Lecture 27
(Ch 9: 1-2)

Topic 9: Fluids and Solids

College Physics, 11e
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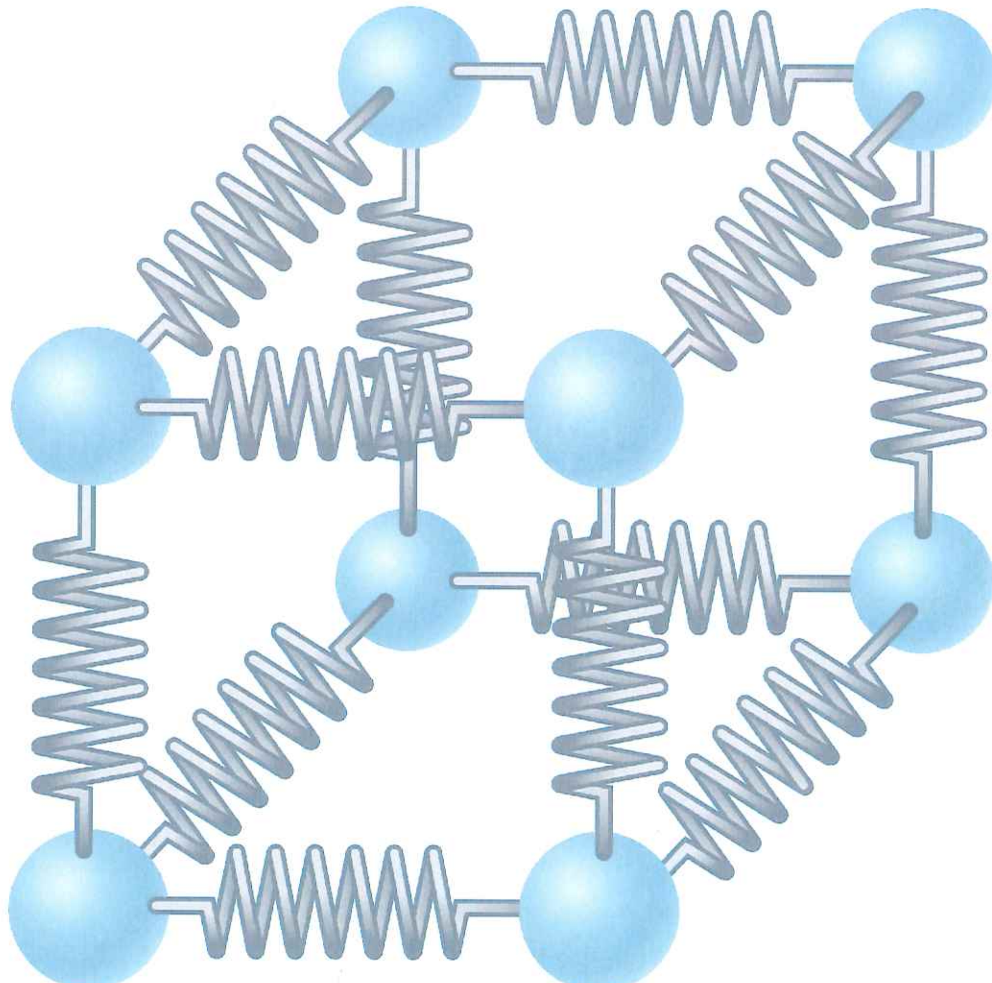
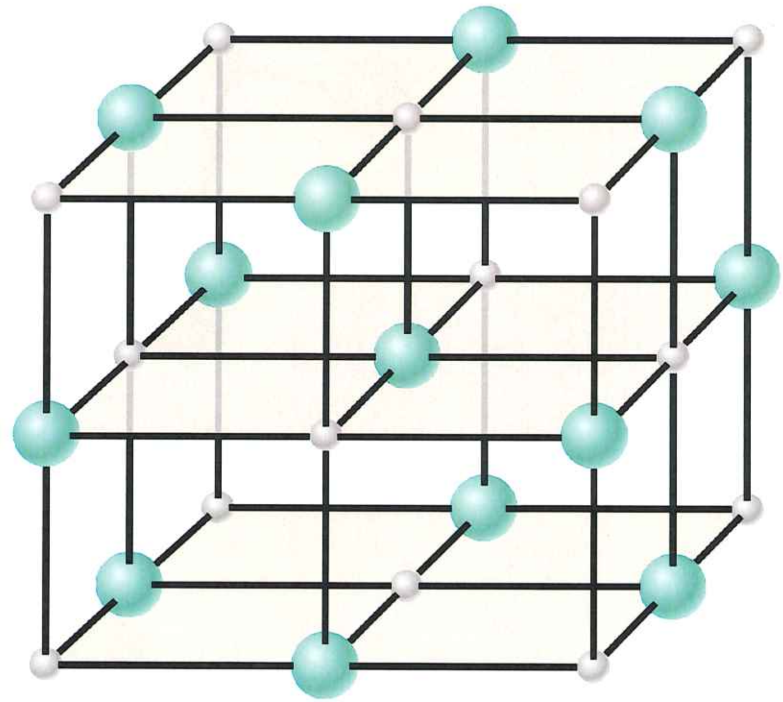
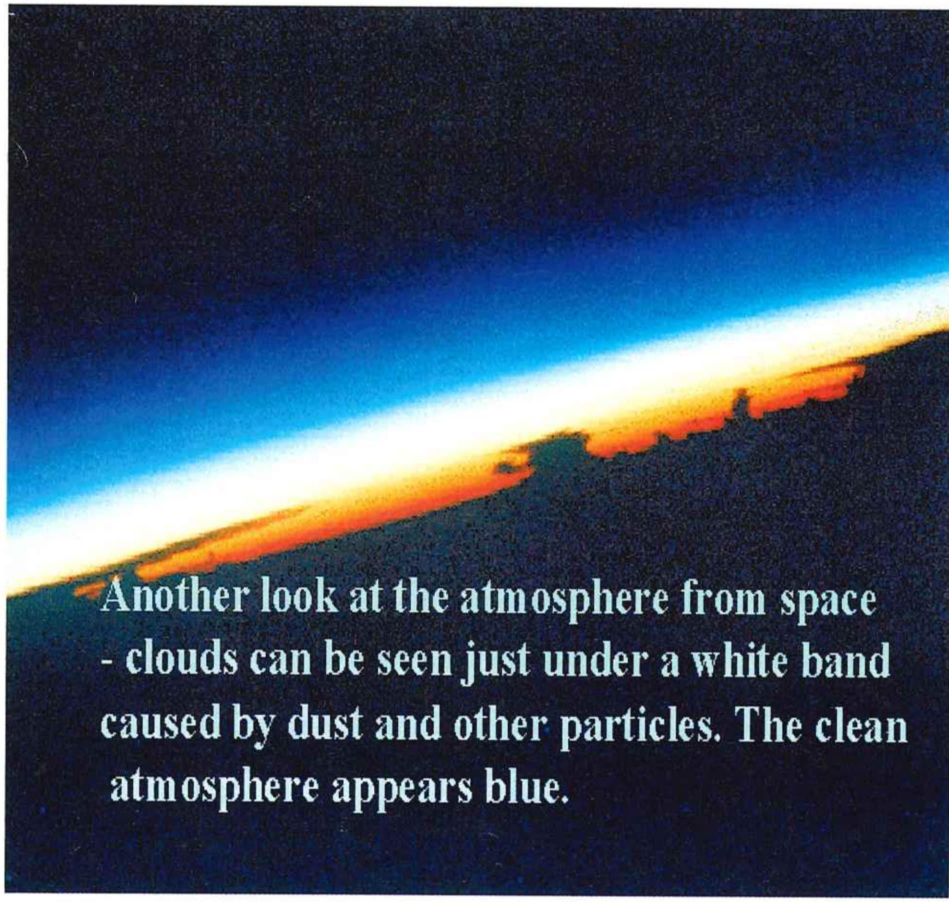
States of Matter

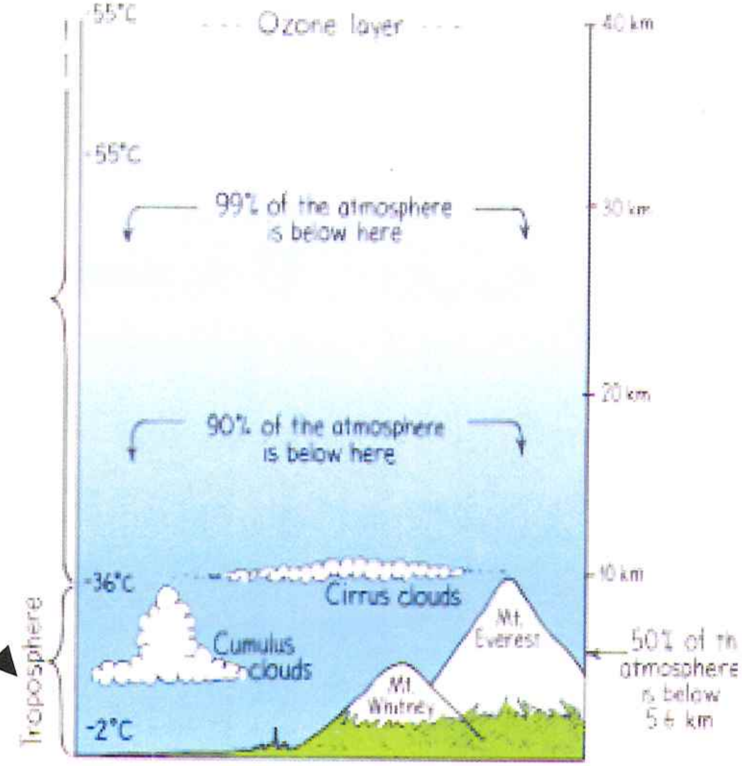


States of Matter



Liquids



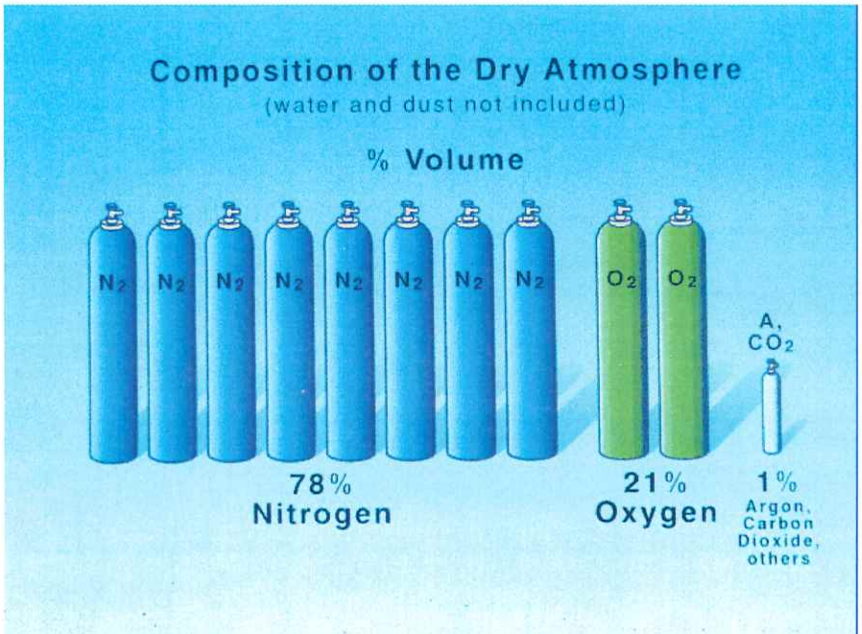


Fluid - a substance that can flow

No shearing stress; yes - compression!

Solids → Fluids

mass → Density



Material	Density[kg/m^3]
Interstellar space	10^{-20}
Laboratory vacuum	10^{-17}
Air: 20^0 C, 1 atm.	1.21
20^0 C, 50 atm	60.5
Water: 20^0 C, 1 atm	0.99×10^3
20^0 C, 50 atm	1.00×10^3
Mercury	13.6×10^3
Uranium nucleus	3×10^{17}

$$\rho = \Delta m / \Delta V$$

$$\rho = \frac{m}{V} \left[\frac{Kg}{m^3} \right]$$

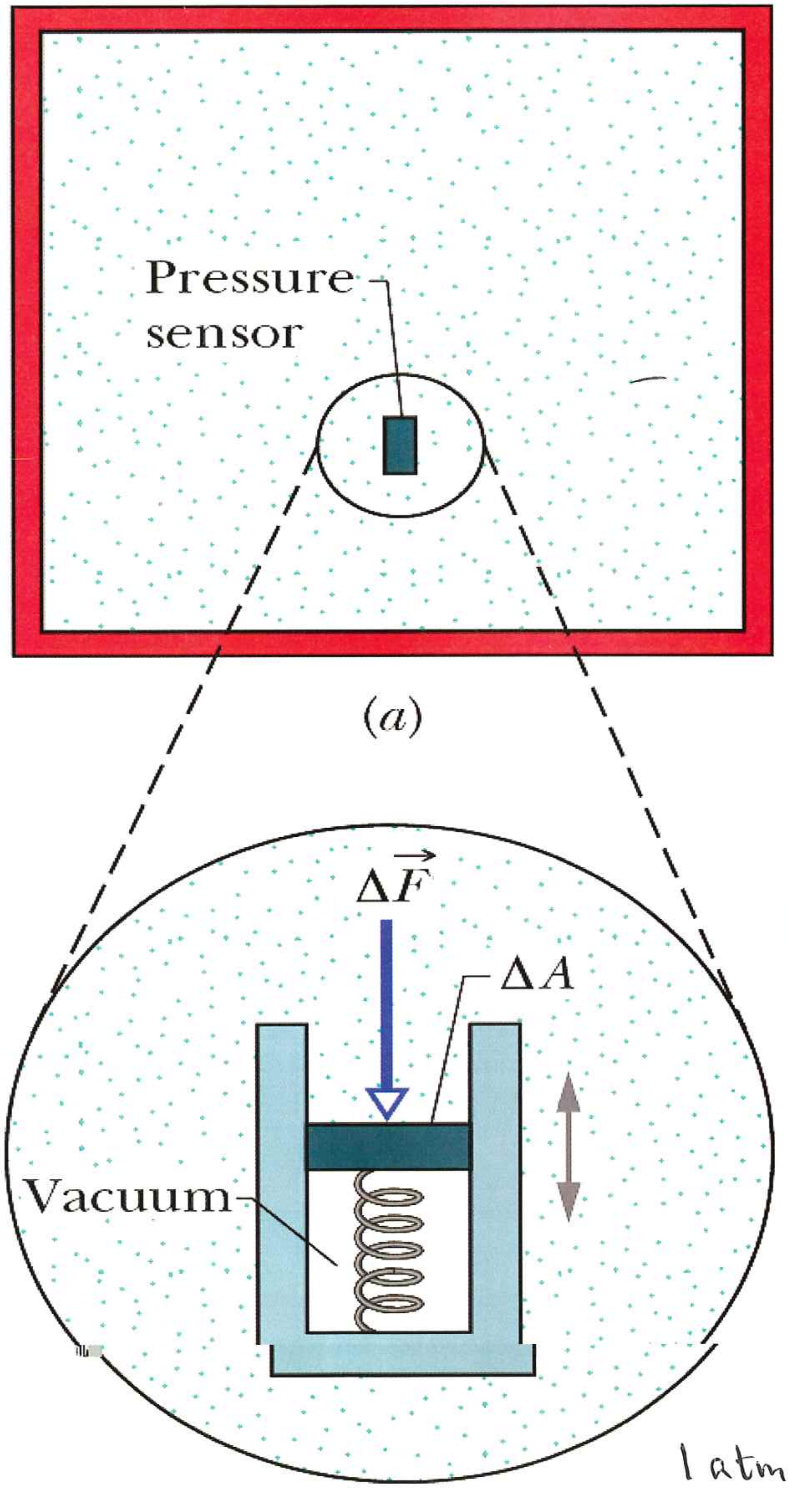
Density and Pressure

$$\rho \equiv \frac{M}{V}$$ SI unit: kilogram per meter cubed $\left(\text{kg/m}^3\right)$

Table 9.1 Densities of Some Common Substances

Substance	ρ (kg/m^3)[a]	Substance	ρ (kg/m^3)[a]
Ice	0.917×10^3	Water	1.00×10^3
Aluminum	2.70×10^3	Glycerin	1.26×10^3
Iron	7.86×10^3	Ethyl alcohol	0.806×10^3
Copper	8.92×10^3	Benzene	0.879×10^3
Silver	10.5×10^3	Mercury	13.6×10^3
Lead	11.3×10^3	Air	1.29
Gold	19.3×10^3	Oxygen	1.43
Platinum	21.4×10^3	Hydrogen	8.99×10^{-2}
Uranium	18.7×10^3	Helium	1.79×10^{-1}

[a]All values are at standard atmospheric temperature and pressure (STP), defined as 0°C (273 K) and 1 atm (1.013×10^5 Pa). To convert to grams per cubic centimeter, multiply by 10^{-3}.



(b)

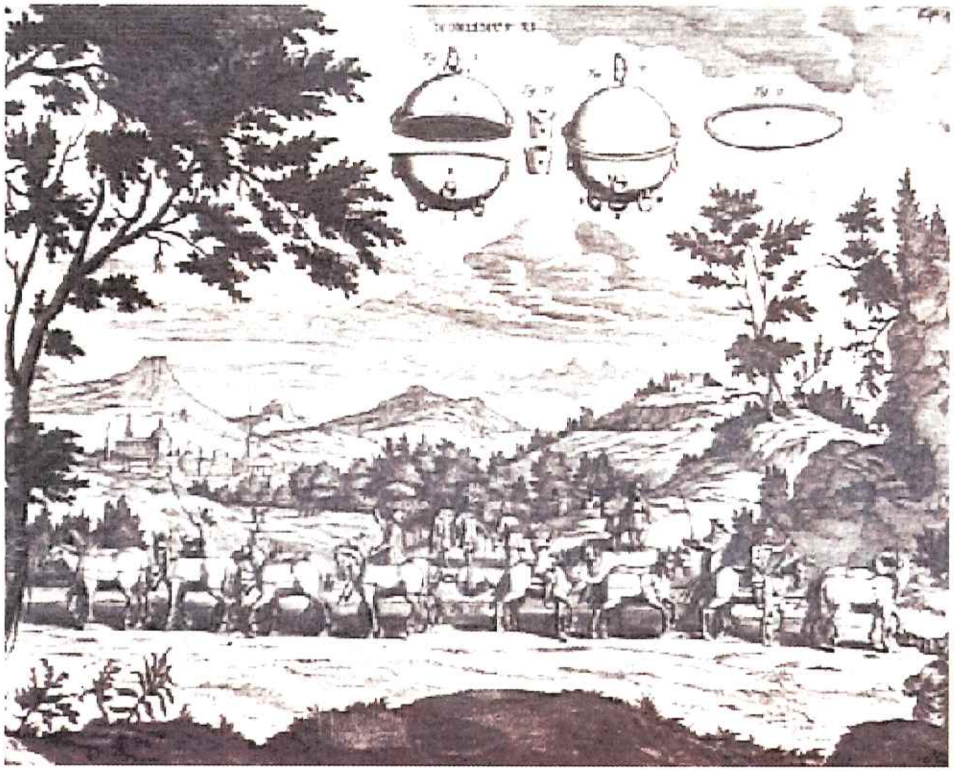
$$P = \frac{\Delta F}{\Delta A}$$

P – scalar

$$[Pa] = \frac{1N}{m^2}$$

$$1\,atm = 1.01 \times 10^5\ Pa = 14.7\ lb/in^2$$
$$= 760\ torr$$

$\frac{\text{Solids}}{\text{Force}}$ ⟶ Pressure / Fluids



The most renowned Otto von Guericke experiment, Magdeburg 1654

Some pressures	[Pa]
Center of the sun	2×10^{16}
Deepest ocean trench	1.1×10^{8}
Automobile tire	2×10^{5}
Atmosphere at sea level	1.0×10^{5}
Normal blood pressure	1.6×10^{4}
Best laboratory vacuum	10^{-12}

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

$$P = \Delta F/\Delta A \ [N/m^2]$$

$$1 \text{ atm} = 1.01 \times 10^5 \text{ Pa} = 760 \text{ torr} = 14.7 \text{ lb/in}^2$$

[psi]

4. T Calculate the mass of a solid gold rectangular bar that has dimensions of $4.50 \text{ cm} \times 11.0 \text{ cm} \times 26.0 \text{ cm}$.

9.4 $M_{bar} = \rho_{Au}V_{bar} = \rho_{Au}(1 \times w \times h) = (19.3 \times 10^3 \text{ kg/m}^3)[(0.045\,0 \text{ m})(0.110 \text{ m})(0.260 \text{ m})]$

or $M_{bar} = \boxed{24.8 \text{ kg}}$

2. The British gold sovereign coin is an alloy of gold and copper having a total mass of 7.988 g, and is 22-karat gold.

   a. Find the mass of gold in the sovereign in kilograms using the fact that the number of karats = 24 × (mass of gold)/(total mass).

   b. Calculate the volumes of gold and copper, respectively, used to manufacture the coin.

   c. Calculate the density of the British sovereign coin.

9.2 **(a)** The mass of gold in the coin is

$$m_{Au} = \frac{(\#\text{ karats})m_{total}}{24} = \frac{22}{24}m_{total} = \frac{11}{12}(7.988\times10^{-3}\text{ kg}) = \boxed{7.322\times10^{-3}\text{ kg}}$$

and the mass of copper is $m_{Cu} = m_{total}/12 = (7.988 \times 10^{-3}\text{ kg})/12 =$

6.657×10^{-4} kg

(b) The volume of the gold present is

$$V_{Au} = \frac{m_{Au}}{\rho_{Au}} = \frac{7.322\times10^{-3}\text{ kg}}{19.3\times10^{3}\text{ kg/m}^3} = \boxed{3.79\times10^{-7}\text{ kg}^3}$$

and the volume of the copper is

$$V_{Cu} = \frac{m_{Cu}}{\rho_{Cu}} = \frac{6.657\times10^{-4}\text{ kg}}{8.92\times10^{3}\text{ kg/m}^3} = \boxed{7.46\times10^{-8}\text{ m}^3}$$

(c) The average density of the British sovereign coin is

$$\rho_{Cu} = \frac{m_{total}}{V_{total}} = \frac{m_{total}}{V_{Au}+V_{Cu}} = \frac{7.988\times10^{-3}\text{ kg}}{3.79\times10^{-7}\text{ m}^3 + 7.46\times10^{-8}\text{ m}^3} = \boxed{1.76\times10^{4}\text{ kg/m}^3}$$

5. **Q|C** The nucleus of an atom can be modeled as several protons and neutrons closely packed together. Each particle has a mass of 1.67×10^{-27} kg and radius on the order of 10^{-15} m.

a. Use this model and the data provided to estimate the density of the nucleus of an atom.

Answer

b. Compare your result with the density of a material such as iron. What do your result and comparison suggest about the structure of matter?

9.5 **(a)** If the particles in the nucleus are closely packed with negligible space between them, the average nuclear density should be approximately that of a proton or neutron. That is

$$\rho_{\text{nucleus}} = \frac{m_{\text{proton}}}{V_{\text{proton}}} = \frac{m_{\text{proton}}}{4\pi r^3/3} \sim \frac{3(1.67\times10^{-27}\text{ kg})}{4\pi(1\times10^{-15}\text{ m})^3} = \boxed{\sim4\times10^{17}\text{ kg/m}^3}$$

(b) The density of iron is $\rho_{Fe} = 7.86\times10^3$ kg/m^3 and the densities of other solids and liquids are on the order of 10^3 kg/m^3. Thus, the nuclear density is about 10^{14} times greater than that of common solids and liquids, which suggests that atoms must be mostly empty space. Solids and liquids, as well as gases, are mostly empty space.

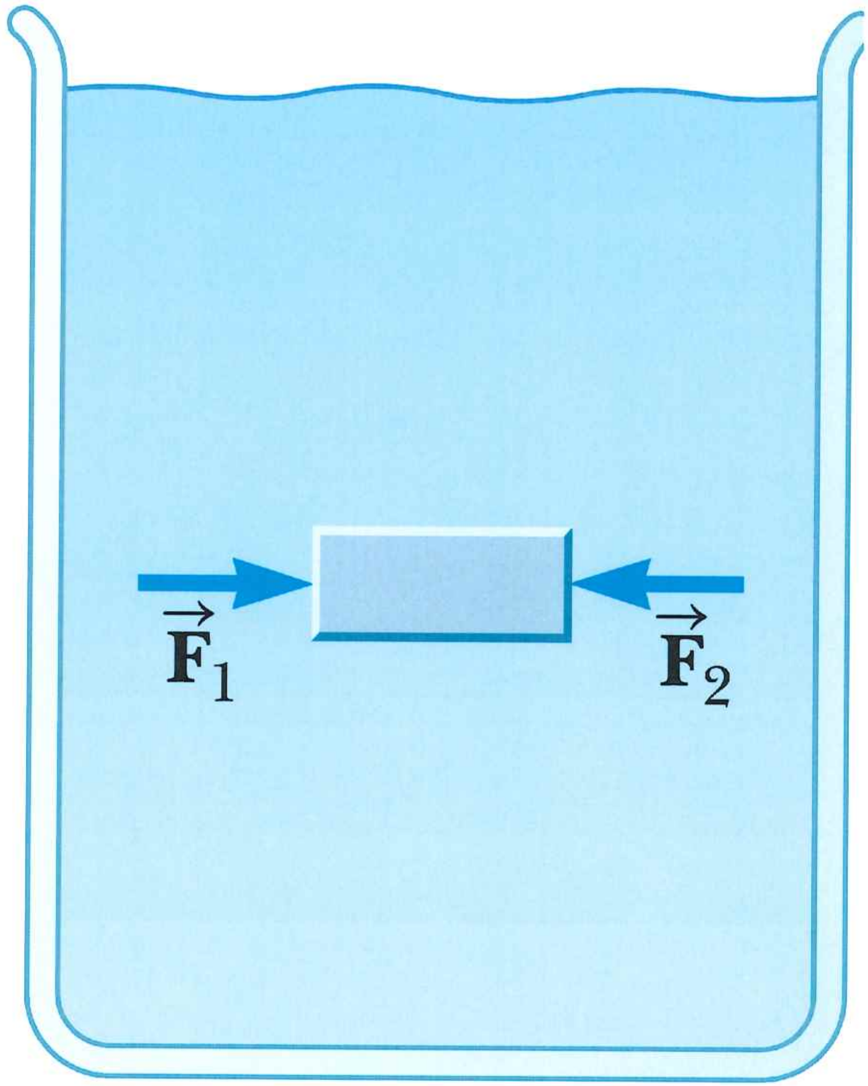
3. The weight of Earth's atmosphere exerts an average pressure of 1.01×10^5 Pa on the ground at sea level. Use the definition of pressure to estimate the weight of Earth's atmosphere by approximating Earth as a sphere of radius $R_E = 6.38 \times 10^6$ m and surface area $A = 4\pi R_E^2$.

9.3 Apply the definition of pressure, taking A to be the surface area of a sphere of radius R_E:

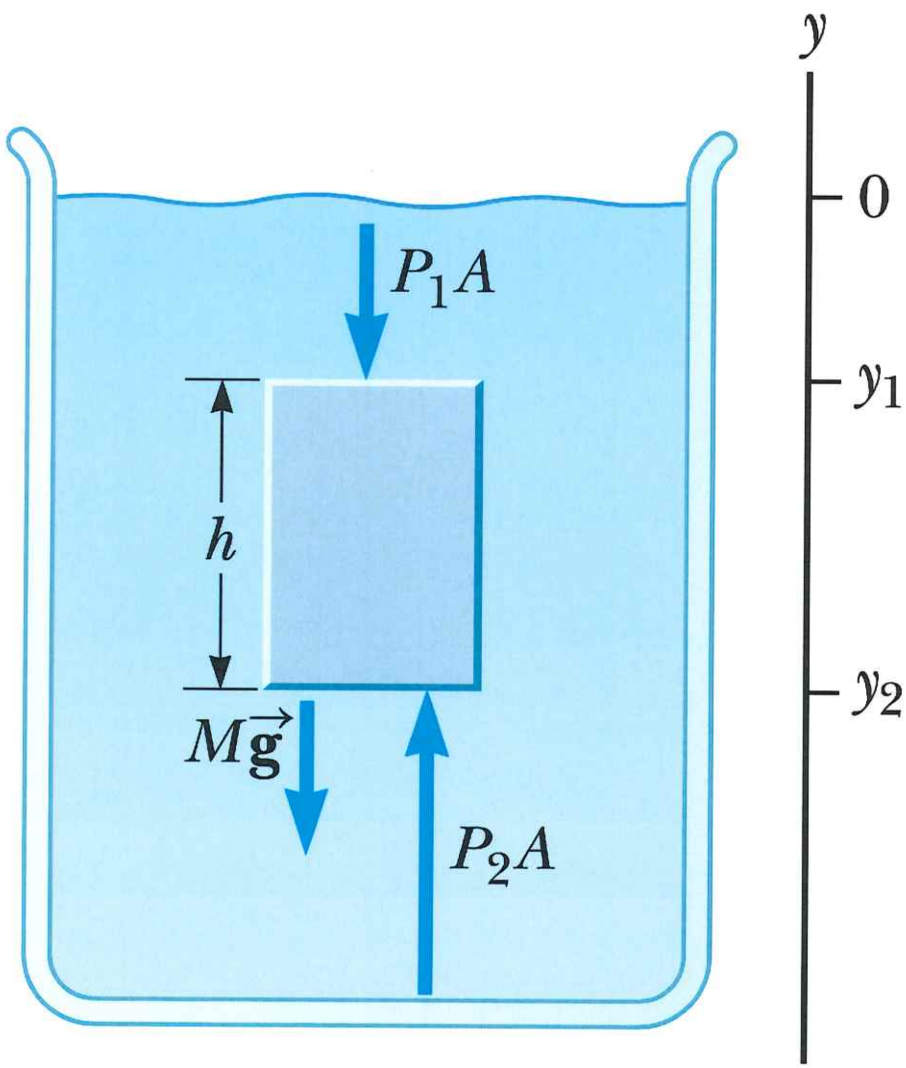
$$P = \frac{F}{A} = \frac{w}{4\pi R_E^2} \rightarrow w = P\left(4\pi R_E^2\right)$$

$$w = \left(1.01 \times 10^5 \text{ N/m}^2\right)\left(4\pi R_E^2\right) = \boxed{5.17 \times 10^{19} \text{ N}}$$

Variation of Pressure with Depth



Variation of Pressure with Depth



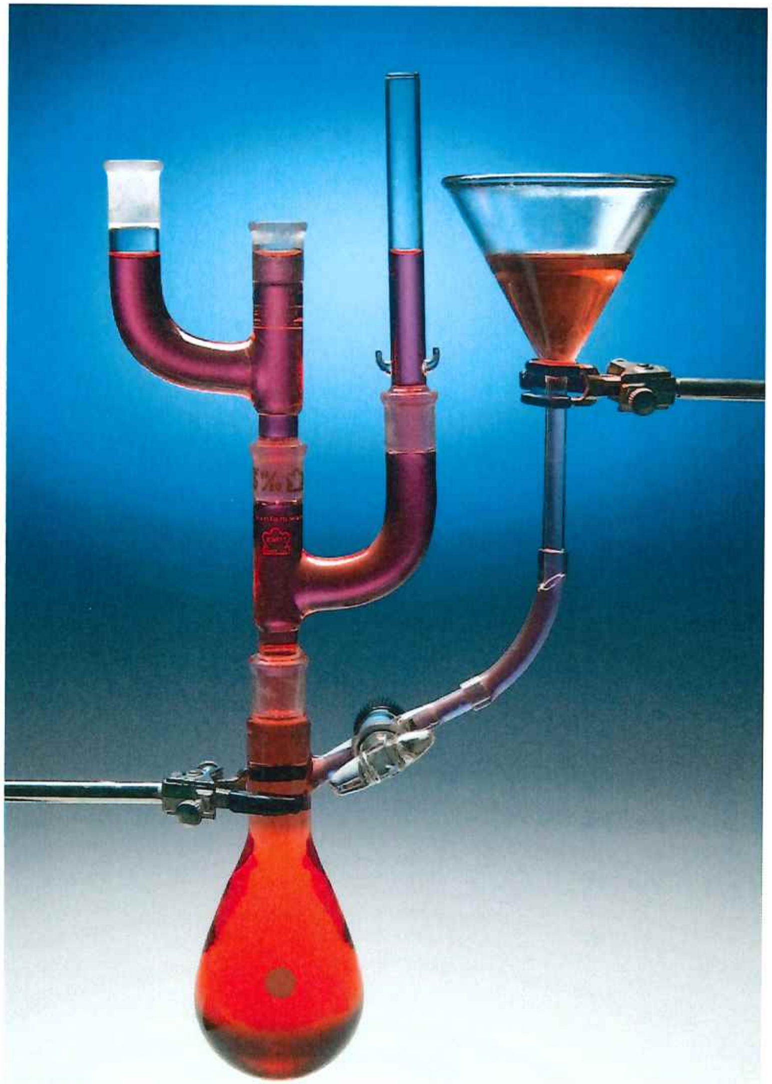
$$P_2 A - P_1 A - Mg = 0$$

$$\rho = \frac{M}{V} \rightarrow$$

$$M = \rho V = \rho A\left(y_1 - y_2\right)$$

$$P_2 = P_1 + \rho g\left(y_1 - y_2\right)$$

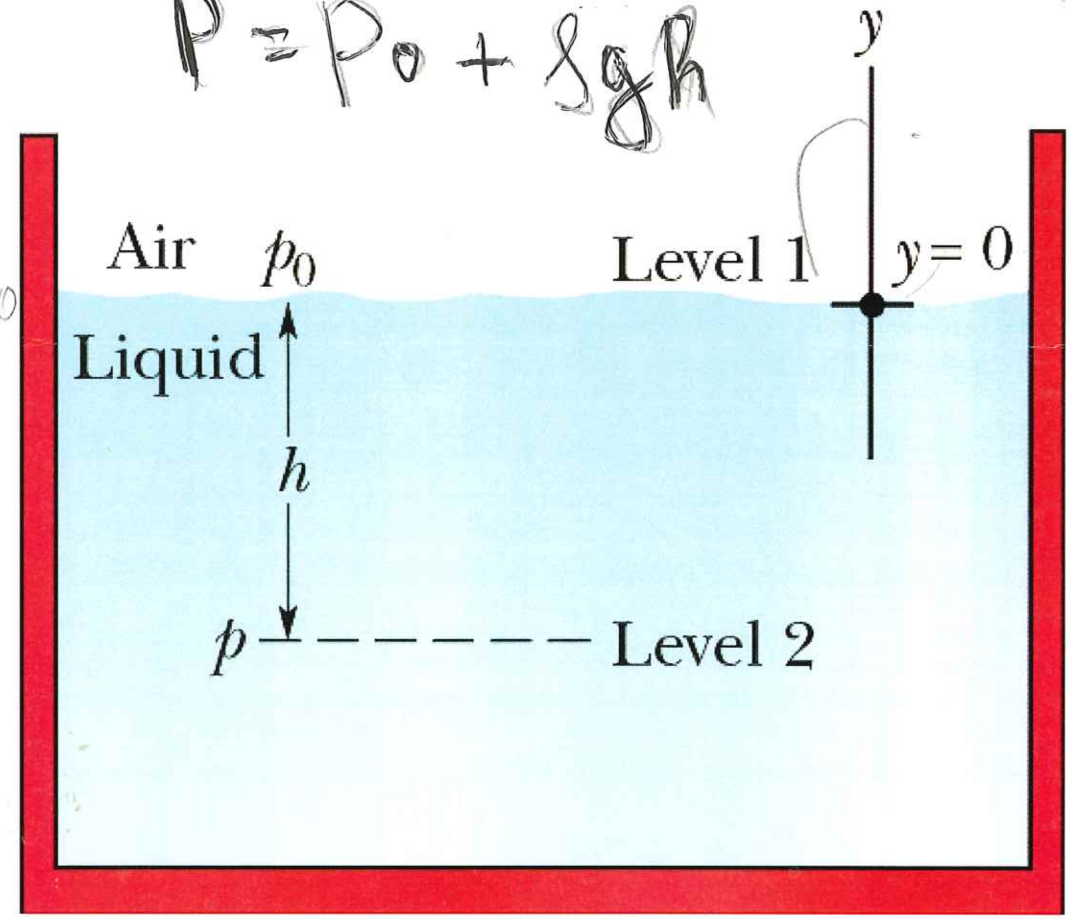
Variation of Pressure with Depth



$$P_0 = 1.013 \times 10^5 \text{ Pa}$$

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

$P = P_0 + \rho g h$



P – Absolute pressure

$P = P_0 + \rho g h$

$P - P_0 = \rho g h$ gauge pressure

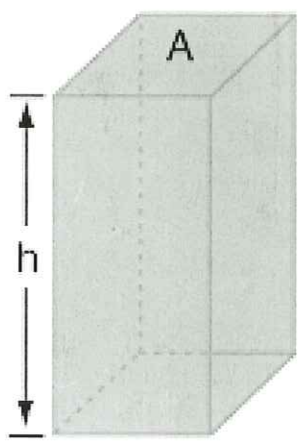
Static Fluid Pressure

The pressure exerted by a static fluid depends only upon the depth of the fluid, the density of the fluid, and the acceleration of gravity.

The pressure in a static fluid arises from the weight of the fluid and is given by the expression

$$P_{\text{static fluid}} = \rho g h \quad \text{where} \quad \begin{aligned} \rho &= m/V = \text{fluid density} \\ g &= \text{acceleration of gravity} \\ h &= \text{depth of fluid} \end{aligned}$$

The pressure from the weight of a column of liquid of area A and height h is

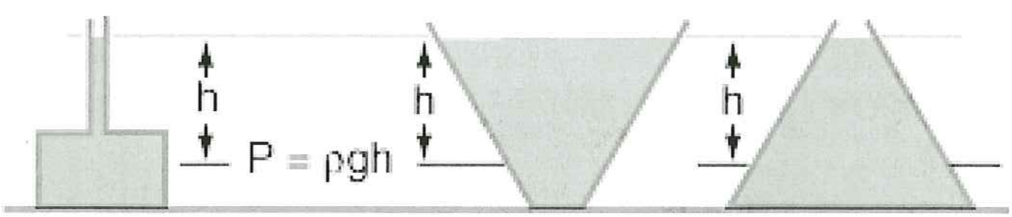


$V = hA =$ volume

weight = mg

Static fluid pressure does not depend on the shape, total mass, or surface area of the liquid.

$$\text{Pressure} = \frac{\text{weight}}{\text{area}} = \frac{mg}{A} = \frac{\rho V g}{A} = \rho g h$$



The most remarkable thing about this expression is what it does not include. The fluid pressure at a given depth does not depend upon the total mass or total volume of the liquid. The above pressure expression is easy to see for the straight, unobstructed column, but not obvious for the cases of different geometry which are shown.

1. An 81.5-kg man stands on a horizontal surface.

What is the volume of the man's body if his average density is 985 kg/m^3?

Answer

What average pressure from his weight is exerted on the horizontal surface if the man's two feet have a combined area of 4.50×10^{-2} m^2?

9.1 **(a)** Apply the definition of density to find

$$\rho = \frac{M}{V} \rightarrow V = \frac{M}{\rho} = \frac{81.5 \text{ kg}}{985 \text{ kg/m}^3} = \boxed{8.27 \times 10^{-2} \text{ m}^3}$$

(b) From the definition of pressure:

$$P = \frac{F}{A} = \frac{mg}{A} = \frac{(81.5 \text{ kg})(9.80 \text{ m/s}^2)}{4.50 \times 10^{-2} \text{ m}^2} = \boxed{1.77 \times 10^4 \text{ Pa}}$$

6. The four tires of an automobile are inflated to a gauge pressure of 2.0×10^5 Pa. Each tire has an area of $0.024\ m^2$ in contact with the ground. Determine the weight of the automobile.

9.6 Let the weight of the car be W. Then, each tire supports $W/4$, and the gauge pressure is $P = F/A = (W/4)/A = W/4A$. Thus,

$$W = 4AP = 4(0.024\ m^2)(2.0 \times 10^5\ Pa) = \boxed{1.9 \times 10^4\ N}$$

9.

Calculate the absolute pressure at the bottom of a freshwater lake at a depth of 27.5 m. Assume the density of the water is $1.00 \times 10^3\ \text{kg/m}^3$ and the air above is at a pressure of 101.3 kPa.

Answer

What force is exerted by the water on the window of an underwater vehicle at this depth if the window is circular and has a diameter of 35.0 cm?

9.9 **(a)**

$$P = P_0 + \rho g h = 101.3\times10^3\ \text{Pa} + \left(1.00\times10^3\ \text{kg/m}^3\right)\left(9.80\ \text{m/s}^2\right)\left(27.5\ \text{m}\right)$$

$$= \boxed{3.71\times10^5\ \text{Pa}}$$

(b) The inward force the water will exert on the window is

$$F = PA = P\left(\pi r^2\right) = \left(3.71\times10^5\ \text{Pa}\right)\pi\left(\frac{35.0\times10^{-2}\ \text{m}}{2}\right)^2 = \boxed{3.57\times10^4\ \text{N}}$$

8. BIO A normal blood pressure reading is less than 120/80 where both numbers are gauge pressures measured in millimeters of mercury (mmHg). What are the

a. absolute and

b. gauge pressures in pascals at the base of a 0.120 m column of mercury?

9.8 **(a)** The absolute pressure at the base of a 0.120 m column of mercury is:

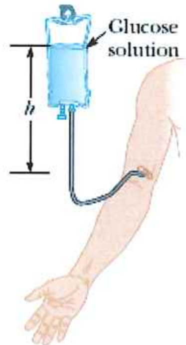
$$P = P_0 + \rho g h$$
$$= 1.01\times10^5\ \text{Pa} + \left(13.6\times10^3\ \text{kg/m}^3\right)\left(9.80\ \text{m/s}^2\right)\left(0.120\ \text{m}\right)$$
$$= \boxed{1.17\times10^5\ \text{Pa}}$$

(b) The corresponding gauge pressure is

$$P_{\text{gauge}} = P - P_0 = \rho g h$$
$$= \boxed{1.60\times10^4\ \text{Pa}}$$

11. BIO A collapsible plastic bag (Fig. P9.11) contains a glucose solution. If the average gauge pressure in the vein is 1.33×10^3 Pa, what must be the minimum height h of the bag to infuse glucose into the vein? Assume the specific gravity of the solution is 1.02.

Figure P9.11



9.11 The density of the solution is $\rho = 1.02\rho_{water} = 1.02 \times 10^3\ \text{kg/m}^3$. If the glucose solution is to flow into the vein, the minimum required gauge pressure of the fluid at the level of the needle is equal to the gauge pressure in the vein, giving

$$P_{gauge} = P - P_0 = \rho g h_{min} = 1.33 \times 10^3\ \text{Pa}$$

and $h_{min} = \dfrac{1.33 \times 10^3\ \text{Pa}}{\rho g} = \dfrac{1.33 \times 10^3\ \text{Pa}}{\left(1.02 \times 10^3\ \text{kg/m}^3\right)\left(9.80\ \text{m/s}^2\right)} = \boxed{0.133\ \text{m}}$

13. V A container is filled to a depth of 20.0 cm with water. On top of the water floats a 30.0-cm-thick layer of oil with specific gravity 0.700. What is the absolute pressure at the bottom of the container?

9.13 We first find the absolute pressure at the interface between oil and water.

$$P_1 = P_0 + \rho_{oil} g h_{oil}$$
$$= 1.013\times10^5\ \text{Pa} + \left(700\ \text{kg/m}^3\right)\left(9.80\ \text{m/s}^2\right)\left(0.300\ \text{m}\right) = 1.03\times10^5\ \text{Pa}$$

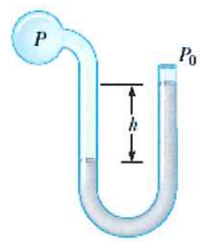
This is the pressure at the top of the water. To find the absolute pressure at the bottom, we use $P_2 = P_1 + \rho_{water} g h_{water}$, or

$$P_2 = 1.03\times10^5\ \text{Pa} + (10^3\ \text{kg/m}^3)(9.80\ \text{m/s}^2)(0.200\ \text{m}) = \boxed{1.05\times10^5\ \text{Pa}}$$

15. BIO A sphygmomanometer is a device used to measure blood pressure, typically consisting of an inflatable cuff and a manometer used to measure air pressure in the cuff. In a mercury sphygmomanometer, blood pressure is related to the difference in heights between two columns of mercury.

The mercury sphygmomanometer shown in Figure P9.15 contains air at the cuff pressure P. The difference in mercury heights between the left tube and the right tube is $h = 115 \text{ mmHg} = 0.115 \text{ m}$, a normal systolic reading. What is the gauge systolic blood pressure P_{gauge} in pascals? The density of mercury is $\rho = 13.6 \times 10^3 \text{ kg/m}^3$ and the ambient pressure is $P_0 = 1.01 \times 10^5 \text{ Pa}$.

Figure P9.15



9.15 The gauge pressure required to support a 0.155-m deep column of mercury is

$$P_{\text{gauge}} = P - P_0 = \rho g h$$

$$= \left(13.6\times10^3 \text{ kg/m}^3\right)\left(9.80 \text{ m/s}^2\right)\left(0.115 \text{ m}\right) = \boxed{1.53\times10^4 \text{ Pa}}$$