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S1 New Curriculum Physics

Theme: Mechanics and properties of Matter

Chapter 4 – Hooke’s Law

Materials

"Materials" are the building blocks of everything you see and touch in the physical world. From the wood in your furniture to the fabric in your clothes, the concrete under your feet to the plastic in your phone — all of these are made from different kinds of materials. They can be natural (like cotton, stone, water) or man-made (like plastic, glass, steel).

Examples of materials



Mechanical properties of materials

Mechanical properties of materials include:

- (i) **Stiffness**

Stiffness is a measure of how much a material resists being deformed when a force is applied to it. In simple terms, it tells you how hard it is to bend or stretch something.

For example rubber has low stiffness because it is easy to bend or stretch while steel has high stiffness because it is too hard to stretch, bend or twist.

(ii) **Ductility**

Ductility is a property that describes how much a material can stretch or deform without breaking — especially when it's being pulled. A material such as copper and aluminium that are highly ductile can be drawn into a wire or undergo a lot of strain before it snaps.

(iii) **Brittleness**

A brittle material such as glass and clay breaks or shatters easily when force is applied, without much bending or stretching. It can handle some pressure — but once it hits its limit, it snaps suddenly instead of deforming gradually.

(iv) **Elasticity**

Elasticity is the ability of a material to return to its original shape after being stretched, compressed, or deformed — once the force causing the change is removed. For example rubber is elastic while glass is not.

(v) **Plasticity**

Plasticity is the ability of a material to undergo permanent deformation without breaking when a force is applied — and *not* return to its original shape once the force is removed. Example: plasticine.

(vi) **Hardness of a material**

Hardness of a material refers to its resistance to localized deformation such as indentation, scratching, cutting or abrasion. It tells you how well a material can stand up to forces that try to dent or damage its surface.

(vii) **Malleable material**

A malleable material is one that can be hammered, rolled, or pressed into different shapes without breaking or cracking.

Examples of highly malleable materials:

- **Gold** – famously the most malleable metal; it can be beaten into thin sheets called gold leaf.
- **Silver** – also very malleable, used in jewelry and decorative items.
- **Copper** – widely used in electrical wiring and pipes due to its malleability and conductivity.

- **Aluminum** – lightweight and easy to shape, often used in packaging and construction.

(viii) Flexible material

A flexible material is one that can bend or stretch without breaking, and it returns to its original shape (or close to it) when the force is removed. Flexibility is super useful in everything from clothing and electronics to architecture and aerospace.

Here are some common flexible materials:

- **Rubber** – Classic go-to for elasticity. Think tires, hoses, and elastic bands.
- **Silicone** – Heat-resistant and flexible, often found in bakeware, sealants, and even phone cases.
- **Plastics** like **polyethylene** or **PVC** – Used in piping, packaging, and more; some variants are surprisingly bendy.
- **Textiles and fabrics** – Cotton, spandex, nylon—these keep clothes comfy and adaptable.
- **Foams** – Like memory foam, which can squish and then slowly regain its shape.

Hooke's law

Hook's law states that the extension of a material is proportional to the force provided by the elastic limit is not exceeded.

Intension $e \propto$ stretching force provide elastic limit is not exceed i.e. the material returns to its original length when the force is removed.

In short $F = ke$

where k is the constant of the material in N/m

F is the stretching force e is the extension in metres.

extension $e = \text{new length} - \text{original length}$

Example 1

(a) A spring increases its length from 20cm to 25cm when a force is applied. If the spring is constant is 100N/m. Calculate the force

$$L_0 = 20\text{cm} = 0.2\text{m}, L_n = 25 = 0.25\text{m}$$

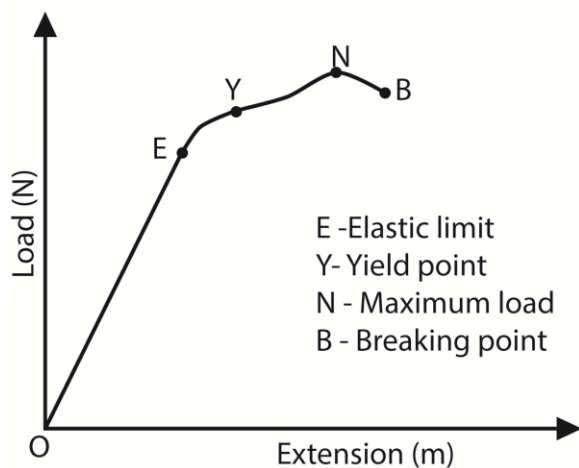
$$e = L_n - L_0 = 0.25 - 0.2 = 0.05\text{m}$$

$$k = 100\text{N/m}$$

$$F = ke$$

$$= 100 \times 0.05 = 50\text{N}$$

A graph of load against extension of a elastic material



Explanation

OE mean that the load is proportion to extension in that the extension increases as the load increases.

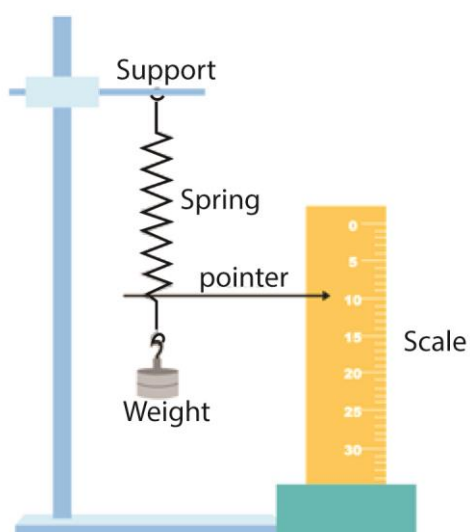
Point "E" is called elastic limit

Beyond E (elastic limit) the graph is not straight line meaning that extension is no longer proportional to the load.

Beyond E the material become plastic. This is indicated by a kink at Y which is called yield point.

Beyond Y the material behaves plastically i.e. does not regain its shape and size. So it undergoes plastic deformation. This goes on to this breaking point N.

Experiment to verify Hook's law



Procedure

- (i) Attach an optical pin (pointer) at one end of the spring using plasticise.
- (ii) Clamp the spring and half metre rule with the pointer adjacent to it and make sure the spring is vertical.
- (iii) Read the initial reading P_0 of the pointer on the metre rule.
- (iv) Suspend a mass of 0.1kg from the free end as shown in the figure above.
- (v) Record the new position P , of the pointer on the metre rule.
- (vi) Find the extension, $e = P - P_0$ of the spring
- (vii) Repeat (iv) to (vi) for masses of 0.2, 0.3, 0.4, 0.5 and 0.6 kg.
- (viii) Fill your results in the table below

m (kg)	F (N)	P (m)	E (m)

- (ix) Plot a graph of F (on vertical axis) against e (on horizontal axis)
- (x) Find the slope of the graph.
- (xi) A straight line graph is obtained whose slope is spring constant. Thus load is proportional to extension "e"

Young's Modulus

Young's Modulus, also called the *modulus of elasticity*, is a measure of how stiff a material is. More precisely, it describes how much a material will stretch (or compress) when a force is applied—so long as the material stays within its elastic limit, meaning it returns to its original shape when the force is removed.

$$\text{Young's Modulus} = \frac{\text{Stress}}{\text{Strain}}$$

$$\text{Tensile strain} = \frac{\text{extension}}{\text{original length}} = \frac{e}{L_0}$$

It has no units

Example 2

A wire increases in length from 20cm to 25cm when a force is applied. Calculate the tensile strain.

$$L_0 = 20\text{cm}, L_n = 25\text{cm}$$

$$e = L_n - L_0$$

$$25 - 20$$

$$5\text{cm}$$

$$\text{Strain} = \frac{e}{L_0} = \frac{5}{20} = 0.25$$

$$\text{Tensile stress} = \frac{\text{Stressing force } (F)}{\text{Cross section area } (A)} = \frac{F}{A}$$

The SI unit is N/m^2

Example 3

Calculate the tensile stress when a force of 25N acts on a wire of cross sectional area 5m^2 .

$$A = 5\text{m}^2$$

$$F = 25\text{N}$$

$$\text{Tensile stress} = \frac{F}{A} = \frac{25}{5} = 5\text{Nm}^{-2}$$

Example 4

A spring is stretched 0.05m by weight of 5N hung from one end. What weight will stretch by 0.03m

$$F_1 = 5\text{N}$$

$$e_1 = 0.05$$

$$F_2 = ?$$

$$e_2 = 0.03\text{m}$$

$$\frac{F_1}{e_1} = \frac{F_2}{e_2}$$

$$\frac{5}{0.05} = \frac{F_2}{0.03}$$

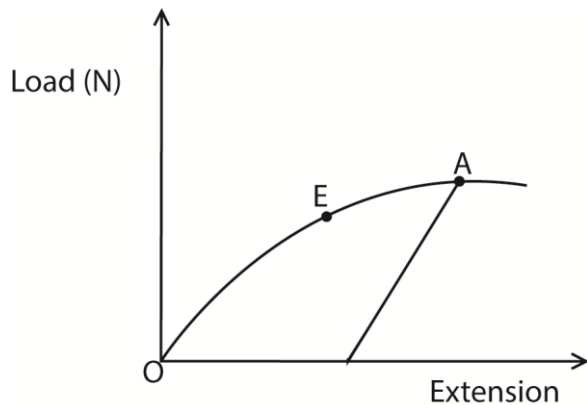
$$\frac{5 \times 0.03}{0.05} = F_2$$

$$3\text{N} = F_2$$

Trial 1

1. A wire extends by 0.5cm when a load of 0.4N hanging from it. What load will be required to cause an extension of 1.5cm? [1.2N]
2. A spring stretches from 20.0cm to 25.0cm when a force is applied on it. If the spring constant is 100Nm^{-1} . Calculate the force used to stretch the spring [5N]
3. Bbosa and Fahad stretched a rubber band by 0.05m when they tied a weight of magnitude 5N at one end of the rubber band. Find the weight they would tie on the rubber band to stretch it by 0.03m. [3N]
4. A wire of natural length 1.5m is extended by 0.005m using a force of 0.8N. What will be its length when a load of 3.2N is hanged from it. [1.52m]

Explanation of sketch of load against extension according to kinetic theory



OE the molecules are pulled slightly farther apart but can move back to original position when stretching force is removed. The deformation is called elastic.

Beyond A layers of atoms slip over each other, the molecule move farther apart but cannot move back to original position when stretching force is removed.

Tensile, shear and compression forces

Compression force



Compression is when the force acts as in the diagram above. The particles pushed to each other. So the Length of the material decreases but the thickness of the material increase.

Tensile force



Tensile force is when the forces act in the diagram above. This results in the particles of the material to be pulled further apart from one another. A material under tensile force increases with the length but its thickness decreases.

Differences between tensile and compression force

Tensile

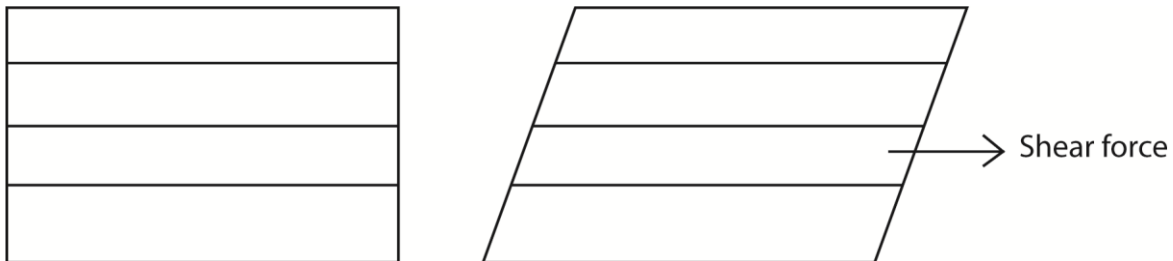
- i) particles are pulled further
- (ii) length of the material increases
- iii) thickness of the material reduces

Compression

- (i) particles are pushed close to each other
- (ii) length of the material decreases
- (iii) Thickness of the material increase

Shear force

Shear force is the force needed to fracture the material in a direction parallel to the applied force in that one section of the material slides over its neighbour. A shear is produced when two equal but opposite forces are applied to an object at a distance from one another so that they twist the body. The effect depends on the turning effect or movement of the force.



Building materials

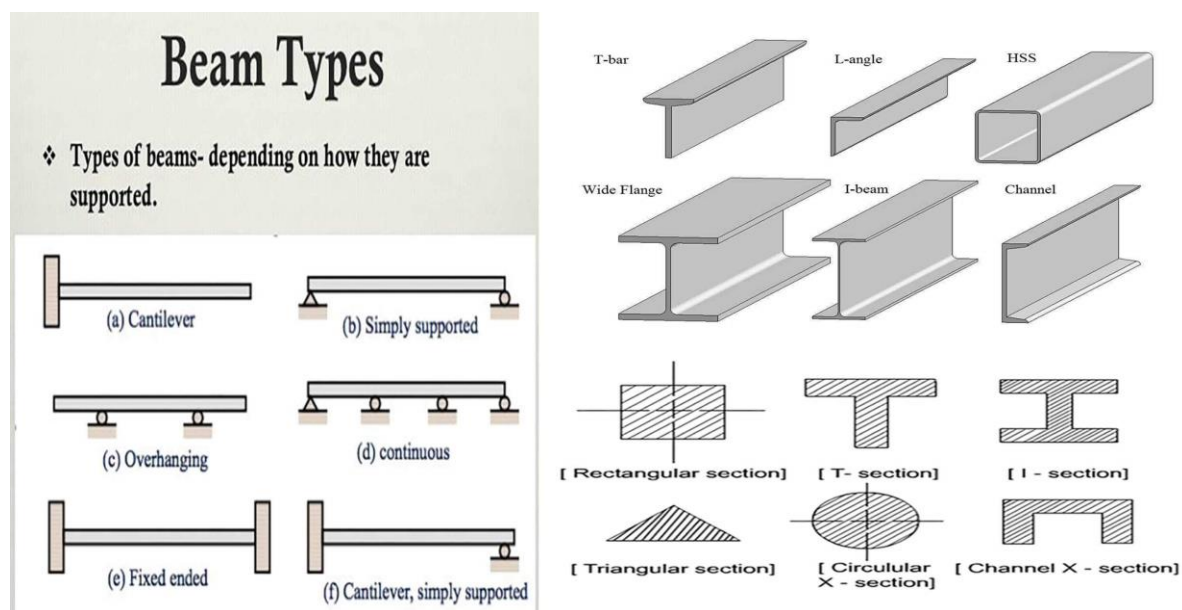
1. **Metal:** Large variety of metals are available from which different alloys or combinations of these metals are made into various shapes. Metal can be rolled, pressed, and drawn, and are usually strong, rigid and elastic. Some of the common metals are copper, iron, zinc, lead etc.
2. **Alloys:** Alloys are made by mixing one metal with one or more other metals and in some cases non-metals. E.g. Steel (iron and carbon), **Invar** (nickel –iron), etc.
3. **Bricks:** Are made by moulding a mixture of clay and water and heating the mixture strongly.
4. **Safety glass:** Is used for motor vehicle wind screen. Safety glass is made by heating plate glass cooling the two surfaces in a stream of air. These contract and compress the glass in the middle resulting a very strong glass which when hit hard enough breaks into small fragments that are less dangerous than larger pieces.
5. **Wood:** Wood is a poor conductor of both heat and electricity. It is used in roofing, and poles.

Beams

A **beam** is a horizontal structural element that supports loads and transfers them to vertical supports like columns or walls. They're essential in buildings, bridges, and even vehicles, resisting bending and shear forces to keep everything standing tall.

There are several types of beams, each with its own purpose:

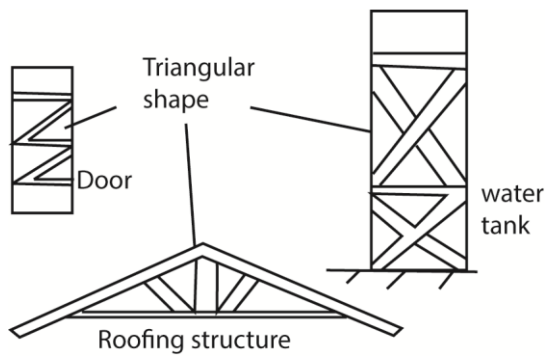
- **Simply supported beams:** Rest on two supports and are free to rotate.
- **Cantilever beams:** Fixed at one end and free at the other — think balconies.
- **Continuous beams:** Span over more than two supports, great for long structures.
- **Fixed beams:** Rigidly held at both ends, offering high resistance to movement



Structures

A **Structure** is an object made up of different parts which collectively work together to support loads. Structures should be rigid, strong and stable. The strength of the structure depends on its geometrical shape and strength of the materials used. For example, a steel structure is stronger than a wooden one.

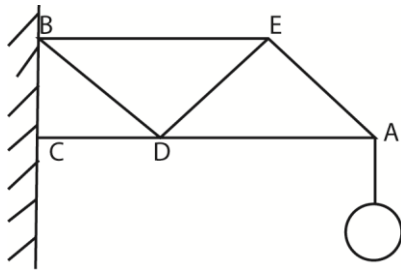
Triangular structures are more rigid than others. So, rectangular structure can be made rigid by adding a diagonal piece so that the rectangular structure changes into two triangular structures which are more rigid. This is why door, water tank, roofing tops are supported by triangular structures.



Girders

These are short pieces of materials added to structures to improve strength. Girders under tension are known as **ties** and those in compression are **struts**.

For example in the diagram below:



AE is a tie

ED is a strut

AC is a strut

CD is a strut

DA is a strut

BE is tie

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