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**Lab 4: Gravity and 2-D Ballistic Motion**

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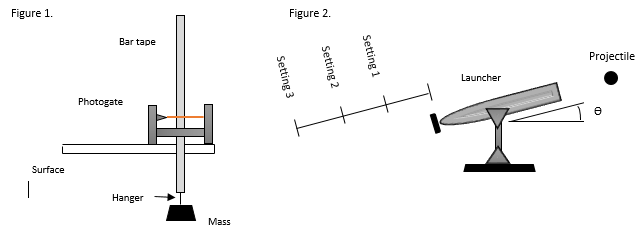
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6. **Abstract**

The purpose of this lab is to analyze projectile motion under the influence of gravity and to measure gravitational acceleration. A launcher was used to launch a ball in different conditions by adjusting the angle and launching the ball in three different settings. A photogate was used to measure the gravitational acceleration by attaching different masses on the hanger and dropping it through the photogate. A value of 9.61 is attained for gravity which is closely accurate to the true value, which is 9.8

**2) Theory**

**2.0) Lab Setup**

Refer to the figure below for an example of a projectile motion that will be presented in this experiment. For both the horizontal and vertical launches, a launcher is used to launch an object into the air. The launched is hooked up to Logger Pro to record the initial velocity of the ball at different settings. Each setting is different by speed, with setting 1 as the low speed and setting 3 as the high speed. The distance is measured by a meter stick while the initial velocity given by the launcher is measured by the logger pro. Also, a box with the same height as the launcher is used for the horizontal launch. For this experiment, air resistance is ignored.

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**2.1) Newton’s Laws**

1. An object at rest stays at rest and an object in motion stays in motion with the same speed and in the same direction unless a net external force acts on it.
2. F⃗net = m⃗a. A net force on a body causes the body to accelerate in the same direction as the net force. If the forces acting upon the body are balanced, then the acceleration of that body is zero.
3. For every action, there is an equal and opposite reaction. If body A exerts a force on body B, then body B exerts a force on body A. These two forces have the same magnitude but opposite in direction.

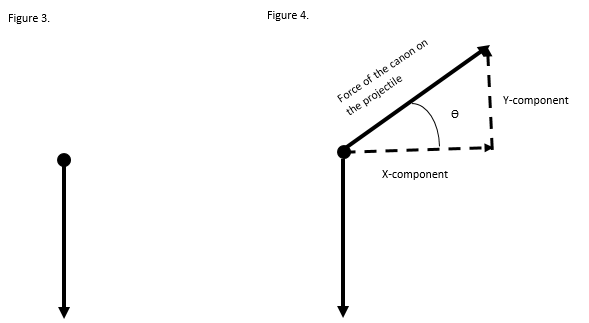
Newton’s first law tells us that when a body is acted on by zero net force, it moves with constant velocity and zero acceleration. The second law, on the other hand, states that if there is constant force acting on an object, then the object is moving at a constant acceleration. If the magnitude of the net force is constant, then so is the magnitude of the acceleration. So, under the assumption of constant acceleration, the following kinematic equations can be obtained.

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**2.2) Projectile Motion Assumptions**

A projectile is any body that is given an initial velocity and then follows a parabolic path determined by gravitational effects and other external forces such as air resistance and the curvature and rotation of the earth. However, for this experiment, we will not take these externalities into consideration and only study the influence of gravity on the motion. The key to analyzing projectile motion is to treat the x- and y-coordinates separately. The x-component of acceleration is zero while the y-component of acceleration is constant and vertically downward. Overall, we can analyze projectile motion as a combination of horizontal motion with constant velocity and vertical motion with constant gravitational acceleration.

**2.3) Expectations**

By looking at Newton's Laws and the free body diagrams of the lab setup, we can make some general predictions. As the force of the launcher increases, so will the initial velocity, total velocity, total change in x position and total change in y position. Furthermore, as the angle Ø, between the ground increases, the total change in x position will continue to decrease since the velocity in the x direction shrinks. In addition, the total change in y position will start to increase, since the velocity in the y direction grows.

**2.4) Statistics**

1. The mean () or average is obtained by summing up all the measurements made and dividing it by the number of measurements *n*.

2) Standard deviation (σ) shows how much variation from the average exists within a set of measurements. The significance of the standard deviation is that it allows us to set a limit on the upper and lower bound of the error in our measurement. More specifically, it can be taken to be the uncertainty involved in an individual measurement of a set of measurements. The mathematical formula for the standard deviation is

σ

3) The standard error of the mean (σ or just SEOM) estimates how well the mean of the data set estimates the mean we would get if we took a large number of measurements. SEOM is also referred to as the uncertainty of the mean that results from a data set. It is defined as

SEOM (σ )

**3) Data**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| mass () | () | () | () | () |
| 0 | 9.32 | 9.54 | 9.03 | 9.43 |
| 100 | 9.71 | 9.83 | 9.61 | 9.32 |
| 300 | 9.75 | 9.74 | 9.29 | 9.67 |

Table 1: Data table for accelerations of tape measurements

|  |  |  |  |
| --- | --- | --- | --- |
| mass () | Mean () | Standard deviation σ () | SEOM () |
| 0 | 9.33 | 0.219 | 0.110 |
| 100 | 9.62 | 0.213 | 0.107 |
| 300 | 9.61 | 0.219 | 0.110 |

Table 2: Data table for the statistics of the accelerations of tape measurements

**Launcher Height (m):** 0.1610.0005

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Trial | Setting 1 | | Setting 2 | | Setting 3 | |
|  |  |  |  |  |  |
| 1 | 0.515 | 3.25 | 0.675 | 4.37 | 0.748 | 5.13 |
| 2 | 0.520 | 3.31 | 0.670 | 4.42 | 0.760 | 5.68 |
| 3 | 0.550 | 3.30 | 0.665 | 4.38 | 0.815 | 5.68 |
| 4 | 0.440 | 2.79 | 0.670 | 4.30 | 0.817 | 5.69 |
| 5 | 0.515 | 3.37 | 0.675 | 4.37 | 0.833 | 5.71 |

Table 3: Data table for horizontal distance, and initial speed measurements

|  |  |  |  |
| --- | --- | --- | --- |
|  | Setting 1 | Setting 2 | Setting 3 |
|  | 0.508 | 0.671 | 0.795 |
|  | 0.181 | 0.181 | 0.181 |
| photogate | 3.20 | 4.37 | 5.58 |
| calculated | 2.81 | 3.71 | 4.39 |
|  | 0.101 | 0.004 | 0.017 |
| difference | 13.9 | 17.8 | 27.1 |

Table 4: Data table for horizontal motion times of flight, muzzle speeds, and errors

**Launcher Height (m):** 0.310.005

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Trial | Setting 1 | | Setting 2 | | Setting 3 | |
|  |  |  |  |  |  |
| 1 | 0.790 | 3.10 | 1.11 | 4.14 | 1.67 | 5.48 |
| 2 | 0.805 | 3.06 | 1.14 | 4.10 | 1.66 | 5.30 |
| 3 | 0.820 | 3.07 | 1.14 | 4.10 | 1.70 | 5.46 |
| 4 | 0.810 | 3.12 | 1.15 | 4.12 | 1.71 | 5.49 |
| 5 | 0.785 | 3.06 | 1.15 | 4.13 | 1.69 | 5.30 |

Table 5: Data table for vertical motion distance and initial speed measurements

|  |  |  |  |
| --- | --- | --- | --- |
|  | Setting 1 | Setting 2 | Setting 3 |
|  | 0.802 | 1.14 | 1.69 |
| photogate | 3.08 | 4.12 | 5.41 |
| calculated | 3.96 | 4.72 | 5.75 |
| difference | 22.2 | 12.7 | 5.89 |

Table 6: Data table for vertical motion distances and muzzle speeds

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |
| Setting 1 | 0.503 | 0.871 | 1.01 | 0.871 | 0.503 |
| Setting 2 | 0.919 | 1.59 | 1.84 | 1.59 | 0.919 |
| Setting 3 | 1.63 | 2.84 | 3.27 | 2.84 | 1.63 |

Table 7: Data table for our prediction of distances at different firing angles

**Setting 1 (low speed)**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Trial | at | at | at | at | at |
| 1 | 0.598 | 0.590 | 0.960 | 0.810 | 0.360 |
| 2 | 0.598 | 0.800 | 0.940 | 0.810 | 0.370 |
| 3 | 0.598 | 0.800 | 0.940 | 0.820 | 0.370 |
|  | 0.598 | 0.730 | 0.947 | 0.813 | 0.367 |

**Setting 2 (medium speed)**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Trial | at | at | at | at | at |
| 1 | 0.740 | 1.36 | 1.65 | 0.420 | 0.610 |
| 2 | 0.940 | 1.37 | 1.66 | 0.420 | 0.620 |
| 3 | 0.950 | 1.38 | 1.67 | 0.460 | 0.630 |
|  | 0.873 | 1.37 | 1.66 | 0.433 | 0.620 |

**Setting 3 (high speed)**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Trial | at | at | at | at | at |
| 1 | 1.55 | 2.46 | 3.78 | 2.38 | 1.33 |
| 2 | 1.51 | 2.41 | 3.74 | 2.42 | 1.35 |
| 3 | 1.53 | 2.41 | 3.72 | 2.42 | 1.37 |
|  | 1.53 | 2.43 | 3.75 | 2.41 | 1.35 |

Table 8: Data tables for horizontal distance measurements at different firing angles

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |
| Setting 1 % error | 18.9 | 16.2 | 6.24 | 6.66 | 27.0 |
| Setting 2 % error | 5.01 | 13.8 | 9.78 | 72.8 | 32.5 |
| Setting 3 % error | 6.13 | 14.4 | 14.7 | 15.1 | 17.2 |

Table 9: Data table for percent errors in our measured average horizontal distances compared to predicted values

|  |  |  |  |
| --- | --- | --- | --- |
|  | Setting 1 | Setting 2 | Setting 3 |
|  | 1.01 | 1.84 | 3.27 |

**Setting #: 2 : 4.25 m/s = 45**

Table 10: Data table for calculating

**Launcher Height (m):** 0.2620.0005

|  |  |  |  |
| --- | --- | --- | --- |
| Trial | Setting 1 | Setting 2 | Setting 3 |
| 1 | 0.890 | 1.45 | 2.18 |
| 2 | 0.890 | 1.45 | 2.19 |
| 3 | 0.890 | 1.47 | 2.19 |
| Avg. | 0.890 | 1.46 | 2.19 |

Table 11: Data table for horizontal distances of launching off the table at

**4) Calculations**

Example equation from Table 3 to find theoretical time:

, ,

Example calculations from Table 3 to find data for Table 4 for first setting:

Experimental: = 3.20

Theoretical:

σ

% difference

Example calculations from Table 4 to find data for Table 6:

Example calculations to find predictions for setting 1:

Example calculations to find for Table 10:

**5) Results, Analysis, and Conclusions**

In the “Freely Falling Object” Experiment we achieved gravitational accelerations of 9.33, 9.62, 9.61 meters per second squared. Each value is the average of the velocities measured at 0g 100g and 300g respectively. Assuming no interference from drag, friction or air resistance the estimated acceleration for gravity is the constant 9.8 meters per second squared. The object in free fall did of course succumb to external forces which attributed to errors of 4.795%, 1.836% and 1.938% respectively. Despite the subtle differences in calculations the object fell with an acceleration that acted independently of the mass.

In other experiments such as the “Horizontal Launch” and “Vertical Launch” experiments we were to make predictions about how an object in various conditions while in projectile motion. In these experiments we were given a computer generated velocity and were asked to calculate velocity with known variables in the experiment. The resulting computer generated initial velocity was held at 3.08 (m/s), 4.12 (m/s), and 5.41 (m/s) with calculated predictions of 3.96 (m/s), 4.72 (m/s) and 5.75 (m/s). The percent errors (22.2%, 12.7%, 5.89%) were notably large due to the fact that there was a large amount of speculation as to the projectile's maximum height in mid-flight resulting in a severe overestimation of the object's initial velocity.. In the “Horizontal Launch” the photogate found average initial velocities of 3.2 (m/s), 4.37 (m/s), and 5.58 (m/s). With estimated predictions of 2.81 (m/s) 3.71 (m/s) and 4.39 (m/s) attributed at percent errors of 13.9%, 17.8% and 27.1% respectively fault was found in the setup of our system.The design of the experiment required that the barrel of the launcher was equal in height to the landing pad. In our setup the height of the landing pad was 2-2.5 inches above the barrel of the gun resulting in an underestimate of the distance traveled. Because distance is proportional to the in the equation a decrease in the value of the distance traveled resulted in a decrease in the value of the initial velocity. What was found was that time, velocity, distance, acceleration, and initial velocity were all variables dependent on each other and equations such as could be manipulated to find values of other variables.Additionally it was found that angles of optimized distance traveled with time of flight.

Likely the most problematic experiment had to have been the “Freely Falling Object” Experiment. What was dangerous about this lab was that there was a severely high aptitude for data to be tainted by external factors to the point where the data became unusable. While we concluded that gravitational acceleration acted independently of mass there were various reasons as to why the averaged velocity was not exactly 9.8 meters per second squared. The largest factor that hampered our results was friction between the bar tape and the photogate as the bar tape entered free fall. while mass and gravitational acceleration do act independently when the bar tape had no mass on it its momentum was low enough such that it’s velocity vector could be influenced easily by outside stimulus. Because the bar tape had very little momentum the friction of the photogate put more of a force on it as it fell and as a result the averaged velocity was lower than that of the trials where the bartap had higher momentum. Air drag and air resistance remained largely negligible but were still present at some degree but the only other thing that hampered data collection was simply human error from letting the bar tape go at one moment and recording its data at another. To make the experiment optimal for the calculation of gravity we would have to have an object thick enough such that when it falls it does not collide with the walls of the photogate alternatively it it is to thick then air drag becomes a non-negligible force. The best way to improve upon the experiment would be to use a plastic rod with a hole in the bottom where the hanger can be attached.

In the Projectile motion experiments what played the largest role influencing trivial data was the angle of rotation. The projectile was meant to be aimed at the center of the landing pad, however changing the latitude of the launchers position introduced a second angle that would veer the ball into some other direction. Of course there were a few trials wherein the ball was launched poorly or succumbed to other factors but for the most part the largest error was that of human error. To optimize the results of the experiments one would need to have a surface perfectly level to the barrel, eliminate the friction between the barrel and the projectile acting against its motion restricting the ball's initial velocity, and have the barrel of the launcher point directly towards the center of the launch pad. Of course there is little we can do with the friction and so long as the launcher is pointed approximately towards the center of the landing pad it is sufficiently aligned. The best way however, to improve upon the accuracy of the experiment would be to have a platform that could adjust to the exact height of the barrel, by doing so the ball is not in the air for more or less time than it needs to be and thus the most accurate flight distance can be found.

**6) Questions**

For this experiment, we used different methods and different equipment to experimentally show how kinematic equations and Newton’s Law play a significant role in describing how an object behaves while it is moving in the air. In the first section of the lab, our values for gravity are closely similar to the value we are expected to get, which is 9.8 **(6.1.Q1)** As a constant acceleration, one can apply the formula We will find that if objects dropped from rest, the initial velocity will be zero. If the initial velocity is zero, then we will have the equations or in which We see that mass is not a term in the equations, so all objects should fall at the same rate in the absence of air resistance. Our results, however, do not support this idea as we have different values for our acceleration being **(Q2)** With the 100g on the mass hanger, its acceleration is closer to gravity in comparison to the other masses. **(Q3)** One source of error is our incorrect time measurements. Clicking “Stop” on the data collection too late would result in an error on the graph. The slope of the velocity vs. time graph will not be as accurate as it will be less steep.Another source of error is the fact that we ignored friction. Friction would cause acceleration to be smaller than the theoretical value. We did not account for the drop distance as well. The reading might be more accurate if the drop distance is increased.

**(6.2.Q1) Q1)** For a horizontal motion, there are no forces acting upon the ball once it leaves the launcher. The only force acting on the ball only occurs in the vertical motion, which is the gravitational force. It is directed vertically downward. **(Q2)** The flight times for all three settings are about the same. This is what we would expect after considering the formula Since this was a horizontal launch, the velocity in the vertical direction is zero. So, what we have left of the equation is We know that for all three settings, the initial launcher height was the same. We also know that the value for the vertical acceleration is always constant, with gravity= 9.8 The equation does not take into account the initial velocity so therefore, the flight times for all three settings will be the same. **(Q3)** The setting with the smallest percent difference in was setting 1.

**(Q 6.3.1)** In the vertical launch experiment the angle of elevation and the gravitational acceleration stayed the same. However, the initial velocity of the projectile changed at each different power setting. As the pin was pulled further back the ball achieved a higher initial velocity leaving the barrel, and as a result the average DY increased each time the launcher was brought to a higher setting. **(Q 6.3.2)** In comparison to the actual measured the percent difference was most minimal at its middle power setting with a difference of 3.36%.

**(6.4.Q1)** We know that the initial velocity for the launcher should be about the same for both vertical and horizontal motions. So, values used to calculate the predictions are computed by taking the average between the average horizontal velocity and the average vertical velocity for each setting.

**(6.5.Q1)** The problem was in the theoretical predictions. A source of error can be the inconsistency with the initial velocities of the shot. The velocity calculated for each setting is computed by taking the averages of all velocities from both the horizontal launch and vertical launch. **(Q2)** In comparison with the actual distance traveled and the predicted distance traveled the lowest percent error was when the launcher as at its 2nd power setting at 45° with an error of 0.00% **(Q3)** The minimum velocity occurs at the maximum height of the trajectory, where the vertical velocity is zero. This is because at the apex the velocity’s value is purely the x-component of the launch rather than a pythagorean product of the x and y components for velocity.

**(6.6.Q1)** At launch angle the projectile will go the furthest horizontally if it lands at the same height it is launched. **(Q2)** No. The angle needed to be changed. **(Q3)** Another possible angle and initial speed combination that would allow the ball to hit the target would be at an angle of at an initial velocity of 5.54

**(6.7.Q1,2)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Setting 1 | | Setting 2 | | Setting 3 | |
| Maximum height (m) | .390 | | .497 | | .655 | |
| Time of flight (s) | .329 | | .244 | | .188 | |
| Horizontal distance (m) | .896 | | .897 | | 4.91 | |
| Components of ball’s final velocity (m/s) | x-Comp | y-Comp | x-Comp | y-Comp | x-Comp | y-Comp |
| 2.72 | -1.66 | 3.68 | -0.269 | 4.91 | 1.57 |
| Magnitude and angle (N) | 1.89 @ | | 3.69 @ | | 5.15 @ | |
| Percent error (%) | 0.670 | | 62.8 | | 55.4 | |