Acceleration Due to Gravity

Purpose

To find the acceleration of a freely falling steel ball in two different ways, and to practice two new methods of data analysis: (1) making multiple measurements and (2) plot analysis.

Pre-Lab Exercises

1. Read these lab instructions carefully.
2. In preparation for your pre-lab quiz, you should derive formulas for the acceleration due to gravity g and the uncertainty δg for a ball falling from rest in terms of the quantities you will *measure* in this lab (ignoring air resistance).

Introduction

Near the Earth's surface, the magnitude of the acceleration due to gravity g is nearly constant, and the motion of an object moving only under the influence of gravity can be described by the kinematic equations for constant acceleration. In this experiment, you will be dropping a ball from a determined height and measuring the change in velocity as it falls. Figure 1 is a representation of the experimental setup and an associated coordinate system.

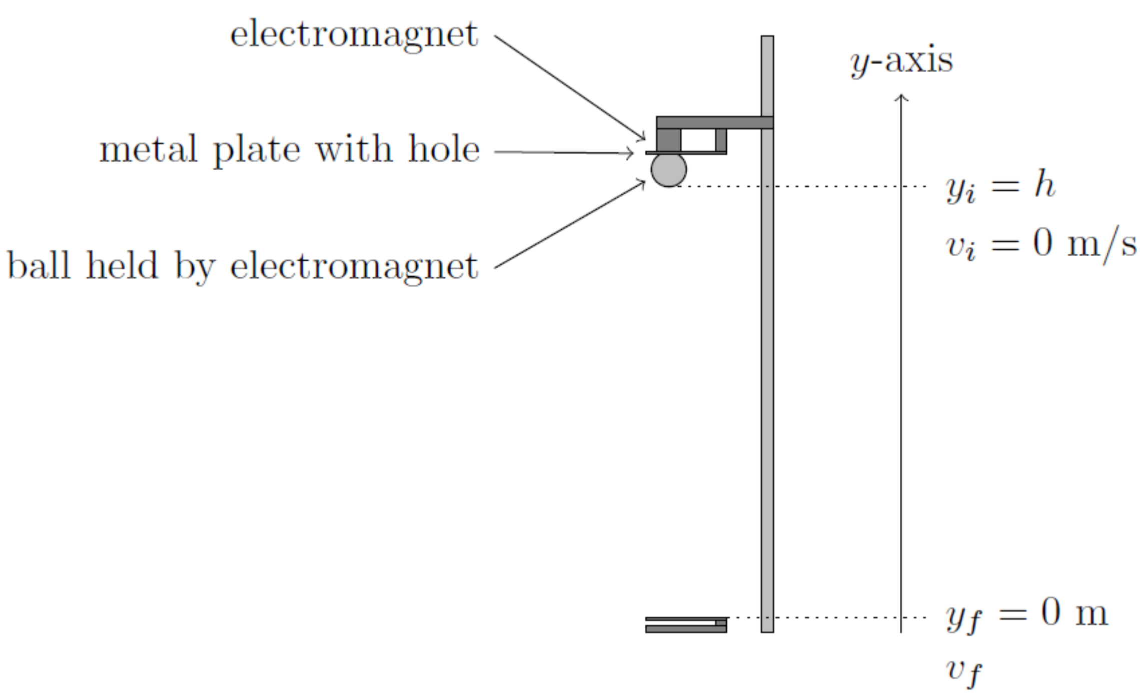

Figure 1: Free-fall apparatus with coordinate system. The lowest position (final position) of the ball will be chosen to be the origin, and the highest position (initial position) has a measured value h. The initial velocity is $0\ m/s$ and you will determine the final velocity v_f.

Using the coordinate system of Figure 1, the vertical acceleration of the freely falling ball is $a_y = -g$. The ball is released from rest ($v_{iy} = 0m/s$). The kinematic equations that describe the motion of an object experiencing constant acceleration are:

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

Eq. 1

$$v_{fy} = v_{iy} + a_y t$$

Eq. 2

Solving the second equation for time and plugging it into the first equation yields a relationship between the distance, acceleration, and change in velocity:

$$v_f^2 - v_i^2 = 2a_y\Delta y$$

Eq. 3

In this lab the acceleration $a_y = -g$ and the change in the distance $\Delta y = -h$. To determine the final velocity of the ball, you will measure the time that it takes the ball to pass between two closely spaced photogates and use the equation:

$$v_f = \frac{\Delta d}{\Delta t}$$

Eq. 4

where Δd is the distance between the two photogates.

Note that the value h from this introduction will be replaced by the calculated value Δh when you are working with your real data, as you will need to measuring the ball's initial and final positions (h_{top} and h_{bottom}) and calculate the difference to find the change in distance.

Procedure – Part I

1. Measure and record the distance between the two "eyes" of the photogates using a ruler to determine Δd. Record the uncertainty in the distance $\delta\Delta d$. (You will use these same values for $\Delta d \pm \delta\Delta d$ in Part II)
2. Adjust the height of the electromagnet so the ball will drop approximately half a meter from the electromagnet to the photogates below.
3. Turn on the electromagnet by turning on the DC Power Supply at your lab station, which should already be set to supply about $4\ \mathrm{V}$, and place the ball against the hole in the metal plate on the electromagnet. The ball should be held firmly by the electromagnet.
4. Measure from the tabletop to the **bottom** of the ball and record this position as $h_{top} \pm \delta h_{top}$. Measure from the tabletop to the **midpoint** between the photogates and record this position as $h_{bottom} \pm \delta h_{bottom}$. The difference between these two positions Δh is equivalent to h in Figure 1.
5. Release the ball and record the time Δt it takes the ball to pass between the two photogates. Repeat for a total of 10 times.
6. Calculate $\Delta h \pm \delta\Delta h$ using your measurements from Step 4 above.
7. Use your (10) multiple measurements of Δt to find $\overline{\Delta t} \pm \delta\overline{\Delta t}$.
8. Determine your experimental result $g \pm \delta g$ for Part I.

Procedure – Part II

For this part of the lab, you will drop the ball from at least 5 different starting positions (one drop for each position), taking new measurements of $\Delta t \pm \delta\Delta t$ and $h_{top} \pm \delta h_{top}$ for each. As long as you have not adjusted the position of your photogates, you may continue to use the same values for $h_{bottom} \pm \delta h_{bottom}$ that you recorded in Part I.

For each of these 5 drops, calculate the ball's final velocity $v_f \pm \delta v_f$ and the ball's displacement $\Delta h \pm \delta\Delta h$.

For the sake of our graphical analysis, we are also interested in the values $v_f^2 \pm \delta(v_f^2)$ for each of the 5 drops. Calculate these values, using the second Power-Product Rule "shortcut" for the uncertainty calculations.

Using the provided Python plotting template, plot $v_f^2 \pm \delta v_f^2$ on the vertical axis against $2\Delta h$ on the horizontal.

☑ *What does the slope of the line represent?*

Once you have generated your plot, use it to determine your Part II experimental results for $g \pm \delta g$.

Final Considerations

You should be prepared to address the following questions:

1. Do your results from Part I agree with the standard acceleration due to gravity ($g = 9.81\ m/s^2$)?
2. Do your results from Part II agree with the standard acceleration due to gravity ($g = 9.81\ m/s^2$)?

⚠ Make sure you have submitted the GitHub link to your plot through Canvas *before* lab starts next week!