Lab Report 6: Newton's Second Law

PHY121

October, 17th, 2024

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Purpose

The purpose of this lab was to observe the relationship between force and acceleration, thus demonstrating Newton's Second Law.

Theory

Procedure

Horizontal Gun

1. Measured height of the gun above ground using a **meter stick**.
2. Fired gun, then measured distance travelled.
3. Marked where the ball landed on the ground with tape.
4. Repeaated steps 1-3, five times to calculate average distance.
5. With the average distance and height of the gun above the ground, used equations of kinematics to calculate the ball's time in the air and initial velocity.

Inclined Gun

6. Guessed where the ball would land, marking our expectations with tape.
7. Inclined gun to 40°.
8. Measured new height of the gun above ground.
9. Calculated expected time in the air and horizontal distance using the initial velocity found in step 5.
10. Marked expected distance on the ground with tape.
11. Shot ball from the angled gun five times.
12. Calculated average distance and standard deviation of trials in step 4.
13. Repeated steps 6-12 at a different angle.

Calculations & Graphs

Equations of Kinematics For Vertical & Horizontal Motion

$$y = Vo_y t + \frac{1}{2} a_y t^2 \tag{1}$$

$$x = Vo_x t \tag{2}$$

Sample Calculation
hang time and inital velocity of horizontal launch

Knowns:

$$\begin{aligned} y &= \boldsymbol{-0.276\, m} \\ Vo_y &= \boldsymbol{0\, m/s} \\ a_y &= \boldsymbol{-9.8\, m/s^2} \\ x &= \boldsymbol{1.231\, m} \end{aligned}$$

Calculating Hang Time:

$$\begin{aligned} y &= Vo_y t + \frac{1}{2} a_y t^2 \\ -0.276 &= (0)(t) + \frac{1}{2}(-9.8)t^2 \\ -0.276 &= -4.9t^2 \\ 0.05\overline{632} &= t^2 \\ \sqrt{0.05\overline{632}} &= t \\ t &= \boxed{0.2373\, s} \end{aligned}$$

Calculating Initial Velocity:

$$\begin{aligned} x &= Vo_x t \\ 1.231 &= (Vo_x)(.2373) \\ Vo_x &= \boxed{5.187\, m/s} \end{aligned}$$

Equations for Vertical & Horizontal Components of Initial Velocity

$$Vo_y = Vosin(\theta) \tag{3}$$
$$Vo_x = Vocos(\theta) \tag{4}$$

Sample Calculation
inclined gun at 40 degrees

Knowns:

$$Vo = \mathbf{5.187}\, \boldsymbol{m/s}$$

Calculating Vertical Initial Velocity:

$$\begin{aligned} Vo_y &= Vosin(\theta) \\ &= (5.187)(sin(40°)) \\ Vo_y &= \boxed{3.334\, m/s} \end{aligned}$$

Calculating Horizontal Initial Velocity:

$$\begin{aligned} Vo_x &= Vocos(\theta) \\ &= (5.187)(cos(40°)) \\ Vo_x &= \boxed{3.973\, m/s} \end{aligned}$$

Average Value Formula

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

Sample Calculation
average distance of horizontal ball launch

$$\begin{aligned} \overline{a} &= \frac{1.331 + 1.279 + 1.228 + 1.2 + 1.118}{5} \\ &= \boxed{1.231\, m} \end{aligned}$$

Standard Deviation Formula

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

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

Sample Calculation
std horizontal ball launches

$$\sigma = \sqrt{\frac{(1.331 - \overline{a})^2 + ... + (1.118 - \overline{a})^2}{5}} = \sqrt{\frac{0.0260428}{5}} = \boxed{0.07217\,m}$$

Relative Error Formula

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

$\boldsymbol{V_A}$: Actual value observed
$\boldsymbol{V_E}$: Expected value

Sample Calculation
inclined launch at 40 degrees - measured vs calculations

$$RE = \left|\frac{2.925 - 2.704}{2.704}\right| \text{ x } 100\% = \boxed{8.157\%}$$

Horizontal Launch

Trials

Trials	**Distances (m)**
1	1.331
2	1.279
3	1.228
4	1.2
5	1.118
Average (m)	1.231
Standard Deviation (m)	0.07217

Table 1: Horizontal Launch Trials

Calculations

X	$x^{!}$	Vo_x	V_x	a_x	t
	$1.231\,m$	$5.18\,m/s$	$5.187\,m/s$	$0\,m/s^2$	$0.237\,s$

Y	$y^{!!}$	Vo_y	V_y	a_y
	$-0.276\,m$	$0\,m/s$	$-2.322\,m/s$	$-9.80\,m/s^2$

! Average distance of horizontal launch trials
!! Height of gun to ground

Table 2: Horizontal Launch Calculations

Inclined Launch at 40°

Calculations

$V^{!}$	θ
$5.187\,m/s$	40°

X	x	Vo_x	V_x	a_x	t
	$2.704\,m$	$3.973\,m/s$	$3.973\,m/s$	$0\,m/s^2$	$0.680\,s$

Y	y	Vo_y	V_y	a_y
	$-1.05\,m$	$3.334\,m/s$	$0\,m/s$	$-9.80\,m/s^2$

! Taken from horizontal launch trials since gun compression was the same.

Table 3: Inclined Launch at 40° Calculations

Trials

Trials	Distances (m)	Relative Error (%)
1	2.925	8.157
2	3.054	12.92
3	2.87	6.123
4	2.927	10.81
5	2.734	3.683
Average (m)	2.902	
Standard Deviation (m)	0.1034	

Table 4: Inclined Launch at 40° Trials

Inclined Launch at 55°

Calculations

$V^!$	θ				
$5.187\,m/s$	55°				
X	x	Vo_x	V_x	a_x	t
	$2.580\,m$	$2.975\,m/s$	$3.975\,m/s$	$0\,m/s^2$	$0.867\,s$
Y	y	Vo_y	V_y	a_y	
	$-1.05\,m$	$4.249\,m/s$	$0\,m/s$	$-9.80\,m/s^2$	

! Taken from horizontal launch trials since gun compression was the same.

Table 5: Inclined Launch at 55° Calculations

Trials

Trials	Distances (m)	Relative Error (%)
1	2.748	6.5
2	2.52	2.324
3	2.723	5.523
4	2.542	1.475
5	2.733	5.914
Average (m)	2.653	
Standard Deviation (m)	0.1001	

Table 6: Inclined Launch at 55° Trials

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 use the measurements from a ball launched horizontally to determine the distance that ball would travel when launched at an angle. By applying the equations of kinematics and recognizing the independence of a motion's horizontal and vertical components, we were able to make our calculations. First we measured the average distance of the ball, when launched horizontally five times. We measured an average distance of 1.231 meters (see Table 1). With a standard deviation of 7.2127x10^{-2} meters (Table 1), our measurements were precise. We measured the height of the gun to be 0.276 meters (Table 1) and, by applying equation 1, determined the ball's time in the air to be 0.2373 seconds (Table 1). Using equation 2, we determined the initial velocity of the ball to be 5.187 m/s (Table 1).

Our calculations for the distance the ball would travel when launched at an incline of 40°, required us to split the initial velocity into horizontal and vertical components. Since we did not change the compression of the gun, only the angle, we used the initial velocity for x that we calculated in Table 1. Applying equations 1 and 2, we calculated the horizontal distance the ball would travel to be 2.704 meters (Table 3). The average distance of our inclined launch trials was 2.902 meters with a standard deviation of 0.1034 meters so our measurements were precise (see Table 4). While most our trials were within 10% error of our calculations, trials 2 and 4 had relative errors of 12.92% and 10.81% error respectively (Table 4). The higher relative error observed in the data can be attributed to the less than ideal conditions in which the experiment was conducted. External environmental factors such as vibrations of the table on which the gun was placed caused by the presence and activity of other people in the room, could have impacted the launch. To reduce this impact as much as possible, a repeat of this experiment could have the gun on an isolated platform, such that vibrations or similar environmental disturbances cannot affect the gun launch.

In contrast to the inclined launch at 40°, our calculations and subsequent trials for the inclined launch at 55° were much closer. We calculated the horizontal distance the gun would travel to be 2.580 meters (Table 5). The average distance of our trials at 55° was 2.653 meters with a standard deviation of 0.1001 meters (Table 6). All of our measurements were within 10% error, so not only were our measurements precise, they were also accurate. These trials were conducted near the end of class time when less people were around, so it's possible there was less environmental interference on our launches.