AS Level Physics

Chapter 5 – Materials

5.1.1 Springs

Notes

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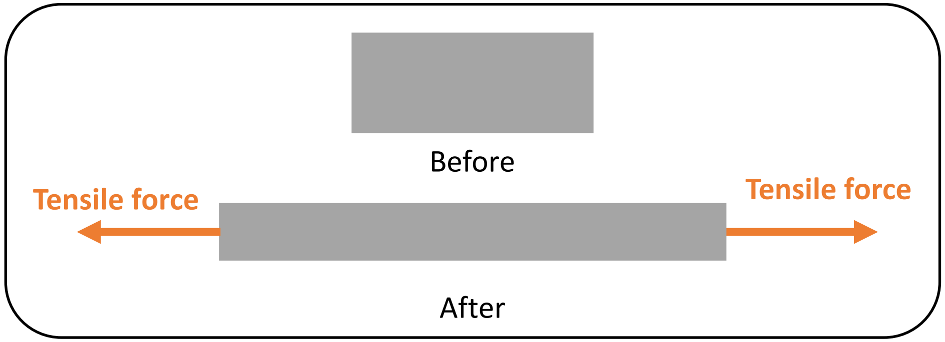
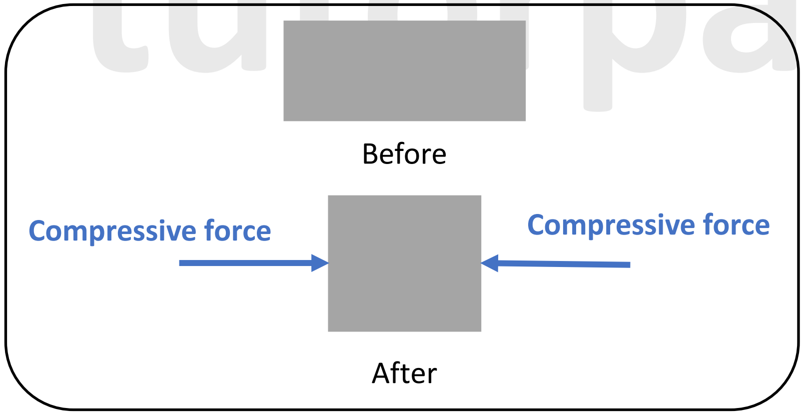
TENSILE AND COMPRESSIVE DEFORMATION

It takes a **pair of forces** to change the shape of a solid object.

Forces that **stretch** a solid object are called **TENSILE** forces.

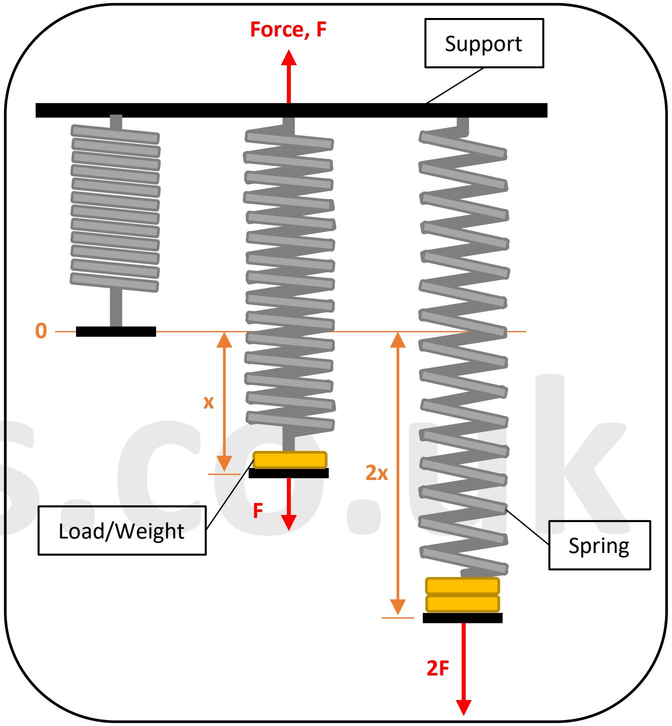


Forces that squeeze or shorten an object are called compressive.



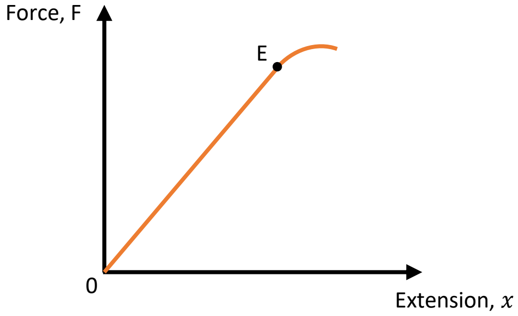
HOOKE'S LAW

- When a weight is attached to a helical spring (supported at the top) it will stretch. This weight will pull down on the spring with force, F producing an equal and opposite force at the support.



- If you continue to use the same spring and add different amount of weight on it you will notice that the greater the load (the force stretching the spring), the greater its extension (increase in length).
- Recording the amount of weight (or force) and the extension, you can plot a force (F) against extension (x) graph.

HOOKE'S LAW



- The graph is a straight line from **0E**, therefore applied load, F, is proportional to extension, x. This means:

$$\boldsymbol{Extension\ (x) \propto Force(F)}$$

- An equation can be formed from the where the constant of proportionality is called the **force constant, k**. From which:

$$\boldsymbol{F = kx}$$

Where:

F = Applied force measured in N.

k = force constant, spring constant or stiffness measured in $N\ m^{-1}$.

x = extension measured in m.

$\boldsymbol{k = F/x}$

- The gradient from the F/x graph will give us k.
- k tells us how many newtons are needed to stretch the spring by 1 metre.
- The stiffer the spring, the greater is the k-value.

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HOOKE'S LAW

For section 0E, the spring obeys Hooke's Law:

- For a spring to obey Hooke's Law the extension needs to be directly proportional to the applied force.
- Hooke's Law is only valid as long as the ELASTIC LIMIT is not exceeded.

Beyond point E, the graph is no longer a straight line.

- This is because the spring is permanently deformed due to a greater force being applied. Thus, when this force is removed the spring can not go back to its original shape.

Point E is known as the ELASTIC LIMIT. This is where:

1. The graph starts to curve and is no longer straight.
2. Hooke's law is no longer obeyed by the material.
3. Permanent deformation occurs.
4. The material no longer behaves elastically.

Metals obey Hooke's law up to a point called the limit of proportionality, which is very close to the elastic limit.

Other materials such as rubber only obey Hooke's law for very small extensions.

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HOOKE'S LAW

Hooke's Law can also work by compressing a spring.

This just results in an reduction of x and $F = kx$ still applies.

Hooke's Law – states that extension is proportional to force applied as long as the elastic limit is not exceeded.

HOOKE'S LAW

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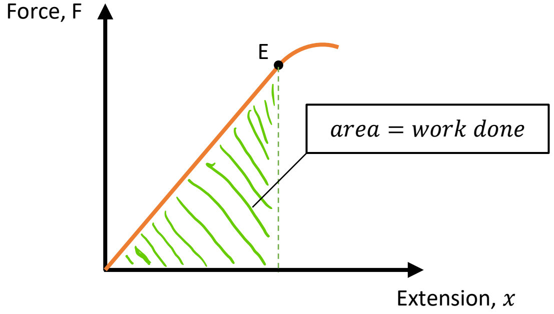
ELASTIC POTENTIAL ENERGY (EPE)

Energy is stored when an object is stretched or compressed elastically (i.e. inelastic deformation has not occurred and elastic limit hasn't been reached). This energy is known as the elastic potential energy.

The area under a force-extension graph is equal to the work done on the wire in stretching. This work done is equal to the energy stored.



Elastic potential energy stored in the wire = work done by the average force

$$EPE = average\ force \times extension$$

$$EPE = \frac{1}{2} \times F \times x$$

EPE measured in Joules, J
F measured in newtons, N
x measured in metres, m
k measured in Nm^{-1}

You need to take the average force because the force **isn't constant**. It rises from zero to force, F.

$$\boldsymbol{EPE = \frac{1}{2}Fx}$$

Because **Hooke's law is obeyed**, $\boldsymbol{F = kx}$

$$Therefore: EPE = \frac{1}{2} \times (kx) \times x$$

$$\boldsymbol{EPE = \frac{1}{2}kx^2}$$

EPE is stored until the force is removed and the object springs back to its original shape, doing work in the process.

If the material is stretched beyond the elastic limit (E), some work is done separating the atoms and deforming the material. This work done will not be stored and is non-recoverable.

ELASTIC POTENTIAL ENERGY (EPE)

Conservation of energy in stretches

Elastic potential energy is stored in a spring when it has a mass suspended vertically below causing it to stretch.

When this mass is released, the springs stored EPE is transferred to kinetic energy (as the spring contracts) and gravitational potential energy (GPE).

As the spring is now compressing, the KE is transferred back to stored EPE.

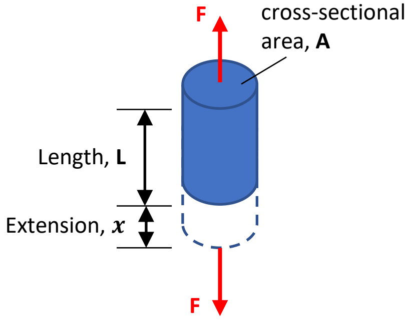
In reality, some KE is always transferred to heat and is lost. However, we generally ignore these losses in energy conservation calculations.

Overall the energy changes in an oscillating spring can be summed up as:

$$\Delta KE = \Delta PE$$

Where Potential energy (PE) includes both GPE and elastic potential energy.

STRESS AND STRAIN



Consider a wire sample of **original length (L)** and **cross-sectional area (A)** subjected to a **force (F)** and undergoing an **extension (x).**

- **Strain (or tensile strain)**

Strain is defined as the **extension, e** (change in length) of a material per **unit original length, L**.

Both extension, e and length, L are measured in **metres.**

$$strain = \frac{e}{L}$$

- **Strain has no units.**

This is because extension and length are measured in metres and as extension is divided by the length the metres cancel themselves out.

Stress (or tensile Stress)

Stress is defined as **applied force, F** acting per unit **cross-sectional area, A** of the material.

$$stress = \frac{\overset{(N)}{F}}{\underset{(m^2)}{A}}$$

Stress is measured in Pascals (Pa or Nm^{-2})

STRESS AND STRAIN

Stress is a measure of the force put over an area of an object that causes deformation. Tensile stress is when forces pull on an object and causes its elongation for example stretching of an elastic band. Compressive stress is when forces cause a compression of an object.

Strain measures how much an object is stretched or deformed and is focused around the change in length of an object. Tensile strain is when strain is under tensile stress.

Stress and strain can have a linear relationship where the greater the stress, the greater the strain. However, this is not always the case.

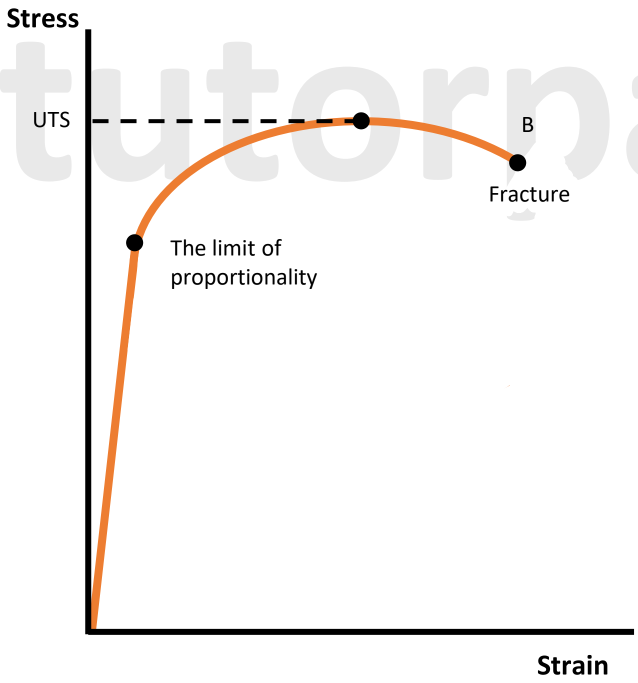
Stress and strain can be used to compare two materials and their properties.

Whether the force producing the strain and stress are tensile or compressive, the formula is still the same.

However, tensile force is usually considered to be positive whereas compressive force is considered to be negative.

ULTIMATE TENSILE STRESS (UTS)

- The stress on a material increases as the tensile force applied on the material increases.
- Stress results in the atoms to be pulled apart from one another.
- At a point, where the stress becomes so large, the atoms separate completely leading to the material to break. This is shown below at point B. The stress at which this occurs is called the fracture stress (or breaking stress).
- Ultimate tensile stress (UTS) is the maximum stress the material can withstand while being stretched or pulled.



YOUNG'S MODULUS

The stress and strain of a material are proportional to each other up to the point of limit of proportionality.

Thus, stress divided by strain is a constant below this limit. This constant is known as the Young's modulus, E.

$$\boldsymbol{Young's\ Modulus, E = \frac{Stress}{Strain} = \frac{F/A}{x/l} = \frac{F\,L}{A\,x}}$$

Where:

E = Young's Modulus in Pascals (Pa)

F = force in N

A = cross-sectional area in m^2

$\boldsymbol{x}$ = extension in m

$\boldsymbol{l}$ = initial length in m

NOTE:

- The Young's modulus (E) is the ratio of stress to strain and it tells us the how easily a material can stretch and be deformed.
- A high Young's modulus value means a solid is inelastic or stiff. Therefore when Engineers are choosing materials for beams, used in bridges to allow them to withstand larger loads, they consider materials with high Young's modulus.
- Young modulus has the same units as stress since strain has no units.
- The units of Young modulus is the Pascal (Pa) – $(1Pa = 1\ Nm^{-2})$

EXPERIMENT TO DETERMINE YOUNG MODULUS

Apparatus:

- Test wire, Weight (or mass), Ruler, Micrometre, Pulley, tape and a fixed support.

Method:

1) Start by attaching the test wire to the fixed support. The longer and thinner the wire, the more it will extend for the same force.

2) Place the smallest weight necessary to straighten the wire.

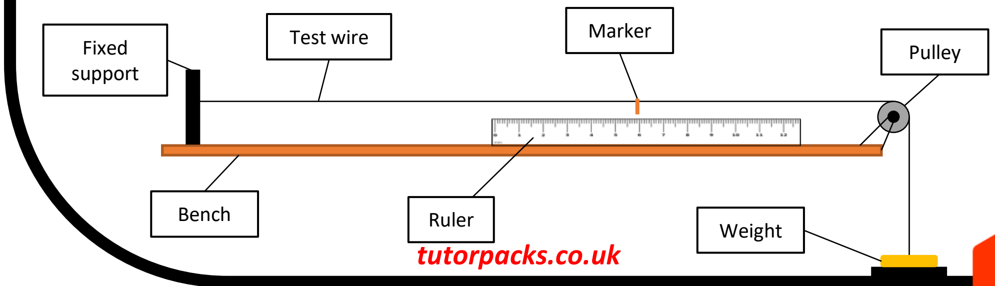
3) Use a micrometre, to measure the diameter of the wire at least 3 times in several different places. Then calculate the average of your measurements and use that to work out the average cross-sectional area of the wire.

4) Use a tape to make a marker on the test wire. Then measure the distance between the fixed end of the wire and the marker – this is the initial length (l).

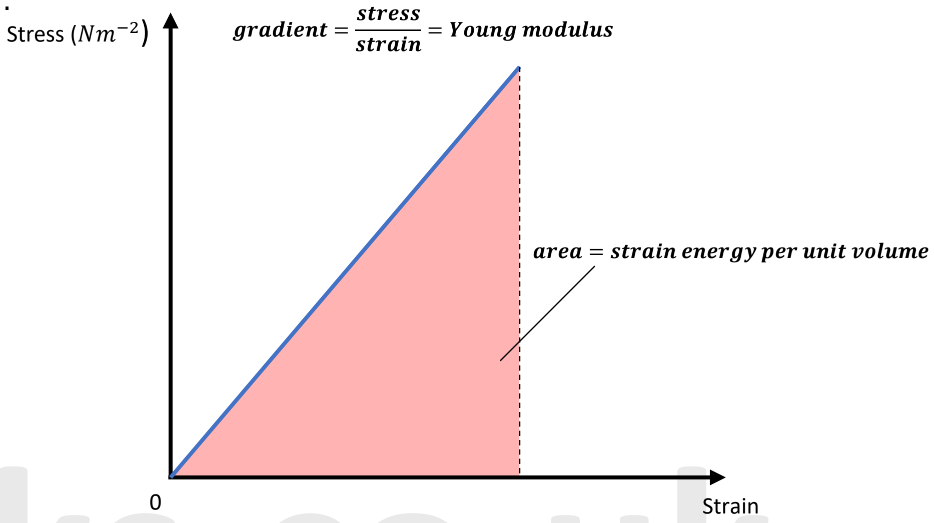
5) Then gradually increase the weight which will cause the wire to stretch and in turn will move the marker. Make sure to record the marker reading each time.

6) Calculate the extension by subtracting the marker reading and the unstretched length.

7) Once you have all your readings you can calculate the stress and strain values in order to plot a stress against strain graph.



STRESS-STRAIN GRAPH



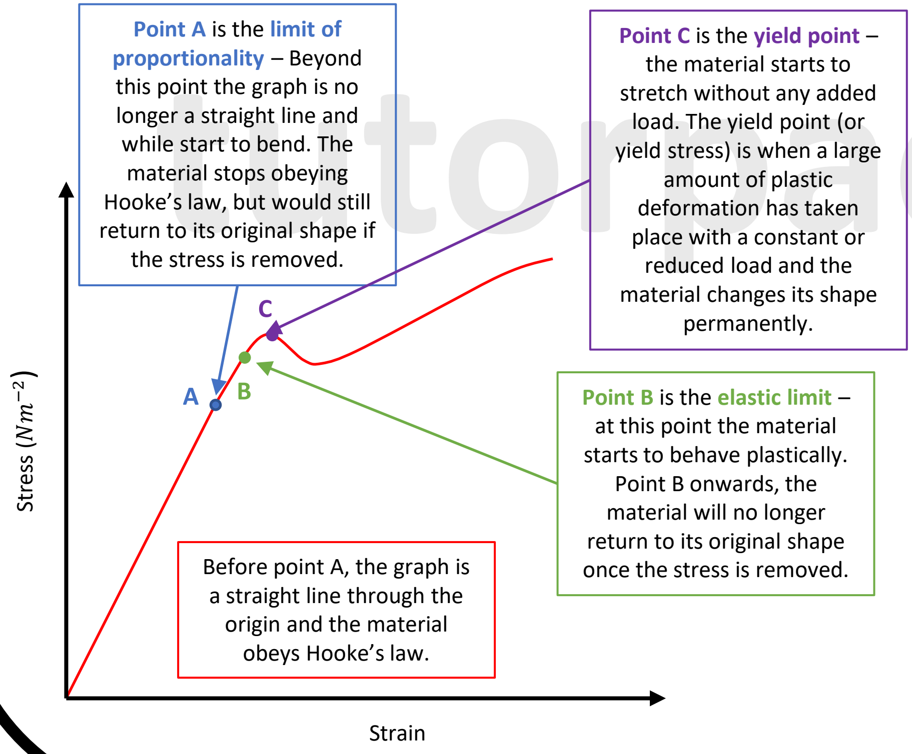
- The gradient of the graph represents the Young modulus, **E**.
- The strain energy (or energy stored) is represented by the area under the graph. This is the energy stored in a body due to deformation and it allows a material to return to its original shape when the applied force is released. This can only occur as long as Hooke's law is obeyed.
- The stress-strain graph is a straight line provided that Hooke's law is obeyed, so you can calculate the strain energy as shown below:

$$energy = \frac{1}{2} \times stress \times strain$$

DUCTILE, BRITTLE AND POLYMERIC MATERIALS

- Ductile material – have the ability to be drawn out into a thin wire or can plastically deform without fracture. It gives us an indication of how malleable a material is.
- Ductile materials can be deformed while maintaining their strength and toughness.
- **Example of ductile materials:** pure iron, copper, steel, aluminium, gold, silver and platinum.

The diagram below shows a stress-strain graph for a typical ductile material – e.g, a copper wire.



Point A is the **limit of proportionality** – Beyond this point the graph is no longer a straight line and while start to bend. The material stops obeying Hooke's law, but would still return to its original shape if the stress is removed.

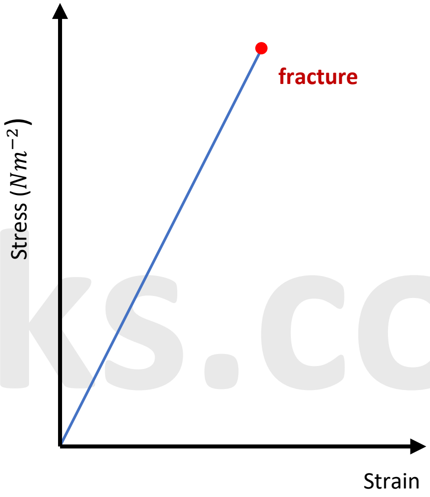
Point C is the **yield point** – the material starts to stretch without any added load. The yield point (or yield stress) is when a large amount of plastic deformation has taken place with a constant or reduced load and the material changes its shape permanently.

Point B is the **elastic limit** – at this point the material starts to behave plastically. Point B onwards, the material will no longer return to its original shape once the stress is removed.

Before point A, the graph is a straight line through the origin and the material obeys Hooke's law.

DUCTILE, BRITTLE AND POLYMERIC MATERIALS

- Brittle Materials – are materials that break or snap suddenly without deforming plastically. They have an elastic region but distort very little.
- **Example**: cast iron (which has carbon it in), glass and concrete.



The graph starts with a straight line through the origin and therefore brittle materials obey Hooke's law.

As the stress is gradually increased on a brittle material, the material stretches slightly, however, further increase in the applied stress causes fracture.

When large stress is suddenly applied to a brittle material, it will cause the material to shatter (i.e. dropping it on a hard surface).

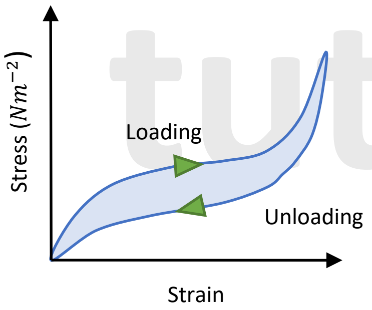
DUCTILE, BRITTLE AND POLYMERIC MATERIALS

- **POLYMERIC MATERIAL:** materials made of long, repeating chain of molecules each containing many atoms.

Some polymers behave in a brittle way where they stretch elastically up to a point and then break, for example Perspex. However, their behaviour can be changed by heating the material. This prevents the material from being brittle and instead becomes malleable allowing it to be formed into a desired shape.

Other polymers are easy to deform such as polythene. These materials are able to stretch plastically up to a point and then become stiffer and snap.

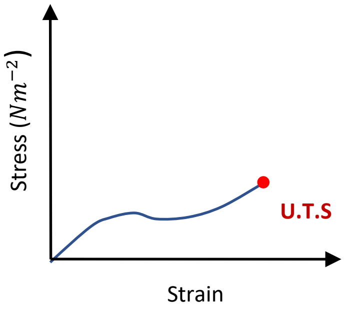
The stress-strain graph for rubber (a polymer) is shown below:



Rubber behaves elastically therefore it is able to return to its original length when the load is removed.

This graph shows a stress-strain graph of a polymeric material.

Polymetric material do not show linear behaviour, e.g. polyethene.



ELASTIC AND PLASTIC DEFORMATIONS MATERIALS

Elastic:

Elastic deformation is when a material can return to its original shape when the applied force is removed.

1) Without actually changing positions in a material, atoms are able to move small distances relative to their equilibrium point.
2) When a load is applied to a material, the material is put under tension. This causes the atoms in the material to be pulled apart slightly from one another.
3) Therefore when the applied force is removed, the atoms are able to return to their equilibrium which in turn means the material goes back to its original shape.

For a metal, elastic deformation happens as long as Hooke's law is obeyed.

Plastic:

Plastic deformation is when a material is permanently stretched/deformed.

1) Atoms in a material are able to move positions relative to one another.
2) So, when the applied load is removed, the atoms do not move back to their original position and the material is permanently deformed.

Metals stretched past their elastic limit show plastic deformation.

Brittle materials (such as glass, Perspex, cast iron) fracture before they reach the elastic limit and don't behave plastically.

Please see **'5.1.2 Springs Worked Examples'** pack for exam style questions.

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