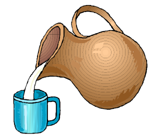
Chapter 9

Fluids

What is a fluid



- A substance that can flow
  - Liquids (difficult to compress)
  - Gases (easy to compress)
- Basic properties:
  - Fluids take the form of the container.
  - When shear stress is applied they flow.
  - The molecules in fluids are in constant random motion (Brownian motion).
- The field of science that describes the fluid motion is called "Fluid Mechanics"

Density

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

- Mass per unit volume.
- Unit kg/m^3.
- The density can be different at each point of the fluid.
- An object is uniform if the density is constant at any point of the body
- A fluid is incompressible if the density does not change as a result of an applied pressure.

Some examples

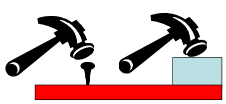
Interstellar space	10^{-20} kg/m^3
Laboratory vacuum	10^{-17} kg/m^3
Air (1 atm 20C)	1.21 kg/m^3
Ice	0.917×10^3 kg/m^3
Water	0.998×10^3 kg/m^3
Seawater	1.024×10^3 kg/m^3
Earth	5.5×10^3 kg/m^3
Neutron star	10^{18} kg/m^3

Pressure

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

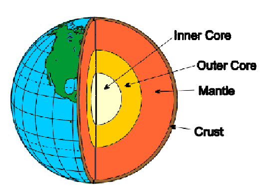
- Force per unit area (the force is perpendicular to the surface)
- Scalar: the pressure has the same value in all directions!
- Units: 1Pa=1N/1m^2.
- Other popular units

  1 atm = 1 bar = 1.01×10^5 Pa = 760 torr = 14.7 lb/in^2



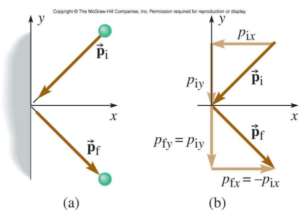
Some Examples

Sea level atm. pressure	10^5 Pa
Bottom of the ocean	1.1×10^8 Pa
Center of the Earth	4×10^{11} Pa
Center of the Sun	2×10^{16} Pa



Fluid Pressure

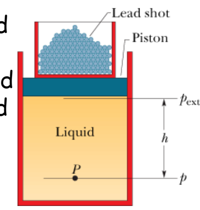
Pressure arises from the collisions between the particles of a fluid with another object (container walls for example).



There is a momentum change (impulse) that is away from the container walls. There must be a force exerted on the particle by the wall.

Pascal's Principle

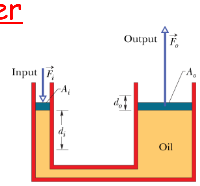
- A change in the pressure applied to an enclosed incompressible fluid is transmitted undiminished to every portion of the fluid and to the walls of the container.



$$\Delta p = \Delta p_{ext}$$

Hydraulic Lever

- An input force applied over a distance is transformed into bigger force over a shorter distance



$$\Delta p = \frac{F_i}{A_i} = \frac{F_o}{A_o} \qquad F_o = F_i \frac{A_o}{A_i} > F_i$$

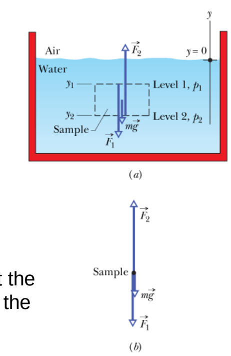
- The work done by the input force and the output force is the same!

$$V = A_i d_i = A_o d_o \qquad W = F_o d_o = d_o F_i \frac{A_o}{A_i} = d_o F_i \frac{d_i}{d_o} = F_i d_i$$

Gravity's Effect on Fluid Pressure

- Static equilibrium

$$F_2 = F_1 + mg$$
$$F_1 = p_1 A \qquad F_2 = p_2 A$$
$$p_2 A = p_1 A + \rho V g$$
$$V = A(y_1 - y_2)$$
$$p_2 = p_1 + \rho g (y_1 - y_2)$$



If the top of the fluid column is placed at the surface of the fluid, then $P_1 = P_{atm} = P_0$ if the container is open.

$$p = p_{atm} + \rho g h$$

Hydrostatic pressure

Example (text problem 9.19): At the surface of a freshwater lake, the pressure is 105 kPa. (a) What is the pressure increase in going 35.0 m below the surface?

$$P = P_{atm} + \rho g d$$
$$\Delta P = P - P_{atm} = \rho g d$$
$$= \left(1000\ \text{kg/m}^3\right)\left(9.8\ \text{m/s}^2\right)\left(35\ \text{m}\right)$$
$$= 343\ \text{kPa} = 3.4\ \text{atm}$$

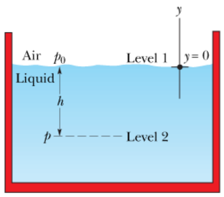
Example: The surface pressure on the planet Venus is 95 atm. How far below the surface of the ocean on Earth do you need to be to experience the same pressure? The density of seawater is 1025 kg/m^3.

$$P = P_{atm} + \rho g d$$
$$95\ \text{atm} = 1\ \text{atm} + \rho g d$$
$$\rho g d = 94\ \text{atm} = 9.5\times10^6\ \text{N/m}^2$$
$$\left(1025\ \text{kg/m}^3\right)\left(9.8\ \text{m/s}^2\right)d = 9.5\times10^6\ \text{N/m}^2$$
$$d = 950\ \text{m}$$

Gauge pressure

- Absolute pressure = total pressure
- Gauge pressure = total - atmospheric
- The atmospheric pressure on the free surface of a liquid is often neglected.

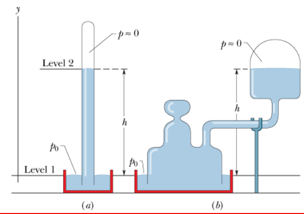
$$p_{gauge} = \rho g h$$



Measuring pressure

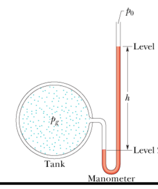
- Mercury barometer: measures the atmospheric pressure.

$$p_0 = \rho g h$$



- Open tube manometer: measures the gauge pressure of a gas.

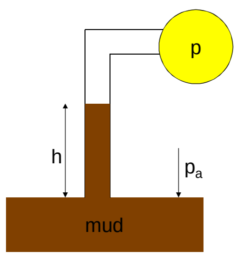
$$p_g = p - p_0 = \rho g h$$



Sample problem

- What gauge pressure must a machine produce to suck mud of density 1800 kg/m^3 up a tube by a height of 1.5 m?

$$p_g = p - p_{atm}$$
$$p_{atm} = p + \rho g h$$
$$p_g = -\rho g h = -2.6\times10^4\, Pa$$

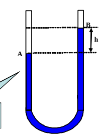


Fluids at Rest: Examples

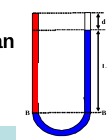
- **The closed U-tube shown in the figure contains a liquid of density ρ. What is the pressure difference $\Delta P = P_A - P_B$?**

$$P_A = P_B + \rho g h \qquad P_A = P_B + \rho g h$$
$$\Delta P = P_A - P_B = \rho g h$$

Manometer



- **The (open) U-tube shown in the figure contains two liquids in static equilibrium: Water of density ρ_W is in the right arm, and an oil of unknown density ρ_X is in the left arm. What is the density of the unknown oil in terms of d and L?**



$$P_B = P_0 + \rho_x g (L + d) \qquad P_B = P_0 + \rho_W g L \qquad \rho_X = \frac{L}{L+d}\rho_W$$

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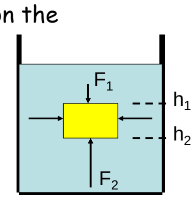
Archimedes Principle-Buoyancy Force $\vec{F}_b$

- When a body is partially or fully submerged in a fluid a buoyant force from the surrounding fluid acts on the body.
- The buoyancy force is upward*
- It is applied at CM (displaced fluid)
- The magnitude is:

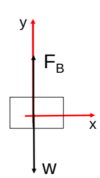
$$F_b = F_2 - F_1$$
$$F_b = \rho_f g h_2 A - \rho_f g h_1 A = \rho_f g V$$
$$F_b = m_f g$$



where m_f is the mass of the displaced fluid!

Example (text problem 9.28): A flat-bottomed barge loaded with coal has a mass of 3.0×10^5 kg. The barge is 20.0 m long and 10.0 m wide. It floats in fresh water. What is the depth of the barge below the waterline?

FBD for the barge



Apply Newton's 2nd Law to the barge:

$$\sum F = F_B - w = 0$$
$$F_B = w$$
$$m_w g = (\rho_w V_w) g = m_b g$$
$$\rho_w V_w = m_b$$
$$\rho_w (Ad) = m_b$$

$$d = \frac{m_b}{\rho_w A} = \frac{3.0\times10^5\ \text{kg}}{(1000\ \text{kg/m}^3)(20.0\ \text{m} * 10.0\ \text{m})} = 1.5\ \text{m}$$

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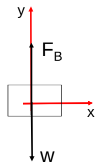
Example (text problem 9.40): A piece of metal is released under water. The volume of the metal is 50.0 cm^3 and its specific gravity is 5.0. What is its initial acceleration? (Note: when v = 0, there is no drag force.)

FBD for the metal



Apply Newton's 2nd Law to the piece of metal:

$$\sum F = F_B - w = ma$$

The magnitude of the buoyant force equals the weight of the fluid displaced by the metal.

$$F_B = \rho_{\text{water}} V g$$

Solve for a: $a = \frac{F_B}{m} - g = \frac{\rho_{\text{water}} V g}{\rho_{\text{object}} V_{\text{object}}} - g = g\left(\frac{\rho_{\text{water}} V}{\rho_{\text{object}} V_{\text{object}}} - 1\right)$

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Example continued:

Since the object is completely submerged $V=V_{\text{object}}$.

$$\text{specific gravity} = \frac{\rho}{\rho_{\text{water}}}$$

where ρ_{water} = 1000 kg/m^3 is the density of water at 4 ° C.

Given $\text{specific gravity} = \frac{\rho_{\text{object}}}{\rho_{\text{water}}} = 5.0$

$$a = g\left(\frac{\rho_{\text{water}} V}{\rho_{\text{object}} V_{\text{object}}} - 1\right) = g\left(\frac{1}{S.G.} - 1\right) = g\left(\frac{1}{5.0} - 1\right) = -7.8 \text{ m/s}^2$$

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