

Acceleration Due to Gravity

Subject Area(s)	Physics, Math
Associated Unit	None
Associated Lesson	None
Activity Title	Measuring g
Header	Insert Image 1 here, right justified

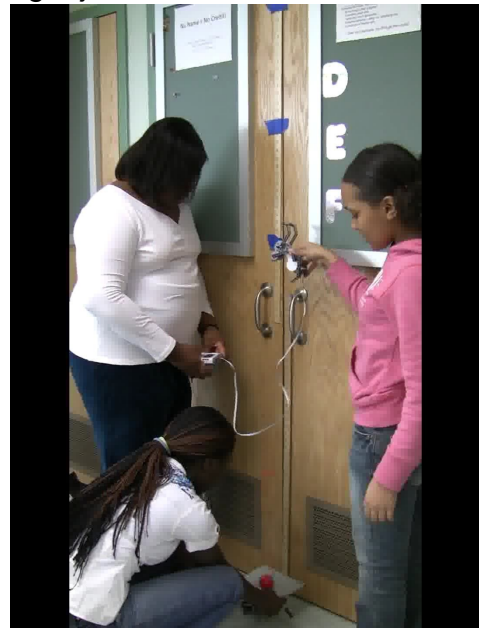
Image 1

ADA Description: Students measuring g

Caption: None

Image file name: gravity_lab_image1.jpg

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Group Size	3-4
Expendable Cost per Group	US \$5
Grade Level	8
Time required	35-40 minutes

Summary

Using the Lego Mindstorms kit, students will construct an experiment where the time to travel a specified distance by a free falling body is measured. Students will use the touch sensor, rotational sensor, and the NXT brick, to measure the time of flight for the falling object, at different release heights. After the object is released from its holder and travels a specified distance, a touch sensor is triggered and time of object's descent from release to impact at touch sensor is recorded and displayed on the screen of the NXT. Students will calculate the velocity of the falling object at each point of release, and construct a graph of velocity versus time. A best fit line will then be applied to this graph, of which the slope will be obtained and compared to the standard value of g .

Engineering Connection

The concepts of Physics are apparent in all areas of our world. A fundamental understanding of the role of gravity is the foundation for many feats of engineering that we see in our everyday lives, such as bridges, buildings, airplanes, boats, etc. This experiment is designed to show how similarly shaped objects, of different weights, will have the same acceleration when in free fall.

Engineering Category

Category 3: Engineering analysis and partial design

Keywords

Forces, gravity, free falling bodies, Lego Mindstorms NXT, plotting data using spreadsheet software, best fit line, slope

Educational Standards

- New York, science, 2009, PS 5.1a, b: Patterns of motion, frame of reference and position, direction, and speed.
- New York, science, 2008, PS 5.1c: Newton's First Law of Motion: Inertia
- New York, science, 2008, PS 5.1d: Newton's Second Law: $F = ma$

Pre-Requisite Knowledge

Basic programming with Lego Mindstorms NXT

Basic understanding of graphing in Cartesian coordinates

Learning Objectives

After this activity, students should be able to:

- Construct a plot of velocity versus time
- Show how closely the relationship of velocity and time are to a straight line
- Propose explanations for the difference in the calculated and standard g
- Plot data using spreadsheet software

Materials List

Each group needs:

- Lego Mindstorms Education NXT Base set (www.legoeducation.com, \$279.95)
- 2, custom cut flexi-cables (1 meter in length) for NXT (www.mindsensors.com, \$3.95 each)
- Computer (PC or MAC)
- Two or three balls of similar shape and different weights
- Tape measure
- Scale

Introduction / Motivation

Gravity is commonly thought of as a universal force that holds matter together. It results from the net force the Earth exerts on objects in its vicinity. On the surface, gravity is the net force that is responsible for downward motion of free falling objects. It accelerates all objects at the same rate, that is, two objects of roughly the same size

and shape, but different weights, when dropped from the same height, will hit the ground at the same time. To illustrate this, the experimental apparatus will be constructed using the Lego Mindstorms kit.

Newton's second law states that the net force on an object is equal to the mass of the object times its acceleration;

$$F = ma \quad (1)$$

where m is mass and a is acceleration. For an object in free fall, equation one can be written as;

$$F = mg \quad (2)$$

where m is mass and g is the acceleration due to gravity. Equating equations 1 and 2 shows that the acceleration of the object is due to force of gravity and is independent of mass;

$$F = ma = mg \rightarrow a = g \quad (3)$$

For a conservative system, the total amount of energy remains constant. In our setup, only forces in the vertical direction come into play (neglect air resistance). At the beginning of the experiment, the object is fixed at a specified distance above some base level (e.g. the ground). At the starting position, the object is considered to have potential energy (PE) but no kinetic energy (KE). As soon as the object is released, some of its PE is converted to KE, and the object begins to fall (due to gravity). As freefall continues more of its PE is converted to KE and the velocity of the object increases. This change in the objects velocity as it falls is the acceleration due to gravity, g , which has a constant value of 9.8 m/s^2 .

If we only look at the downward motion of the object (one dimension), its acceleration, g , is defined as the rate of change of its velocity with respect to time. Mathematically, the acceleration is derivative of velocity with respect to time, such that;

$$g = \frac{dv}{dt} \quad (4)$$

Assuming that the object accelerates from some initial velocity, v_0 to some final velocity, v_f , over a time interval of t_0 to t , then applying these conditions to the integration of equation (4) yields the final velocity of the object:

$$v_f = v_0 + gt \quad (5)$$

Velocity is defined as the change of an object's position with respect to time;

$$v = \frac{dx}{dt} \quad (6)$$

Assuming that the object travels from some initial position, x_0 to a final one, x , over the same time interval as before (t_0, t), an equation for position can be derived. Combining equations (2) and (3) and integrating over the conditions of x_0 to x , and t_0 to t , the position of the object is;

$$x = x_0 + v_0t + \frac{1}{2}gt^2 \quad (7)$$

For this activity, students will be measuring the average velocity, such that:

$$v_{\text{avg}} = \frac{1}{2} (v_f + v_0) \quad (8)$$

where v_f and v_0 are the final and initial velocities, respectively. Substitution of equation 5 into equation 2 yields:

$$v_{\text{avg}} = v_0 + \frac{1}{2} gt \quad (9)$$

IMAGE Insert Figure 1 here, centered

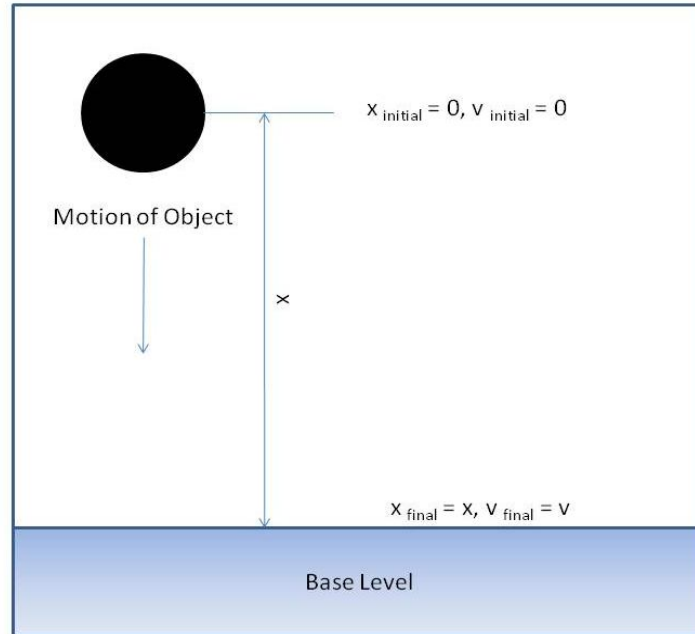


Figure 1

ADA Description: Schematic of a free falling object.

Caption: Figure 1: An object with an initial velocity of 0, will hit the ground (base level) with a final velocity in accordance with equation 2.

Image file name: Acceleration_due_to_gravity_figure1.jpg

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Vocabulary / Definitions

Word	Definition
Potential Energy	The energy of position
Kinetic energy	The energy of motion
Gravity	the force of attraction by which terrestrial bodies tend to fall toward the center of the earth
Velocity	The rate of change of position with respect to time.
Acceleration	The rate of change of velocity with respect to time.

Procedure

Before the Activity

- Construct the experimental apparatus according to the attached building instructions.
- Load the attached Lego Mindstorms program.
- Distribute attached experimental worksheet
- **With the Students**
 1. Place ball in object holder.

IMAGE Insert Image 2 here, centered

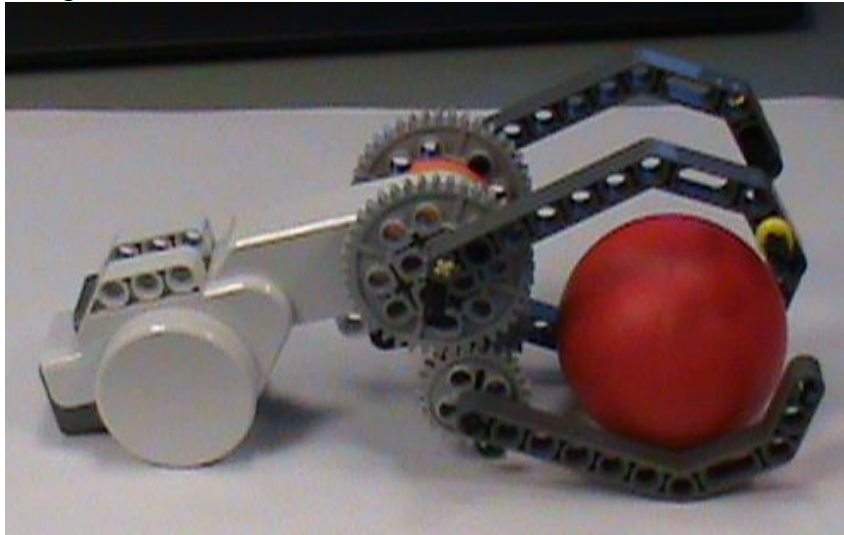


Image 2

ADA Description: Starting position of ball in object holder

Caption: Image 2: A ball is placed in the object holder

Image file name: Gravity_lab_image2.jpg

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2. Measure the vertical distance between the object and the base plate of the touch sensor.
3. Run the Lego Mindstorms program.
4. Using the experimental worksheet, record the time needed for the object to collide the touch sensor. This time will be displayed on the screen of the Mindstorms NXT. Record the data on attached worksheet.
5. Calculate average velocity of each run using the following equation:
$$\text{velocity} = \frac{\text{distance}}{\text{time}}$$
6. Repeat steps 1 -5 while either raising or lowering the starting position of the object. Record data in chart for four additional starting positions.

7. Repeat for another object of different weight.

IMAGE Insert Image 3 here, centered

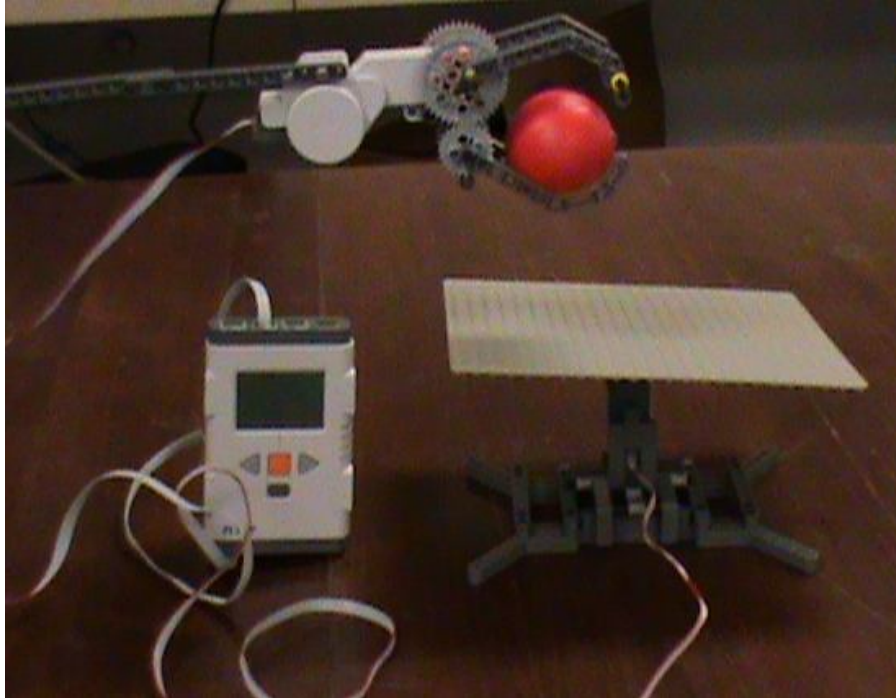


Image 3

ADA Description: Complete experimental setup

Caption: Image 3: A ball is placed in the object holder and held at a vertical distance from the touch sensor

Image file name: Gravity_lab_image3.jpg

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8. Using spreadsheet software, construct a graph of velocity versus time for all objects tested.
9. Perform a linear regression analysis (a best fit line) of the data and obtain the equation for the line (in the form of $y = mx + b$) as well as the square of error (R^2).
10. The value for the slope (m) is the acceleration of the free falling object. Compare this value to the standard value of g .
11. Compare the values for the measured acceleration of the different the objects tested

Assessment

Activity Embedded Assessment

Analysis

Students should compute the value of g for the different objects tested and compare their calculated value to the accepted value of g (9.8 m/s^2). Additionally, they should be able to comment on how well the data for the graphs of velocity versus time adheres to

a straight line (R^2 value). Students should research explanations for the difference in the values for the calculated and accepted values of g (9.8 m/s^2).

Attachments

Acceleration_due_to_gravity_worksheet.doc
Acceleration_due_to_gravity_program.rbt
Acceleration_due_to_gravity_building_instructions_complete.lxf
Acceleration_due_to_gravity_building_instructions_complete.html

Activity Extensions

None

Additional Multimedia Support

None

References

1. Dictionary.com. Dictionary.com, LLC. Accessed August 2, 2009 (Source of some vocabulary definitions, with some adaption) <http://dictionary.reference.com/>
2. Lego.com. The Lego Group. Accessed August 2, 2009 www.Minstorms.lego.com
3. Mindsensors.com. Mindsensors.com 2005-2009. Accessed August 2, 2009 www.mindsensors.com

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Owner

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