Report for Experiment 4
Newton's Second Law

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TA: Isaac Newton

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Abstract

Acceleration is the coupling strength between the mass of a system and the force acting on it. This experiment will compare the acceleration of a frictionless system to the gravitational force on an object, thereby obtaining a value for gravity. One hanging mass of variable weight is attached to either one puck (Investigation 1) or two pucks (Investigation 2) on a frictionless air table. A spark timer gives a direct way to measure velocity and time of the system, calculating acceleration for three hanging weights. Plotting acceleration vs. the reduced mass of the hanging weights gives a value for gravity. Using one puck, the data within uncertainty is equal to the standard value of gravity. Using two pucks, the data was not equal to gravity within error, as rotational and frictional forces were not included in the linear model.

Introduction

This experiment will test Newton's second law and how it relates to different forces. The law can be summarized by the equation, F = ma. It is the point of this experiment to find an acceleration of an object based on a given force and mass of that object. This will effectively solve Newton's second law in the form a = F/m. In the first investigation we measured the displacement of an air hockey puck as it was pulled by three differing weights, using a spark timer. We calculated the velocity of the puck and graphed velocity vs. time for each weight combination, which gave the acceleration of the puck. To verify Newton's second law we graphed the accelerations vs. the reduced mass of the system and then compared the slope of that graph to the known value of gravity, 9.81 m/s^2. The second investigation used two pucks strapped together, thereby changing the reduced mass ratio, but otherwise worked the same way as Investigation 1 to calculate the known value of gravity.

Investigation 1

Setup & Procedure

The air table is set up with a pulley attached to a side. Two pucks are connected to a High Voltage (HV) source to create a circuit for the spark timer. Carbon paper is laid on the table with white paper laying on top of this carbon paper. The second puck is to the side but still on the paper so as not to interfere with the motion of the puck under observation. Weights of either 50, 100, or 200 grams is attached to the puck by the pulley and string. When the HV is on, the weight is dropped and the puck generates a spark every 30 ms. The spark will leave a black carbon dot from the carbon paper on the white paper, which can be measured for displacement. The spark timer is set to 30 Hz, so the time between each dot is 0.0333 s. Ten dots are counted and the displacement between them measured. Using this data, the velocity is calculated and used to graphically find the acceleration of the system.

Data & Analysis

Table 1 – Displacement and time data from a single puck with different weights hanging down. (a) Data from the 50g hanging weight; (b) Data from the 100g hanging weight; (c) Data from the 200g hanging weight.

hanging weight	50	g				
puck (g)	548					
displacement #	Δx (cm)	Δt (s)	t (s)	δΔx (cm)	v (cm/s)	δv (cm/s)
1	1.9	0.0333	0.033	0.3	28.528	4.504
2	2	0.0333	0.066	0.3	30.030	4.504
3	2.1	0.0333	0.1	0.3	31.531	4.504
4	2.2	0.0333	0.133	0.3	33.033	4.504
5	2.4	0.0333	0.166	0.3	36.036	4.504
6	2.5	0.0333	0.2	0.3	37.537	4.504
7	2.6	0.0333	0.233	0.3	39.039	4.504
8	2.8	0.0333	0.266	0.3	42.042	4.504
9	2.9	0.0333	0.3	0.3	43.543	4.504

hanging weight	100	g				
puck (g)	548					
displacement #	Δx (cm)	Δt (s)	t (s)	δΔx (cm)	v (cm/s)	δv (cm/s)
1	2.3	0.0333	0.033	0.3	34.534	4.504
2	2.5	0.0333	0.066	0.3	37.537	4.504
3	2.8	0.0333	0.1	0.3	42.042	4.504
4	3.1	0.0333	0.133	0.3	46.546	4.504
5	3.5	0.0333	0.166	0.3	52.552	4.504
6	3.6	0.0333	0.2	0.3	54.054	4.504
7	3.8	0.0333	0.233	0.3	57.057	4.504
8	4.2	0.0333	0.266	0.3	63.063	4.504
9	4.5	0.0333	0.3	0.3	67.567	4.504

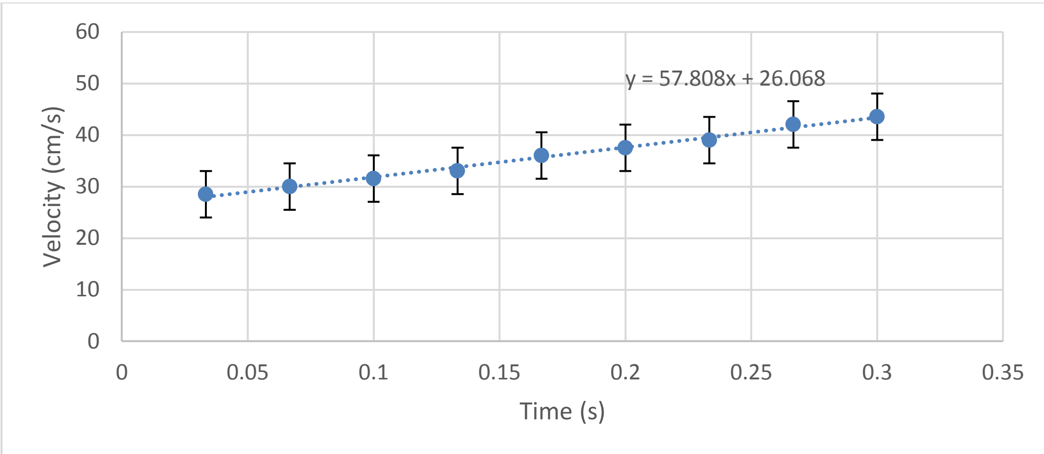
hanging weight	200	g				
puck (g)	548					
displacement #	Δx (cm)	Δt (s)	t (s)	δΔx (cm)	v (cm/s)	δv (cm/s)
1	2.1	0.0333	0.033	0.3	31.531	4.504
2	2.7	0.0333	0.066	0.3	40.540	4.504
3	3.2	0.0333	0.1	0.3	48.048	4.504
4	3.5	0.0333	0.133	0.3	52.552	4.504
5	4	0.0333	0.166	0.3	60.060	4.504
6	4.4	0.0333	0.2	0.3	66.066	4.504
7	5	0.0333	0.233	0.3	75.075	4.504
8	5.6	0.0333	0.266	0.3	84.084	4.504
9	5.9	0.0333	0.3	0.3	88.588	4.504

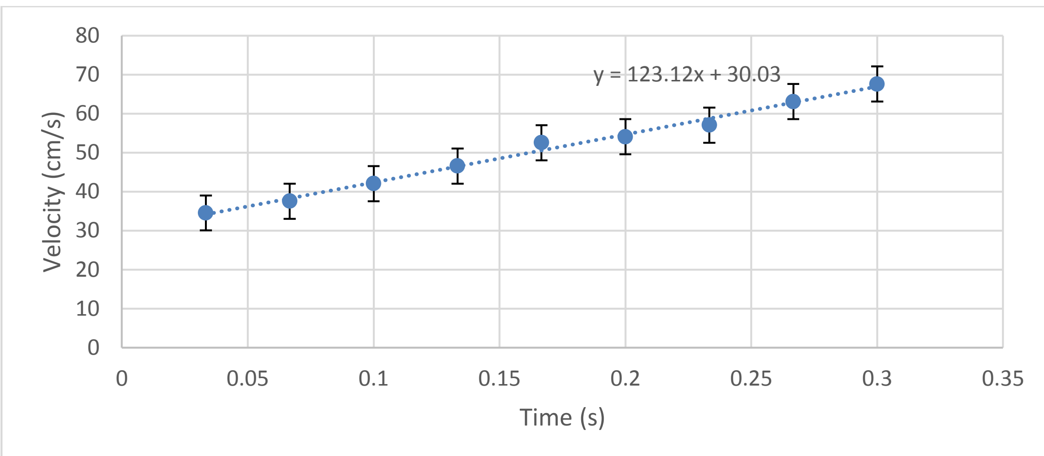
On the paper, each trail of dots was labeled for the specific weight used on the pulley. Our TA helped pick a starting dot, and the dots were numbered 1-10. We measured the displacement between two consecutive dots and labeled it Δx. For example, for displacement #1, we measured the distance between dots 1 and 3. For displacement #2 we measured the distance between dots 2 and 4, etc. The next column in the data, Δt (s), is the time between each carbon dot. The column after that is the total time elapsed from the first dot. The uncertainty of the displacement was determined by the difficulty to accurately measure the middle of the dot, the size of the dot, and the fact that the ruler could not touch the paper directly. The relative uncertainty of the time measurement has been pre-determined to be 0.1%. This is effectively negligible in comparison to the uncertainty of the physical measurements.

The velocity of the puck was calculated using the equation $v = \Delta x/(2\Delta t)$. The uncertainty to the velocity was calculated in Eq. (1),

$$\delta v = \frac{\delta \Delta x}{\Delta x} \times v \qquad (1)$$

From this, we created a graph of velocity vs. time for each weight, seen in Fig. (1). Error bars and an equation of the trend line were added. We imputed the data into the IPL error calculator and found an uncertainty of the slope of 17.4 cm/s^2 for each graph.





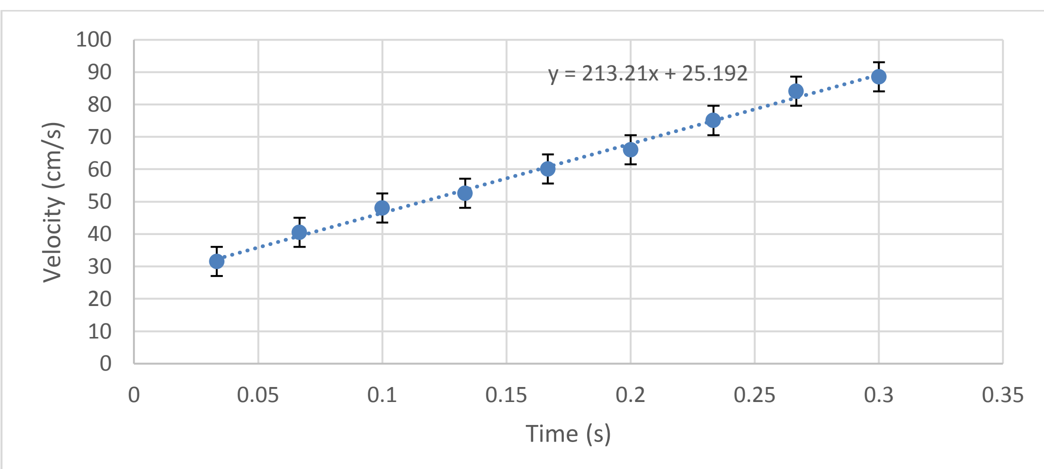


Figure 1 – Acceleration from pucks using different weights. (a) Puck acceleration from hanging 50g weight; (b) Puck acceleration from hanging 100g weight; (c) Puck acceleration from hanging 200g weight.

The slope of each graph is the acceleration of the puck. Newton's second law states that the sum of all forces equals mass times acceleration. Since gravity acting on the weight is the only force acting on the puck (as long as friction is negligent), then Newton's law can be written as

$$m_w g = (m_p + m_w)a, \tag{2}$$

where m_p is the mass of the puck, m_w is the mass of the weight, a is the acceleration, and g is gravity. If acceleration is graphed against $m_w/(m_p+m_w)$, then the slope of the line will be equal to the acceleration of gravity. This is done in Fig. (2).

Table 2 – Reduced mass and acceleration data.

Weight added (g)	Reduced mass $m_w/(m_p+m_w)$	a (cm/s^2)	δa (cm/s^2)
50	0.154	57.8	17.4
100	0.214	123.1	17.4
200	0.313	213.2	17.4

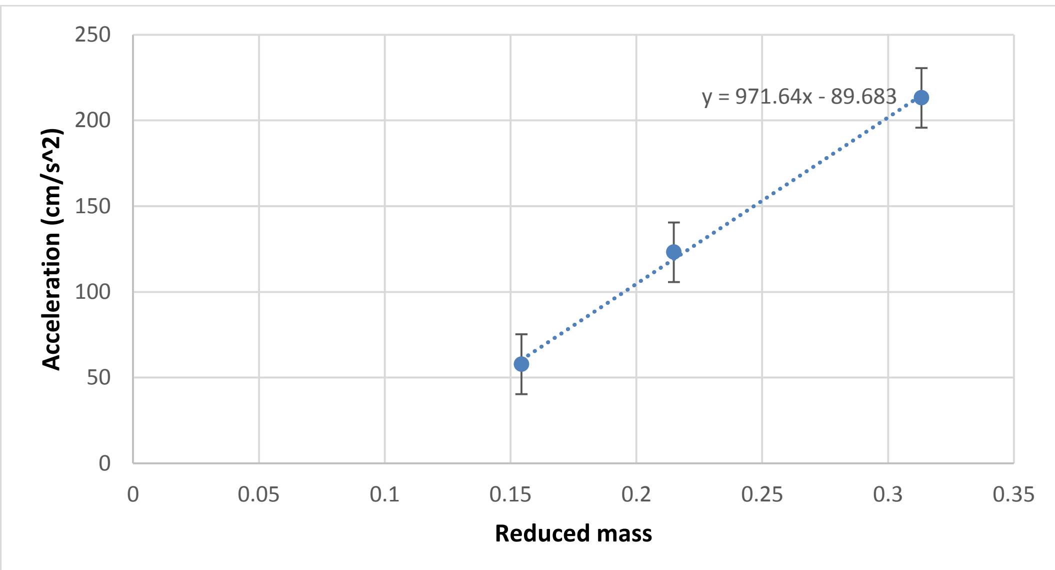


Figure 2 – Average gravitational acceleration of the three trials.

The slope of our graph is 971.64 cm/s^2. We used the IPL calculator to get the uncertainty of our calculated gravity, 153.36 cm/s^2. This means our value of gravity 971.64 cm ±153.36 cm is equal to 9.81m/s^2, so Newton's second law is verified.

Investigation 2

Setup & Procedure

We used the same set up as Investigation 1, but instead of one puck we used both pucks Velcroed together. All setup, procedures, equations, and graphs were the same as before.

Table 3 – Displacement and time data from two pucks with different weights hanging down. (a) Data from the 50g hanging weight; (b) Data from the 100g hanging weight; (c) Data from the 200g hanging weight.

hanging weight	50	g				
puck (g)	1096					
displacement #	Δx (cm)	Δt (s)	t (s)	$\delta\Delta x$ (cm)	v (cm/s)	δv (cm/s)
1	2	0.0333	0.033	0.3	30.030	4.504
2	2.1	0.0333	0.066	0.3	31.531	4.504
3	2.2	0.0333	0.1	0.3	33.033	4.504
4	2.3	0.0333	0.133	0.3	34.534	4.504
5	2.4	0.0333	0.166	0.3	36.036	4.504
6	2.5	0.0333	0.2	0.3	37.537	4.504
7	2.4	0.0333	0.233	0.3	36.036	4.504
8	2.5	0.0333	0.266	0.3	37.537	4.504
9	2.7	0.0333	0.3	0.3	40.540	4.504

hanging weight	100	g				
puck (g)	1096					
displacement #	Δx (cm)	Δt (s)	t (s)	$\delta\Delta x$ (cm)	v (cm/s)	δv (cm/s)
1	1.5	0.0333	0.033	0.3	22.522	4.504
2	1.7	0.0333	0.066	0.3	25.525	4.504
3	1.8	0.0333	0.1	0.3	27.027	4.504
4	2.1	0.0333	0.133	0.3	31.531	4.504
5	2.2	0.0333	0.166	0.3	33.033	4.504
6	2.4	0.0333	0.2	0.3	36.036	4.504
7	2.6	0.0333	0.233	0.3	39.039	4.504
8	2.6	0.0333	0.266	0.3	39.039	4.504
9	2.7	0.0333	0.3	0.3	40.540	4.504

hanging weight	200	g				
puck (g)	1096					
displacement #	Δx (cm)	Δt (s)	t (s)	$\delta\Delta x$ (cm)	v (cm/s)	δv (cm/s)
1	3.6	0.0333	0.033	0.3	54.054	4.504
2	3.7	0.0333	0.066	0.3	55.555	4.504
3	4	0.0333	0.1	0.3	60.060	4.504
4	4.2	0.0333	0.133	0.3	63.063	4.504
5	4.4	0.0333	0.166	0.3	66.066	4.504
6	4.7	0.0333	0.2	0.3	70.570	4.504
7	4.8	0.0333	0.233	0.3	72.072	4.504
8	5.1	0.0333	0.266	0.3	76.576	4.504
9	5.3	0.0333	0.3	0.3	79.579	4.504

We use the same equations for calculation of velocity and uncertainty as Investigation 1. Velocity vs. time was graphed for each of the three weights used, as seen in Fig. (3).

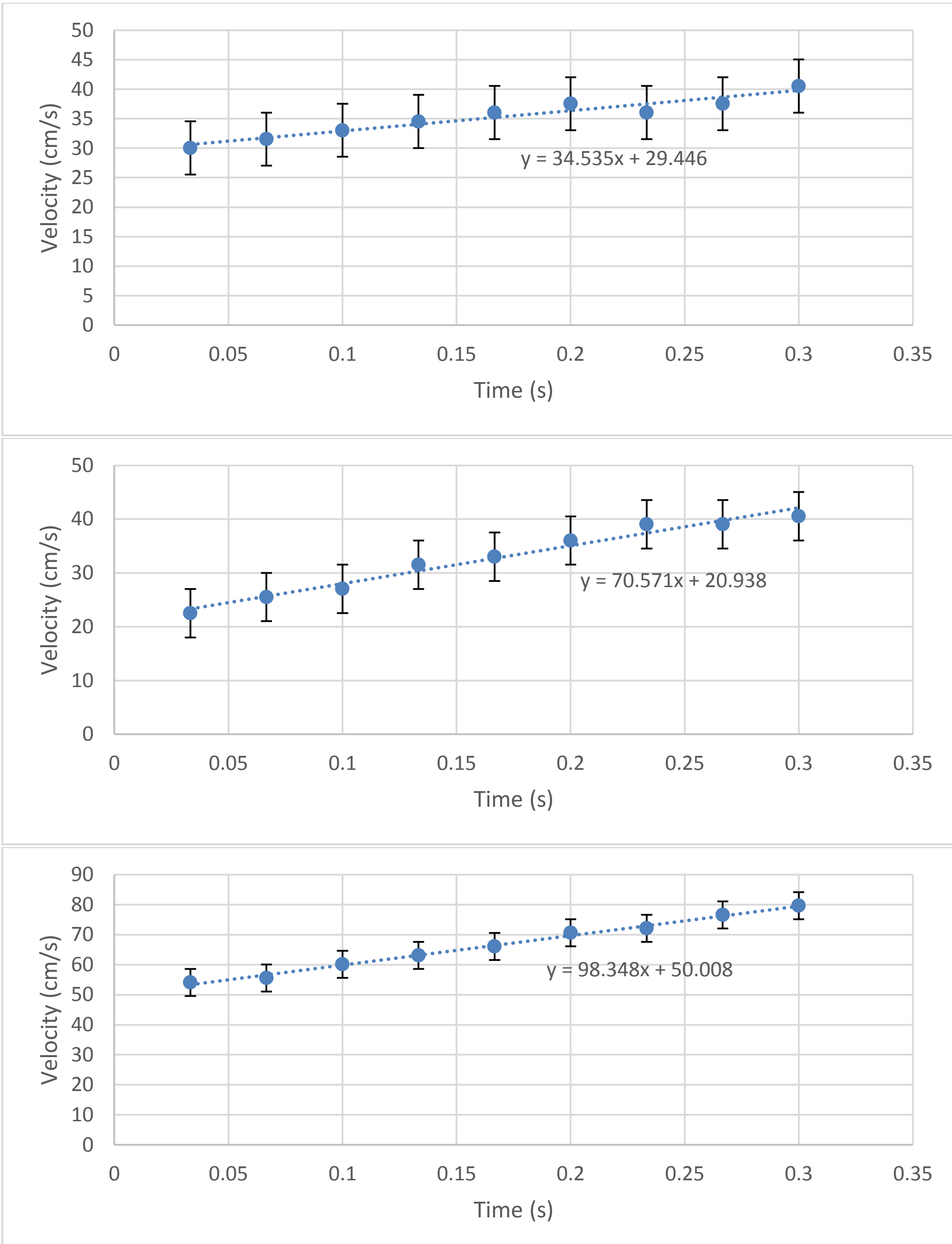


Figure 3 – Acceleration from pucks using different weights. (a) Puck acceleration from hanging 50g weight; (b) Puck acceleration from hanging 100g weight; (c) Puck acceleration from hanging 200g weight.

Since the uncertainty of velocity did not change at all, the uncertainty for each slope is still 17.4 cm/s^2. The acceleration of the pucks was again graphed against $m_w/(m_p+m_w)$ and error bars and an equation of the trend line were added.

Table 4 – Reduced mass and acceleration data for the double puck configuration.

Weight added (g)	Reduced mass $m_w/(m_p+m_w)$	a (cm/s^2)	δa (cm/s^2)
50	0.084	34.5	17.4
100	0.120	70.6	17.4
200	0.186	98.3	17.4

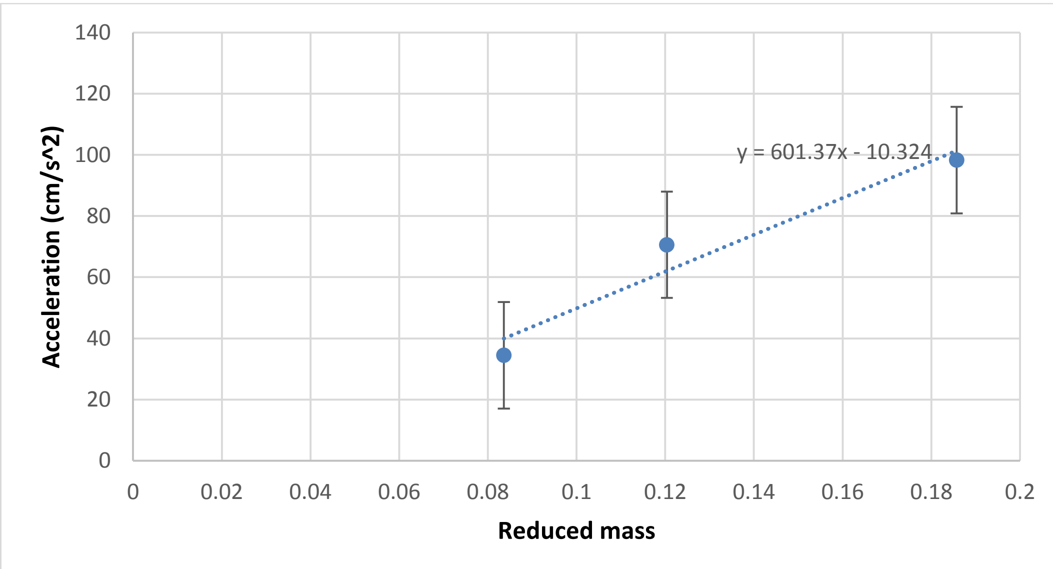


Figure 4 – Average gravitational acceleration of the three trials using two pucks.

Since uncertainties did not change, the uncertainty to Fig. (4) is again 153.36 cm/s^2. Our graph shows that our value for gravity of 601.37 ± 153.36 cm/s^2 is not equal to 9.81 m/s^2. There are many reasons why our value is not equal. It could be off because of the pucks turned while they were pulled down the table, which would change some of the linear force into rotational force and thus reduce acceleration. Also, the pucks weren't secured very well with the string and Velcro tied to it, so that one puck always lurched forward instead of both pucks traveling together smoothly. This would greatly affect the spacing of the spark data points on the table. There may have also been enough friction on the string against the pulley to affect the acceleration of the system.

Conclusion

In our first investigation we measured gravity as 971.64 ± 153.36 cm/s^2, which is equal the given value of 9.81m/s^2. But in our second investigation our gravity of 601.37 ± 153.36 cm/s^2 is not equal to 9.81 m/s^2. Extra forces that we didn't account for, or rotational effects, could have decreased the acceleration of the pucks. Newton's second law tells us no matter the amount of weight our gravity should still equal 9.81m/s^2, but that was not the case in our second investigation. A different method of tying and Velcroing the two pucks together might alleviate the rotational effects if the experiment was performed over again.

Questions

1. In each investigation, you measure mass and acceleration. Which measurement has the greater percent error? Don't just say yes or no. Be quantitative in your answer.

   The answer to Question 1 goes here, including all relevant calculations.

2. Assume that the spark timer error is 1%. Can it be neglected compared to the error in x? Explain!

   The answer to Question 2 goes here, including all relevant calculations.

3. What is the acceleration of the system if the hanging mass is doubled and the puck's mass is doubled?

   The answer to Question 3 goes here, including all relevant calculations.

4. What is the acceleration if the hanging mass is doubled and the puck's mass is halved?

   The answer to Question 4 goes here, including all relevant calculations.

Acknowledgements

This experiment would not have been possible without the help of my TA, Sir Isaac Newton, who developed these physical principles in the first place. I'd also like to thank my lab partner, Maxwell. A special thank you goes to Andrew Taylor for his valuable help in understanding how to calculate uncertainty for both velocity and acceleration.

References

[1] H.Young and R.Freedman, University Physics, 13th edition, Pearson Education.
[2] O.Batishchev and A.Hyde, Introductory Physics Laboratory, pp 31-36, Hayden-McNeil, 2015.

Appendix A

Extra data from Pasco Capstone for Investigation 1:

x (m)	t (s)
1.302	2.8
1.28	2.85
1.255	2.9
1.23	2.95
1.206	3

1.181	3.05
1.157	3.1
1.134	3.15
1.111	3.2
1.088	3.25
1.065	3.3
1.042	3.35
1.02	3.4
0.999	3.45
0.977	3.5
0.955	3.55
0.935	3.6
0.914	3.65
0.894	3.7
0.874	3.75
0.854	3.8
0.834	3.85
0.815	3.9
0.796	3.95
0.777	4
0.759	4.05
0.741	4.1
0.724	4.15
0.707	4.2
0.692	4.25
0.676	4.3
0.661	4.35
0.646	4.4
0.632	4.45
0.619	4.5
0.606	4.55
0.594	4.6
0.583	4.65
0.573	4.7
0.563	4.75
0.551	4.8
0.545	4.85
0.537	4.9
0.529	4.95
0.523	5
0.514	5.05
0.508	5.1
0.503	5.15

0.502	5.2

Appendix B

Extra data from Pasco Capstone for Investigation 2:

0.496	**5.25**
0.493	5.3
0.494	5.35
0.493	5.4
0.49	5.45
0.49	5.5
0.491	5.55
0.493	5.6
0.495	5.65
0.497	5.7
0.503	5.75
0.507	5.8
0.512	5.85
0.515	5.9
0.52	5.95
0.529	6
0.535	6.05
0.542	6.1
0.55	6.15
0.558	6.2
0.567	6.25
0.576	6.3
0.586	6.35
0.596	6.4
0.607	6.45
0.618	6.5
0.63	6.55
0.642	6.6
0.655	6.65
0.668	6.7
0.681	6.75
0.695	6.8
0.709	6.85
0.724	6.9
0.739	6.95
0.754	7
0.77	7.05
0.785	7.1