

Exercise walk-through

6.1

Stress and strain

A-Level Physics

6.1 Hooke’s law and the spring constant

Name: _____ Class: _____ Date: _____

Total: 24 marks

- KEY WORDS** Hooke’s law
- limit of proportionality
 - spring constant
 - load
 - extension

Objective

Answer exam questions on **Hooke's law** and the **spring constant** : the words for deformation, reading a force–extension graph, and springs joined in series and in parallel. Syllabus 6.1, learning outcomes 1 to 4.

You must be able to:

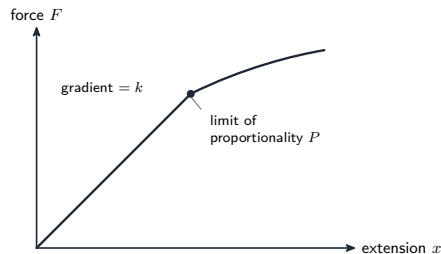
- use the terms tensile, compressive, load, extension, compression and limit of proportionality
- state Hooke's law, and use the spring constant $k = F/x$
- read a force–extension graph: its gradient, and where it stops being straight

- find the extension and the spring constant of springs joined in series or in parallel

1 Key knowledge and worked examples

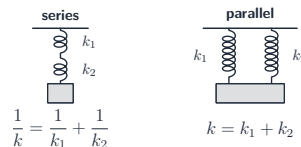
■ Key knowledge: the words and the law

Term	Meaning
tensile / compressive forces	a pair of forces that stretch / squash an object (one force alone would accelerate it)
load	the force applied, often the weight of hung masses, $F_W = mg$
extension / compression	the increase / decrease in length from the original length
Hooke's law (2 marks)	the extension is proportional to the load, provided the limit of proportionality is not exceeded
limit of proportionality	the point beyond which the force-extension graph is no longer a straight line
spring constant	force per unit extension, $k = \frac{F}{x}$, in N m^{-1} : the gradient of the straight part of a force-extension graph



- a stiffer spring has a larger k and a steeper force-extension line
- extension is measured from the **original length**: new length – original length

■ Key knowledge: springs joined together



Joined	Load on each spring	Extension of the pair	Pair constant (two identical springs)
series	full load F	extensions add	$k/2$
parallel	half the load $F/2$	same as each spring	$2k$

■ Worked example: a spring constant

A spring extends by 2.4 cm when a load of 6.0 N hangs from it.

1. **Spring constant** – $k = \frac{F}{x} = \frac{6.0 \text{ N}}{0.024 \text{ m}} = 250 \text{ N m}^{-1}$.
2. **A new load** – a mass of 0.40 kg: $F = mg = 3.9 \text{ N}$, so from Hooke's law $x = \frac{F}{k} = \frac{3.9}{250} = 0.016 \text{ m}$, provided the limit of proportionality is not passed.
3. **New length** – if the unstretched spring is 15.0 cm long, it becomes $L = L_0 + x = 15.0 + 1.6 = 16.6 \text{ cm}$.

■ Worked example: reading a force–extension graph

A spring's force–extension graph is a straight line from the origin to (4.0 cm, 12 N), then it curves.

1. **Spring constant** – the gradient of the straight part: $k = \frac{\Delta F}{\Delta x} = \frac{12 \text{ N}}{0.040 \text{ m}} = 300 \text{ N m}^{-1}$.
2. **Limit of proportionality** – where the line stops being straight: at a load of 12 N. Beyond it, $F = kx$ no longer holds.

■ Worked example: two springs, two ways

Two identical springs each have $k = 200 \text{ N m}^{-1}$. They carry a load of 12 N.

1. **In series** – each spring carries the whole 12 N, so each extends by $x = \frac{F}{k}$, and the two extensions add:

$$x = \frac{F}{k} = \frac{12 \text{ N}}{200 \text{ N m}^{-1}} = 0.060 \text{ m}, \quad x_{\text{pair}} = 2x = 0.12 \text{ m}$$

$$k_{\text{pair}} = \frac{F}{x_{\text{pair}}} = \frac{12 \text{ N}}{0.12 \text{ m}} = 100 \text{ N m}^{-1}$$

2. **In parallel** – each spring carries half the load, 6.0 N, and the pair extends as far as one spring:

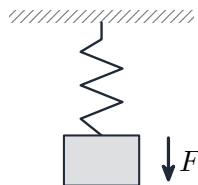
$$x = \frac{F}{k} = \frac{6.0 \text{ N}}{200 \text{ N m}^{-1}} = 0.030 \text{ m}$$

$$k_{\text{pair}} = \frac{F}{x} = \frac{12 \text{ N}}{0.030 \text{ m}} = 400 \text{ N m}^{-1}$$

Exercises 2.1·2.2

2.1 State Hooke's law.

[2]



2.2 Define the **spring constant** of a spring.

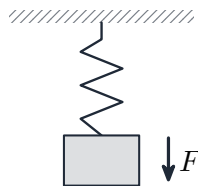
[1]

spring constant

Exercises 2.1·2.2

2.1 State Hooke's law.

[2]



2.1

- the extension of a spring is proportional to the load (force) on it
- provided the limit of proportionality is not exceeded

2.2 Define the **spring constant** of a spring.

[1]

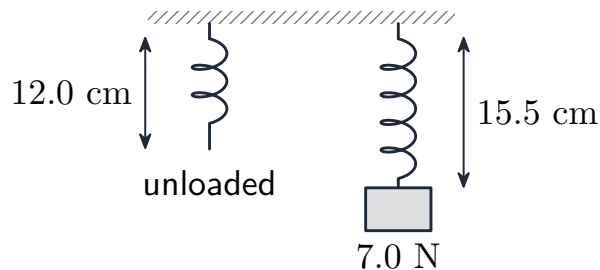
spring constant

2.2

- the force per unit extension, $k = F/x$

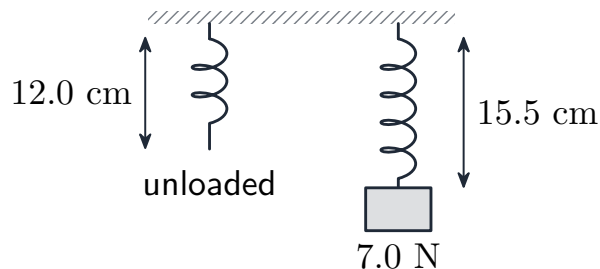
Exercise 2.3

2.3 A spring of original length 12.0 cm is 15.5 cm long when it supports a load of 7.0 N. Calculate its spring constant. [2]



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2.3

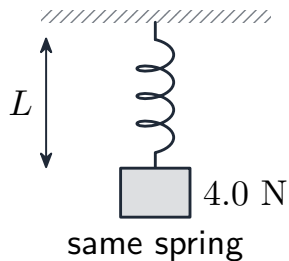
- extension $x = L - L_0 = 15.5 - 12.0 = 3.5 \text{ cm} = 0.035 \text{ m}$

$$k = \frac{F}{x} = \frac{7.0 \text{ N}}{0.035 \text{ m}} = \mathbf{200 \text{ N m}^{-1}}$$

Exercise 2.4

2.4 The spring in **2.3** now supports a load of 4.0 N. Calculate its length.

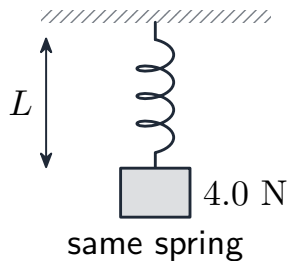
[2]



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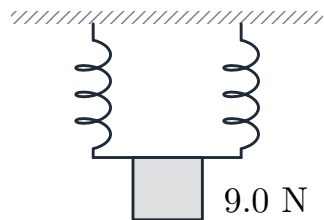


2.4

- Hooke's law, $x = \frac{F}{k} = \frac{4.0}{200} = 0.020 \text{ m} = 2.0 \text{ cm}$
- length $L = L_0 + x = 12.0 + 2.0 = \mathbf{14.0 \text{ cm}}$

Exercise 2.5

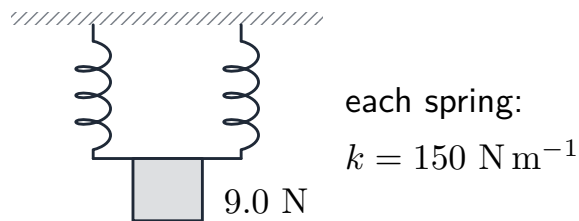
2.5 Two identical springs, each of spring constant 150 N m^{-1} , hang side by side and together support a load of 9.0 N . Calculate the extension of the springs. [2]



each spring:
 $k = 150 \text{ N m}^{-1}$

Exercise 2.5

2.5 Two identical springs, each of spring constant 150 N m^{-1} , hang side by side and together support a load of 9.0 N . Calculate the extension of the springs. [2]



2.5

- in parallel each spring carries 4.5 N

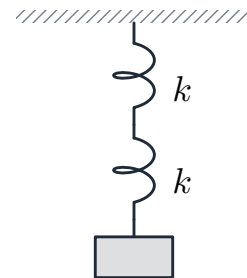
$$x = \frac{F}{k} = \frac{4.5 \text{ N}}{150 \text{ N m}^{-1}} = \mathbf{0.030 \text{ m}}$$

Exercise 3.1

3.1 Two identical springs, each of spring constant k , are joined end to end in series. What is the spring constant of the combination? [1]

☐

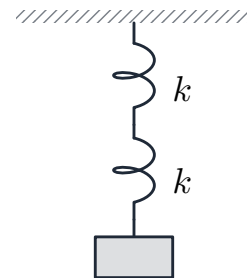
- A** $\frac{k}{2}$
B k
C $2k$
D $4k$



Exercise 3.1

3.1 Two identical springs, each of spring constant k , are joined end to end in series. What is the spring constant of the combination? [1]

- ☐ A $\frac{k}{2}$
☐ B k
☐ C $2k$
☐ D $4k$



3.1 A

- each spring carries the whole load, so the extensions add: twice the extension for the same force means half the spring constant
- C is two springs in parallel

Exercise 3.2

3.2 What is meant by the **limit of proportionality** of a spring?

[1]

☐

A the largest load for which the spring returns to its original length

limit of proportionality

B the point beyond which the extension is no longer proportional to the load

C the load at which the spring breaks

D the extension at which the spring constant is greatest

Exercise 3.2

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A the largest load for which the spring returns to its original length

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B the point beyond which the extension is no longer proportional to the load

C the load at which the spring breaks

D the extension at which the spring constant is greatest

3.2 B

- beyond the limit of proportionality the force–extension graph is no longer straight
- **A** describes the elastic limit, a different point

Exercise 3.3 (a)

3.3 A student hangs loads from a spring and measures the extension. The force–extension graph is a straight line through the origin up to a load of 8.0 N and an extension of 5.0 cm, and then curves.

(a) State **Hooke's law**.

[2]

Exercise 3.3 (a)

3.3 A student hangs loads from a spring and measures the extension. The force–extension graph is a straight line through the origin up to a load of 8.0 N and an extension of 5.0 cm, and then curves.

(a) State **Hooke's law**.

[2]

(a) the extension is proportional to the load

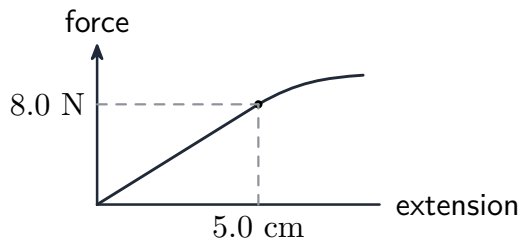
- provided the limit of proportionality is not exceeded

Exercise 3.3 (b)

3.3 A student hangs loads from a spring and measures the extension. The force–extension graph is a straight line through the origin up to a load of 8.0 N and an extension of 5.0 cm, and then curves.

(b) **Determine** the spring constant of the spring.

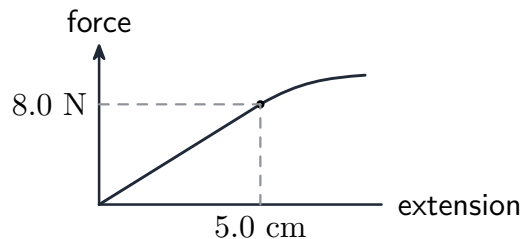
[2]



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(b) **Determine** the spring constant of the spring. [2]



(b) the gradient of the straight part, $k = \frac{F}{x}$

$$k = \frac{F}{x} = \frac{8.0 \text{ N}}{0.050 \text{ m}} = \mathbf{160 \text{ N m}^{-1}}$$

Exercise 3.3 (c)

3.3 A student hangs loads from a spring and measures the extension. The force–extension graph is a straight line through the origin up to a load of 8.0 N and an extension of 5.0 cm, and then curves.

(c) A mass of 0.45 kg hangs from the spring. Calculate the extension.

[2]

Exercise 3.3 (c)

3.3 A student hangs loads from a spring and measures the extension. The force–extension graph is a straight line through the origin up to a load of 8.0 N and an extension of 5.0 cm, and then curves.

(c) A mass of 0.45 kg hangs from the spring. Calculate the extension. [2]

(c) $F = mg = 0.45 \times 9.81 = 4.4 \text{ N}$, within the straight part

$$x = \frac{F}{k} = \frac{4.4 \text{ N}}{160 \text{ N m}^{-1}} = \mathbf{0.028 \text{ m}}$$

Exercise 3.3 (d)

3.3 A student hangs loads from a spring and measures the extension. The force–extension graph is a straight line through the origin up to a load of 8.0 N and an extension of 5.0 cm, and then curves.

(d) The 0.45 kg mass is now hung from two of these springs joined in series. Calculate the total extension.

[1]

Exercise 3.3 (d)

3.3 A student hangs loads from a spring and measures the extension. The force–extension graph is a straight line through the origin up to a load of 8.0 N and an extension of 5.0 cm, and then curves.

(d) The 0.45 kg mass is now hung from two of these springs joined in series. Calculate the total extension. [1]

(d) in series each spring carries the whole load, so the extension doubles: **0.055 m**

Exercise 3.3 (e)

3.3 A student hangs loads from a spring and measures the extension. The force–extension graph is a straight line through the origin up to a load of 8.0 N and an extension of 5.0 cm, and then curves.

(e) State why the answer to (c) could not be found with the same method for a load of 10 N.

[1]

Exercise 3.3 (e)

3.3 A student hangs loads from a spring and measures the extension. The force–extension graph is a straight line through the origin up to a load of 8.0 N and an extension of 5.0 cm, and then curves.

(e) State why the answer to (c) could not be found with the same method for a load of 10 N. [1]

(e) 10 N is beyond the limit of proportionality, so the extension is no longer F/k

Exercise 3.4 (a)

3.4 A spring in a car suspension has a spring constant of $3.2 \times 10^4 \text{ N m}^{-1}$. Four such springs share the weight of a car of mass 1100 kg equally.

(a) State whether the springs are in tension or in compression.

[1]

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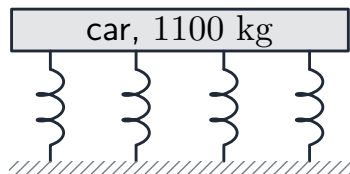
(a) **compression**

Exercise 3.4 (b)

3.4 A spring in a car suspension has a spring constant of $3.2 \times 10^4 \text{ N m}^{-1}$. Four such springs share the weight of a car of mass 1100 kg equally.

(b) Calculate the compression of each spring.

[2]



four springs

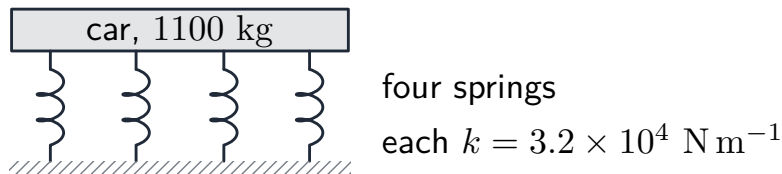
each $k = 3.2 \times 10^4 \text{ N m}^{-1}$

Exercise 3.4 (b)

3.4 A spring in a car suspension has a spring constant of $3.2 \times 10^4 \text{ N m}^{-1}$. Four such springs share the weight of a car of mass 1100 kg equally.

(b) Calculate the compression of each spring.

[2]



(b) each spring carries a quarter of the weight: $F = \frac{mg}{4} = \frac{1100 \times 9.81}{4} = 2700 \text{ N}$

$$x = \frac{F}{k} = \frac{2700 \text{ N}}{3.2 \times 10^4 \text{ N m}^{-1}} = \mathbf{0.084 \text{ m}}$$

Exercise 3.4 (c)

3.4 A spring in a car suspension has a spring constant of $3.2 \times 10^4 \text{ N m}^{-1}$. Four such springs share the weight of a car of mass 1100 kg equally.

(c) Four passengers with a total mass of 280 kg get in. Calculate how far the car sinks.[2]

Exercise 3.4 (c)

3.4 A spring in a car suspension has a spring constant of $3.2 \times 10^4 \text{ N m}^{-1}$. Four such springs share the weight of a car of mass 1100 kg equally.

(c) Four passengers with a total mass of 280 kg get in. Calculate how far the car sinks.[2]

(c) extra force on each spring, a quarter of the extra weight: $\Delta F = \frac{\Delta m g}{4} = \frac{280 \times 9.81}{4} = 687 \text{ N}$

$$\Delta x = \frac{\Delta F}{k} = \frac{687 \text{ N}}{3.2 \times 10^4 \text{ N m}^{-1}} = \mathbf{0.021 \text{ m}}$$