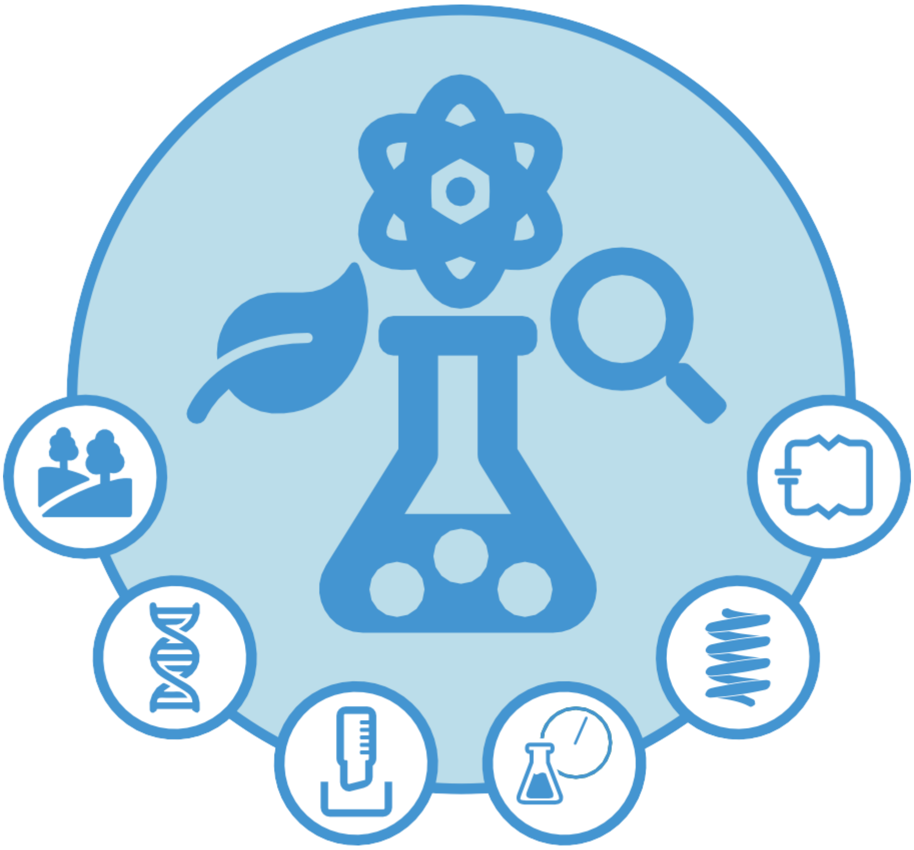
EXEMPLAR LESSON

OpenSTEM Africa

SPRING MASS SYSTEM 1: DETERMINING A SPRING FORCE CONSTANT



Acknowledgements

Ministry of Education

The Ministry of Education, Ghana, for their oversight, support and guidance which has been essential in ensuring that OpenSTEM Africa aligns with and complements other education initiatives and programmes.

CENDLOS, Ghana, for their collaboration and innovation in providing essential avenues for OpenSTEM Africa to reach learners and teachers.

Ghana Education Service, and the expert SHS science teachers, for their expertise in producing materials that are rooted in the Ghanaian school context, accessible and useful to learners and teachers.

For information on OpenSTEM Africa see:
www.open.edu/openlearncreate/OpenSTEM_Africa

OPITO for their generous support, which has made OpenSTEM Africa and the development of the Virtual Laboratory and these materials possible.

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Exemplar lessons for the OpenSTEM Africa Virtual Laboratory applications

All the **exemplar lessons** are examples of lessons which could be used both individually and by whole classes of Senior High School (SHS) students in the elective sciences of Biology, Chemistry and Physics. Each of the lessons is linked specifically to one of the applications in the OpenSTEM Africa Virtual Laboratory. The exemplar lesson is created to give, both to SHS students and to SHS teachers, a clear example of the ways in which the applications can be used in the learning and teaching of practical science. There is a focus throughout the lesson on the student's development of the practical and experimental skills which, along with knowledge and understanding, are integral to the profile of learning, teaching and assessment in SHS sciences.

The 'you' in this lesson is 'you', the Senior High School student. Remember that you can repeat the experiments and activities in this lesson as often as you have time for in class. This freedom to repeat experiments and activities is also important if you are accessing the lesson outside the classroom, for example for homework. Every application in the OpenSTEM Africa Virtual Laboratory contains real data – the experiments are real experiments. This means you might make mistakes the first or second or third time you try an experiment or an activity – and that is exactly what often happens in the real world in the sciences. So, it is helpful for you as a student to share in some of the real-world trial and error of science as you develop your skills as a scientist.

The exemplar lesson also contains a set of teaching notes at the end of this document for 'you' the SHS science teacher, to suggest how you might want to set up this particular lesson with one of your classes. Hopefully it will also generate ideas for other lessons on the same topic, or other lessons which use the same OpenSTEM Africa Virtual Laboratory application.

Determining a spring force constant

This is the first of two lessons using the OpenSTEM Africa Spring mass system application.

Lesson objectives

By the end of the lesson, you will be able to:

- Transform data into the units used for Hooke’s law.
- Describe the proportionality of a spring in terms of applied force and extension and elastic limit.
- Use Hooke’s law to calculate the force constant of a spring.
- Compare the properties of different springs.
- Describe how the stiffness of a spring relates to its force constant.

The following practical and experimental Skills will be developed:

- Observations
- Plotting
- Analysing
- Interpretation
- Reporting

Background

Springs are found in most mechanical devices from the propelling mechanism used by a simple mechanical pencil, to the source of energy storage in a wind-up clock and the shock absorbers in the suspension of trucks and trains (Figure 1).

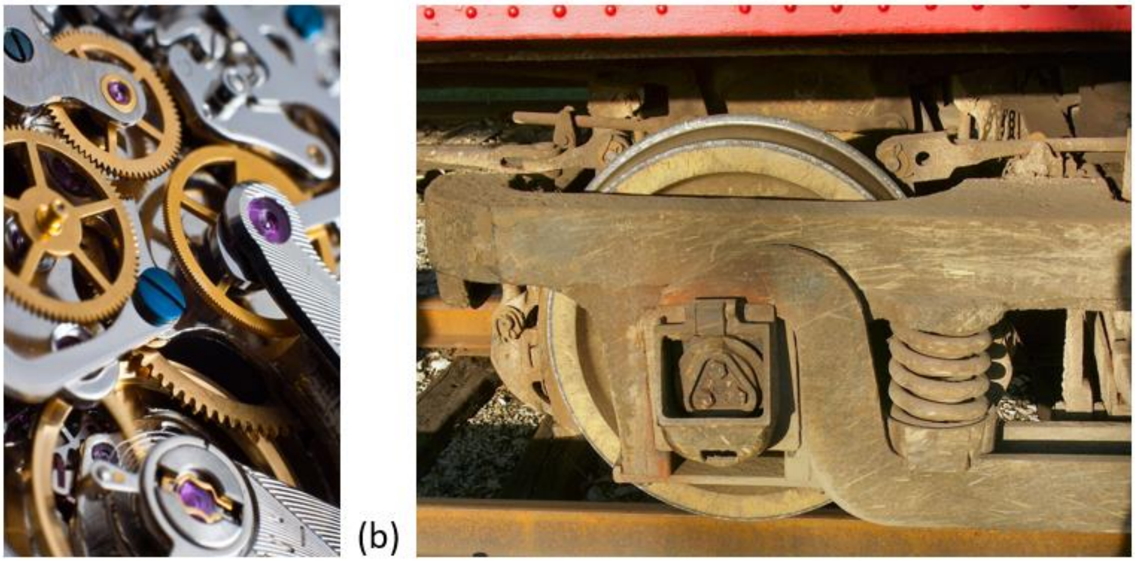


Figure 1 (a) a spring used as an energy store in a mechanical clock (the spring is located in the lower portion of the image); (b) a spring used as a shock absorber in the undercarriage of a train.

A key property of a spring is that when it is either compressed or extended by the application of a force, it will return to its original shape and length once that force is removed. This property is call **elasticity**. Forces that stretch or pull a spring are called **tensile forces** and those that compress a spring are called **compressive forces**.

Metal springs are elastic because the bonds between the metal atoms are also elastic. The elasticity and stiffness of a spring is determined by the type of metal or metal alloy it is constructed from and the thickness and shape of the wire. Figure 2 shows the characteristic behaviour of a coiled spring, which extends as more weight is added to it.

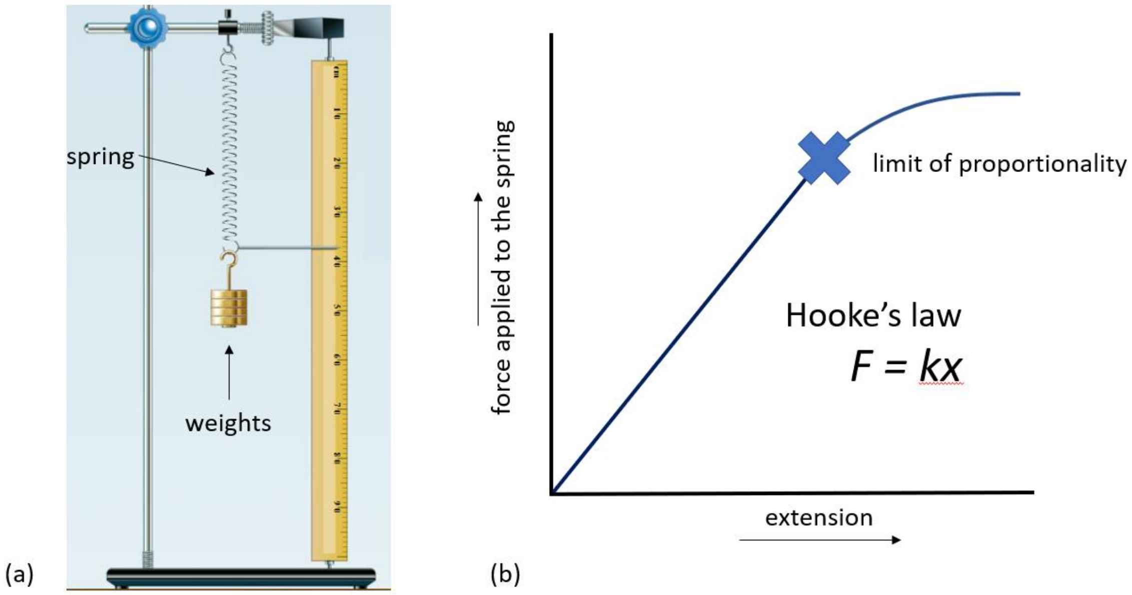


Figure 2 (a) a spring mass system used to measure the extension of a spring as more weights are added to it; (b) a graph showing the extension of a spring with increasing force.

What type of force is being applied to the spring shown in Figure 2?
Go to Appendix 3 for the answer.

The graph of extension against applied force in Figure 2 shows that the initial change in the length of the spring is linear and proportional to the force applied. However, as more force is applied the **elastic limit** of the spring is reached, after which point, if more force is applied the spring will have been stretched beyond its ability to return to its original length, and inelastic deformation of the spring occurs. The point at which the amount of extension is no longer proportional to the applied force is called the **limit of proportionality**, as indicated in Figure 2 (b). The graph in Figure 2 shows that beyond the limit of proportionality the spring resists extension, however in some instances a spring might undergo a sudden increase in extension before breaking. The point at which this sudden increase occurs is called the **yield point.**

The **spring force constant** of a spring is a measure of its stiffness up to the limit of proportionality and the behaviour of a spring during the region of proportionality is described by **Hooke's law**:

$$F = kx$$

Where *F* is the force applied in **newtons** (N) to a spring; *k* is the spring constant and *x* is the extension of the spring in metres (m). You will discover how weight (mass) is converted to newtons in the 'Practical activity' section of this lesson.

By rearranging the Hooke's law equation, it is possible to calculate the spring force constant if both the force and extension are known:

$$k = F/x$$

As force is measured in newtons (N) and the extension in metres (m), the units for the force constant are N/m:

$$k\ (\mathrm{N/m}) = F\ (\mathrm{N})/x\ (\mathrm{m})$$

In this lesson you will use a spring mass system to measure the force constant of three different springs with varying degrees of stiffness.

Practical activity

In this experiment you will measure the spring force constant of a spring. There are three springs to choose from, each with a different degree of stiffness. Your teacher may ask you to measure the spring constants for all three or may ask you to focus on a particular spring.

Copy the following table headings into your laboratory notebook:

Trial no.	Spring	Mass /g	Initial reading /cm	Weight reading /cm	Extension /cm	
						X

Figure 3 Table headings used by the spring mass system experiment.

You will use this to record the data generated by the spring mass system. The initial reading is the length of the spring in centimetres at rest before any weights are added to the spring.

If the initial reading of a spring is 12 cm and 15.5 cm after the application of a 50 g weight, by how many centimetres has the spring been extended by the weight applied?
Go to Appendix 3 for the answer.

Once you have accessed the Spring mass system application homepage (*do not do this until you read the following instructions thoroughly*), select the 'Determining a spring force constant' option and enter the experiment. Your first task is to select a spring (you have a choice of a soft, medium or stiff spring). Once you have selected a spring, record the initial reading before adding any weights to extend it. Weights are then added sequentially, starting with 50 g (this is the weight of the 'weight holder') and then adding more weight in 50 g increments until the final weight of 250 g is reached.

Once you have collected your observations you will need to create a new table in your laboratory notebook where the gram (g) weights are converted to force values in newtons (N) and the extension values in centimetres (cm) are converted to metres (m).

If you are unfamiliar with the relationship between mass and force, at sea level 1 kg of mass is equal to a force of 9.8 N, so 100 g is equal to 0.98 N.

What is 250 g in newtons?
Go to Appendix 3 for the answer.

Once you have converted your values into newtons and metres, plot a graph of force against extension for your chosen spring, and then fit a best fit line running through the plotted data points – such as the example shown in Figure 4.

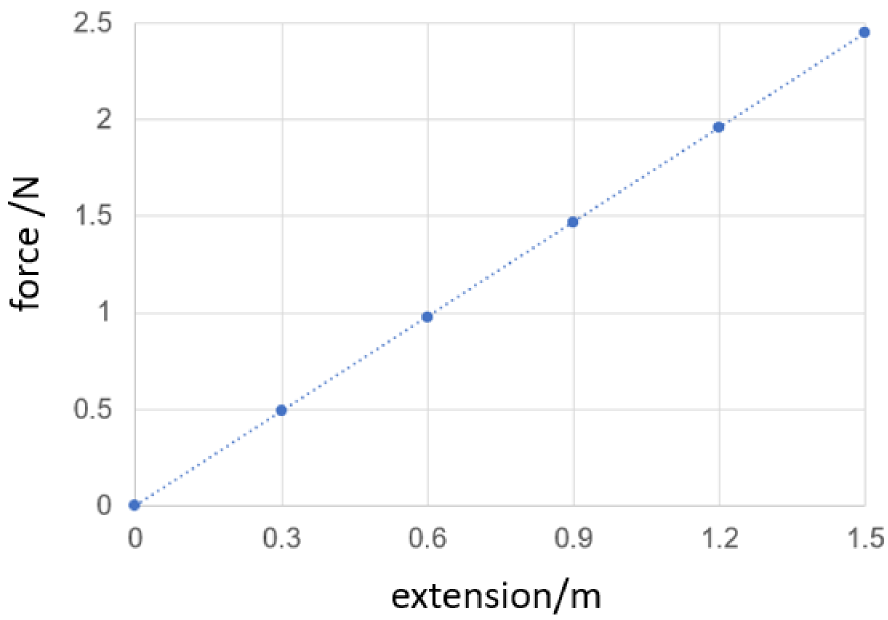


Figure 4 A graph showing the extension of a spring as a function of the applied force.

The slope of your graph is a measure of the stiffness of the spring. The data plotted in the example shown in Figure 4 is linear, meaning that the limit of proportionality has not been reached and because the relationship between applied force and extension is proportional, Hooke's law can be used to calculate the spring force constant.

So, if a force of 2.45 N (the equivalent for 200 g) produces an extension of 1.2 m, the slope is calculated by dividing 2.45 N by 1.2 m – giving a value of 1.635 N/m.

Look at the graph plotted in Figure 4. Which variable has been plotted against each axis?
Go to Appendix 3 for the answer.

The normal convention when plotting data is to plot the dependent variable on the y-axis and the independent variable on the x-axis. However, because the spring force constant is expressed as N/m, this convention is reversed when applying Hooke's law, such that the dependent variable (extension, m) is now plotted on the x-axis and the independent variable (force, N) on the y-axis and hence, the resulting slope is expressed as N/m.

Spring mass system
Go to the OpenSTEM Africa Virtual Laboratory. Click on the icon to access the Spring mass system application homepage. Watch the introductory video before entering the experiment.

Summary

You have used the spring mass system to study the properties of metal springs. You have collected data, recorded your observations in a table, and converted them to the appropriate units. You then plotted your data so that the proportionality of the slope can be considered and then used Hooke's to calculate the spring force constant. Based on your observations and those of your classmates, you should also be able to describe the stiffness of a spring in terms of its force constant. In the next lesson using the spring mass system, you will discover how the spring force constant can be calculated by examining the oscillations of a spring.

For further explanation of some of the terms used in this lesson, go to the **Glossary**.

Quiz

Answer the question, then search for the correct answers in Appendix 4.

Question 1

The unit used to describe the force constant of a spring N/m. Which one of the following is the force in newtons for a 15 g weight?

a) 0.147 N (correct)
b) 1.475 N
c) 0.048 N
d) 9.8 N

Question 2

If a spring is extended elastically by 20 cm when a force of 30 N is applied, how much force would be needed to extend that same spring by 10 cm?

a) 20 N
b) 15 N (correct)
c) 10 N

Question 3

If a spring is extended elastically by 0.1 m when a force of 7 N is applied to it, what is the spring's force constant?

a) 0.7 N/m
b) 3.5 N/m
c) 70 N/m (correct)

Question 4

Which one of the following statements is correct?

a) The spring force constant for a shock absorber on a train is higher than the force constant of a spring used in a mechanical propelling pencil. (correct)
b) Stiff springs have lower force constants than soft springs.
c) Hooke's law only applies when a spring is extended beyond the limit of proportionality.

Glossary

Compressive force – An applied forced that compresses a spring (makes it shorter).

Elasticity – The ability for a spring to return to its original shape and length once a force is removed.

Elastic limit – The point at which a spring has been stretched/deformed beyond its ability to return to its original shape and length – the spring has been damaged.

Hooke's law – $F = kx$ where F is the applied force in newtons (N), k is the spring force constant and x is the extension of the spring measured in metres (m). A spring force constant has the units of N/m. Hooke's law only holds below the limit of proportionality.

Limit of proportionality – The point at which the relationship between force and extension is no longer linear and proportional.

Newton – A measure of force due to the acceleration of gravity. At sea level (where mass = weight), a 1 kg mass has a force of 9.8 newtons (N).

Tensile force – An applied force that stretches/extends a spring – (makes it longer)

Yield point – A point beyond the limit of proportionality when a spring undergoes a sudden increase in extension prior to breaking.

Appendix 1: Teacher notes – organisation of the lesson

Teaching notes for the spring mass system (Determining a spring force constant) and the lesson: Physics SHS3, Section 2, Unit 1 Deformation of solids.

This lesson, using the spring mass system and links directly to SHS and the teaching and learning activities associated with it.

Ideas for organising this exemplar lesson link directly to activities and teaching examples in the OpenSTEM Africa CPD units on Using ICT to support learning, and Approaches to active notetaking.

A full list of the OpenSTEM Africa CPD units can be found at: https://www.open.edu/openlearncreate/CPD_units

Overview

If possible, this lesson should take place in the ICT Lab in your school if this can be arranged through your Head of Science and the Head of ICT. If the lesson takes place in the ICT Lab, it may be possible for each student to work individually at a computer; otherwise divide the class so that students are in small groups at a computer.

If it is not possible to use the ICT Lab for this lesson, then try to set up this lesson in your classroom. You may be lucky enough in your school to have a set of 'empty' tablets or mobile phones which students can use. Or you may be able to bring into the classroom a laptop connected to the internet or to your school intranet – and perhaps connected to a projector to make it possible for the whole class to view at once. If access to ICT is a real challenge in your school but you want your students to view an experiment, you might be able demonstrate it to small groups of your students at a time, using your own mobile phone

Whatever way(s) you set up the class, it would still be helpful to the students to be able to work in pairs or small groups for at least some of the lesson. Do remember as well that students need desk space to be able to write in their notebooks and to draw tables and diagrams.

Steps in organising the lesson

Step 1: This takes place at the beginning of the lesson where you and your class access the OpenSTEM Africa Virtual Laboratory spring mass application. Have students work in pairs to pre-read the Background section of the exemplar lesson and ask each other the questions in the Background section. While they are doing so, you may want to walk round the class and check their laboratory notebooks, as accurate note-taking and filling in the tables is important for this exemplar lesson.

Step 2: Check students' understanding by asking them the questions in the Background section. Have each person in the pair create the tables in their own laboratory notebook in preparation for their data collection.

Step 3: Once the students have seen the video one time, and if it is helpful to do so, give the class a set time to draw spring mass system in their laboratory notebook and label it. Within each pair, have them check each other's work.

Step 4 Make sure that each pair has access to/can see the computer screen to begin the actual experiments. Ensure that each pair knows how to carry out the experiments– or if you are using a laptop/projector, that you draw on the expertise of the class as you go through each step of the spring mass system experiments – i.e., ask them what the next step is

Step 5: Have the class follow the instructions for each of the spring mass experiments. Make sure, if working in a pair on a PC, that each student in the pair gets to follow all the steps; if working in a group on a PC,have the group leader ensure that everyone in the group is involved.

Step 5: What they write in their tables will be agreed between the pair or within the group but allow enough time for everyone in the class to fill in their own set of tables. Have them check each other's writing.

Step 6: Ten minutes before the end of the lesson, tell the students to complete the quiz.

Appendix 2: Teacher notes – outputs of the lesson

Syllabus sections addressed by this lesson

Teaching Syllabus for Physics (SHS 1–3)

SHS3 Mechanics Section 1 Unit 1 Deformation of solids

- 2.1.3 Explain the behaviour of elastic material under stress (introduces Hooke's law and elastic limit).

The following Practical and Experimental Skills will be developed:

- Observations
- Analysing
- Interpretation
- Reporting

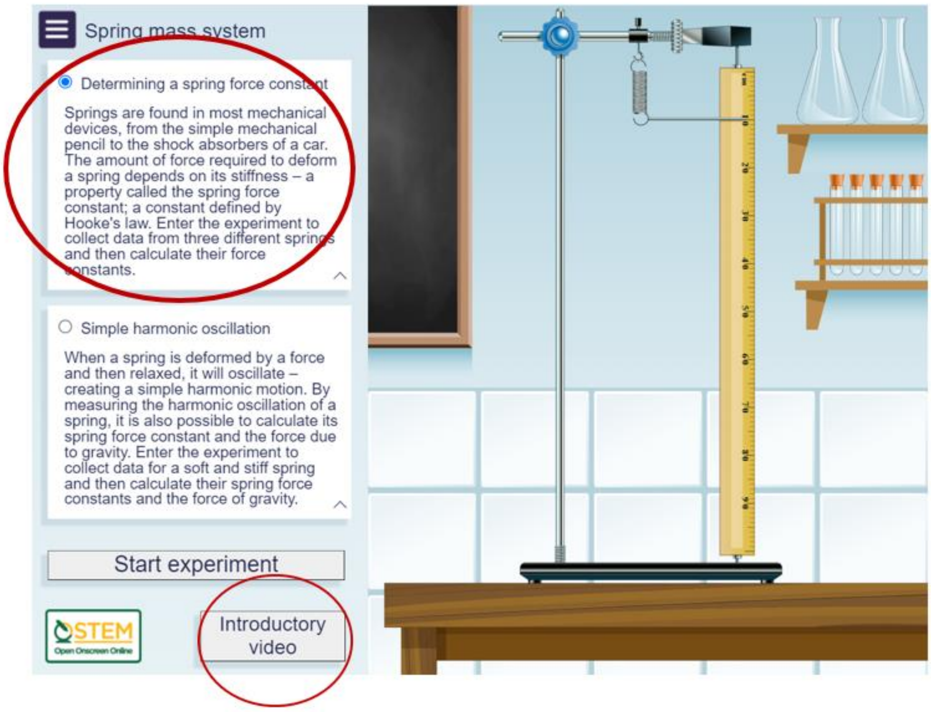
Setting up equipment

To carry out this lesson, students can work on a computer individually or in pairs.

Students need their laboratory notebooks, pen, pencil (for diagrams) and ruler.

Using the spring mass system to determine a spring force constant

The estimated lesson time is 60 minutes, but it could be completed in less time. Students should first watch the introductory video on the application homepage and then select the 'Determining a spring constant' before starting the experiment.



Once a student has entered the experiment the first task is to select a spring (for the purposes of this worked example, the soft spring has been selected).

Once a spring has been selected the weights are added by using the sliding bar.

And once the spring has reached its new equilibrium point, the extension and other details can then be recorded using a laboratory notebook or stored using the 'Record data' option. The latter will enable the recordings to be later downloaded as a CSV spreadsheet.

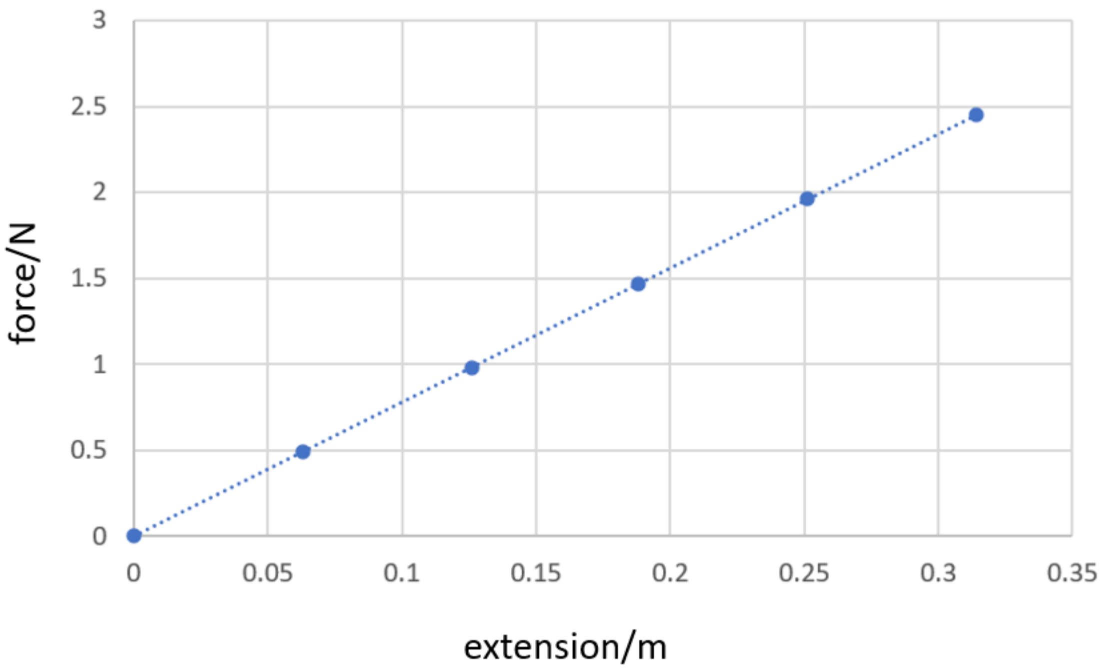
Below is the data output for a soft spring:

Trial no.	Spring	Mass /g	Initial reading /cm	Weight reading /cm	Extension /cm	
5	Soft	250	21.2	52.7	31.4	X
4	Soft	200	21.2	46.4	25.1	X
3	Soft	150	21.2	40	18.8	X
2	Soft	100	21.2	33.9	12.6	X
1	Soft	50	21.2	27.6	6.3	X

To use Hooke's law to measure the spring force constant, the data must be transformed into the appropriate units (mass to force in newtons; cm to m) as shown below.

Mass (g)	Force (N)	Extension (cm)	Extension (m)
0	0	0	0
50	0.49	6.3	0.063
100	0.98	12.6	0.126
150	1.47	18.8	0.188
200	1.96	25.1	0.251
250	2.45	31.4	0.314

Hooke's law can only be used for data collected below the limit of proportionality. To check the proportionality of the data, force (N) is plotted against extension (m).



The plotted data shows that the data is linear and proportional and therefore Hooke's law can be used to calculate the spring force constant (the slope (gradient) of the plotted data represents the spring force constant).

$$k = F/x$$

The spring force constant for the soft spring is 7.81 N/m.

Appendix 3: In-text question answers

What type of force is being applied to the spring shown in Figure 2?
Answer: The spring is being pulled or stretched by tensile forces.

If the initial reading of a spring is 12 cm and 15.5 cm after the application of a 50 g weight, by how many centimetres has the spring been extended by the weight applied?
Answer: The amount of extension is calculated by subtracting the initial reading from the weight reading. So 15.5 cm – 12 cm gives us an extension of 3.5 cm.

What is 250 g in newtons?
Answer: There are several ways that this conversion can be done, but perhaps the simplest is to use 100 g = 0.98 N. So the Newton force for 250 g can be calculated by multiplying 0.98 N by a factor of 2.5 (250 g/100 g = 2.5): $250\ g = 0.98\ N \times 2.5 = 2.45\ N$

Look at the graph plotted in Figure 4. Which variable has been plotted against each axis?
Answer: The independent variable (the applied force) is plotted on the y-axis and the dependent variable (the amount of extension) is plotted on the x-axis.

Appendix 4: Quiz answers

Correct answers are **highlighted in green**.

Question 1

The unit used to describe the force constant of a spring N/m. Which one of the following is the force in newtons for a 15 g weight?

- **e) 0.147 N**
- f) 1.475 N
- g) 0.048 N
- h) 9.8 N

Feedback

1 g equals 0.0098 N, so 15 g is equal to 0.147 N

$$15\,g\;x\;0.0098\,N = 0.147\,N$$

Question 2

If a spring is extended elastically by 20 cm when a force of 30 N is applied, how much force would be needed to extend that same spring by 10 cm?

- d) 20 N
- **e) 15 N**
- f) 10 N

Feedback

Because extension is proportional to the force applied, only half of the force required to extend a spring by 20 cm is needed to extend it by 10 cm. 30 N/2 = 15 N.

Question 3

If a spring is extended elastically by 0.1 m when a force of 7 N is applied to it, what is the spring's force constant?

- a) 0.7 N/m
- b) 3.5 N/m
- **c) 70 N/m**

Feedback

Using Hooke's law, the force constant is calculated by dividing the applied force in newtons by the extension in metres.

$$7\,N/0.1\,m = 70\,N/m$$

Question 4

Which one of the following statements is correct?

- **d) The spring force constant for a shock absorber on a train is higher than the force constant of a spring used in a mechanical propelling pencil.**
- e) Stiff springs have lower force constants than soft springs.
- f) Hooke’s law only applies when a spring is extended beyond the limit of proportionality.

Feedback

A shock absorber is much stiffer than the weak spring used in a mechanical pencil. You will recall from your experimental observations that the stiff spring had a higher force constant than the soft spring – so, a shock absorber has a higher spring force constant than the spring used in a mechanical pencil.

ACKNOWLEDGEMENTS

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