

Acceleration of Falling Objects



Part I: Introduction

Freely falling objects are those whose motion is only under the influence of gravity. When up is taken as the positive direction, objects fall with a constant downward acceleration a of

$$a_y = -g = -9.81 \text{ m/s}^2$$

The motion of objects in free-fall obeys the kinematics equations governing one-dimensional motion, but with the acceleration always equal to the above constant.

The displacement in the y -direction is given by

$$y = y_0 + v_{0y}t + \frac{1}{2}a_yt^2 = y_0 + v_{0y}t - \frac{1}{2}gt^2$$

where y and y_0 are the final and initial positions in the y -direction, v_{0y} is the initial velocity in the y -direction and t is the time.

Part I: Introduction

The instantaneous velocity, v_y , may be found as the slope of the tangent to a displacement versus time graph at any point. In relation to other kinematics variables, instantaneous velocity is given by

$$v_y = v_{0y} + a_y t = v_{0y} - gt$$

Plotting one kinematics variable versus another allows you to see these relationships, as well as to find constants such as the acceleration due to gravity and initial velocity.

Interpreting Graphical Results:

To draw physical meaning from graphical results, it is necessary to compare the physics equations relating the plotted variables to the fit results.

As given on the previous page, the vertical displacement of an object in free fall is given by

Part I: Introduction

$$y = y_0 + v_{0y}t - \frac{1}{2}gt^2$$

which may be rewritten as

$$y = -\frac{1}{2}gt^2 + v_{0y}t + y_0$$

A plot of y vs t will be fitted to a quadratic form:

$$y = At^2 + Bt + C$$

The coefficients in each of the two forms must be compared to determine which physical quantity is represented by A , B and C .

Similarly, velocity of an object is given by

$$v_y = v_{0y} - gt$$

which is rearranged to give

Part I: Introduction

$$v_y = -gt + v_{0y}$$

A plot of v vs t will be fit to the linear form

$$v = mt + b$$

Comparing the two equations indicates the physical meaning of the parameters m and b .

In this experiment, you will study the motion of a falling ball which experiences constant acceleration.

You will use a **Motion Detector** to measure the position of the ball as a function of time.

Part I: Objectives

The objectives of this experiment are:

1. To represent the motion of an object through graphs of position, velocity, and acceleration versus time.
2. To investigate the displacement versus time, velocity versus time, and acceleration versus time graphs of a given motion.
3. To determine the value of the acceleration due to gravity g .

Part II: Apparatus

Check if you have the following pieces of equipment on your bench. If anything is missing let us know.

- Ball
- Motion sensor
- Support rods (long, medium and short)
- Clamps (2)
- Cable
- LabPro

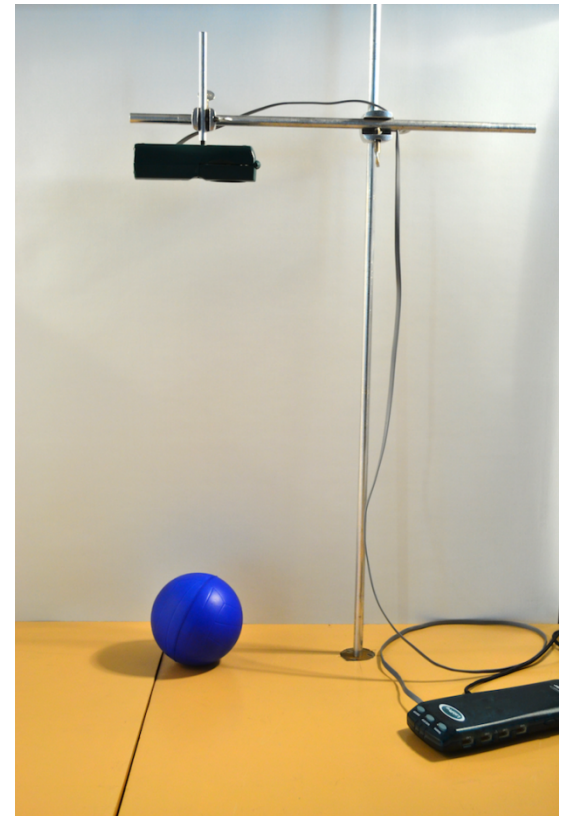


Part II: Apparatus Setup

Assemble your apparatus as shown in the picture.

Remember:

The motion detector only records position within a range of $0.15 - 6\text{ m}$. Be sure to remain within this range during the experiment.



Part III: Data Acquisition

Make sure that the LabPro is connected to the computer and that the motion detector is plugged into DIG/SONIC 1.

Open *Logger Pro* by clicking on the icon below:



Logger Pro should open three graphs:

position vs time,
velocity vs time, and
acceleration vs time.

The time axis should have a maximum value of 3 seconds.

If *Logger Pro* does not contain these graphs, consult an instructor.



Part III: Data Acquisition

We want to measure the position of the ball relative to the table top, i.e. the table top has to correspond to $x = 0$ m. To do this we need to “zero” our motion detector. Follow those steps to achieve this:

1. Remove anything from the bench below motion detector.
2. In LoggerPro click “**Experiment**” and then “**Zero**”.

You should hear the motion detector making a clicking sound for a few seconds. Make sure you do not insert anything (e.g. your hand) between the bench top and the motion detector when this happens.




Part III: Data Acquisition

Collect your data by following the steps outlined below:

1. Hold the ball approximately 15 cm below the motion detector.
2. Click (or ask your partner to do that) the collect button in LoggerPro.
3. When you hear the clicking noise, release the ball.
4. Wait until data collection stops.

LoggerPro should now display three graphs representing the ball's motion: *position vs time*, *velocity vs time*, and *acceleration vs time*.

At this point the graphs normally need to be **autoscaled**. Click anywhere on the graph window to select it and then click the blue  in the toolbar. Do this for each of the three graphs.



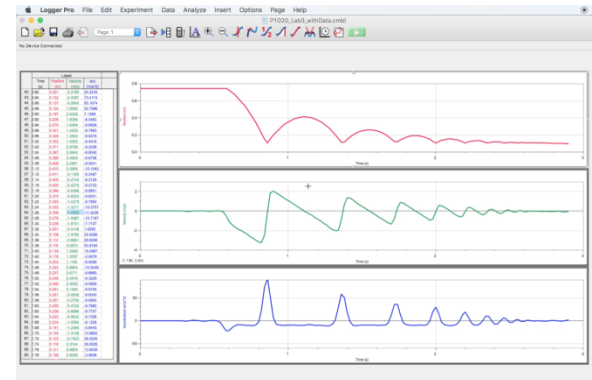
Examine your data. Are your graphs reasonable? If not, repeat the experiment or consult an instructor.

Part IV: Data Analysis

Make sure your data shows at least two clear bounces. Have an instructor check your graphs and initial your lab report.

QUESTION 1: Does the shape of your position vs time graph on *LoggerPro* match the graph from Prelab Question 1? Comment on any differences.

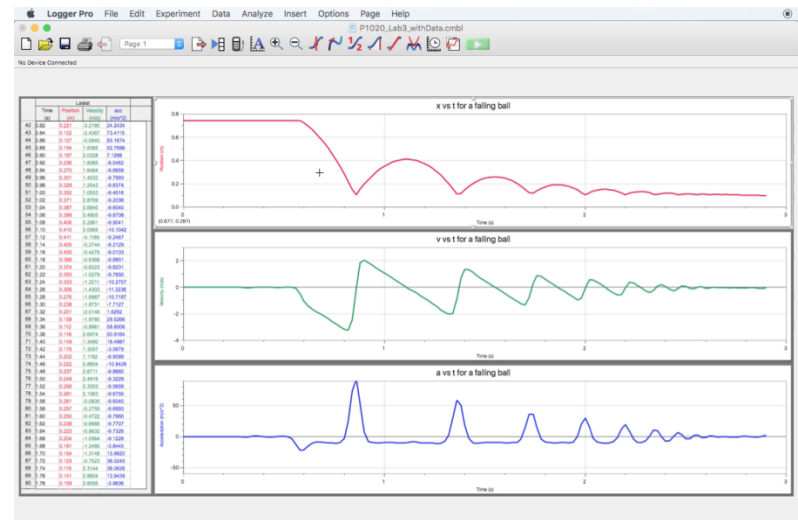
Add titles to all 3 graphs by double clicking on the white area, selecting “Graph Options” and typing in a suitable title in the “Title” field.



Part IV: Print your graphs

Print your graphs in landscape orientation by following these simple steps:

1. Click **File** then **Page Setup**.
2. Select **landscape** orientation and click **OK**.
3. Click **File** then **Print** (not Print Graph).
4. Enter your names in the **Printing Options** pop-up window and click **OK**.



5.IMPORTANT:

In the **Print** window change number of copies to **2** (one for each partner) and **Pages** From: 1 to: 1.

Part IV: Data Analysis

Staple your printed graph on appropriate page in your laboratory workbook. In **LoggerPro**, click the first graph to activate it and then go to **Analyze** menu and select **Examine** option.

Turn on the **Examine** function for the other two graphs.

On your printed graphs:

Label the point that shows where the ball hits the table for the first time on all 3 graphs as t_1 .

Moving your cursor on the screen to the correct point on the first graph should help with identifying the corresponding points on the other 2 graphs with the Examine function turned on.

Part IV: Data Analysis (cont.)

LW

On your *position vs. time* graph and your *velocity vs time* graph, circle one region where the ball is in **free fall and moving down**. Label this “A”

LW

On your *position vs. time* graph and your *velocity vs time* graph, identify one region where the object is in **free fall and moving up**. Label this “B”.

LW

On all three graphs, circle the region where the motion changes **from moving down to moving up**. Label this “C”.

LW

On all three graphs, identify the region where the motion changes **from moving up to moving down**. Label this “D”

Part IV: Data Analysis

Q

QUESTION 2: Examine your position vs time graph (on the computer) and record the time t_1 at which the ball first hits the table. Also record t_2 , the time at which the ball hits the table for the second time. You do not need to record their uncertainties.

Q

QUESTION 3: What are the values of position and velocity at time t_1 ? Are these values expected? Comment.

Q

QUESTION 4: What is the maximum **upward** velocity and the maximum **downward** velocity between times t_1 and t_2 ?

Q

QUESTION 5: How are these two velocities related? Explain.

Part IV: Data Analysis

The vertical displacement of an object in free fall is described by the following kinematics equation:

$$y = y_0 + v_0 t - \frac{1}{2} g t^2$$

which may be rearranged to give

$$y = -\frac{1}{2} g t^2 + v_{0y} t + y_0$$

where y_0 is the initial vertical displacement, v_{0y} the initial vertical velocity, and g is the acceleration due to gravity.

The last equation is of the general form

$$y = At^2 + Bt + C$$

Part IV: Data Analysis

In the last equation on the previous slide the letters **A**, **B** and **C** are called fit parameters.

Q

QUESTION 6: Compare the last two equations from the previous slide. Write down the physical quantity corresponding to the fit parameter **A**? Explain or show your workings.

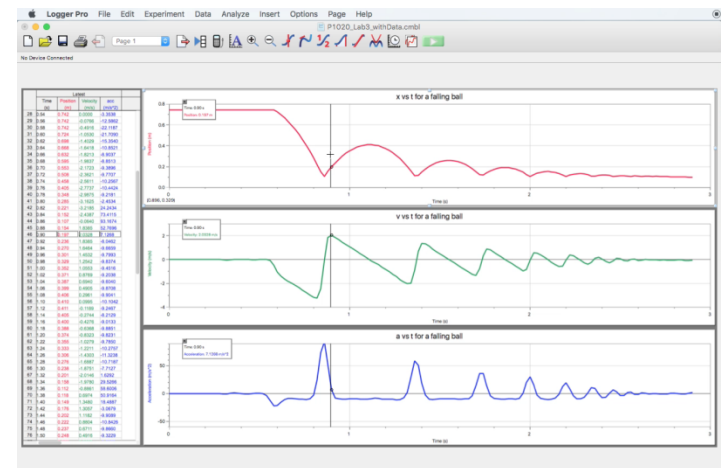
LW

What value do you expect for parameter **A** (including units)? Record this value in **Table 1**.

Part IV: Data Analysis

Follow the steps below to determine the value of the fit parameter **A** by performing curve fitting procedure in LoggerPro:

1. Click on your **distance vs time** graph to activate it.
2. Highlight the region **between t_1 and t_2** .
3. Select **Analyze** and then **Curve Fit**.
4. Under **Options: Fit Type** select "**Automatic**".
5. Select **Quadratic** from the **General Equation** list and click **Try Fit**.
6. Click **OK**.



You should see a thin, dotted, black line going through your data points in the selected region. If that is not the case repeat the above steps.



Part IV: Data Analysis

The results of the fit, i.e. the values of all 3 fit parameters **A**, **B** and **C**, together with their absolute uncertainties should now be visible on your graph.

 LW

Write down the value of the parameter **A** from the automatic fit in **Table 1** of your lab book. Use proper significant digits rules for recording a quantity with its uncertainty.

 Q

QUESTION 7: Use the value of **A** you just found together with your answer to Question 6 to calculate the value of g (acceleration due to gravity) and its uncertainty. Show your workings. Follow the significant digits rules to write down your final answer.

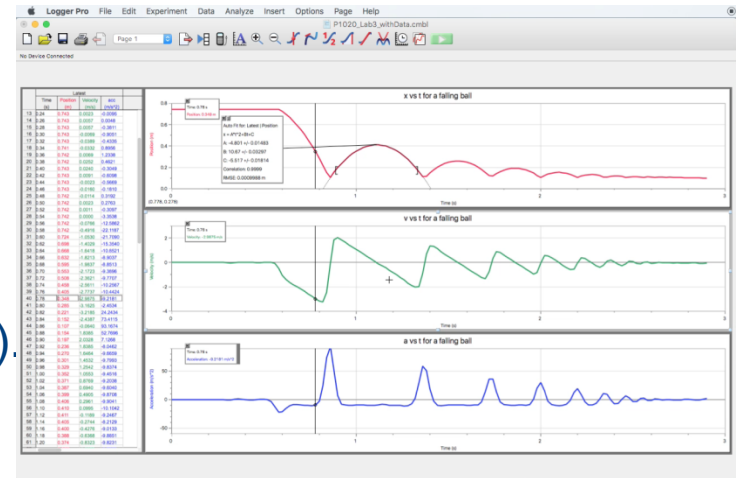
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NOTE: g should be a positive value

Part IV: Data Analysis

The slope of the velocity vs time curve is the object's acceleration. We will use a Linear Fit procedure to find that value from our data. To do so follow the steps below:

1. Click on your **velocity vs time** graph to activate it.
2. Highlight **ONLY THE LINEAR PORTION** of that graph between t_1 and t_2 (as shown opposite).
3. Go to **Analyze** menu and select **Linear Fit**.
4. Double click the results window which just appeared on your graph and select the **"Show Uncertainties"** option then click **OK**.



Data Analysis

 LW

Enter the slope and its uncertainty in **Table 2** in your laboratory workbook

The velocity of a falling object is given by the following kinematics equation:

$$v = -gt + v_0$$

The equation of a straight line is:

$$y = mx + b$$

Compare these two equations and answer the following

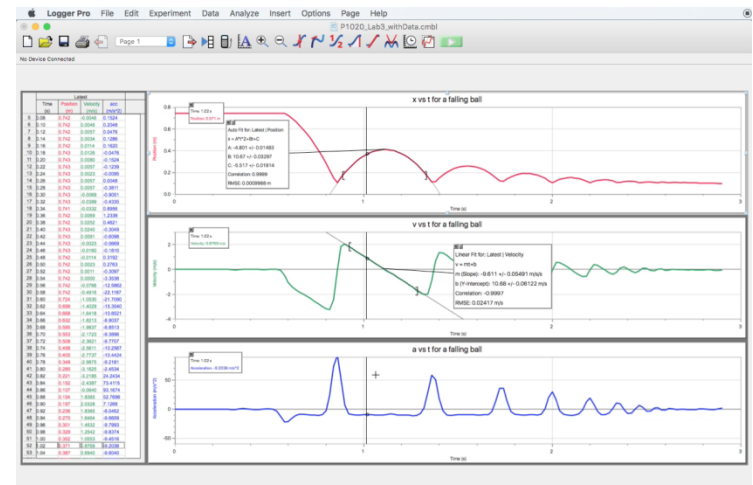
 Q

QUESTION 8: What is the value of g and its uncertainty from the velocity vs time graph? Follow the significant figures rules to write down your final answer.

Part IV: Data Analysis

We can also look at the acceleration vs time graph and determine what was the average acceleration of the ball when it was in free fall. To do this follow the steps outlined below:

1. Click on your acceleration vs time graph to activate it.
2. Highlight **ONLY THE REGION OF CONSTANT ACCELERATION** between times t_1 and t_2 (as shown).
3. Go to **Analyze** menu and select **Statistics**.
4. The average value (the mean) of the ball's acceleration should show up on your graph.



Part V: Data Analysis

LW

Enter the **Mean**, **Standard Deviation** and **Samples** values from your graph in **Table 3** in your Lab book.

LW

Calculate **Standard Error** (error in the mean) based on your results and enter it in **Table 3**.

Q

QUESTION 9: What is the value of g and its uncertainty from the acceleration versus time graph?

P

Print your graph in Landscape orientation as before but with your analysis results (the white boxes on your graphs) clearly visible. Make 2 copies and select Pages From: 1 to: 1.

Part V: Summary

Q

Table 4: Fill in Table 4 with the accepted value g and all your three values of g (Questions 7, 8 and 9), the uncertainties and the range of values for each g . In the last column, indicate with “yes” or “no” whether the value of g compares with the accepted value of $9.81 \pm 0.01 \text{ m/s}^2$.

Q

QUESTION 10: Identify two sources of uncertainty in this experiment and classify them as random or systematic.

!

- **Make sure you attached your Prelab and your graphs on the appropriate pages in your Lab book.**
- **Place your lab book on appropriate shelf.**
- **Don't forget to sign out.**