three times ($t_A$, $t_B$, and $t_{AB}$) in Table 1.
3. Now, move photogate B so that it is 0.1 m below photogate A. Repeat step 2.
4. Repeat step 2 for for all the distances listed in Table 1. Remember to only record data from good drops. At this time, you will not calculate the speed of the marble at each photogate.

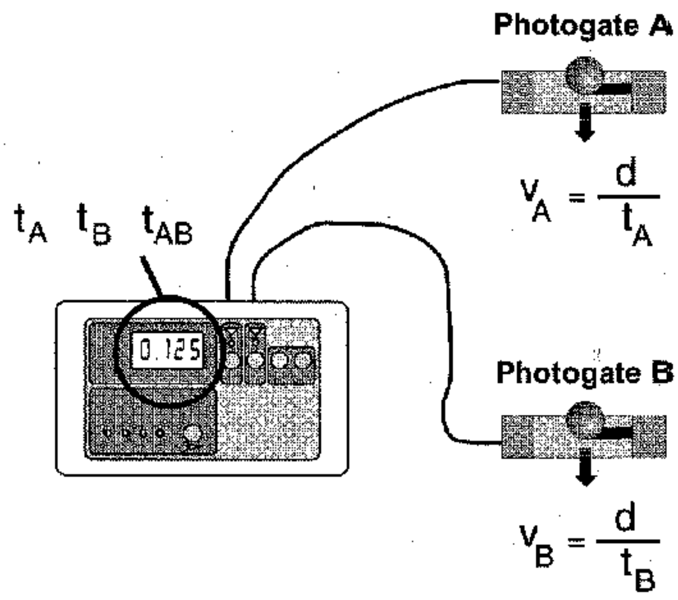



**Table 1: Time and Speed Data**

| Falling distance (m) | Time A to B $t_{AB}$ (sec) | Time from A $t_A$ (sec) | Speed at A $v_A$ (m/sec) | Time from B $t_B$ (sec) | Speed at B $v_A$ (m/sec) |
|---|---|---|---|---|---|
| 0.05 | | | | | |
| 0.10 | | | | | |
| 0.15 | | | | | |
| 0.20 | | | | | |
| 0.25 | | | | | |
| 0.30 | | | | | |
| 0.35 | | | | | |
| 0.40 | | | | | |
| 0.45 | | | | | |
| 0.50 | | | | | |
| 0.55 | | | | | |
| 0.60 | | | | | |
| 0.65 | | | | | |
| 0.70 | | | | | |
| 0.75 | | | | | |

**a.** Describe what happens as the marble falls through the light beam of a photogate. Write your answer as a series of steps.

**b.** Compare the times at photogate A to photogate B. Are they the same or different? Do you see a pattern? If so, what is it?

## 4 Calculating speed

Speed is distance ($d$) traveled divided by time taken ($t$) to travel that distance. The time is the interval that the light beam is broken. The distance the marble travels during the time the light beam is broken is equal to its diameter. The speed is calculated by dividing the diameter of the marble (0.019 meters) by the time the light beam was broken in either photogate A or B.

Using the equations below, calculate the speed of the marble at A ($v_A$) and at B ($v_B$) using the times from Table 1 and diameter of the marble as the distance. Record your results in Table 1.

$$v_A = \frac{0.019\,\text{m}}{t_A} \qquad v_B = \frac{0.019\,\text{m}}{t_B}$$

## 5 Analyzing the data

**a.** How does the speed of the marble at photogate B change as you move it further down the physics stand pole?

**b.** Write a short paragraph describing the motion of the marble as it falls.

## 6 Graphing the data

There is a clear pattern in the measurements, but it is not easy to see by looking at the data in Table 1.

1. **Graph 1: Speed versus Distance**
   Make a graph with the speed of the marble at photogate B on the $y$-axis and the distance from A to B on the $x$-axis.
2. **Graph 2: Speed versus Time**
   Make another graph with the speed of the marble at photogate B on the $y$-axis and the time from photogate A to photogate B on the $x$-axis.

**a.** Describe what each graph looks like.

**b.** Using a ruler, draw a straight line (in pencil) through the points on each graph. The line should match the general pattern of the points. Do not draw the line so that the points are connected dot-to-dot.

**c.** Which of the graphs has the clearest pattern?

## 7 Predicting speed



The speed of the marble can be predicted using the equation below where $v_B$ is the speed at photogate B, $v_A$ is the speed of the marble at photogate A, $a$ is the acceleration, and $t$ is the time from photogate A to photogate B.

$$v_B = v_A + at$$

You measured $t$ and $v_B$ for many different points. Use your graph to determine $a$ and $v_A$. Write your values in Table 2. Once you determine $a$ and $v_A$, use the equation above to calculate the predicted speeds for the times given in Table 3.

**Table 2: Speed and Acceleration Values**

| $v_A$ = | $a$ = |
|---|---|

**Table 3: Predicting Speed**

| Time (sec) | 0.010 | 0.090 | 0.170 | 0.250 | 0.330 | 0.410 |
|---|---|---|---|---|---|---|
| Predicted speed at B $v_B = v_A + at$ | | | | | | |

**a.** Plot the times and predicted speeds on the graph with the pattern. Use a different symbol to tell the calculated points from the measured points.

**b.** How do your predicted values (theoretical values) compare with the line that represents the experimental values?

**c.** The acceleration of gravity is 9.8 m/sec$^2$. The acceleration you calculated for Table 2 represents the acceleration of gravity. What is the percent difference between your value and the actual value for the acceleration of gravity (9.8 m/sec$^2$)?

**d.** Look at the graph you modified by drawing a straight line through the data points. How could you use this graph to determine a value for the acceleration of gravity? Hints: Think about the variables on the graph, the definition of acceleration, and the equation above.

## 8 Gravity challenge: Improving your experimental technique

In working with the gravity drop, you learn quickly that you need to pay attention to your technique. More often than not, you might get results that indicate experimental error. The percent difference between your acceleration value and 9.8 m/sec$^2$ indicates the experimental error in the experiment.

**a.** List some sources of experimental error that occur in the gravity drop.

**b.** It is challenging to get accurate values for the gravity drop because the distances and times you are working with are very small. For example, the distance you use to calculate speed is 0.019 meter. If the marble is a little off-center, the distance might actually be different by as much as1.5 millimeters. Calculate speed using a time of 0.0191 sec and a distance of 0.019 m. Then, calculate speed using the same time but 0.018 m. What is the percent difference between these two values?

**c.** Re-examine the experimental technique you used in the Investigation. List three ways that you can reduce experimental error.

**d.** Once you have refined your technique for using the gravity drop, repeat the Investigation, paying close attention to detail and be sure to use your new techniques. Your goal is to reduce your experimental error to 10% or less.