MATERIALS

AQA Physics

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Materials

- ***Candidates should be able to*** *:*
  - *Describe how deformation is caused by a force in one dimensionand can be* ***tensile*** *or* ***compressive.***
  - *Describe the behaviour of springs and wires in terms of* ***force, extension, elastic limit, Hooke's Law*** *and the* ***force constant*** *(i.e. force per unit extension or compression).*
  - *Select and apply the equation* $F = kx$*, where* k *is the forceconstant of the spring or the wire.*
  - *Determine the* ***area under a force / extension (or compression) graph*** *to find the* ***work done by the force.***
  - *Select and use the equations for elastic potential energy* $E = \frac{1}{2} Fx$ *and* $E = \frac{1}{2} kx^2$*.*
  - *Define and use the terms* ***stress, strain, Young modulus*** *and* ***ultimate tensile strength (breaking stress).***
  - *Describe an experiment to determine the* ***Young modulus*** *of ametal in the form of a wire.*
  - *Define the terms* ***elastic deformation*** *and* ***plastic deformation*** *of a material.*
  - *Describe the shapes of the* ***stress / strain graphs*** *for typical*

ductile, brittle *and* ***polymeric*** *materials.*

3.4.2 Materials

3.4.2.1 Bulk properties of solids

Content	Opportunities for skills development
Density, $\rho = \frac{m}{V}$ Hooke's law, elastic limit, $F = k\Delta L$, k as stiffness and spring constant. Tensile strain and tensile stress. Elastic strain energy, breaking stress. $energy\ stored = \frac{1}{2}F\Delta L$ $= area\ under\ force-extension\ graph$ Description of plastic behaviour, fracture and brittle behaviour linked to force–extension graphs. Quantitative and qualitative application of energy conservation to examples involving elastic strain energy and energy to deform. Spring energy transformed to kinetic and gravitational potential energy. Interpretation of simple stress–strain curves. Appreciation of energy conservation issues in the context of ethical transport design.	**MS 0.2, 4.3 / PS 3.3, 4.1** Students can compare the use of analogue and digital meters. **MS 0.4, 4.3 / AT e** Estimate the volume of an object leading to an estimate of its density.

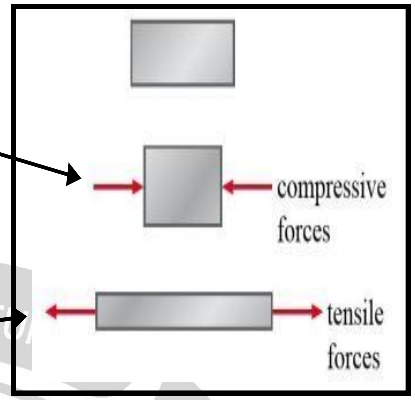
3.4.2.2 The Young modulus

Content	Opportunities for skills development
$Young\ modulus = \frac{tensile\ stress}{tensile\ strain} = \frac{FL}{A\Delta L}$ Use of stress–strain graphs to find the Young modulus. (One simple method of measurement is required.)	**MS 3.1**
Required practical 4: Determination of the Young modulus by a simple method.	

• A **pair of forces** is needed to change the **size and shape** of a spring or wire.

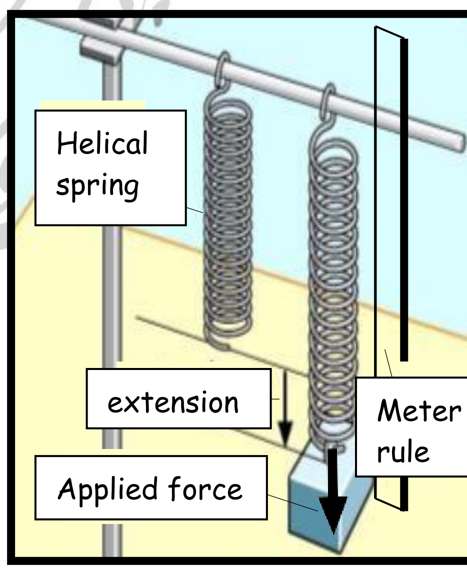
COMPRESSIVE forces are applied if the spring is being **shortened or compressed.**

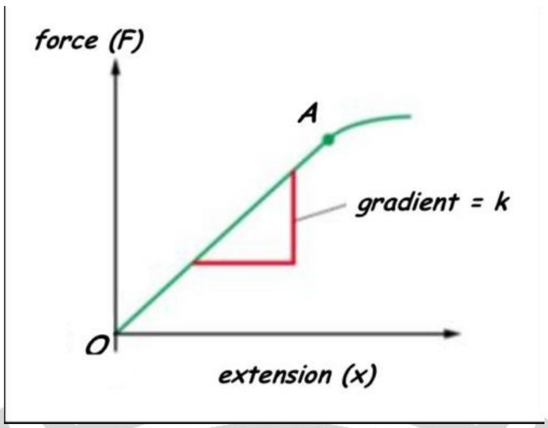
TENSILE forces are applied if the spring is being stretched or extended



Stiffness of a spring

A helical spring hangs from a rod clamped in a retort stand as shown opposite.
Using a mass hanger and 100 g slotted masses a force is applied to the spring and this is gradually increased.
The **EXTENSION (x)** (i.e. the increase in length of the spring) produced for each value of the **APPLIED FORCE (F)** is recorded.





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FORCE (F)/N versus **EXTENSION (x)/m graph** is plotted.
Section **OA** of the graph is a straight,line passing through the origin, so for This section :
Extension (x) is directly propotional to Force (F)
From which :

F = Kx K = F/x

F(N)
K(Nm^{-1})
X(m)

K is called the **SPRING CONSTANT** or **STIFFNESS.**
and can be determined from the **GRADIENT OF THE F/x GRAPH.** the **STIFFER** the spring is, the **GREATER** is the **k-VALUE.**

Beyond point ***A****, the graph is no longer a straight line. This is because the spring has been* **permanently deformed***; it has been stretched beyond its* **ELASTIC LIMIT.**

*The **ELASTIC LIMIT** of a sample is that value of the stretching force beyond which the sample becomes permanently deformed (i.e. it stops behaving elastically).*

For section OA, the spring obeys HOOKE'S LAW.

A material obeys HOOKE'S LAW if the EXTENSION is directly proportional to the APPLIED FORCE. This is true as long as the material's ELASTIC LIMIT is not exceeded.

TERMS USED IN SPRINGS AND MATERIALS

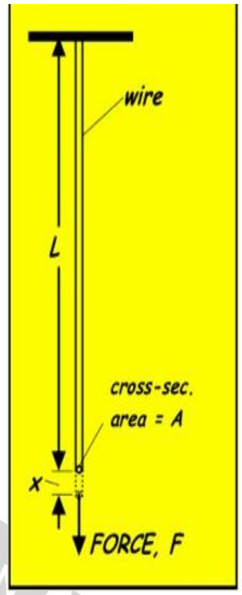
Consider a wire sample of original length (L) and cross-sectional area (A) subjected to a force (F) and suffering an extension (x).

$$\textbf{strain} = \frac{\textbf{extension (x)}}{\textbf{original length (L)}}$$

The STRAIN of a material sample is the EXTENSION produced per UNIT LENGTH.

NOTE : Strain has no units and it is sometimes given as a percentage.

The STRESS on a material sample is the FORCE acting per unit.



CROSS-SECTIONAL AREA of the sample.

$$\text{Stress} = \frac{\text{Force (N)}}{\text{Area } (m^2)}$$

The unit of STRESS is the PASCAL (Pa).

*The **STIFFNESS** of the material being stressed is called the **YOUNG MODULUS (E)** of the material.*

$$\textbf{YOUNG MODULUS, } E = \frac{\text{Stress}}{\text{Strain}} = \frac{F/A}{x/L} = \frac{F\,L}{A\,x}$$

NOTE

- *The unit of E is the* **PASCAL (Pa)** *- (1 Pa = 1 N m^{-2}).*
- *E is usually a large number and so it is sometimes given in :*

megapascal (MPa) *(i.e. Pa x 10^6) or* **gigapascal (GPa)** *(i.e. Pa x 10^9).*

E = Gradient of a stress/strain graph

DETERMINATION OF THE YOUNG MODULUS (E)

- Two long wires (P & Q) of the same material,

length and diameter are hung from a commonTo common support. Q is the wire under test and P is the support

comparison wire which is used as a reference so as to avoid errors due to :

- Expansion occurring as a result of reference wire

  temperature change.
- Sagging of the support.

- The ORIGINAL LENGTH (L) of wire Q is measured using a metal tape measure.
- The CROSS-SECTIONAL AREA (A) is determined by using a micrometer screw gauge to measure the diameter of Q at several points along the length of the wire. The mean diameter and hence the mean radius (R) is calculated.

  Then A = ∏R2.
- The EXTENSION (x) of wire Q when it is loaded, is accurately measured by the vernier arrangement between P and Q.
- The test wire Q is then incrementally loaded and the corresponding extensions are measured and noted. The results are used to plot a graph of FORCE (LOAD) (F) versus EXTENSION (x) whose gradient = F/x. Then :

Young modulus, E = stress = F/A = F L = gradient of F/x graph x L

Strainx/L x A

ELASTIC AND PLASTIC DEFORMATION

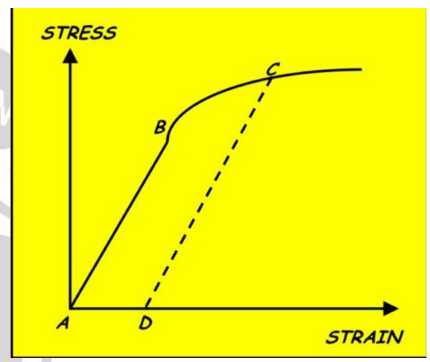
ELASTIC behaviour is shown by a wire or spring if it returns to its original length when the applied deforming force (load) is removed.

- All materials show ELASTIC behaviour up to the ELASTC LIMIT.
- When a sample (e.g. spring, wire..) is loaded beyond its ELASTIC LIMIT, it does not regain its original dimensions when the load is removed (i.e. it suffers permanent deformation).

PLASTIC behaviour is shown by some materials when they are loaded beyond the elastic limit. The material is permanently deformed (or strained) when the load is

A to B

*There is **ELASTIC** deformation – When the stress is removed, the sample goes back to its original dimensions (i.e. there is zero strain).*



B onwards

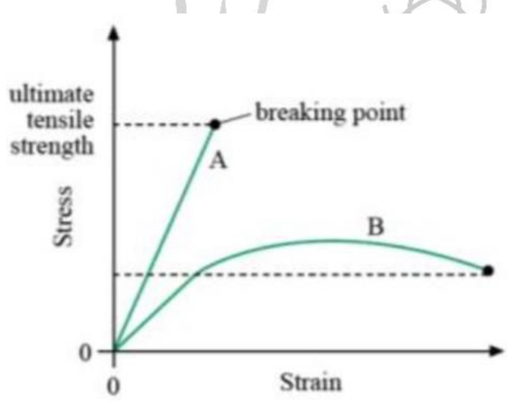
*There is **PLASTIC** deformation –When the stress is removed,the sample is left permanently deformed(i.e. there is residual strain = **AD**).*

MATERIAL STRENGTH

- *When we talk about the **STRENGTH** of a material, we are referring to the **STRESS** value at which the material breaks.*

*The **ULTIMATE TENSILE STRENGTH** or **BREAKING STRESS** of a material is the stress value at which the material breaks.*

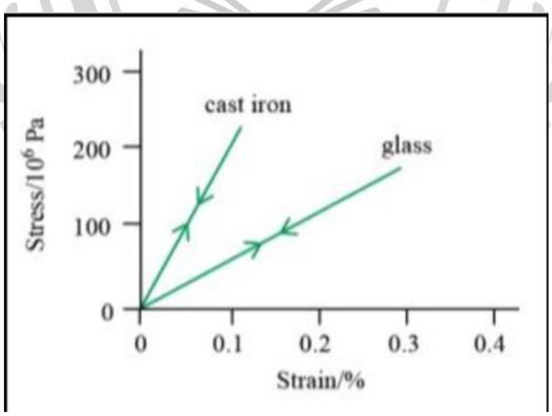
*Consider the **STRESS/STRAIN** graphs for two different materials **A & B** shown opposite.*



***Material A** has a **greater UTS value** than **material B** and this means that material A is **stronger** than material B.*

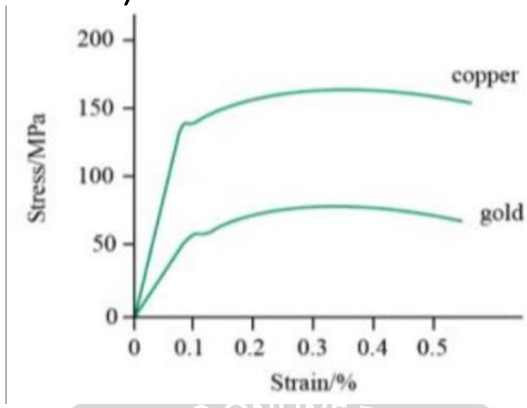
***BRITTLE MATERIALS** (e.g. glass, cast iron)*

- *As the stress on a **brittle** material is gradually increased, it stretches slightly, but further increase in the applied stress causes fracture.*
- ***Brittle** materials show **ELASTIC** behaviour up to the point of fracture (Up to that point, if the applied stress is removed the sample returns to its original length).*
- *Sudden application of a large stress will cause a **brittle** material to shatter(e.g. dropping it onto a hard floor).*



***DUCTILE MATERIALS** (e.g. copper, gold)*

- *As stress is applied to a **ductile** material it will behave elastically up to the **ELASTIC LIMIT**, but beyond this stress value the sample stretches more and more and it does not return to its* *original length when the stress is removed. The material shows **PLASTIC** behaviour and it is then permanently strained.*



Ductile *materials can be shaped by stretching, rolling, squashing and hammering (useful for making wires,jewellery etc.).*

MATERIAL BEHAVIOUR SUMMARY

- All materials show ELASTIC behaviour up to the ELASTIC LIMIT.

- BRITTLE materials break at the ELASTIC LIMIT and shatter when subjected to a large , sudden stress.

- DUCTILE materials exhibit PLASTIC behaviour (i.e. suffer permanent deformation) when they are stretched beyond the ELASTIC LIMIT.
- The value of the stress at which a material breaks is called the ULTIMATE TENSILE STRESS (UTS) or the BREAKING STRESS.

POLYMERIC MATERIALS (e.g. polythene, perspex)

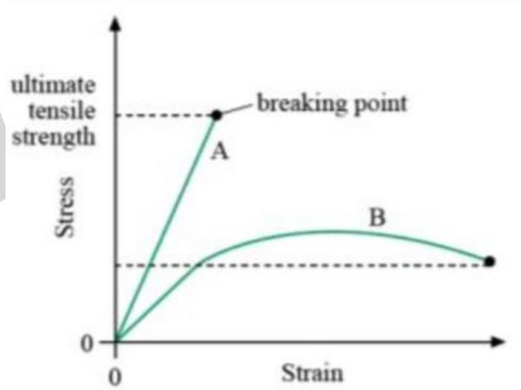
The behaviour of different polymers depends on their temperature aswell as their molecular structure.

The infamous shopping carrier bag is made of polythene and as we all know, it is very stretchy and easy to deform.

Under stress, polythene quickly undergoes PLASTIC deformation and stretches a lot before becoming much stiffer and snapping (behaving much like a DUCTILE metal).

- Perspex is a very tough, hard plastic which, when stressed, stretches elastically until it snaps (BRITTLE material behaviour). When it is warmed however, it ceases to be brittle and can be moulded into any shape. It is used for contact lenses, dentures, artificial eyes and a huge variety of other industrial uses.

In the stress/strain graph shown opposite, material A is stronger than material B, since its UTS is greater.



- ELASTIC POTENTIAL (STRAIN) ENERGY
- This is the energy stored when a solid is stretched or compressed.

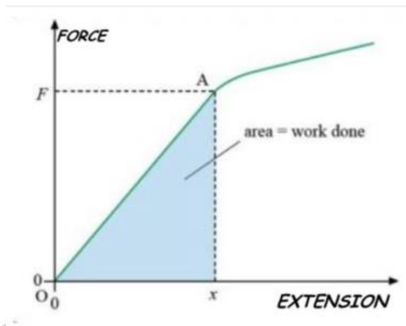
- If the solid has been strained ELASTICALLY, the stored energy can be recovered.

If the solid has been strained PLASTICALLY, some of the work done has gone into moving atoms past each other and the energy is non-recoverable.

- Consider a wire subjected to a gradually FORCE increasing force.

Up to the elastic limit :

Extension α applied force



Initial value of force = 0

Final value of force = F EXTENSION

Average value of force = ½ F

Elastic Potential Energy stored in the wire = Work done by the average force

= average force x extension

= ½ F x x

Elastic Potential energy stored in the wire = ½ Fx

- *Elastic Potential Energy stored in the wire = Area Enclosed by the F/x Graph*
  = ½ x base x height
  = ½ x x F
  = ½ Fx