Edexcel GCSE Physics

Your notes

Forces & Elasticity

Contents

Changing Shape

Your notes

Forces & Changing Shape

- For stationary objects, **multiple forces** have to be applied to **change** their **shape**
- Objects can change their shape by:
  - Stretching
  - Bending
  - Compressing
- A combination of all three shape changes can also occur

Compression

- An object is **compressed** when forces act
  - In opposite directions
  - Towards the object
- An example of **compression** is placing a mass on top of a spring placed on a flat surface
- The two forces are:
  - The weight of the mass on the spring
  - The reaction force of the surface on the spring

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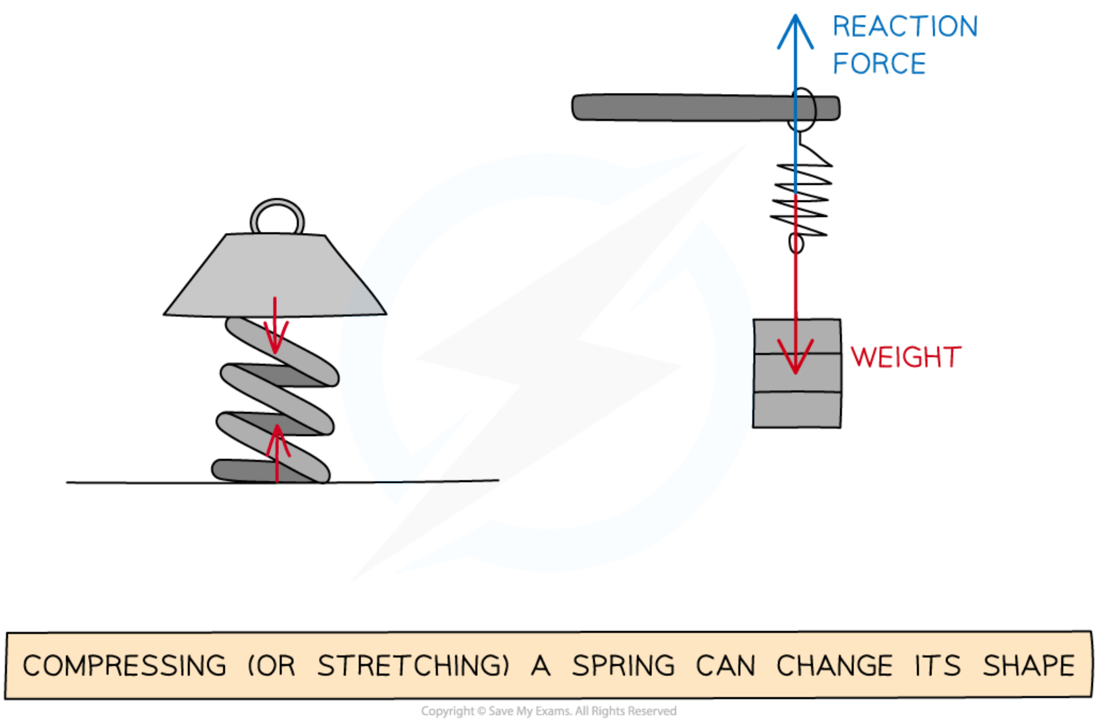


The compression or stretching of a spring requires two forces

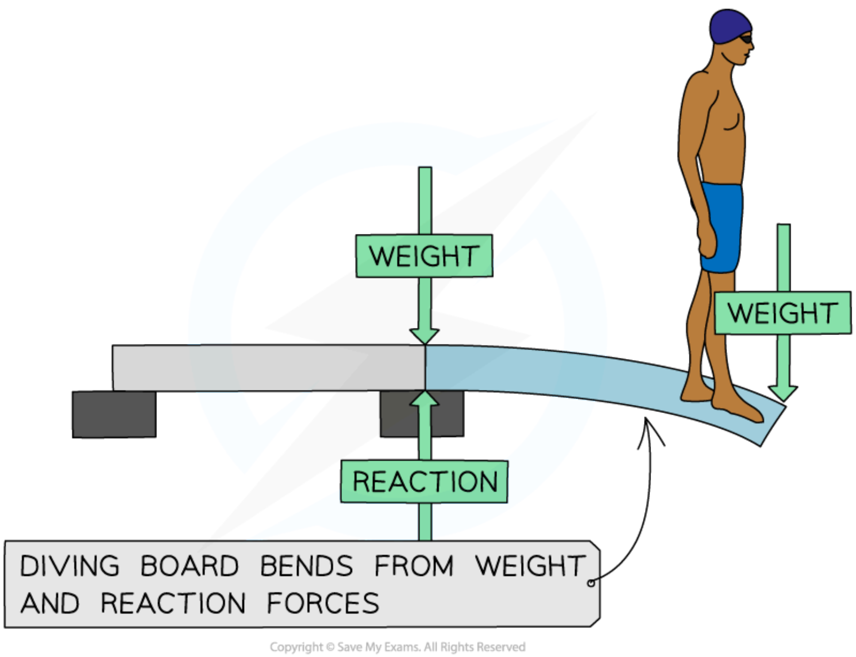
Stretching

- An object is **stretched** when forces act:
  - In opposite directions
  - Away from the object
- An example of **stretching** is placing a mass on the bottom of a spring hanging vertically from a rod
- The two forces are:
  - The **weight** of the mass of the mass on the spring
  - The tension in the spring
- These two opposing forces cause a **tension force** in the spring

Bending

- An object is **bent** when multiple forces act:
  - In opposing directions

- At different points on the object
- An example of **bending** is a diving board bending when a swimmer stands at the far end
- The two forces are:
  - The **weight** of the swimmer on the diving board
  - The **reaction force** of the block on the dividing board



Forces on a diving board cause it to be bend when a swimmer stands on one end

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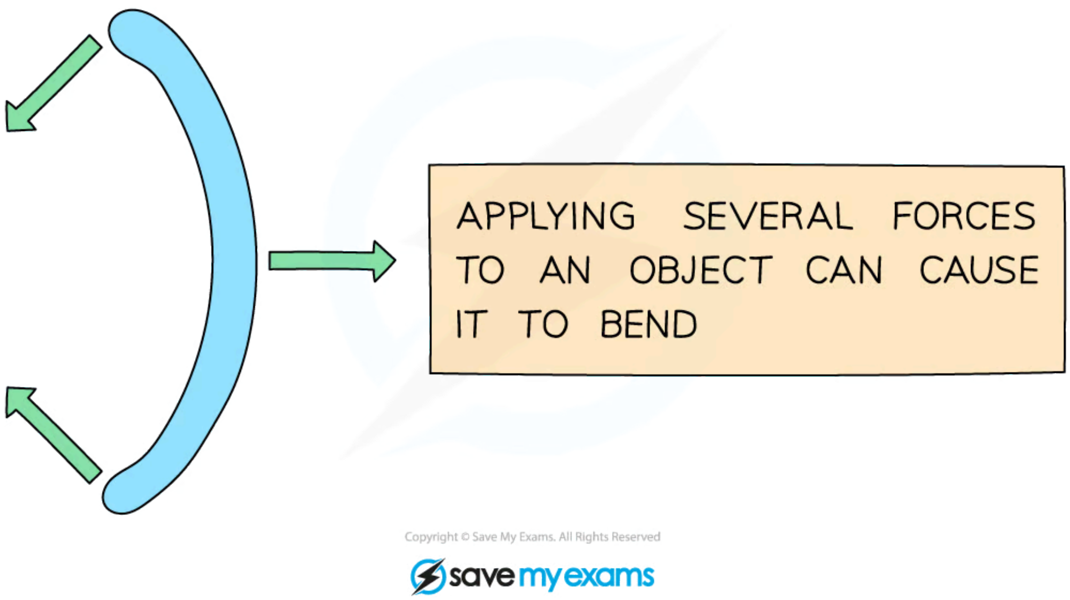

More than one force on an object can cause it to bend

Elastic & Inelastic Distortion

- When some objects, such as springs or rubber bands, are stretched they will return to their original shape and length once the forces are removed
  - Other materials, such as plastic, remain permanently distorted (stretched)

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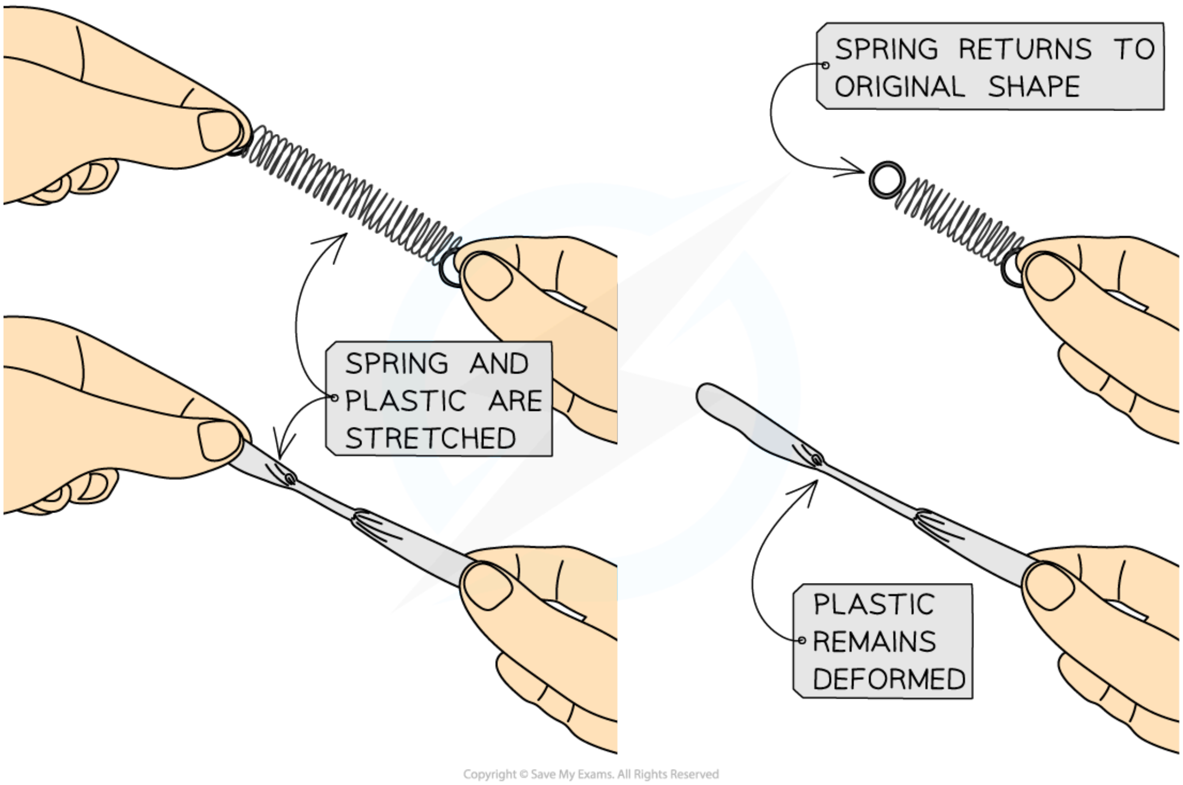

Elastic materials return to their original shape and size after stretching whilst plastic materials don't

- A change of shape is called a **distortion** and can either be:
  - Elastic
  - Inelastic

Elastic Distortion

- Elastic distortion occurs:

  When objects return to their original shape when the stretching force is removed

- Examples of materials that undergo elastic distortion are:
  - Rubber bands
  - Fabrics
  - Steel springs

Inelastic Distortion

- Inelastic distortion occurs:

  When objects remain stretched and do not return completely to their original shape even when the stretching force is removed

- Examples of materials that undergo inelastic distortion are:
  - Plastic
  - Clay
  - Glass

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Hooke's Law

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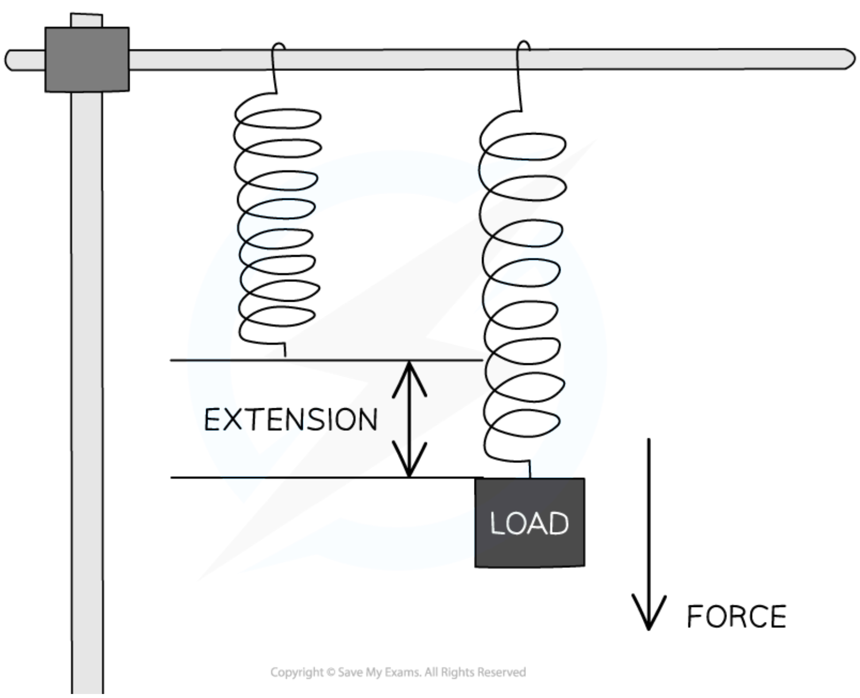
Hooke's Law

- The relationship between the extension of an elastic object and the applied force is defined by **Hooke's Law**
- Hooke's Law states that:

  The extension of an elastic object is directly proportional to the force applied, up to the limit of proportionality

- Directly proportional means that as the force is increased, the extension increases
  - If the force is doubled, then the extension will double
  - If the force is halved, then the extension will also halve
- The **limit of proportionality** is the point beyond which the relationship between force and extension is no longer directly proportional
  - This limit varies according to the material



Hooke's Law states that a force applied to a spring will cause it to extend by an amount proportional to the force

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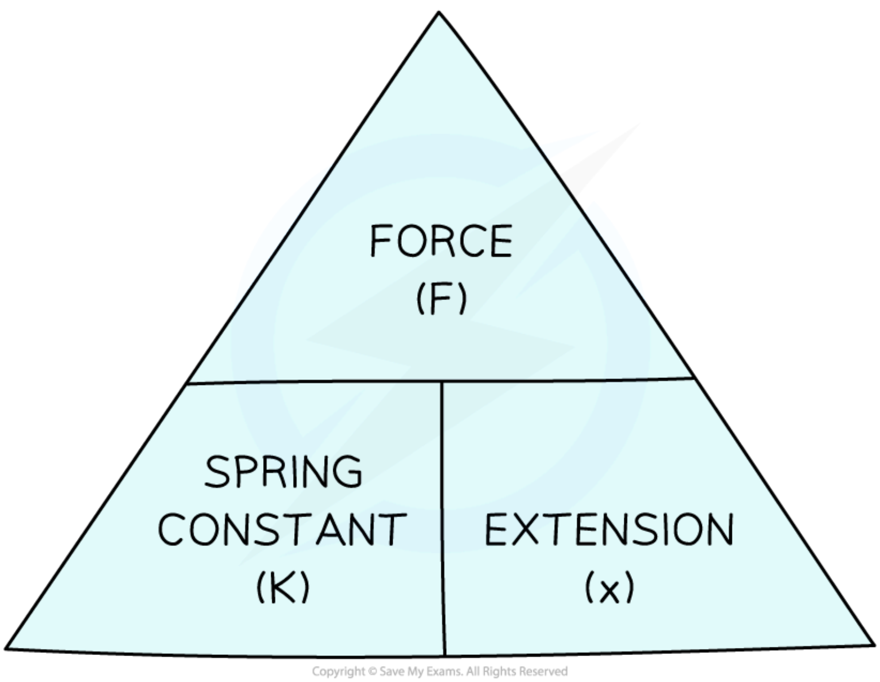
- Hooke's Law is defined by the equation:

$$F = k \times x$$

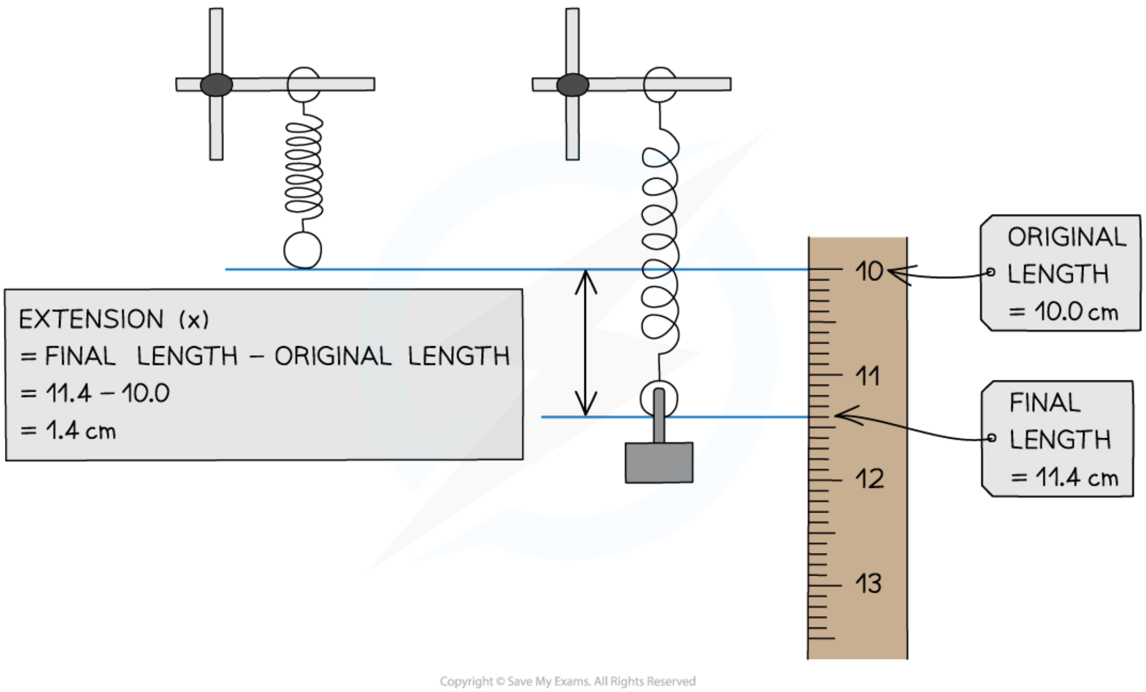
- Where:
  - F = force in newtons (N)
  - k = spring constant in newtons per metres (N/m)
  - x = extension in metres (m)
- The symbol x can represent either the extension **or** compression of an elastic object
- The Hooke's law equation can be rearranged using the following formula triangle:



- The spring constant represents how **stiff** a spring is
  - The higher the **spring constant**, the higher the **stiffness**
- The extension of an object can be calculated by:

Final length – Original length

- The extension of the spring can be measured by marking the position of bottom of the unstretched spring
- When the spring is stretched the final length must be measured from the bottom of the spring



The extension measured from its final and original length

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Worked Example

The figure below shows the forces acting on a child who is balancing on a pogo stick. The child and pogo stick are not moving.

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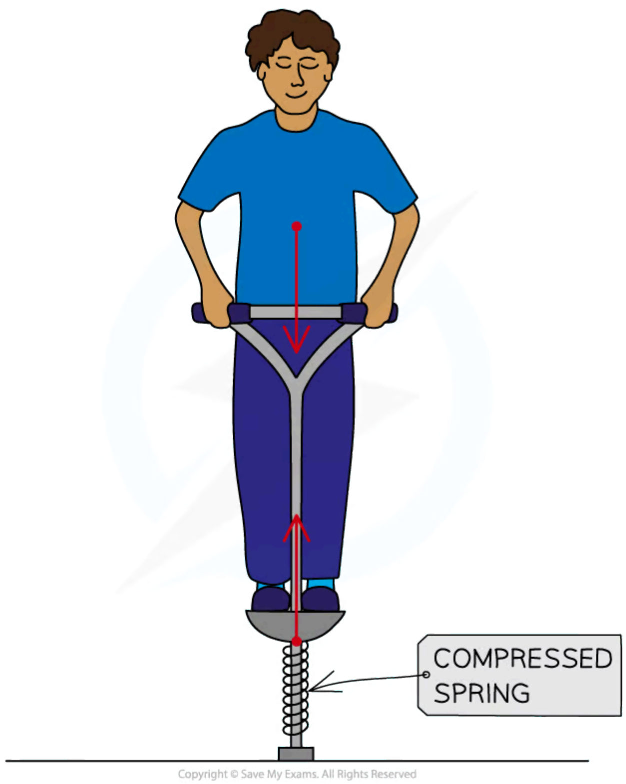

The spring constant of the spring on the pogo stick is 4900 N/m. The weight of the child causes the spring to compress elastically from a length of 40 cm to a new length of 33 cm. Calculate the weight of the child.

Answer:

Step 1: List the known quantities

- Spring constant, k = 4900 N/m
- Original length = 40 cm
- Final length = 33 cm

Step 2: Write the relevant equation

$$F = kx$$

Step 3: Calculate the extension, x

$$x = \text{final length} - \text{original length} = 40 - 33 = 7 \text{ cm}$$

Step 4: Convert any units

- Since the spring constant is given in N/m, x must be in metres (m)

$$7 \text{ cm} = 0.07 \text{ m}$$

Step 5: Substitute the values into the Hooke's Law equation

$$F = 4900 \times 0.07 = \mathbf{343\ N}$$

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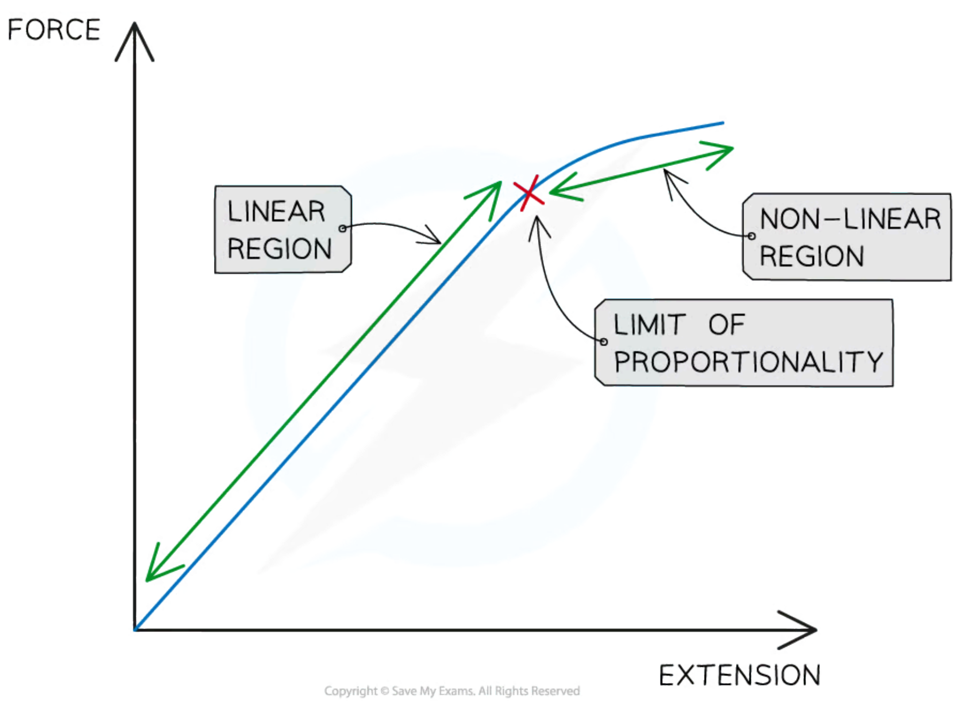
Examiner Tips and Tricks

Look out for unit conversions! Unless the spring constant is given in N/cm, make sure the extension is converted into **metres** (÷ 100) before substituting values into the Hooke's Law equation

Linear & Non-Linear Stretching

- Hooke's law is the **linear** relationship between force and extension
  - This is represented by a **straight line** on a force-extension graph
- Materials that do **not** obey Hooke's law, i.e they do not return to their original shape once the force has been removed, have a **non-linear** relationship between force and extension
  - This is represented by a **curve** on a force-extension graph
- Any material beyond its limit of proportionality will have a non-linear relationship between force and extension



Linear and non-linear regions of a force-extension graph

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Examiner Tips and Tricks

Remember these important mathematical terms:

- **Proportional** = when a graph is a straight line going through the origin
- **Linear** = when a graph is a straight line (but does not necessarily go through the origin)
- **Non-linear** = when a graph is not a straight line

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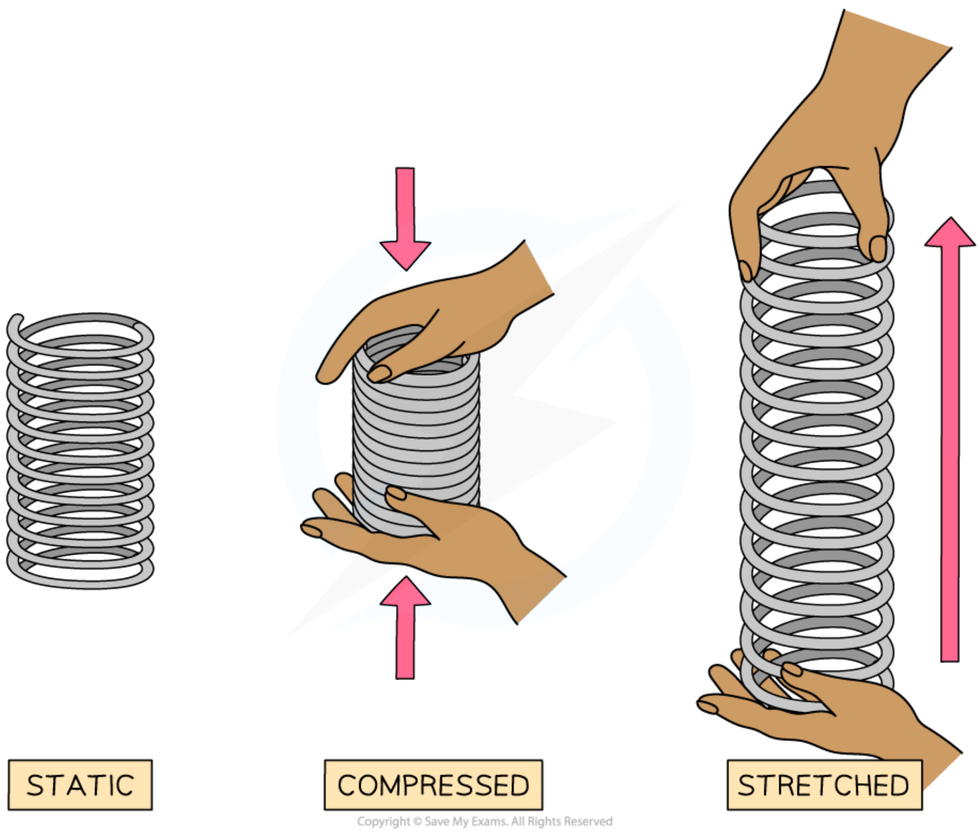
Elastic Potential Energy

Elastic Potential Energy

- When a spring is stretched or compressed by a force, **work** is done by the spring
- Work done is the transfer of energy
  - The energy is transferred to its **elastic potential energy** store



When a spring is stretched or compressed, there is work done and elastic potential energy is stored

- Elastic potential energy is defined as:

  The energy stored in an elastic object when work is done on the object

- Provided the spring is not inelastically distorted (i.e has not exceeded its limit of proportionality), the work done on the spring and its elastic potential energy stored are **equal**

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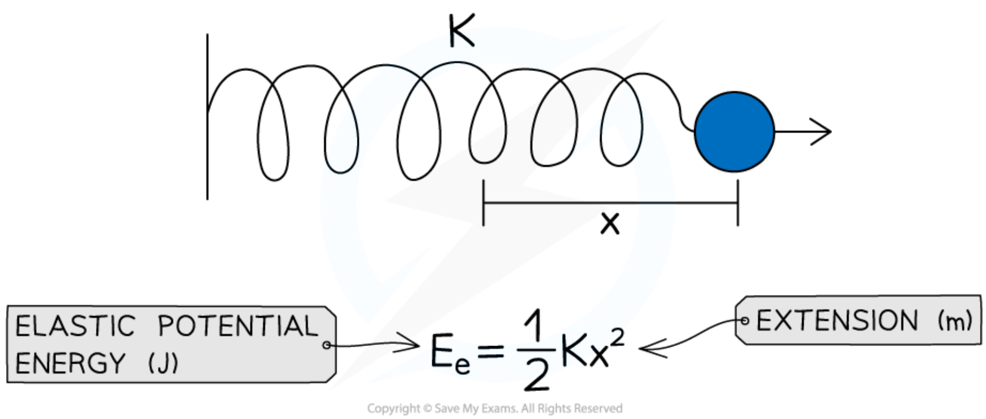
- The work done, or the elastic potential energy stored, while stretching or compressing a spring can be calculated using the equation:

$$E = \tfrac{1}{2} k x^2$$

- Where:
  - E = elastic potential energy (energy transferred in stretching) in joules (J)
  - k = spring constant in newtons per metre (N/m)
  - x = extension in metres (m)



The elastic potential energy in a stretched spring depends on its spring constant and extension

- This equation is only for springs that have not been stretched beyond their **limit of proportionality**
  - The term x^2 means that if the extension is **doubled** then the work done is **quadrupled**
  - This is because $2^2 = 4$

Worked Example

A mass is attached to the bottom of a hanging spring with a spring constant *k* and 0.2 J of work is done to stretch it by 4.5 cm. Calculate the spring constant, *k* for this spring.

Answer:

Step 1: List the known quantities

- Work done / elastic potential energy, $E = 0.2$ J
- Extension, $x = 4.5$ cm

Step 2: Write down the relevant equation

$$E = \frac{1}{2}kx^2$$

Step 3: Rearrange for the spring constant, *k*

- Multiply by 2 on both sides

$$2E = kx^2$$

- Divide by x^2 to make k the subject

$$\frac{2E}{x^2} = k$$

Step 4: Convert any units

- The extension should be in metres

$$4.5 \text{ cm} = 0.045 \text{ m}$$

Step 5: Substitute the values into the equation

$$k = \frac{2 \times 0.2}{(0.045)^2} = 198 \text{ N/m}$$

Examiner Tips and Tricks

Remember: when calculating the work done the extension, x, is **squared** (x^2)!

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Core Practical: Investigating Force & Extension

Core Practical 7: Investigating Force & Extension

Aim of the Experiment

- The aim of this experiment is to investigate the relationship between force and extension for a spring

Variables:

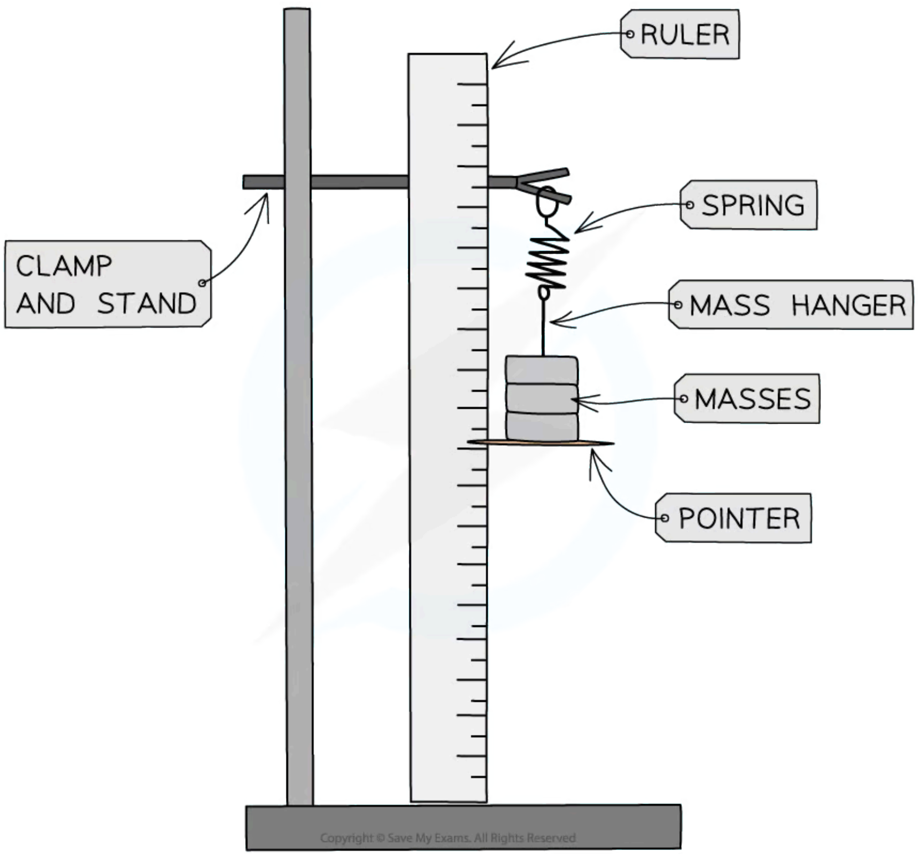
- **Independent variable** = Force, *F*
- **Dependent variable** = Extension, *x*
- Control variables:
  - Spring constant, *k*

Equipment List

Equipment	Purpose
Clamp and stand	To hold the spring and masses
Ruler	To measure the extension of the spring
Spring	To measure the extension of
5 × 100g masses	To apply a force to the spring
100g mass hanger	To hold the additional masses
Pointer (fiducial marker)	To accurately read the extension from the ruler

- **Resolution** of measuring equipment:
  - Ruler = 1 mm

Method



Investigating Hooke's law apparatus

1. Set up the apparatus as shown in the diagram, initially without any masses hanging from the spring
2. Align the marker to a value on the ruler, record this initial length of the spring
3. Add the 100 mass hanger onto the spring
4. Record the mass (in kg) and position (in cm) from the ruler now that the spring has extended
5. Add another 100 g to the mass hanger
6. Record the new mass and position from the ruler now that the spring has extended further
7. Repeat this process until all masses have been added
8. The masses are then removed and the entire process repeated again, until it has been carried out a total of three times, and an average length is calculated

- An example table of results might look like this:

F = mg

AVERAGE LENGTH – ORIGINAL

MASS/kg	FORCE/N	LENGTH 1/m	LENGTH 2/m	LENGTH 3/m	AVERAGE LENGTH/m	EXTENSION/m
0						
0.1						
0.2						
0.3						
0.4						
0.5						
0.6						

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Analysis of Results

- The force, *F* added to the spring is the **weight** of the mass
- The weight is calculated using the equation:

$$W = mg$$

- Where:
  - *W* = weight in newtons (N)
  - *m* = mass in kilograms (kg)
  - *g* = gravitational field strength on Earth in newtons per kg (N/kg)
- Therefore, multiply each mass by gravitational field strength, *g*, to calculate the force, *F*
  - The force can be calculated by multiplying the mass (in kg) by 10 N/kg
- The extension of the spring is calculated using the equation:

Final length – Original length

- The final length is the length of the spring recorded from the ruler when the masses were added
- The original length is the length of the spring when there were **no** masses

1. Plot a graph of the force against extension

2. Draw a line of best fit
3. If the graph has a **linear** region (is a straight line), then the force is **proportional** to the extension and the spring obeys Hooke's law for these forces and extension

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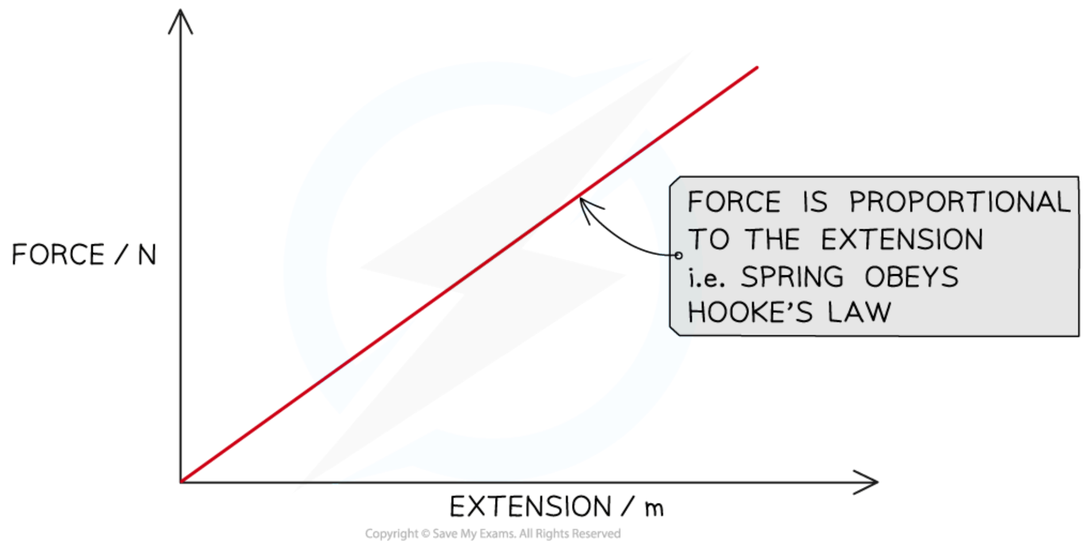

Example force-extension graph for a spring that obeys Hooke's law

Evaluating the Experiment

Systematic Errors:

- Make sure the measurements on the ruler are taken at eye level to avoid **parallax error**

Random Errors:

- The accuracy of such an experiment is improved with the use of a pointer (a fiducial marker)

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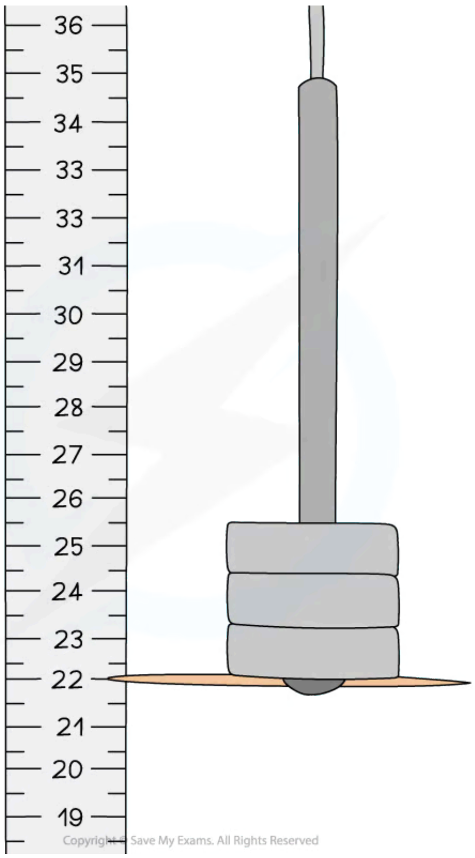

Fiducial marker to measure the extension more accurately

- Wait a few seconds for the spring to fully extend when a mass is added, before taking the reading for its new length
- Make sure to check whether the spring has not gone past its **limit of proportionality** otherwise, it has been stretched too far and will stop obeying Hooke's law

Safety Considerations

- Wear goggles during this experiment in case the spring snaps
- Stand up while carrying out the experiment making sure no feet are directly under the masses
- Place a mat or a soft material below the masses to prevent any damage in case they fall
- Use a G clamp to secure the clamp stand to the desk so that the clamp and masses do not fall over
  - As well as this, place each mass carefully on the hanger and do not pull the spring too hard that it breaks or pulls the apparatus over

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Examiner Tips and Tricks

Remember - the extension measures how much the object has stretched by and can be found by **subtracting the original length from each of the subsequent lengths.** A common mistake is to calculate the increase in length by each time instead of the total extension – if each of your extensions is roughly the same then you might have made this mistake!