DUTCHESS COMMUNITY COLLEGE

Lab Report 4: Free Fall

PHY121

October, 3rd, 2024

Professor R. Lathrop — Professor T. Zito

Abereni Opuiyo

Table of Contents

Purpose

The purpose of this lab was to measure the acceleration due to gravity by dropping an object through a timer and recording its motion.Using the data we collected, we determined the approximate rate at which the object's velocity changed in the air.

Theory

If *velocity* is the rate & direction of an object's *position* over a certain time interval, then *acceleration* is the rate & direction of an object's *velocity* over a certain time interval. So long as an object's velocity is changing, it has acceleration.

Velocity and acceleration are both *vector* quantities, meaning both have vertical and horizontal components. The vertical component of an object's acceleration is impacted by the Earth's gravity. The acceleration due to gravity on Earth's surface has been measured to be $9.80\,m/s^2$.

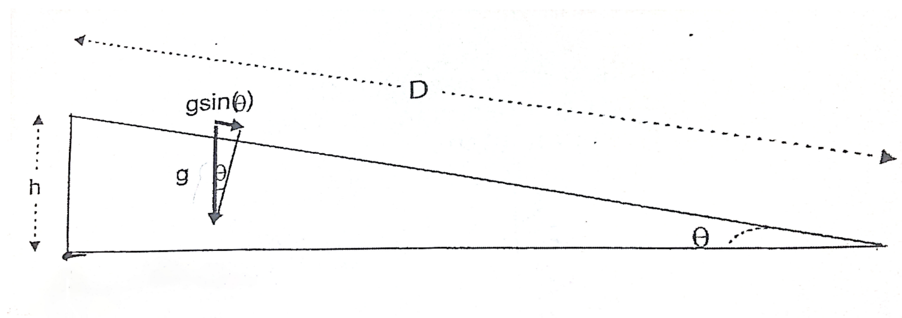

Figure 1: Incline plane

When objects fall straight down, assuming there's no air resistance, the vertical component of the object's acceleration is simply $9.80\,m/s^2$. However, if the object is launched at an angle, then the object's acceleration in the vertical direction must be determined in a different way. Just as one would determine the horizontal & vertical components of velocity for objects thrown at angles using trigonometric functions, so too can the acceleration due to gravity of such objects be calculated. More specifically, for objects that move along *inclined planes* (see figure 1), the component of the acceleration vector parallel to the plane can be calculated with the following equation:

$$a = gsin\theta \tag{1}$$

The plane angle (figure 1) can be determined using:

$$sin\theta = \frac{\Delta h}{D} \tag{2}$$

Procedure

Free Fall

Setup

1. Plugged in **Accessory Photogate Timer** into Ch. 1 on **Lab Pro** interface
2. Opened **Logger Pro**
3. Tested sensor by pressing *"collect"* on **Logger Pro**

Measure Times & Find Acceleration

4. Dropped **picket fence** vertically through **Photogate Timer**
5. Recorded data from *Velocity vs Time* plot
6. Calculated slope of velocity by hand and record your calculations
7. Used the linear regression function on **Logger Pro** to find the average velocity of the object
8. Saved graph of acceleration
9. Repeated steps 4-5, five more times and recorded the average acceleration of the trials

Inclined Plane

Setup

1. Connected **Motion Detector** to **Lab Pro**
2. Tested sensor by pressing *"collect"* on **Logger Pro**
3. Placed sensor at bottom of track
4. Used a **meter stick** to measure 0.40 m of distance between the motion sensor and the cart and marked it.

Starting at the Top

5. Held cart at marked spot and released it
6. Recorded average acceleration of linear region in the data using linear fit function in **Logger Pro**
7. Repeated steps 5-6 another three times
8. Calculated and recorded average acceleration of cart during the four trials

9. Used **meter stick** to measure D and h of the track as described in figure 1 to calculate angle of track using equation (2)
10. Calculated difference between average acceleration in trials and acceleration from equation (2)

Starting at the Bottom

11. Practiced pushing cart up track at least 0.40 m from the motion sensor
12. Recorded motion of track when moving from the bottom and calculated its acceleration.
13. Repeated and recorded motion trial three more times, then calculated average acceleration

Calculations & Graphs

Average Value Formula

$$\overline{a} = \frac{sum\, of\, values}{total\, \#\, of\, values}$$

Sample Calculation
average acceleration of free fall trials

$$\begin{aligned}\overline{a} &= \frac{9.751 + 9.758 + 9.749 + 9.620 + 9.769 + 9.837}{6} \\ &= \boxed{9.747\, m/s^2}\end{aligned}$$

Standard Deviation Formula

$$\begin{aligned}\sigma &= \sqrt{\frac{\Sigma(x_i - \overline{a})^2}{N}} \\ &= \sqrt{\frac{SS}{N}}\end{aligned}$$

N : Total number of values
$\overline{\mathbf{a}}$: Average value
$\mathbf{x_i}$: Each value from the data set
SS : Sum of squares

Sample Calculation
std of free fall trials

$$\begin{aligned}\sigma &= \sqrt{\frac{(9.751-\overline{a})^2+...+(9.837-\overline{a})^2}{6}}\\ &= \sqrt{\frac{0.024865333}{6}}\\ &= \boxed{0.06439\,m/s^2}\end{aligned}$$

Relative Error Formula

$$RE = \left|\frac{V_A - V_E}{V_E}\right| \text{ x } 100\%$$

$$\begin{aligned}\boldsymbol{V_A} &: \text{ Actual value observed}\\ \boldsymbol{V_E} &: \text{ Expected value}\end{aligned}$$

Sample Calculation
acceleration of free fall trial 1

$$\begin{aligned}RE &= \left|\frac{9.751-9.80}{9.80}\right| \text{ x } 100\%\\ &= \boxed{0.4917\%}\end{aligned}$$

Free Fall

Trial 1

Time(s)	Velocity(m/s)
0.0532	1.199
0.08952	1.553
0.1189	1.841
0.1444	2.087
0.1671	2.31
0.1878	2.513
Average Acceleration (m/s^2)	9.751

Table 1: Velocity vs Time — Free Fall Trial 1

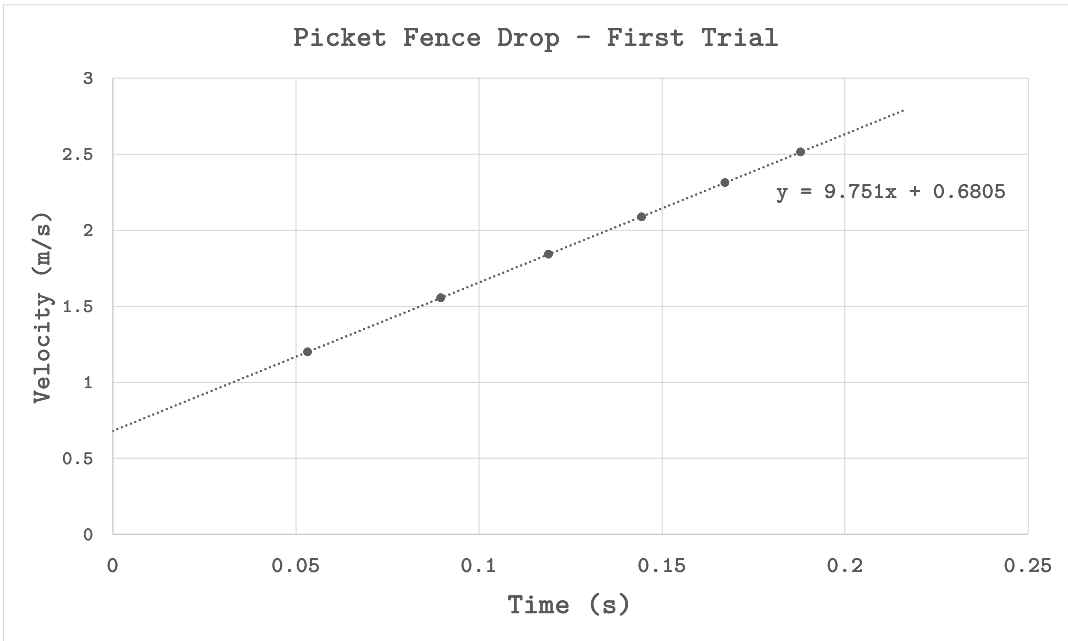

Figure 2: Velocity vs Time Graph — Free Fall Trial 1

Trials 1-6

Trials	Acceleration	Relative Error (%)
1	9.751	0.4917
2	9.758	0.4271
3	9.749	0.5108
4	9.62	1.829
5	9.769	0.3135
6	9.837	0.3877
Average ($\boldsymbol{m/s^2}$)	9.747	
Standard Deviation ($\boldsymbol{m/s^2}$)	0.06439	

Table 2: Free Fall Acceleration — Trials 1-6

Inclined Plane

Plane Angle

$$sin\theta = \frac{\Delta h}{D}$$

$\boldsymbol{\Delta h}$: height of the track at two points = $\boxed{.01870\,m}$

D : distance along the track between two points = $\boxed{.3\,m}$

$$sin\theta = 0.0623 = \boxed{3.57^\circ}$$

Acceleration Vector on Incline Plane

$$a = gsin\theta$$

g : Acceleration due to gravity on Earth = $\boxed{9.80\,m/s^2}$

$\boldsymbol{sin\theta}$: Angle of track

$$a = gsin\theta = \boxed{-.6105\,m/s^2}$$

Starting From The Top - Trial 1

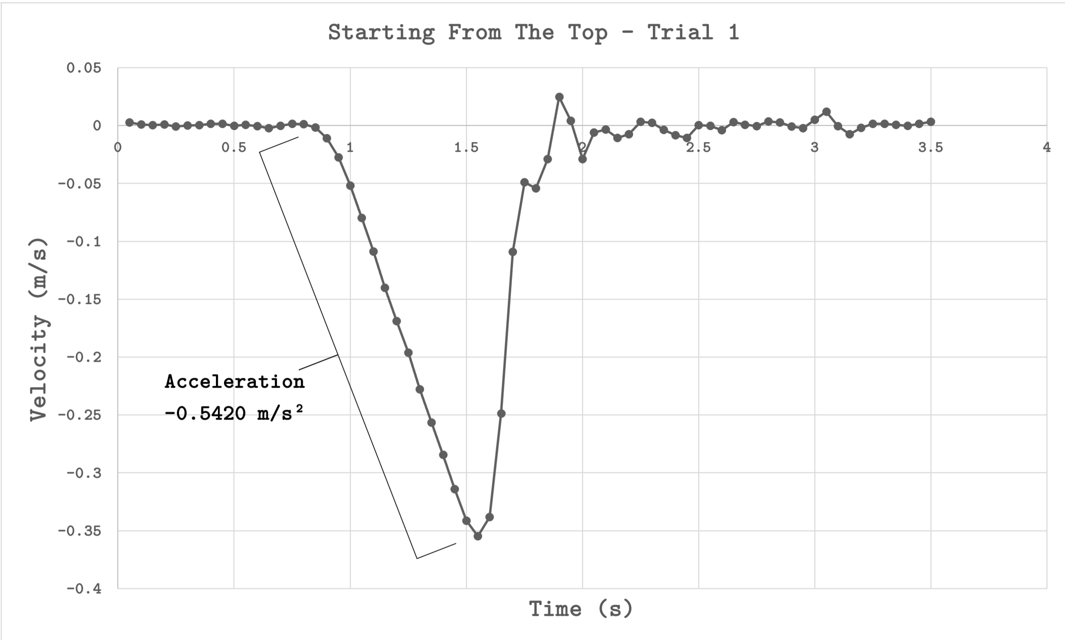

Figure 3: Starting From The Top Graph — Trial 1

Starting From The Top - Trials 1 - 4

Trials	Acceleration	Relative Error (%)
1	-0.542	11.22
2	-0.5315	12.94
3	-0.529	13.34
4	-0.5244	14.1
Average (m/s^2)	-0.5317	
Standard Deviation (m/s^2)	0.006455	

Table 3: Starting From The Top — Trials 1-4

Starting From The Bottom - Trial 1

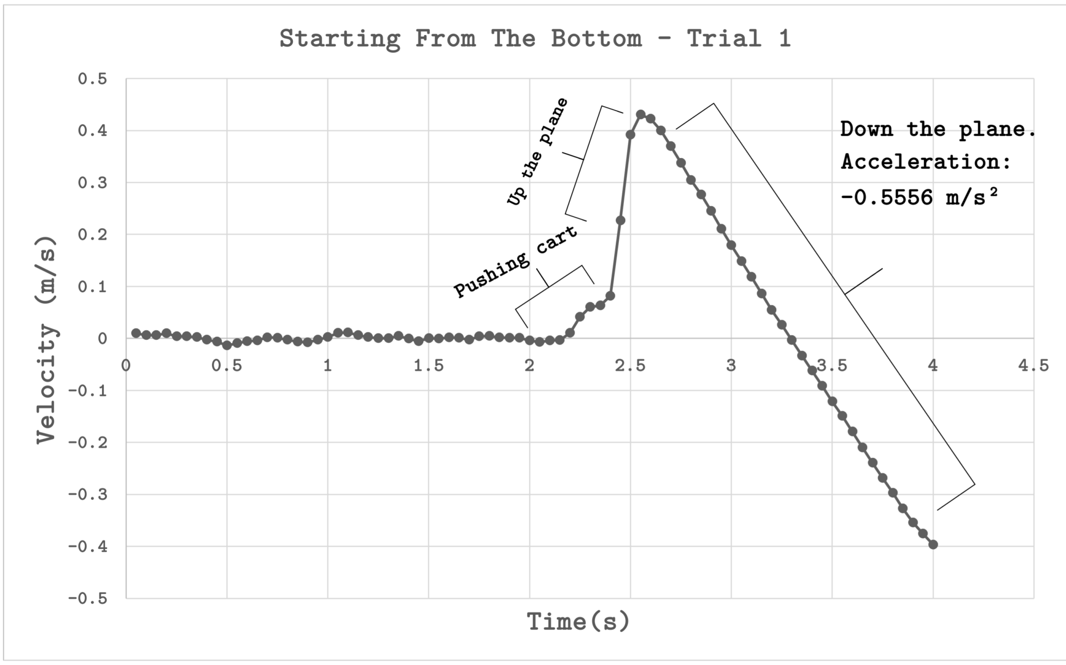

Figure 4: Starting From The Bottom Graph — Trial 1

Starting From The Bottom - Trials 1 - 4

Trials	Acceleration	Relative Error (%)
1	-0.5556	8.992
2	-0.5755	5.733
3	-0.5622	7.911
4	-0.5639	7.633
Average (m/s^2)	-0.5643	
Standard Deviation (m/s^2)	0.007171	

Table 4: Starting From The Bottom — Trials 1-4

Incline Plane Averages - Relative Error

	Acceleration (m/s^2)	Relative Error (%)
SFTT	-0.5317	12.9
SFTB	-0.5643	7.567

Table 5: Inclined Plane Averages — Relative Error

Questions

1. **What do you expect the acceleration of the picket fence to be? Is it exactly this value? If yours is higher or lower provide explanations as to why that might be.**

   We expected the acceleration of the picket fence to be around $9.80\,m/s^2$. Our calculations ended up being slightly slower but well within 10.0% of difference. The difference in values could be due to air resistance, or the small breeze produced by multiple bodies moving at the same time in a room.

2. **Do you expect that the detector's measurement of time is exactly correct? What might affect the detector's measurement of time?**

   The detector itself has a few seconds of delay so the measurement of time wouldn't be completely accurate. It's also possible that the detection algorithm of the device is finely tuned such that the minute blending of colors at the borders on the picket fence would cause times to be off. The angle at which the picket fence was dropped could also have affected the Photogate's readings.

3. **What is your average value, standard deviation, and relative error for the acceleration due to gravity, g?**

   For the acceleration due to gravity, g, our average value was $9.747\,m/s^2$, our standard deviation was $0.06439\,m/s^2$, and the relative error was .5408%.

4. **Would dropping the Picket Fence from higher above the Photogate timer change the measured value of g? Explain.**

   Dropping the Picket Fence from higher above the Photogate timer should not change the measured value of g by any significant amount. The measured value of g should change incredibly slightly since it's being dropped from a distance that is slightly farther from the Earth's surface.

5. **Does the acceleration found from the velocity vs time graphs in section 2.2 and 2.3 match each other? Should they be similar? Explain.**

   The acceleration found from the velocity vs time graphs in section 2.2 and 2.3 *do* match other. The accelerations should be similar since no part of the track has been changed (angle and height is the same). The biggest source of difference between the graphs should be because of the cart being pushed up to the top of the track in 2.3, as opposed to being let go from it in 2.2. From the point where the cart starts coming back down in 2.3, the acceleration should be similar to 2.2, which the data shows.

6. **Using $a = gsin\theta$ and $9.8\,m/s^2$ as the accepted value of g, calculate what you should have gotten from the motion detector for the acceleration along the ramp. Compare this value with the average**

value you found for the cart moving down the ramp and the average from the up and down the ramp. Is it within 10% error?

After our calculations, the value that we should have gotten from the motion detector for the average acceleration along the ramp was -0.6105 m/s^2. While our average for starting from the top of the track had a relative error of 12.9%, our average for starting from the bottom had a relative error of 7.567%.

Conclusion

The purpose of this lab was to measure the acceleration due to gravity by measuring the velocity of of objects in motion at different times. First we measured the velocity of a picket fence in free fall. Though our average value after six trials wasn't exactly 9.80 m/s^2, we were well within 10% of error, with our highest being only 1.829% (see Table 2). Our standard deviation for the free fall trials was low at 0.06439 m/s^2, meaning our measurements were precise (see Table 2). Considering our low relative error and standard deviation, the difference between our values and the accepted value for the acceleration due to gravity can be explained by air resistance. Were the experiment to be conducted again, we could try to minimize air resistance in the room, if not by using a vacuum chamber (unlikely), then by reducing the clutter in the room and improving ventilation throughout it.

For the second part of our experiment, we measured the acceleration due to gravity of an object, specifically a cart, on an inclined plane. Since gravity only impacts the vertical motion of objects, we first needed to calculate the expected value for g using equation 1. We calculated the expected acceleration due to gravity along our track to be $-0.6105\,m/s^2$. Our trials of the cart when released at the top of the track, produced an average acceleration of $-0.5317\,m/s^2$. Though the standard deviation for our trials was very low at $6.455 \text{ x } 10^{-3}\,m/s^2$, the relative error for all our trials were more than 10% (see Table 3). Besides air resistance, taking our low standard deviation into account, the difference between our measurements and our calculations is most likely due to an incorrect measurement for the angle of the track. When measuring the height and distance of the track, we did not take into account the motion sensor at the bottom of the track, which would influence *both* the height and distance measurements. When conducting this experiment again, greater consideration for the offset caused by the motion sensor should be made.

The standard deviation of the cart when starting from the bottom of the track, also had a low standard deviation at $7.171 \text{ x } 10^{-3}\,m/s^2$ (Table 4), but a lower relative error than starting from the top, at 7.567% (Table 5). A review of the graphs (see Figure 3) & Figure 4) shows that the motion sensor had many more data points for velocity when the cart started from the bottom compared to when it started from the top. For that reason, it's likely the acceleration measured when starting from the bottom is closer to the actual acceleration of the cart. Similar to starting from the top, the difference between our measurements and the calculated acceleration along the plane is most likely a result of incorrect measurements for the angle of the track.