IB PHYSICS SL
INTERNAL ASSESSMENT

THEO LAGO

Research Question:

How does the diameter of a nylon thread affect its spring constant?

Introduction:

Nylon threads are used for various purposes, however musicians believe that the thread's role in music is one of its most important ones. The reason it was decided to investigate this topic is due to the fact that musicians are said to always have trouble tightening guitar/ukulele (or other string instruments) strings too much and it snapping, and it is believed that an ukulele is much easier to accidentally snap due to its thin diameter. The aim of this experiment is to find out how different diameters of strings affect their spring constant. This may be useful for many musicians to know when to be extra careful when tightening their strings since each musical instrument has its own strings, with varied materials, lengths and diameters.

Background Information:

Materials all have different spring constants, which is represented by Hooke's Law:

$$\mathbf{F = - kx}$$

F= Force (N)
k= Spring Constant (N/m)
x= extension (m)

The formula will be rearranged to **-k = F/x** so that we solve for spring constant, by inputting the extension and the force. We will use graphical methods of extension vs force and determine the gradient to give the spring constant. Then plot a graph of diameter vs spring constant. The original Hooke's law method experiment with a vertical coil and ruler can be seen on figure 1 below:[1]

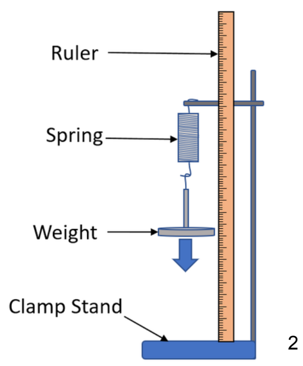


Figure 1 (Original hooke's law method)

[1] Utk.edu. (2020). Hooke's law. [online] Available at: http://labman.phys.utk.edu/phys221core/modules/m3/Hooke%27s%20law.html.
[2] Keystagewiki.com. (2019). *GCSE Physics Required Practical: Investigating Hooke's Law - Key Stage Wiki*. [online] Available at: https://keystagewiki.com/index.php/GCSE_Physics_Required_Practical:_Investigating_Hooke%27s_Law.

This method was not used due to the fact that since a nylon string was used this method led to larger uncertainties such as weight sway and inaccurate readings which were much more frequent. Finally due to convenience, all weights that should be negative (force pushing down) and spring constant or other value that would be negative being multiplied by gravity was converted into its positive value. This was done so the graphs would be easier to interpret since the y axis would be negative.

Hypothesis:

It is expected that as a consequence of the diameter of the strings increasing, their spring constant will increase as well, hence the hypothesis; The diameter of a thread (or a wire) is directly proportional to its spring constant. Additionally based on Hooke's law it can be expected that when multiple strings are placed in parallel, the total spring constant can be found by adding each individual string constant of each string.Thus it may be predicted that the diameter of multiple parallel strings is proportional to their total spring constant.

[3]To calculate the spring constant the equation below is used:

$$-k = F/x$$

F= Force (N)
k= Spring Constant (N/m)
x= extension (m)

Will be used. I will get a value of the force in kilograms then transfer it into Newtons using the equation below by multiplying it by the gravity on Earth:

$$300 \text{ kg} \times -9.81 \text{ N/kg} = -2943 \text{ N}$$

Then converting extension from centimetres, to metres (for example);

$$37.5\text{cm} \times 10^{-2} = 0.375\text{m}$$

Afterwards inputting the values into the equation;

$$2943\text{N}/0.375\text{m} = -7848\text{N/m}$$

Next converting value into three significant figures;

$$-7848 \text{ N/m} = -7850 \text{ N/m}$$

Therefore;

Positive k = 7850 N/m

[3] Utk.edu. (2020). Hooke's law. [online] Available at: http://labman.phys.utk.edu/phys221core/modules/m3/Hooke%27s%20law.html.

Finally comparing spring constant to diameter of the string:

Spring Constant (N/m)	Diameter (mm)
0	0
160.9	0.20
310.3	0.40
390.2	0.50
540.5	0.60
640.6	0.80
780.3	1.00

Figure 2 (theoretical data table)

And analysing the data, hence concluding that diameter is directly proportional to Spring Constant.

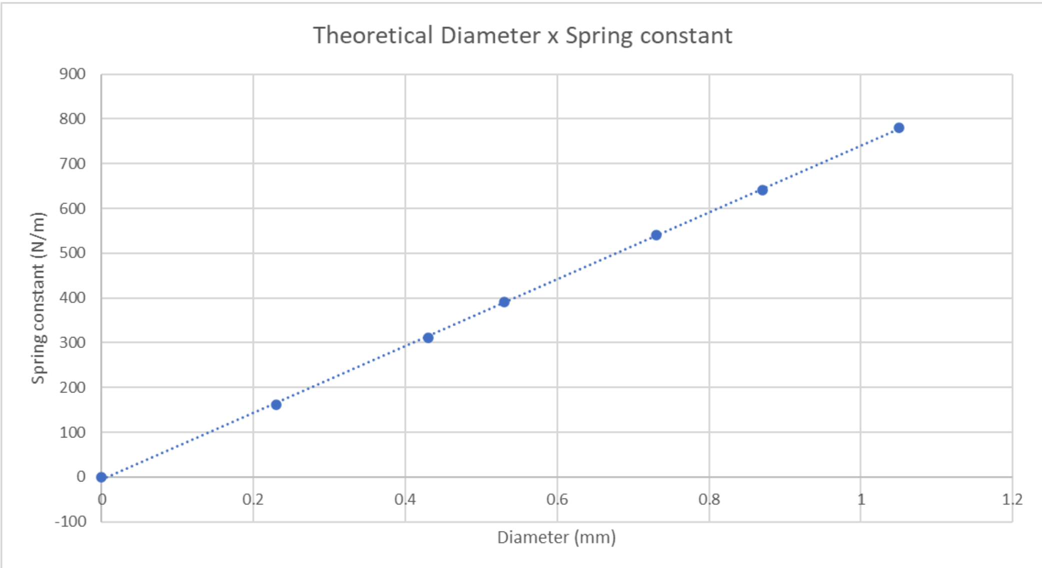


Figure 3 (theoretical data graph)

This is what a perfect correlation diameter x Spring constant graph would look like. This hypothesis was determined through research about hooke’s law and common sense.

NOTICE

(All data in hypothesis is theoretical)

Methodology:

-Independent Variable:

The independent variable of the experiment is the diameter of the six different strings. The diameters are: 0.23mm, 0.43mm,0.53,mm,0.73mm,0.87mm,1.05mm

-Dependent Variable:

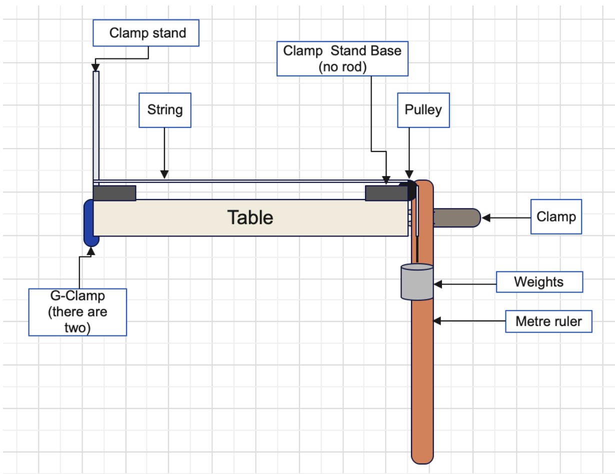
The dependent variable of this experiment is the Spring constant which I found the values by measuring the extension of the thread using the final and the original length and (changing the) force of each thread and using Hooke's law.

Controlled Variables	Possible impact on the experiment	Method to control the variable
Original length of the nylon thread	If thread lengths were not constant they would have different uncertainties	Measure string length with a metre ruler and have them all being 93cm.
Material of the nylon thread	If the material of the threads were different they would have very different Spring constants	Using only threads made from nylon. Provided by the same supplier
Temperature of room	Temperature can change the elasticity of the material	The experiment was all done in the same room always with the air conditioner on.
Metre ruler	Inaccuracies on the ruler would impact each measurement differently	Used the same metre ruler for all measurements
Same set and order of which masses were placed on the hanger	Would affect the extension therefore the spring constant	Masses were measured precisely with a 0.1g mass balance and placed on the same order on the hanger each time
The method of tying the knot of the thread to the clamp stand and the mass hanger.	Knots might be tightening instead of the thread extending which would impact the extension therefore the spring constant	Using the hangman noose knot for each knot and tightening the knot as tightly as possible.

Figure 4 (controlled variables table)

Apparatus list:

- metre ruler ± 0.1cm
- Pulley
- Clamp
- 2 Clamp stands
- 2 G-clamps
- Mass balance ± 0.1g
- 15 slotted masses and hanger (of 100g)
- 6 reels of nylon fishing threads of diameter stated above
- Micrometer Vernier calliper ± 0.001cm



[4]

Figure 5 (Experiment diagram made by author)

Method:

1. Get 6 bundles of strings each with a different diameter, measure their diameter exactly using a micrometre and take a note of it.
2. Cut them all at the same length, then tie a noose knot on both ends for all strings.
3. To create an average, repeat 3 times for all strings, totalling 18 strings.
4. Get 16 weights of approximately 100g, with an absolute error of ±0.0001kg.
5. Weigh each of the slotted masses using a mass balance and take note of the masses.
6. Number the weights so they are always put in the same order on the string as to prevent variation in incrementation.
7. Prepare the experiment following *Figure 5*
8. Place a clamp stand on the edge of the table. Place two G-clamps on the clamp stand so it is stable.
9. Place a clamp stand base on the other edge of the table so the string will be on the same height at both ends and not at an angle.
10. Place a pulley on the edge of the table below the clamp stand base
11. Place a ruler metre next to the pulley and clamp it in place so it does not move.

[4] Made in: www.edrawmax.com. (n.d.). [OFFICIAL] EdrawMax Online: All-in-One Diagram Maker & Software. [online] Available at: https://www.edrawmax.com.

12. Place the string noose knot around the metal rod of the clamp stand, bring it across the table, run it through the pulley and measure its initial length at the actual knot (not the end of the noose) with no weight.
13. Add weight by putting the hook of the weight holder on the noose knot and measure the extension.
14. Add slotted masses one of the times very carefully so there is not a sudden increase in force, and use a pulley to make the string vertical so there will be little space for string to move. Additionally when reading measurement, always align eyes with the weight so eye level is on the same height as the weights.
15. Repeat until all weights have been used. Remove weights in the order they were put.
16. Change the string to a new one of the same length, since the previous string will have suffered a permanent extension due to the weight acted upon it.
17. Repeat steps 10-13 two times.
18. Finally repeat steps 10-14 for all string diameters.

Safety & Environment:

Safety precautions which were taken were: Wearing safety glasses to avoid any snapping nylon damaging the eye, clearly marking out the area where weight would drop with tape to avoid accidents such as weight falling on one's feet. Regarding the environment, the harm that the experiment would cause would be due to the purchase of the nylon strings which are plastic. However the string which was not utilised, were and should be re-utilised for fishing or other purposes. Additionally the nylon string is recyclable.

Data Analysis:

Raw Data:

	Diameter: 0.23mm		
Mass (g)	Ext 1 (cm)	Ext 2 (cm)	Ext 3 (cm)
0.00	0.00	0.00	0.00
102	1.30	1.10	1.50
202	3.00	2.70	3.00
302	4.70	4.30	4.60
401	6.20	5.80	6.10
501	7.90	6.80	7.00
601	8.70	7.90	8.00
700	9.80	8.60	8.90
800	10.4	9.30	9.50
900	SNAP	9.90	10.2
1000	N/A	10.3	11.1
1100	N/A	SNAP	SNAP
1200	N/A	N/A	N/A
1299	N/A	N/A	N/A
1399	N/A	N/A	N/A
1499	N/A	N/A	N/A
1599	N/A	N/A	N/A

	Diameter: 0.43mm		
Mass (g)	Ext 1 (cm)	Ext 2 (cm)	Ext 3 (cm)
0.00	0.00	0.00	0.00
102	0.60	0.70	0.70
202	1.20	1.10	1.50
302	2.10	1.50	2.10
401	2.80	2.30	2.80
501	4.00	2.80	3.60
601	4.40	3.30	4.20
700	5.00	4.00	4.80
800	5.50	4.60	5.40
900	5.90	5.30	5.80
1000	6.40	6.40	6.30
1100	6.90	6.60	6.80
1200	7.20	6.90	7.30
1299	7.70	7.50	7.60
1399	8.10	7.80	8.10
1499	8.40	8.10	8.40
1599	8.60	8.50	8.70

	Diameter: 0.53mm		
Mass (g)	Ext 1 (cm)	Ext 2 (cm)	Ext 3 (cm)
0.00	0.00	0.00	0.00
102	0.40	0.20	0.30
202	1.10	0.50	0.80
302	1.30	0.80	1.00
401	1.80	1.00	1.20
501	2.30	1.20	1.40
601	2.70	1.60	1.80
700	3.30	1.80	2.10
800	3.80	2.10	2.40
900	4.10	2.50	2.70
1000	4.30	2.80	3.10
1100	5.00	3.00	3.40
1200	5.30	3.50	3.50
1299	5.40	3.80	3.90
1399	5.80	4.10	4.30
1499	6.00	4.40	4.60
1599	6.20	4.70	4.80

Diameter: 0.73mm			
Mass (g)	Ext 1 (cm)	Ext 2 (cm)	Ext 3 (cm)
0.00	0.00	0.00	0.00
102	0.20	0.20	0.20
202	0.40	0.40	0.40
302	0.70	0.70	0.70
401	1.10	0.90	0.90
501	1.30	1.20	1.10
601	1.50	1.50	1.20
700	1.70	1.70	1.40
800	2.00	1.90	1.60
900	2.20	2.10	1.90
1000	2.50	2.20	2.10
1100	2.70	2.50	2.30
1200	2.90	2.70	2.50
1299	3.20	2.90	2.70
1399	3.40	3.10	3.00
1499	3.50	3.30	3.10
1599	3.70	3.50	3.40

Diameter: 0.87mm			
Mass (g)	Ext 1 (cm)	Ext 2 (cm)	Ext 3 (cm)
0.00	0.00	0.00	0.00
102	0.20	0.20	0.20
202	0.50	0.30	0.50
302	0.70	0.50	0.70
401	0.90	0.80	1.00
501	1.20	1.10	1.30
601	1.30	1.20	1.40
700	1.50	1.40	1.50
800	1.70	1.70	1.70
900	1.90	1.80	1.90
1000	2.10	2.00	2.00
1100	2.30	2.10	2.20
1200	2.40	2.30	2.40
1299	2.60	2.60	2.50
1399	2.80	2.80	2.70
1499	3.00	2.90	3.00
1599	3.20	3.10	3.10

Diameter: 1.05mm			
Mass (g)	Ext 1 (cm)	Ext 2 (cm)	Ext 3 (cm)
0.00	0.00	0.00	0.00
102	0.20	0.20	0.10
202	0.50	0.50	0.20
302	0.60	0.60	0.30
401	0.80	0.70	0.50
501	0.80	0.80	0.60
601	0.90	0.90	0.80
700	1.00	1.00	0.90
800	1.10	1.20	1.10
900	1.30	1.30	1.20
1000	1.40	1.40	1.30
1100	1.50	1.50	1.40
1200	1.60	1.60	1.50
1299	1.70	1.70	1.60
1399	1.80	1.80	1.70
1499	2.00	1.90	1.80
1599	2.10	2.10	1.90

Figure 6

Processed Data:

PROCESSED					
Diameter: 0.23mm					
Weight (N)	AVG Ext (m)	Weight Max	Weight Min	Ext Avg Max	Ext Avg Min
0.00	0.00	0.00	0.00	0.00	0.00
1.00	0.01	1.00	1.00	0.01	0.01
1.98	0.03	1.98	1.98	0.03	0.03
2.96	0.05	2.96	2.96	0.05	0.05
3.93	0.06	3.93	3.93	0.06	0.06
4.91	0.07	4.92	4.91	0.07	0.07
5.89	0.08	5.89	5.89	0.08	0.08
6.87	0.09	6.87	6.87	0.09	0.09
7.85	0.10	7.85	7.85	0.10	0.10
8.83	0.07	8.83	8.83	0.07	0.07
9.81	0.07	9.81	9.81	0.07	0.07
10.8	N/A	10.8	10.8	N/A	N/A
11.8	N/A	11.8	11.8	N/A	N/A
12.7	N/A	12.7	12.7	N/A	N/A
13.7	N/A	13.7	13.7	N/A	N/A
14.7	N/A	14.7	14.7	N/A	N/A
15.7	N/A	15.7	15.7	N/A	N/A

PROCESSED					
Diameter: 0.43mm					
Weight (N)	AVG Ext (m)	Weight Max	Weight Min	Ext Avg Max	Ext Avg Min
0.00	0.00	0.00	0.00	0.00	0.00
1.00	0.01	1.00	1.00	0.01	0.01
1.98	0.01	1.98	1.98	0.01	0.01
2.96	0.02	2.96	2.96	0.02	0.02
3.93	0.03	3.93	3.93	0.03	0.03
4.91	0.03	4.92	4.91	0.03	0.03
5.89	0.04	5.89	5.89	0.04	0.04
6.87	0.05	6.87	6.87	0.05	0.05
7.85	0.05	7.85	7.85	0.05	0.05
8.83	0.06	8.83	8.83	0.06	0.06
9.81	0.06	9.81	9.81	0.06	0.06
10.8	0.07	10.8	10.8	0.07	0.07
11.8	0.07	11.8	11.8	0.07	0.07
12.7	0.08	12.7	12.7	0.08	0.08
13.7	0.08	13.7	13.7	0.08	0.08
14.7	0.08	14.7	14.7	0.08	0.08
15.7	0.09	15.7	15.7	0.09	0.09

PROCESSED					
Diameter: 0.53mm					
Weight (N)	AVG Ext (m)	Weight Max	Weight Min	Ext Avg Max	Ext Avg Min
0.00	0.00	0.00	0.00	0.00	0.00
1.00	0.00	1.00	1.00	0.00	0.00
1.98	0.01	1.98	1.98	0.01	0.01
2.96	0.01	2.96	2.96	0.01	0.01
3.93	0.01	3.93	3.93	0.01	0.01
4.91	0.02	4.92	4.91	0.02	0.02
5.89	0.02	5.89	5.89	0.02	0.02
6.87	0.02	6.87	6.87	0.02	0.02
7.85	0.03	7.85	7.85	0.03	0.03
8.83	0.03	8.83	8.83	0.03	0.03
9.81	0.03	9.81	9.81	0.03	0.03
10.8	0.04	10.8	10.8	0.04	0.04
11.8	0.04	11.8	11.8	0.04	0.04
12.7	0.04	12.7	12.7	0.04	0.04
13.7	0.05	13.7	13.7	0.05	0.05
14.7	0.05	14.7	14.7	0.05	0.05
15.7	0.05	15.7	15.7	0.05	0.05

PROCESSED					
Diameter: 0.73mm					
Weight (N)	AVG Ext (m)	Weight Max	Weight Min	Ext Avg Max	Ext Avg Min
0.00	0.00	0.00	0.00	0.00	0.00
1.00	0.00	1.00	1.00	0.00	0.00
1.98	0.00	1.98	1.98	0.00	0.00
2.96	0.01	2.96	2.96	0.01	0.01
3.93	0.01	3.93	3.93	0.01	0.01
4.91	0.01	4.92	4.91	0.01	0.01
5.89	0.01	5.89	5.89	0.01	0.01
6.87	0.02	6.87	6.87	0.02	0.02
7.85	0.02	7.85	7.85	0.02	0.02
8.83	0.02	8.83	8.83	0.02	0.02
9.81	0.02	9.81	9.81	0.02	0.02
10.8	0.03	10.8	10.8	0.03	0.02
11.8	0.03	11.8	11.8	0.03	0.03
12.7	0.03	12.7	12.7	0.03	0.03
13.7	0.03	13.7	13.7	0.03	0.03
14.7	0.03	14.7	14.7	0.03	0.03
15.7	0.04	15.7	15.7	0.04	0.04

PROCESSED					
Diameter: 0.73mm					
Weight (N)	AVG Ext (m)	Weight Max	Weight Min	Ext Avg Max	Ext Avg Min
0.00	0.00	0.00	0.00	0.00	0.00
1.00	0.00	1.00	1.00	0.00	0.00
1.98	0.00	1.98	1.98	0.00	0.00
2.96	0.01	2.96	2.96	0.01	0.01
3.93	0.01	3.93	3.93	0.01	0.01
4.91	0.01	4.92	4.91	0.01	0.01
5.89	0.01	5.89	5.89	0.01	0.01
6.87	0.02	6.87	6.87	0.02	0.02
7.85	0.02	7.85	7.85	0.02	0.02
8.83	0.02	8.83	8.83	0.02	0.02
9.81	0.02	9.81	9.81	0.02	0.02
10.8	0.03	10.8	10.8	0.03	0.02
11.8	0.03	11.8	11.8	0.03	0.03
12.7	0.03	12.7	12.7	0.03	0.03
13.7	0.03	13.7	13.7	0.03	0.03
14.7	0.03	14.7	14.7	0.03	0.03
15.7	0.04	15.7	15.7	0.04	0.04

PROCESSED					
Diameter: 1.05mm					
Weight (N)	AVG Ext (m)	Weight Max	Weight Min	Ext Avg Max	Ext Avg Min
0.00	0.00	0.00	0.00	0.00	0.00
1.00	0.00	1.00	1.00	0.00	0.00
1.98	0.00	1.98	1.98	0.00	0.00
2.96	0.00	2.96	2.96	0.01	0.00
3.93	0.01	3.93	3.93	0.01	0.01
4.91	0.01	4.92	4.91	0.01	0.01
5.89	0.01	5.89	5.89	0.01	0.01
6.87	0.01	6.87	6.87	0.01	0.01
7.85	0.01	7.85	7.85	0.01	0.01
8.83	0.01	8.83	8.83	0.01	0.01
9.81	0.01	9.81	9.81	0.01	0.01
10.8	0.01	10.8	10.8	0.01	0.01
11.8	0.02	11.8	11.8	0.02	0.02
12.7	0.02	12.7	12.7	0.02	0.02
13.7	0.02	13.7	13.7	0.02	0.02
14.7	0.02	14.7	14.7	0.02	0.02
15.7	0.02	15.7	15.7	0.02	0.02

Figure 7

Uncertainties Calculations:

The uncertainty of weight (X-axis) was found by uncertainty of the mass balance which is ±0.1g. When this is converted into newtons it will be 9.81(0.1/1000)= ±0.000981N The uncertainty of Avg extension (Y-axis) was found by using the formula:

$$(x_{max} - x_{min})/2$$

x = Extension (m)

The table of uncertainties can be seen in the processed data. The uncertainties are mostly the same due to the fact that the uncertainty is so small that the difference can only be seen in over 6 significant figures, which can additionally show that the investigation is accurate and reliable.

Average Extension vs Weight Graphs:

Figure 8

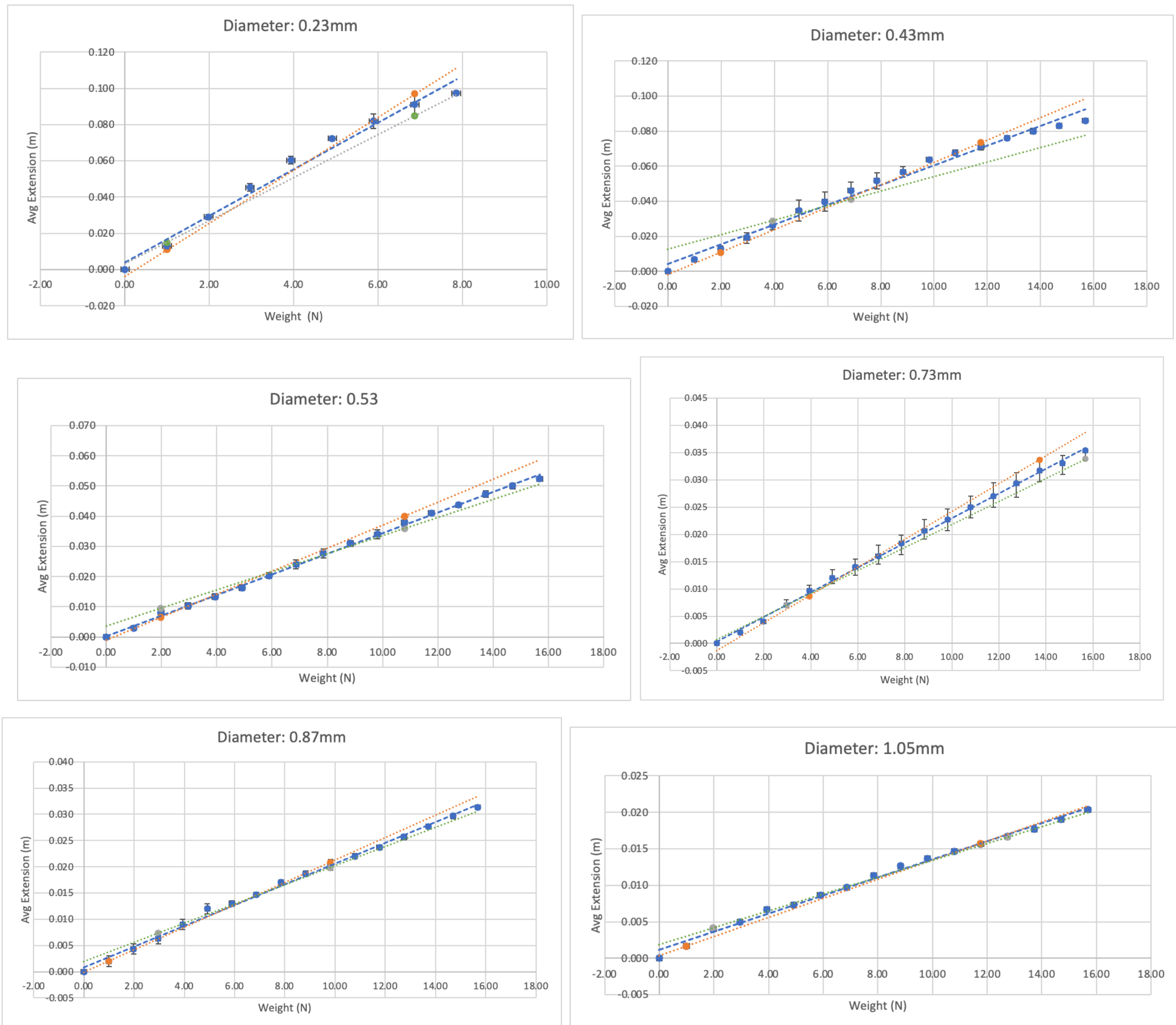
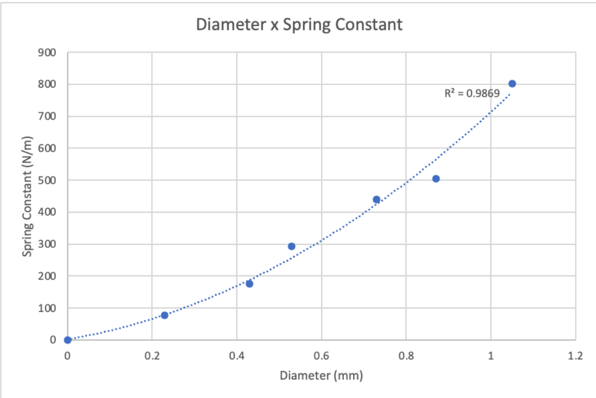


Figure 8 (all graphs are joint into one figure; figure 8)

Max min slopes were done by adding/subtracting the average extension by the extension uncertainty. The maximum slope shows the highest extension, and the minimum slope shows the lowest extension. Due to the low uncertainty, as demonstrated by the similarity between the Max and Min slopes to the original graph, it is likely that the investigation's results would be reliably repeatable.

Concluded Graphs to address research question:



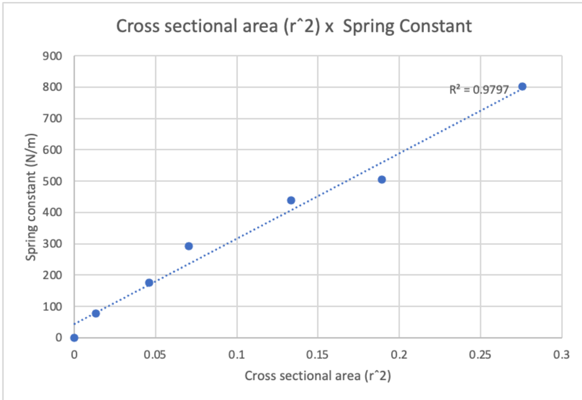


Figure 9 (diameter x Spring constant graph) *Figure 10 (cross sectional area x Spring constant graph)*

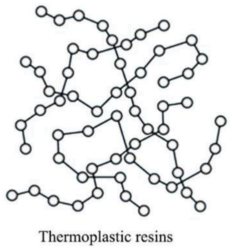
Analysis:

After graphing all the extension & weight trials the gradients of all six graphs were used to make a final graph (*Figure 9*) . After identifying through *Figure 9* that the relationship between diameter and spring constant is parabolic, it could be concluded that a cross sectional area (rˆ2) vs spring constant graph should be plotted so a linear graph would be present since spring constant seems to be proportional to diameter squared. This was done by using the formula:

$$\mathbf{(D/2)^2}$$

D = Diameter

And repeating for all diameters then plotting it versus spring constant. Which resulted in a final linear graph shown in *Figure 10*. The parabolic relationship in *Figure 9* shows that as the diameter increases, the force needed to deform the string increases so the shape of the graph k versus D is parabolic; meaning that diameter and spring constant have a positive correlation but are not directly proportional. However in *Figure 10* the linear relationship shows that, as the cross sectional area increases, the amount of force needed to deform the string increases at a constant rate; meaning that cross sectional area and spring constant are directly proportional. *Figure's 9* & *10* also led to an analysation that; nylon is a thermoplastic which under stress (through weights) causes the intermolecular van der Waals forces of attraction between the polymer chains to break down, thus, if the nylon has a larger cross sectional area, it will have more polymer chains causing the intermolecular van der Waals forces of attraction needing more force acting upon it to break down.[5]



6

Figure 11 (Nylon molecular structure showing the bonds and polymer chains)

Conclusion:

Finally after analysing both *Figure*(s) *9* & *10* and taking polymer bonds into account , it may be concluded that an increase in the cross sectional area would result in an increase in the number of polymer units and thus the number of bonds in a nylon string would also consequently be increased. Hence with both *Figure*(s) *9* & *10* it can be analysed that there is a strong positive correlation between diameter and spring constant, and there is a directly proportional correlation between cross sectional area and Spring constant. Which answers the research question; the diameter of a nylon thread affects its spring constant due to the fact that if the diameter is increased, the spring constant will also increase at an exponential rate. Although there is a positive correalation with diameter, it is not directly proportional to spring constant as stated in the hypothesis. Therefore, the hypothesis is not fully supported as what is directly proportional to spring constant, is cross sectional area.

[5] Secondary Science 4 All. (2014). Polymer structure and intermolecular forces. [online] Available at: https://secondaryscience4all.wordpress.com/2014/08/12/polymer-structure-and-intermolecular-forces/. (info on polymer structure used for analysis)

[6] ResearchGate. (n.d.). Figure 2. Molecular Structure of Thermoplastic and Thermoset Polymers [8]. [online] Available at: https://www.researchgate.net/figure/Molecular-Structure-of-Thermoplastic-and-Thermoset-Polymers-8_fig2_329156276.

Evaluation:

(There are no error bars in both *Figure*(s) *9* & *10* due to the fact that there is little to no variation in the gradient of *Figure 8 (all graphs)*.)

Problem	Correction	Effect on result	Type
Finding initial length of string with no weight through the pulley	Use a nail or something to hold the string in the same place for all trials	There will be errors in the initial readings	Random
Using the naked eye to measure extension	Using a laser or something that can point exactly what the extension is in the metre ruler	Will cause slightly inaccurate readings in the measurements of extension, since there could be parallax & human errors (looking at ruler at an angle could cause the position of the markings to appear shifted & human eye can not perfectly perceive fine details (precise ruler measurements))	Random
Size of the knot	Tying all knots at the same size	Size of knots varied causing slightly inaccurate measurement readings	Systematic
Not accurate ruler	Getting a more accurate ruler	Knicks and bumps on old rulers made the measurements inaccurate	Random
Inconsistencies in the diameters of the threads	Check surface area in various different points	The spring constant and point in which they snap will be different and random	Systematic

How the investigation could be extended:

The investigation could be extended by increasing the amount of strings used, so more different diameters, a larger amount of weights, and more trials could be done for each diameter. This would make the experiment even more reliable. Additionally different material strings could be used to further prove the relationship between diameter and spring constant.

Bibliography:

ResearchGate. (n.d.). Figure 2. Molecular Structure of Thermoplastic and Thermoset Polymers [8]. [online] Available at: https://www.researchgate.net/figure/Molecular-Structure-of-Thermoplastic-and-Thermoset-Polymers-8_fig2_329156276. (Figure 11)

Secondary Science 4 All. (2014). Polymer structure and intermolecular forces. [online] Available at: https://secondaryscience4all.wordpress.com/2014/08/12/polymer-structure-and-intermolecular-forces/. (info on polymer structure used for analysis)

Utk.edu. (2020). Hooke's law. [online] Available at: http://labman.phys.utk.edu/phys221core/modules/m3/Hooke%27s%20law.html. (used for information on Hooke's law)

www.edrawmax.com. (n.d.). [OFFICIAL] EdrawMax Online: All-in-One Diagram Maker & Software. [online] Available at: https://www.edrawmax.com. (used to make figure 5)

Keystagewiki.com. (2019). *GCSE Physics Required Practical: Investigating Hooke's Law - Key Stage Wiki*. [online] Available at: https://keystagewiki.com/index.php/GCSE_Physics_Required_Practical:_Investigating_Hooke%27s_Law. (Figure 1)