Chapter 9:Static Equilibrium

Lecture 3

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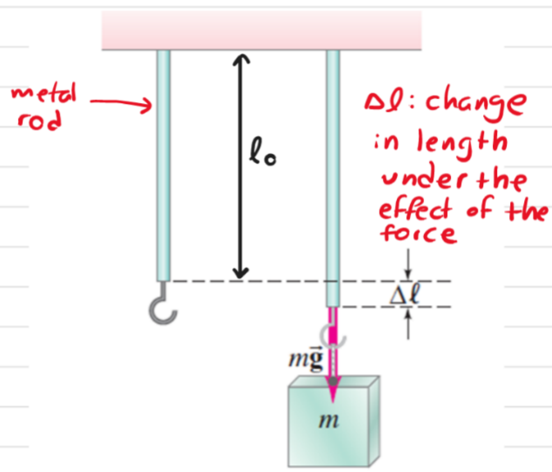
9-5] Elasticity, Stress and Strain

What effects do forces have on objects?



Elasticity and Hooks Law

metal rod changes length under the force due to the weight of the block

When $\Delta \ell \ll \ell_0$ $\Rightarrow$

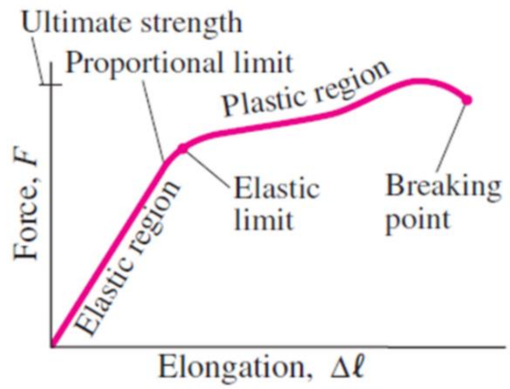
$$F = k\,\Delta \ell \qquad \text{(Hook's law)}$$

↑ proportionality constant

The above relation is almost valid for any material from iron to bones

Elastic region: Hook's law applies, $F = k\Delta l$ and object returns to its original length after force is removed.

Elastic limit: maximum value of Δl such that the object returns to its original length whe the force is removed



Breaking Point: The maximum force that can be applied without the object breaking.

Elastic region: region from the origin to the elastic limit

Plastic Region: Region from elastic limit to breaking point. In this region the object becomes permenantly deformed.

Young's Modulus

For a given force (F) the elongation (Δl) is proportional to:
- the length l_0 of the object
- cross sectional area of the object (A)

$\Delta l \propto \frac{F}{A} l_0$

$\Delta l = \frac{1}{E} \frac{F}{A} l_0$

└ constant of proportionality called Young's Modulus.

The value of E depends on the type of the material

It does NOT depend on the shape or size of the material

E has units of N/m^2.

Material	$E\ (N/m^2)$
steel	200×10^9
bone (limb)	15×10^9

EXAMPLE 9–10 **Tension in piano wire.** A 1.60-m-long steel piano wire has a diameter of 0.20 cm. How great is the tension in the wire if it stretches 0.25 cm when tightened?

APPROACH We assume Hooke's law holds, and use it in the form of Eq. 9–4, finding E for steel in Table 9–1.

SOLUTION We solve for F in Eq. 9–4 and note that the area of the wire is $A = \pi r^2 = (3.14)(0.0010\,\text{m})^2 = 3.14 \times 10^{-6}\,\text{m}^2$. Then

$$F = E \frac{\Delta \ell}{\ell_0} A$$

$$= (2.0 \times 10^{11}\,\text{N/m}^2)\left(\frac{0.0025\,\text{m}}{1.60\,\text{m}}\right)(3.14 \times 10^{-6}\,\text{m}^2)$$

$$= 980\,\text{N}.$$

NOTE The large tension in all the wires in a piano must be supported by a strong frame.

Stress and Strain

stress: force per unit area F/A, has units of N/m^2

strain: ratio of change in length to original length $\Delta l / l_0$

Remember $\Delta l = \frac{1}{E} \frac{F}{A} l_0$

$$\therefore \quad E = \frac{F}{A} \times \frac{l_0}{\Delta l} = \frac{F/A}{\Delta l / l_0} = \frac{\text{stress}}{\text{strain}}$$

$$\therefore \quad \text{strain} = \frac{1}{E} \text{ stress} \Rightarrow$$

strain α stress in elastic region.

Tension (Tensile Stress)

In Fig(a), rod is under tension (tensile stress)

Tensile stress exists throughout the rod. If we split the rod into two halfs, the lower half is acted on by an upward force due to the upper half.

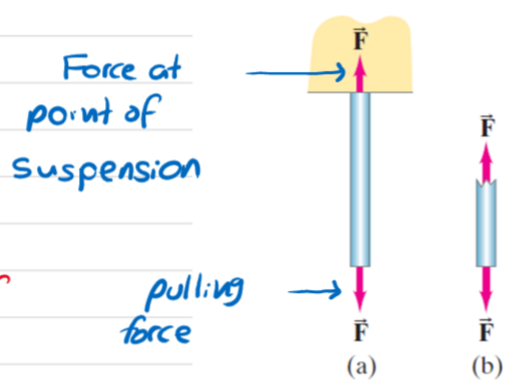
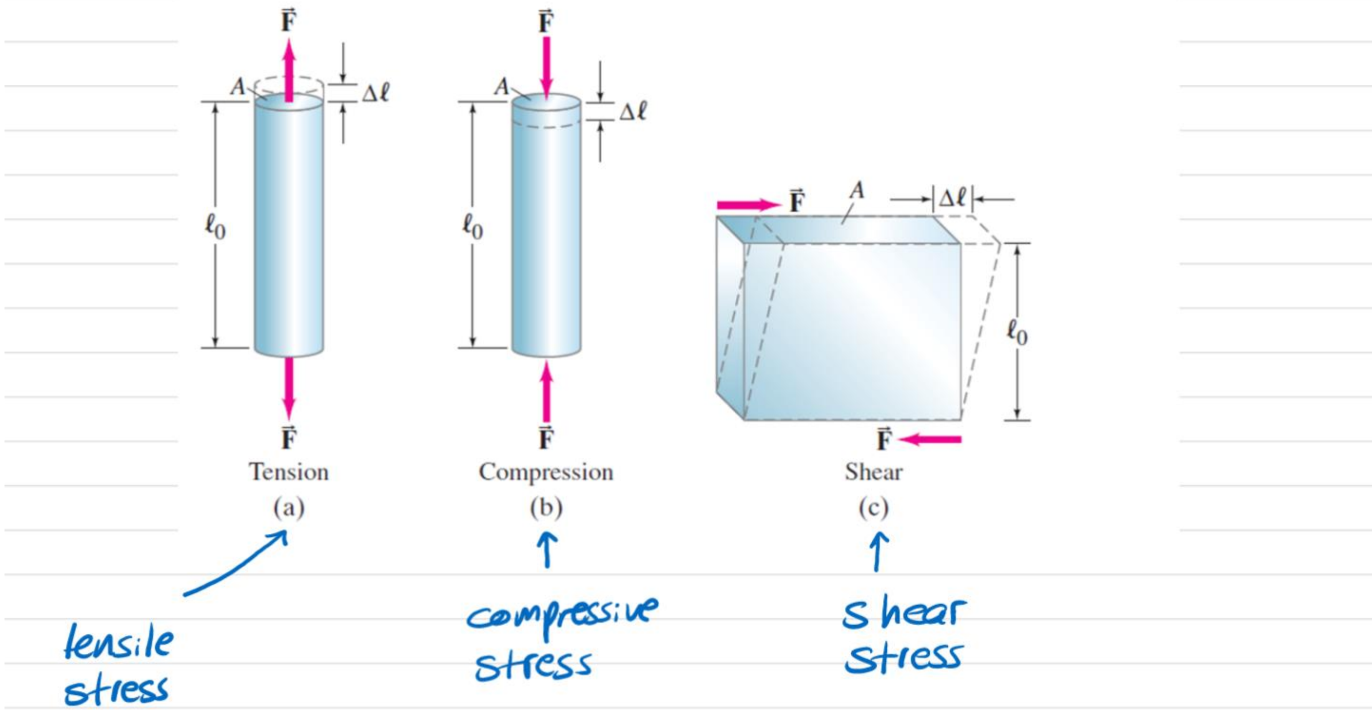


FIGURE 9–20 Stress exists *within* the material.

In addition to tensile stress, we have compressive stress and shear stress as shown below:



In shear stress, the demensions of the object don't change much, but the shape changes.

We may write:

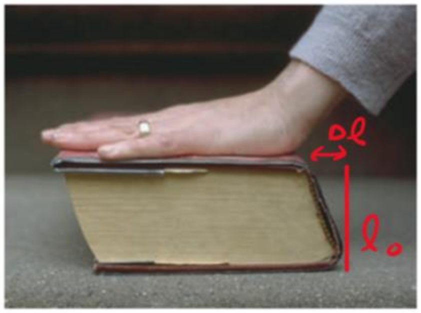
$$\Delta l = \frac{1}{G}\frac{F}{A} l_0$$

but A is the area parallel to the force as in Fig(c)

$$\frac{\Delta l}{l_0} = \frac{1}{G}\frac{F}{A}$$

$$\text{shear strain} = \frac{1}{G}\ \text{shear stress}$$

G: shear modulus has units of N/m^2



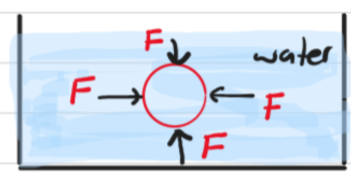
(a)

(b)

For thick book on the left (large l_0)
Δl is greater than that for thin book (small l_0)
on the right.

Volume change - bulk modulus

The water acts with forces in all direction on the ball
⇒ pressure which is force per unit area



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

∴ pressure is equivalent to stress.

V_0: original volume

ΔV: change in volume due to pressure (stress)

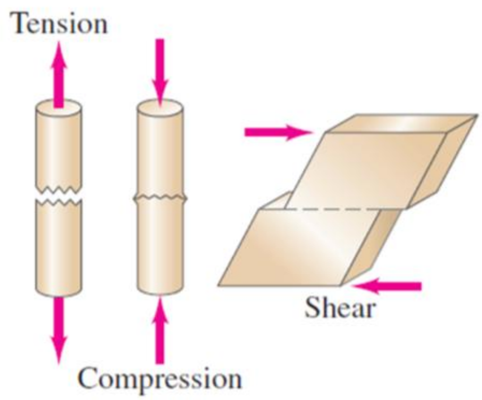
$$\frac{\Delta V}{V_0} = -\frac{1}{B}\Delta P \qquad (\text{note } \Delta V < 0)$$

$$\therefore \quad B = -\frac{\Delta P}{(\Delta V / V_0)}$$

note that ΔV decreases when pressure increases

9-6] Fracture

When stress on an object is large, the object may break.



maximum values before object breaks (approximate values)

TABLE 9–2 Ultimate Strengths of Materials (force/area)

Material		Tensile Strength (N/m^2)	Compressive Strength (N/m^2)	Shear Strength (N/m^2)
Iron, cast		170×10^6	550×10^6	170×10^6
Steel		$500\text{–}2500 \times 10^6$	500×10^6	250×10^6
Brass		250×10^6	250×10^6	200×10^6
Aluminum		200×10^6	200×10^6	200×10^6
Concrete		2×10^6	20×10^6	2×10^6
Brick			35×10^6	
Marble			80×10^6	
Granite			170×10^6	
Wood (pine)	(parallel to grain)	40×10^6	35×10^6	5×10^6
	(perpendicular to grain)		10×10^6	
Nylon		500×10^6		
Bone (limb)		130×10^6	170×10^6	