Lab Report 6: Newton's Second Law

PHY121

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Professor R. Lathrop — Professor T. Zito

Abereni Opuiyo

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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

According to Newton's Second Law, *force* is equal to *mass* multiplied by *acceleration.*

$$F = ma$$

To increase the force of an object, either its mass or acceleration must increase. Since acceleration is inversely proportional to mass, increasing an object's mass decreases its acceleration and vice versa. In this lab, we varied the net force acting to accelerate a system, by shifting the distribution of mass within that system towards the hanging mass and keeping the total mass of the system constant. The only force acting vertically on the hanging mass is gravity, so by increasing its mass, its force will also increase.

Friction is the force keeping the glider in place. More specifically, when objects are at rest, *static friction* acts on the object. Static friction is proportional to an object's *normal force*, the opposing contact force to gravity as described by Newton's third law which states that every force has an equal and opposite force acting against it. Reducing an object's contact with a surface reduces the force of friction. The air track reduces the force of friction acting on the glider by blowing air against it. This allows the glider to move, as the force of the hanging mass falling is applied to it. The expected acceleration of the glider along the track can be calculated using the following equation:

$$a = \frac{F}{m}$$

$\boldsymbol{F}$: force of the hanging mass falling down.
$\boldsymbol{m}$: mass of the entire system

Acceleration is the change in velocity over time. By making sure the glider has an initial velocity as close to zero as possible and measuring the time the glider travelled between photogates, we can calculate the acceleration of the glider using the following equation.

$$a = \frac{2\Delta x}{t^2}$$

Procedure

Setup

1. Added a 50 g mass to each side of glider.
2. Added 20 g in increments of 5 g to each side of the glider.
3. Using an electronic scale, measured and recorded mass of whole system including the **glider**, **riding masses**, **mass hanger**, and **string**.
4. Confirmed that **air supply** was connected to **glider** track and working.
5. Placed **glider** on track, with masses parallel to track and conducted a trial run.
6. Placed **photo gates** on track with 66 cm of space between them.
7. Determined exactly where **photo gates** started and stopped timing, by incrementally sliding glider to each gate and marking the position where the timers activated as *x1* and *x2* respectively.
8. Repeated step 7 four times until measurements were precise to the nearest millimeter.
9. Placed tape on **photo gates** to lock them in place.
10. Set **photo timer** mode to *PULSE*.

Data Collection

11. Placed one 5.0 g mass taken from the **glider** onto the **hanger**.
12. Recorded mass of **hanger** with added weight.
13. Brought **glider** to *x1* and held it in place.
14. Turned on **air supply**.
15. Waited three seconds before releasing **glider**.
16. Recorded time between **photo gate timers**.
17. Repeated steps 13-16 two more times.
18. Repeated steps 11-17 until 40 g of mass were on the **hanger**.

Calculations & Graphs

Force & Acceleration

$$F = ma \tag{1}$$

$$a = \frac{F}{m} \tag{2}$$

$\boldsymbol{F}$: Force of object
$\boldsymbol{m}$: mass of object
$\boldsymbol{a}$: acceleration of object

Sample Calculation

Force of hanging mass at 10 grams

Knowns:

$$m = \mathbf{.01\,kg}$$
$$a = \mathbf{9.8\,m/s^2}$$

Calculating Force of Hanging Mass:

$$\begin{aligned} F &= ma \\ &= (.01)(9.8) \\ F &= \boxed{0.098\,\mathrm{N}} \end{aligned}$$

Sample Calculation

Acceleration of glider when hanging mass at 10 grams

Knowns:

$$F = \mathbf{0.098\,N}$$
$$m = \mathbf{0.3409\,kg}$$

Calculating Expected Acceleration of Glider:

$$\begin{aligned} a &= \frac{F}{m} \\ &= \frac{0.098}{0.3409} \\ a &= \boxed{0.2874\,\mathrm{m/s^2}} \end{aligned}$$

Acceleration Between Two Points with Initial Velocity Close to Zero

$$a = \frac{2\Delta x}{t^2} \tag{3}$$

$\boldsymbol{\Delta x}$: Distance between photogates
$\boldsymbol{t}$: average time between photogates

Sample Calculation
Measured acceleration of glider with hanging mass at 10 grams

Knowns:

$$\Delta x = \mathbf{0.669\,m}$$
$$t = \mathbf{2.058\,s}$$

Calculating Measured Acceleration of Glider:

$$\begin{aligned} a &= \frac{2\Delta x}{t^2} \\ &= \frac{(2)(0.669)}{(2.058)^2} \\ a &= \boxed{0.3156\,\mathrm{m/s^2}} \end{aligned}$$

Average Value Formula

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

Sample Calculation
average time between photogates of glider with hanging mass at 10 grams

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

$$= \frac{2.043 + 2.067 + 2.067}{3}$$

$$\overline{a} = \boxed{2.059\,\mathrm{s}}$$

Standard Deviation Formula

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

$\mathbf{N}$: 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 of photogate times with hanging mass at 10 grams

$$\begin{aligned}\sigma &= \sqrt{\frac{(2.043 - \overline{a})^2 + ... + (2.067 - \overline{a})^2}{3}}\\ &= \sqrt{\frac{0.000384}{3}}\\ &= \boxed{0.01131\,\mathrm{s}}\end{aligned}$$

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
acceleration of glider on air track with hanging mass at 10 grams - measured vs calculations

$$\begin{aligned}RE &= \left|\frac{V_A - V_E}{V_E}\right| \text{ x } 100\%\\ &= \left|\frac{0.3156 - 0.2874}{0.2874}\right| \text{ x } 100\%\\ RE &= \boxed{9.80\%}\end{aligned}$$

Tables

Table 1: Known values

g (m/s^2)	x_1 (m)[!]	x_2 (m)[!]	Δx (m)	M (kg)[!!]
9.8	1.169	0.5	0.669	0.3409

[!] Positions of photogates 1 and 2
[!!] Mass of entire system

Table 2: Accelerating System of Mass M - New Measurements

Measurement #	1	2	3	4	5	6	7	8
m (g)[!]	0.01	0.015	0.02	0.025	0.03	0.035	0.04	0.045
F_{net} (N)	0.098	0.147	0.196	0.245	0.294	0.343	0.392	0.441
a(predicted) (m/s^2)	0.2874	0.4312	0.5749	0.7186	0.8623	1.0060	1.1498	1.2935
T_1 (s)	2.043	1.698	1.515	1.298	1.223	1.083	0.9914	0.9405
T_2 (s)	2.067	1.732	1.435	1.316	1.223	1.075	1.045	0.9811
T_3 (s)	2.067	1.739	1.491	1.298	1.207	1.143	1.037	1.008
T_{avg} (s)	2.059	1.723	1.48	1.304	1.217	1.1	1.024	0.9765
T_{std} (s)	0.01131	0.0179	0.03351	0.008485	0.007542	0.03034	0.0236	0.02774
a(measured) (m/s^2)	0.3156	0.4506	0.6108	0.7868	0.9033	1.105	1.276	1.403
Percent Error (%)	**9.80**	**4.51**	**6.25**	**9.49**	**4.75**	**9.84**	**10.98**	**8.47**

[!] Hanging mass only

Table 3: Accelerating System of Mass M - Old Measurements

Measurement #	1	2	3	4	5	6	7	8
m (g)[!]	0.01	0.015	0.02	0.025	0.03	0.035	0.04	0.045
F_{net} (N)	0.098	0.147	0.196	0.245	0.294	0.343	0.392	0.441
a(predicted) (m/s^2)	0.2874	0.4312	0.5749	0.7186	0.8623	1.0060	1.1498	1.2935
T_1 (s)	2.627	1.970	1.774	1.664	1.599	1.463	1.265	1.172
T_2 (s)	2.501	1.990	1.704	1.562	1.580	1.436	1.355	1.248
T_3 (s)	2.630	1.980	1.727	1.699	1.538	1.336	1.298	1.152
T_{avg} (s)	2.586	1.980	1.735	1.642	1.573	1.412	1.306	1.191
T_{std} (s)	0.06016	0.008124	0.02923	0.05805	0.02562	0.05441	0.03683	0.04161
a(measured) (m/s^2)	0.2000	0.3411	0.4442	0.4961	0.5408	0.6710	0.7838	0.9429
Percent Error (%)	**30.42**	**20.89**	**22.73**	**30.96**	**37.29**	**33.30**	**31.83**	**27.10**

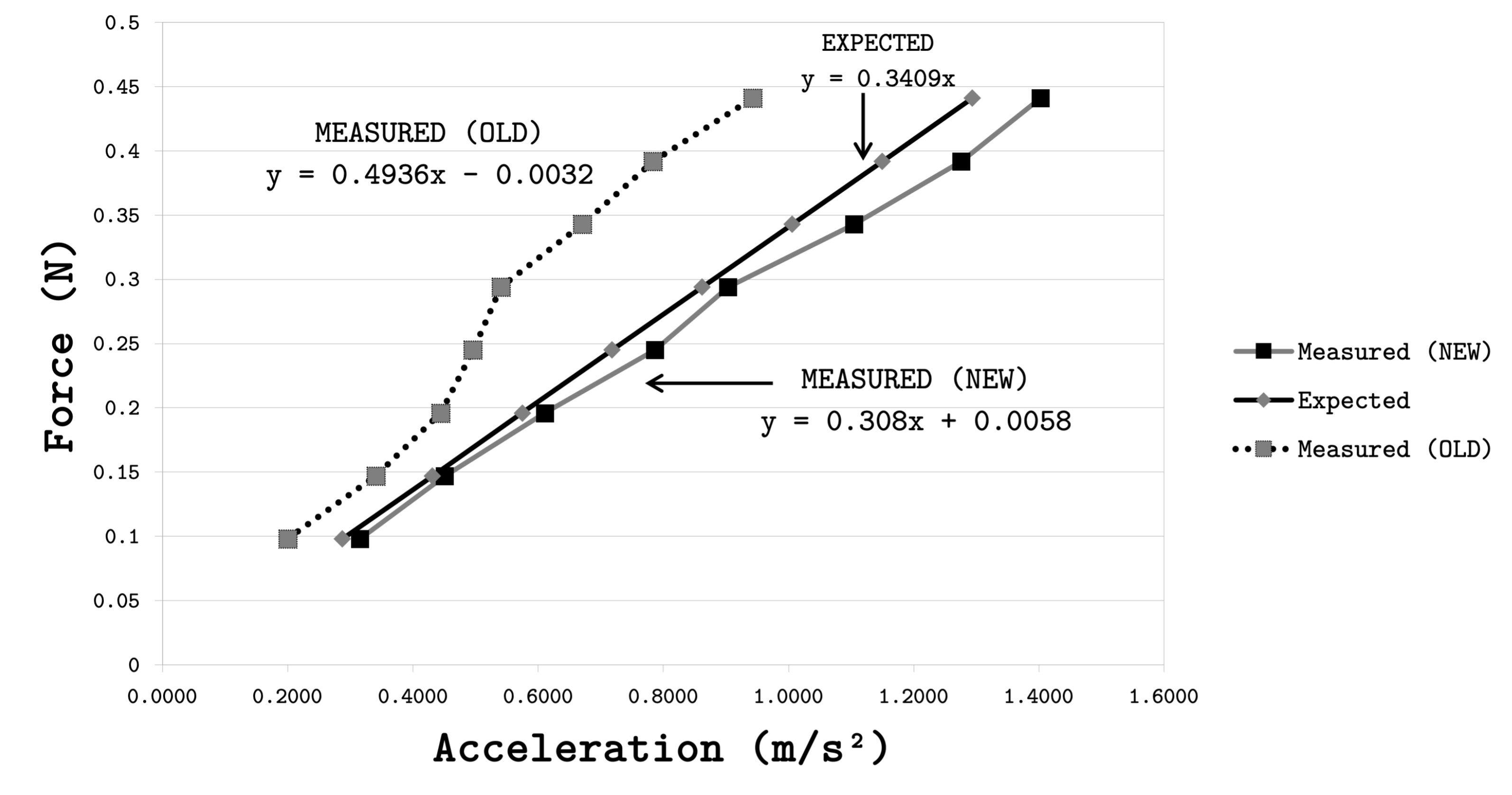
[!] Hanging mass only

Table 4: Measured Acceleration - Fractional Discrepancy of Slope (Mass)

	Slope (Mass)	**Fractional Discrepancy**
Expected	0.3409	
Measured (New)	0.3080	10.17%
Measured (Old)	0.4936	36.59%

Graphs

Figure 1: Force vs. Acceleration



Questions

1. **Calculate the fractional discrepancy between the slope of your graph and the mass of your system as measured on the balance. Report this as $\frac{\Delta M}{M}\%$.**

   The fractional discrepancy between the slope of our graph & the mass of the system as measured on the balance was 10.17%.

2. **Two possible sources of systematic error in this experiment are (a) giving the glider a head start, that is, starting up higher than x1 or accidentally giving it a push, and (b) if the air is not turned on high enough and there is friction. Discuss how each of these would affect your result (that is, the mass of the system as determined from the graph, and why. Accordingly, which do you think may have had a greater influence on your result?**

   Two possible sources of systematic error in this experiment are giving the slider a head start and not turning the air high enough to reduce friction on the air track. Giving the glider a head start would give it more time to accelerate, so our readings would be higher than they should be. Since mass is equal to $\frac{F}{a}$, where F is force and a is acceleration, an increased acceleration would result in a reduced mass. Not turning the air to a high enough setting to effectively reduce the force of friction and allow the glider to move, would result in the mass being higher than it should be since the measured acceleration would decrease. Based on our data, it's most likely the case that we gave the glider a head start during our trials, especially towards the end, as the mass after calculation is 10.17% lower than our measured value of 0.3409 kg.

3. **What is the y-intercept of your graph? Is this what you expected? If not, what did you expect and why? What is the significance of the y-intercept you actually obtained?**

   The y-intercept of our graph was 0.0058 N.

4. **During the experiment does the glider accelerate at a rate of $9.8 m/s^2$, slightly less, or significantly less along the frictionless track?**

   During the experiment, the glider accelerates at a rate significantly less than 9.80 m/s^2.

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 **??**). With a standard deviation of 7.2127x10^{-2} meters (Table **??**), our measurements were precise. We measured the height of the gun to be 0.276 meters (Table **??**) and, by applying equation **??**, determined the ball's time in the air to be 0.2373 seconds (Table **??**). Using equation **??**, we determined the initial velocity of the ball to be 5.187 m/s (Table **??**).

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 **??**. Applying equations **??** and **??**, we calculated the horizontal distance the ball would travel to be 2.704 meters (Table **??**). 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 **??**). 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 **??**). 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 **??**). The average distance of our trials at 55° was 2.653 meters with a standard deviation of 0.1001 meters (Table **??**). 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.