PUTTING IN THE WORK: PHYSICS SPRING ENERGY LAB

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Introduction

Purpose:

- The purpose of this lab was to design an experiment which analyzes the conservation of energy in a spring based system.

Researchable Question:

- How does increasing the length that a rubber band is stretched from its the midpoint when held by two posts affect the distance a mass travels when launched by said rubber band until it stops?

Hypothesis:

- If the length that a rubber band is stretched back to launch an object is increased, then the distance that the object travels from the launch point until stopping would increase, where $d \propto (\Delta x)^2$.

Methodology

Diagrams:

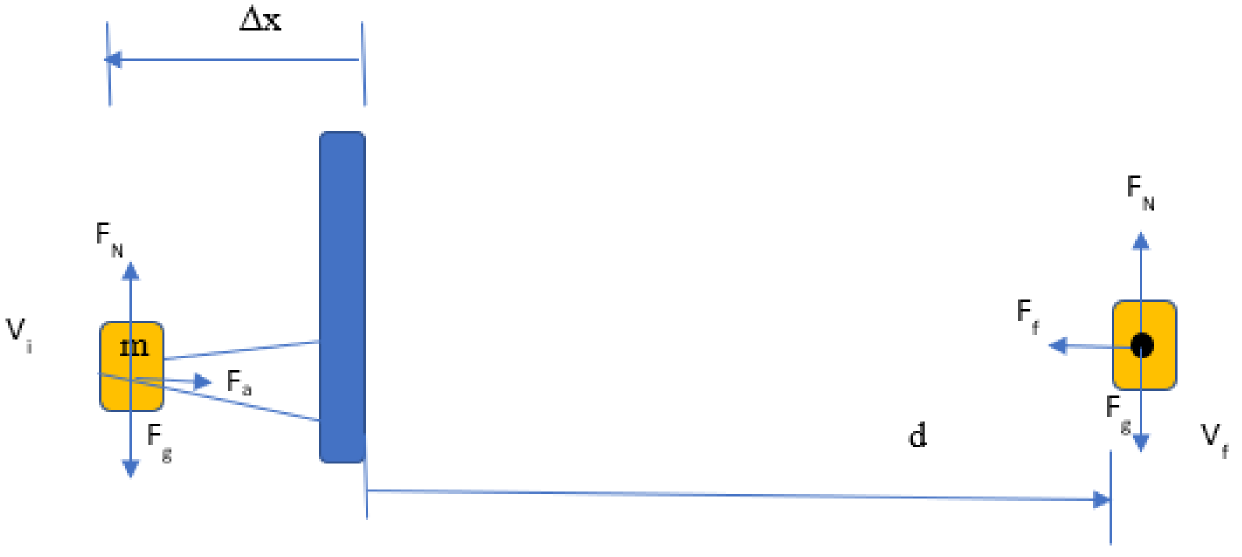

Figure 1: Diagram of the experiment seen from a side view

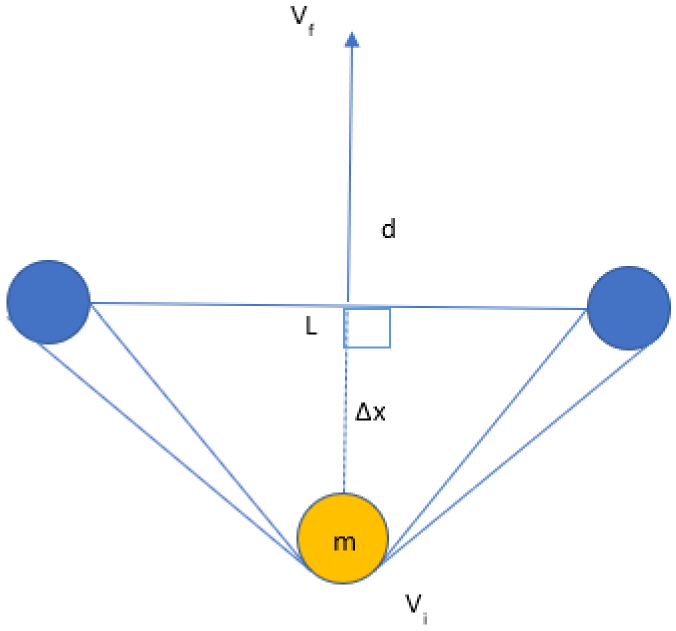

Figure 2: Diagram of the experiment seen from a top view

Methodology

Procedure for creating the apparatus:

- A rubber band was looped with two other rubber bands on both ends, and that elongated rubber band was looped onto the front legs of a chair underneath the seat
- The middle of the band was marked, and the chair was placed so the middle was directly above a tile crack
- The IV settings, the length the middle of the band was pulled back, were measured with a meter stick and marked with tape so that the middle would be pulled straight back in line with the tile crack and the position of the chair was marked with tape
- See Appendix A for experimentation done to find the spring constant

Methodology

Procedure for experimentation:

- Michelle sat on the chair so it would not move.
- Matt pulled the rubber band back to the first marked setting, from the middle of the band without twisting it, placed the object in front of the band with the band touching the object just above the ground, held the top front of the object, and let it go without pushing or pulling it.
- Josh marked the place where the object stopped with tape.
- After testing the same setting for 10 trials, the distances were measured using a tape measure and the marked meter increments.
- If the object did not follow the tile cracks (did not go straight upon launch), or rolled, the trial would be repeated.
- These steps were repeated for all the IV settings.

Methodology

Constants

$$m = 1.0010\ kg$$

$$L = 0.4045\ m$$

$$v_i = 0\frac{m}{s}$$

$$v_f = 0\frac{m}{s}$$

$$F_f = 0.219\ N\ (see\ Appendix\ B)$$

$$k = 43.55\frac{N}{M}\ (see\ Appendix\ A)$$

Equations

$$\sum E_i = \sum E_f$$

$$KE = \frac{1}{2}mv^2$$

$$PE_s = \frac{1}{2}k\Delta x^2$$

$$F = k\Delta x$$

$$D_T = \frac{(\frac{1}{2}k\Delta x^2 - \Delta x)}{F_f}\ \textit{(see Appendix C)}$$

Results

Summary Data Table:

	Δx	davg	STDEV	%RSD	dT	|%err|	TEi	TEf	% E Change
	(m)	(m)	(m)	of davg	(m)	of d	(J)	(J)	%
IV1	0.0800	0.3380	0.0403	11.920	0.2711	24.687	0.1394	0.0000	100.00
IV2	0.1000	0.4980	0.0354	7.102	0.5377	7.386	0.2178	0.0000	100.00
IV3	0.1400	1.0170	0.0524	5.152	1.3096	22.345	0.4268	0.0000	100.00
IV4	0.1700	2.0919	0.2116	10.117	2.0974	0.264	0.6293	0.0000	100.00
IV5	0.2550	3.9980	0.2258	5.648	5.3013	24.585	1.4159	0.0000	100.00
			Avg	7.988	Avg	15.853			

Figure 5: Summary data table showing IV settings (stretch length), average distance for each setting, %RSD, theoretical distance, percent error, total initial energy, total final energy, percent change of energy (see Appendix D for full table of raw data)

Results

Chart:

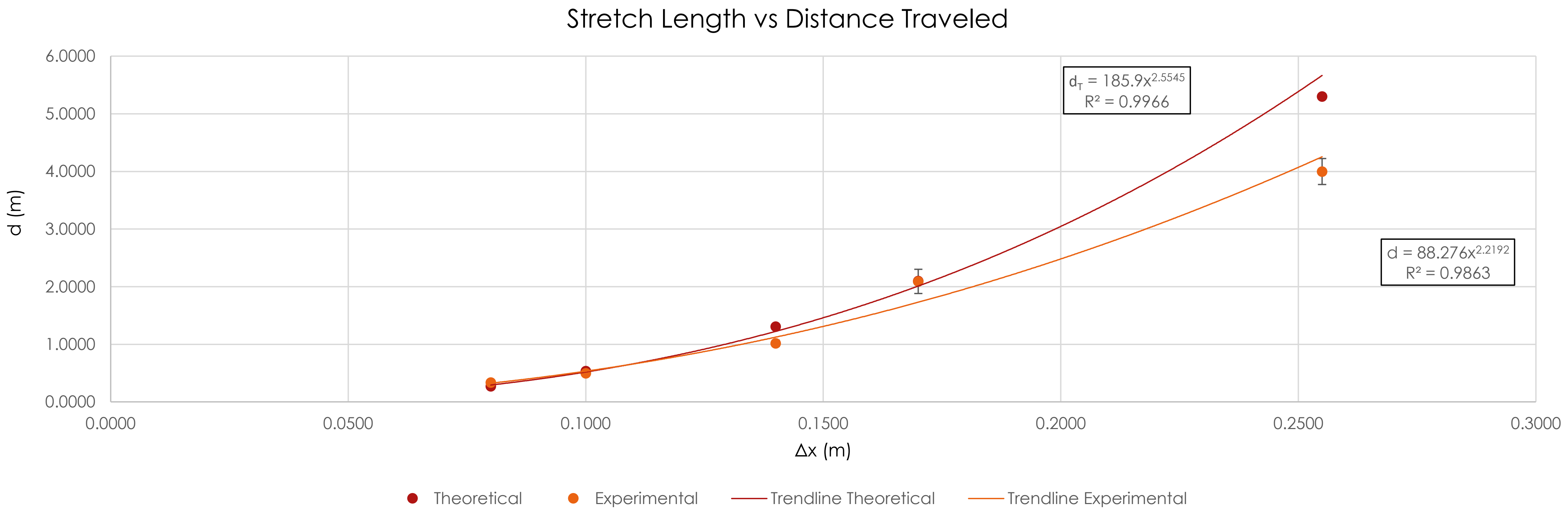

Figure 6: Graph of stretch length versus distance traveled before stopping with experimental and theoretical data points plotted, error bars are present on all experimental plotted points

Results

Photographs:

Figure 3: Michelle sits on the chair as Matt gets ready to launch the object

Figure 4: Matt places the object in front of the rubber band

Analysis

Discussion:

- The trend of the graph shows that as stretch length increased, so did distance traveled before stopping.
- The power of the experimental trendline, 2.2192, was close to the predicted power of 2. The relationship between stretch length and distance traveled is nonlinear, so distance traveled increased exponentially with an increase in stretch length.
- The experimental trendline does not increase as much as the theoretical trendline does with stretch length, meaning generally the theoretical stopping distances were greater than the experimental stopping distances, and there was a greater loss in energy as stretch length increased.
- The 100% change in energy in all settings shows that all the energy in the system was loss at the end.

Statistical Analysis:

- The average %RSD for the experimental data was 7.988% which means the data was moderately precise.
- The R^2 value for the experimental line was 0.9863 meaning the graph represents a strong mathematical model.
- The data was moderately accurate with an average 15.853% percent error, however the 0.1700 m setting was highly accurate with a 0.257% error and the 0.140 m and 0.0800 m had low accuracy with 22.339% and 24.700% errors respectively.

Conclusion

Sources of error:

- A major source of error was treating the spring constant as linear. It was nonlinear because when the band was pulled back, the force was exerted outwards at two vectors. A nonlinear k would affect theoretical calculations and make the theoretical R^2 value 1.
- Another error source was the negative y intercept of the spring constant graph, instead of at (0,0). Had this error been accounted for, it would affect the starting energy in the system and theoretical equation derivation.
- The theoretical calculations were generally greater than the experimental due to energy being lost in the system from sources of error like not accounting for static friction, rotational energy of the mass, the mass not moving in a completely straight line, and non smooth surfaces of the floor.
- Some of the experimental calculations were higher than the theoretical, possibly due to human error; the object could have been pushed when it was being launched.
- These sources of error could be taken into consideration in future iterations

Conclusion

Outcomes:

- The data supports the hypothesis because the distance that the object traveled increased with stretch length at a power of 2.2192 (close to the predicted power of 2).
- The distance traveled was nearly proportional to the square of the stretch length, similar to what was predicted.
- The experiment was moderately precise and accurate, so it could be improved.

Extensions:

- In the future, one could account for the nonlinear spring constant, or account for the negative y intercept of the spring constant graph when finding initial energy.
- Another possibility would be to create an apparatus that launches the mass to minimize human error

Appendix A

Spring constant:

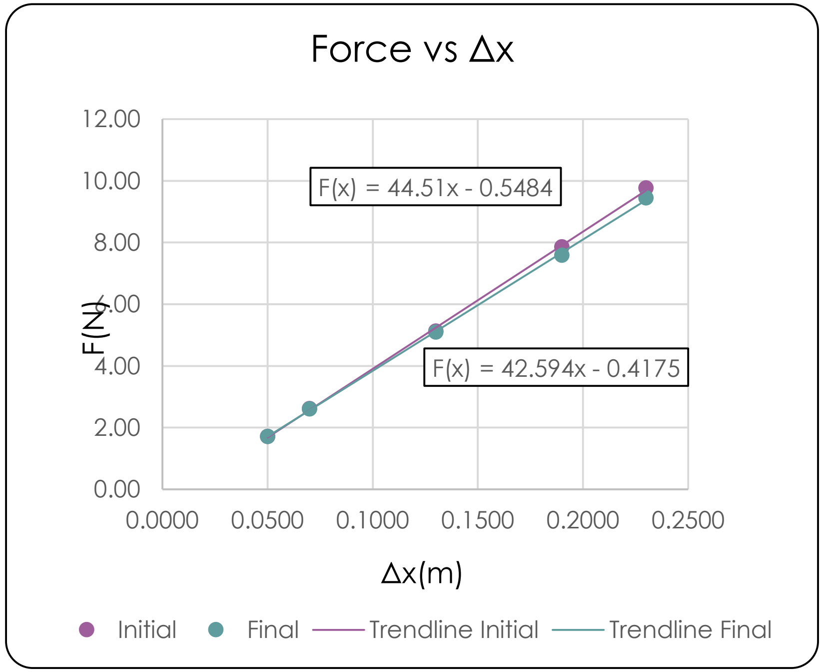

Figure 2A: Graph of stretch distance versus force initially and after testing, force was measured with logger pro

Δx (m)	F_i (N)	F_{end} (N)	k_i (N/m)	k_f (N/m)	k_{avg} (N/m)
0.0500	1.71	1.71	44.51	42.59	43.55
0.0700	2.61	2.60			
0.1300	5.13	5.10			
0.1900	7.86	7.59			
0.2300	9.77	9.45			

Figure 1A: Data table of the stretch lengths tested with a force probe before and after experimentation with the initial, final and average spring constants shown

- To find the spring constant (k), five stretch lengths were chosen and the forces that it took to pull the band to that length were measured before and after experimentation.
- The stretch lengths by force were graphed to find the slopes before and after, which are the k values because $k = F/\Delta x$.
- The average of the slopes (initially k was 44.51 N/m and after it was 42.59 N/m) was taken to find and average spring constant, which was used in the derivation for the theoretical distances. The average was 43.55 N/m.

Appendix B

Friction:

- Friction was calculated with a logger pro force probe
- The object was pulled across the floor (same surface as the surface used during experimentation) with an increasing force until the object started to move
- As it moved, it was pulled along with the constant force necessary to move it for 4 seconds
- The average of the force when it was being pulled with that constant force was taken (not including the peak of the data which was static friction) to find kinetic friction, used in the theoretical distance derivation
- The force of kinetic friction was 0.219 N. Normal force and μ were not found because the mass and surface did not change; the frictional force was directly used to derive the theoretical equation.

Appendix C

Derivation of theoretical distance equation:

$$\sum E_i \pm W = \sum E_f$$

$$PE_s - W_{F_f} = \text{KE}$$

$$\frac{1}{2}k\Delta x^2 - F_f\,(d + \Delta x) = \frac{1}{2}mv^2$$

$$\frac{1}{2}k\Delta x^2 = \frac{1}{2}m(0)^2 + F_f\,(d + \Delta x)$$

$$\frac{\frac{1}{2}k\Delta x^2}{F_f} = (d + \Delta x)$$

$$d_T = \frac{\frac{1}{2}k\Delta x^2 - \Delta x}{F_f} \rightarrow d_T = \frac{\frac{1}{2}(43.55)\Delta x^2 - \Delta x}{0.219}$$

Appendix D

Full raw data table:

	Δx	d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8	d_9	d_{10}	d_{avg}	STDEV	%RSD	d_T	|%err|	TE_i	TE_f	% E Change
	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	of d_{avg}	(m)	of d	(J)	(J)	%
IV1	0.0800	0.2850	0.3000	0.3200	0.3100	0.3350	0.3400	0.3500	0.3600	0.4300	0.3500	0.3380	0.0403	11.920	0.2711	24.687	0.1394	0.0000	100.00
IV2	0.1000	0.4850	0.4900	0.4900	0.4900	0.4900	0.4900	0.4650	0.4650	0.5300	0.5850	0.4980	0.0354	7.103	0.5377	7.386	0.2178	0.0000	100.00
IV3	0.1400	0.9300	0.9650	0.9550	1.0200	1.0300	1.0050	1.0500	1.0600	1.0750	1.0800	1.0170	0.0524	5.152	1.3096	22.345	0.4268	0.0000	100.00
IV4	0.1700	2.3500	2.0950	2.2100	1.6600	1.9100	2.0350	2.0400	2.0185	2.2500	2.3500	2.0919	0.2116	10.117	2.0974	0.264	0.6293	0.0000	100.00
IV5	0.2550	3.7050	3.7050	3.8400	3.8650	4.0100	4.0900	4.2250	4.2250	4.3600	3.9550	3.9980	0.2258	5.648	5.3013	24.585	1.4159	0.0000	100.00
													Avg	7.988	Avg	15.853			

Figure 3A: Table of all of the raw data collected with calculations