**AP PHYSICS: Lab #4 – Projectile Motion Lab** Mr. O’Hagan

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**I SUMMARY**

This lab was performed to determine if the equations of motion accurately predict projectile motion. Calculations were made to predict how far a small steel ball would travel before hitting the ground when it is rolled of a lab bench. An experiment was run to see how far the ball actually goes.

Before performing the experiment, I believed the equations of motion would predict how far a ball goes. Although the equations do not take into account air resistance, it was felt that air resistance would not appreciably affect the results because the ball was small, heavy and relatively slow moving.

After performing the experiment, I do not believe the equations of motion alone can predict projectile motion. The predictions did not match up with the actual test even when uncertainties are taken into account. To accurately predict projectile motion, air resistance must be taken into account.

**II THEORETICAL MODEL OF PROJECTILE MOTION**

Kinematic equations are used to determine how far a projectile goes before hitting the ground. Since there is an independence of the horizontal and vertical motion of a projectile, finding the distance can be broken down into two separate problems. The first problem finds how long the projectile is in the air. The second problem finds how far the projectile goes while it is in the air.

The kinematic equation that is used to find the amount of time the projectile is in the air is

$d=v\_{0}t+\frac{1}{2}at^{2}$,

where the initial velocity is zero (ball is launched horizontally), the displacement is how far the ball drops and the acceleration is the acceleration due to gravity. The quadratic equation is used to solve for time. Once the time is known, use the definition of average velocity,

$v\_{avg}=\frac{d}{t}$ ,

to determine how far the ball goes before hitting the ground. This equation can be used since the horizontal velocity of the ball remains constant the entire time the ball is in the air (assuming negligible air resistance). The average velocity is measured in the experiment.

**III DESCRIPTION OF EXPERIMENT**

A sketch of the experiment setup and a list of the equipment needed are shown below:

track

carbon

paper

computer

photogate

steel

ball

 Computer with data acquisition software

 Photogate

 Small metal ball

 Meter stick

 Various lab stands and clamps

 Carbon paper (to make mark where ball lands)

 Track for ball to roll down

 Calipers (to find diameter of ball)

The experiment was set up as shown above. A steel ball was rolled down the ramp, through the photogate and then off the edge of the lab bench. The computer measured the amount of time required for the ball top pass through the photogate. Using the diameter of the ball and the time the ball took to pass through the photogate, the ball’s velocity was calculated. This velocity is the horizontal velocity for the rest of the calculations. The height of the lab bench was measured to get the vertical displacement of the ball during the projectile motion. The prediction of the distance traveled was calculated from the bench height and the horizontal velocity.

Paper was taped down to the floor approximately where the ball would land. Carbon paper was placed over it so there would be a mark where the ball actually landed. The horizontal distance from the edge of the lab bench to the mark on the paper was measured to get the actual distance traveled by the ball.

**IV DATA**

|  |  |  |  |
| --- | --- | --- | --- |
| **MEASURED** | **CALCULATED** | **MEASURED** |  |
| Ball diameter(m) | Time in photogate(s) | Bench height(m) | Gravitionalacceleration(m/s2) | Initialvelocity(m/s) | Timein air(s) | Range(m) | ActualRange(m) | Percent difference |
| 0.0253 | 0.0241 | 0.847 | 9.80333 | 1.0498 | 0.4157 | 0.436 | 0.394 | +10.66 |

The gravitational acceleration comes from the National Oceanic and Atmospheric Administration (NOAA). See Attachment A for the prelab, which includes the raw data.

Sample calculation for the initial velocity (horizontal) of the ball:

 $v\_{0}=\frac{dist}{time}$ $v\_{0,x}=\frac{0.0253}{0.0241}$

 $v\_{0,x}=\frac{ball diameter}{time in photogate}$ $v\_{0,x}=1.0498 {m}/{s}$

Sample calculation for the time the ball is in the air:

 $d\_{y}=v\_{0,y}t+\frac{1}{2}at^{2}$

 $v\_{0,y}=0$ $t=\sqrt{\frac{2\left(-0.847\right)}{-9.80333}}$

 $t=\sqrt{\frac{2d\_{y}}{a}}$ $t=0.4157 s$

Sample calculation for the distance the projectile goes:

 $v\_{avg,x}=\frac{d\_{x}}{t}$

 $d\_{x}=\left(1.0498\right)\left(0.4157\right)$

 $v\_{avg,x}=v\_{0,x}$

 $d\_{x}=0.436 m$

 $d\_{x}=v\_{0,x}t$

Sample calculation for the percent difference:

 $\% diff=\left(\frac{predicted-actual}{actual}\right)×100\%$

 $\% diff=\left(\frac{0.436-0.394}{0.394}\right)×100\%$ $\% diff=10.66\%$

Calculations for the uncertainty analysis can be found in Appendix B.

**V ANALYSIS OF DATA**

The percent difference being +10.66% indicates that the equations of motion probably do not accurately predict the projectile motion.

The analysis of the uncertainties indicates the equations of motion do not accurately predict projectile motion. The predicted distance is from 0.438 m to 0.434 m. The measurement of the actual distance is somewhere between 0.399 m and 0.389 m. These two ranges do not overlap. See the graph below for the data presented with uncertainties taken into account. Note that the ranges of the predicted and measured distances are so small compared to the difference between the two distances that they hidden by the size of the data points themselves.

Attachment B shows the detailed analysis of the uncertainties.

**VI CONCLUSIONS**

The equations of motion alone are not adequate to accurately predict projectile motion. They predict too far of a distance (+10.66%). The other indicator that can help to determine if the equations of motion are adequate are the ranges for predicted and actual displacement found using the uncertainties. The ranges do not overlap which shows there is something else going on that the equations of motion do not take into account.

In the absence of any glaring mistakes made when performing the experiment, the most obvious reason why the equations are not predicting correctly is that they do not take into account air resistance. Air resistance would slow the horizontal velocity of the ball. The equations used assumed a constant horizontal velocity. This change would cause the predictions to be too large – which is what happened. Air resistance would also increase the amount of time it takes for the ball to reach the ground. This change would cause the predictions to be too small – not what happened. One possible explanation for this discrepancy is that the effect of the change in horizontal velocity outweighs the effect of the change in time.

**VII FUTURE STUDIES**

This experiment could be improved having a smoother transition from the ramp to the table. This would eliminate much of the bouncing the ball does as it heads towards the photogate (and the edge of the lab bench).

This experiment brings to light air resistance as the probable reason why our predictions do not match what actually happened. Unfortunately, including air resistance in our theoretical model is not really feasible without a tremendous amount of further study to understand how to calculate the drag force. Even so, a different experiment could be run to verify that the air resistance is the missing part of our theoretical model. Basically rerun this experiment with balls of the same size, but of different masses. Air resistance would affect the balls with the smaller masses more than the balls with the bigger masses. If the percent differences between predicted and actual displacements decrease as the balls become more massive, air resistance is the missing element.

**APPENDIX A**

**Put your pre-lab here…**

**APPENDIX B**

**Put your uncertainty calculations here…**