Lecture

General Physics

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Elasticity

When an external force is applied to the surface of any material:

- If the material returns to its original shape, it is said to be elastic in nature, and this property is known as **‘elasticity’.**

- If the material does not regain its original shape, it is said to be plastic in nature, and this property is known as **‘plasticity’.**

Elasticity

is not a measure of the ability to stretch or distort because of forces,

but

<u>the ability to return to original form (size and shape) when the distorting force is removed.</u>

Load

Load is the external force acting on a body causing a change in dimensions .

Stress

The restoring force per unit area set up inside the body. The stress is equal to the load per unit area but opposite in direction.

Stress =F /A

- The stress is may be compressive or expansive (i. e. tensile) according as a decrease or an increase in volume is involved.
- Its dimensions are the same as pressure, $M\ L^{-1}\ T^{-2}$, and its units are (N/m^2 , $dyne/cm^2$)

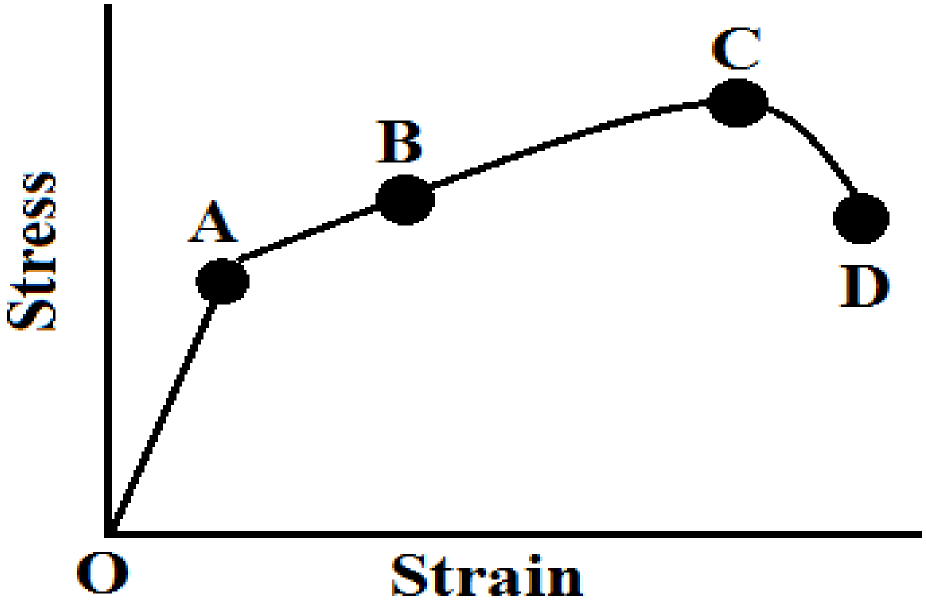
Strain

It is the change produced in the dimensions of a body under a system of forces.

$$\text{Strain} = \frac{\text{Change in dimension}}{\text{Initial dimension}}$$

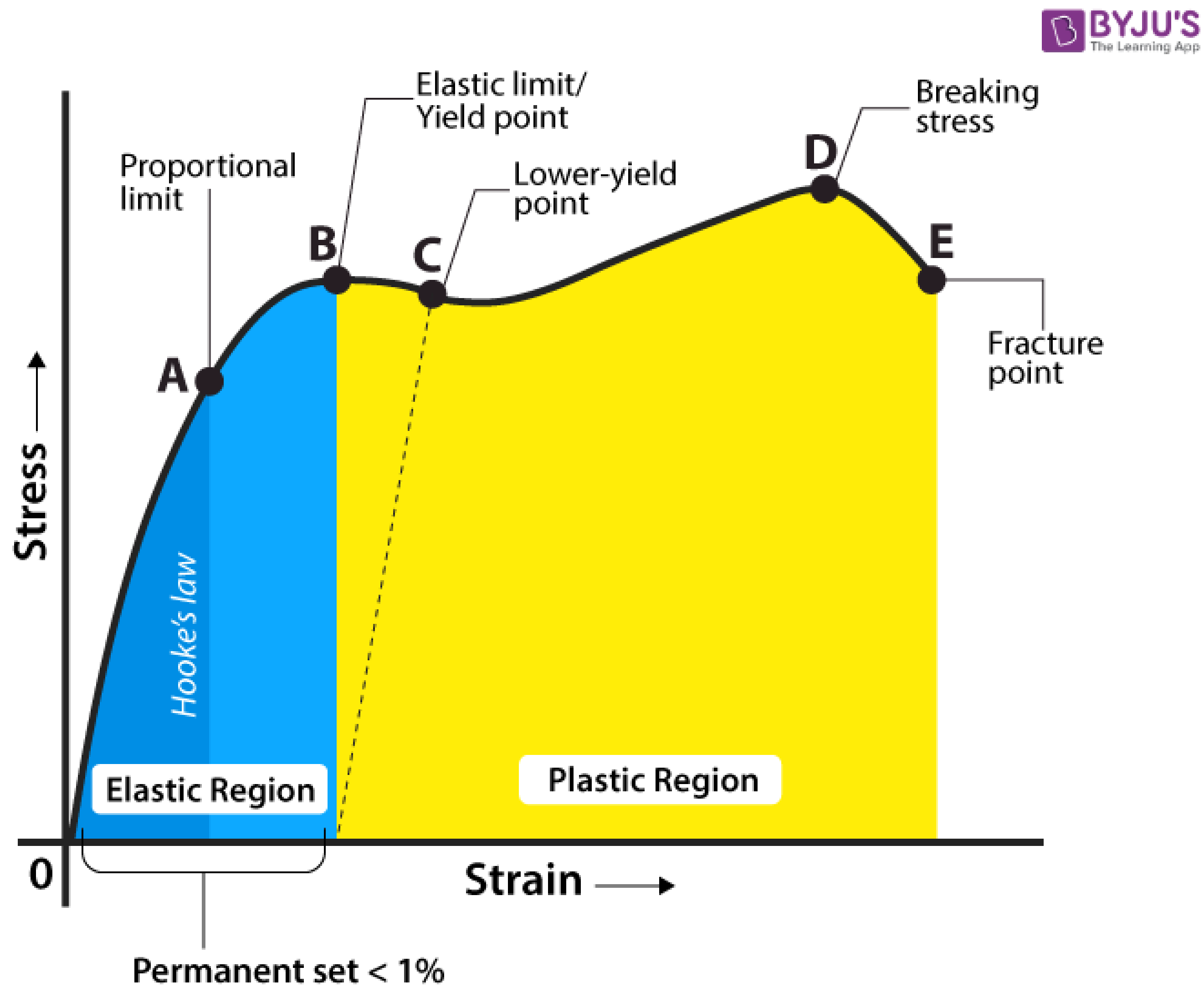
Dimensionless
&Unit less

Explanation of Stress-Strain Curve



Column A	Column B
Point "A"	The proportional limit
Point "B"	The elastic limit or Yield point
Point "C"	Ultimate stress point
Point "D"	Fracture or break point
From O to A	Hook's law region
From O to B	The material is said to be elastic
From B to D	The material undergoes plastic flow or plastic deformation.

Stress-Strain Curve



(i). Proportional Limit:

It is the region in the strain curve which obeys Hook’s law . In this limit the ratio of stress with strain gives us proportionality constant known as young’s modulus.

(ii). Elastic Limit:

It is the point in the graph up to which the material returns to its original position when the load acting on it is completely removed

(iii). Yield Point or Yield Stress Point:

Yield point is defined as the point at which the material starts to deform plastically. After the yield point is passed there is a permanent deformation develops in the material which is not reversible. There are two yield points and it is upper yield point and lower yield point.

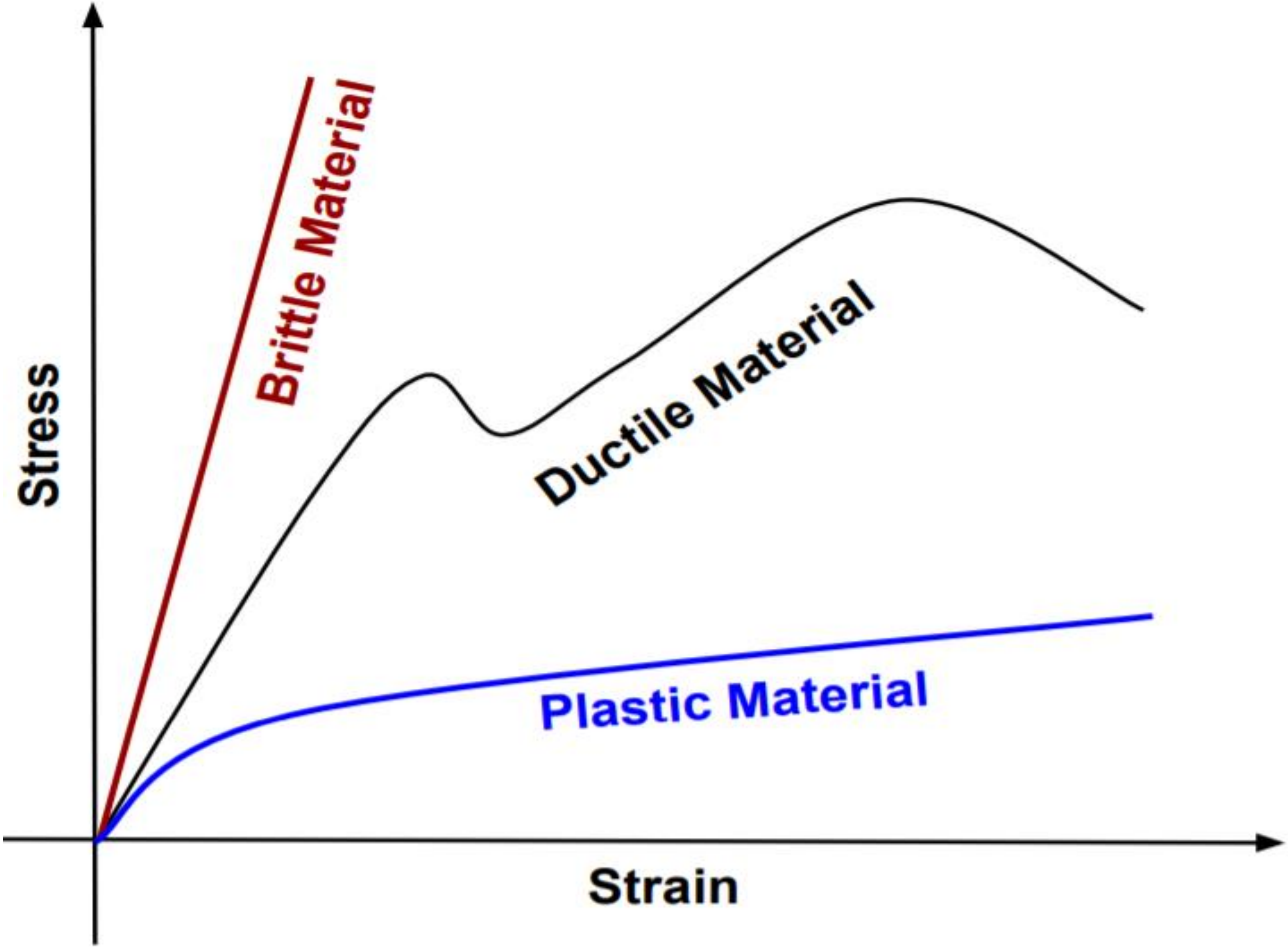
(iv) Ultimate(Breaking) Stress Point:

It is the maximum strength point of the material that can handle the maximum load. Beyond this point the failure takes place.

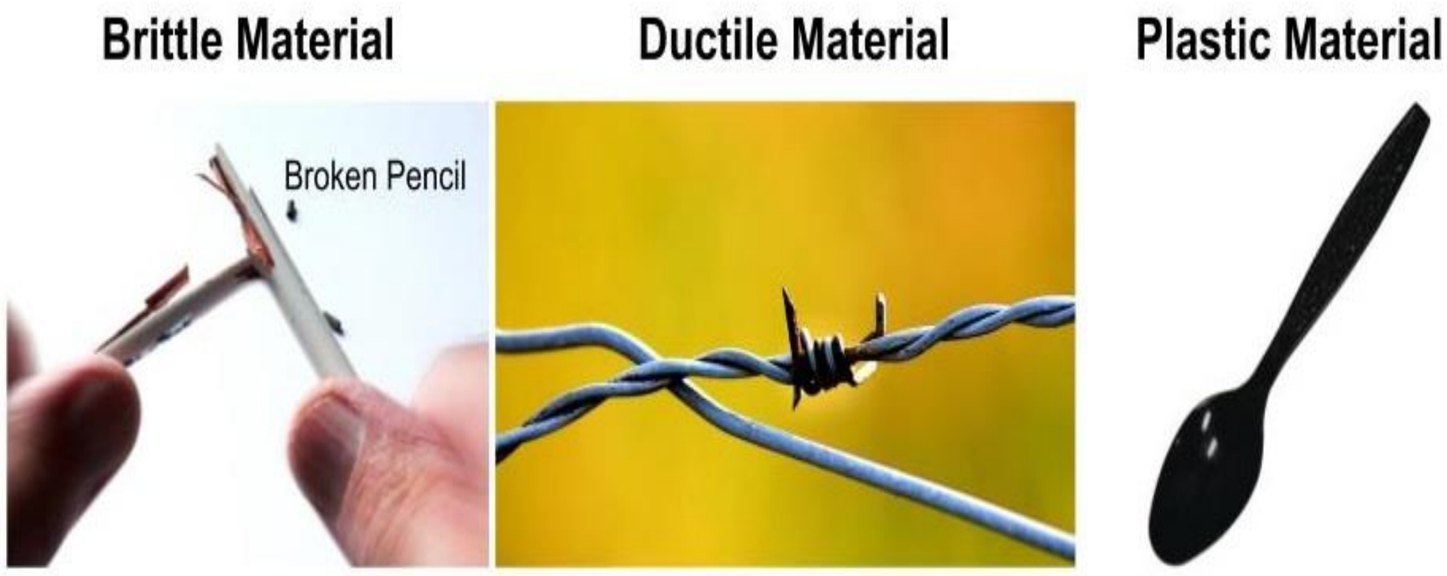
(v) Fracture Point:

It is the point in the stress strain curve at which the failure of the material takes place.

Stress Strain Curve Comparison
(Ductile , Brittle and Plastic Materials)


Brittle Material
Ductile Material
Plastic Material
Stress
Strain

Products that we use in our daily life are made of brittle, ductile, Plastic or rubber material. These materials behave differently when external force is applied.



Ductile Materials

Ductile material exhibits elastic and plastic deformation. As shown in stress strain diagram, for ductile materials ultimate stress point and fracture point are not the same. Copper, Aluminum, Steel etc are ductile materials.

Brittle Materials

When an external force is applied, Brittle material breaks with very small elastic deformation and without plastic deformation. For brittle materials elastic limit, yield strength, ultimate tensile strength and breaking strength are the same. They absorb relatively little energy prior to fracture. Example of brittle materials are ceramic, wood, glass, graphite, cast iron etc,

Plastic Materials

As shown in the stress strain curve for plastic materials. Similar to ductile materials, some plastic materials exhibit elastic properties up to proportional limit. But plastic material requires very less stress compared to ductile materials to produce deformation. Plastic materials do not show any work hardening during plastic deformation.

TYPES OF STRESS

1-Linear Stress

2-Bulk Stress

3-Shear Stress

TYPES OF STRAIN

1-Linear Strain

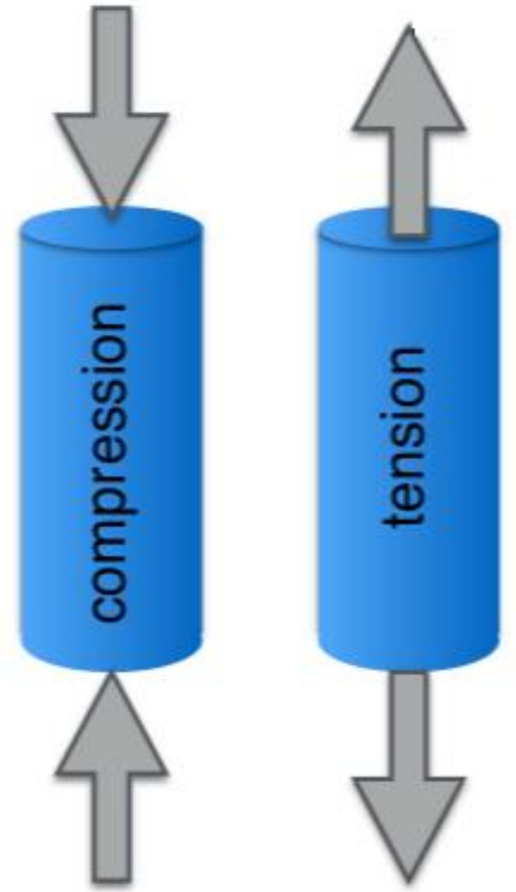
2-Bulk Strain

3-Shear Strain

1-Linear Stress and Strain

It has 2 types:
-Tensile
-Compression

The main difference between tensile and compressive stress is that ***tensile stress*** results in ***elongation*** whereas ***compressive stress*** results in ***shortening***.



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

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

2-Bulk Stress and Strain

Bulk stress is possible in liquids and gases as well as in solids. This is a uniform pressure exerted normally across any area of the material and defined as a force per unit area.

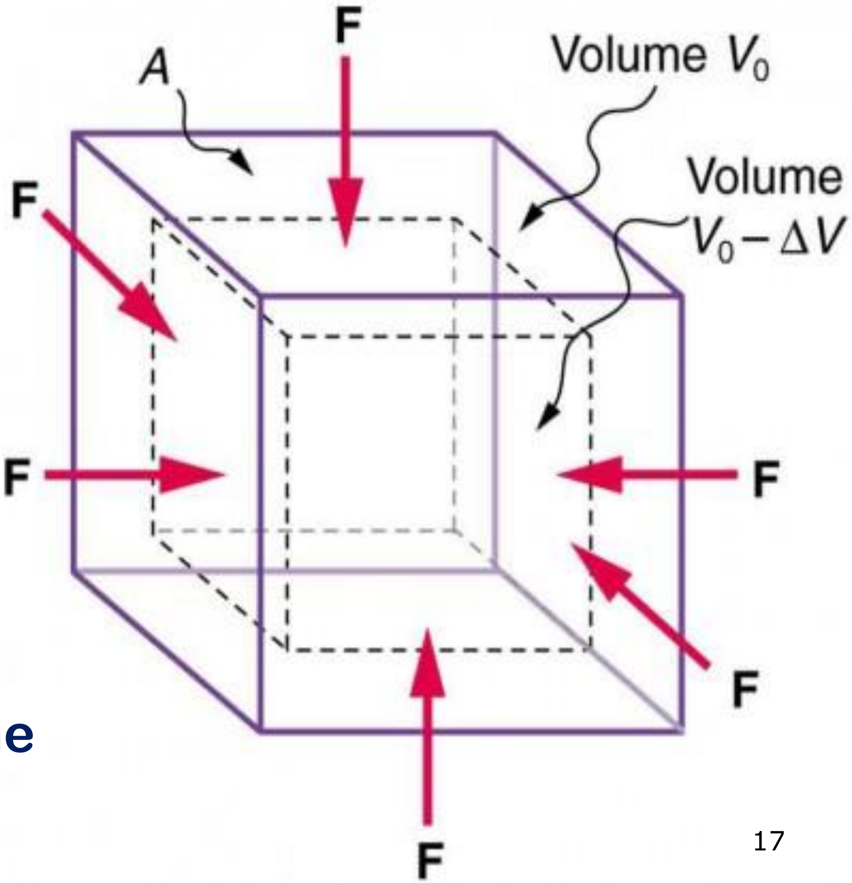
Bulk Stress is the pressure change

$$=\Delta P = \frac{F}{A}$$

Bulk strain is the fractional decrease in volume

$$=\frac{-\Delta V}{V}$$

A negative sign is used because the volume decreases as the pressure increase.



3-Shear Stress and Strain

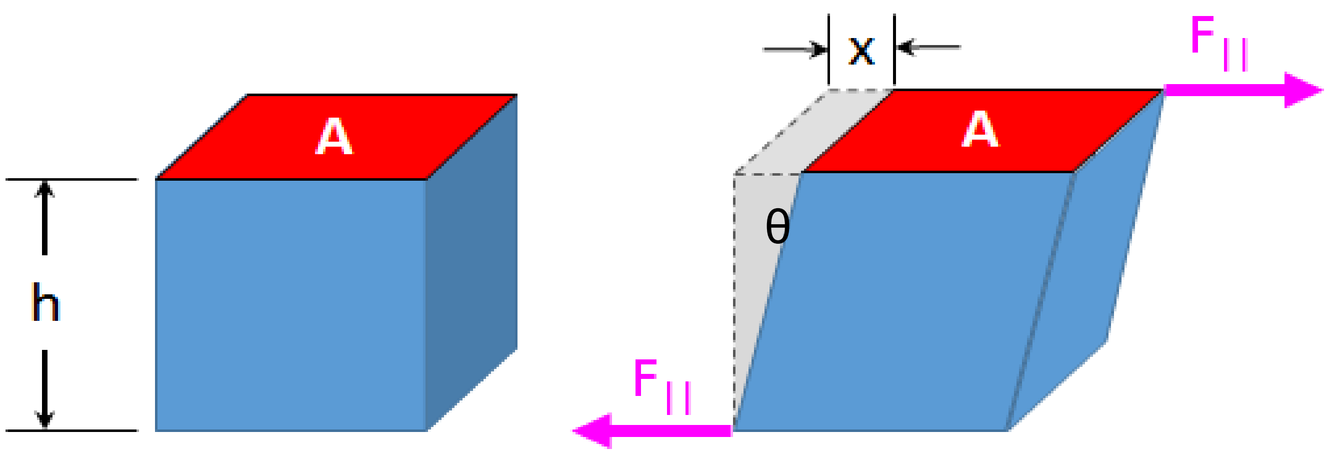
Shear stress and shear strain arise when a torque is applied to a solid body. The top face moves slightly to the right through a small distance Δx.

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

Shear Strain $= \frac{Displacement}{Height} = \frac{\Delta x}{h}$

tan θ= $\frac{\Delta x}{h} \therefore$

Shear Strain = θ ,(When θ is v. small)



Initial State

Shear Stress

Types of elastic moduli

$$\textbf{Elastic modulus} = \frac{Stress}{Strain}$$

and its units are (N/m^2 , $dyne/cm^2$)

1) **Young modulus (Y)**
2) **Bulk modulus (B)**
3) **Rigidity modulus (N)**

1) - Young modulus (Y)

$$\frac{FL}{\Delta L\ A} = \frac{F/_{A}}{\Delta L/_{L}} = \mathbf{Y} = \frac{Linear\ stress}{Linear\ strain}$$

2) - Bulk modulus (B)

$$\frac{-\Delta P\ V}{\Delta V} = \frac{\Delta P}{-\Delta V/_{V}} = \mathbf{B} = \frac{Pressure\ change}{Bulk\ strain}$$

3) -Rigidity modulus (N)

$$\mathbf{N} = \frac{Tangential\ or\ shearing\ stress}{Shearing\ strain}$$

$$\mathbf{N} = \frac{F\ y}{A\ \Delta x} = \frac{\mathrm{F}}{\mathrm{A}\tan\theta}$$

Hook’s Law :

Stress is directly proportional to strain within the elastic limit.

$$\frac{F}{A} \alpha \frac{\Delta L}{L} \Rightarrow \frac{F}{A} = y \frac{\Delta \mathrm{L}}{\mathrm{L}}$$

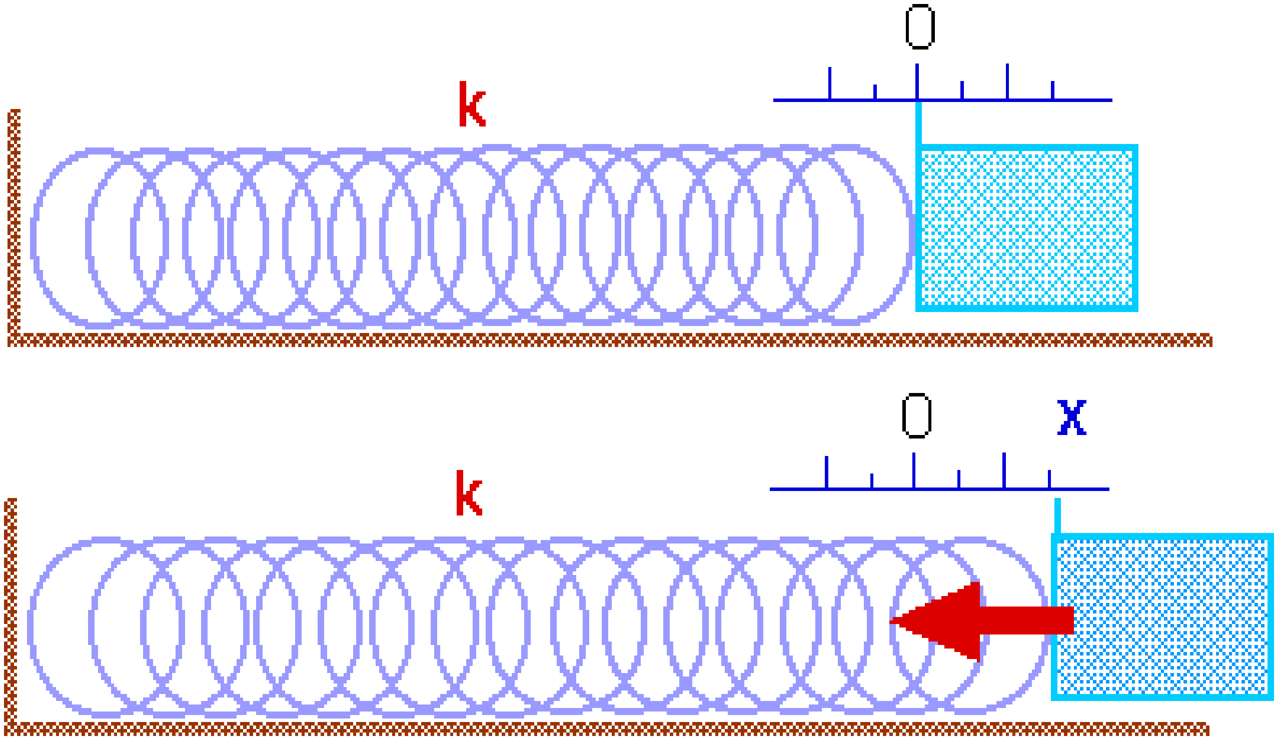
$$\Rightarrow \mathrm{F} = \frac{A\,Y}{L} \Delta \mathrm{L}$$

Where A, Y, & L are constants for the same elastic material.

$$\mathrm{F} = \mathrm{K}\,\Delta \mathrm{L}$$

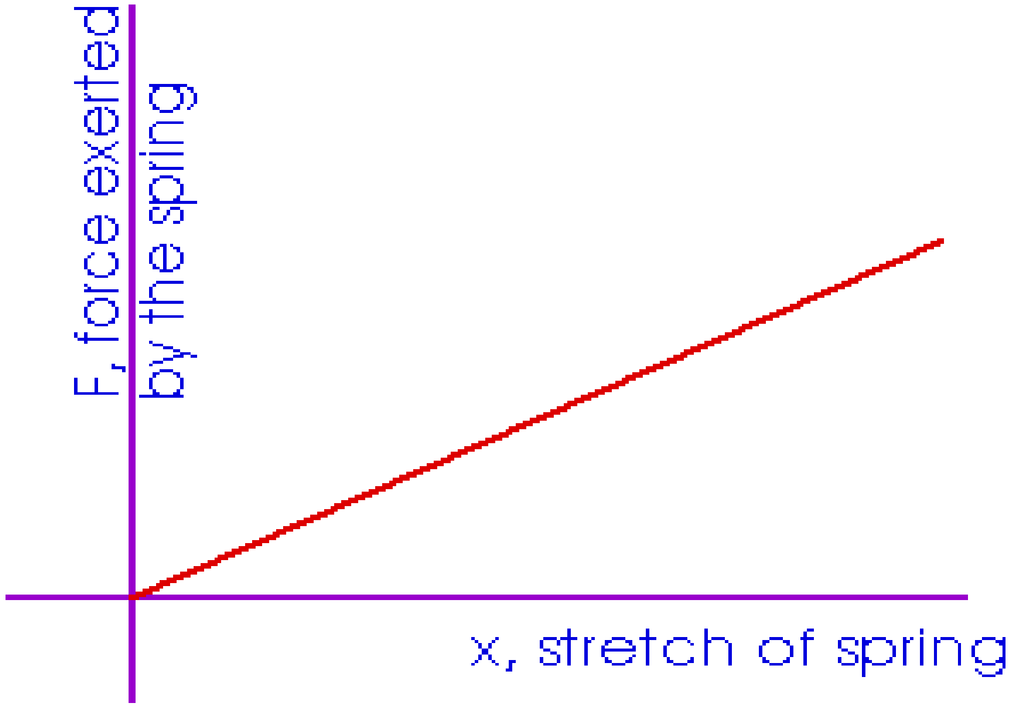
(K) is the elastic constant and its units are (N/m) or (dyne/cm).

How much work is done when we stretch a spring a distance x from its equilibrium position?



First, we need to know about the general characteristics of a spring.

Experimentally, we find



This is known as Hooke's law

Poisson's ratio

When a wire is *stretched*, its length *increases* but its diameter *decreases*. In general, when an *elongation* is produced by a *longitudinal stress* in a certain direction a contraction results in the lateral dimensions of the body under strain. The lateral strain is proportional to the *longitudinal strain* so long as it is small. The ratio

$$\frac{\text{Lateral Strain}}{\text{longitudinal Strain}}$$

is called *Poisson's ratio (σ).*

$$\sigma = \frac{d/D}{x/h} = \frac{\beta}{\alpha}$$

Where β is lateral strain, α is the longitudinal strain, **D** is the diameter of the wire & **d** is the corresponding decrease in diameter.

EXERCISES

Q1.

A wire of length 1m has a force 22N applying on it and causes an increase in the wire's length by 1mm. Calculate the diameter of this wire if its elastic modulus equals 1.1×10^{-12} N/m^2.

Sol.

$$Y = \frac{F\ L_\circ}{A\ \Delta L}$$

$$\therefore A = \frac{F\ L_\circ}{Y\ \Delta L}$$

$$\pi r^2 = \frac{22 * 1}{1.1 * 10^{-12} * (1 * 10^{-3})}$$

$$\therefore r = \sqrt{\frac{22 * 1}{\pi(1.1 * 10^{-12}(1 * 10^{-3})}}$$

$$= 7.891 * 10^{-5} m = 0.07891$$

$$\therefore d = 2r = 0.15962\ mm$$

Q2.

A steel wire of length 1m and area of cross section 0.04 cm^2. Find the force required to make the wire be elongated by 0.3cm where young modulus of steel equals 2×10^{11} N/m^2.

Sol.

$$Y = \frac{F\ L_\circ}{A\ \Delta L}$$

$$F = \frac{Y\ A\ \Delta L}{L_\circ}$$

$$= 2.4 * 10^3\, N$$

Q3.

If a body of mass 500kg is attached to the end of a wire of length 3m and area of cross section 0.15m^2. Calculate the resultant elongation and young modulus equals 2×10^{11} N/m^2.

Sol.

$$Y = \frac{F\,L_\circ}{A\,\Delta L}$$

$$\Delta L = \frac{F\,L_\circ}{A\,Y} = \frac{m\,g\,l}{A\,Y}$$

$$= \frac{500 * 9.8 * 3}{0.15 * 2 * 10^{11}}$$

$$= 4.8 * 10^{-3}\,m = 4.8\,mm$$

Q4.

If the volume of a ball is $0.5m^3$ and its bulk modulus is 7.7×10^9 pa. Calculate the change in volume for this ball if it's affected by a stress of 2×10^7 pa.

Sol.

$$B = \frac{-P\,V_\circ}{\Delta V}$$

$$\Delta V = -\frac{P\,V_\circ}{B}$$

$$= -\frac{2 * 10^7 * 0.5}{7.7 * 10^9}$$

$$= -1.3 * 10^{-3}\,m^3$$

Q5.

Calculate the biggest value of the length of a wire to be attached vertically without cutting if shear stress equals 7.9×10^{9} N/m^2 and density of the wire equals 7.9 gm/cm^3.

Sol.

$$\sigma = \frac{F}{A} = \frac{m\,g}{A} = \frac{\rho\,V\,g}{A}$$

$$\therefore \sigma = \frac{A\,L\,\rho\,g}{A}$$

$$\therefore L = \frac{\sigma}{\rho\,g} = \frac{7.9 * 10^{9}}{7.9 * 9.8 * 10^{2}}$$

$$L = 1.02 * 10^{6}\ cm$$

Q6.

2 wires are fabricated from different materials, the 1st wire's length equals half the 2nd wire's length and the 2nd wire's diameter equals the 1st wire's radius. The 2 wires are affected by the same tensile force and the resulted elongation in the 1st wire equals quarter of that of the 2nd wire. Calculate the ratio between young modulus in the 2 wires.

Sol.

$L_1 = \frac{1}{2} L_2 \qquad r_1 = 2r_2 \qquad F_1 = F_2 = F \qquad \Delta L_1 = \frac{1}{4} \Delta L_2$

$$Y_1 = \frac{F_1\ L_1}{A_1\ \Delta L_1}$$

$$= \frac{F(^1/_2)L_2}{\pi(2r_2)^2(^1/_4)\Delta L_2}$$

$$\therefore Y_1 = \frac{F\ L_2}{2\pi r_2^2\ \Delta L_2} \qquad \leftarrow 1$$

$$Y_2 = \frac{F_2\ L_2}{A_2\ \Delta L_2} = \frac{F\ L_2}{\pi r_2^2\ \Delta L_2}$$

$$Y_2 = \frac{F\ L_2}{\pi r_2^2\ \Delta L_2} \qquad \leftarrow 2$$

1/2:

$$\frac{Y_1}{Y_2} = \frac{F\ L_2}{2\pi r_2^2\ \Delta L_2} \Big/ \frac{F\ L_2}{\pi r_2^2\ \Delta L_2}$$

$$\therefore \frac{Y_1}{Y_2} = \frac{1}{2}$$

THANKS