Forces and elasticity

4.5.3 · Forces · revision notes

Stretching, squashing or bending an object needs more than one force. You need F = k e, the difference between elastic and inelastic deformation, the limit of proportionality, force–extension graphs and the required practical on a spring. The equation for elastic potential energy, $E_e = ½ k e^2$, is given on the equations sheet.

Key facts

- F = k e (force = spring constant × extension)
- Extension = stretched length − original length
- F ∝ e up to the limit of proportionality
- $E_e = ½ k e^2$ (on the equations sheet)
- Units: F in N, k in N/m, e in m
- Elastic deformation: returns to original shape; inelastic deformation: does not
- Gradient of a force–extension graph (force on the y-axis) = k
- Work done stretching = elastic potential energy stored (if the spring returns to its original length)

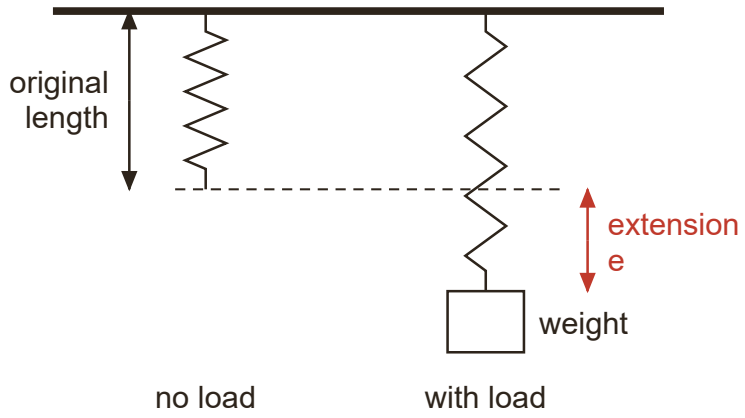
Notes

Changing shape

- To stretch, bend or compress an object you need **more than one force**. To stretch a spring, you pull on both ends, or hang a weight from it while a clamp holds the top.
- With only one force on it, a stationary object would start to move instead of changing shape.
- **Elastic deformation**: the object returns to its original length and shape when the forces are removed.
- **Inelastic deformation**: the object does not return to its original length and shape when the forces are removed.

Force and extension: F = k e

- force = spring constant × extension: **F = k e**
- F in newtons (N), k in newtons per metre (N/m), e in metres (m).
- Extension is the **increase** in length: extension = stretched length − original length. The same equation works for compression.

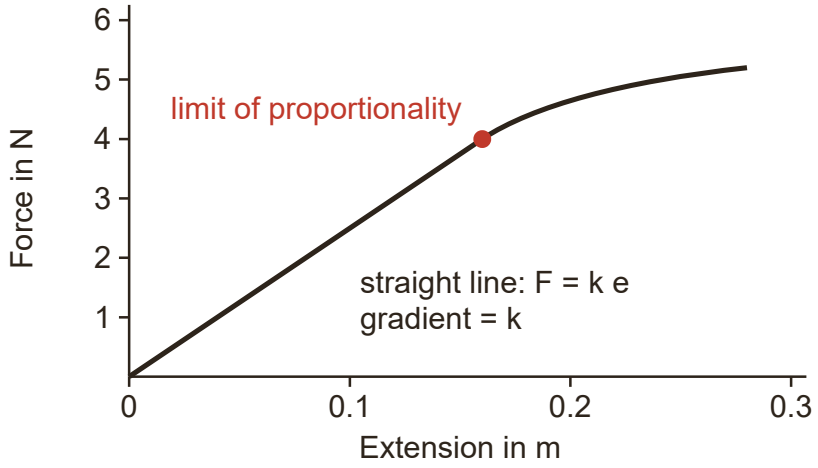


Extension = stretched length − original length.

- The extension of an elastic object is **directly proportional** to the force applied, provided the **limit of proportionality** is not exceeded.

Force–extension graphs

- With force on the y-axis and extension on the x-axis, the graph is a straight line through the origin (linear) up to the limit of proportionality.
- The gradient of this straight section is the spring constant, k.
- Beyond the limit of proportionality the line curves (non-linear): extension is no longer proportional to force.



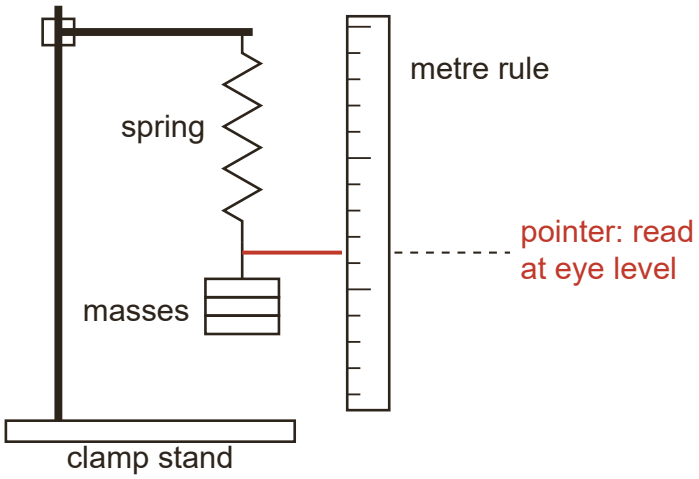
Straight up to the limit of proportionality (here k = 4.0 ÷ 0.16 = 25 N/m), then it curves.

Elastic potential energy

- A force that stretches or compresses a spring does work, and elastic potential energy is stored in the spring.
- Provided the spring goes back to its original length (it is not inelastically deformed), the work done on the spring equals the elastic potential energy stored.
- $E_e = ½ k e^2$ (given on the equations sheet), with E_e in joules (J). Only use it up to the limit of proportionality.

Required practical: force and extension of a spring

- Clamp the spring next to a vertical metre rule and measure its original length.
- Hang weights in equal steps. Each time, measure the new length and calculate the extension. Read the ruler at eye level, using a pointer on the bottom of the spring.



Force and extension of a spring: add masses in equal steps and read the pointer each time.

- Independent variable: the force. Dependent variable: the extension. Control variable: the same spring.
- Wait for the spring to stop moving before each reading. Take at least five readings.
- Hazard: falling masses or a snapping spring. Keep feet clear, put a tray under the masses and wear eye protection.
- Plot force against extension. A straight line through the origin shows extension is directly proportional to force.

How to answer each type of question

Calculate using F = k e

2 to 3 marks | Grade 5

1. Work out the extension (new length − original length).
2. Convert it to metres.
3. Substitute into F = k e (or rearrange for k or e).

Example. A spring has a spring constant of 25 N/m. Its original length is 12.0 cm. A force stretches it to a length of 18.0 cm. The limit of proportionality is not exceeded.
Calculate the force.

Model answer.

extension = 18.0 − 12.0 = 6.0 cm = 0.060 m (1)

F = 25 × 0.060 (1)

F = 1.5 N (1)

Interpret a force–extension graph

2 to 3 marks | Grade 5

1. Check which quantity is on each axis.
2. Use a point on the straight section to find k = F ÷ e.
3. A curve shows that the limit of proportionality has been exceeded.

Example. A student's force–extension graph for a spring is a straight line through the origin up to a force of 4.0 N, when the extension is 0.16 m. After that, the line curves.
(a) Calculate the spring constant.
(b) What does the curved part of the graph show?

Model answer.

(a) k = 4.0 ÷ 0.16 (1)

k = 25 N/m (1)

(b) The limit of proportionality has been exceeded, so the extension is no longer directly proportional to the force (1).

Calculate elastic potential energy

2 to 3 marks | Grade 5

1. Make sure the extension is in metres.
2. Square the extension first, then multiply by k and by 0.5.
3. Give the answer in J.

Example. A spring with a spring constant of 80 N/m is stretched by 0.25 m. It does not pass its limit of proportionality.
Calculate the elastic potential energy stored in the spring.

Model answer.

$E_e = 0.5 \times 80 \times 0.25^2$ (1)

$E_e = 2.5$ J (1)

Describe the required practical

4 to 6 marks | Grade 5

1. Say how the spring and ruler are set up and what you measure first.
2. Say how you change the force and what you measure each time.
3. Say how you calculate the extension and make readings accurate.
4. Say what you plot.

Example. Describe how a student could investigate the relationship between the force on a spring and its extension.

Model answer.

Clamp the spring vertically next to a metre rule and measure its original length (1).
Hang a known weight (e.g. 1.0 N) on the spring and measure the new length (1).
Read the ruler at eye level / use a pointer attached to the bottom of the spring (1).
Calculate the extension = new length − original length (1).
Repeat for at least five different weights (1).
Plot a graph of force against extension (1).

Don’t lose marks

- Using the stretched length instead of the extension.
- Forgetting to convert cm or mm to metres.
- Using $E_e = ½ k e^2$ beyond the limit of proportionality.
- Plotting extension on the y-axis and calling the gradient k. With extension on the y-axis, the gradient is 1 ÷ k.
- Squaring k × e instead of squaring only the extension.

More tips

Memory tricks

- Extension, not length: always subtract the original length first.
- cm to m: divide by 100, so 6.0 cm = 0.060 m.
- Stiff spring = steep force–extension line = big k.
- For ½ k e^2, square the extension first, then multiply by k, then halve.

Exam technique

- $F = k\,e$ and $E_e = ½\,k\,e^2$ are both on the equations sheet: pick the right one, convert the extension to metres and rearrange.
- Before using a graph, check which quantity is on each axis.
- In method questions, name the instrument (metre rule), what you measure (length), what you calculate (extension) and what you plot.

What each grade needs

What you need to be able to do, from the first marks up to the top grade.

Grade 3

Explain why more than one force is needed

To stretch, bend or compress an object, forces must act on it in different directions.

Grade 4

Distinguish elastic and inelastic deformation

An elastically deformed object returns to its original shape when the forces are removed; an inelastically deformed one does not.

Grade 5

Calculate force or extension with F = ke

For example, k = 40 N/m and e = 0.15 m give F = 6.0 N.

Grade 5

Describe the spring extension required practical

Hang known weights on a spring, measure its length each time, calculate the extension and plot force against extension.

Grade 5

Interpret linear and non-linear force–extension graphs

A straight line through the origin shows $F \propto e$ with gradient k; the line curves beyond the limit of proportionality.

Grade 5

Calculate elastic potential energy stored

Use $E_e = 0.5 \times k \times e^2$, up to the limit of proportionality.

Grade 7

Link work done to energy stored

As long as the spring goes back to its original length, the work done stretching it equals the elastic potential energy stored.

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