Velocity, Acceleration and g
Lab 1

Jenny Fan, Alessandro Giovanni Castillo, Jake Torres

Figure 1:
Coeffecient of Restitution: $e_j = |\frac{v_f}{v_i}|$
X Component of Acceleration: $a_x = gsin\theta$
$sin\theta = \frac{h}{L}$
Conservation of Energy: $\frac{1}{2}mv_1^2 = mgl_2sin\theta$
Indication of friction: $\Delta = \frac{v_1^2}{2a_xl_2} - 1$

Abstract

This document provides a basic template for the 2-page extended abstract and some submission guidelines. The authors' names and affiliations should not be included. [1] Including an abstract is optional, as the document itself is an extended abstract. If included, an abstract should be a single paragraph.

1 Introduction

The purpose of the Velocity, Acceleration and g lab was to study an object moving at uniform constant velocity and acceleration and to observe the effects of universal gravitational acceleration, g. The effects of uniform acceleration or constant are pivotal to understand as they are seen commonly in every aspect of life. To observe these effects, we used an air track to simulate a nearly friction-less surface and metal shims to life the air track slightly and allow for a cart to experience the force of gravity and that alone. To simulate a constant velocity we leveled the air track to make sure the cart wasn't experiencing any gravitational forces and performed an "elastic" collision. Normally in an elastic collision energy is conserved however, it is not possible to create a completely elastic collision as some energy is lost to heat or sound, but we will be able to test to see how close the rubber bumper is to being "elastic". *Figure 1* displays all of the equations we will require for basic analysis of the data we will be collecting using a sonic ranger hooked up to a computer. More equations will be presented in the Analysis section.

2 Methods

In order to analyze a moving object moving under uniform acceleration, we used an air track that allowed for friction-less movement of the cart. To set up the track, we leveled it using a turning screw on the leveling foot of it. We determined the track was level when the cart was placed on it and the cart wouldn't move in either direction or for when it was pushed it would move back and forth without turning around or speeding up. For the first part of the lab (*Figure 2*), we set up the cart by starting it on the sonic rangers side of the track. We would push it and start measuring data as soon as it was about to hit the elastic bumper so that we could record the velocity before and after the collision along with the error on the calculated velocity to account for that later. We will use these values to see how "elastic" the collision is or how much energy was lost when the cart hit the bumper.

For the second part of the lab (*Figure 3*), we used 1 mm thick metal shims to rise one end of the track. This allowed for us to observe the cart moving under a constant acceleration. We would start the cart at the 150m mark on the track's ruler and drop it and start taking measurements when the cart was about to hit the bumper. We would measure 2 values. The velocity after the cart rebounded off the bumper and the height the cart traveled up the ramp. These values were then used to perform a linear least squares fit to calculate the slope and its uncertainty. We then compared this with the quadratic fit and its quadratic coefficient to analyze the results. We repeated these steps 10 times for 5 different amounts of shims.

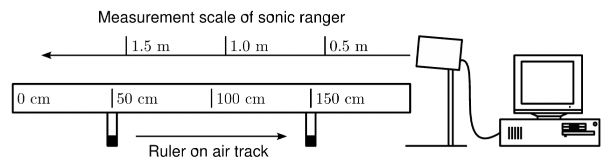

Figure 2: Air track setup

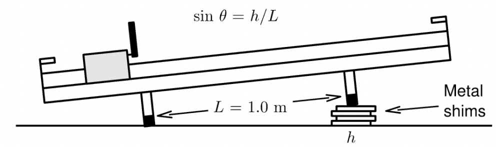

Figure 3: Air track metal shim setup

3 Results & Analysis

To complete our analysis, we use a Google Sheet and Python with Pandas and Numpy.

[1]Footnotes are also in smaller font. See Table **??** for a list of font sizes.

$$\sigma = \sqrt{\left(\frac{\Sigma(e_j-\bar{e})^2}{N-1}\right)}$$
$$\sigma_{\bar{e}=\frac{\sigma}{\sqrt{N}}}$$

Figure 4: Unweighted error equations

3.1 Constant Velocity

This section of our results is mostly a statistical analysis to compare the weighted average of coefficient of restitutions to the unweighted average and see if there is any conclusions we can make from the data.

Unweighted Average of $\bar{e}$

The unweighted average of $\bar{e}$ can be calculated simply by summing all of the e_j for every trial. The result of this was a value of 0.864. We can then use the equations in *Figure 4* to calculate the error of $\bar{e}$. The results of these calculations is a $\sigma_{\bar{e}}$ of 0.00979.

Weighted average of $\bar{e}$

To perform a weighted average we have to divide the coeffecient of resitution by its error squared for every element and sum it and divide by the inverse of the sum standard error squared at each element. The resulting weighted average $\bar{e_w}$ and weighted average standard error $\sigma_{\bar{e_w}}$ were 0.872 and 0.00290. The weighted average is very similar to the unweighted average however the standard error is pretty significantly different.

Comparing the results

A suggested question to pose after observing the results was if the uncertainties are truly independent from one another for final and initial velocity. I believe that they are independent because of how the sonic ranger records data by using an ultrasonic wave many times throughout data collection. Also there seems to be no correlation between the initial velocity standard error and the final velocity standard error. However, it seems like the higher the velocity, the larger the error which makes sense. If the object is moving faster the sonic ranger has less time to record data between movements. Comparing $\bar{e}$ and $\bar{e_w}$ it seems like half the data points are higher and half the points are lower and it seems pretty random. Another thing to note is the relationship between e and v_i shown in *Figure 5*.

It seems like as the initial velocity is increased, the coefficient of restitution decreases somewhat linearly. This makes sense with our assumptions. If an object has a faster initial velocity, it is going to create more noise and produce more heat in its collision and lose more energy. Thus the ratio of final velocity to initial velocity (which is the coefficient of restitution) is going to be smaller. When an object is moving slower, it produces less effect on its collision because its momentum is smaller and it has less kinetic energy thus its ratio between its final and initial velocity would be quite small since the object is less proportionally less energy than if it was moving faster.

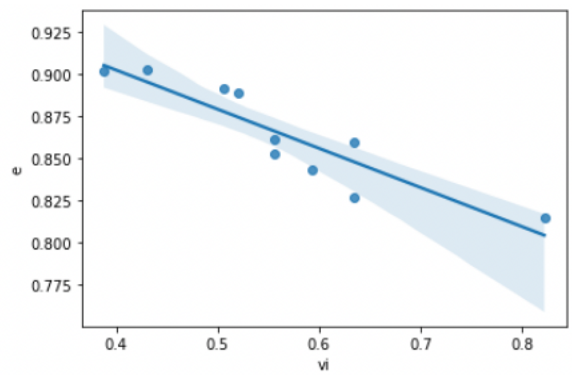

Figure 5: Relationship between e and v_1

This shows that the collision with the rubber bumper was not perfectly elastic but gets very close to it when an object is moving with a slow speed.

3.2 Gravitational Acceleration

In this analysis section we will try to recalculate g and see how close our experiment was to simulating an object moving only under the effects of gravity. The first thing we will do is calculate the unweighted average of all of the accelerations provider by the sonic ranger's velocity over time graph and slope functionality. I calculated the unweighted averages and errors of each of the different heights to be: $\{0.0105, 0.022, 0.0343, 0.0445, 0.0547\}$ and $\{2.464e^{-8}, 9.89e^{-8}, 1.6e^{-7}, 4.417e^{-7}, 4.930e^{-6}\}$. Using these values, I am able to plot the x component of acceleration as a function of the height to find the gravitational constant or an estimate for it since we said earlier in *Figure 1* that $a_x = gh/L$. We can see in *Figure 5* this plot. Calculating the slope, I got the g value is equal to $11.1m/s$, which isn't too far off from the original value, $9.8m/s$. A steeper slope may be more accurate for measuring the actual value of g because it will be the most significant force acting on the object by a large amount. The reason the acceleration may be different from what we expecting may be due to friction and the sonic rangers measuring abilities. A pendulum may be more precise at measuring the gravitational constant because there are no other forces acting on the pendulum besides gravity, unless there is some error due to the string.

Friction

Using the other equations in *Figure 1* we were able to calculate the friction between the cart and the air track and found it to be a non-zero value. This means that there definitely is some statistical error due to friction which may have caused our numbers to be off from the actual values under perfect conditions. Some of these values can be seen in *Figure 6*.

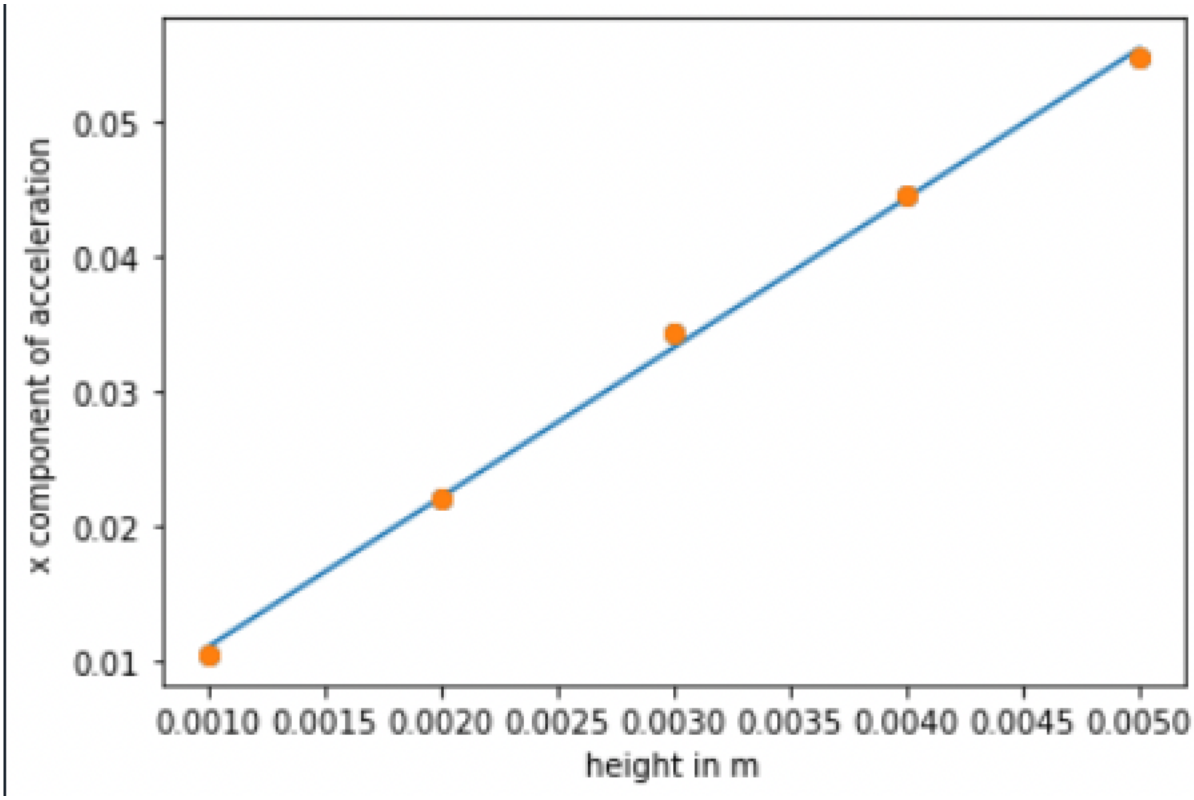

Figure 6: Relationship between a_x and h

fric
-0.027720
-0.169419
0.045568
0.000327
-0.120561
0.358811
-0.054237
-0.137473
0.137398
-0.062757
0.038275
-0.179302
0.136364
0.490359
-0.123065
-0.268788
-0.016538
0.265706
0.104932
0.178305
[illegible]

Figure 7: Values of friction in some trials