Purpose

To experimentally determine the magnitude of the acceleration due to gravity $g$ near the surface of the Earth by measuring the time of flight for a ball dropped from a known height.

Introduction

Near the Earth’s surface, the magnitude of the acceleration due to gravity $g$ is nearly constant. If this is true, then the motion of an object moving only under the influence of gravity can be described by the kinematic equations. In this experiment, you will be dropping a ball from a measured height and measuring the time it takes to fall. Figure 1 is a representation of the experimental setup and has a coordinate system attached to it.

![Free fall apparatus with coordinate system.](image)

Using the coordinate system from Figure 1, the vertical acceleration of the freely falling ball is $a_y = -g$. Knowing the ball is released from rest ($v_{iy} = 0 \text{ m/s}$), the kinematic equations can be used to determine the relationship between the measured values and the acceleration.

$$\Delta y = v_{iy}\Delta t + \frac{1}{2}a_y\Delta t^2$$  \hspace{1cm} (1)

$$(0 - h) = (0)(t - 0) + \frac{1}{2}(-g)(t - 0)^2$$  \hspace{1cm} (2)

$$h = \frac{1}{2}gt^2$$  \hspace{1cm} (3)

Procedure — Part I

1. Place the receptor pad on the table so that the ball will fall onto the pad.

2. Turn on the electromagnet by closing the switch to the power supply by pushing the red switch on the blue switch box.

   - The closed position (power on) is indicated by the stylized one: \(|\)
   - The open position (power off) is indicated by the stylized zero: \(\circ\)

3. Place the ball on the hole in the metal plate. It should be held firmly by the electromagnet.
4. Adjust the height of the electromagnet so the ball will drop approximately 0.5 m.

5. Measure the height $h$ from the top of the receptor pad to the bottom of the ball.

6. Determine the uncertainty $\delta h$ of the height of the ball above the receptor pad.

Using a good meter stick, distance measurements normally have an uncertainty of 0.001 m. Note that this assumes that you make very careful measurements. This is certainly true for the position of the top of the ball before it drops; but the position of the bottom of the ball when the timer turns off is less certain. Think carefully about how far the ball actually falls before the timer stops. Examine the pad carefully to determine how and when it turns the timer off.

7. Determine the fractional uncertainty $\delta h/h$ of the height measurement.

8. Turn on the Computer and open the Free Fall program.

9. Do the following steps 10 times.

   (a) Turn on the electromagnet.
   (b) Place the ball on the hole in the metal plate. It should be held firmly by the electromagnet.
   (c) Click on the white run arrow icon by the menu bar. The icon will turn into a black run arrow and the large oval on the screen will turn bright green indicating the apparatus is ready to take measurements. The timer should reset to zero seconds.
   (d) Turn off the electromagnet to release the ball. Once the ball is released the timer is automatically activated and stops when the ball hits the receptor pad.
   (e) Record the time $t$ the ball was falling.

10. Determine the uncertainty $\delta t$ of the ball’s falling time by taking the difference between the largest and smallest values you have for the falling time.

$$\delta t = t_{\text{max}} - t_{\text{min}}$$

11. Calculate the average time $t_{\text{avg}}$ the ball fell.

12. Determine the fractional uncertainty $\delta t/t_{\text{avg}}$ for the aggregated falling time measurement.

13. Calculate the square of the averaged time value $t_{\text{avg}}^2$.

14. Calculate your final value of $g$.

### Procedure — Part II

1. Place the receptor pad on the floor and rotate the electromagnet so that it is above the receptor pad.

2. Do the following steps 5 times. Begin with the electromagnet at approximately 2 m, and then lower the position of the electromagnet by approximately a quarter of a meter for each successive trial.

   (a) Adjust the vertical position of the electromagnet so that it is at the appropriate location.
   (b) Turn on the electromagnet.
   (c) Place the ball on the hole in the metal plate. It should be held firmly by the electromagnet.
   (d) Measure the height $h$ from the top of the receptor pad to the bottom of the ball.
   (e) Determine the uncertainty $\delta h$ of the height of the ball above the receptor pad.
   (f) Determine the fractional uncertainty $\delta h/h$ of the height measurement.
Click on the white run arrow icon by the menu bar. The icon will turn into a black run arrow and the large oval on the screen will turn bright green indicating the apparatus is ready to take measurements. The timer should reset to zero seconds.

Turn off the electromagnet to release the ball. Once the ball is released the timer is automatically activated and stops when the ball hits the receptor pad.

If the ball misses the receptor pad, you will need to redo the current trial.

Record the time $t$ the ball was falling.

Determine the uncertainty $\delta t$ of the ball’s falling time. Use the value you found in Part I.

Determine the fractional uncertainty $\delta t/t$ for the falling time measurement.

Calculate the square of each time value $t^2$.

When you are done making measurements, make sure your electromagnet is off.

Plot the falling height versus the squared falling time. The height $h$ is to be plotted along the vertical axis and the squared time $t^2$ is to be plotted along the horizontal axis.

Fit a trend line to the data points and determine the slope of the line. Be prepared to turn in your finished graph during the next laboratory session.

From the slope of the trend line, determine the value of the acceleration due to gravity $g$.

By comparing Equation (3) to the general slope-intercept form of the equation of a line, you can determine how the slope relates to the acceleration due to gravity.

$$
\frac{h}{y} = \frac{(\frac{1}{2}g)}{(m)} \left( \frac{t^2}{(x)} \right) + b
$$

Thus you can see that $\frac{1}{2}g = [\text{slope}]$.

### Determining Uncertainties in Your Final Values

In the results section of your notebook, state the results of both parts of your experiment in the form $g \pm \delta g$. Note, $\delta g$ should be equal to the value of $g$ multiplied by the largest fractional uncertainty from your values of height or time.

$$
\delta g = g \times \max \left( \frac{\delta h}{h}, \frac{\delta t}{t_{avg}} \right) \quad (\text{Part I})
$$

$$
\delta g = g \times \max \left( \frac{\delta h}{h}, \frac{\delta t}{t} \right) \quad (\text{Part II})
$$

Even though Part II had 5 trials, the expression for finding $\delta g$ doesn’t show the fractional uncertainties for each trial. If it did, then the expression would be much larger.

$$
\delta g = g \times \max \left( \frac{\delta h_1}{h_1}, \frac{\delta h_2}{h_2}, \frac{\delta h_3}{h_3}, \frac{\delta h_4}{h_4}, \frac{\delta h_5}{h_5}, \frac{\delta t_1}{t_1}, \frac{\delta t_2}{t_2}, \frac{\delta t_3}{t_3}, \frac{\delta t_4}{t_4}, \frac{\delta t_5}{t_5} \right) \quad (6)
$$

In the interest of efficiency, the repeated measurements made over all the trials are represented by a single term. Just pick the maximum of the fractional uncertainties over all the trials.

You should also address the following questions:

1. Do you think your result for $g$ is independent of mass?

2. Do your results match the actual value of $g$ in the Clapp Building of 9.80665 m/s$^2$ within the their uncertainties? IF NOT, what might be some possible reasons? Be sure to back up your claims with quantitative estimates. For example, if the distance the ball had to fall in order to compress the pad and stop the timer was more than what you measured by 2 mm, how would this affect your final value of $g$? Is this a reasonable explanation? You should “run some numbers” for two or more situations to see how either the distance measurement or time measurement varying would affect your final value of $g$, and state whether or not you think it is is reasonable and why.