A Level Physics Knowledge Organiser

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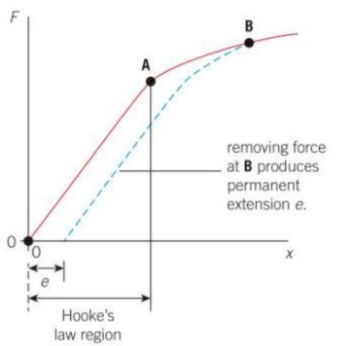
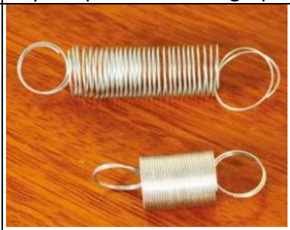
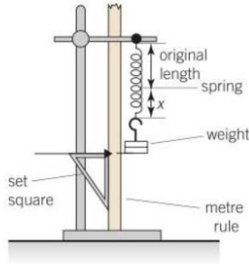
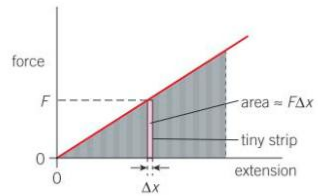
1. Springs and Hooke's law

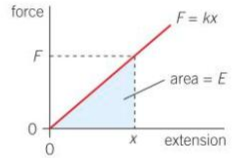
Extension	The increase in length of an object when a tensile force is exerted on it.
Compression	The decrease in length of an object when a compressive force is exerted on it.
Tensile force	Equal and opposite forces acting on a material to stretch it.
Compressive force	Two or more forces together that reduce the length or volume of an object.
Tensile deformation	A change in the shape of an object due to tensile forces.
Compressive deformation	A change in the shape of an object due to compressive forces.
Force-extension graph	
Elastic limit	The value of stress or force beyond which elastic deformation becomes plastic deformation, and the material or object will no longer return to its original shape and size when the stress or force is removed. Point A on the graph.
Elastic deformation	A reversible change in the shape of an object due to a compressive or tensile force – removal of stress or force will return the object to its original shape and size (no permanent strain).

Plastic deformation	An irreversible change in the shape of an object due to a compressive or tensile force – removal of the stress or force produces permanent deformation. Beyond point A on the graph.
Example	 You can easily identify the spring that has been stretched beyond its elastic limit.
Hooke's law	The force applied is directly proportional to the extension of the spring unless the limit of proportionality is exceeded. F = k x F – force (N) k – force constant (N m^{-1}) x – extension (m)
F = k x	The equation can be applied to almost any object that can be elastically squashed or extended.
Force constant	A quantity determined by dividing force by extension (or compression) for an object obeying Hooke's law – called constant of proportionality k in Hooke's law, measured in N m^{-1}. - Can be determined from the gradient of the linear region of the force-extension graph.
Stiffness	The ability of an object to resist deformation.

Investigating Hooke's law	- You can investigate Hooke's law using a spring and some standard masses.  - You can improve the accuracy of the length measurements using a set square, and by taking readings at eye level to reduce parallax errors. - You might also measure the mass of each slotted mass using a digital balance. - To obtain reliable results, aim to make at least six different readings and to repeat each one at least once.

2. Elastic potential energy

Energy stored in an elastic material	Can be determined from the force-extension graph  Area under a force-extension graph = work done The work done on a spring is transferred to elastic potential energy within the spring.

Work done – fully recovered	When a material is compressed or extended without going beyond its elastic limit.
Work done – not fully recovered	When a material has gone through plastic deformation. Some of the work done has gone into moving its atoms to new permanent positions.
Elastic potential energy of a spring or wire	E = area under graph = area of shaded triangle  $E = \frac{1}{2}Fx$ E – elastic potential energy (J) F – force producing an extension (N) x – extension (m) Spring obeys Hooke's law F = k x Substituting this equation $E = \frac{1}{2}Fx = \frac{1}{2}(kx) \times x$ $E = \frac{1}{2}kx^2$ k – force constant (N m^{-1}) E is directly proportional to extension squared, so doubling the extension quadruples the energy stored.

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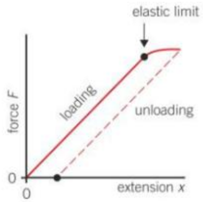
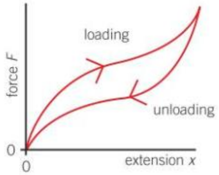
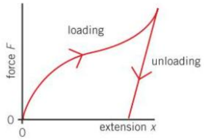
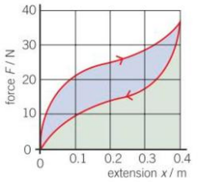
3. Deforming materials

Loading and unloading curves for a metal wire	- For a metal wire, its loading and unloading curves are the same provided its elastic limit is not exceeded. Meaning that the wire returns to its original length when it is unloaded. - However, when it exceeds the elastic limit, the unloading line is parallel to the loading line.  - In the case of a wire, the wire becomes slightly longer when it's unloaded and therefore there is a permanent extension.
Loading and unloading curve for a rubber band	- For a rubber band, the change of length during unloading is greater than during loading, for a given change in tension. - Rubber band returns to original length, but the unloading curve is below the loading the curve except at zero and maximum extension. - Rubber band remains elastic as it regains original length.  - The 'loop' formed by the loading and unloading curves is called a hysteresis loop.

Loading and unloading curve for a polythene strip	- For a polythene strip, the extension during unloading is greater than during loading. - Strip does not return to the same initial length when it is completely unloaded. - The polythene strip has a low limit of proportionality and suffers plastic deformation. 

Strain energy
Area under the line of a force-extension graph = work done to stretch the wire.
Work done to deform the object is referred to as strain energy.

Metal wire or a spring	- The limit of proportionality is not exceeded. - Graph of tension against extension is the same for loading as it is for unloading. - All the energy stored in the wire can be restored when the wire is unloaded. $E = \frac{1}{2}kx^2$
Rubber band	- The area under a force-extension graph is equal to work done. - Thermal energy is released when the material is loaded than unloaded, represented by the area inside the hysteresis loop. 

Polythene strip	- As it doesn't regain initial length, the area between the loading and unloading curve represents work done to deform the material permanently.

4. Stress, strain, and the Young modulus

Tensile stress
The force per unit cross-sectional area.

$$\text{tensile stress} = \frac{\text{force}}{\text{cross-sectional area}}$$

You can write this as

$$\sigma = \frac{F}{A}$$

σ – tensile stress(Greek letter sigma) (Pa)
F – applied force (N)
A – cross-sectional area (m^2)

Tensile strain
The extension per unit length, a dimensionless quantity. Can be written in percentage.

$$\text{tensile strain} = \frac{\text{extension}}{\text{original length}}$$

You can write this as

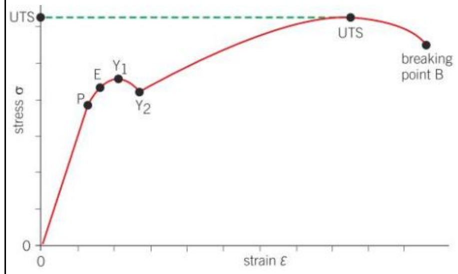
$$\varepsilon = \frac{x}{L}$$

ε – tensile strain (Greek letter epsilon)
x – extension (m)
L – original length (m)

Ductile	Property of a material that has a large plastic region in a stress-strain graph, so can be drawn into wires or hammered into sheets.
Limit of proportionality	The value of stress or force beyond which stress is no longer directly proportional to strain.
Yield point	A point on a stress-strain graph beyond which the deformation is no longer entirely elastic.

Breaking strength	The stress value at the point of fracture, calculated by dividing the breaking force by the cross-sectional area.
Ultimate tensile strength - UTS	The maximum stress that a material can withstand before it breaks.
Strong material	A material with a large value for the ultimate tensile strength. Copper is stronger than lead, but mild steel is stronger than copper.

Stress-strain graph for mild steel wire



- From 0 to the limit of proportionality P, the tensile stress is proportional to the tensile strain.
- E represents the elastic limit.
- Elastic deformation occurs up to elastic limit, and plastic deformation beyond it.
- Y1 and Y2 are upper and lower yield points where the material extends rapidly.
-UTS – ultimate tensile strength.
- After UTS material may become longer and thinner and eventually snaps at its breaking point B.- The stress value at the point of fracture is known as the breaking strength of the material.

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Young modulus

The ratio of tensile stress to tensile strain when these quantities are directly proportional to each other, measured in Pa.

$$\text{Young modulus} = \frac{\text{tensile stress}}{\text{tensile strain}}$$

$$E = \frac{\sigma}{\varepsilon}$$

E – Young modulus (N m^{-2} or Pa)
σ – tensile stress (Pa)
ε – tensile strain (no unit)
- The young modulus of a material is the gradient of the linear region of the stress-strain graph. (from 0 to P).
- It only depends on a material, not its shape and size.

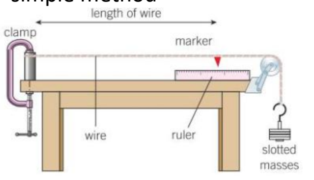
Stiffness of a materials	- You can compare the stiffness of a materials by comparing their Young modulus values. - A material with a large modulus is stiffer than one with a smaller Young modulus.

Young modulus of some materials

Material	E / Pa
polystyrene	$\sim 3 \times 10^{9}$
lead	1.8×10^{10}
aluminium	7.0×10^{10}
mild steel	2.1×10^{11}
graphene	1.1×10^{12}
diamond	1.2×10^{12}

Determining the Young modulus of a wire

- by measuring its diameter, applying various loads to it, and measuring its length each time.
- simple method



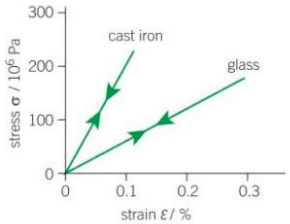
Method

- Starting length of the wire is greater than 1.00 m.
- The wire is clamped securely at one end, passed over a pulley, and loaded with slotted masses at the other end.
- The diameter *d* of the wire can be measured using a micrometer.
- Cross-sectional area

$$A = \frac{\pi d^2}{4}.$$

- More accurate diameter – by averaging measurements from several places along the wire.
- The tensile force – can be calculated from the hanging mass *m* using
  F = m g
- The extension is calculated
x = extended length – original length L
- You can improve accuracy by taking readings for at least six different masses, and repeating them.
- Stress and strain values for each load are calculated and used to plot a stress-strain graph.
- The modulus can be determined from the gradient of the linear section of the graph.

Stress-strain graph for brittle materials



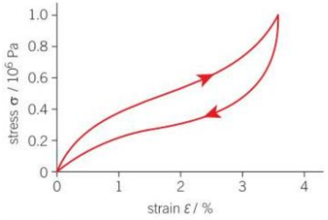
- A brittle material shows elastic behaviour up to its breaking point, without plastic deformation.

Polymers

Polymers are materials that consist of long molecular chains.

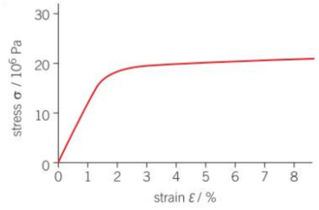
Stress-strain graph for rubber

- The rubber is a polymer.
- The rubber shows elastic behaviour.

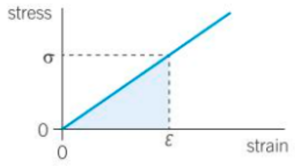


Stress-strain graph for polythene

- The polythene is a polymer.
- The polythene shows plastic behaviour.



Stress-strain graph for an elastic material



Different material properties

Aluminium alloy	Strong and stiff. (high Young modulus)
Ceramics	Can withstand high temperatures and are very strong. Brittle and show no plastic deformation.
Rubber	Has elastic properties and is an excellent shock absorber.