Solid Material Properties

IAS Physics-Materials

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Students will be assessed on their ability to:

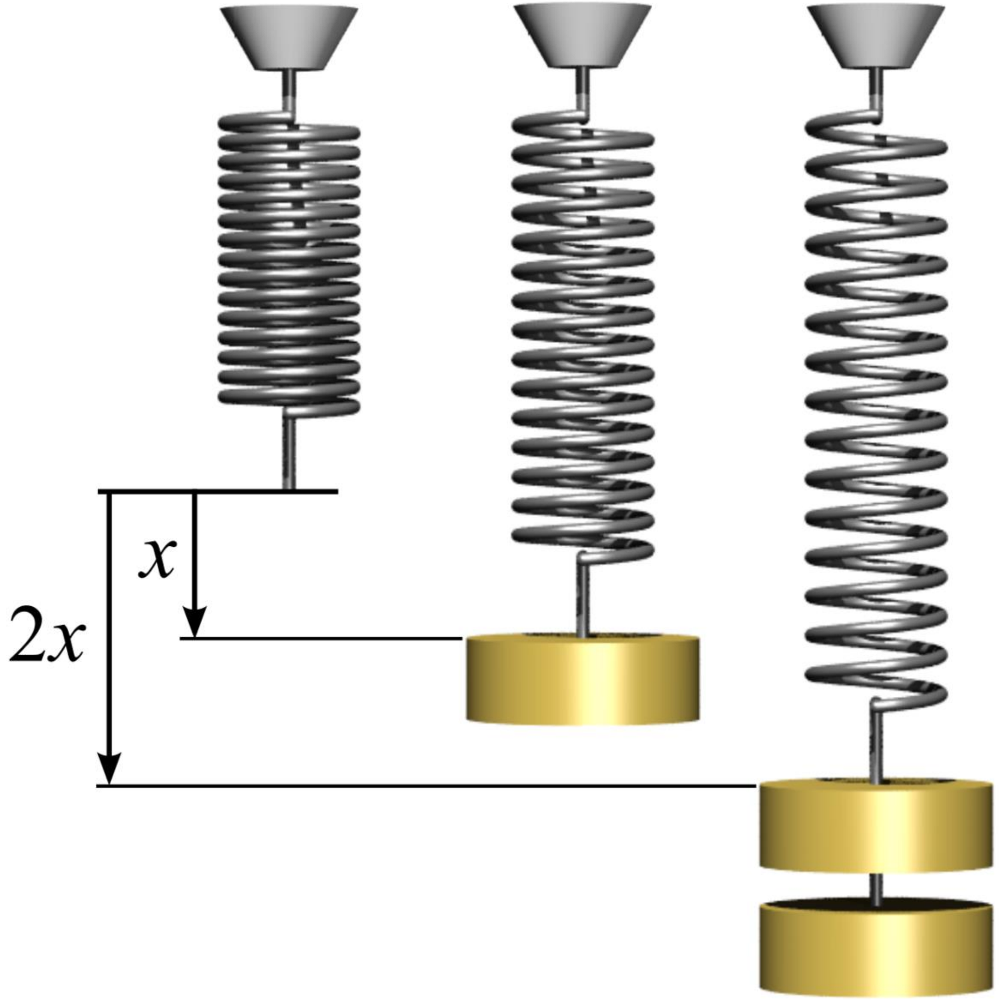
27	be able to use the Hooke's law equation, $\Delta F = k\Delta x$, where k is the stiffness of the object
28	understand how to use the relationships • *(tensile or compressive) stress = force/cross-sectional area* • *(tensile or compressive) strain= change in length/original length* *Young modulus = stress/strain.*
29	a be able to draw and interpret force-extension and force-compression graphs b understand the terms limit of proportionality, elastic limit, yield point, elastic deformation and plastic deformation and be able to apply them to these graphs
30	be able to draw and interpret tensile or compressive stress-strain graphs, and understand the term *breaking stress*
31	**CORE PRACTICAL 3: Determine the Young modulus of a material**
32	be able to calculate the elastic strain energy E_{el} in a deformed material sample, using the equation $\Delta E_{el} = \frac{1}{2}F\Delta x$, and from the area under the force-extension graph *The estimation of area and hence energy change for both linear and non-linear force-extension graphs is expected.*

Hooke's law

The force needed to extend a spring is directly proportional to the extension of the spring.

Mathematically,

$$\Delta F = k\Delta x$$



$k - stiffness\ constant (spring\ constant)$

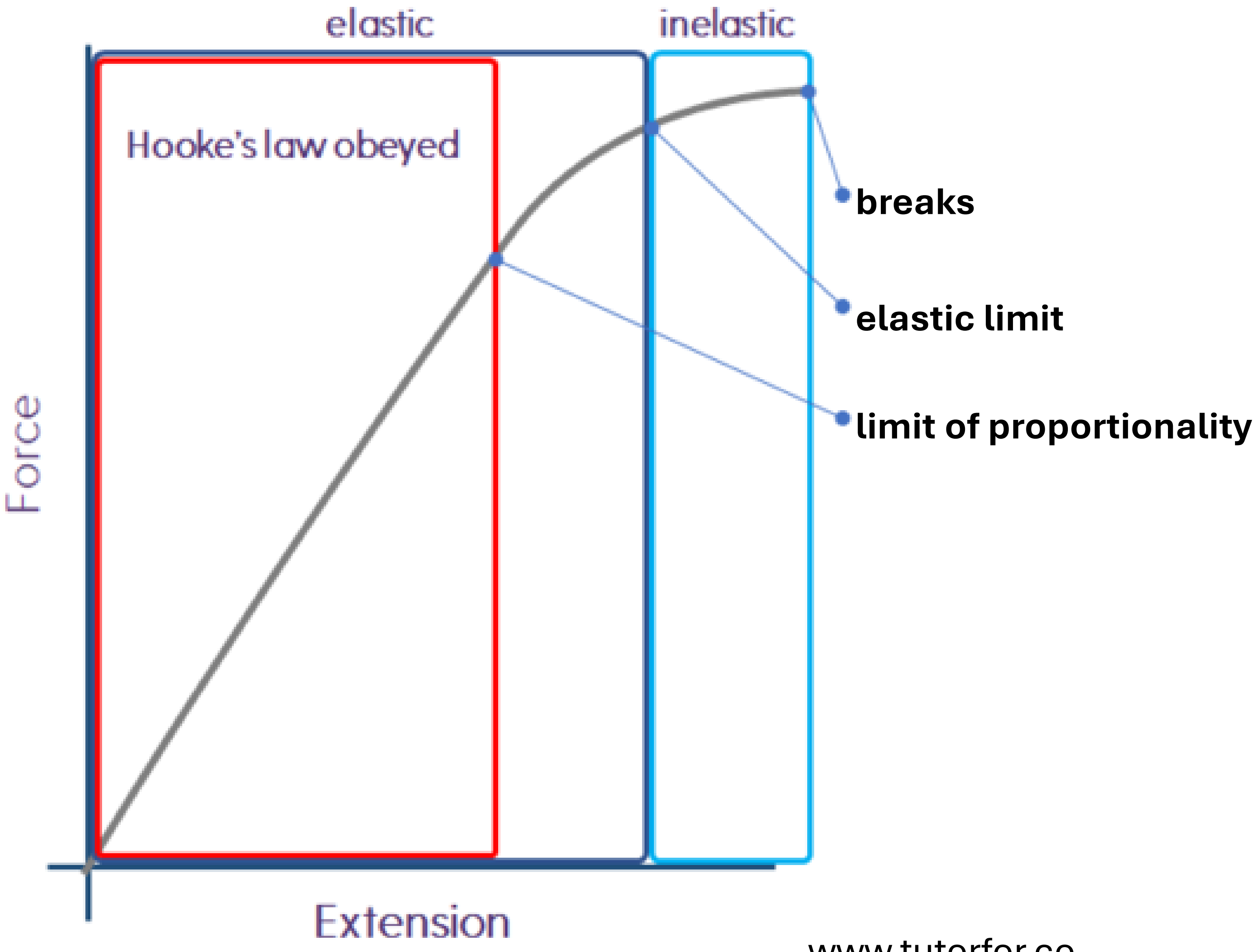
$\Delta x - extension$

$\Delta F - force\ applied$

Hooke’s law-graph

- A material only obeys Hooke's law if it has not passed what is called the **limit of proportionality.**

- When the force is removed, it returns to its original size and shape, as long as the **elastic limit** was not passed.



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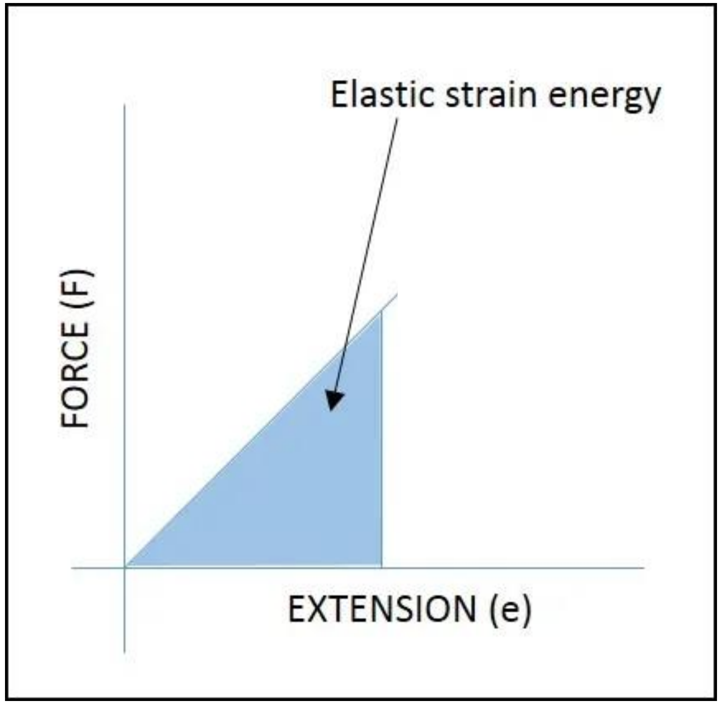
Elastic strain energy.

The work done in deforming a material sample before it reaches its elastic limit will be stored 'Within the material as elastic strain energy.



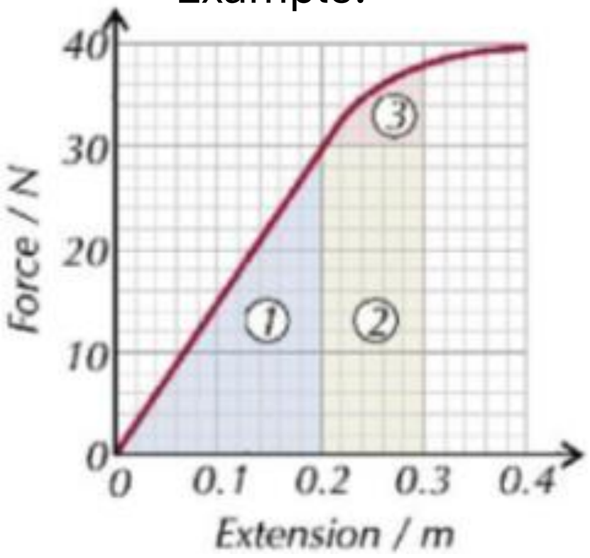
The work done in deforming a material is calculated by multiplying the extension or compression by an appropriate average force value.

$$\Delta E_{el} = \frac{1}{2} \Delta F \Delta x$$

Elastic strain energy calculation-using graph

- It represents the potential energy stored in the material' structure as its molecules are displaced from their equilibrium positions.
- This stored energy is released when the material returns to its original shape after the force is removed

Example:



You can approximate the area using triangles and rectangles:

Area 1: ½ × 30 N × 0.2 m = 3 J

Area 2: 30 N × 0.1 m = 3 J

Area 3: ½ × 8 N × 0.1 m = 0.4 J

Total energy ≈ 3 J + 3 J + 0.4 J = 6.4 J

Concept Learning Questions

1) A spring has a spring constant (k) of 200 N/m. If a force of 50 N is applied to the spring, how much will it deform?

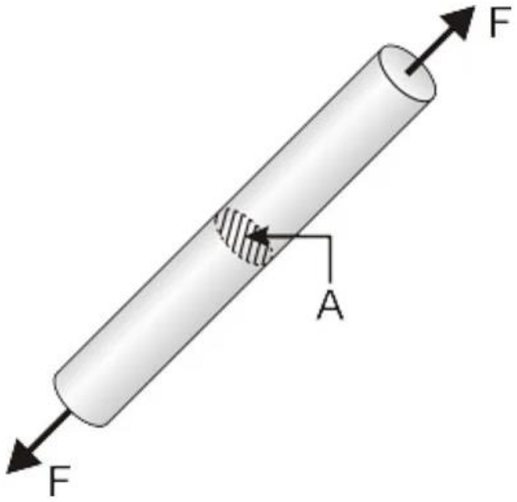
2) Find the elastic strain energy of the spring.

Stress, strain and Young modulus

Stress

Stress is the force applied to a material per unit area, causing deformation or change in shape, often measured in units of pressure.

$$Stress(Nm^{-2}, Pa) = \frac{Force(N)}{Cross\ sectional\ Area(m^2)}$$



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

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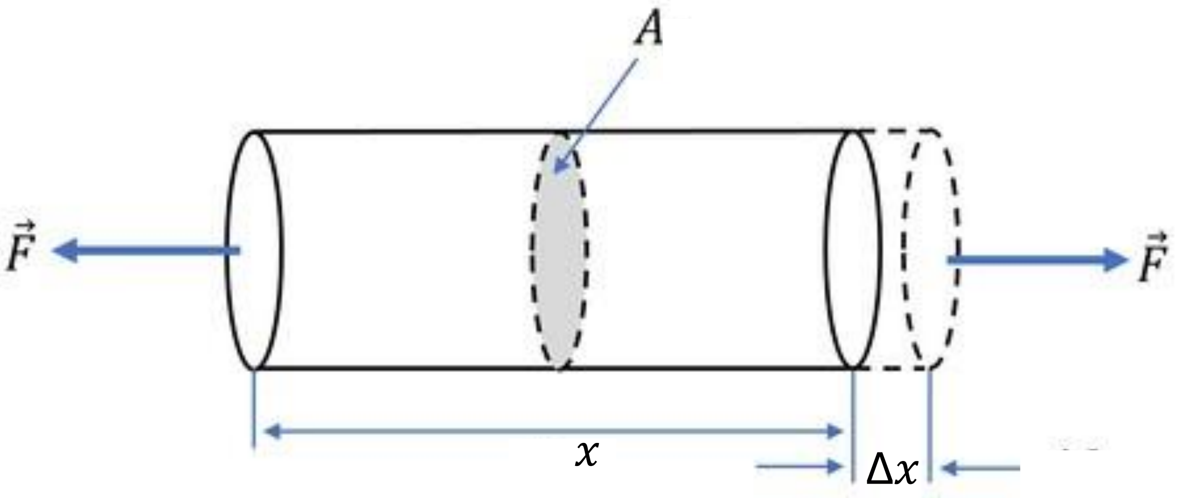
Concept Learning Questions

1) A force of 5000 Newtons is applied to a steel rod with a cross-sectional area of 0.005 square meters. Calculate the stress experienced by the steel rod.

Strain

Strain is the measure of deformation in a material relative to its original size, typically caused by applied forces.



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

$$\text{Strain(no units)} = \frac{extension(m)}{original\ length(m)}$$

Concept Learning Questions

1) A steel rod with an original length of 2 meters experiences an elongation of 0.02 meters when subjected to a tensile force. Calculate the strain experienced by the steel rod.

Young modulus(E)

Young's Modulus is a measure of a material's stiffness, indicating how much it deforms under stress, calculated as stress divided by strain.

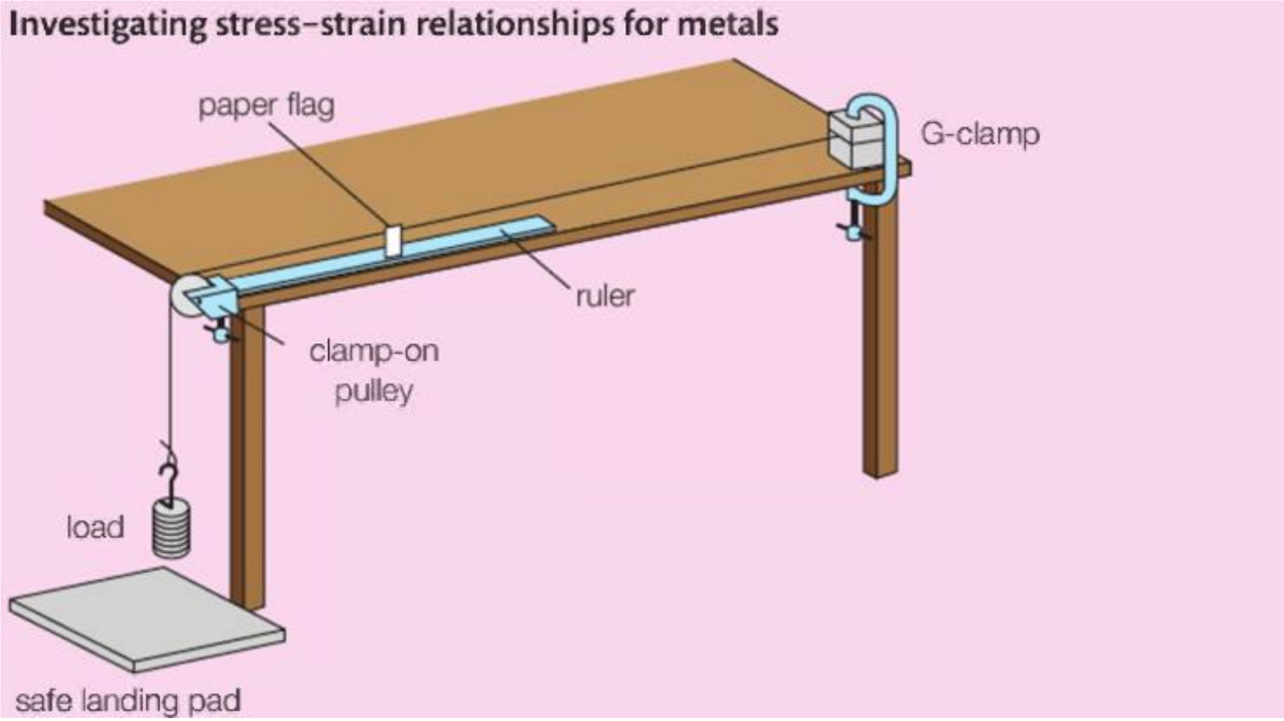
- **The stiffness constant is called the Young modulus**

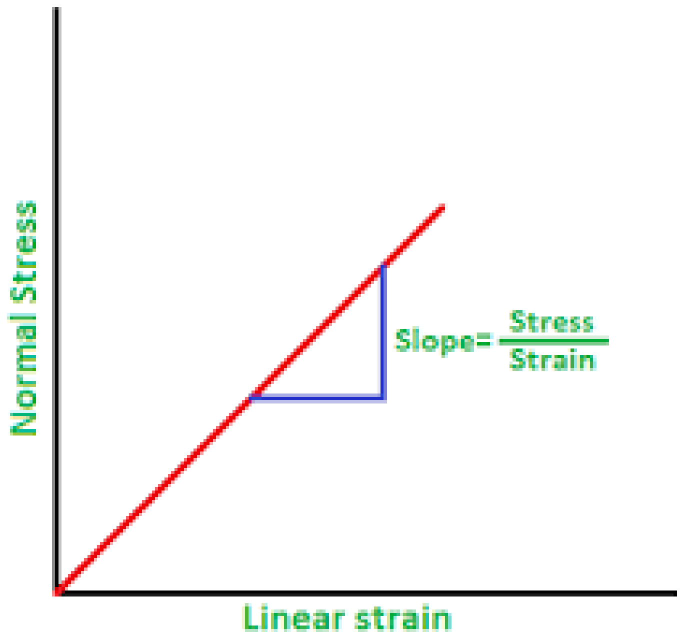
$$Young\ modulus = \frac{Stress}{Strain}$$

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

$$\boldsymbol{E = \frac{Fx}{A\Delta x}}$$

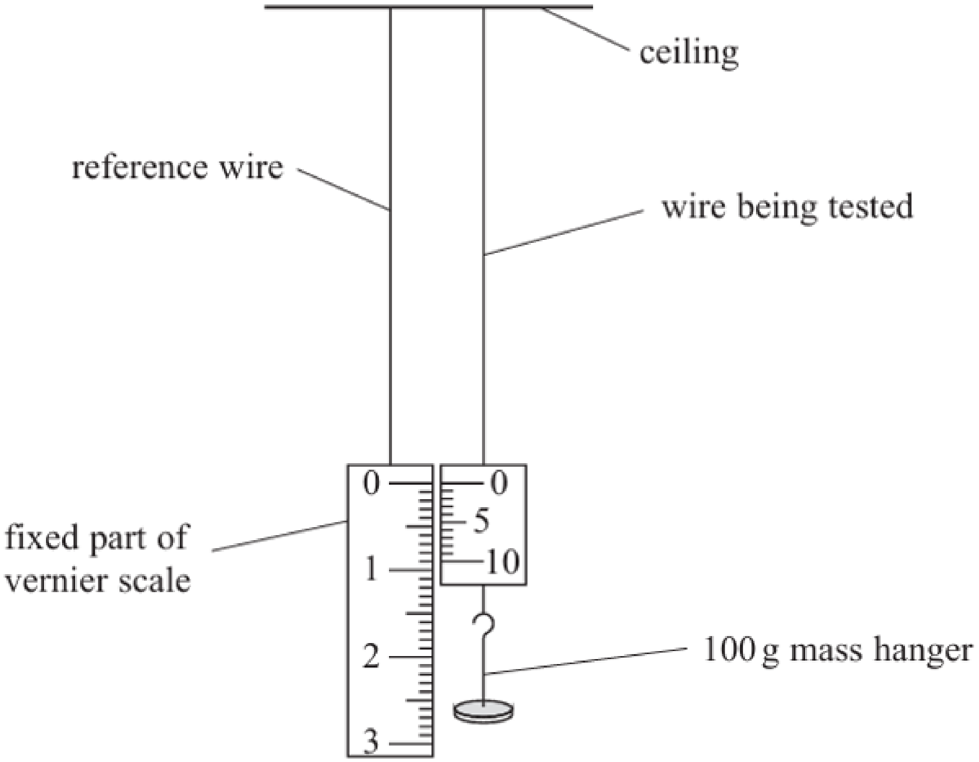
Core-Practical-Determine Young modulus of a material





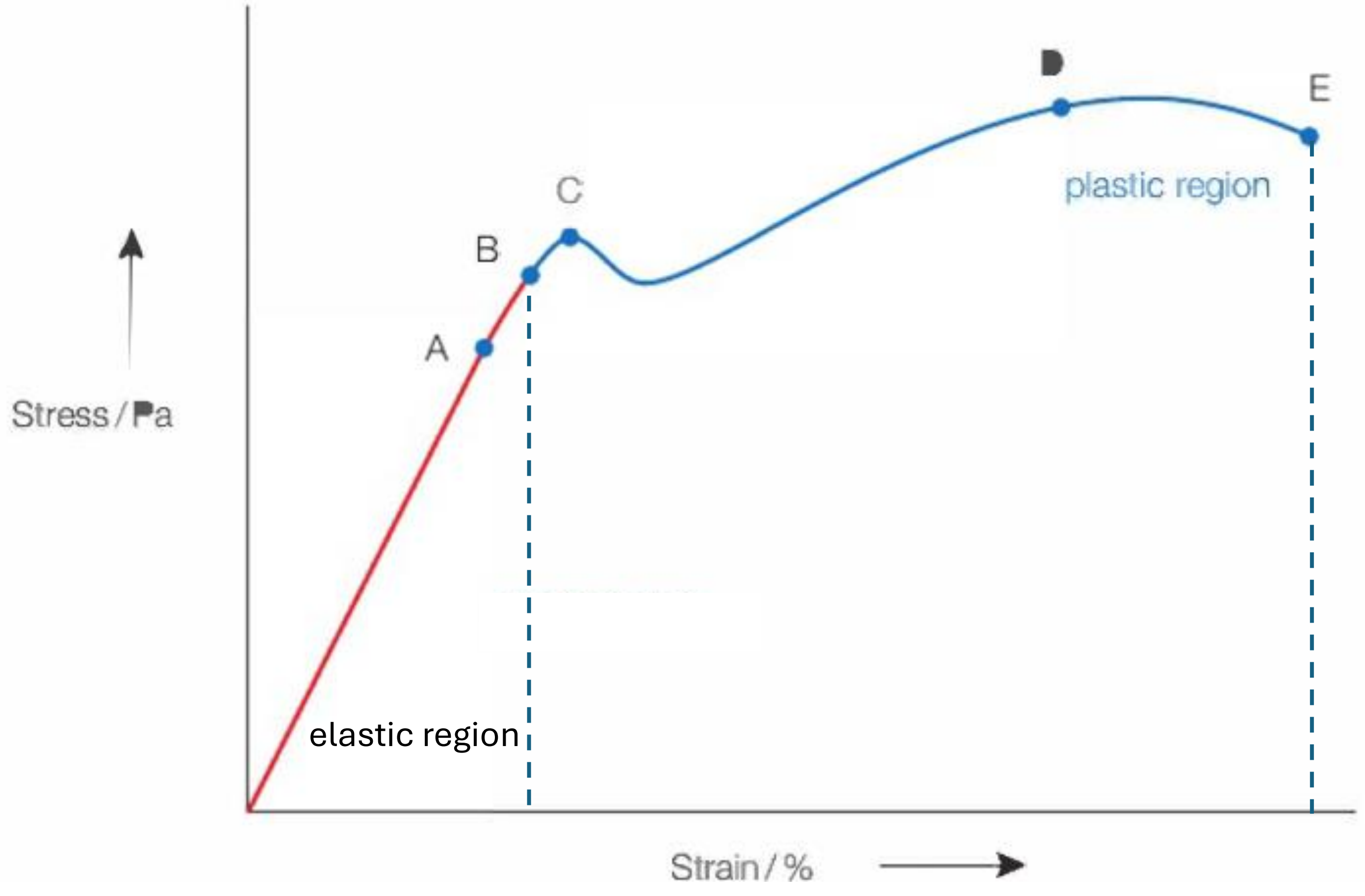
$$Young\ modulus(E) = gradient\ of\ the\ graph \frac{\Delta Y}{\Delta X} = \frac{\sigma}{\varepsilon}$$

Searle's apparatus



Searle's apparatus, as shown in figure is used in experiments to find the Young modulus fair a metal wire. With this apparatus, the test wire hangs vertically, parallel to an identical control wire. Weights are added to load the, test wire only, and its extension measured as an excess over the length of the control wire rather than from its original length, is calculated.

Stress-Strain graph



A- limit of proportionality

B- elastic limit

C- yield point

D- ultimate tensile stress

E- fracture stress

Point A is the limit of proportionality Slightly beyond this point the metal may still behave elastically; but it cannot be relied upon to increase strain in proportion to the stress.

Point B is the elastic limit Beyond this point the material is permanently deformed and will not return to its original size and shape, even when the stress is completely released.

Point C is the yield point, beyond which the material undergoes a sudden increase in extension as its atomic substructure is significantly re-organized. The metal gives just beyond its yield point as the metal's atoms slip past each other to new positions where the stress is reduced.

Point D represents the highest possible stress within this material. It is called the Ultimate Tensile Stress or UTS.

Point E is the fracture stress, or breaking stress. It is the value that the stress will be in the material when the sample breaks.

Important notes

- Hardness measures a material's resistance to localized deformation like indentation or scratching, while stiffness quantifies its resistance to deformation under load.

- Ductility is a mechanical property of materials that measures their ability to undergo plastic deformation, typically by elongation or stretching, without fracture. In other words, it describes how much a material can be stretched or deformed before it breaks.

- Malleability is a mechanical property of materials that refers to their ability to deform under compressive stress, typically by flattening or forming into thin sheets, without fracturing. In other words, malleable materials can be hammered, rolled, or pressed into various shapes or configurations without breaking or cracking.

Concept Learning Questions

1) A steel rod with a length of 2 meters and a cross-sectional area of 0.01 square meters is subjected to a tensile force of 10,000 Newtons. If the rod extends by 0.01 meters under this force, what is the Young's Modulus of the steel?