Physics 185F2013 Lecture Ten

Dec 3, 2013

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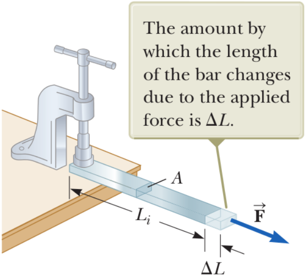
December 3, 2013

Elastic properties

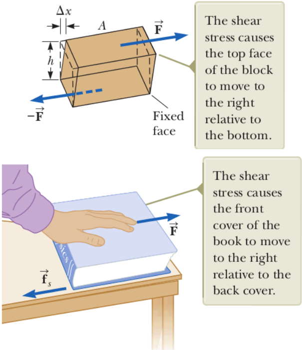
- Young's modulus: measures resistance of a solid to a change in its length.
- Shear modulus: measures the resistance to motion of the planes within a solid parallel to each other.
- Bulk modulus: measures the resistance of solids or liquids to changes in their volume.
- Stress: quantity that is proportional to the force causing deformation. Unit force per cross-sectional area.
- Strain: Measure of degree of deformation.
- Elastic modulus = stress / strain

Young's Modulus



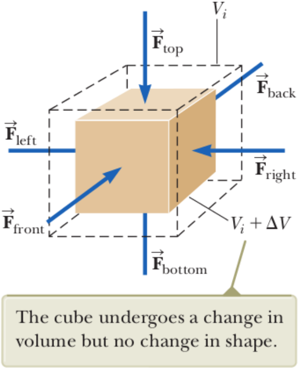
- tensile stress: ratio of magnitude of external force F to cross-section area A
- tensile strain: ratio of change in length ΔL to original length.
- Young's modulus: $Y = \frac{F/A}{(\Delta L)/L}$

Shear Modulus



- shear stress: ratio of tangential force to the area A being shared
- shear strain: ratio of distance sheared surface moves over height of object.
- Shear modulus: $S = \frac{F/A}{(\Delta x)/h}$

Bulk Modulus



- volume stress: ratio of magnitude of total force exerted on surface to the area A of that surface.
- Pressure: $P = F/A$
- volume strain: ratio of change in volume over initial volume
- Bulk modulus: $B = -\frac{\Delta F/A}{\Delta V/V_o} = -V_o \frac{\Delta P}{\Delta V}$

Density

The average density is defined as,

$$\text{Average Density} = \frac{\text{Mass}}{\text{Volume}}$$

Or for an infinitesimal volume:

$$\rho = \frac{\text{dm}}{\text{dV}}$$

For fluids, we tend to use the liter (L) as the unit of measure, where $1\text{L} = 10^{-3}\text{m}^3 = 10^3\text{cm}^3$.

Substance	ρ (kg/m^3)	Substance	ρ (kg/m^3)
Air	1.29	Iron	7.86×10^3
Air (at 20°C and atmospheric pressure)	1.20	Lead	11.3×10^3
		Mercury	13.6×10^3
Aluminum	2.70×10^3	Nitrogen gas	1.25
Benzene	0.879×10^3	Oak	0.710×10^3
Brass	8.4×10^3	Osmium	22.6×10^3
Copper	8.92×10^3	Oxygen gas	1.43
Ethyl alcohol	0.806×10^3	Pine	0.373×10^3
Fresh water	1.00×10^3	Platinum	21.4×10^3
Glycerin	1.26×10^3	Seawater	1.03×10^3
Gold	19.3×10^3	Silver	10.5×10^3
Helium gas	1.79×10^{-1}	Tin	7.30×10^3
Hydrogen gas	8.99×10^{-2}	Uranium	19.1×10^3
Ice	0.917×10^3		

Find weight from density

The mattress of a water bed is 2.00 m by 2.00 m and 0.30 m tall. What is the weight of water in the mattress?

Density of water is $\rho_{\mathrm{w}} = 1000\frac{\mathrm{kg}}{\mathrm{m}^3}$.
Total mass is

$$\mathrm{M} = \rho \mathrm{V} = (1000)(2.00)(2.00)(0.30) = 1.20 \times 10^3 \mathrm{kg}$$

The weight is:

$$\mathrm{W} = \mathrm{Mg} = 1.20 \times 10^3 \mathrm{kg}(9.80\frac{\mathrm{m}}{\mathrm{s}^2}) = 1.18 \times 10^4 \mathrm{N}$$

Pressure Under Water

We can say that a column of water with cross-sectional area A and height δh has a volume of $V = A\delta h$.

The weight of that column is $Mg = \rho Vg = \rho A\Delta hg$.

Since pressure is force per unit area, the pressure from that column is $P = F_g/A = \rho g\Delta h$. But there is a column of air sitting on top of it which has a pressure of P_0 at the surface of the water, so the total pressure felt under water is:

$$P = P_0 + \rho g\Delta h$$

How far below the ocean will the pressure be 5.00 atm, that is, five times the pressure of air at sea-level and 20° C?

Pascal and atm

New notation, for pressure, we use the pascal (Pa):

$$1\text{Pa} \equiv 1\frac{\text{N}}{\text{m}^2}$$

and for atmospheric pressure we use the notation atm:

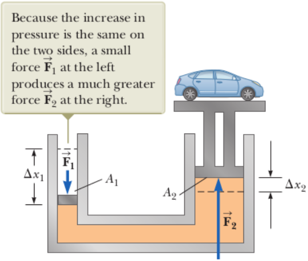
$$1 \text{ atm} = 1.013 \times 10^5 \text{ Pa}$$

Which is typical atmospheric pressure at sea level.

Pascal's Law

A change in pressure applied to a fluid is transmitted undiminished to every point of the fluid and to the walls of the container.

Pressure (Car lift example)



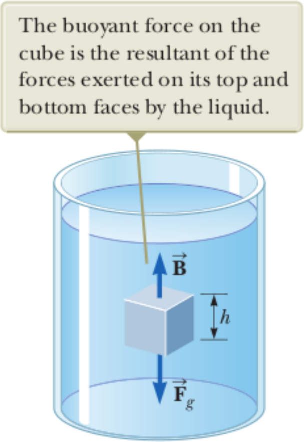
Compressed air forces a small piston $r_1 = 5.00$ cm downward, the force is transmitted by liquid to a piston $r_2 = 15.0$ cm. What force is needed to lift a 13300 N car?

- $P_1 = P_2 \;\rightarrow\; \frac{F_1}{A_1} = \frac{F_2}{A_2}$
- $F_1 = \frac{A_1}{A_2} F_2 = \frac{\pi (5.00 \times 10^{-2} \mathrm{m})^2 (1.33 \times 10^4 \mathrm{N})}{\pi (15.0 \times 10^{-2} \mathrm{m})^2}$
- $F_1 = 1.48 \times 10^3$ N

Example 2

The surface area of the eardrum is about $1 \times 10^{-4}\text{m}^2$ or 1cm^2. What pressure will it feel at the bottom of a 5.0 m deep pool?

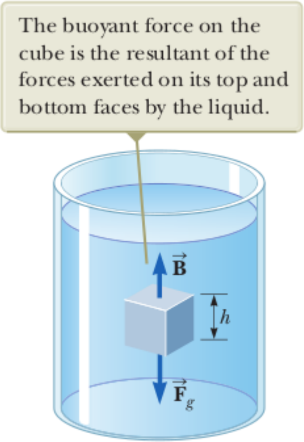
Buoyancy



Archimedes' Principle

A body wholly or partially submerged in a fluid is buoyed up by a force equal to the weight of the displaced fluid.

Buoyancy



$$
\begin{aligned}
B &= (P_{bot} - P_{top})A \\
&= (\rho_{fluid})ghA \\
&= (\rho_{fluid})g(V_{displaced})
\end{aligned}
$$

Example 3

Archimedes was asked to determine whether a crown made for the king was pure gold, or whether the king was cheated (which will have very bad consequences for the manufacturer). He first weighed the crown in air (7.84 N) and then in water (6.84 N). Will the manufacturer be richly rewarded or will he find a darker fate?

Example 3