WARD'S™
DataHub
The Power of Twelve
The Convenience of One

Free Fall:
Observing and Analyzing the Free Fall Motion of a Bouncing Ping-Pong Ball and Calculating the Free Fall Acceleration
(Teacher's Guide)

OVERVIEW

Students will measure the variation in distance (motion) of a bouncing ping-pong ball when dropped from a height of 80 cm. They will analyze the data and calculate acceleration of gravity based on the empirical result to compare it with the information provided in the teacher background.

MATERIALS NEEDED

Ward's DataHub
USB connector cable*
Ping-pong ball

** – The USB connector cable is not needed if you are using a Bluetooth enabled device.*

NUMBER OF USES

This demonstration can be performed repeatedly.

FRAMEWORK FOR K-12 SCIENCE EDUCATION © 2012

* The Dimension I practices listed below are called out as **bold** words throughout the activity.

Dimension 1 Science and Engineering Practices				
	✓	Asking questions (for science) and defining problems (for engineering)	✓	Use mathematics and computational thinking
	✓	Developing and using models	✓	Constructing explanations (for science) and designing solutions (for engineering)
	✓	Planning and carrying out investigations		Engaging in argument from evidence
	✓	Analyzing and interpreting data	✓	Obtaining, evaluating, and communicating information

Dimension 2 Cross Cutting Concepts				
		Patterns	✓	Energy and matter: Flows, cycles, and conservation
	✓	Cause and effect: Mechanism and explanation		Structure and function
		Scale, proportion, and quantity		Stability and change
	✓	Systems and system models		

Dimension 3 Core Concepts	Discipline	Core Idea Focus
	Physical Science	PS2: Motion and Stability: Forces and Interactions
		PS2.A: Forces and Motion

NGSS Standards	Middle School Standards Covered	High School Standards Covered
	MS.PS-FM: Forces and Motion	HS.PS-FM: Forces and Motion

NATIONAL SCIENCE EDUCATION STANDARDS © 2002

Content Standards (K-12)			
✓	Systems, order, and organization		Evolution and equilibrium
✓	Evidence, models, and explanation		Form and Function
✓	Constancy, change, and measurement		

	Physical Science Standards Middle School		Physical Science Standards High School
✓	Properties and Changes of Properties in Matter		Structure of Atoms
✓	Motions and Forces	✓	Structure and Properties of Matter
	Transfer of Energy		Chemical Reactions
		✓	Motions and Forces
			Conservation of Energy and Increase in Disorder
		✓	Interactions of Energy and Matter

✓ Indicates Standards Covered in Activity

LEARNING OBJECTIVES

Core Objectives (National Standards):

- Develop the ability to refine ill-defined questions and direct to phenomena that can be described, explained, or predicted through scientific means.
- Develop the ability to observe, measure accurately, identify and control variables.
- Decide what evidence can be used to support or refute a hypothesis.
- Gather, store, retrieve, and analyze data.
- Become confident at communicating methods, instructions, observations, and results with others.

Activity Objectives:

The purpose of this activity is to calculate free fall acceleration, proving Newton's 2nd Law. A hypothesis will be created and tested using the Ward's DataHub motion (distance) sensor.

Time Requirement:

45 - 60 minutes

VOCABULARY

Acceleration: The rate at which velocity changes.

Force: A push or pull exerted on an object.

Gravity: The force that pulls objects towards each other.

Inertia: The tendency of an object to resist any change in its motion.

Kinetic Energy: Energy that an object has due to its motion.

Law of Conservation of Mass: The total momentum of an object or group of objects remains the same, or is conserved, unless outside forces act on the object(s).

Mass: A measure of the amount of matter in an object.

Momentum: The product of an object's mass and velocity.

Motion: The state in which one object's distance from another is changing.

Newton: A unit of measure that equals the force required to accelerate 1 kilogram of mass at 1 meter per second.

Newton's First Law of Motion: An object at rest will remain at rest, and an object moving at a constant velocity will continue moving at a constant velocity, unless it is acted upon by an unbalanced force.

Newton's Second Law of Motion: Acceleration depends on the object's mass and on the net force acting on the object.

Newton's Third Law of Motion: If one object exerts a force on another object, then the second object exerts a force of equal strength in the opposite direction on the first object.

Parabola: The curve formed by a set of points.

Potential Energy: Stored energy that results from the position or shape of an object.

Speed: The distance an object travels per unit of time.

Velocity: Speed in a given direction.

Weight: The force of gravity on a object at the surface of a planet.

Teacher Notes

INTRODUCTION

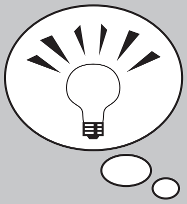
Have you ever wondered why you don't fly into space when you jump up? It sounds like an absurd question, but it makes us realize that "something" keeps us on the ground and doesn't let us escape. We see the same phenomenon when a ping-pong ball or basketball bounces, they always reach a certain height and then fall back to the ground.

- **Suppose you jump as high as you can. How would you describe the feeling during each moment of the jump, i.e. when you go up, when you reach the highest point and when you go down again?**

- **How do you think it feels (physiologically) when a person jumps out of an airplane? Explain.**

Carry out the experiment with your class so that at the end, students will be able to answer the following question:

- **How does the distance between an object and the ground vary when the object falls to the ground and bounces?**

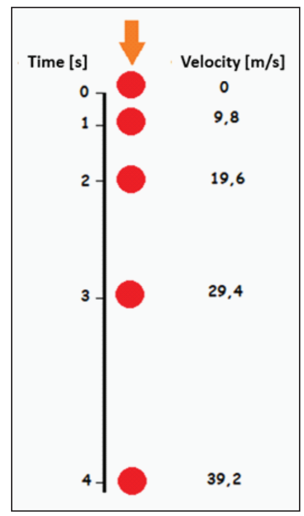


DID YOU KNOW?

A falling object doesn't fall fast, it continually falls faster. The acceleration of gravity varies with location on Earth's surface. Its value increases slightly with latitude (because of the Earth's rotation) and decreases with altitude. However, the variation is only about 0.3 percent at the most.

BACKGROUND

Objects that fall to the ground from different heights move differently than objects that change location on a surface. The first case of motion is called free fall and is an example of linear motion with constant acceleration. On a theoretical basis, no real object on Earth describes this kind of movement, because we consider free fall to happen when gravity is the only force acting on the object. In this case, it would be independent of shape or mass and would occur only in a vacuum where there is no friction force. On Earth, air (or any other gas or fluid) exerts friction force on the object, changing the conditions of the fall. Yet over short distance free fall activities, this friction force has minimal effect.



The form of acceleration that occurs on objects in free fall is called acceleration of gravity (g). Its magnitude is approximately 9.8 m/s^2 and is a consequence of the force of gravity that attracts the object towards the center of the Earth. An acceleration of 9.8 m/s^2 means that the object will increase its velocity by 9.8 meters each second, as shown in the figure on the right.

The value of g will be positive for a body that moves toward the surface of the Earth, and negative as it moves away (e.g., on a vertical shot).

The distance covered by an object in free fall is equal to the height (h).

The formula on the right represents the relationship between quantities involved in free fall: initial velocity (V_i), final velocity (V_f), acceleration of gravity (g), height (h), and time (t).

$$V_f = V_i + gt$$

$$t = \frac{V_f - V_i}{g}$$

$$Vf^2 = V_i^2 + 2gh$$

$$h = V_i t + 1/2gt^2$$

At this point, encourage students to formulate a hypothesis to test as part of this activity. Students may find it helpful to formulate their hypothesis as an answer to the following question:

- **Suppose having dropped a ping-pong ball you are able to measure the variation in the distance as it moves downwards in free fall from the initial point. What would you expect the variation in distance to be?**

CONNECTING THE WARD'S DATAHUB TO A COMPUTER

If you are using a Bluetooth communication device:

Right-click on the Bluetooth icon in the lower right corner of the screen and select the Ward's DataHub you are using. The icon will change from gray to blue, as shown at right, indicating that the Ward's DataHub and the computer are now connected via Bluetooth.

If you are using a USB communication device:

In order to use USB communication, connect the Ward's DataHub and the computer with the USB cable supplied. Click on the USB icon at the lower right corner of the screen. This icon will change from gray to blue, as shown at right, indicating that the Ward's DataHub is connected to the computer via USB.

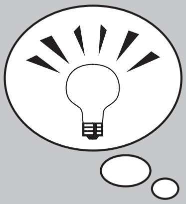
USING THE WARD'S DATAHUB

 = Select key  = On/Off and Escape key  = Scroll key

To collect measurements with the Ward's DataHub, it must first be configured as follows:

1. Turn on the Ward's DataHub by pressing the On/Off/Esc key.	
2. Go to setup by using the Scroll key; then select Setup by pressing the Select key.	then
3. Select the Set Sensors option by pressing the Select key.	
4. If any sensor(s) appear on the screen, press the key representing that sensor to deactivate it. Once you have a blank screen, press the **Motion (Distance) Sensor** key until Motion Sensor shows up on screen.	 may be paired with the accelerometer sensor
5. Press the On/Off/Esc key once to return to the setup menu.	
6. Press the Scroll key to highlight the Sampling Rate and then press the Select Key	then
7. Press the Scroll key until "**25/sec**" is highlighted, then press the Select key.	then

8. Press the On/Off/Esc key to return to the setup menu.	
9. Press the Scroll key to highlight the Number of Samples and then press the Select Key.	then
10. Press the Scroll key until "**1000**" is highlighted, then press the Select key.	then
11. Press the On/Off/Esc key three times to return to the main operating screen.	x 3
12. **Press the Select key to start measuring.** (You are collecting data when there is an icon of a Runner in the upper left hand corner of the screen.)	
13. Once you have finished measuring, stop the Ward's DataHub by pressing the Select key, followed by the Scroll key.	then



DID YOU KNOW?

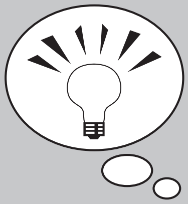
When a cannon is fired, an explosion propels a cannon ball out the open end of the barrel. It flies a kilometer or two to its target. At the same time, the cannon itself is pushed backward a meter or two. This is action and reaction at work (Newton's 3rd Law). The force acting on the cannon and the ball is the same. What happens to the cannon and the ball is determined by Newton's 2nd Law. The cannon ball has a small mass and a large acceleration and the cannon has a large mass and a small acceleration.

ACTIVITY

1. Once you have configured the DataHub, place it 1.2 meters above the floor. Have the distance sensor facing the floor and start the data recording by pressing  .

2. Drop a ping-pong ball from 80 cm. above the floor, directly below the distance sensor. The Ward's DataHub should always remain at the same level above the floor. Observe the ball's height as it bounces.

3. After you receive data for three bounces, stop the data recording.



DID YOU KNOW?

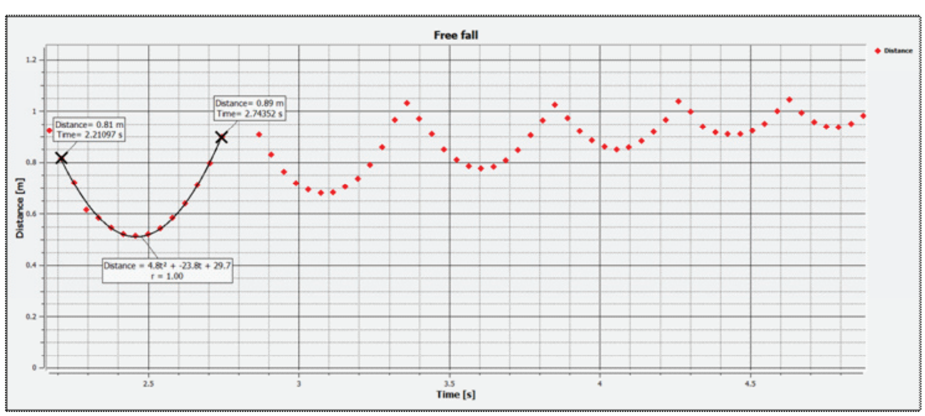
You can apply Newton's 2nd Law to seat belts! When applying Newton's 2nd Law of Motion to car accidents and the use of seat belts, the net external force on the passenger's body is the mass of the vehicle multiplied by its acceleration. The proper use of a seat belt reduces the external force of an accident and disperses the initial inertia of the collision across the body. Without a seat belt, the passenger's acceleration coupled with the car's deceleration, increases the total acceleration. When this acceleration is being multiplied by a very large mass, even a small change in acceleration results in a large increase in the force applied to the accident victim.

RESULTS AND ANALYSIS

The following steps explain how to analyze the experiment results.

1. Connect the DataHub to the computer either using the USB connector or the Bluetooth function.
2. Observe the graph displayed on the screen.
3. Identify the section of the graph that represents the bounces of the ping-pong ball. Then, activate the markers , placing one at the start point and a second at the end point of the bounce section.
4. Crop the samples to the right and the left of the markers. Press and click "accept" on the message displayed on the screen. The graph will now contain only the selected section between the two markers.
5. A right-click on the distance legend to the right of the graph window will change the line graph to sample icons.
6. Select the start and end points of one bounce and press the quadratic regression button to obtain the equation of the parabola.
   - **How do the results relate to your initial hypothesis? Explain.**
   - **Did you find similarities between the equation provided by the software and the free fall equation?**
   - **What happens to the parabola amplitude during the experiment?**

The graph below should be similar to what the students obtained.



CONCLUSIONS AND ASSESSMENTS

1. What is the initial velocity in free fall (in the case of the ping-pong ball)?

   Students should point out that in free fall where an object is dropped from a given height (or distance), the initial velocity is 0.

2. Using the equation from the graph and the equation for the height of a falling object ($h = V_i t + 1/2gt^2$), **calculate** the value of the experimental acceleration of gravity.

   Students should recognize that the expression $1/2gt^2$ from the height equation is equal to the first term of the quadratic regression obtained on the chart (e.g., $4.8\ t^2$).

   We can establish these two expressions to be equal by the following equation:

   $1/2\ gt^2 = 4.8\ t^2$

   Therefore we can state:

   $1/2\ g = 4.8$

   $g = 4.8 \times 2$

   $g = 9.6$

   We remember the units of g from the teacher background and obtain $g = 9.6\ m/s^2$.

3. **Calculate** the experimental error by comparing your empirical result with the theoretical value of g.

   Students should calculate the percentage difference of both values of g. For example, if we use the value obtained previously ($g = 9.6\ m/s^2$), our percentage difference is 2.1%

4. How would you **explain** the differences between the theoretical and empirical values of g?

   Students should establish that the friction force exerted by the air on the ball may change the value of acceleration.

5. In which section of the graph did you observe a positive value of g? Did you observe a negative value of g? **Argue** why you picked those specific points.

   Students should remember that acceleration of gravity is positive when the object approaches the surface of Earth, and negative if it moves away from the ground. Therefore, g will be positive when the ball is moving downwards and negative when it is moving upwards.

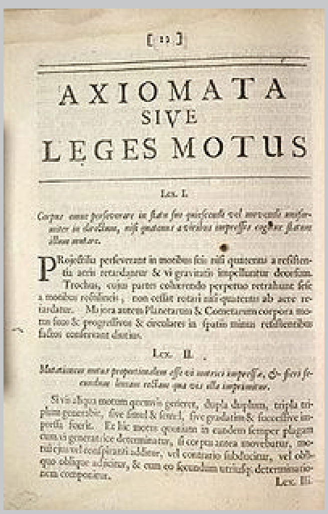
6. Write a **concluding** paragraph describing what you observed during the experiment.

   Students should reach the following conclusions:

   If objects fall from a given height, they move with free fall motion. Free fall can be represented by a graph of distance as a function of time. If the object bounces, consecutive parabolas are created on the graph. We can obtain lots of information with the parabola equation and compare them to the mathematical expressions in the theoretical background. For example, we can calculate the experimental value of the acceleration of gravity.

DID YOU KNOW?

Newton's three laws of motion were first compiled by Sir Isaac Newton in his work *Philosophiae Naturalis Principia Mathematica*, first published in 1687.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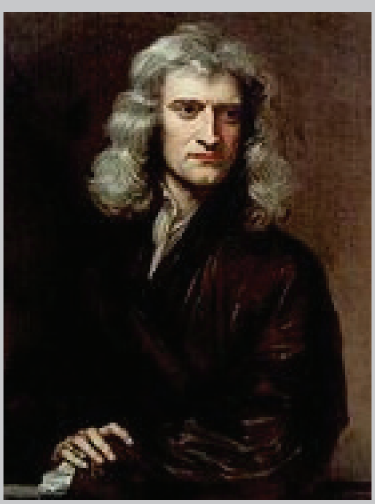


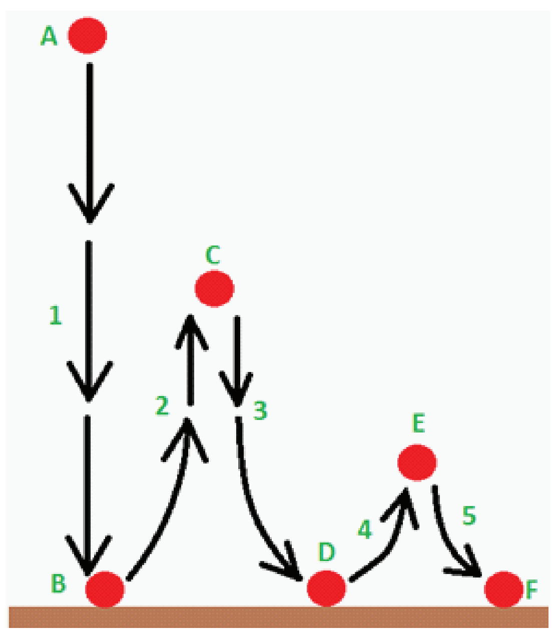
ACTIVITIES FOR FURTHER APPLICATION

The aim of this section is for students to extrapolate the knowledge acquired during this class and apply it to different contexts and situations. Furthermore, it is intended that students question and present possible explanations for the experimentally observed phenomena.

1. What happens when someone jumps from a plane by parachute?

   Students should indicate that if someone opens a parachute during the fall, they expand the surface area in contact with the air. Therefore, the system slows down because the friction force is dramatically increased, compared to the friction force exerted on the person without a parachute.

2. Label the diagram indicating at what moments (A, B, C, D, E or F) the velocity of the ball is zero. Indicate where the ball velocity is increased or decreased due to the g acceleration, in each of the sections (1, 2, 3, 4, and 5). **Explain** why.



   Students should explain that at points A, C and E the velocity of the ball is 0. At 1, 3 and 5 the velocity increases because of the g acceleration. In 2 and 4 the g acceleration slows or decreases the ball velocity.

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ACTIVITIES FOR FURTHER APPLICATION

(continued)

3. A falling stone takes three seconds to reach the ground. From what height above the ground did the stone fall?

   Students should suppose that the initial velocity of the stone is zero. They should use the last equation from the teacher background and solve the problem.

   Data:

   $t = 3\ s$

   $V_i = 0$

   Solution:

   $h = \cancel{V_i \times t} + 1/2\ gt^2$

   $h = 1/2\ gt^2$

   $h = 1/2\ 9.8\ m/\cancel{s^2} \times 3^2\ \cancel{s^2}$

   $h = 44.1\ m$

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For technical assistance,
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