Disobeying Hooke's Law

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Introduction

The purpose of this study was to find out what happened when one stretches either one spring or multiple springs, whether they obeyed or disobeyed Hooke's Law, and how this differs to when one stretches a rubber band.

Hypothesis

Springs obey Hooke's law – the extension of a spring should be proportionate to the force applied. [1] However, a spring will only behave in this way until it has reached its elastic limit, after which it will stretch but also deform and will not return to its previous length.

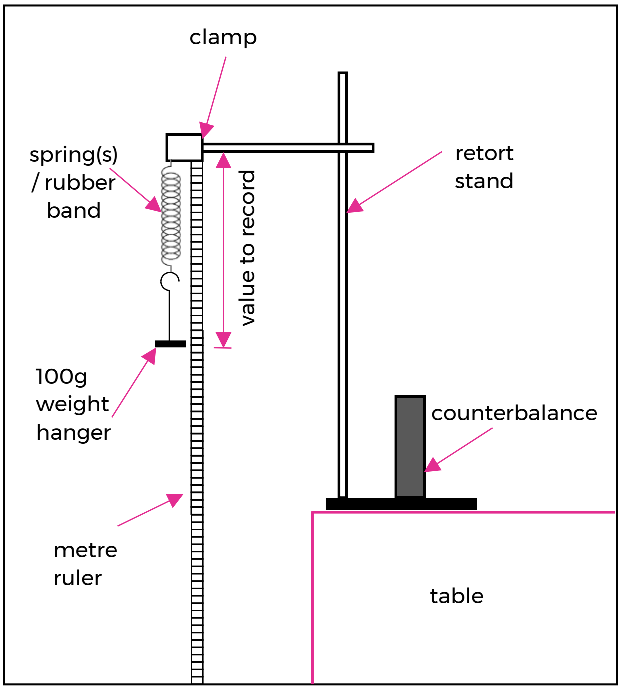
Abstract

Each spring passed the elastic limit when more than 10N of force was applied, while two springs in parallel passed the limit when more than 22N of force were applied. Measurements were taken while loading the weights onto the weight hanger. However, rubber bands behave quite differently and not linearly, so results were taken both during loading and unloading.

Method

Equipment: Retort stand, spring(s) / rubber band, 100g and 50g weights, weight hanger, metre ruler, counterbalance.

1. Record just the length of the spring from the top hook to the bottom hook with no force applied.
2. Set up the equipment as shown in the diagram, hooking the weight hanger onto the bottom of the spring(s) / rubber band.
3. Add weights, after each addition record the value on the ruler from the bottom of the weight hanger.
4. If using a rubber band, also record the values during unloading after removing each weight.



A counterbalance was found to be a necessary addition in order to prevent the equipment from falling over.

The hanger's length (14cm) limits the number of weights available to place. To record values incrementing by 50 grams, the observer placed a 50g weight, recorded the value and then substituted it for a 100g weight to conserve space on the hanger.

Results

The observer repeated the experiment four times: hooking the weights onto just one spring, two springs in series, two springs in parallel and a rubber band.

Regular spring

The observer clamped the spring and then hooked the weight hanger on the bottom. A metal pointer attached to the bottom of the hanger pointed to the reading on the ruler.

The readings for *Total spring length* do not include the length of the hanger (14cm). The readings for *Total extension* are equivalent to the readings for *Total spring length* subtract the length of the spring with no force applied.

1N ≈ 100g (on Earth)

Force applied / N	Total spring length / cm	Total extension /cm
0.0	5.0	0.0
1.0	9.0	4.0
1.5	11.2	6.2
2.0	13.3	8.3
2.5	15.4	10.4
3.0	17.2	12.2
3.5	19.4	14.4
4.0	21.5	16.5
4.5	23.7	18.7
5.0	25.7	20.7
5.5	28.0	23.0
6.0	30.2	25.2
6.5	32.3	27.3
7.0	34.3	29.3
7.5	36.4	31.4
8.0	38.3	33.3
8.5	40.4	35.4
9.0	42.4	37.4
9.5	44.3	39.3
10.0	46.3	41.3

Two springs in series

The observer connected one spring onto another to the connect the two in series. The springs passed the elastic limit and irreversibly deformed after 9N force, so a value for 10N was not recorded.

Force applied / N	Total spring length / cm	Total extension / cm
0	10.2	0.0
1	17.2	7.0
2	23.9	13.7
3	31.6	21.4
4	39.6	29.4
5	46.7	36.5
6	54.7	44.5
7	62.4	52.2
8	69.6	59.4
9	79.3	69.1

Two springs in parallel

The observer connected two springs in parallel with a metal wire at both top and bottom and attached them to the clamp.

Force applied / N	Total spring length / cm	Total extension / cm
0	3.9	0.0
1	6.2	2.3
2	8.9	5.0
3	10.9	7.0
4	13.0	9.1
5	15.0	11.1
6	17.1	13.2
7	19.0	15.1
8	21.0	17.1
9	23.1	19.2
10	24.9	21.0
11	26.8	22.9
12	28.9	25.0
13	30.8	26.9
14	32.7	28.8
15	34.9	31.0
16	36.8	32.9
17	38.6	34.7
18	40.8	36.9
19	42.6	38.7
20	44.8	40.9
21	47.5	43.6
22	50.5	46.6

Rubber band

The observer clamped the rubber band at the top and hooked the hanger onto it. Rubber bands behave differently to springs [3], so values were taken both during loading and unloading.

Rubber band (loading)

Force applied / N	Rubber band loading length	Total extension / cm
0	5.1	0.0
1	8.9	3.8
2	12.1	7.0
3	16.0	10.9
4	19.2	14.1
5	23.0	17.9
6	26.4	21.3
7	28.9	23.8
8	30.8	25.7
9	32.6	27.5
10	34.2	29.1

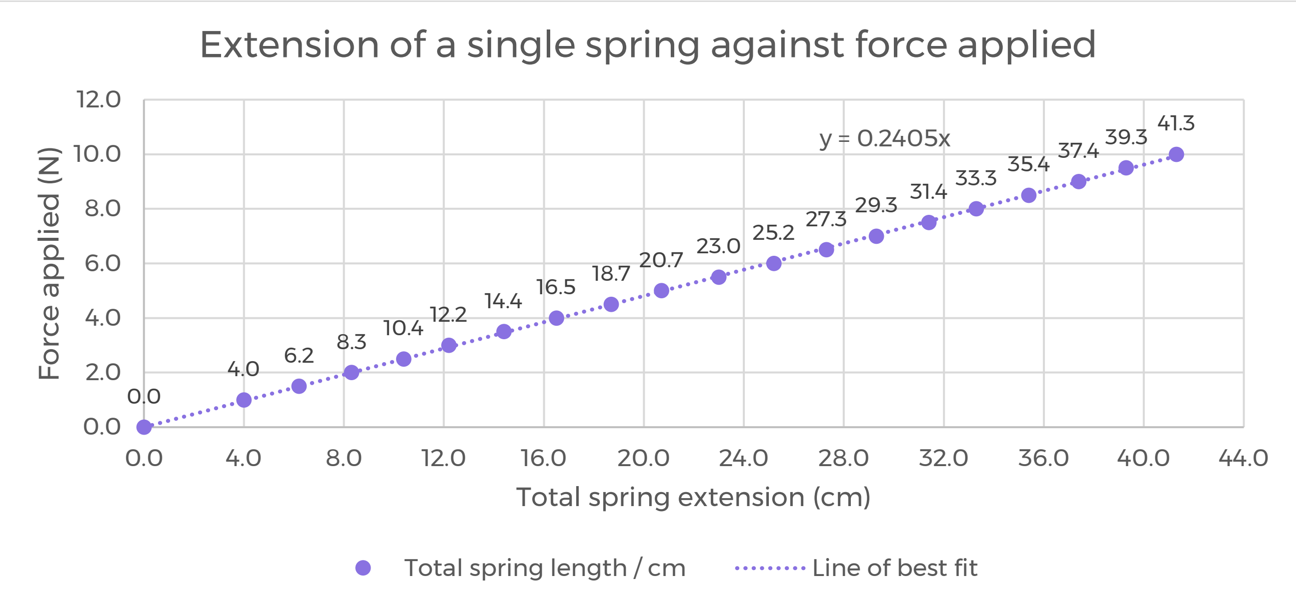
Rubber band (unloading)

Force applied / N	Rubber band unloading length	Total extension / cm
10	34.2	29.1
9	34.0	28.9
8	33.8	28.7
7	33.4	28.3
6	32.8	27.7
5	32.2	27.1
4	30.9	25.8
3	28.0	22.9
2	21.2	16.1
1	13.1	8.0
0	5.1	0.0

Discussion and graphs

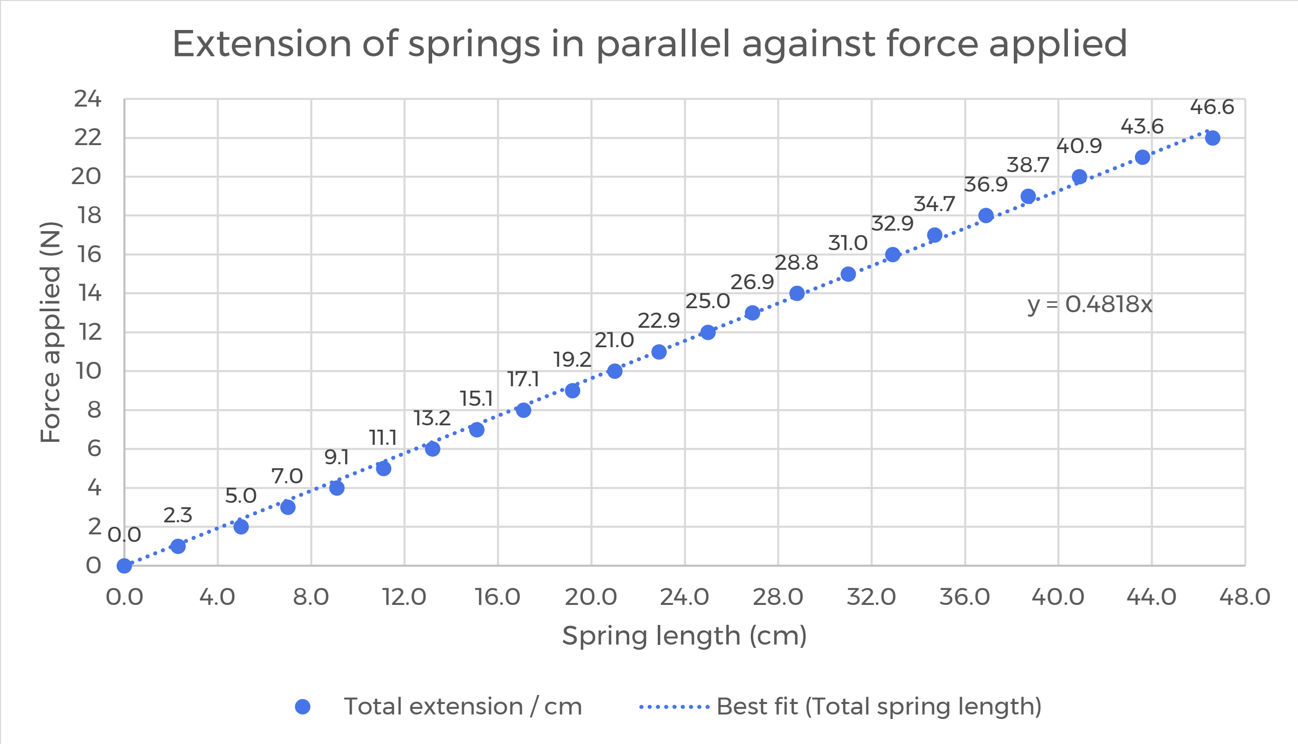
Graphs are plotted with the results of the *Total extension column* against the *Force applied* column.

Graph 1 – Single spring



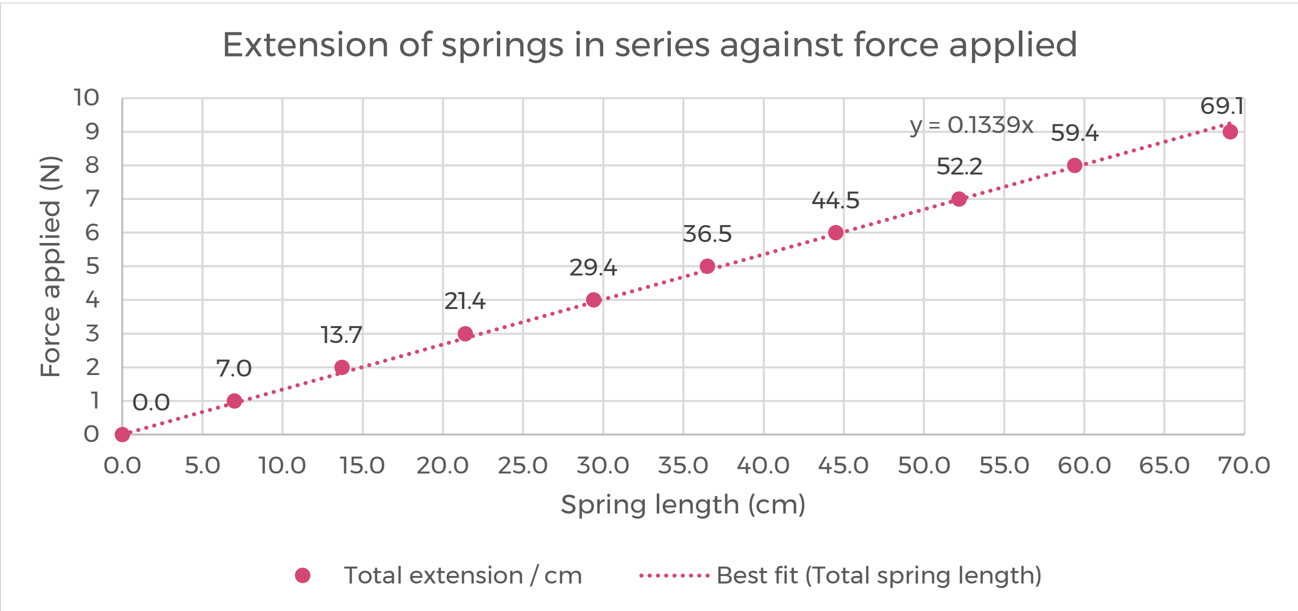
This graph shows that the results are linear and that one can express the line of best fit with the formula **y = 0.2405x.** This equation relates to Hooke's Law – **F = k x e** [2], where **k = 0.2405.** The equation for a line is y = mx + c, however, in this case, **c = 0**, showing that extension *is* directly proportionate to the force applied.

Graph 2 – Springs in parallel



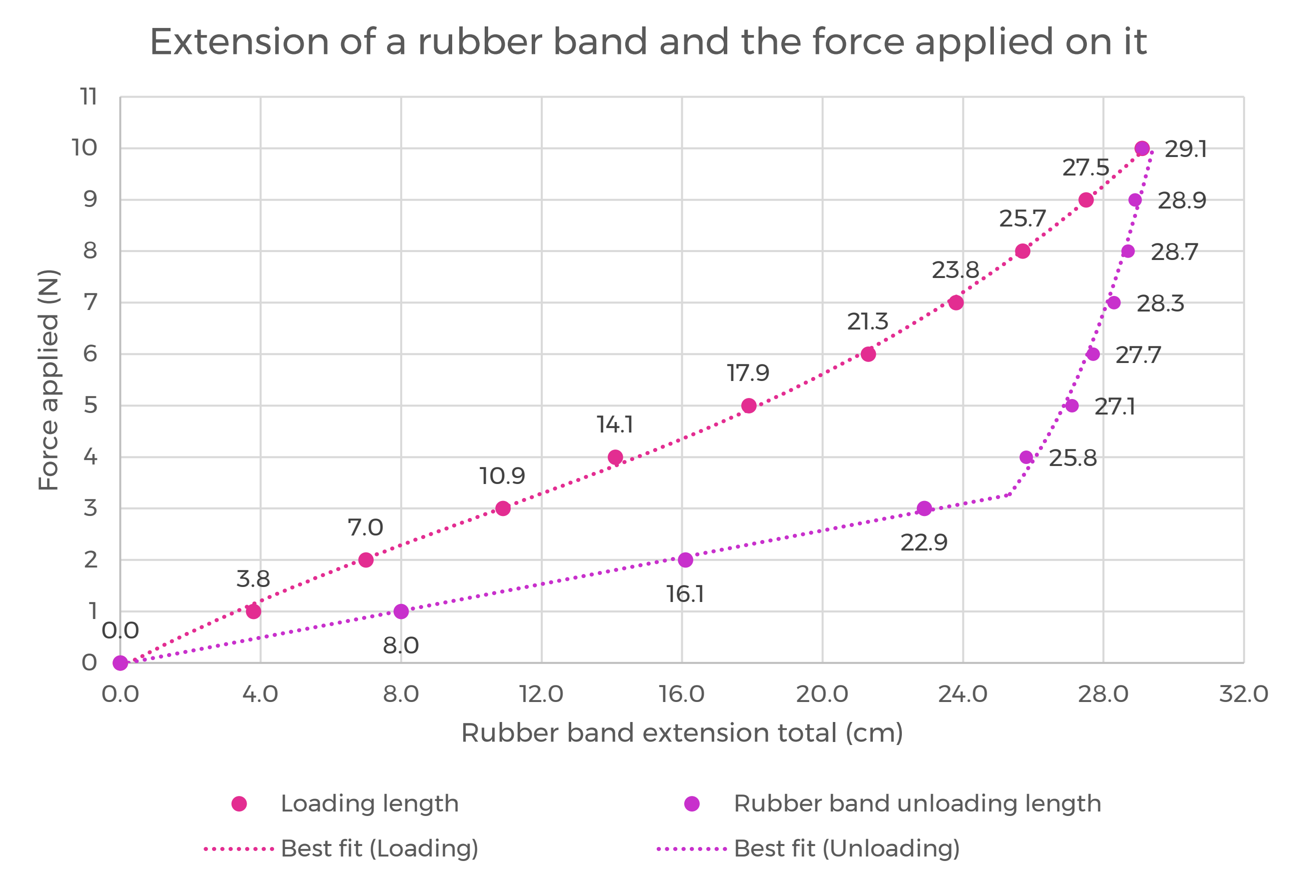
This graph's line of best fit is also linear and the average spring constant here is almost precisely twice as large, due to the two springs in parallel acting in the same way as one spring that is twice as stiff would. The last recorded value when 22N of force was applied has a somewhat longer extension since it is the start of the graph's plateau due to the springs passing their elastic limit.

Graph 3 – Springs in series



In this case, the spring constant is half of the regular spring, with the two springs in series extending twice as much for each extra newton of force.

Graph 4 – Rubber band



The rubber band disobeyed Hooke's Law, but not entirely. While loading, the rubber band almost behaved linearly. During unloading, however, the rubber band did something very different – its extension decreased very little until just over 3N of force were still being applied, when the rubber band's pattern abruptly became linear, and the extension once again was directly proportionate to the force applied.

Conclusion

Overall, springs *do* obey Hooke's Law, and the results support the hypothesis. On average, a single spring extended 4.2 cm for each extra Newton of force. Two springs in parallel extended roughly twice as little, at 2.0 cm extension per Newton, while two springs in series extended twice as much, extending by 7.7 cm for each added Newton of force. Rubber bands, however, are not springs, and only somewhat followed Hooke's Law. Due to the different behaviour of rubber bands, two separate sets of results were recorded.

References

1. Hooke, R. (1678). *De Potentia Restitutiva, or of Spring*.
2. Timoshenko, S. (1953). *History of Strength of Materials*, pp.17-20.
3. University of British Columbia. (2013). *UBC - Rubber band write-up*. [online] Available at: http://c21.phas.ubc.ca/sites/default/files/rubber_band_write_up.pdf [Accessed 18 Feb. 2018]