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.

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.

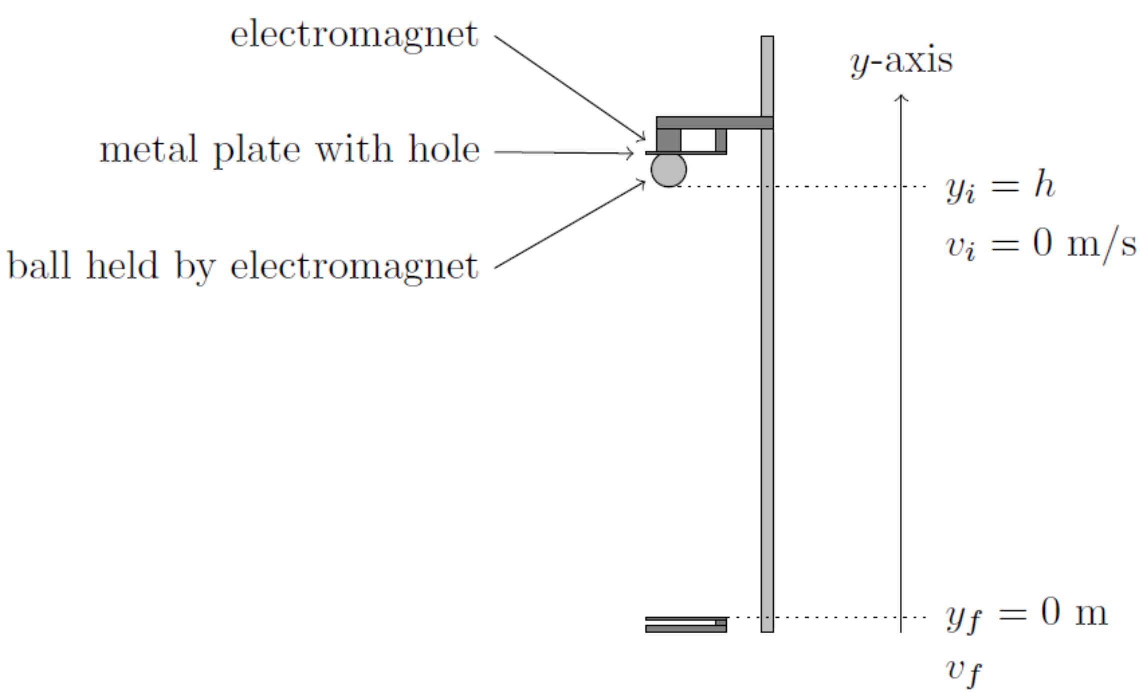

Figure 1: Free-fall apparatus with coordinate system. The lowest position (final position) of the ball will be chosen to be the origin, and the highest position (initial position) has a measured value h. The initial velocity is $0\ m/s$ and you will determine the final velocity v_f.

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.

Procedure – Part I

1. Measure and record the distance between the two “eyes” of the photogates using calipers to determine Δd. Record the uncertainty in the distance $\delta\Delta d$.
2. Adjust the height of the electromagnet so the ball will drop approximately half a meter. Measure the height between the **bottom** of the ball and the **midpoint** between the photogates using a meter stick and record the height h and its uncertainty δh.
3. Turn on the electromagnet and place the ball on the hole in the metal plate. It should be held firmly by the electromagnet. Do not exceed 4 volts.
4. 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.
5. Calculate the final velocity v_f using your average time $\Delta\bar{t}$ and the distance between the two photogates Δd.
6. Calculate g and its uncertainty δg using the appropriate rule of error propagation.

Measurement Uncertainties – Part I

$\delta\Delta\bar{t}$ Use the spread in a Gaussian distribution to determine the uncertainty as detailed in *Treatment of Data*.

$$\delta\Delta\bar{t} = u_x = \frac{s_x}{\sqrt{n}}$$

δh This will depend on the uncertainty of your measurement of the bottom of the ball when attached to the electromagnet δh_{top} and the uncertainty in your measurement to the mid-point of the photogates δh_{bottom}. When you have determined a reasonable estimate for the uncertainty in these measurements, you must combine the two numbers in quadrature using the Sum Rule or error propagation to find δh--you cannot simply add the two uncertainties.

Procedure – Part II

For this part of the lab, take measurements of Δt and h for at least 5 different heights. Graph your data and uncertainties as detailed below to determine $g \pm \delta g$.

Measurement Uncertainties – Part II

δt Because all the time measurements are not expected to be the same, you cannot use the spread in a Gaussian distribution to determine the uncertainty. Instead, treat the measurements as single readings on a digital display.

δh Use the same method as outlined in Part I.

Graphing and Analysis

Using the provided Python plotting template, analyze your data by plotting v_f^2 on one axis against h on the other. You will need to calculate δv_f^2 and use it and δh to help answer the following questions:

- What quantity should you treat as the horizontal variable?
- What quantity should you treat as the vertical variable?
- What does the slope of the line represent?

Once you have generated your plot, use it for the following:

- Determine your value for the acceleration due to gravity g.
- Determine your uncertainty for the acceleration due to gravity δg.

Final Considerations

You should be prepared to address the following questions for BOTH procedures:

1. Do your results agree with the standard acceleration due to gravity ($g = 9.81\ m/s^2$) within their uncertainties?
2. The uncertainty that you have calculated is only statistical (random); if your results don't agree it may indicate the presence of systematic error(s) in the experiment. If you don't understand the difference, re-read that section in *Treatment of Data*. If your results indicate that systematic error(s) may be present, try to determine some possible sources of systematic error in the experiment. For each suggested source, determine if it would affect the result in the same direction as the discrepancy in your result.

Before you arrive to next week's lab and start the in-class quiz for this week's experiment, make sure you have done the following:

- You have completed your analysis of the experiment.
- You have submitted the GitHub link for your plot, and verified that the link you provided will take your instructor to a **displayed** plot (not just the code).