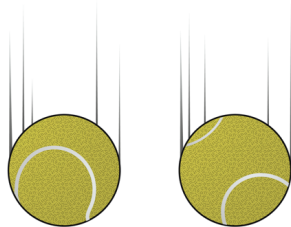# Gravitation on Earth

You have lived your entire life within a gravitational force field on Earth. Can you feel it, right now? Do you know how the gravitational field of the Earth is measured or defined? In this activity you will investigate Earth's gravity two different ways.

Figure 1

PRELIMINARY OBSERVATIONS

1. Observe two objects of the same size but different mass as they are dropped at the same time from the same height.

2. Discuss your observations with your group or class. Questions to consider include:
    - What do you notice?
    - Can we identify the forces acting on each object?
    - Is there a way to eliminate all the forces on the object except gravity?

3. Draw a qualitative graph that represents the motion. Label the axes and add a few words of explanation.

4. Observe two objects with different masses as you hold or lift them.

5. Discuss your observations with your group or class. Questions to consider include:
    - What do you notice?
    - What makes these objects feel different from each other?
    - Does gravity affect what we feel when we hold or lift an object?

PROCEDURE

Part I

1. Discuss and decide what variables you will use to describe the motion of an object moving only under the influence of the force of gravity on Earth.
    - Consider any previous models of motion you have developed.
    - Plan to have a quantitative result (a number and units).

2. Develop a purpose and a procedure for your investigation.
    * Your purpose should ask a question or propose a model for describing the motion of an object moving only under the influence of the force of gravity on Earth.
    * Include the measurement equipment you will use.
    * Decide how much data or observation to take in order to have enough information to satisfy your purpose and stand up to questioning by your peers.

3. Carry out the investigation and record your data and observations. Make sure all group members have access to the data.

Part II

1. Discuss and decide what variables you will use to describe the quantity of the force of gravity acting on an object.
    * Consider what factors may affect the force of gravity on an object and how you could vary them.
    * Remember that only one independent variable may be changed at a time.

2. Develop a purpose and a procedure for your investigation.
    * Your purpose should ask a question or propose a model for determining the force of gravity on an object on Earth.
    * Include the measurement equipment you will use.
    * Decide how much data or observation to take in order to have enough information to satisfy your purpose and stand up to questioning by your peers.

3. Carry out the investigation and record your data and observations. Make sure all group members have access to the data.

ANALYSIS

For the two parts, ask yourself: Is the graph linear? If not, you may need to perform one or more mathematical operations on your data. Develop a mathematical model for your data and discuss with your group how your variables fit into the model. When you discuss the results with your class, be sure to share your model and ideas.

Examine your graphs and those of your peers. Look for patterns and consistencies. In class discussion, come to a consensus model for motion of a falling object on Earth and a consensus model for the force of gravity on any object on Earth. How confident are you that these models will work elsewhere on Earth? You may need to do some reading or some research.

EXTENSION

Find a video of the *Feather & Hammer Drop on Moon* on the Internet and download a copy of the video that can be analyzed using video analysis. Perform video analysis of the falling feather and hammer to determine if gravity models are dependent on the planetary body.

Gravitation on Earth

OVERVIEW

The goal of this activity is for students to determine that objects in free fall on Earth experience an acceleration of 9.8 m/s^2 and that the force of gravity acts on all objects on Earth at a ratio of 9.8 N of force for every kilogram of mass.

In the Preliminary Observations, students observe falling objects and hold and/or lift similarly-shaped objects of different mass.

During their investigations, students should determine that objects without appreciable air resistance fall at 9.8 m/s^2 regardless of mass and that for every kilogram of mass, gravity pulls with an additional 9.8 N of force.

You may choose to have half the lab groups perform one investigation and half perform the other investigation, or choose to have all groups do both parts.

WHAT SHOULD STUDENTS KNOW BEFORE DOING THIS ACTIVITY

To do Part I, students should be familiar with the concept of mass as a measurement of an amount of matter. They should also be able to use a balance for measuring mass. Students should also be familiar with using a force sensor to collect force data.

For Part II, students should be comfortable with linear acceleration and the graphical and mathematical representations of accelerated motion. They should be able to determine acceleration from the slope of a velocity *vs*. time graph. Students should be familiar with data collection tools that can be used to measure acceleration, and they should know more than one way to determine the acceleration of an object (e.g., using a motion detector or video analysis).

Finally, students should be familiar with the concept of force and the idea that gravitational force arises from the interaction between objects and Earth. They do not need to understand Universal Gravitation and the inverse square law, but they should be able to identify that the gravitational force acts on all the objects they encounter every day. Student practice drawing free body diagrams ahead of time is useful as well.

LEARNING OUTCOMES

- Identify variables, design and perform investigations, collect and analyze data, draw a conclusion.
- Relate acceleration of gravity on Earth (*g*) and gravitational field strength on earth.

NEXT GENERATION SCIENCE STANDARDS

Disciplinary Core Ideas	Crosscutting Concepts	Science and Engineering Practices
PS2.A Forces and Motion PS2.B Types of Interactions	Patterns Cause and Effect Systems and System Models	Planning and carrying out investigations Analyzing and interpreting data Using mathematics and computational thinking Constructing explanations and designing solutions Science models, laws, mechanisms, and theories explain natural phenomena

ESTIMATED TIME

Students should be able to complete the Preliminary Observations, planning, and data collection in the space of one 40-minute class period. Data analysis and class discussion leading to a conclusion will take an additional 40-minute class period.

MATERIALS

Make the following materials available for student use. Items in bold are needed for the Preliminary Observations.

> **objects of the same size but different mass, such as differently weighted tennis or racquet balls**
> computer, Chromebook, or mobile device
> data-collection program
> data collection interface (if necessary)
> photogate
> Picket Fence
> force sensor or spring scale
> clay
> balance (electronic or triple-beam)
> a variety of objects with different unknown masses
> additional items at student request

PRELIMINARY OBSERVATIONS

The Preliminary Observations are best done as a whole class. Students should observe that two objects of the same size and shape but different mass will seem to fall together when dropped at the same time and from the same height. They should see the two objects move together and hear them hit the floor or table at the same time. For example, use two racquetballs or tennis balls, of which one has been altered to be a different mass. Or, use two same-size items of different materials from a density demonstration set.

A second observation should be made in which students pass around and hold similarly-sized objects of different mass. These can be the same as the objects used in the previous observation.

Students should observe the differences they feel when holding objects with different masses. Larger masses feel heavier than smaller masses.

A BBC preview on YouTube dealing with falling objects in a large vacuum chamber is a very dramatic example that students will enjoy. The full title is *Brian Cox visits the world's biggest vacuum chamber - Human Universe: Episode 4 Preview - BBC Two*. The clip is less than 5 minutes long. You may want to end the clip at 3:53 to avoid confusion between Newtonian gravity, mentioned right before the 3:53 mark, and Einsteinian gravity, which is mentioned right after the 3:53 mark.

After the Preliminary Observations and discussion, frame the investigation. Challenge students to use experimental methods to determine both how gravity affects an object's motion and how gravity affects an object's weight.

IMPLEMENTATION

Part I Determine how gravity affects an object's motion

There are two possibilities for students to investigate in Part I: position *vs.* time or velocity *vs.* time. If students suspect acceleration, steering them towards velocity *vs.* time graphs will simplify analysis because students can examine the slope of the linear graph.

We recommend using either video analysis or a photogate and picket fence for this part. If students have never used a photogate, spend some time demonstrating the setup or direct students to visit **http://vnr.st/v156** and watch the video. The first 4 minutes are relevant for this investigation. If students watch further, they will see that the demonstrator gets a value of 9.7 m/s^2 for the slope of the velocity *vs.* time graph.

Part II Determine how gravity affects an object's weight

For Part II, there may be some discussion about how to approach the question. Students may require guidance regarding what quantity to use as the independent variable. One way to address this is to ask students to think about being in a swimming pool with a massive object (such as another person). Does the mass of the object change when it is moved into the water? Within the swimming pool, is it easier to lift, harder to lift, or the same as when it is not within the pool? Students should recognize that mass does not change but weight may appear to change, so mass should be the independent variable and should be on the horizontal axis of the graph they will create.

ANALYSIS

Students should discover linear relationships for both velocity *vs.* time in Part I and force of gravity *vs.* mass in Part II. The slopes should be very similar. During class discussion of the results, encourage student groups to average their slopes. If there are multiple sections, collect slope values on a shared document or on a corner of the chalkboard/whiteboard so different sections of the class can also compare their data. Also, consider a shared online document with all the mass and force data on it, from all groups.

SAMPLE RESULTS

Part I The acceleration of a falling object

Regardless of the mass of the falling object, the slopes of the velocity *vs.* time graphs should average about 9.8 m/s^2. Students graphing position *vs.* time should use a quadratic fit; the coefficient of the squared term should be about 4.9 m/s^2.
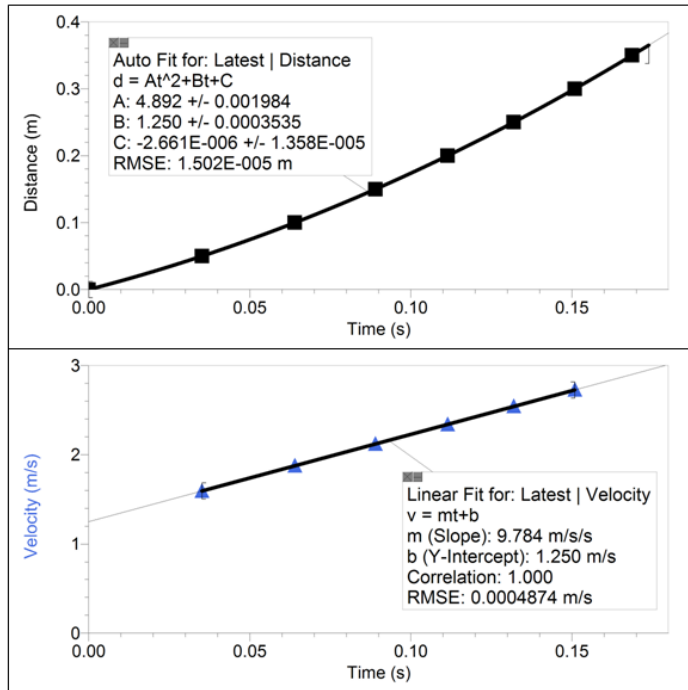

Figure 1 Data collected from a Picket Fence dropped through a photogate

Part II Force of gravity dependence on mass

Students should find that the force of gravity on an object on Earth is proportional to the mass of the object, and the slope of the force *vs.* mass graph is also about 9.8, but with units of N/kg. For the data in Figure 2, the slope is 9.71 N/kg.
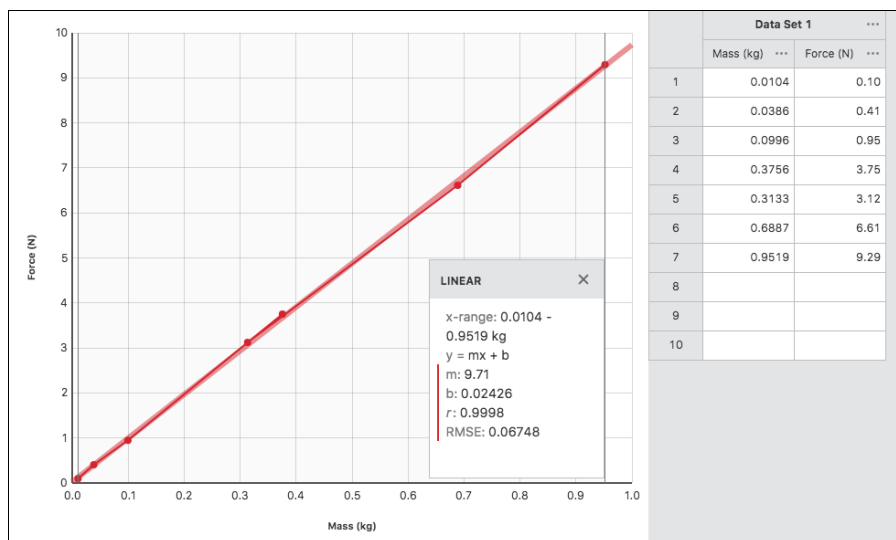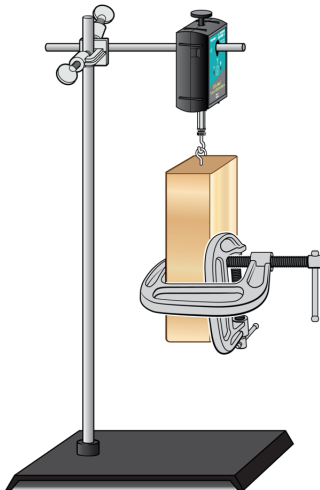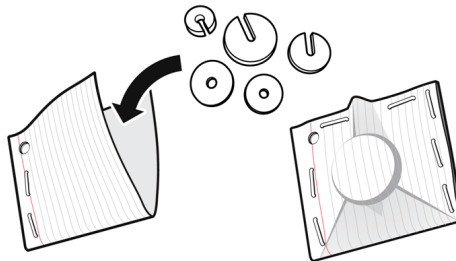

Figure 2

TIPS

1. In the Electronic Resources you will find many useful files, including sample program and a PDF of the student pages so you can print the activity for your students or distribute the file to them electronically. Sign in to your account at **vernier.com/account** to access the Electronic Resources. See Appendix A for more information.

2. For observations, racquetballs or tennis balls can be useful. Cut open one ball and fill completely or partially with sand or metal shot. Reseal the ball with hot glue. Drop the two balls from the same height and at the same time. Then pass the two same-sized but differently massed balls around the room for students to hold and observe.

3. Providing a substantial quantity of objects to mass and weigh can be challenging. One way is to offer many c-clamps and laboratory clamps and allow students to connect them. Blocks of wood with a screw eye in one end (used in friction labs) are also useful (see Figure 3), as are carabiners, paper clips, balls of string, small toys, and items that are found in a classroom. Hooked masses or other laboratory masses are not recommended, as they often have the mass in grams imprinted upon them. Students may assume this mass is exact and not bother using the balance. However, enclosing one or more slotted masses in an index card and hooking it with a paperclip quickly creates an "unknown" mass (see Figure 4).

Figure 3 Combine objects to create a larger amount of mass.

Figure 4 Create an unknown mass with an index card and some known masses or coins.

4. The best data for measuring the acceleration of a falling object are obtained by dropping a picket fence through a photogate beam, with video analysis as a close second choice. Motion detectors suffer from the fact that sound echoes bouncing off a solid object take enough time returning to the sensor that the acceleration tends to be inaccurate at high rates (where 9.8 m/s^2 is considered a high rate).

5. The mass of a Picket Fence can be varied by adding clay, allowing the Picket Fence to be used to determine the acceleration for a variety of masses. If the clay covers any of the clear plastic on the Picket Fence, it may affect the size of the blocked section of the first fence and cause the first data point on a position vs time or velocity *vs*. time graph to be inaccurate.

6. In this investigation, we are explicitly neglecting air resistance. Choose objects for dropping that will have minimal air resistance.

7. When using the Dual-Range Force Sensor, use the ±10 N setting as much as possible. Switch to the ±50 N setting only when objects weigh more than the lower setting can handle. The ±10 N setting allows for greater precision in measurements. The force sensors on the Wireless Dynamics Sensor System (WDSS) and Go Direct Force and Acceleration do not require this adjustment.

8. Either an electronic balance or a triple-beam balance can be used for measuring the mass of objects. If objects are too massive for a single balance, use two balances and place the object across both balances at once. The sum of the readings is the total mass.

9. A low-tech alternative to using a force sensor is to use spring scales. Recommend to students that they use the most precise scale possible for weighing each object.

EXTENSIONS

Assign the following extension and/or engage in the Post-Lab Discussion once students have concluded their investigations. While we provide guidance for what to expect from students in response to the extensions, we do not include sample data or conclusions.

1. Find a video of the "Feather and Hammer Drop on the Moon" on the Internet and download a copy of the video that can be analyzed using video analysis. Perform video analysis of the falling feather and hammer to determine if gravity models are dependent on the planetary body.

    Video analysis of "Feather and Hammer Drop on the Moon": Students should find that the acceleration of these falling objects is substantially less than 9.8 m/s^2. Then they can consider doing video analysis on extra-planetary scenes from movies (*Armageddon* is a good example) and discuss the realism of these movies. It is also interesting to do video analysis on video games and determine if they take place under Earth-like conditions.

2. Optional Post-Lab Discussion: These results are valid here on Earth, what about elsewhere? Introduce Newton's law of universal gravitation:

$$\vec{F}_g = G \frac{m_1 m_2}{r^2} \hat{r}$$

    (at an appropriate level of complexity)