Experiment 6

Determining the Acceleration Due to the Force of Gravity

Equipment List: A ball that bounces (rubber ball, or tennis ball, or racquetball, or similar), a hard floor (no carpeted floors\*), a wall or doorway where the hard floor is located, a cell phone with Phyphox app., centimeter scale ruler, tape\*\*, something to tap with (I used a spoon).

\*If all of the available floor space is carpeted, place a cookie sheet (or something similar) on the floor so that the ball striking it will make a sharp sound.

\*\*Masking tape, or painter’s tape works well. Sticky notes cut to narrow widths can be substituted.

In this experiment you will determine the acceleration due to the force of gravity on a freely falling body (ball). On the application Phyphox there is a function listed in the “Timers” section called “Acoustic Stopwatch”. This function measures the amount of time between two successive loud sounds. You will use this to measure how much time it takes for a ball to fall from various heights. These heights will be given to you by your lab instructor during lab time.

When an object is in free fall the velocity of the object will follow the equation of motion:

This is an equation that relates the instantaneous velocity at a particular time due to the acceleration of the object. Notice that this equation is of the same form as the general straight line equation.

As you can see, the **slope** of the instantaneous velocities versus time line is equal to the **acceleration** due to the force of gravity.

This experiment does not have the means to measure instantaneous velocities directly. But, the average velocities can be determined over specific time intervals. When an object is subjected to a constant acceleration, the average velocity over a time interval is equal to the instantaneous velocity at the midpoint of that same time interval. In this experiment you will plot the average velocities at the midpoints of the time intervals. This way you can properly graph the instantaneous velocities.

Since the ball will be dropped, it will start out with a zero velocity, and reach a final velocity when the ball strikes the floor. This amounts to the initial velocity in the above equation of motion to be equal to zero. The equation now becomes:

The Experiment:

Once you have located either a wall or doorway that has a hard floor next to it, use small pieces of tape to mark positions on the wall or doorway equal to the positions (distances) given to you by your lab instructor. Use your ruler to carefully place the pieces of tape.

For each of the specified heights you will drop the ball 5 times, recording these times onto the Excel worksheet. This will be done using the Phyphox app. Place your phone on the floor near where the ball will strike the floor (you don’t want to hit your phone with the ball). Start the “Acoustic Stopwatch”. Hold the ball up at the same height as your first tape position. With your other hand you will tap the wall with the spoon (or other item) to make a sound, dropping the ball at the same instant that you tapped. The sound of the tap will start the stopwatch. Once the ball strikes the floor the sound from the ball hitting the floor will turn off the stopwatch. Record the time. Press the Reset button to ready the next time measurement.

If you feel that you have let the ball go “too early” or “too late” with regard to your tapping the wall, then re-do that timing. Complete all 5 time measurements for this first position, then go the next tape position that you have marked on the wall. Repeat taking 5 good time measurements for each tape position (distance).

Calculations:

Determine the average time, and the associated standard deviation, for each of these heights. You will notice that the standard deviation values are inconsistent due to variation of time when letting go of the ball. Because of this you will determine an average standard deviation and use this value to determine the total uncertainty in time. Calculate the midpoint in the time interval for each of the heights (distances) and the uncertainty in the midpoint time. Each of these is equal to half of the average time for each distance. Determine the average velocity for each height (distance) using the average time for each distance. Calculate the uncertainties for these average velocities. These uncertainties are roughly the same value. Determine the average of these uncertainties for the average velocities. It is these uncertainties in midpoint time and velocity that will designate the size of the errors bars for the data points graphed.

Graphing:

Use Excel to graph the average velocities (y-axis) versus the midpoint times (x-axis). Add the trendline and the equation of the trendline. Use the Format Trendline Label to change the number of decimal places to 3.

Add error bars to the data points. Click anywhere on the graph and three symbols will appear. Choose the “plus” sign. This is the Chart Elements button. Click on Error Bars and click on the arrow that appears and choose “More Options”. Choose “Fixed Value” and type in the length of the error bar (equal to the total uncertainty for that measurement). Once you have completed that, click on ERROR BAR OPTIONS near the top and choose the other axis and declare the size of those error bars.

To draw the parallelogram, click on INSERT, then Shapes, and then Line. Draw a line parallel to the trendline and move it to coincide with the error bar of the appropriate data point above the trendline. Copy this line and paste to make another parallel line. Place this to coincide with the error bar of the appropriate data point below the trendline. Draw two more vertical lines and place at the two ends, completing the parallelogram. INSTRUCTIONS are in the Uncertainty Analysis Information file in the Contents portion of this online lab on Pilot.

From this parallelogram you will be able to determine the maximum and minimum slope that your trendline can have, and from this determine the uncertainty in the slope of the line.

The slope of the line is your determination for the acceleration due to the force of gravity, g. The uncertainty in the slope of the line is equal to the uncertainty in your determination of g.

Results:

Compare your experimentally determined value for the acceleration due to the force of gravity with the accepted value (Dayton, Ohio) of 9.80 meters/second2. Also, determine how precise your value for g is with the handbook value using the percent error equation. Comment on how well your value agrees with the handbook value.

Questions for Discussion:

1. Make a list of the various sources which cause uncertainty in this experiment. Within your list state which source is a random uncertainty, and which source is a systematic uncertainty. Review the Uncertainty Analysis Information file to help answer this question.
2. A time interval occurs between two time values, call them t2 and t1. At these points in time an object undergoing constant acceleration will have corresponding velocities of v2 and v1. Using the equation for the midpoint in time of a time interval being equal to (t2 +t1)/2, and the equation used in this experiment, v = at, show mathematically that the average velocity over a time interval is equal to the instantaneous velocity at the midpoint of that same time interval. Show all step-by-step work.
3. Using your experimentally determined acceleration due to the force of gravity, determine with what velocity (including uncertainty) the ball would have if the ball was dropped (initial velocity of zero) a distance of 5 meters. Show all work.
4. Explain why two objects of different masses fall with the same acceleration.