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Lab 1
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Acceleration of Gravity

1 Introduction

In this lab, we will measure the acceleration of gravity. While gravity is the weakest of the four fundamental forces of nature, it is the one most apparent to us in everyday life. As an object falls, its velocity and position will continually increase due to the effects of Earth's gravity. By measuring the position of a free-falling object over constant time intervals, we can calculate its velocity and acceleration, which should just equal that of Earth's.

2 Methods

For this experiment we use a tape timer, tape, and a heavy mass. By attaching the mass to the tape and letting the tape run through the tape timer as the mass falls, points will be recorded on the tape at constant time intervals. We index every other point to insure there is no confusion with the initial measurements (as they can be too close together to differentiate). We then measure the distance between each indexed point and the starting point. Finally, we take the difference between each adjacent point to get the distance interval. Below is a figure of the setup.

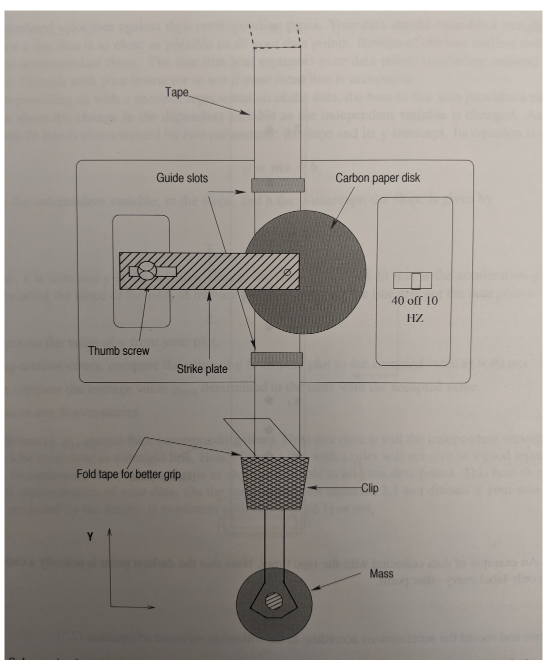

Figure 1: Experimental setup. Source: pg. 9 of the lab manual.

3 Analysis

Using the distance intervals and the constant time interval, we calculate the velocities and accelerations of the mass at each position. To calculate the velocity, we use the equation:

$$v_i = \frac{\Delta x_i}{\Delta t} \tag{1}$$

where $\Delta t = 0.05\,\mathrm{s}$. As an example, for the first point this value is calculated as follows:

$$v_i 1 = \frac{\Delta x_1}{\Delta t} = \frac{0.3\,\mathrm{cm}}{0.05\,\mathrm{s}} = 6.0\,\mathrm{cm/s}.$$

To calculate the acceleration, we use the equation:

$$g_{i+1,i} = \frac{v_{i+1} - v_i}{\Delta t} \tag{2}$$

As an example, for the first two points this value is calculated as follows:

$$g_{2,1} = \frac{v_2 - v_1}{\Delta t} = \frac{34.0\,\mathrm{cm/s} - 6.0\,\mathrm{cm/s}}{0.05\,\mathrm{s}} = 560.0\,\mathrm{cm/s^2}.$$

The velocities and accelerations are listed in Table 1, below.

Time Index	x_i (cm)	Δx_i (cm)	v_i (cm/s)	$g_{i+1,i}$ (cm/s^2)
0	0.0	-	-	-
1	0.3	0.3	6.0	-
2	2.0	1.7	34.0	560
3	5.5	3.5	70.0	720
4	11.4	5.9	118.0	960
5	19.7	8.3	166.0	960
6	30.4	10.7	214.0	960
7	43.4	13.0	260.0	920
8	58.6	15.2	304.0	880
9	76.2	17.6	352.0	960
10	96.1	19.9	398.0	920
11	118.8	22.7	454.0	1120
12	143.7	24.9	498.0	880
-	-	-	-	$g_{avg} = 894.5$

Another way to find the acceleration is to visualize it on a plot of the data. From equation (2.2) in the lab manual, we see that the acceleration is the slope when velocity is plotted against time. Therefore, if we plot our data values for V_i vs. t, a line of best fit should give us a value for acceleration.

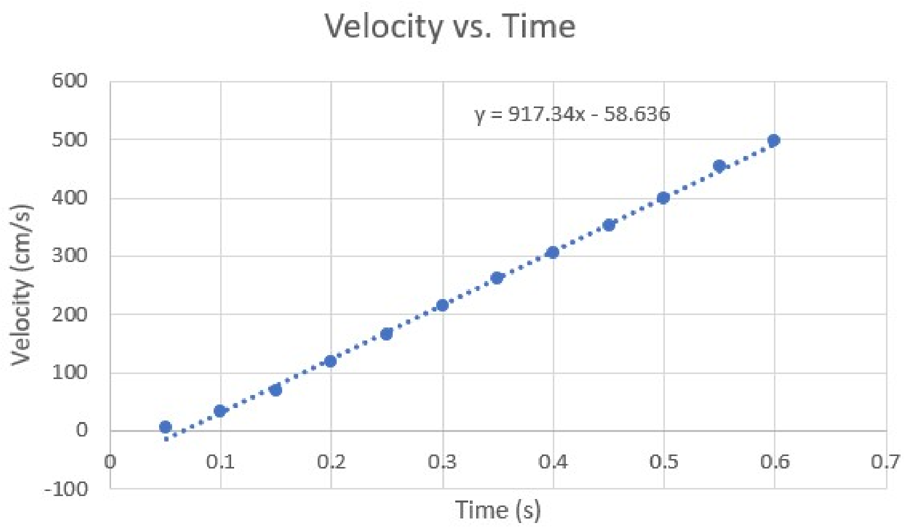

Figure 2: Visualization of the velocity changing over time.

From Figure 2, we see that the slope of the line, and therefore our acceleration, is $g = 917.34\,\mathrm{cm/s^2}$.

Using relative error, we can compare our calculated values of acceleration with the accepted value of Earth's gravity, $g = 9.8\,\mathrm{m/s^2}$. Using g_{avg} from Table 1, we find that the relative error is 8.8%. Using the slope from Figure 2, we find that the relative error is 6.4%. Plotting gives a slightly more accurate result, mostly likely because outliers (such as points 1, 2, and 11) are easier to account for with fitting techniques.

We now plot the distances over time to ensure that our data follows the expected behavior shown in equation (2.1). Rather than a linear plot like velocity, we should instead see a quadratic relationship in the shape of a parabola. We also plot equation (2.1) on the same figure for comparison.

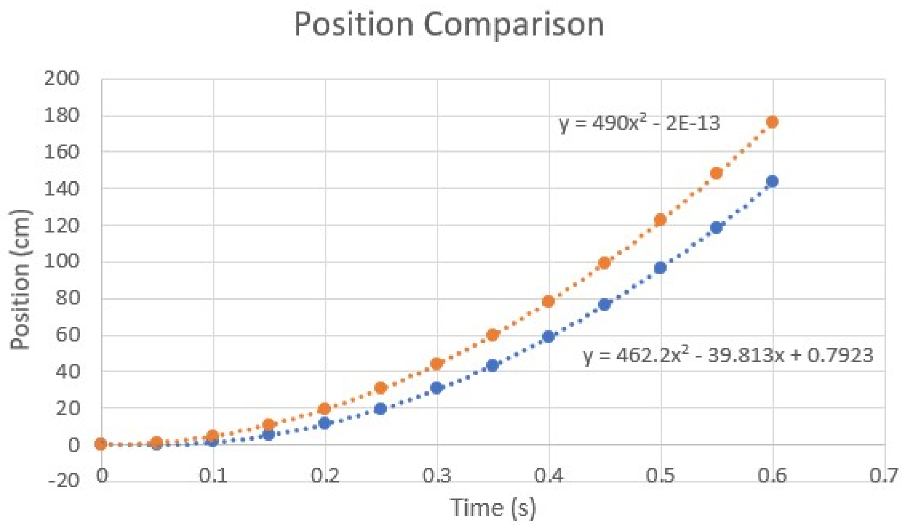

Figure 3: Visualization of the position changing over time. Experimental data is in blue, while theoretical position is in orange.

We can see immediately that our data does indeed have a parabolic nature. To confirm, a polynomial fit is applied, and the best fit is a quadratic, as expected. The theoretical position is shown to be slightly larger than our measured data, but the general trend is intact. Causes of error are discussed below.

4 Discussion and Conclusion

Overall this experiment was a success. Our analysis proved that a freely-falling object is subject to the acceleration due to gravity, and our data was consistent with the equations of motion used in theory. When comparing our measured values of g to the accepted value, we found that our errors were both relatively low at $< 10\%$, indicating that our experiment was successful at measuring an accurate value of gravity. When comparing our position data, we see that our measurements follow the expected behavior of an object in free-fall, with an error of 5.7% when compared to the theory. These small discrepancies are likely a result of experimental errors, such as the tape undergoing a small amount of friction as it slides through the tape timer, or the effect of air resistance on the mass. Future experiments could be improved by obtaining smoother tape to decrease the effects of friction, or by increasing the free-fall height in order to obtain more data points.