Department of Biological, Chemical, and Physical Science
Illinois Institute of Technology
General Physics I: Mechanics (PHYS 123-02)

Newton's 2nd Law

Lab 3

Emily Pang, Coby Schencker (lab partner)
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TA: Mithila Mangedarage
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STATEMENT OF OBJECTIVE

The objective of this lab was to devise and conduct experiments that tested Newton's 2nd Law and proved that it is impossible to use a simple inclined plane to test whether acceleration was inversely proportional to the mass

THEORY

The basis of these experiments rest on determining whether Newton was correct in his 2nd Law of Motion:

$$\vec{F}_{\text{net}} = m\vec{a} \tag{1}$$

with units Newtons. When the system we are investigating is on a simple inclined plane, then it becomes important to define the xy plane. For our experiment, we declared the hypotenuse of the incline plane as parallel to the x direction and the y direction as perpendicular to the hypotenuse.Thus, we have the following equation for the forces in the x direction.

$$\begin{aligned} F_g \sin\theta &= m\vec{a} \\ \cancel{m} g \sin\theta &= \cancel{m} a \\ g\sin\theta &= a \end{aligned} \tag{2}$$

θ can be found by measuring either the angle or the two sides. However, for a we have to use a kinematic equation, which is as follows

$$\begin{aligned} v_f^2 &= \cancelto{0}{v_0^2} + 2a\Delta x \\ a &= \frac{v_f^2}{2\Delta x} \end{aligned} \tag{3}$$

In this equation, we can control Δx and measure v_f. The resulting equations combined is as follows

$$g\sin\theta = \frac{v_f^2}{2\Delta x} \tag{4}$$

Note that the mass cancels out in these equations, showing that mass cannot be shown to be proportional using a simple inclined plane. However, the devised experiment outlined in the procedure below will show it explicitly. For the first experiment, in order to prove whether Newton's 2nd Law was correct in acceleration being proportional to the effective force applied to the glider, we will measure θ, v_f, and Δx. If both sides are equal, then we show that Newton's 2nd Law holds for the aforementioned proportionality.

EQUIPMENT

- one PASCO Capstone software

- one glider
- one air track
- one dial caliper
- one scale
- one meter stick
- four 20 gram weights
- one photogate
- four wooden blocks
- one white flag

PROCEDURE

For the first experiment, we first recorded Δx, or from where the glider started to when it was recorded by the photogate. We then recorded three different masses of the glider: the glider itself and the glider with varying amounts of supplemental masses. Each time θ was changed, the distance the air track was lifted and the distance from the wooden blocks to the end of the air track was recorded as well, as we didn't have a protractor. Finally, for each variation in θ, the average velocity calculated by the photogate was recorded.

Note that since the mass was varied with each new θ, we can verify whether the mass changes the acceleration and matches what our theoretical findings showed us in Equation Set 2.

DATA

The data is as follows for the experiments:

	Opposite (m)	Adjacent (m)	Resulting θ
Angle 1	0.00790	1.370	0.330388059
Angle 2	0.0344	1.330	1.481605622
Angle 3	0.0580	1.220	2.721848358
Angle 4	0.0842	1.295	3.720095414

Table 1: Calculated Angles

The meter and dial caliper were used to measure the distances, while the photogate measured the final (average) velocity for each glider run. The scale was used to record the masses of each glider.

	m_1	m_2	m_3
Measured Mass (kg)	0.1968	0.2367	0.2769
	0.1967	0.2367	0.2769
	0.1967	0.2367	0.2768
Avg. Mass (kg)	0.196733333	0.2367	0.276866667

Table 2: Average Masses

	v_f of m_1 ($\frac{\text{m}}{\text{s}}$)	v_f of m_2 ($\frac{\text{m}}{\text{s}}$)	v_f of m_3 ($\frac{\text{m}}{\text{s}}$)	Avg Velocity ($\frac{\text{m}}{\text{s}}$)
$\theta = 0.330$	0.24	0.20	0.20	
	0.20	0.19	0.20	
	0.24	0.20	0.20	
Avg v_f ($\frac{\text{m}}{\text{s}}$)	0.226666667	0.19666667	0.20	0.207777779
$\theta = 1.48$	0.48	0.45	0.45	
	0.47	0.45	0.45	
	0.48	0.45	0.45	
Avg v_f ($\frac{\text{m}}{\text{s}}$)	0.476666667	0.45	0.45	0.458888889
$\theta = 2.72$	0.61	0.61	0.61	
	0.62	0.61	0.61	
	0.61	0.61	0.61	
Avg v_f ($\frac{\text{m}}{\text{s}}$)	0.613333333	0.61	0.61	0.611111111
$\theta = 3.72$	0.74	0.74	0.74	
	0.74	0.74	0.74	
	0.74	0.74	0.74	
Avg v_f ($\frac{\text{m}}{\text{s}}$)	0.74	0.74	0.74	0.74

Table 3: Velocities for varying angles and masses

ANALYSIS OF DATA

The two sides of Equation 4 are calculated in the table below. The volume of the cylinders was calculated using Formula 2. The density can then be calculated using the density formula illustrated earlier in Formula 1. Table 4 showcases these calculations and their results for the aluminum cylinders. The same calculations were done for the unknown material in Table 5.

Cylinder	1	2	3
Avg Volume (cm^3)	4.10	7.33	1.44
Avg Mass (g)	14.4	26.3	6.2
Avg Density ($\frac{\text{g}}{\text{cm}^3}$)	3.50	3.59	4.30

Table 4: Aluminum cylinder density calculations

The average density of all the aluminum cylinders was calculated to be 3.80 $\frac{\text{g}}{\text{cm}^3}$.

Angle	Eq 2 Calc	Eq 2 Result	Eq 3 Calc	Eq 3 Result	PE (%)
$\theta = 0.330$	$(9.8)\frac{\mathrm{m}}{\mathrm{s}}\sin(\theta)$	0.056510009	$\frac{(0.207777779\frac{\mathrm{m}}{\mathrm{s}})^2}{2(0.478)\mathrm{m}}$	0.045158583	error

Cylinder	1	2	3	4
Avg Volume (cm^3)	3.99	6.67	15.89	20.12
Avg Mass (g)	5.8	9.6	13.0	16.8
Avg Density ($\frac{\mathrm{g}}{\mathrm{cm}^3}$)	1.46	1.43	0.808	0.837

Table 5: Unknown material cylinder density calculations

The average density of all the unknown material cylinders was calculated to be 1.13 $\frac{\mathrm{g}}{\mathrm{cm}^3}$.

Weight	1	2	3	4
Avg Mass (kg)	0.2304	0.2103	0.1301	0.0700
Avg Distance (m)	0.175	0.159	0.0987	0.05
Avg Calculated Force (N)	2.268	2.061	1.275	0.6860
Avg Force (N)	2.26	2.06	1.26	0.67
Avg Calculated k ($\frac{\mathrm{N}}{\mathrm{m}}$)	12.9	13.0	12.9	13.72

Table 6: Masses and their calculated forces and k spring constants

The calculated force and k spring constant were obtained through Newton's 1st Law, shown in Formula 4, when the known acceleration is 0 $\frac{\mathrm{m}}{\mathrm{s}^2}$:

$$\begin{aligned}
\vec{F}_{\text{net}} &= 0 \\
F_{\text{spring}} - F_{\text{gravity}} &= 0 \\
F_{\text{spring}} &= F_{\text{gravity}} \\
F_{\text{spring}} &= mg \\
-kx &= mg \\
k &= \frac{-mg}{x}
\end{aligned} \tag{5}$$

Table 6 showcases the calculated values and their resemblance to the values PASCO showed.

After collecting data from the third table, it was realized that the two springs used in the experiment were different. Although the springs were not switched out from the three measurements of the same weight, they could be different from weight to weight. This discrepancy would be a problem because the experiment was determining whether Hooke was correct in his equation. If two different springs were used and it was assumed they were the same, then the inconsistency could be incorrectly labeled as evidence against Hooke's formula. The best solution to this problem was to take note of it. If there were inconsistencies between two weights in terms of force, this would be attributed to the springs' differences in spring constants.

DISCUSSION OF RESULTS

The results for the aluminum cylinders did not match with the documented density of aluminum (Nave, 2017)[1]. Polyurethane was the closest guess for the unknown material, which has a wide range of density values. Since the process for finding the density of the aluminum cylinders were incorrect, the densities for the unknown material were probably also incorrect.

For the results in examining Hooke's Law, the results for the calculated force based on the measurements were fairly close to the expected force from PASCO. The spring constants were also consistent across all weights except for the fourth one, which jumps significantly. It is likely that this was the different spring as the researchers completed the last spring experiment as further data after the first three, when the spring was taken off the hook (no pun intended).

FURTHER STUDY

There were many mistakes made in the conduction of this lab. Starting with the procedure itself, it would have been more beneficial to conduct the entire experiment twice: once with one spring, and once with a different spring. This would also include confirming the identities of the two springs to prevent mixing. While the problem was duly noted and acknowledged, this experiment's results cannot be used for further proof or disproof of Hooke's Law because whether or not the results matched Hooke's Law were entirely dependent on whether they matched in the first place.

Second, there was a gross inconsistency in the measurements with both cylinder measurements. While the two aluminum cylinders gathered around 3.50 $\frac{\text{g}}{\text{cm}^3}$, the third cylinder was completely off with 4.30 $\frac{\text{g}}{\text{cm}^3}$, not including the fact that the documented density of aluminum is around 2.7 $\frac{\text{g}}{\text{cm}^3}$ (Nave, 2017).

Future experiments would take more time to carefully measure all parts of the experiment, especially regarding the density measurements. The springs would also be documented as different, and researchers should be careful that they label the springs, even if the springs are said to be the same.

[1] Nave, C. R. (2017). Densities of Common Substances. Retrieved from http://hyperphysics.phy-astr.gsu.edu/hbase/Tables/density.html