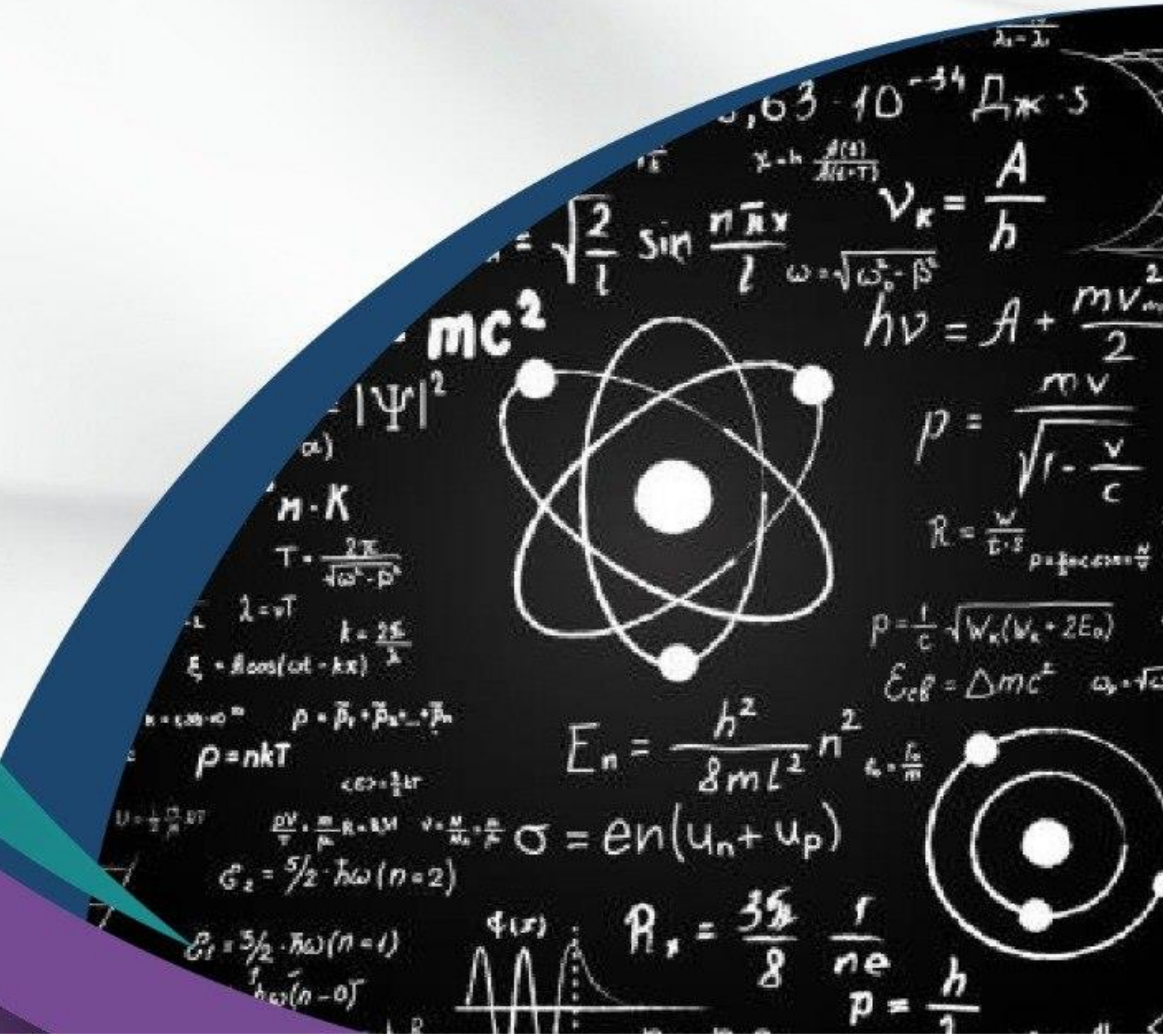
Physics 105

File: Chapter 8+9

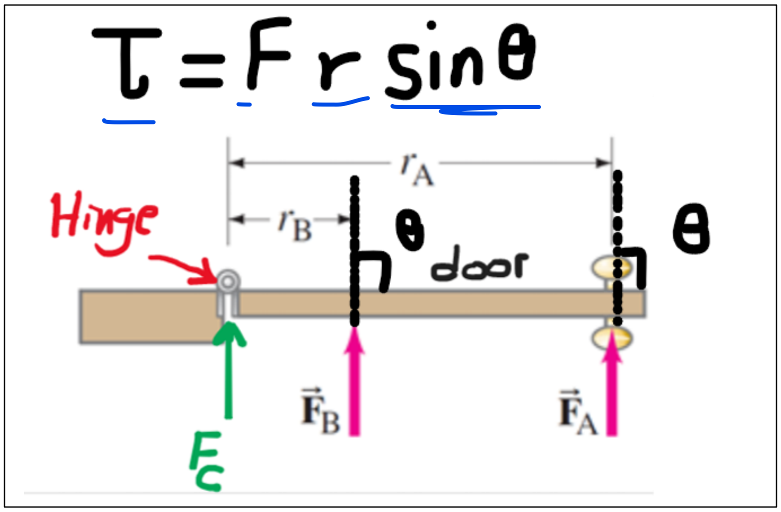
Concept:

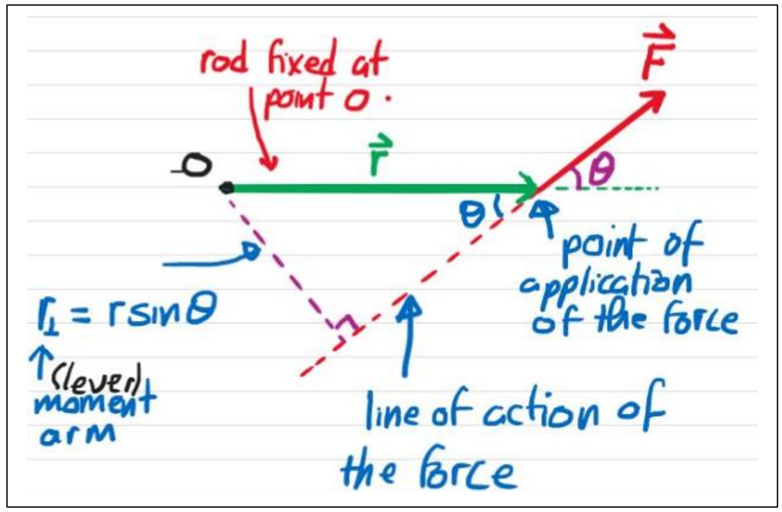


Chapter 8

Torque: Ability to cause rotation around an axis

Torque = (Length between hinge and force) x (Force) x (sin “angle between length and force”)





→ When torque equals “zero”?

1) When Force equals zero
2) When the force is applied on the hinge “distance = zero”
3) When the angle = zero or 180

→ Why do we use Sin “angle” and not cos ”angle”?

Because (sin) is the Y component of the force, and it’s what really causes movement

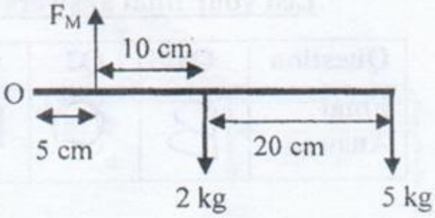
→ Torque is greatest when angle = 90

→ Clockwise = negative

→ Anti-clockwise = positive

→ Past papers on chapter 8:

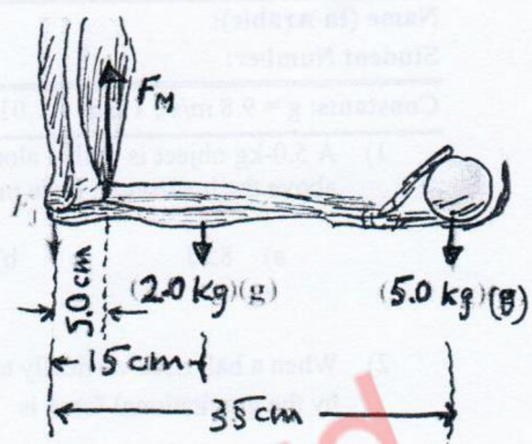
Q6) How much force (F_M in N) must the biceps muscle exert when a 5.0-kg mass is held in the hand with the arm horizontal as in the figure. Assume that the mass of forearm and hand together is 2.0 kg.



A) 803 C) 50 E) 106
B) 201 D) 402

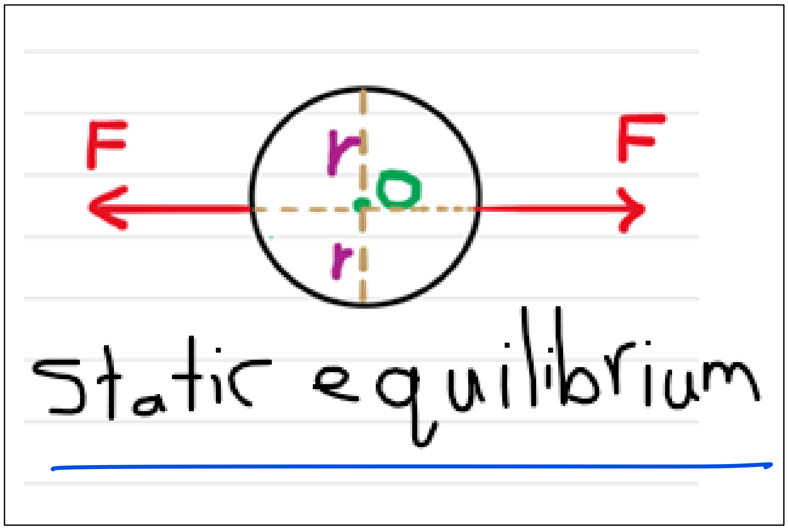
8) How much force (F_M) must the biceps muscle exert when a 5.0-kg mass is held in the hand with the arm horizontal as in the figure. Assume that the mass of forearm and hand together is 2.0 kg and their CG is as shown.

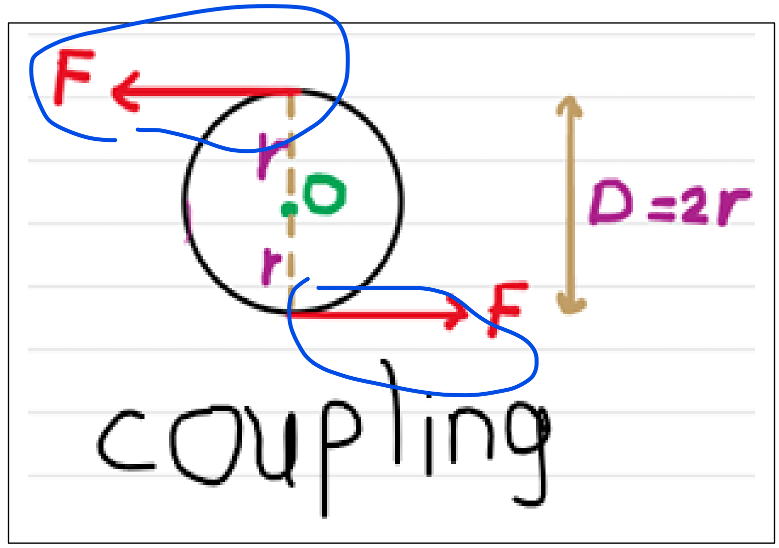
a) 800 N b) 400 N c) 100 N
d) 200 N e) 50 N



Chapter 9

Static equilibrium: NO MOVEMENT AT ALL





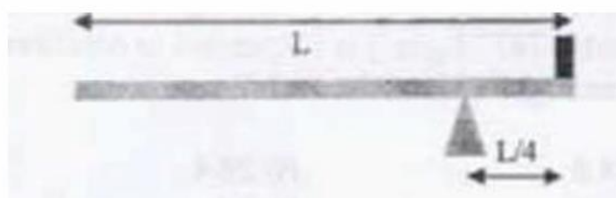
Conditions for static equilibrium

i) $\Sigma \tau = 0$ } Both must be

ii) $\Sigma F = 0$ } satisfied simultaneously.

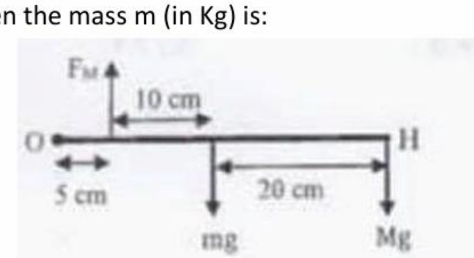
A 40Kg box is placed at the end of a uniform board of length L and mass M. the pivot is placed a distance L/4 from the end of the board as shown. If the board is in static equilibrium, then the weight of the board (in N) is:

A. 200
B. 392
C. 120
D. 196
E. 784

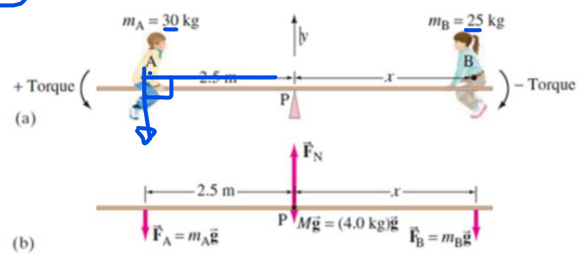


The figure represents a forearm of mass m in a horizontal position as shown. The elbow joint, O, is 5 cm from the force exerted by the biceps muscle, F_M. when a mass M is held in the hand at the position H, the forearm is in static equilibrium. If F_M = 185 N , and M = 2.0 Kg, then the mass m (in Kg) is:

A. 1.9
B. 2.1
C. 0.5
D. 1.1
E. 1.6



$\tau = F d \sin\theta$



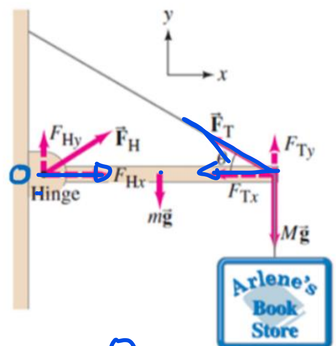
Balancing a seesaw. A board of mass serves as a seesaw for two children, as shown in Fig. a. Child A has a mass of 30 kg and sits 2.5 m from the pivot point, P (his center of gravity is 2.5 m from the pivot). At what distance x from the pivot must child B, of mass 25 kg, place herself to balance the seesaw? Assume the board is uniform and centered over the pivot.

$\sum \tau = 0 \rightarrow \tau_A + \tau_B = 0$

$\sum F = 0 \quad m_A g\, d \sin\theta + m_B g (x) \sin\theta = 0$

$30(10)2.5 - 25(10)(x) = 0$

$x = 3\,m$



Hinged beam and cable. A uniform beam, 2.20 m long with mass m= 25 kg is mounted by a small hinge on a wall as shown in the Figure. The beam is held in a horizontal position by a cable that makes an angle $\theta = 30°$ The beam supports a sign of mass suspended from its end. Determine the components of the force that the (smooth) hinge exerts on the beam, and the tension in the supporting cable.

$M = 28\,kg$

$\sum \tau = 0 \quad \tau_1 + \tau_2 + \tau_3 = 0$

$\sum F = 0 \quad -25(10) - 28(10)(2.2) + F_T (2.2) \frac{1}{2} = 0$

$\boxed{F_T = 794\ N}$

$\sum F_x = 0 \quad F_{Tx} = F_{Hx}$

$(794 \cos 30) = F_{Hx}$

$\sum F_y = 0$

$280 + 250 = 794 \sin 30 + F_{Hy}$

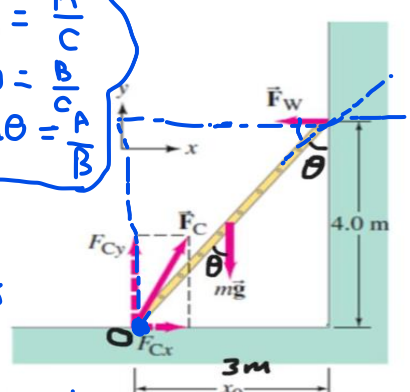
Ladder. A 5.0-m-long ladder leans against a wall at a point 4.0 m above a cement floor as shown in the Figure. The ladder is uniform and has mass m = 12.0 kg. Assuming the wall is frictionless, but the floor is not, determine the forces exerted on the ladder by the floor and by the wall.

$\text{Ladder} = \sqrt{3^2 + 4^2} = 5$

$\sin\theta = \frac{A}{C}$

$\cos\theta = \frac{B}{C}$

$\tan\theta = \frac{A}{B}$



$\sum \tau = 0 \quad \tau_{mg} = \tau_w$

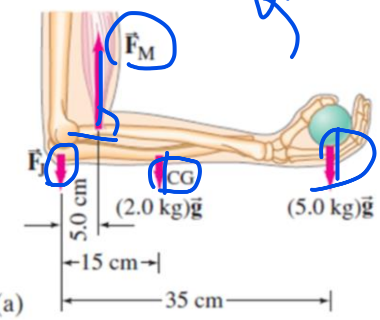
$\sum F = 0 \quad \frac{\left(120\left(\frac{5}{2}\right)\left(\frac{3}{5}\right)\right)}{4} = \frac{F_w (\cancel{5}) \frac{4}{\cancel{5}}}{4}$

$F = 44\,N$

$\sum F_x \quad F_{Cx} = 44$

$\sum F_y \quad F_{Cy} = 120$

Force exerted by biceps muscle. How much force mustthe biceps muscle exert when a 5.0-kg ball is held in the hand with the arm horizontal as in the Fig. a. The biceps muscle is connected to the forearm by a tendon attached 5.0 cm from the elbow joint. Assume that the mass of forearm and hand together is 2.0 kg and their CG is as shown.



(a)

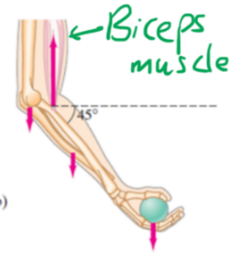
$$\sum \tau = 0 \qquad \tau_{FM} = \tau_B + \tau_{FA}$$

$$\frac{F_m(0.05)}{0.05} = \frac{50(0.35) + 20(0.15)}{0.05}$$

$$\sum F_x = 0$$

$$\sum F_y = 0 \qquad F_m = F_j + F_{FA} + F_B$$

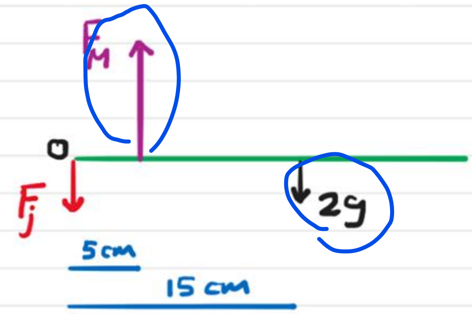
Do the same example but with formarm making an angle of 45° as shown.



(b)

Example: same example as above but no weight is carried by the fore arm.

$$\circlearrowleft^{+} \; \underset{F_a}{F_M}(0.05) - \underset{F_L}{2g}(0.15) = 0$$



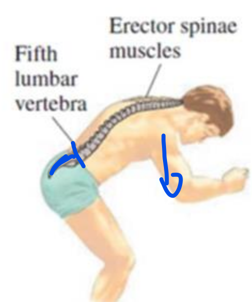
$$\therefore \quad F_M = \frac{0.15}{0.05}(2g) = 58.8\,N$$

∴ Muscle exerts 58.8 N to carry the weight of the fore arm of 19.6 N !! Is the hand a good lever? To answer, calculate the mechanical advantage (MA)

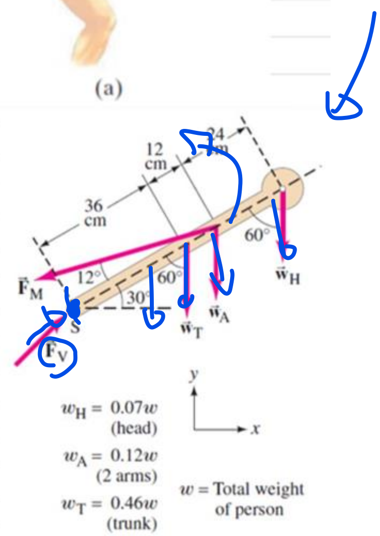
$$MA = \frac{F_L}{F_a} = \frac{X_a}{X_L} = \frac{0.05}{0.15} = \frac{1}{3} < 1 \Rightarrow$$ Not a good lever.

Forces on your back. Calculate the magnitude and direction of the force acting on the fifth lumbar vertebra as represented in Fig. 9–14b.

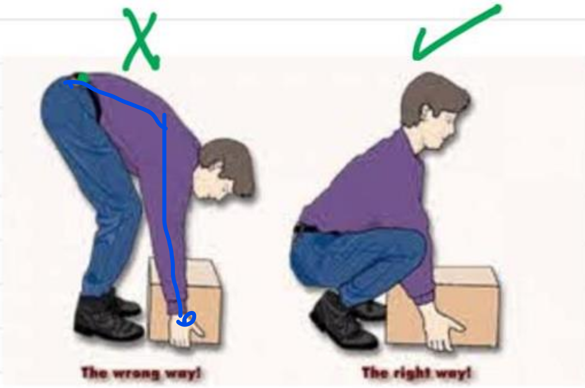
FM



(a)

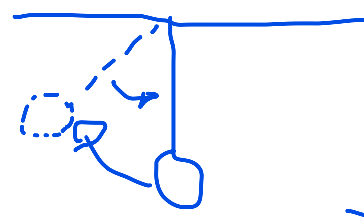


(b)

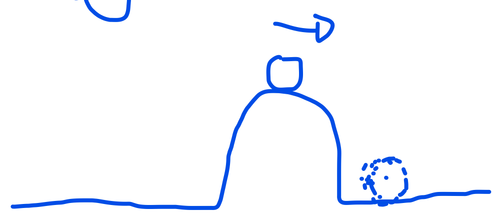


→ Types of equilibrium :

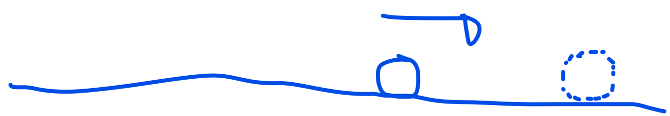
1) Stable equilibrium: Return to normal state



2) Unstable equilibrium: Moves away from normal state



3) Neutral equilibrium: neither stable nor unstable

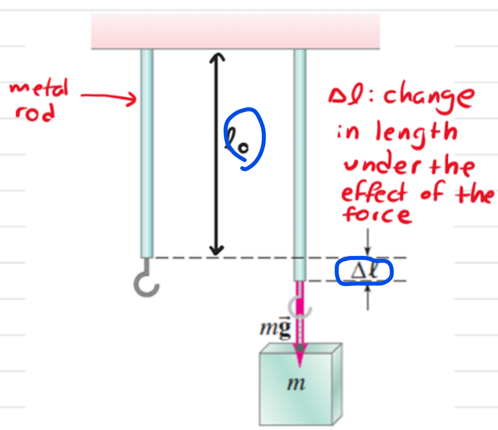


9-5] Elasticity, Stress and Strain

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



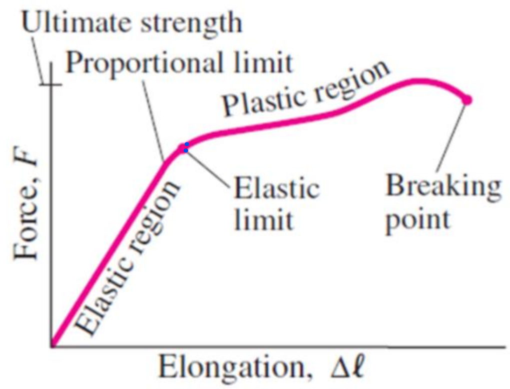
When $\Delta l \ll l_0$ →

$F = k\,\Delta l$ (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

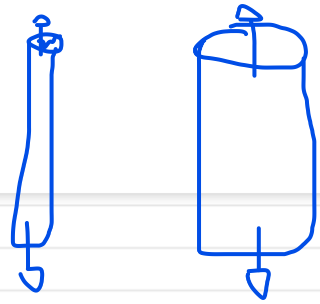
Breaking Point: The maximum force that can be applied without the object breaking.

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)



$\Delta \ell \propto \frac{F}{A} \ell_0$

$\frac{\Delta \ell}{\ell_0} = \frac{1}{E} \frac{F}{A} \cancel{\frac{\ell_0}{\ell_0}}$

↳ 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.

$\text{Strain} = \frac{1}{E} (\text{stress})$

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

$$
\begin{aligned}
F &= E \frac{\Delta \ell}{\ell_0} A \\
&= (2.0 \times 10^{11}\,\text{N/m}^2)\left(\frac{0.0025\,\text{m}}{1.60\,\text{m}}\right)(3.14 \times 10^{-6}\,\text{m}^2) \\
&= 980\,\text{N}.
\end{aligned}
$$

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

$\frac{1}{10}$

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 $\propto$ stress in elastic region.

$l_0 + \Delta l$

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.

Force at point of suspension

pulling force

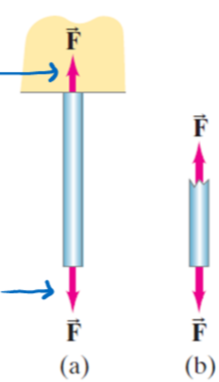
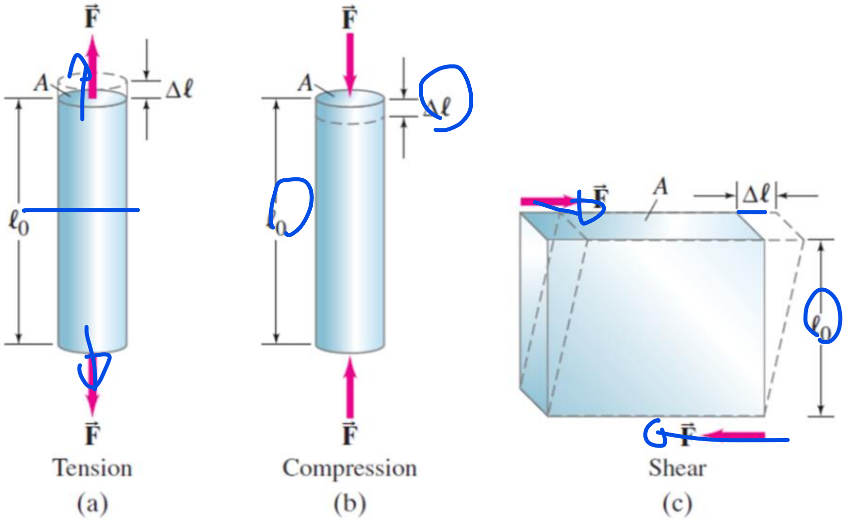


FIGURE 9–20 Stress exists *within* the material.

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

$l_0 - \Delta l$



tensile stress

compressive stress

shear stress

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

We may write:

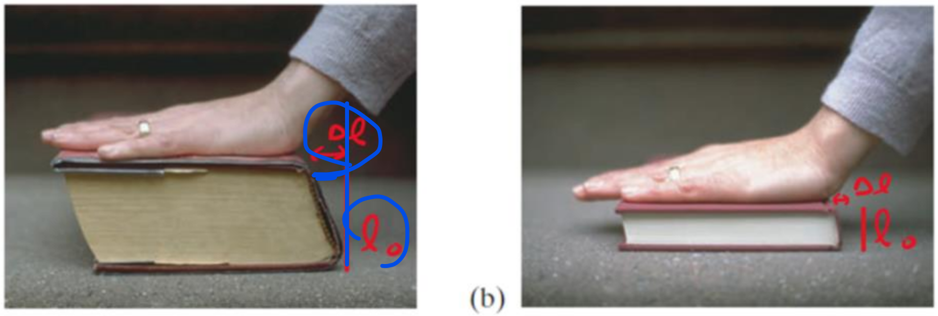
$$\Delta l = \frac{1}{G} \frac{F}{A} l_0$$

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

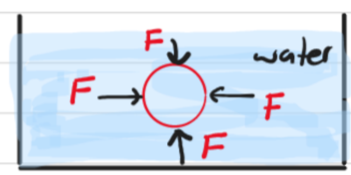


(a) (b)

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)

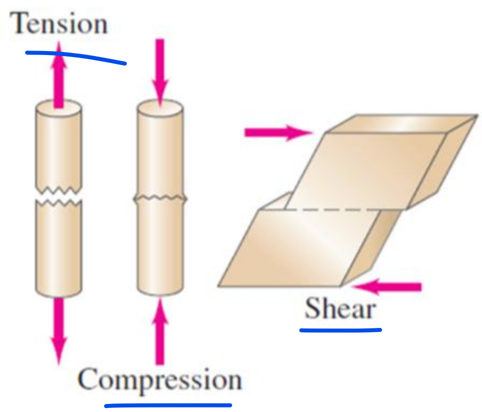
$$\boxed{\frac{\Delta V}{V_0} = -\frac{1}{B}\,\Delta P}$$ (note $\Delta V < 0$)

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

note that ΔV decreases when pressure increases

9-6] Fracture

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



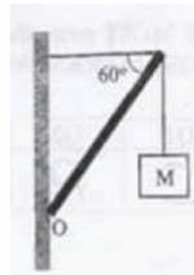
maximum values before object breaks (approximate values)

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		$500–2500 \times 10^6$	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	

Past papers

A 25.0 Kg uniform beam is attached to the wall by a hinge at point O. it is held in static equilibrium by connecting it to a 1.5 m horizontal rope which is tied to the wall. A mass M=18.0Kg is suspended in equilibrium from the beam using another vertical rope as shown. The magnitude of the horizontal component of the hinge force (in N) that acts on the beam at point O is:



A. 172.6

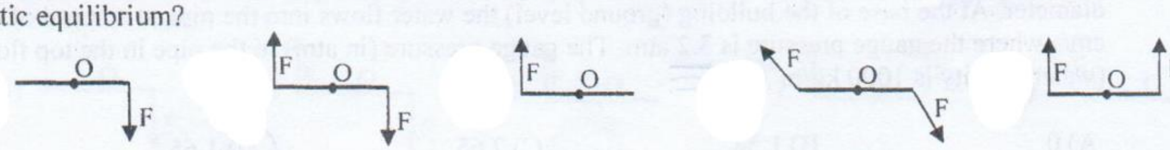
B. 297.9

C. 99.6

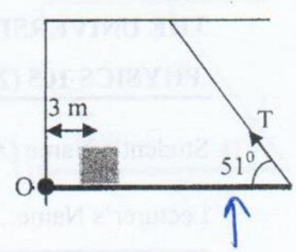
D. 122.1

E. 23.5

Q5) The figure shows a uniform beam fixed at its midpoint O. The beam can only rotate about an axis perpendicular to the page and passes through point O. Which of the following graphs represents static equilibrium?

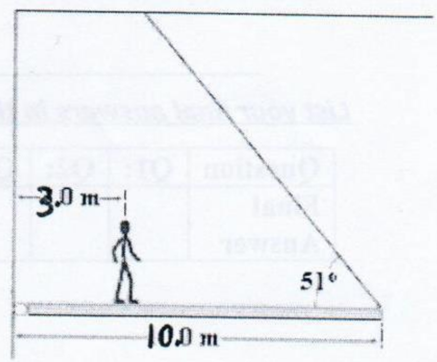


Q7) The figure shows a uniform, horizontal beam (length = 10 m, mass = 25 kg) that is pivoted at the wall at point O, with its far end supported by a cable that makes an angle of 51° with the horizontal. If a load (mass = 60 kg) is placed 3.0 m from the pivot. Determine the horizontal component of the hinge force (in N) acting at point O.



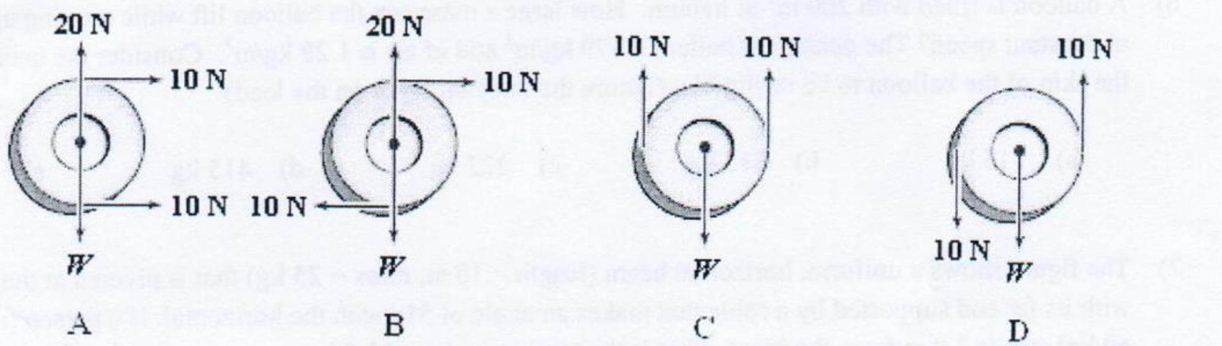
298 189 264 242 50

The figure shows a uniform, horizontal beam (length = 10 m, mass = 25 kg) that is pivoted at the wall, with its far end supported by a cable that makes an angle of 51° with the horizontal. If a person (mass = 60 kg) stands 3.0 m from the pivot, what is the tension in the cable?



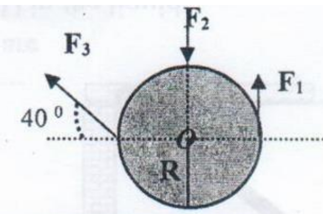
a) 0.83 kN b) 0.30 kN c) 0.42 kN
d) 3.0 kN e) 0.38 kN

The diagrams below show forces applied to a wheel that weighs 20 N. The symbol *W* stands for the weight. In which diagram(s) is (are) the wheel in static equilibrium? (the wheel is **NOT** pivoted)



a) A b) B c) C d) D e) B and C

4. If $F_1 = 15$ N, $F_2 = 22$ N, $F_3 = 9$ N, the magnitude of the net torque around point O (in N.m) applied to the wheel of radius R= 0.80 m is:



7.4 5.2 4.6
2.9 1.5

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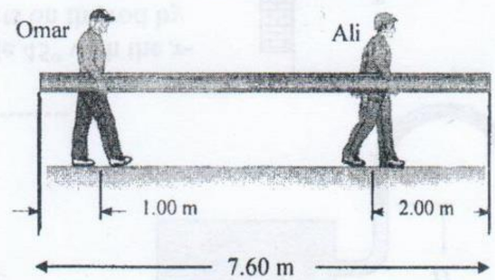
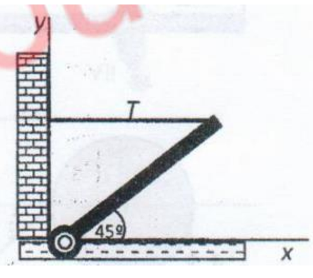
5. A uniform beam of length 7.60 m and weight 3.50×10^2 N is carried by two workers, Omar and Ali, as shown in the figure. The force that Omar exerts on the beam (in N) is:



176 137 96
470 320

8. In the figure, the weight of the rod $W = 431$ N, and its length L = 8 m. The rod is at equilibrium making an angle 45° with the x-axis. The vertical component of the reaction force that acts on the rod by the hinge (in N)?



352 N 500 N
707 N 100 N 431
