Lecture 5 (Feb. 6)

- Pressure in liquids and gases
- Measuring and using pressure
- Archimedes' principle (float or sink?)

Pressure

master formula

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

$$(\text{SI units: } 1\ N/m^2 \equiv 1\ Pa)$$

- Measuring device: fluid pushes against "spring", deduce force from displacement
- Pressure exists at all points, not just walls (like tension in string)
- Pressure is *same* in <u>all</u> directions at a point
- Pressure <u>increases</u> with depth in liquid (*not* in gas)

Causes of Pressure

- Difference in pressure between liquids and gases due to (in)compressibility
- compare 2 jars containing mercury liquid and gas: without gravity (outer space) and with gravity
- 2 contributions to pressure:

(i) Gravitational: fluid pulled down, exerts forces on bottom and side

(ii) Thermal: collisions of gas molecules with walls

Pressure in Gases

- For lab.-size container, gravitational contribution negligible → pressure is same at all points

- increases with density (more collisions with wall)

Atmospheric pressure

- Density decreases as we go away from earth's surface → atmospheric pressure decreases
- At sea-level: 101, 300 Pa = 1 atm. (not SI unit)
- Fluid exerts pressure in all directions → net force = 0 ("sucking" force due to no air on one side)

Pressure in liquids (I)

- Gas fills entire container (compressible) vs. liquid fills bottom, exerting force: gravitational contribution dominant
- Pressure at depth d (assuming density constant: not for gas):

$$
\begin{aligned}
mg + p_0 A &= pA \\
m &= \rho A \\
p &= p_0 + \rho g d
\end{aligned}
$$

pressure at surface

master formula

Pressure in liquids (II)

- Connected liquid rises to *same* height in all open regions of container
- Pressure same at all points on horizontal line

master formula

- Pascal's principle: change in pressure same at all points:

$$p = p_0 + \rho g d \rightarrow p' = p_1 + \rho g d$$
$$\text{(change in pressure at surface)}$$
$$\Rightarrow \Delta p = p_1 - p_0 \text{ for all } d$$

Strategy for hydrostatic problems

- draw picture with details...
- pressure at surface: atmospheric or gas or F/A (piston)
- pressure same along horizontal line
- $p = p_0 + \rho g d$

Measuring Pressure

Gauge pressure, p_g = p - 1 atm.

- Manometer (for gas pressure):

$$p_1 = p_{gas}$$
$$\text{equal to}$$
$$p_2 = p_{atm.} + \rho g h$$
$$\Rightarrow p_{gas} = p_{atm.} + \rho g h$$

- Barometer (for atmospheric pressure)

$$p_1 = p_{atm.}$$
$$\text{equal to}$$
$$p_2 = 0 + \rho g h$$
$$\Rightarrow p_{atm} = \rho g h$$

1 atm. = 101.3 k Pa → h = 760 mm of mercury

Hydraulic Lift

- Use pressurized liquids for work (based on Pascal's principle): increase pressure at one point by pushing piston...at another point, piston can push upward

- Force multiplication:

$$p_1 = \frac{F_1}{A_1} + p_0$$

$$\text{equal to } p_2 = \frac{F_2}{A_2} + p_0 + \rho g h$$

$$\Rightarrow F_2 = F_1 \frac{A_2}{A_1} - \rho g h A_2$$

$$\frac{A_2}{A_1} > 1$$

- Relating distances moved by pistons:

$$V_1 = A_1 d_1 \text{ equal to } V_2 = A_2 d_2$$

$$\Rightarrow d_2 = \frac{d_1}{A_2/A_1}$$

- Additional force to move heavy object thru' d_2

$$\Delta F = \rho g \left(A_1 + A_2\right) d_2$$

Buoyancy: Archimedes' principle

- Buoyant force: upward force of a fluid
- Buoyant force, F_B =
  weight of displaced fluid, $\rho_f V_f g$

To float or sink?

- Net force: $F_B - w$

  $F_B \leftarrow \rho_f V_f g \qquad w \leftarrow \rho_{avg.} V_0 g$

- Float or sink or static equilibrium for

  $$\rho_{avg.} < \rho_f \text{ or } \rho_{avg.} > \rho_f \text{ or } \rho_{avg.} = \rho_f$$

  master formula

- ...rather for 1st case **pushed up** till only partly submerged:

  $$F_B = \rho_f V_f g = w = \rho_0 V_0 g$$
  $$\Rightarrow V_f < V_0$$

- Boats: steel plate sinks, but geometry (sides) allows it to displace more fluid than actual steel volume:

  $$\rho_{avg.} = \frac{m_0}{Ah} < \rho_f$$