



Free Fall and the Gravity Drop

Equipment Setup

Gravity Drop Setup. 1

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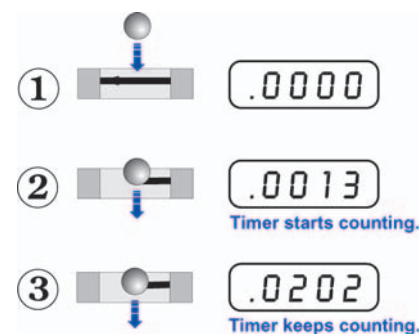
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A-3 Falling Motion

Key Question: How do you graph the motion of a falling marble?

Everyone knows that when you drop something, it falls down. How can you describe this motion? Does an object fall at the same speed until it lands on the ground, or does its speed change? In this Investigation, students discover the answers to these questions on their own by graphing the motion of a falling marble.



Preparation

In the Investigation, students learn to perform an experiment and use a graph to make a prediction. At the end of the Investigation, students learn the difference between speed and acceleration. They also learn that the acceleration of a falling object due to the force of gravity is a constant value.

The calculated acceleration may be higher or lower than the acceleration of gravity due to experimental error. At the end of this teacher's guide, you will find instructions for guiding your students in improving their experimental technique and reducing experimental error.

The gravity drop and the car and ramp set are both useful for studying one-dimensional motion. The gravity drop is more difficult to set up but produces cleaner results. Used together, both sets of equipment illustrate universal concepts about motion.

Setup and Materials


Students work in groups of four at tables. Each group should have:

- One physics stand
- One gravity drop setup (plumb line, steel marble, plastic marble, dropper, and catcher)
- One CPO timer with two photogates (with a 9-volt battery or AC adapter and cords for connecting the photogates)
- A metric ruler (at least 30 centimeters in length)

Each student should have

- Graph paper and a simple calculator
- Copy of the Investigation and answer sheet

The Investigation

Time  One to two class periods

Leading Questions

- How can you graph the motion of a falling object?
- How do you interpret a motion graph?
- What is the difference between speed and acceleration?

Learning Goals

In this Investigation, students will:

- Make a graph of the motion of a falling marble.
- Learn to interpret motion graphs.
- Learn the difference between speed and acceleration.

Key Vocabulary graph, speed, acceleration, hypothesis, gravity

1

- 1a. As the stone falls, its speed steadily increases until it hits the water.
- 1b. As the marble falls, its speed steadily increases until it lands in the catcher.
- 1c. The speed increases because of the effect of the force of gravity. Like all unbalanced forces, the force of gravity causes a change in the motion of the object. In this case, it causes uniform (i.e., unchanging, constant) acceleration. This means the speed of any object increases at a constant rate as it falls.

Note: It is okay at this point if answers and justifications from your students are incorrect.

2

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- 2.1 The distance between the two photogates is 5 centimeters (0.05 m).
- 2.2 Students may need some time to make adjustments to the physics stand and gravity drop apparatus. Circulate to answer questions and offer assistance.

A-3

Falling Motion



Question: How do you graph the motion of a falling marble?

In this Investigation, you will:

1. Make a graph of the motion of a falling marble.
2. Learn to interpret your motion graph.
3. Learn the difference between the terms speed and acceleration.

How does gravity affect the motion of a falling object? A good way to answer this question is to create a graph showing where the motion of a falling object changes or stays the same. The change in speed over time is called *acceleration*.



In this Investigation, you will use the gravity drop to measure the speed of the marble at points in its path as it falls. The data you collect will allow you 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

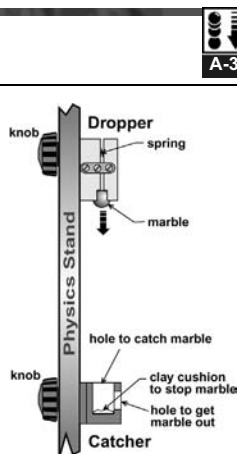
Creating a hypothesis

Describe the motion of the marble as it falls. Your description *before* you have studied the motion of the marble is your *hypothesis*. Your hypothesis will help guide you in the Investigation. By answering the following questions, you will develop your hypothesis for the Investigation.

- a. If you dropped a stone off a bridge into a river, how would you describe the motion of the falling stone? Does the speed of the stone change during the fall?
- b. What about a falling marble? 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 changes as it falls? If so, how will the speed change? Your answers to these questions will be your hypothesis for the Investigation.
- c. Write a short paragraph to justify the hypothesis you created in the previous question.

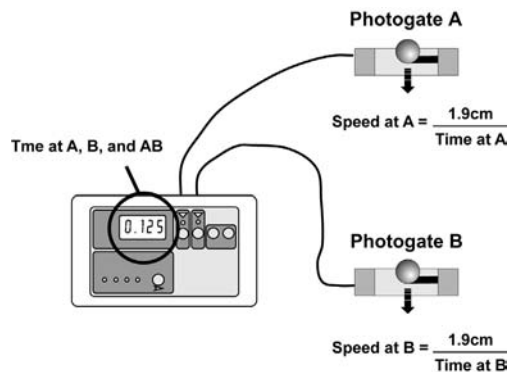
2 Setting up the experiment

- 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?
- Use the plumb line to align the dropper and catcher. 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."
- 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.



3 Doing the experiment

- Connect photogates A and B to the timer with cords as shown in the diagram. Set the timer to interval mode.
- Drop the steel marble until you get a good drop, and record the distance between the photogates (5 cm) and all three times (Time at A, Time at B, and Time from A to B) in Table 1.
- Now, move B so that it is 10 cm below photogate A. Repeat step 2.
- Repeat step 2 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.



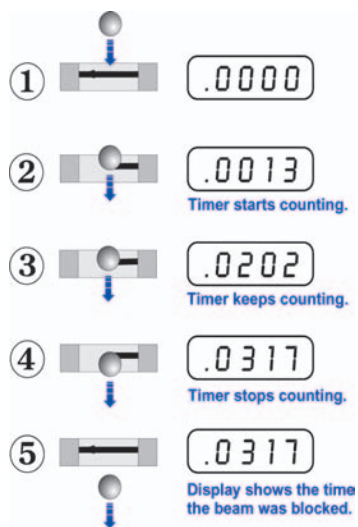
Note: In the next sections, "A" refers to photogate A and "B" to photogate B.

3 Shown on the next page.

Table 1 data:

Falling distance (cm)	Time A to B (sec)	Time from A (sec)	Speed at A (cm/sec)	Time from B (sec)	Speed at B (cm/sec)
5	0.0427	0.0191	100	0.0136	140
10	0.0783	0.0190	100	0.0108	176
15	0.1061	0.0195	97	0.0097	196
20	0.1305	0.0191	99	0.0085	224
25	0.1521	0.0191	99	0.0078	244
30	0.1724	0.0191	99	0.0072	264
35	0.1905	0.0191	99	0.0066	288
40	0.2086	0.0190	100	0.0062	306
45	0.2253	0.0191	99	0.0060	317
50	0.2409	0.0191	99	0.0057	333
55	0.2558	0.0190	100	0.0054	352
60	0.2703	0.0191	99	0.0053	358
65	0.2841	0.0190	100	0.0048	396
70	0.2977	0.0191	99	0.0049	388
75	0.3102	0.0189	101	0.0046	413

3a. Steps for what happens as the marble falls through the light beam:



(1) The marble has not broken the beam yet so the timer is not counting.

(2) The timer starts counting when the front edge of the marble breaks the light beam.

(3) The timer keeps counting as long as the marble is in the light beam.

(4) The timer stops counting as soon as the back edge of the marble passes out of the light beam.

(5) The display shows the time that the light beam was broken.

3b. The times for photogate A are very similar. The times for photogate B decrease as distance increases.

4 Shown on the next page.

Speed values are recorded in Table 1.



Table 1: Time and Speed Data

Falling distance between photogates (cm)	Time from A to B (sec)	Diameter of marble (cm)	Time from A (sec)	Speed at A (cm/sec)	Time from B (sec)	Speed at B (cm/sec)
5						
10						
15						
20						
25						
30						
35						
40						
45						
50						
55						
60						
65						
70						
75						

- Describe what happens as the marble falls through the light beam of a photogate. Write your answer as a series of steps.
- Compare the times at A and the times at B. Are they the same or different? Do you see a pattern? If so, what is it?

4

Calculating speed



The speed of the marble is calculated by dividing the marble's diameter by the time the light beam was broken as the marble drops through a photogate. The diameter of the marble is 1.9 centimeters.

Using the speed equations below, calculate the speed of the marble at A and at B. You will be dividing the diameter of the marble by the time from the timer. Record your results in Table 1.

$$\text{Speed at A} = \frac{1.9 \text{ cm}}{\text{Time at A}} \quad \text{Speed at B} = \frac{1.9 \text{ cm}}{\text{Time at B}}$$

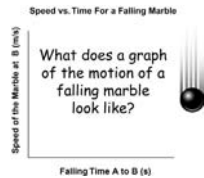
5

Graphing the data



Now, you will create a graph of the data. You will see how a graph gives you a "picture" of the motion of the marble as it falls.

1. Make a graph of speed of the marble at B on the y-axis and the time from A to B on the x-axis.
 2. When you have finished the graph, use a ruler to draw a straight line (in pencil) through the points on the graph. Do not draw the line so that the points are connected dot-to-dot.
- a. What does your graph look like? In your description, include a sentence that describes how the speed of the marble is related to the time it has fallen.
 - b. How does the speed of the marble at B change as you move it further down the physics stand pole?



6

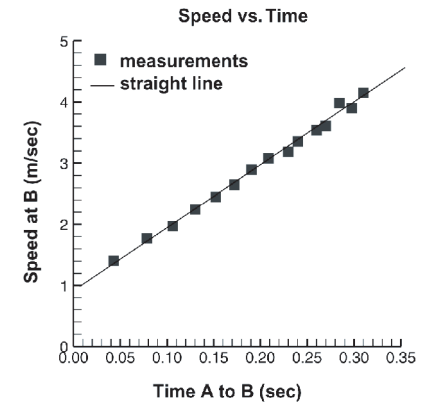
Drawing conclusions

- a. Was the hypothesis you created in Part 1 correct? Explain your answer.
- b. The terms *speed* and *acceleration* are often used to describe motion. The term *acceleration* means a change in speed over time. Based on this definition, was the marble accelerating as it was falling? Explain your answer.
- c. Let's say you dropped a marble from a height of 5 feet. How could you use your graph to find the speed of the marble after it has fallen for 0.4 seconds?

4

5

Graph, right:



5a. The plot of the data is a diagonal line that goes up from left to right. The graph shows that as the time increases from A to B, the speed of the marble increases at photogate B.

5b. As photogate B is moved down the pole, the speed at photogate B increases. This observation supports the fact that the speed of the marble changes as it falls—the marble accelerates.

6

- 6a. The speed versus time graph shows that my hypothesis was correct. As the time from A to B increases (as photogate B is moved down the pole), the speed at B increases.
- 6b. Yes, the marble was accelerating as it was falling because the speed of the marble was increasing.
- 6c. You could extend the x-axis of the graph to include 0.4 seconds and extend the line that is drawn through the points. The intersection of the plot line and a vertical line at 0.4 seconds represents the speed after the marble has fallen 0.4 seconds. From the graph, the estimated speed would be 5.1 m/sec.

1. Acceleration is a change in speed. This means that whenever the speed of an object is changing, it is accelerating. Speed is the distance an object travels divided by the time it takes to go that distance. Units for speed are distance units over time units. Acceleration units are distance units per time unit per time unit. For example, a common acceleration unit is meters per second per second or m/sec^2 .
2. 1, D; 2, B; 3, C; 4, A
3. Line B
- 4.

Time falling (sec)	Speed (m/sec)
1	9.8
2	19.6
3	29.4
4	39.2
5	49.0

Gravity Challenge: Improving experimental technique

When first working with the gravity drop, it is challenging to get data that matches the accepted values for gravity (9.8 m/sec^2). You might expect values to be off by as much as 30% for a first set of values. This kind of result presents an opportunity. Have your students improve their experimental technique and look for ways to reduce experimental error.

Sources of experimental error include: (1) Recording data when the marble is off-center. (2) Not including enough significant figures in the recorded data—rounding numbers off can slightly increase or decrease a value. Since the values used are already small, rounding can cause differences in results. (3) Not making sure the distance between photogates is exact—it is important to measure from the center of the light beam of photogate A to the center of the light beam of photogate B.

Ways to improve experimental technique: (1) Be sure that the surface on which the physics stand is placed is very stable and flat. (2) Only record data from good drops. (2) Measure carefully between the photogates (light beam center to light beam center), (3) Check the alignment of the dropper and catcher frequently.

Encourage students to work together in their groups to reduce experimental error. To encourage teamwork and to generate enthusiasm about reducing experimental error, present error reduction as a competition among groups. Which group can get the lowest experimental error? After the groups have perfected their technique, you can have each group demonstrate dropping the marble and recording times. On the spot calculations of acceleration will allow you to evaluate which groups have mastered their technique and the concepts.

Curriculum Resource Guide: Gravity Drop

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