Lecture 21

Goals:

- Chapter 15, fluids

Assignment

- HW-8 due Tuesday, Nov 16
- Wednesday: Read through Chapter 16

At ordinary temperature, matter exists in one of three states

- Solid - has a shape and forms a surface
- Liquid - has no shape but forms a surface
- Gas - has no shape and forms no surface

What do we mean by “fluids”?

- Fluids are “substances that flow”.... “substances that take the shape of the container”
- Atoms and molecules are free to move.
Fluids

- An intrinsic parameter of a fluid
  - Density (mass per unit volume)

\[ \rho = \frac{m}{V} \]

units: kg/m\(^3\) = 10\(^{-3}\) g/cm\(^3\)

\[ \begin{align*}
\rho_{\text{water}} &= 1.000 \times 10^3 \text{ kg/m}^3 = 1.000 \text{ g/cm}^3 \\
\rho_{\text{ice}} &= 0.917 \times 10^3 \text{ kg/m}^3 = 0.917 \text{ g/cm}^3 \\
\rho_{\text{air}} &= 1.29 \text{ kg/m}^3 = 1.29 \times 10^3 \text{ g/cm}^3 \\
\rho_{\text{Hg}} &= 13.6 \times 10^3 \text{ kg/m}^3 = 13.6 \text{ g/cm}^3
\end{align*} \]

Fluids

- Another parameter
  - Pressure (force per unit area)

\[ P = \frac{F}{A} \]

SI unit for pressure is 1 Pascal = 1 N/m\(^2\)

- The atmospheric pressure at sea-level is

1 atm = 1.013 x10\(^5\) Pa
  = 1013 mbar
  = 760 Torr
  = 14.7 lb/ in\(^2\) (=PSI)
Incompressible fluids (liquids)

What is the pressure at the bottom of the container?

\[ F = Mg = \rho V g \]
\[ F = \rho Ay g \]
\[ \text{Pressure} = F/A = \rho y g \]

\[ P = \rho y g \]

What if there is outside gas?

\[ F = P_0 A + Mg \]

\[ P = P_0 + \rho y g \]
What is the pressure 10m down?

\[ P = P_0 + \rho gy \]
\[ = P_0 + (1000 \text{ kg/m}^3)(10 \text{ m/s}^2)(10 \text{ m}) \]
\[ = P_0 + 10^5 \text{ N/m}^2 \]
\[ = \text{approximately 2 atm} \]

Home exercise: what is the pressure 4 miles down?
Consider the open, connected container shown below. How would the two heights compare?

A) \( y_1 < y_2 \)  

B) \( y_1 = y_2 \)  

C) \( y_1 > y_2 \) 

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**Pressure vs. Depth**

In a connected liquid, the pressure is the same at all points through a horizontal line.
Pressure Measurements: Barometer

• Invented by Torricelli
• A long closed tube is filled with mercury and inverted in a dish of mercury
  • The closed end is nearly a vacuum

\[ P_0 = \rho gh \]

• Measures atmospheric pressure as
  1 atm = 0.760 m (of Hg)

Archimedes’ Principle

• Suppose we weigh an object in air (1) and in water (2).

How do these weights compare?

- a) \( W_1 < W_2 \)
- b) \( W_1 = W_2 \)
- c) \( W_1 > W_2 \)
Buoyancy

\[ F_2 = P_2 \text{ Area} \]
\[ F_1 = P_1 \text{ Area} \]
\[ F_2 - F_1 = (P_2 - P_1) \text{ Area} \]
\[ = \rho g (y_2 - y_1) \text{ Area} \]
\[ = \rho g V_{\text{object}} \]
\[ = \text{weight of the fluid displaced by the object} \]

Float or sink?

- If we immerse the object completely in the liquid:

  \[ \text{weight of the object} < \text{bouyant force} \quad \rightarrow \quad \text{float} \]

  \[ \rho_{\text{object}} V_{\text{object}} < \rho_{\text{fluid}} V_{\text{object}} \quad \rightarrow \quad \text{float} \]

  \[ \rho_{\text{object}} < \rho_{\text{fluid}} \quad \rightarrow \quad \text{float} \]

- How does a steel ship float?

  A) \( \rho_{\text{steel}} < \rho_{\text{water}} \)

  B) overall density of the ship < \( \rho_{\text{water}} \)

  C) none of the above
**Float**

- If the object floats, then we can find the portion of the object that will be immersed in the fluid

\[ F_B = mg \]
\[ V_{\text{immersed}} \rho_{\text{fluid}} g = V_{\text{object}} \rho_{\text{object}} g \]
\[ V_{\text{immersed}} \rho_{\text{fluid}} = V_{\text{object}} \rho_{\text{object}} \]

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**Pascal’s Principle**

Any change in the pressure applied to an enclosed fluid is transmitted to every portion of the fluid and to the walls of the containing vessel.

\[ P = P_0 + \rho g y \]
Pascal’s Principle in action: Hydraulics, a force amplifier

Consider the system shown:

- A downward force $F_1$ is applied to the piston of area $A_1$.

- This force is transmitted through the liquid to create an upward force $F_2$.

- Pascal’s Principle says that increased pressure from $F_1$ ($F_1/A_1$) is transmitted throughout the liquid.

\[
P_1 = P_2 \\
F_1 / A_1 = F_2 / A_2 \\
A_2 / A_1 = F_2 / F_1
\]