Physics 4A

Lab 2: Acceleration Due to Gravity

Objective: To measure the acceleration due to gravity using an incline plane.

Theory:

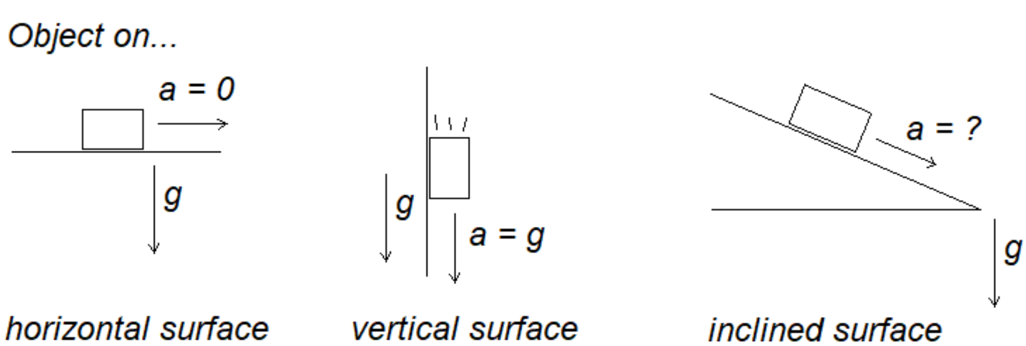
Measuring the acceleration due to gravity from an object falling straight downward is difficult to do because the object falls at a rate of 9.81 m/s2. For each second the object falls, it's velocity increases by 9.81 m/s. If we want to know how far the object will fall in a given distance, we can use the equation $y = y_o + v_o t - 0.5gt^2$. Assuming the object starts from rest and falls a distance of 1 meter, the time it takes to fall is only 0.45 seconds. Attempting to take several measurements of the object during this time would be difficult to do. Instead, we will use a method that Galileo used to measure the acceleration of falling objects.

Galileo Galilei lived in Florence, Italy around the year 1600. As a professor of mathematics, Galileo promoted the revolutionary idea that students should think and discover the world around them and planted the seed, so to speak, for the development of modern science by creating the *scientific method*: the concept that to truly understand the rules of nature we must formulate an idea (i.e. a *hypothesis*), which is essentially an "educated guess" to explain an observed phenomenon, and then we must test that idea through an *experiment*. We can then assess whether the results of the experiment support or refute our hypothesis.

Galileo studied the effect of *gravity*, a phenomenon first described by Aristotle nearly 2000 years prior. He determined that gravity causes objects to accelerate, and he was able to show (contrary to Aristotle's belief) that this rate of acceleration is the same for all objects in *freefall*.

Galileo's timing devices were of very low precision, which is to say that he was not able to measure hundredths or thousandths of a second, as we can today. So, to accurately measure the effect of gravity, he had to devise a clever experiment. Fortunately, Galileo was quite clever.

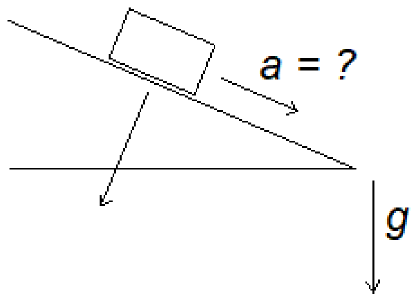
He considered an object in three scenarios, and the role of gravity accelerating the object in each:

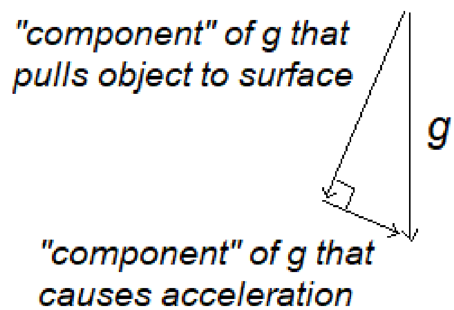


Galileo reasoned that the object on a horizontal surface is not accelerated by gravity, because the motion of the object would have to be perpendicular to the direction of gravity's pull. An object on a vertical surface would effectively be in freefall, with acceleration equal to “g”. But what about an inclined surface?

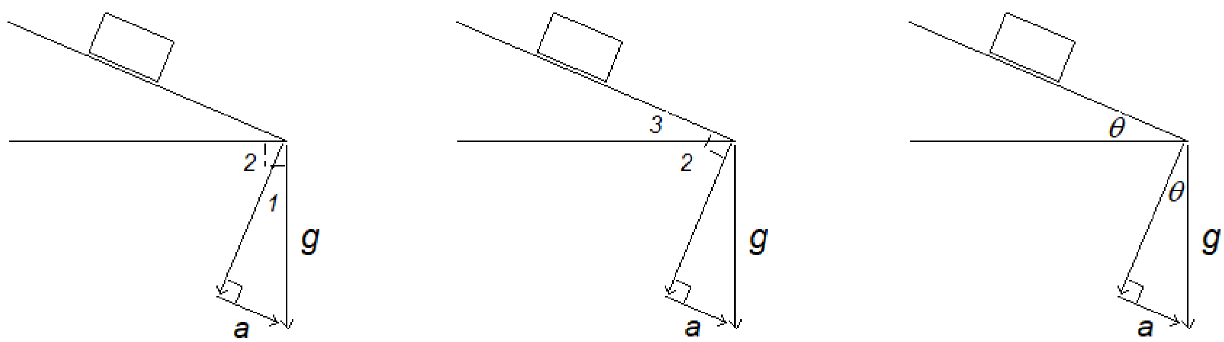
The scenario of the inclined surface merges the characteristics of the first two scenarios. Galileo understood that acceleration is a *vector quantity*, and as such it could be represented by a triangle of “components.” He reasoned that *part of gravity is responsible for the acceleration of the object on the incline.*

The acceleration due to gravity, *g*, can be represented by two components: one that is parallel to the incline, and causes the object’s acceleration; and the other perpendicular to the incline, and pulls the object against the surface (i.e. as in the horizontal surface scenario.)





We can superimpose this triangle on the picture of our inclined surface:

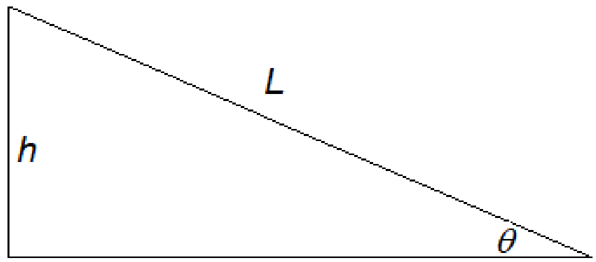


And then we can consider a little geometry. In the first picture above, Angle 1 and Angle 2 are complementary (i.e. together they form a right angle.). In the second picture, Angle 2 and Angle 3 are complementary. Since Angles 1 and 3 are each complementary to Angle 2, then ***Angle 1 and Angle 3 must be the same angle.*** We can label each of these angles with the Greek letter θ.

This means that the angle of the incline determines the component of gravity that causes the acceleration. Of course, this makes perfect sense: the steeper the incline, the greater the acceleration should be.

From the last picture, we can write: $a = g\ sin\theta$

But we can also relate the angle to the geometry of the incline itself. If the length of the incline is L and we measure the height h…



We can write: $$sin\theta = \frac{h}{L}$$

If we combine the two expressions here, we get: $a = g\left(\frac{h}{L}\right)$ or $a = \left(\frac{g}{L}\right)h$

In this lab, we will the length of the hypotenuse, L, the height, h, and the acceleration of the object down the incline, a. When we measure the acceleration at various heights, and plot acceleration vs. height, the slope of the line will be g/L. In this lab we made L a convenient value of 1 meter, making the slope equal to the acceleration due to gravity, g. Notice that mass is not part of the equation, so the mass of the cart in this experiment should not affect the acceleration due to gravity.

Procedure:

1. Background

For each run, two photogates will record three times associated with the motion of the cart. The photogates project a beam of light that is blocked by a tab, **with length 11.0 cm**, attached to the cart. The photogate will measure the amount of time that the beam of light is blocked. We will label these times as t_1 t_2 and t_3. These three times are:

> t_1 : *time for the tab on the cart to pass through the first photogate*
> t_2 : *time between the start of* t_1 *and the start of* t_3
> t_3 : *time for the tab on the cart to pass through the second photogate*

We can use these three times to calculate:

> v_1 : *the average speed of the cart as it passes through the first photogate*
> v_3 : *the average speed of the cart as it passes through the second photogate*

These two speeds are calculated by dividing the length of the tab by the appropriate time (i.e. t_1 to calculate v_1 and t_3 to calculate v_3 .)

We can then use v_1 and v_3 to calculate the acceleration of the cart. We simply need to know the time for the cart to accelerate from a speed of v_1 to a speed of v_3. As these two calculated speeds are the *average* speed of the cart, we know they also represent the *instantaneous* speed of the cart in the middle of the respective time intervals (i.e. v_1 occurs at the middle of t_1 and v_3 occurs at the middle of t_3.)

Since t_2 is the time from the beginning of t_1 to the beginning of t_3, the time from the *middle of t_1 to the middle of t_3* is:

$$t_2 - \frac{1}{2}\, t_1 + \frac{1}{2}\, t_3$$

We can use this to calculate the acceleration for each run:

$$a = \frac{v_3 - v_1}{t_2 - \frac{1}{2} t_1 + \frac{1}{2} t_3}$$

2. Setup and Equipment

Watch the following video, which introduces the equipment and how data will be collected: https://youtu.be/LDARgholmDA. Two trials of data will be taken, one with a lightweight cart, and one with a heavy cart. Each cart will roll down the incline 4 times for 5 different heights, totaling 20 runs for each cart.

3. Lightweight Cart Data Collection

Open up the excel spreadsheet. The spreadsheet has come pre-populated with labels and blank areas were data will be entered.

The mass of the carts is obtained in this video: https://youtu.be/8Xba03wrd2Q. Type the mass and length of the tab into excel.

Watch the following videos and enter height, t_1, t_2, and t_3 for each of the trials.
Lightweight cart data:
Trial 1 https://youtu.be/PEfNSloJrbc
Trial 2 https://youtu.be/4WzW_HVRc3Q
Trial 3 https://youtu.be/GXQGLWCIZOY
Trial 4 https://youtu.be/f0SFSL-9clo
Trial 5 https://youtu.be/8tW1r8YRV6A

4. Velocity Calculations

Calculate v_1, which is the velocity of the cart through gate 1. Type in excel "=B5/B10". To make our computational lives easier, place the $ symbol in front of the B and 5, such that it looks like "=B5/B10". The $ symbol tells Excel that you would like to keep that particular cell the same when copy/pasting, and when using fill across or fill down. In this case, the length of the tab is the same for each run, so we would like to keep the value the same in our calculations. Once v_1 is calculated, click on the cell, and fill down.

Repeat the same calculations for finding v_3, which is the velocity of the cart through gate 2.

5. Acceleration Calculation

To calculate acceleration, use the equation derived in 1. Background. As typed into Excel, the equation looks like "=v_3-v_1/(t_2 - t_1/2 + t_3/2)". Be sure to include the parenthesis so Excel knows the order of operations. Calculate the average and standard deviation of the acceleration.

Repeat this same process for Trials 2-5. To save time, copy and paste the calculated values, v_1, v_2, and *a* into Trials 2-5. When you input values for t_1, t_2, and t_3, all calculated values will update.

6. Height v. Acceleration Table

Complete the table of height v. acceleration. You can type the values of height and acceleration in, or you can type "=" then click on the value you want in that cell. For instance, the height for trial 1 would just be "=C7".

7. Height v. Acceleration Graph

Highlight the height and acceleration values, click on 'Insert' next to 'Home' and 'Draw' at the top of the program. There are small icons that look like tables, move your cursor over to these icons, and find the icon that is for X Y Scatter. Click the image that shows the data points with no lines connecting them (it should be the first option). Click on 'Quick Layout,' located below 'Insert,' and select the first option – it shows data with a title, labels for both x and y axis, and a legend. Select the newly appeared legend and click 'delete,' as we will not need the legend. Click on the title, and x and y axis, and enter appropriate labels.

Right click on one of the data points in the table and select 'Add Trendline.' Select 'Linear' as the trendline, then scroll down and select 'Display Equation on Chart'. You can increase the overall size of the chart by clicking on a corner and dragging outward.

8. Heavy Cart Data Collection

Repeat the same process (steps 3 – 7) for the heavy cart on an incline. Begin by copying all of the lightweight cart data below the heavy cart title, and then edit as needed.

Heavy cart data:

Trial 1 https://youtu.be/WKxlWY5b12Q
Trial 2 https://youtu.be/lZyAi_VZFz4
Trial 3 https://youtu.be/CwZgOAgkmnE
Trial 4 https://youtu.be/rTC8qP_Qcyo
Trial 5 https://youtu.be/-a0-1hUhczo

9. Acceleration due to Gravity

Calculate the acceleration due to gravity, 'g' for the lightweight and heavy cart, and enter under the title 'Results'.

10. Laboratory Report

The results for this lab will be written in a lab report. The lab report should have an overall title and a title to each section. The lab report consists of an objective, equipment, procedure, data, results, and conclusions. The objective is the goal of the lab. The equipment section is a list of equipment used to complete the lab. The procedure outlines what was done to conduct the lab, and should paint an overall big picture (do not include each step of the procedure). For the data section, go ahead and highlight your data from the excel sheet and paste into word. You will have to copy and paste the lightweight cart and the heavy cart separately. Include the graphs. The graphs can be copy/pasted just like the tables. Do not worry about adding lines to the excel spreadsheet. The results section should show the results of the experiment, and discuss the questions in the following section (11. Results). The results section should be the longest section of the report (ignoring the data). Finally, there is the conclusion section, where you take a look at the results and compare the results with the objective, and consider if the objective was met.

11. Results

Answer the following questions in the results section of your laboratory report.

Find the trial that shows a much higher standard deviation than the others. Why is the standard deviation much higher? What could have caused this?

What was the one variable measured that was never used? What does this tell you about the acceleration due to gravity?

The uncertainty in the slope works out to be about ± 0.50 m/s^2. What does this uncertainty tell us about the data and the procedure used to collect it? What would it take to narrow the uncertainty?

Within uncertainty, do the values between the lightweight cart and the heavy cart agree? Should this be the case?