Chapter 10

Solids & Liquids

Next 6 chapters use all the concepts developed in the first 9 chapters, recasting them into a form ready to apply to specific physical systems.

	3/27	Th	Properties of Solids, Liquids & Gases	Ch. 10.1-3	E 10.1-8	G 10.2-3	
13	4/1	T	Buoyancy & Fluid Properties	Ch. 10.4-6	E 10.9-13	G 10.5	**Set 9**
	4/3	Th	Temperature, Heat, Kinetic Theory	Ch. 12.1-4; 13.1-2	E 12.1-13, E 13.1-4	G 12.1-4, G 13.2	
14	4/8	T	Phase Changes, Intro. Thermodynamics	Ch. 13.2-4; 14.1-2	E 13.5-14, E 14.1-6	G 13.3-4, G 14.1-2	**Set 10**
	4/10	Th	**Midterm Exam 3**	Ch. 1-13 (no 7,11)			
15	4/15	T	2nd Law of Thermodynamics, Entropy	Ch. 14.3-5	E14.7-13	G 14.3-4	
	4/17	Th	Oscillations, Waves & Interference	Ch. 7.1-6; 11.1-2	E 7.1-9, E 11.1-5	G 7.1-4, G 11.1-2	
16	4/22	T	Sound, Doppler Effect	Ch. 11.3-5	E 11.6-13	G 11.3-4	**Set 11**
	4/24	Th	Review				
17	4/28	M	**Final Exam 8:00-10:00 pm, Rm TBD**	Ch. 1-14			

10.1 Phases of Matter , Mass Density

THREE PHASES OF MATTER

Solids, Liquids, Gases

Combination of Temperature and Pressure determine the phase.

DEFINITION OF MASS DENSITY

The mass density of a substance is the mass of a substance divided by its volume:

$$\rho = \frac{m}{V}$$

SI Unit of Mass Density: kg/m^3

Mass Densities[a] of Common Substances

Substance	Mass Density ρ (kg/m^3)
Solids	
Aluminum	2700
Brass	8470
Concrete	2200
Copper	8890
Diamond	3520
Gold	19 300
Ice	917
Iron (steel)	7860
Lead	11 300
Quartz	2660
Silver	10 500
Wood (yellow pine)	550
Liquids	
Blood (whole, 37 °C)	1060
Ethyl alcohol	806
Mercury	13 600
Oil (hydraulic)	800
Water (4 °C)	1.000×10^3
Gases	
Air	1.29
Carbon dioxide	1.98
Helium	0.179
Hydrogen	0.0899
Nitrogen	1.25
Oxygen	1.43

Example: Blood as a Fraction of Body Weight

The body of a man whose weight is 690 N contains about 5.2×10^{-3} m^3 of blood.

(a) Find the blood's weight and (b) express it as a percentage of the body weight.

$$m = \rho V$$

$$\text{(a) } W = mg$$

$$= \rho V g$$

$$= \left(1060\,\text{kg/m}^3\right)\left(5.2\times 10^{-3}\,\text{m}^3\right)\left(9.80\,\text{m/s}^2\right) = 54\ \text{N}$$

$$\text{(b) } \% = \frac{54\ \text{N}}{690\ \text{N}} \times 100\% = 7.8\%$$

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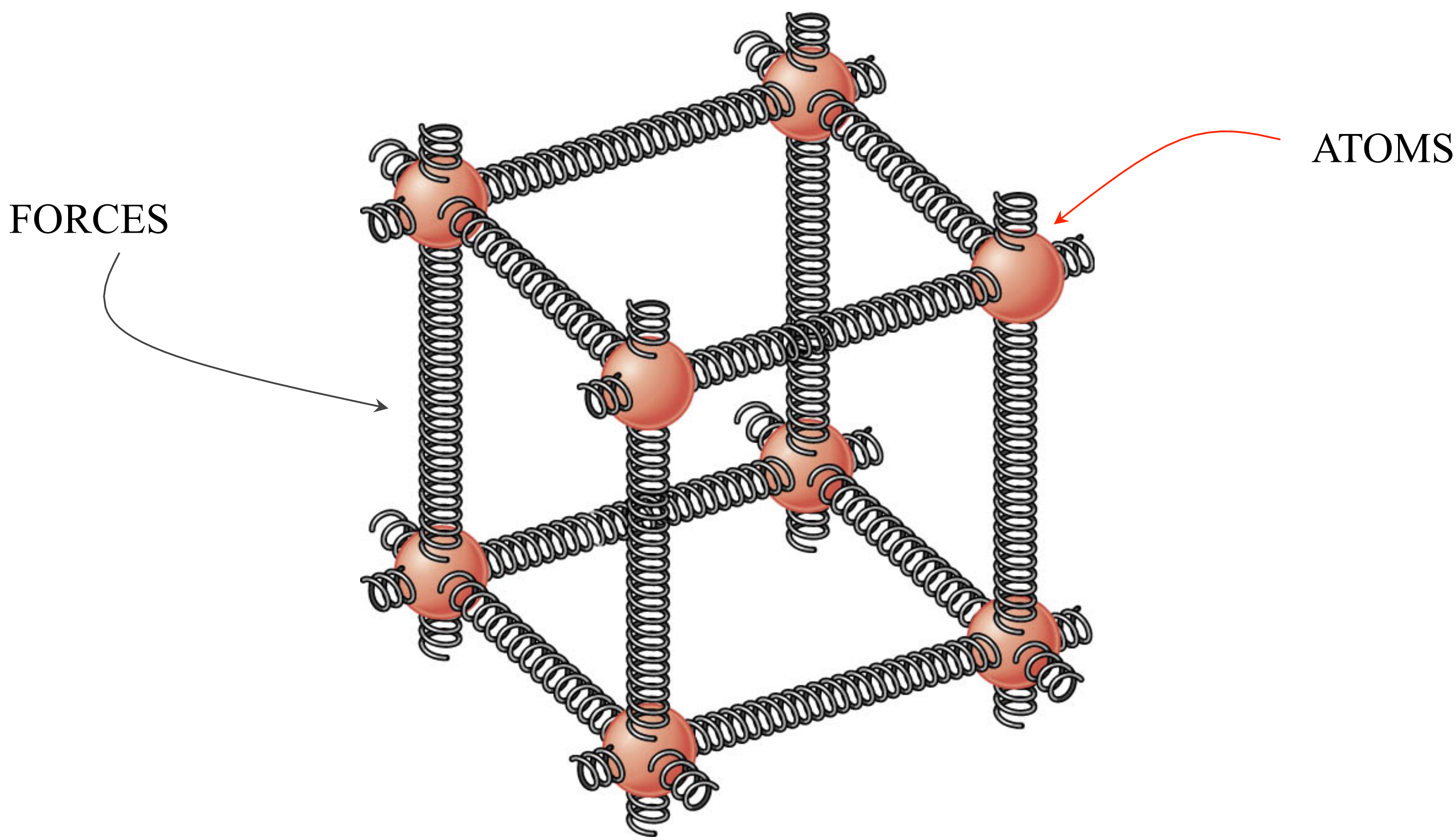
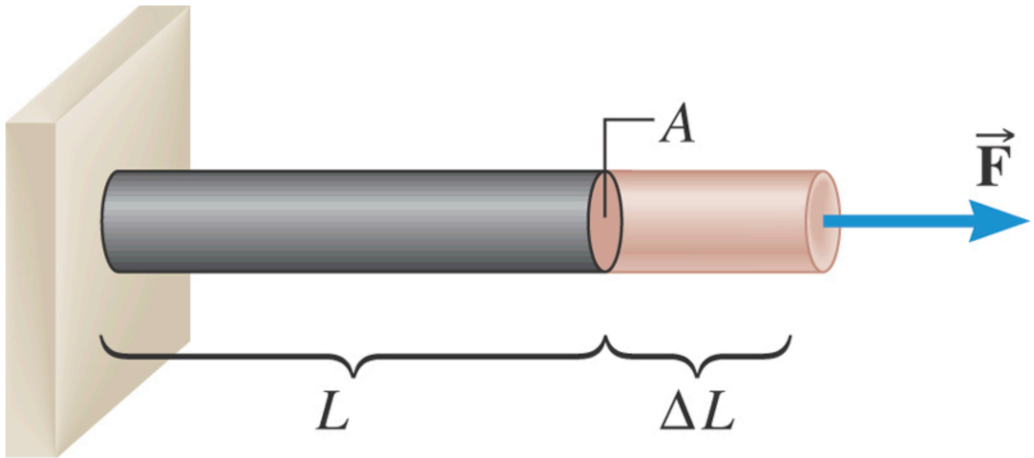
[a] Unless otherwise noted, densities are given at 0 °C and 1 atm pressure.

10.2 Solids and Elastic Deformation

Because of these atomic-level “springs”, a material tends to return to its initial shape once forces have been removed.



STRETCHING, COMPRESSION, AND YOUNG'S MODULUS



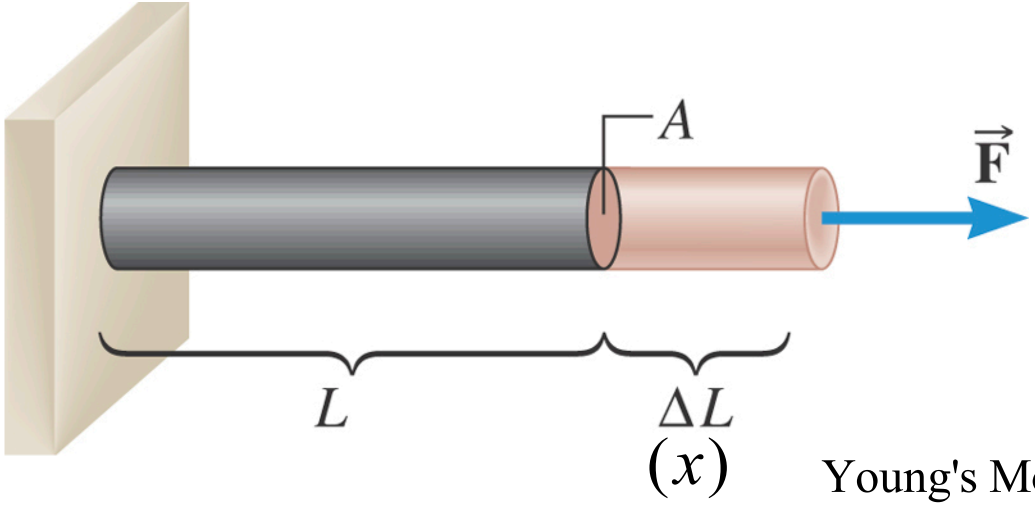
$$F = Y\left(\frac{\Delta L}{L}\right)A$$

Young's modulus has the units of pressure: N/m^2

Young's modulus is a characteristic of the material (see table 10.2)

$$Y_{\text{Steel}} = 2.0\times10^{11}\ \text{N/m}^2$$

Spring Constants and Young's Modulus



Y : Young's Modulus

A, L : Area and length of rod

ΔL : Change in rod length (x)

Young's Modulus & Spring Constants

$$F = Y\left(\frac{\Delta L}{L}\right)A$$

$$= \left(\frac{YA}{L}\right)\Delta L; \quad \text{let } \Delta L = x$$

THEN

$$F = kx \text{ (Hooke's law)}$$

$$\text{with } k = \left(\frac{YA}{L}\right) \text{ (spring constant)}$$

Values for the Young's Modulus of Solid Materials

Material	Young's Modulus Y (N/m^2)
Aluminum	6.9×10^{10}
Bone	
Compression	9.4×10^{9}
Tension	1.6×10^{10}
Brass	9.0×10^{10}
Brick	1.4×10^{10}
Copper	1.1×10^{11}
Mohair	2.9×10^{9}
Nylon	3.7×10^{9}
Pyrex glass	6.2×10^{10}
Steel	2.0×10^{11}
Teflon	3.7×10^{8}
Titanium	1.2×10^{11}
Tungsten	3.6×10^{11}

Note: $1 \text{ Pascal (Pa)} = 1 \text{ N/m}^2$

$$1 \text{ GPa} = 1 \times 10^9 \text{ N/m}^2$$

10.2 Solids and Elastic Deformation

In general the quantity $\frac{F}{A}$ is called the **Stress**.

The change in the quantity divided by that quantity is called the **Strain**:

$$\frac{\Delta V}{V} \qquad \frac{\Delta L}{L} \qquad \frac{\Delta x}{L}$$

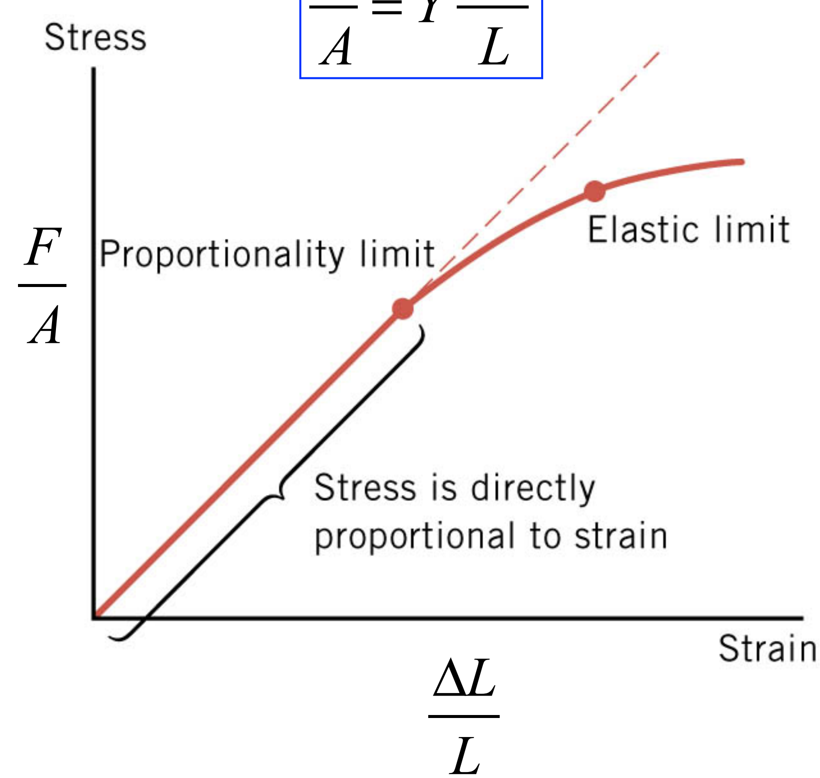
$$\frac{F}{A} = Y\frac{\Delta L}{L}$$

HOOKE’S LAW FOR STRESS AND STRAIN

Stress is directly proportional to strain.
Slope is Young’s modulus Y.

Strain is a unitless quantity, and

SI Unit of Stress: N/m^2



Example: Bone Compression

In a circus act, a performer supports the combined weight (1080 N) of a number of colleagues. Each thighbone of this performer has a length of 0.55 m and an effective cross sectional area of 7.7×10^{-4} m^2. Determine the amount that each thighbone compresses under the extra weight.

$$F = Y\left(\frac{\Delta L}{L}\right)A$$

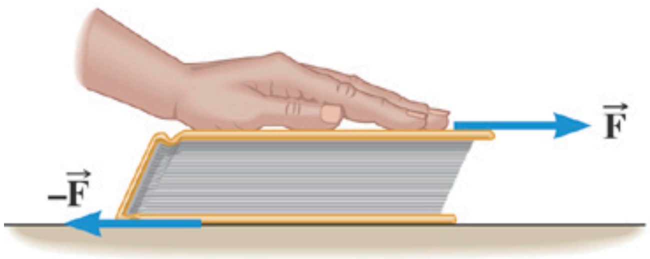
$$\text{each leg} = \frac{1080\ \text{N}}{2}$$

$$\Delta L = \frac{FL}{YA}$$

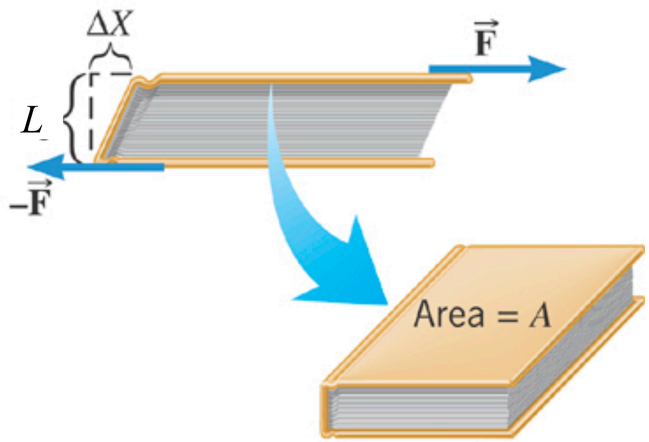
$$= \frac{(540\ \text{N})(0.55\ \text{m})}{(9.4\times10^{9}\ \text{N/m}^2)(7.7\times10^{-4}\ \text{m}^2)}$$

$$= 4.1\times10^{-5}\,\text{m} = 0.041\text{mm}$$

SHEAR DEFORMATION AND THE SHEAR MODULUS



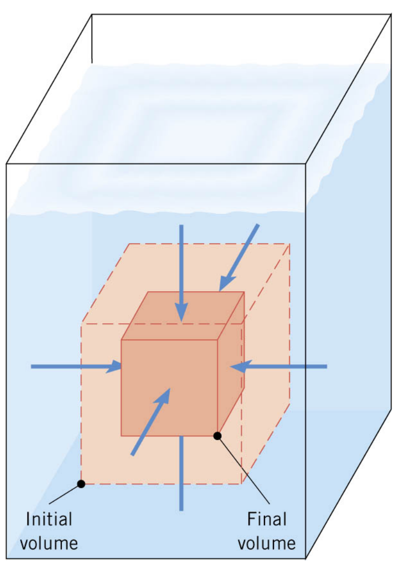
(*a*)



(*b*)

$$F = S\left(\frac{\Delta x}{L}\right)A$$

VOLUME DEFORMATION AND THE BULK MODULUS



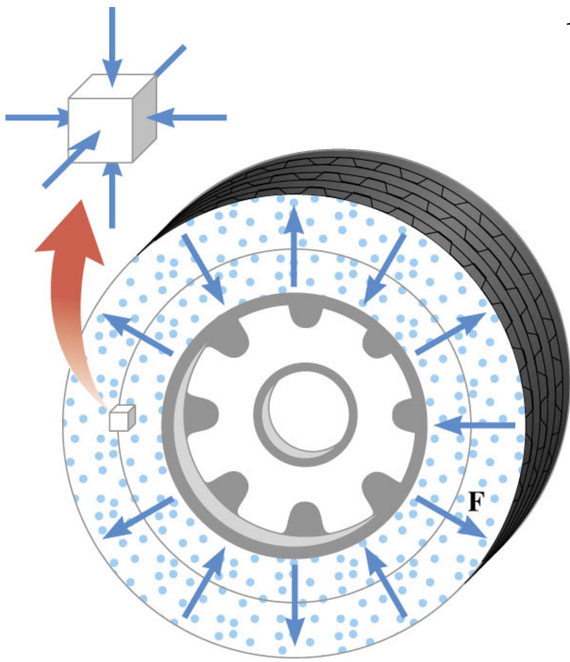
Pressure Change

$$\Delta P = -B\left(\frac{\Delta V}{V}\right)$$

B: Bulk modulus
Table 10.2

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

Pressure = Force per unit Area



The same pressure acts inward in every direction on a small volume.

SI Unit of Pressure: 1 N/m^2 = 1Pa

Pascal

10.3 ***Pressure***

Pressure is the amount of force acting on an area:

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

SI unit: N/m^2

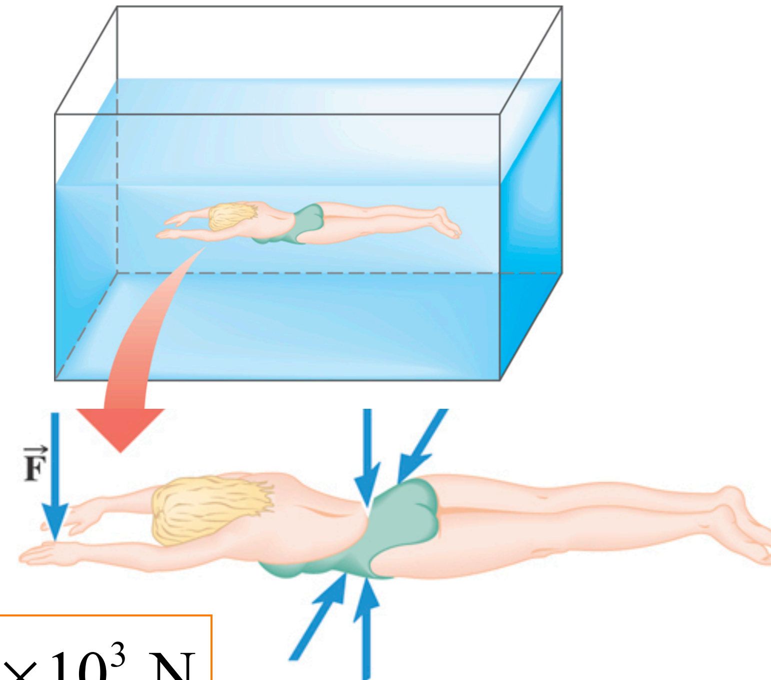
$(1\ Pa = 1\ N/m^2)$

Example: **The Force on a Swimmer**

Suppose the pressure acting on the back of a swimmer's hand is 1.2×10^5 Pa. The surface area of the back of the hand is $8.4 \times 10^{-3} m^2$.

(a) Determine the magnitude of the force that acts on back of the hand.

(b) Discuss the direction of the force.

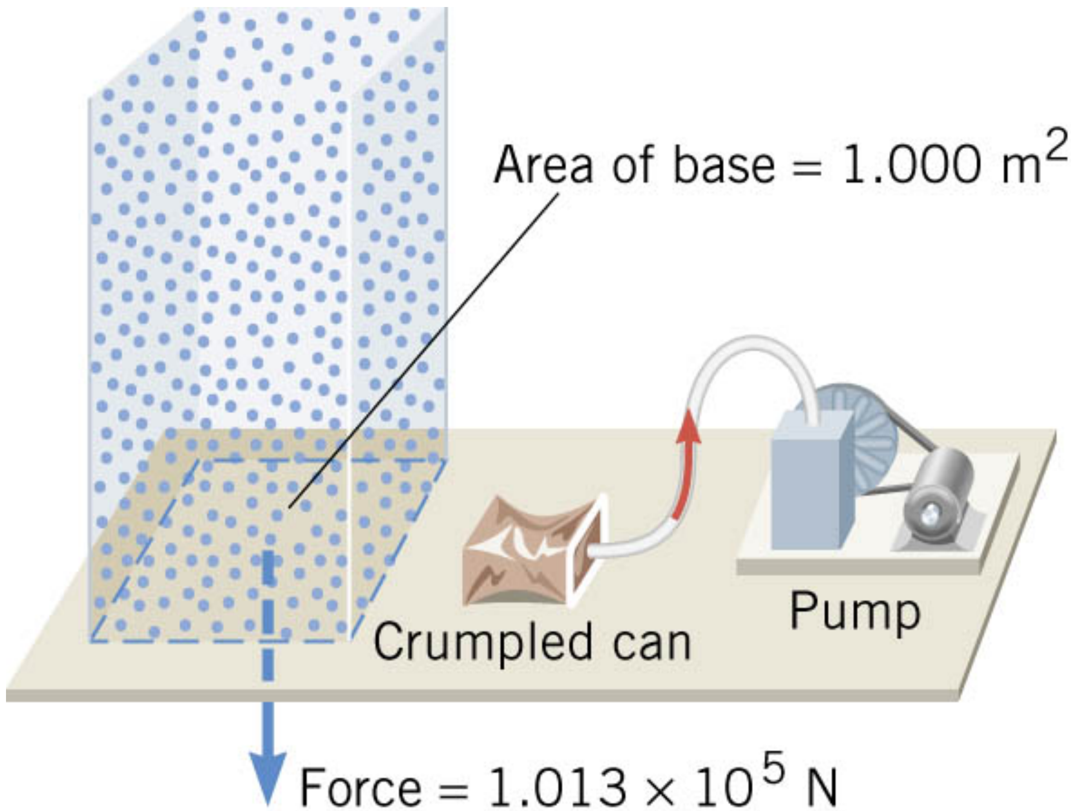


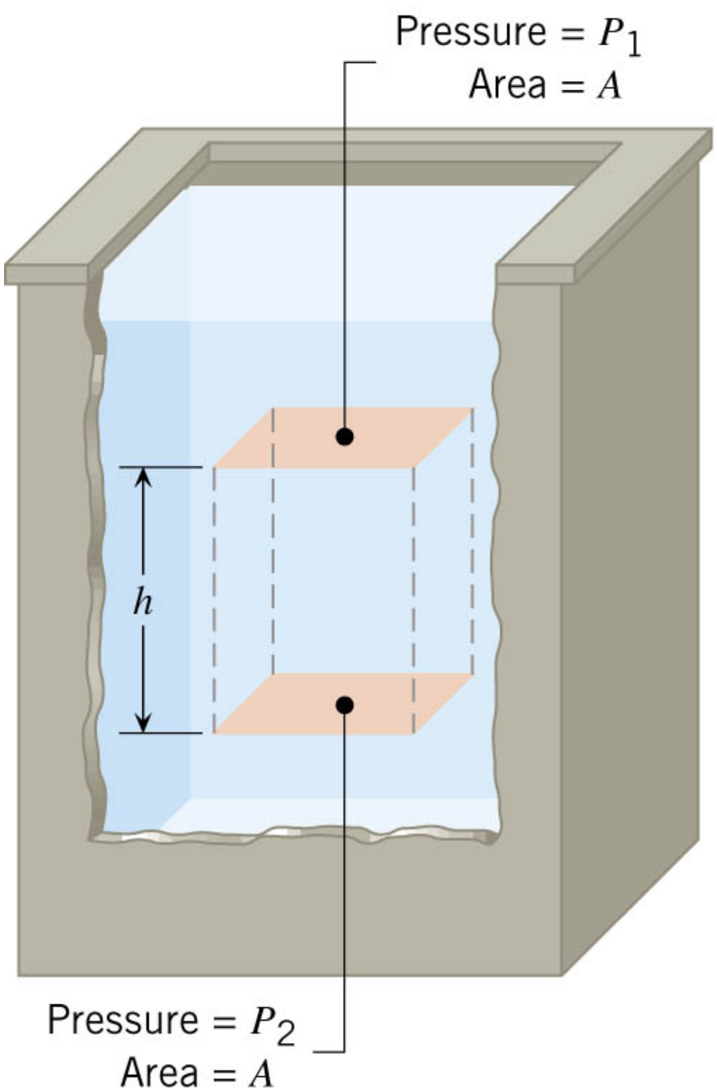
a) $F = PA = (1.2\times10^5)(8.4\times10^{-3})\text{N} = 1.0\times10^3\ \text{N}$

Since the water pushes perpendicularly against the back of the hand, the force is directed downward.

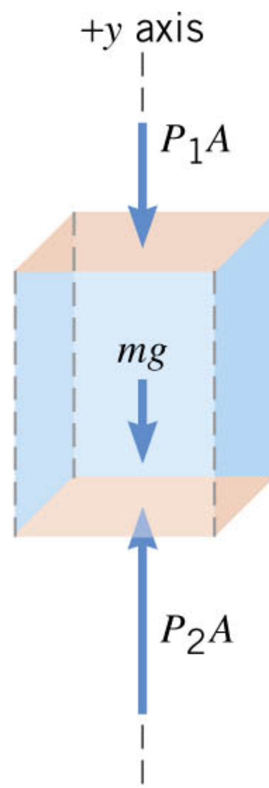
Pressure on the underside of the hand is somewhat greater (greater depth). So force upward is somewhat greater - bouyancy

Atmospheric Pressure at Sea Level: 1.013×10^5 Pa = 1 atmosphere





(a)



(b) Free-body diagram of the column

Fluid density is ρ

Equilibrium of a volume of fluid

$$F_2 = F_1 + mg$$

with $F = PA$, $m = \rho V$

$$P_2 A = P_1 A + \rho V g$$

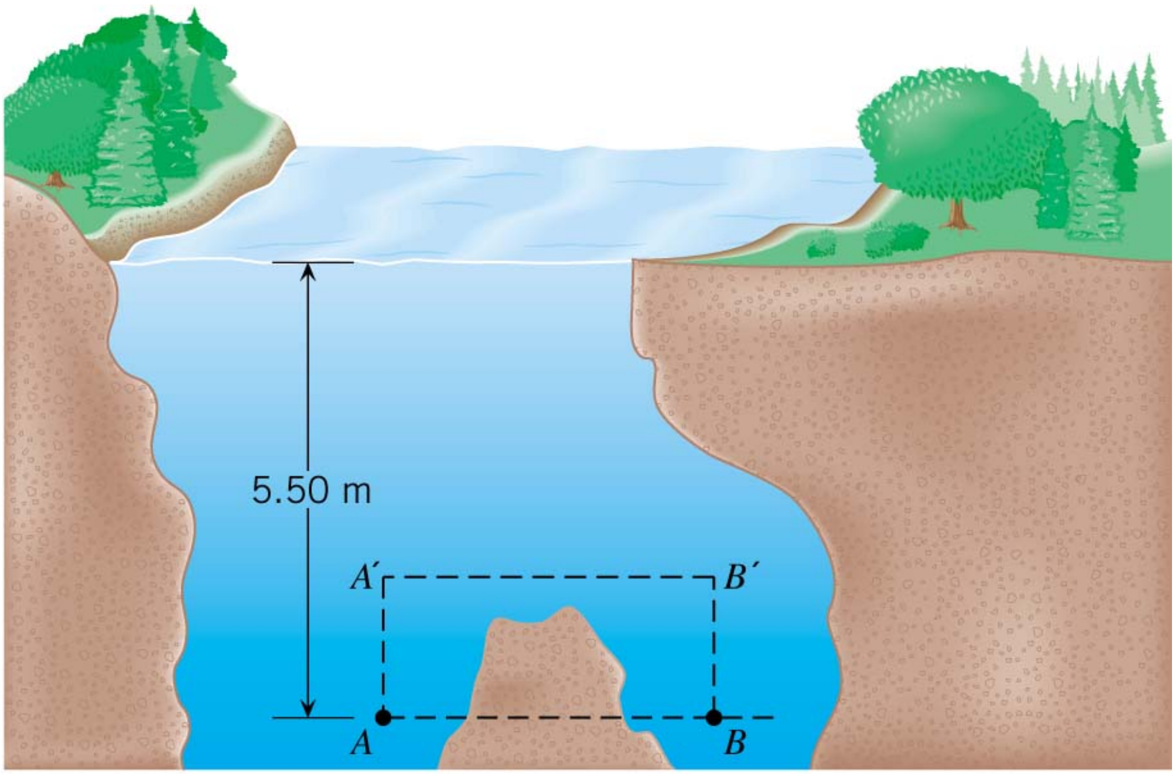
with $V = Ah$

$$P_2 = P_1 + \rho g h$$

Pressure grows linearly with depth (h)

Example: **The Swimming Hole**

Points A and B are located a distance of 5.50 m beneath the surface of the water. Find the pressure at each of these two locations.



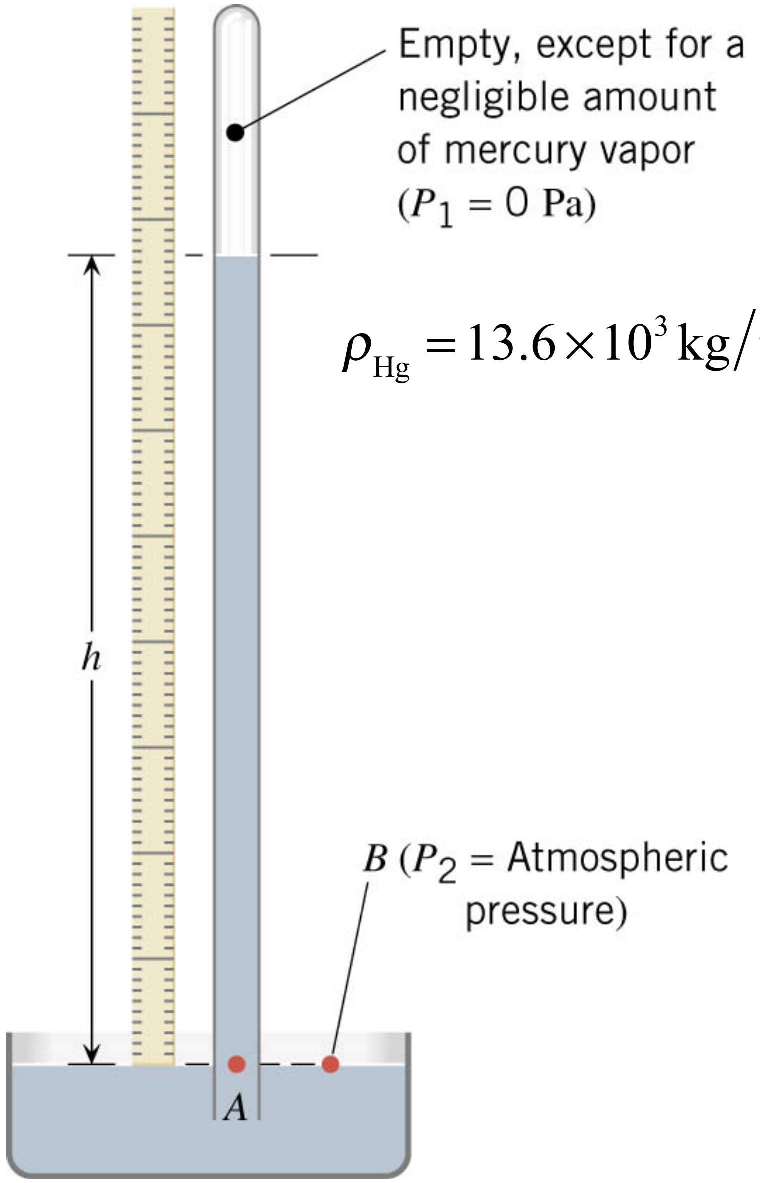
Atmospheric pressure

$$P_1 = 1.01\times 10^5 \text{ N/m}^2$$

$$P_2 = P_1 + \rho g h$$

$$P_2 = P_1 + \rho g h$$
$$= \left(1.01\times 10^5 \text{ Pa}\right) + \left(1.00\times 10^3 \text{kg/m}^3\right)\left(9.80 \text{m/s}^2\right)\left(5.50 \text{ m}\right)$$
$$= 1.55\times 10^5 \text{ Pa}$$

10.3 Pressure Gauges



$$\rho_{\text{Hg}} = 13.6 \times 10^3\,\text{kg/m}^3$$

$$P_2 = P_1 + \rho g h$$

$$P_1 = 0 \text{ (vacuum)}$$

$$P_2 = \rho g h$$

$$P_{atm} = \rho g h$$

$$h = \frac{P_{atm}}{\rho g}$$

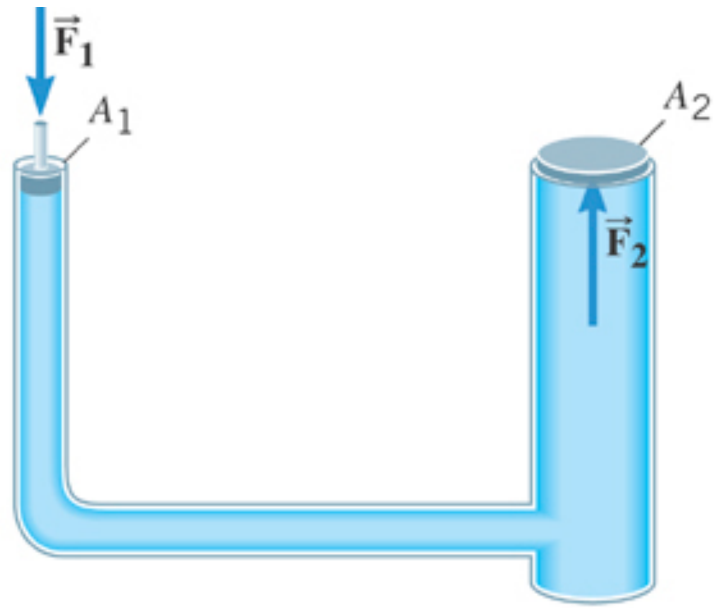
$$= \frac{\left(1.01 \times 10^5 \text{ Pa}\right)}{\left(13.6 \times 10^3\,\text{kg/m}^3\right)\left(9.80\,\text{m/s}^2\right)}$$

$$= 0.760 \text{ m} = 760 \text{ mm of Mercury}$$

10.3 Pascal's Principle

PASCAL'S PRINCIPLE

Any change in the pressure applied to a completely enclosed fluid is transmitted undiminished to all parts of the fluid and enclosing walls.



(a)

$$P_2 = \frac{F_2}{A_2}; \quad P_1 = \frac{F_1}{A_1}$$

Assume weight of fluid in the tube is negligible

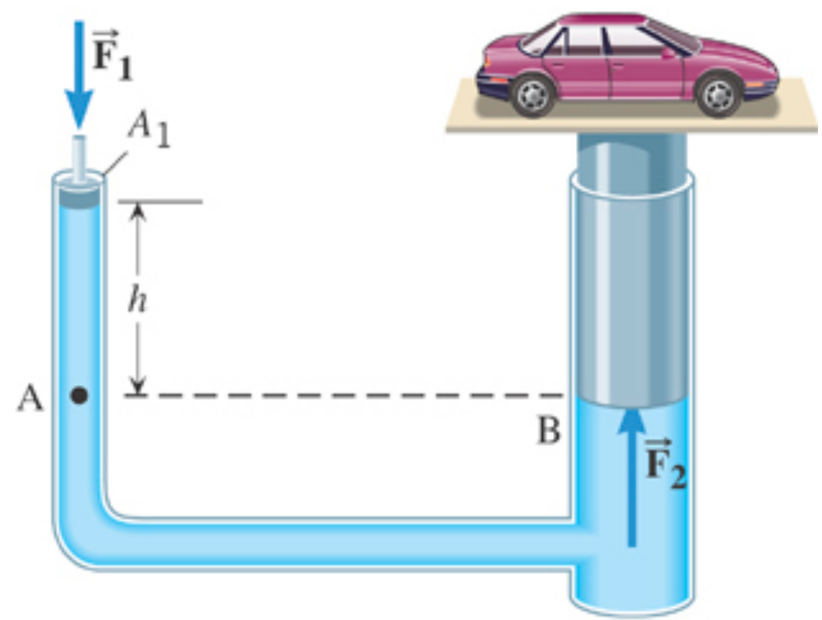
$$\rho g h << P$$

$$P_2 = P_1 + \rho g h$$

$$P_2 = P_1$$

Small ratio

$$\frac{F_2}{A_2} = \frac{F_1}{A_1} \quad \Rightarrow \quad F_1 = F_2\left(\frac{A_1}{A_2}\right)$$



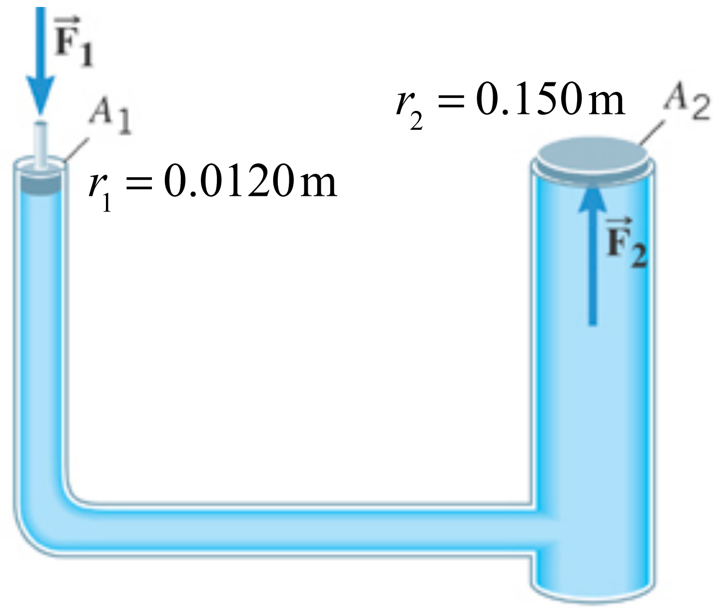
Example: A Car Lift

The input piston has a radius of 0.0120 m and the output plunger has a radius of 0.150 m.

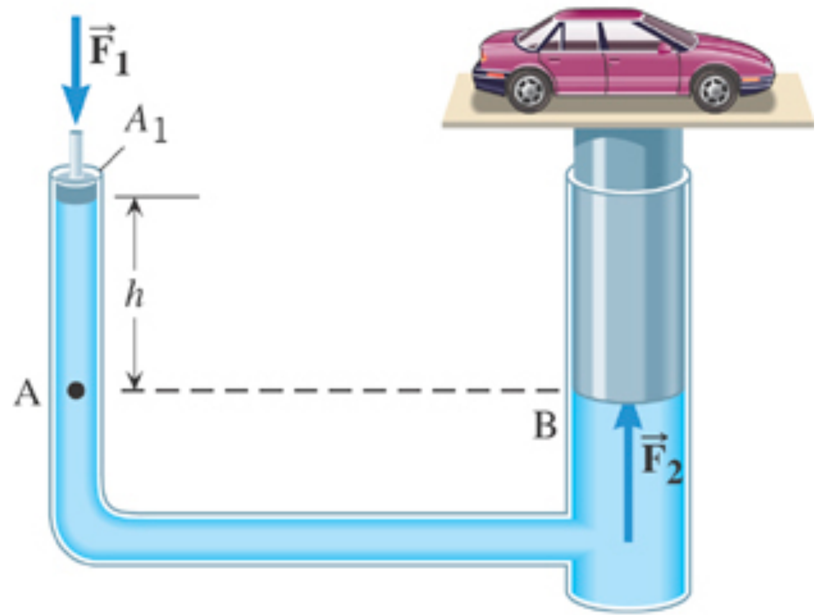
The combined weight of the car and the plunger is 20500 N. Suppose that the input piston has a negligible weight and the bottom surfaces of the piston and plunger are at the same level. What is the required input force?

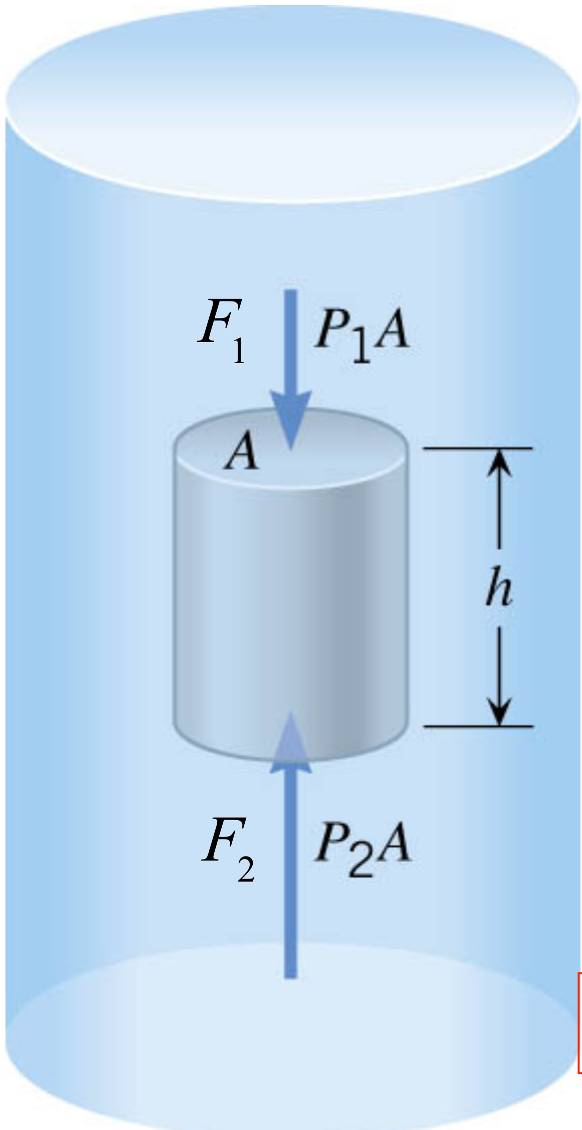
$$F_1 = F_2\left(\frac{A_1}{A_2}\right)$$

$$= (20500\ \text{N})\frac{\pi(0.0120\ \text{m})^2}{\pi(0.150\ \text{m})^2} = 131\ \text{N}$$



(a)





Buoyant Force

force that makes objects float

$$F_B = F_2 + (-F_1)$$
$$= P_2A - P_1A$$
$$= (P_2 - P_1)A \qquad \text{Using: } P_2 = P_1 + \rho gh$$
$$= \rho ghA = \underbrace{\rho V}_{\text{mass of displaced fluid}} g \qquad \text{and } V = hA$$

Buoyant force = Weight of displaced fluid

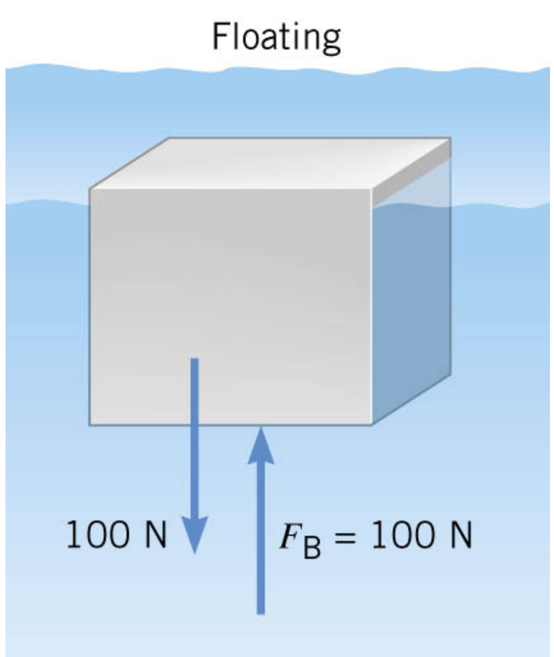
ARCHIMEDES' PRINCIPLE

Any fluid applies a buoyant force to an object that is partially or completely immersed in it; the magnitude of the buoyant force equals the weight of the "displaced" fluid :

$$\underbrace{F_B}_{\text{Magnitude of buoyant force}} = \underbrace{W_{\text{fluid}}}_{\text{Weight of displaced fluid}}$$

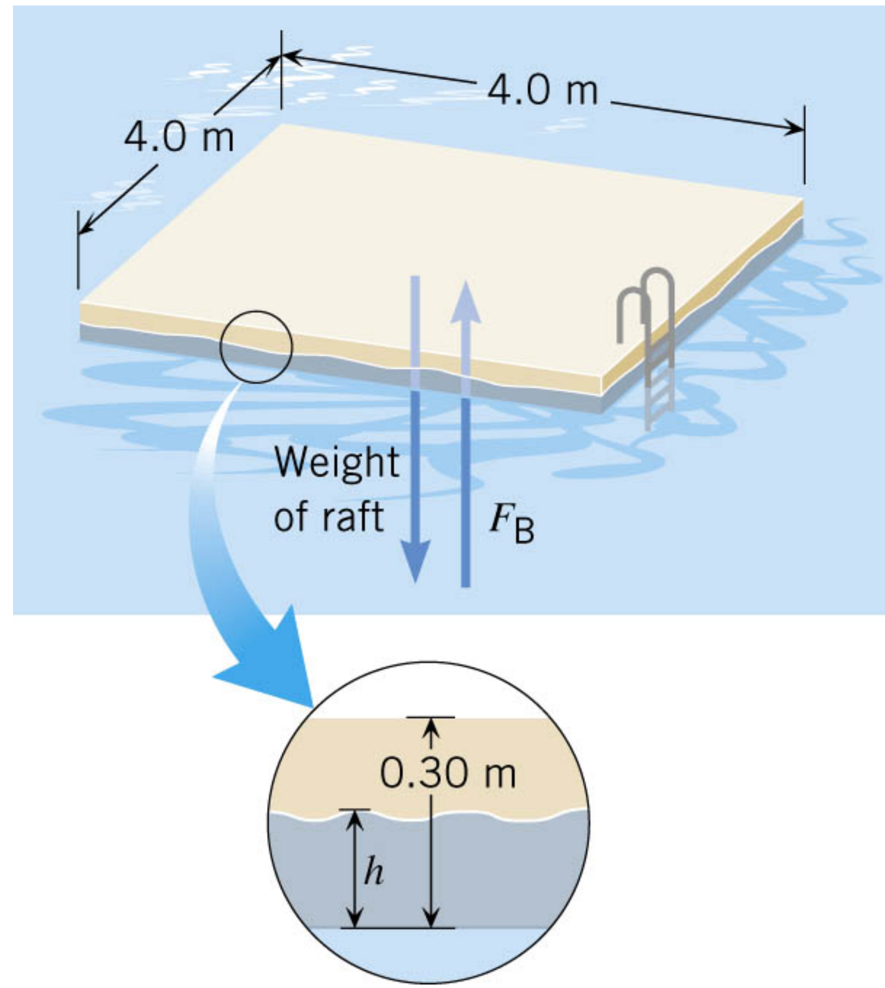
CORROLARY

If an object is floating, then the magnitude of the buoyant force is equal to its weight.



Example: A Swimming Raft

The raft is made of solid square pinewood. Determine whether the raft floats in water, and if it does, how much of the raft is beneath the surface.



$$W_{Raft} = m_{Raft} g = \rho_{Pine} V_{Raft} g$$
$$= (550\,kg/m^3)(4.8\,m^3)(9.80\,m/s^2)$$
$$= 26000\ N$$

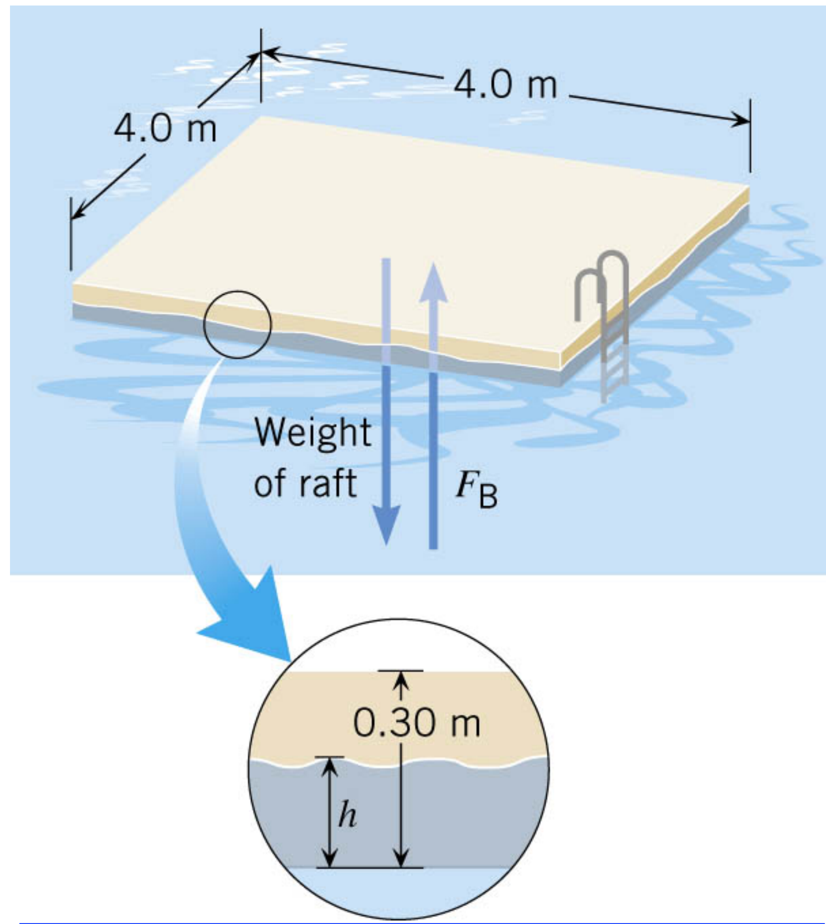
Raft properties

$$V_{Raft} = (4.0)(4.0)(0.30)\,m^3 = 4.8\ m^3$$
$$\rho_{Pine} = 550\ kg/m^3$$

If $W_{Raft} < F_B^{max}$, raft floats

$$F_B^{max} = W_{fluid} \quad \text{(full volume)}$$

$$F_B^{max} = \rho V g = \rho_{Water} V_{Water} g$$
$$= (1000\,kg/m^3)(4.8\,m^3)(9.80\,m/s^2)$$
$$= 47000\ N$$



$W_{Raft} < F_B^{max}$ Raft floats!

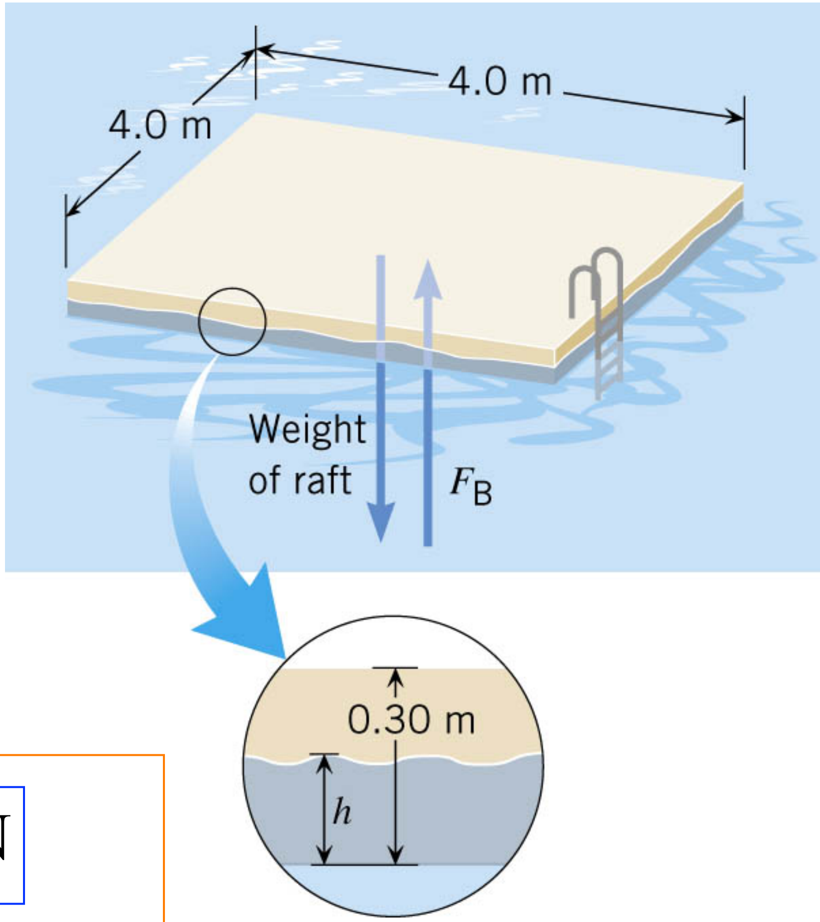
Part of the raft is above water

How much of raft is below water?

Floating object

$$F_B = W_{\text{Raft}}$$

$$F_B = \rho_{\text{Water}} g V_{\text{Water}}$$
$$= \rho_{\text{Water}} g (A_{\text{Water}} h)$$



$$h = \frac{W_{\text{Raft}}}{\rho_{\text{Water}} g A_{\text{Water}}}$$

$$W_{raft} = 26000 \text{ N}$$

$$= \frac{26000\text{N}}{(1000\,\text{kg/m}^3)(9.80\,\text{m/s}^2)(16.0\text{ m}^2)}$$

$$= 0.17 \text{ m}$$