

Universal Gravitation Student Guide

Activity 1 - Earth Gravity Exploration

Using Pasco's ball drop apparatus and various size steel ball bearings, determine the acceleration due to the Earth's gravity: g . Find the mass and diameter of each sphere. Place each sphere so the bottom of the sphere is the same distance above the pedal and drop each sphere at least 5 times.

Using the average time of the drops for a given sphere, calculate the average value of g .

Q1.1: Does the mass or the diameter of the sphere make any difference in the value of g ? If so, what is the trend?

Now vary the height for a given size sphere. Make a table for your data. Use at least 4 different heights and run at least 5 trials at each height. Again, calculate the average time for each height and calculate the average value of g .

Q1.2: Does the height make any difference in the acceleration? If so, what is the trend?

Q1.3: What part of the equation $F = \frac{G m_1 m_2}{r^2}$ equals g if

$$m_1 = m_{\text{earth}} \text{ and } r = r_{\text{earth}} ?$$

Q1.4: What is the value and the units for G ?

Activity 2 - Building a Model for Universal Gravitation (from scratch)

Based on your knowledge of force models, it should be fairly simple to build a model which shows how two objects will move toward each other due to gravitational forces. This model is different from earlier models in that you have two objects, so each object will need its own set of distance, velocity and acceleration icons. Also, since we are interested in the position of each object, the distance stocks should be re-named as position stocks. Also, the net force icon will reflect the fact that the two masses are interacting.

1. Open STELLA.
2. Create a series of stocks, flows and converters to represent position, rate of change of position, velocity, rate of change of velocity, acceleration and mass. You will create two sets of these, one for mass 1 and one for mass 2. All flows should go **into** stocks. Each mass should connect to its acceleration (mass 1 to acceleration 1, mass 2 to acceleration 2). Just to be safe, make sure your velocities can be negative and that your flows are biflows.
3. Create one net force converter. This converter should have connectors going to each of the acceleration converters. Connectors from each of the masses should lead to net force and connectors from each of the distance stocks should lead to net force.

(Note: Answer all questions on a separate sheet of paper.)

Q2.1: Will this net force be constant or will it change? Explain

4. All equations should be as before except for the net force equation. This means that you know what to enter for rate of change of position, rate of change of velocity and acceleration. The initial velocities of both particles will be zero. The initial values for position and the values for mass are discussed below.
5. If all the right connections are made, you should be able to enter the equation for universal gravitation into the net force converter. It should look something like this

$$6.67E-11 * \text{mass1} * \text{mass2} / (\text{Distance1} - \text{Distance2})^2$$

Q2.2: The equation in the book just says d^2 . Why are we subtracting the distances before squaring?

6. Now comes the experimental part. The initial position for mass 1 should probably be 0. That gives us a reference point. The initial position for mass 2 should be somewhere farther away. Try 0.2 (that would be 20 cm). Remember that the gravitational force is very small. Now make the masses large enough (something E5 or in the 100,000's). Create a graph showing the position of each mass. You should set the axes to have the same scale (0 to your position for mass2). Run the model and sketch the graph.

Q2.3: Is the graph what you expected? Explain.

7. Sketch the model on your paper as well. We will build a similar model when we look at electromagnetic forces. Be sure to put your initial positions and masses on the sketch for comparison.

8. Create a second graph. This will be a scatter graph. Put distance_between on the x axis and force on the y axis. Run the model again.

Q2.4: What is the relationship shown by this graph?

9. Return to the first graph (looking at the two positions). Experiment with different initial positions and masses.

Q2.5: What happens if the masses are too large?

Q2.6: What happens if the distances are too large?

10. Save your model as Universal Gravitation.

Activity 2 (Alternate) - Building a Model for Universal Gravitation from the Action-Reaction Model

Building a Universal Gravitation model is simple if you start with the Action-Reaction model. There are a few significant changes such as renaming the distance stocks as position, creating a distance converter and changing the applied force icon so that it will reflect the fact that the two masses are interacting.

1. Open the **Force 2 Objects** model.
2. Change the name of the distance stocks to position and position 2.
3. Create a distance converter. This converter should calculate the difference between the two positions. Later on you will be told to start position2 at a larger number than position1, so set the formula in the distance converter so that the distance will be positive.
3. The applied force converter will hold the equation for Universal Gravitation.

Q2A.1: Before you enter the equation into this converter, what other converters will need to be connected to it?

***Q2A.2:** Will this applied force be constant or will it change? Explain.

4. Make the connections you suggested in Q2.1 above and then enter the Universal Gravitation formula (using STELLA names) into the applied force converter.

Q2A.3: Record here the equation as it appears in your converter.

5. Now comes the experimental part. The initial position for mass 1 should probably be 0. That gives us a reference point. The initial position for mass 2 should be somewhere farther away. Try 0.2 (that would be 20 cm). Remember that the gravitational force is very small. Now make the masses large enough (something E5 or in the 100,000's). Create a graph showing the position of each mass. You should set the axes to have the same scale (0 to your position for mass2). Run the model and sketch the graph.

Q2A.4: Is the graph what you expected? Explain.

6. Create a second graph. This will be a scatter graph. Put distance on the x axis and applied force on the y axis. Run the model again.

***Q2A.4:** What is the relationship shown by this graph?

7. Return to the first graph (looking at the two positions). Experiment with different initial positions and masses.

Q2.5: What happens if the masses are too large?

Q2.6: What happens if the distances are too large?

8. Save your model as Universal Gravitation.

Activity 3: Universal Gravitation Model and the gravitational acceleration of Earth

Once you have a working Universal Gravitation model that has been checked by your instructor, modify the model to so that it represents the attraction between Earth and an object 1500 m above Earth.

Information needed:

Mass of Earth: 5.98×10^{24} kg

Radius of Earth: 6.38×10^6 m

Mass of object: 1 kg

Reminder: The distance in the Universal Gravitation equation is from center to center of the two objects. This was not explicitly part of the earlier models but becomes a crucial point in this one.

Q3.1: If the initial position of Earth is at 0, what is the initial position of an object 1500 m above Earth?

After you have a working model:

Q3.2: What is the average acceleration of the object? _____ Of Earth? _____

Q3.3: Look at the position graph and comment on the motion of the Earth.

Q3.4: Vary the mass of the object from 1 kg to 1000 kg and observe the acceleration of the object. How does mass of a falling object affect the value of the gravitational acceleration?