

The Acceleration Due to Gravity

Introduction:

Acceleration is defined as the rate at which the velocity of a moving object changes with time. Accelerations are always caused by forces. In this laboratory we will investigate the acceleration due to the force of gravity.

Theory:

In its simplest form, Newton's law of force relates the amount of **force** on an object to its **mass** and **acceleration**.

$$\mathbf{F} = m \mathbf{a} \quad (1)$$

or force = mass times acceleration. Therefore, to impart an acceleration to an object, one must impart a force.

One of the most obvious (and the weakest) of all forces in nature is the **gravitational force**. Newton's **Universal Law of Gravitation** describes the gravitational force (F_g) as follows:

$$F_g = \frac{Gmm'}{r^2} \quad (2)$$

This equation states that the force between the two masses m and m' is equal to the product of their masses (mm') multiplied by a constant (G) and divided by the distance between them squared (r^2). The constant (G) is called the **gravitational constant**.

To compute the gravitational force between the Earth and an any object, we substitute the mass of the Earth (M_E) and the distance from the object to the center of the Earth (r). When the objects are on or near the Earth's surface, this distance can be approximated by the value for the radius of the Earth* (R_E) so that Equation (2) becomes:

* We can approximate this because in the scale of the size of the Earth (many hundreds of kilometers) the value for r at the top of our lab table is virtually equal to the value of r at the floor. Algebraically this is shown by:

$$R_E \cong R_E + DR$$

$$F_g = \frac{GmM_E}{R_E^2} \quad (3)$$

in which we see that the force only depends on the mass of the object, because G , M_E , and R_E are all *constants*. This force (measured at the Earth's surface) is called the **weight** of the object.

Now looking at Equation (1) and equating F to the gravitational force (F_g), we see that:

$$ma = \frac{GmM_E}{R_E^2} = mg, \quad (4)$$

where

$$g = \frac{GM_E}{R_E^2}.$$

In this last equation, we see that g , the **gravitational acceleration**, is itself a constant because it depends on quantities which do not change with time.

This result was first demonstrated by Galileo when he dropped cannonballs of different masses (weights) from the Leaning Tower of Pisa to show that although they had different masses, when dropped together, they landed together. This happened in this manner because they both experienced the same acceleration. A similar experiment may also be performed by dropping a coin and a feather. When dropped in air, the coin always lands first, but when they are dropped in a **vacuum**, an environment where there is no air, they land together! In the coin and feather case, the different velocities are due to another force called **air friction**. Our Equation (4) equates the total force to the gravitational force, and therefore neglects the effects of air friction.

We must now try to discover a quantitative method for determining the gravitational acceleration, g . We first look to the equation for one-dimensional motion (motion in one direction) under constant acceleration.

$$x(t) = x_o + v_o t + (1/2) at^2 \quad (5)$$

In Equation (5), the motion is described by the function $x(t)$ which is position as a function of time. On the right, we have the parameters x_o , v_o , and a . These are, respectively, the

initial position, the initial velocity and the acceleration. In this experiment, like Galileo, we will be dropping an object from rest, so that v_o will be zero. If we call the place from which we drop the object to be $x = 0$, then x_o will also be zero. Finally, we will assume that the only acceleration present is due to gravity, so that we can set $a = g$. We then obtain the following equation:

$$x(t) = (1/2) g t^2 \quad (6)$$

the distance the object falls as a function of time.

Now from Equation (6), we have a way to measure g . All we need to do is drop an object through a known distance (x) and then measure how long it takes to fall (t). If we know both x and t , we can solve Equation (6) for g .

$$g = \frac{2x}{t^2} \quad (7)$$

Thus, by measuring the distance traveled and the time of travel for an object falling from rest, we can determine the gravitational acceleration.

Procedure:

1. Use the table rod and test tube holder to set up the timer and two switches so that the ball will fall a distance of slightly less than two meters to the floor.
2. Put the ball in the release mechanism, using the plunger and set screw to hold the ball in place.
3. Release the set screw, thus allowing the ball to fall to the floor, and note where it hits. Place the switch pad on the floor so that the ball will hit it. A slot weight (1 or 2 kg.) or masking tape may be used on the wire to prevent movement of the switch pad.
4. Place the ball in the release switch. Turn the timer off, plug in and connect the power source to the timer using the reset button to set the timer to zero.
5. Do a few trial runs to be certain that the timer starts when the ball is released and stops when the ball hits the switch pad.

6. Use the 2-meter stick (with caliper jaws if desirable) to measure from the bottom of the ball when it is in the release switch to the bottom of the ball when it hits the switch pad. Press down *slightly* on the 2-m stick to close the switch pad which is in the position of the ball at the instant the timer is stopped. Record this distance as x .
7. Loosen the set screw quickly and enough to allow the ball to be released without hindrance to the falling motion. Record the timer reading as t .
8. Replace the ball in the release switch and reset the timer. Change x to a new value by changing the height of the release switch on the table rod. Repeat 6 and 7 for this new height.
9. Measure and record x and t at three more different heights so that four data points are available.
10. Find the mass of the ball using the triple-beam balance and record it.

Data:

Use the given lab form to record all data and extended data (t^2). You should also record m , the mass of the ball. Remember to report all data *with units*.

Calculations and Error Analysis:

1. Using the measured values for x and the calculated values for t^2 , insert these values into Equation (7) to get the measured values for g . Show all calculations and remember to label the appropriate quantities with their respective units.
2. Find the average of the three measurements of g and write this in the lab report. Report this value and the mass of the ball used to the lab instructor. The instructor will list the average g and the masses used by the different groups on the board.
3. As a measure of precision, we will be using the **average deviation from the mean** for the measured value of the gravitational acceleration. See Appendix A for the formula for this type of error analysis.

The final result for the gravitational acceleration should be reported as such:

$$g = g_{ave} \pm S_{ave}$$

4. As a measure of accuracy, use the given accepted value for g and the measured average value of g to compute the % error.

Abstract:

In two or three sentences, state the objective of the experiment, the method used, and the results obtained (remember units and actual error).

Conclusions:

1. Write in your own words what you discovered in this experiment.
2. Look at the data on the board. Did the gravitational acceleration depend at all on the mass of the ball?
3. How did the gravitational acceleration vary with the different heights?
4. If you dropped an object from space onto the surface of the moon, which has no atmosphere, would you expect the gravitational acceleration to be constant? Explain.

Error Analysis:

Describe the major sources of error in this experiment. Consider both the precision and accuracy of your procedure.

Turn in the lab report at the end of the lab period.

The Acceleration Due to Gravity

Name: _____ Station: _____ Section: _____

Abstract:

Data:

trial	x	t	t^2	g	$s = g_{ave} - g $
1					
2					
3					
4					
mass of the ball					σ_{ave}

average measured value for g : _____

accepted value for g : _____ % error: _____

Calculations:

Conclusions:

Error Analysis:

Data Collection / Calculations (40%)

Abstract / Conclusions (40%)

Error Analysis (20%)

Grade:

