LAKE FOREST COLLEGE

Department of Physics

PHYS 114 **Experiment 3: Free-fall Acceleration due to Gravity Fall**
2024

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Preliminary Instructions

As you did in previous weeks, create a folder for you and your lab partner. Save a copy of these instructions for each student to that folder. Include your name in the filename. Save one copy of the Excel template with both your and your partner's name included in the filename.

Experimental purpose of today's experiment

Measure the acceleration of an object in free-fall

Pedagogical purpose of today's experiment

Study the motion of objects undergoing a constant acceleration due to gravity.

Background:

When you drop an object near the surface of the earth it speeds up as it falls toward the ground. This acceleration is due to an attractive force between the mass of the earth and the mass of the object. We want to measure how this force changes the motion of the object. We will do this by two different methods. The first method uses kinematic equations to analyze the time for an object to fall a known distance. An object moving with a constant acceleration can be described by the equation $y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2$, where "up" is in the positive y-direction. The second method uses the definition of average velocity $v_{\text{avg}\,y} = \frac{\Delta y}{\Delta t}$ and average acceleration $a_{\text{avg}\,y} = \frac{\Delta v_y}{\Delta t}$ to analyze data of the position of the object as a function of time.

Part 1: Photogate Timer with Free Fall Adapter

1. Set up the Pasco SMART timer by turning it on, then pushing the **1** button once for a **Time** measurement. Press the **2** button to enter the **Stopwatch** mode. Press the **3** button until an asterisk (*) appears. The Smart Timer is now activated and will record the time interval between release of the ball and contact with the receptor pad.

2. Release the ball in the holder and let it fall directly on top of the receptor pad for the Pasco SMART timer. Make at least 10 time measurements with the same height. Record these times in your Excel table and calculate the mean and sample standard deviation of the times.

Use the sample standard deviation as an estimate of the absolute uncertainty in the time. Calculate the relative uncertainty of the time.

3. Carefully measure the displacement of the ball when it falls. Consider whether you should measure to the top of the ball, middle of the ball, or bottom of the ball. Draw a diagram of the apparatus, and clearly label the distance that you measured. **Paste a picture of your diagram here.** Let up be in the positive *y* direction, so that Δy is negative.

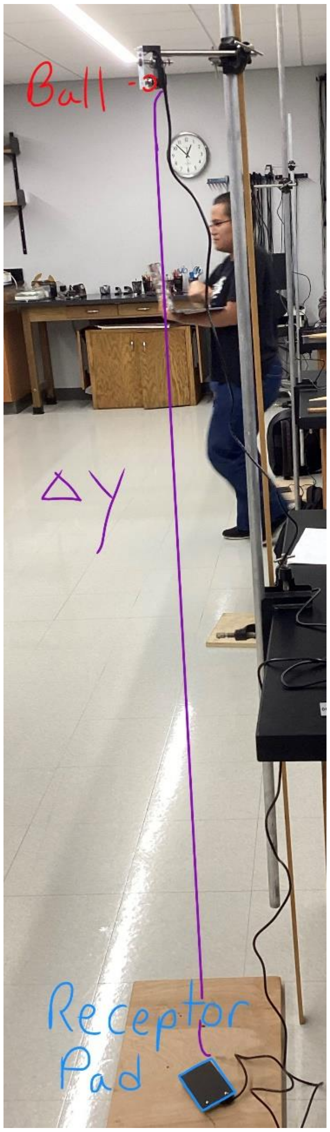

Figure 1. Free fall apparatus. The ball is highlighted in red and thereceptor pad is highlighted in blue. Δy is 1.644 ± 0.005 m and represents the distance between the ball and the receptor pad.

4. Estimate the absolute uncertainty in your measurement of the displacement. Use this to calculate the relative uncertainty of the displacement.

5. Use the kinematics equation, $y = y_0 + v_{y0}t + \frac{1}{2}a_y t^2$, to derive a symbolic expression for the acceleration in terms of the displacement and the time. Use the fact that your object started at rest. **Insert a picture of your derivation here.**

$$y = y_0 + V_{oy}t + \frac{1}{2}a_y t^2$$

$$a_y = \frac{-2y_0}{t^2}$$

rel. un t = abs. un t $/|t|$ rel. un y = abs. un y$/|y|$

rel. un a = rel. un y + (2 · rel. un t)

Figure 2. Equations used in calculating free fall acceleration with photogate timer. Y stands for displacement (m), v stands for velocity (m/s), a stands for acceleration (m/s^2), and t stands for time (s).

6. Use your derived formula in Excel to calculate the acceleration from your displacement and average time measurements.

7. Propagate the errors to find the absolute uncertainty in this acceleration. Refer to the error-propagation handout from the first week (An electronic copy is located on the Class Materials folder on Teams). Write the equations that you use to calculate the absolute uncertainty in the acceleration on your equation sheet. *Hint*: You will first need to find relative uncertainty of the acceleration.

8. Use the ratio test to compare your measured acceleration to the accepted value of $a_y = -9.8029 \pm 0.001\ \mathrm{m/s^2}$. **Is your result consistent with this accepted value?**

   The ratio test agrees that our results are consistent with the accepted value of gravitational acceleration on Earth.

9. Format your Excel table for part 1. Display all digits of the measured quantities. Display absolute uncertainties to 1 sig fig and calculated measurements to the same decimal place. Display relative uncertainties as percentages with 2 sig figs. Display the ratio test to 2 sig figs.

10. Paste your Excel table for part 1 and your equation sheet explaining each of the Excel formulas here.

trial #	time (s)
1	0.5838
2	0.5827
3	0.5791
4	0.5788
5	0.5812
6	0.5800
7	0.5796
8	0.5794
9	0.5759
10	0.5770

Average time (s)	0.5798
St dev of time (s)	0.0024
rel. unc. Of time	0.0041

Δy (m)	1.644
Abs Unc of Δy (m)	0.005
rel. unc. of Δy	0.00

measured a_y (m/s^2)	-9.7825
rel unc of a_y	0.011
abs unc of a_y (m/s^2)	0.110

accepted value of a_y (m/s^2)	-9.807
abs unc of accepted a_y (m/s^2)	0.003

Ratio test comparing measured a_y to accepted value	0.998

Table 1. Measuring free fall using a photogate timer.

Excel formulas:
Average() to calculate average time
Stdev.s() to calculate standard deviation of time
Abs() to take the absolute value of acceleration

11. **Write a brief analysis for part 1 here.** Explain which measurement (height or time) contributes most to the uncertainty of the acceleration. What possible systematic effects could influence your results? Would the effect tend to make the measurement of *g* larger or smaller?

Time creates the most uncertainty as height was kept mostly constant. The height was only measured once so the uncertainty of height could be greater than the estimation listed in the table above. The photogate timer was very finicky which may have lead to more error, there were multiple discarded trails. Measuring the height for each trial would have given a more accurate uncertainty estimate. Density and surface area of objects affect the much g for acts on them. It would be interesting to compare the metal ball to something like a piece of paper or a feather and see how and if the g force differs.

Part 2: Spark-Gap Timer

12. Connect the heavy block to the end of a 1-meter length of spark tape. Drop the block with the tape moving as freely as possible through the spark gap. The sparks occur 60.00 ± 0.02 times in each second. Each spark creates a dot on the tape.

13. Take a picture of the apparatus. **Insert the picture here and label the important pieces**.

Figure 3. Spark Gap Apparatus. The spark tape is marked in blue with the weight attached to it marked in orange. The location where the sparks are made is marked in red. Outside of the range of the photo there is a foam lined box for the weight to land in once dropped.

14. Use drafting tape to secure your spark tape to the lab table. Use a meter stick to measure the positions of at least 20 consecutive spark dots. Do not count the initial dots that are on top of each other. Let the first clearly separated dot be point #0 at time t=0 and position y=0. Define up to be in the positive y direction, so that as the block falls, its y component of position will be negative.

15. Label the number of each spot on your spark tape. **Take a picture of it and insert it here**.

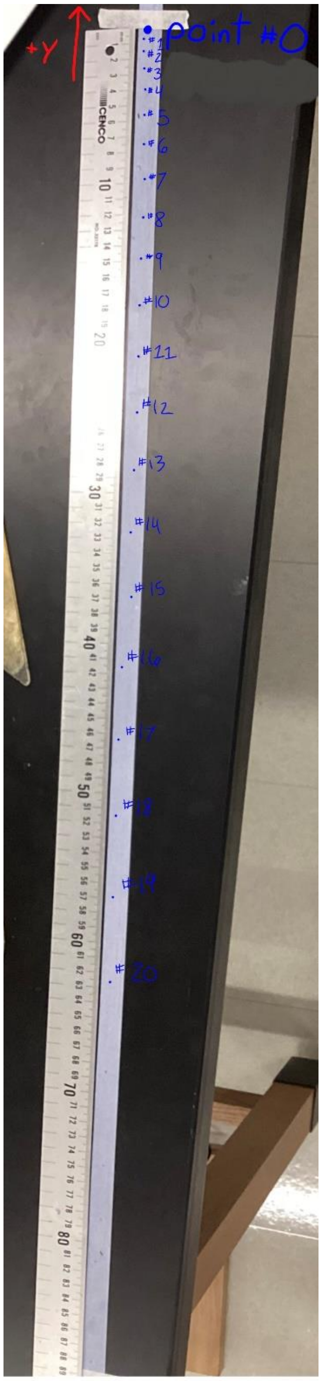

Figure 4. Spark Tape. 20 spark points are marked in blue along the tape. Point 0 is bolded at the top of the image. The positive y axis goes upwards from point 0.

16. Calculate the time of each point given that the time between consecutive sparks is 1/60 seconds.

17. Create formulas in column D to convert the positions of the marks into displacements between neighboring marks, Δy. The first row will be blank.

18. In column E, calculate the average velocity, $v_{\text{avg}\,y} = \dfrac{\Delta y}{\Delta t}$, of the block for each time segment between neighboring marks.

19. Use the computer software *Logger Pro* to make a graph of the average velocity versus the time (cut and paste your data from Excel into *Logger Pro*). If the acceleration is constant then your data will fall on a straight line, because $v_{\text{avg}\,y} \approx v_y = v_{0y} + a_y t$.

20. The slope of this line is the acceleration of the block. Use the software to fit a straight line to your data. Under the "Analyze" menu choose the "Curve Fit" option and $y = mx + b$ (do not use the "Linear Fit" button—it does not automatically display uncertainties). Select the linear form for the fitting function. Click "Try Fit" and then "OK." The best fit parameters and estimates of their uncertainties are shown on your plot.

21. Copy the fitted slope and its uncertainty into your Excel table as the measured acceleration. Copy at least 3 sig figs of the uncertainty and copy the fitted slope to the same decimal place. After copying, adjust the display in Excel to only show the uncertainty to 1 sig fig in the uncertainty and the fitted slope to the same decimal place. (Excel keeps the extra digits hidden, but still uses then in future calculations.)

22. Format your plot to make it easier to read. Add a title to the graph. Label the axes with variables and units. Increase the font size of the fitting parameter box. Adjust the displayed precision of the fit parameters box to show 1 sig fig in the uncertainty and the fitted slope to the same decimal place. Change the data point symbol to a filled circle. **Paste a picture of your graph here.** Save the *Logger Pro* file to your folder.

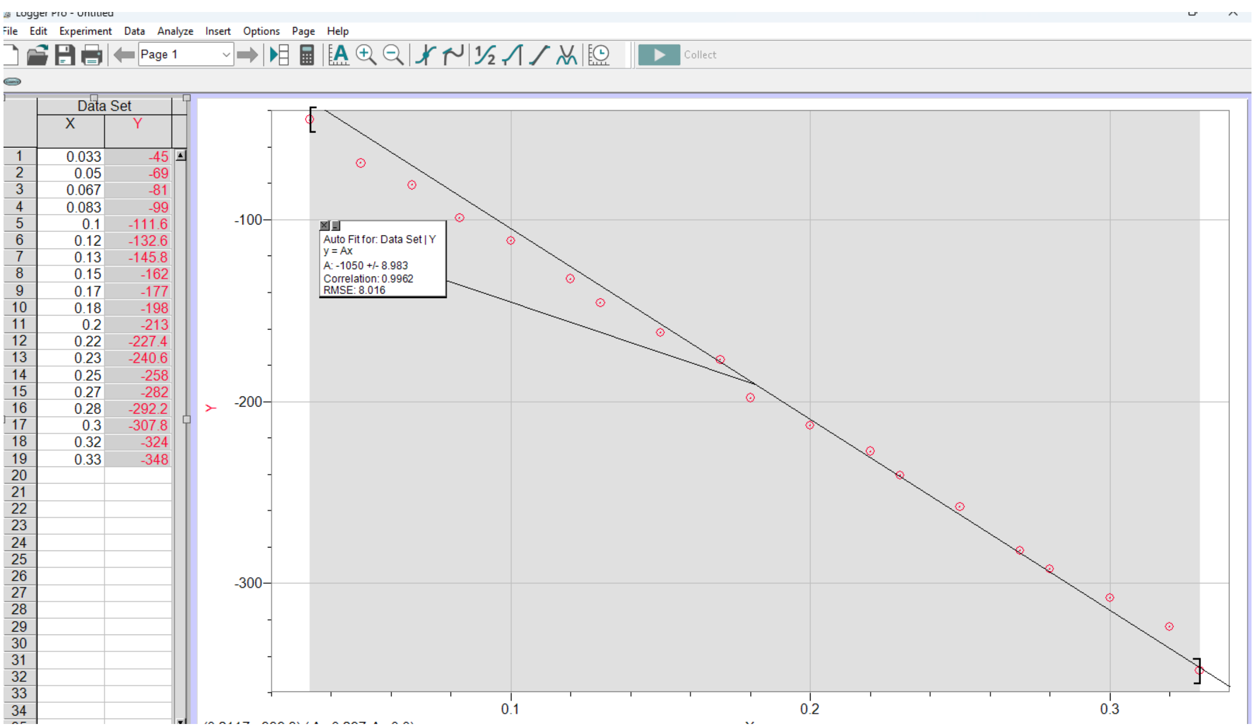

Figure 5. Logger Pro acceleration graph. The x-axis represents time (s) and the y axis represents velocity (cm/s). The line is generated through curve fit and A represents acceleration (cm/s^2).

23. Use a ratio test to compare your measured acceleration to the accepted value. Is your result consistent with this accepted value?

The ratio test agrees that the measured acceleration is consistent with the accepted of gravitational acceleration on earth.

24. **Paste your Excel table for part 2 and your equation sheet explaining each of the Excel formulas here**.

Point number	t (s)	y (cm)	Δy (cm)	v_y (cm/s)
0	0.000	0		
1	0.017	-0.75	-0.75	-45.000
2	0.033	-1.50	-0.75	-45.000
3	0.050	-2.65	-1.15	-69.000
4	0.067	-4.00	-1.35	-81.000
5	0.083	-5.65	-1.65	-99.000
6	0.10	-7.51	-1.86	-111.600
7	0.12	-9.72	-2.21	-132.600
8	0.13	-12.15	-2.43	-145.800
9	0.15	-14.85	-2.7	-162.000
10	0.17	-17.80	-2.95	-177.000
11	0.18	-21.10	-3.3	-198.000
12	0.20	-24.65	-3.55	-213.000
13	0.22	-28.44	-3.79	-227.400
14	0.23	-32.45	-4.01	-240.600
15	0.25	-36.75	-4.3	-258.000
16	0.27	-41.45	-4.7	-282.000
17	0.28	-46.32	-4.87	-292.200
18	0.30	-51.45	-5.13	-307.800
19	0.32	-56.85	-5.4	-324.000
20	0.33	-62.65	-5.8	-348.000

a_y from Logger Pro fit (m/s^2)	-10.5
abs unc in a_y from fit (m/s^2)	.0.08983

accepted value of a_y (m/s^2)	-9.807
abs unc of accepted a_y (m/s^2)	0.003

Ratio test comparing measured a_y to accepted value	1.070663812

Table 2. Measuring free fall using a spark gap timer

$$V = \frac{\Delta y}{\Delta t} = \frac{y_2 - y_1}{t_2 - t_1}$$

$$\text{ratio test} = a_{y\,\text{Logger}} / a_{y\,\text{accepted}}$$

Figure 6. Formula Sheet. Y stands for displacement (cm), v stands for velocity (cm/s), a stands for acceleration (m/s^2) and t stands for time (s).

25. **Write a brief analysis for part 2 here**. What possible systematic effects could influence your results?

Measuring the displacement of the spark points with a yard stick may have created a lot of error in the velocity calculations. Using a computer program to measure the distance between spark points may be more accurate, provided the computer has a size reference. Rounding automatically done by Microsoft excel also may have created error.

26. Write a brief conclusion restating the experiment's goals and summarizing your findings for both parts. Comment whether your experiments succeeded.

Using the Photogate timer to calculate free fall gave us an acceleration of -9.78m/s^2. Using spark-gab and logger pro we got an acceleration of -10.5 m/s^2. The Photogate timer gave a closer acceleration to the accepted gravitational constant of -9.807 m/s^2. Both experiments succeeded, as confirmed by using a ratio test to compare experimental values to accepted constant.

27. Adjust the formatting (pagination, margins, size of figures, etc…) of this report to make it easy to read. Save this report as a PDF document. Upload it to the course Moodle page.

28. Write your name and your partner's name on the spark tape. Give this to your lab instructor.

29. Clean up your lab station. Put your equipment back where you found it. Remove any temporary files from the computer desktop. Make sure to logout of Moodle and your email. Ensure that the laptop is plugged in.

30. Check with the lab instructor to make sure that they received your submission before you leave.