



Lab Report 6: Newton's Second Law

PHY121

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Table of Contents

Purpose	2
Theory	2
Procedure	3
Setup	3
Data Collection	3
Calculations & Graphs	4
Force & Acceleration	4
Sample Calculation	
<i>Force of hanging mass at 10 grams</i>	4
Sample Calculation	
<i>Acceleration of glider when hanging mass at 10 grams</i>	4
Acceleration Between Two Points with Initial Velocity Close to Zero . . .	5
Sample Calculation	
<i>Measured acceleration of glider with hanging mass at 10 grams</i> .	5
Average Value Formula	5
Sample Calculation	
<i>average time between photogates of glider with hanging mass at 10</i>	
<i>grams</i>	5
Standard Deviation Formula	6
Sample Calculation	
<i>std of photogate times with hanging mass at 10 grams</i>	6
Relative Error Formula	6
Sample Calculation	
<i>acceleration of glider on air track with hanging mass at 10 grams</i>	
- <i>measured vs calculations</i>	6
Tables	7
Graphs	9
Questions	10
Conclusion	11

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:

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

F : force of the hanging mass falling down.

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

$$F = ma \quad (1)$$

$$a = \frac{F}{m} \quad (2)$$

F : Force of object

m : mass of object

a : acceleration of object

Sample Calculation

Force of hanging mass at 10 grams

Knowns:

$$m = .01 \text{ kg}$$

$$a = 9.8 \text{ m/s}^2$$

Calculating Force of Hanging Mass:

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

Sample Calculation

Acceleration of glider when hanging mass at 10 grams

Knowns:

$$F = 0.098 \text{ N}$$

$$m = 0.3409 \text{ kg}$$

Calculating Expected Acceleration of Glider:

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

Acceleration Between Two Points with Initial Velocity Close to Zero

$$a = \frac{2\Delta x}{t^2} \quad (3)$$

Δx : Distance between photogates

t : average time between photogates

Sample Calculation

Measured acceleration of glider with hanging mass at 10 grams

Knowns:

$$\Delta x = 0.669 \text{ m}$$

$$t = 2.058 \text{ s}$$

Calculating Measured Acceleration of Glider:

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

Average Value Formula

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

Sample Calculation

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

$$\begin{aligned} \bar{a} &= \frac{\text{sum of values}}{\text{total \# of values}} \\ &= \frac{2.043 + 2.067 + 2.067}{3} \\ \bar{a} &= \boxed{2.059 \text{ s}} \end{aligned}$$

Standard Deviation Formula

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

N : Total number of values

\bar{a} : Average value

x_i : Each value from the data set

SS : Sum of squares

Sample Calculation

std of photogate times with hanging mass at 10 grams

$$\begin{aligned}\sigma &= \sqrt{\frac{(2.043 - \bar{a})^2 + \dots + (2.067 - \bar{a})^2}{3}} \\ &= \sqrt{\frac{0.000384}{3}} \\ &= \boxed{0.01131 \text{ s}}\end{aligned}$$

Relative Error Formula

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

V_A : Actual value observed

V_E : Expected value

Sample Calculation

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

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

Tables

Table 1: Known values

$g \text{ (m/s}^2\text{)}$	$x_1 \text{ (m)}^!$	$x_2 \text{ (m)}^!$	$\Delta x \text{ (m)}$	$M \text{ (kg)}^{!!}$
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
$m \text{ (g)}^!$	0.01	0.015	0.02	0.025	0.03	0.035	0.04	0.045
$F_{\text{net}} \text{ (N)}$	0.098	0.147	0.196	0.245	0.294	0.343	0.392	0.441
$a(\text{predicted}) \text{ (m/s}^2\text{)}$	0.2874	0.4312	0.5749	0.7186	0.8623	1.0060	1.1498	1.2935
$T_1 \text{ (s)}$	2.043	1.698	1.515	1.298	1.223	1.083	0.9914	0.9405
$T_2 \text{ (s)}$	2.067	1.732	1.435	1.316	1.223	1.075	1.045	0.9811
$T_3 \text{ (s)}$	2.067	1.739	1.491	1.298	1.207	1.143	1.037	1.008
$T_{\text{avg}} \text{ (s)}$	2.059	1.723	1.48	1.304	1.217	1.1	1.024	0.9765
$T_{\text{std}} \text{ (s)}$	0.01131	0.0179	0.03351	0.008485	0.007542	0.03034	0.0236	0.02774
$a(\text{measured}) \text{ (m/s}^2\text{)}$	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

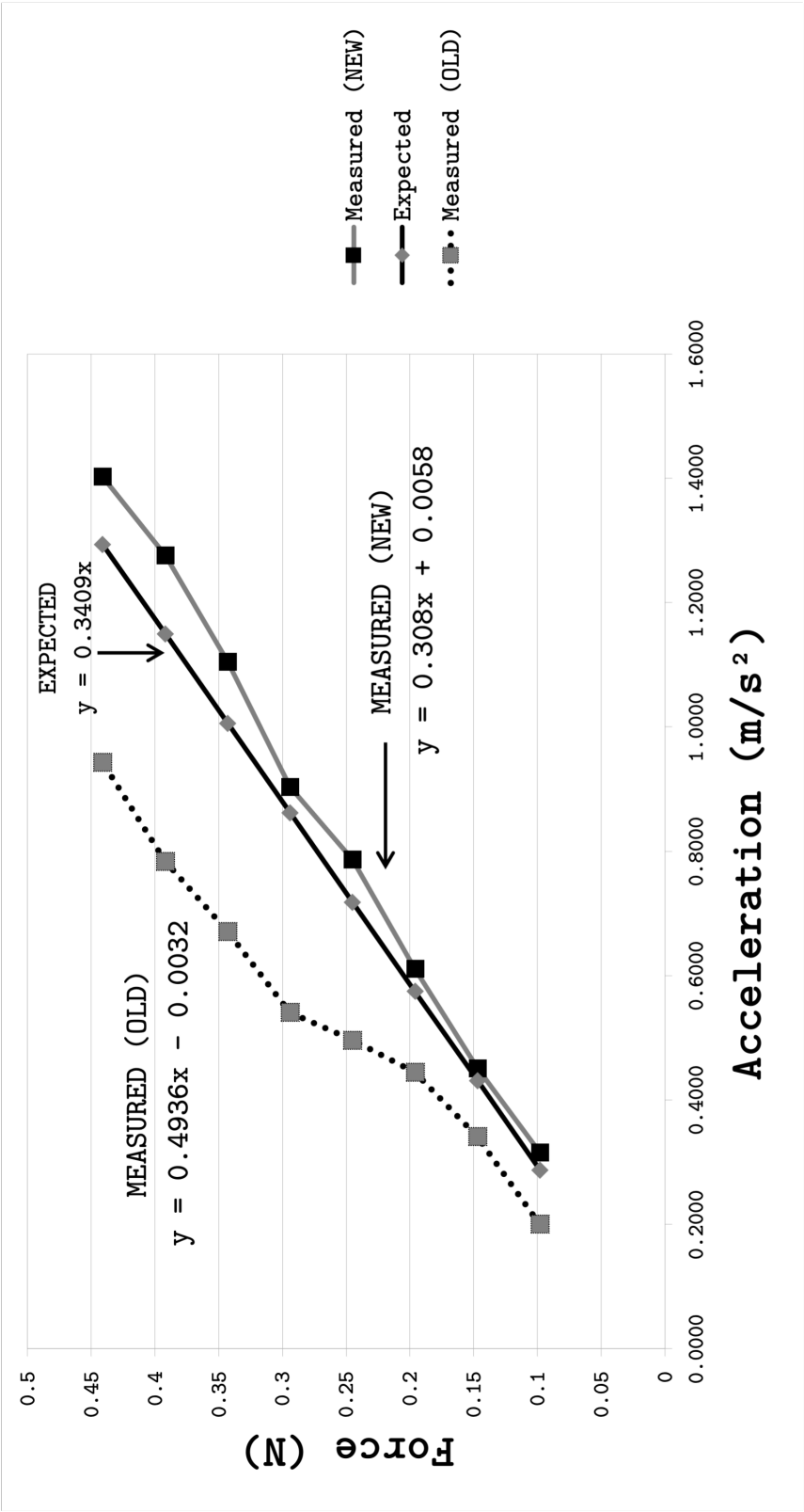
[†] Hanging mass only

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. We expected it to be close to zero so the results are within our expectations. The y-intercept represents the force needed to overcome static friction.

4. **During the experiment does the glider accelerate at a rate of 9.8m/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 observe the relationship between force and acceleration as described by Newton's Second Law. By systematically shifting the mass in our system, we varied the net force applied to it and increase the acceleration of the glider. The standard deviation of our trails were all less than 4%, meaning our measurements were precise (see Table 2). The percent error of our measured accelerations were relatively low to start, with increases towards the end of our trials, and our highest error percentage at 10.88% (see Table 2). A visual presentation of the gradual departure from expected values can be seen in Figure 1, where our slope (mass) and y-intercept (static friction) are higher than expected. The mass of the system was measured to be 0.3049 kg (Table 1), as reflected by the slope of our expected accelerations in Figure 1. The line created based off our measured accelerations resulted in a slope of 0.308 kg, which is 10.17% less than our measured value for the mass of the system (see Figure 1).

The source of these discrepancies is the manner in which our trials were conducted near the end. For all our trials, our measured accelerations were greater than our expected values (see Table 2). This is most likely due to giving the glider a head start. Due to a mistake in data collection prior to these trials in which we didn't wait for the air track to fully startup before releasing the glider (resulting in much lower accelerations and a much higher mass than expected), we had less time to collect new data with better methods (PLEASE see Table 3 and Figure 1). While the initial values of our new trials are much closer to expected, they deviate more as our time runs out. This explains why the slope of our measurements is lower than expected, as, based on Newton's Second Law, increasing acceleration produces a lower mass. Newton's Second Law also explains why the slope of our old trials are much higher than expected, since a lower acceleration would produce a greater mass (see Table 3). Were the experiment to be conducted again, I'd simply wait for the air track to startup before letting go of the glider so that friction doesn't impact our results.