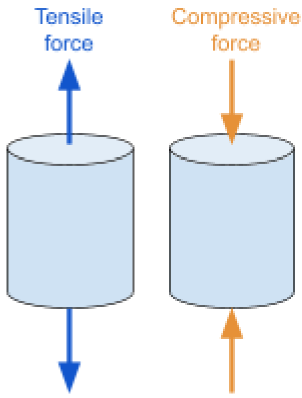
CAIE Physics A-level

Topic 9: Deformation of Solids

Notes

9 - Deformation of Solids

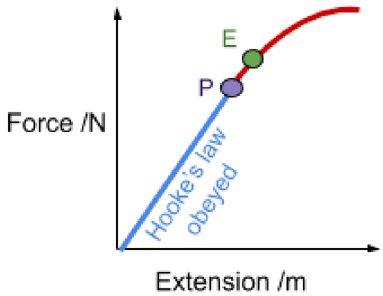
9.1 - Stress and Strain



An object experiencing a force may be caused to **change its shape**, this is known as **deformation**.
There are two types of force, which cause different types of deformation:

- **Tensile -** causes an object to be **stretched** (tensile deformation)
- **Compressive -** causes an object to be **squashed/compressed** (compressive deformation)

Springs (as well as many other materials) follow Hooke's law. **Hooke's law** states that **extension is directly proportional to the force applied**, given that the **environmental conditions (e.g temperature) are kept constant**. This can be shown by the straight part of the force-extension graph shown to the right. A **straight line graph through the origin** shows that the force and extension are **directly proportional**.



The **limit of proportionality (P)** is the point after which Hooke's law is no longer obeyed. The **elastic limit (E)** is just after the limit of proportionality and if you increase the force applied beyond this, the material will deform plastically (be permanently stretched).

Hooke's law can be described as the equation $F = k\Delta L$, where F is the force/load applied, k is the spring constant, which is a measure of the stiffness of the spring, and ΔL is the extension.

Tensile stress - Force applied per unit cross-sectional area.

Tensile strain - This is caused by tensile stress, and is defined as the extension over the original length.

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

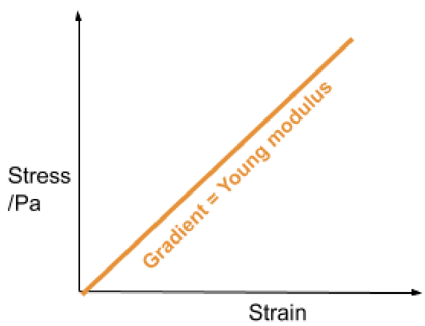
$$Strain = \frac{\Delta L}{L}$$

The **Young modulus** is a value which describes the **stiffness of a material**.
It is known that up to the limit of proportionality, for a material which obeys Hooke's law, stress is proportional to strain, therefore the value of stress over strain is constant. This value is the Young modulus.

$$Young\ Modulus\ (E) = \frac{Tensile\ Stress}{Tensile\ strain}$$

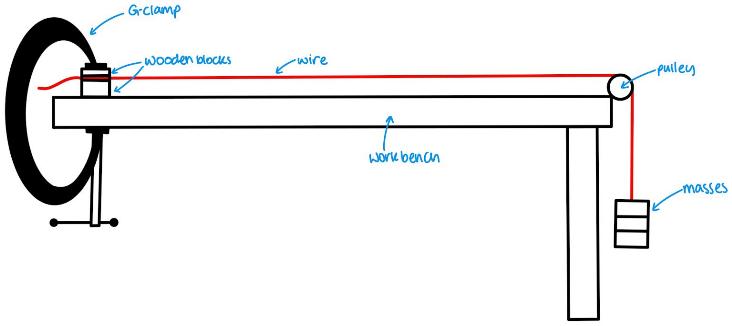
Using the formulas from above, this can be rewritten as:

$$E = \frac{FL}{\Delta LA}$$



You can find the Young modulus of a material from a stress-strain graph by finding the **gradient** of the straight part of the graph.

You can find a value of the Young Modulus of a material experimentally. Below is a method for finding the Young Modulus of a metal in the form of a wire:



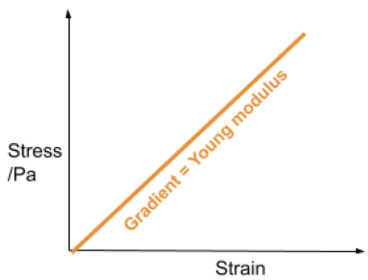
1. Set up the apparatus as shown in the diagram.
2. Measure the diameter of the wire in 3 different places using a micrometer and record these values.
3. Attach the metre ruler to the workbench so that the lower end is facing the G-clamp and place a marker on the wire at 0 cm on the ruler.
4. Measure the length of wire from the blocks of wood to the marker on the wire when it is taut.
5. Attach a mass to the wire and record the total mass attached to the end of the wire in kg. The wire will stretch so the marker will move when this mass increases therefore, record the new position of the marker.
6. Add another 100 g mass and once again record the position of the marker - keep doing this until you have readings for at least 7 mass values.

Calculations:

- ➔ Find the mean diameter of the wire and calculate the average cross sectional area using:

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

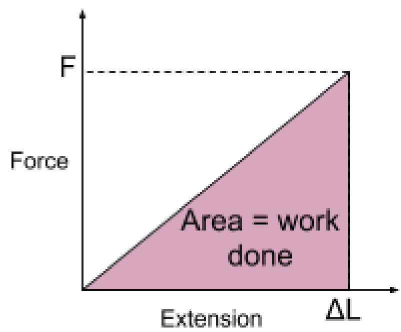
- ➔ Using F = mg calculate the force exerted on the wire for each mass and record these values in a table.
- ➔ Calculate the wire's extension by finding the difference between the marker's final position and its initial position for each mass.
- ➔ Find the **stress** for each mass by dividing the force applied by the cross sectional area of the wire.
- ➔ Find the **strain** on the wire for each mass by dividing the extension ΔL by the original length of the wire.
- ➔ Plot a **graph of stress against strain** and draw a line of best fit.
- ➔ As the Young modulus = stress/strain, the **gradient of the line of best fit is equal to the Young modulus of the metal**.



9.2 - Elastic and Plastic Behaviour

Elastic deformation is where a material **returns to its original shape** once the force applied is removed. This is because **all** the work done is stored as **elastic strain energy**.

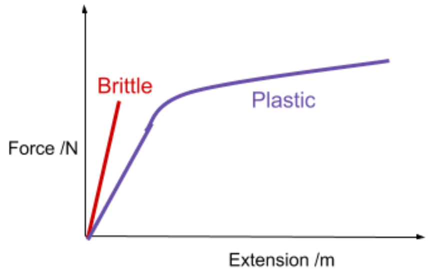
Plastic deformation is where a material shape is **changed permanently**. This is because work is done to move atoms apart, so energy is **not only** stored as elastic strain energy but is also **dissipated as heat**.

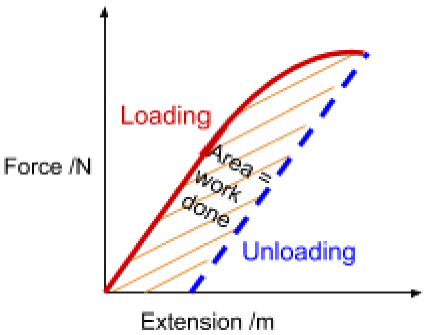


When work is done on a material to stretch or compress it, this energy is stored as **elastic strain energy**. This value cannot be calculated using the formula $W = Fs\cos\theta$ because the force is variable, however you can find it by calculating the **area under a force-extension graph**. Therefore, **elastic strain energy =** $\frac{1}{2}F\Delta L$ (when the graph forms a straight line as shown on the right).

Force-extension graphs can show the properties of a specific object. There are two main behaviours that a material can exhibit on a force-extension graph:

- **Plastic -** This is where a material will experience a large amount of extension as the load is increased, especially beyond the elastic limit
- **Brittle -** This is where a material will extend very little, and therefore is likely to fracture (break apart) at a low extension.





Once a material is stretched beyond its elastic limit, a force-extension graph showing loading and unloading will not return to the origin, however the loading and unloading lines will be parallel because the material's stiffness is constant, as shown on the left. The area between the loading and unloading line is the work done to permanently deform the material.