Phy 212: General Physics II

Chapter 14: Fluids
Lecture Notes

Daniel Bernoulli (1700-1782)

- Swiss merchant, doctor & mathematician
- Worked on:
  - Vibrating strings
  - Ocean tides
  - Kinetic theory
- Demonstrated that as the velocity of a fluid increases its pressure decreases (known as Bernoulli's Principle)

What are fluids?

- Fluids are substances that flow (liquids or gases)
- Mass Density (ρ) is mass per unit volume or

$$\rho = \frac{\Delta m}{\Delta V} \left\{ \textit{for a uniform substance :}\ \rho = \frac{m}{V} \right\}$$

  - SI units are kg/m^3
- Pressure is the magnitude of the normal force (ΔF_N) applied to a surface per unit area (ΔA), or

$$P = \frac{\Delta F_N}{\Delta A} \left\{ \textit{For a uniformly applied force :}\ P = \frac{F_N}{A} \right\}$$

  - SI units are newtons/meters^2 (N/m^2) or pascals (Pa)
- Note: for static fluids (at rest), force can only be applied normal to the surface
- Tangential forces result in fluid flow!

Pressure in Fluids

- Fluids are mobile
  - Fluids do not retain their shape
  - Fluids do not independently support their shape
- The pressure within a fluid varies with depth
  - Pressure within a fluid is constant at all points of the same depth
  - Pressure increases with increasing depth (H)

$$P \sim H$$

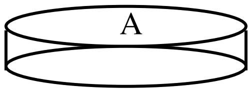
{where H is the depth below the surface of the fluid}

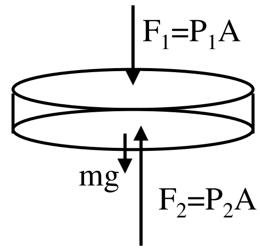
- The pressure difference (ΔP) between 2 points within a fluid is related to the density of the fluid (ρ) & the depth difference between the points
  - The greater the fluid density (ρ), the greater ΔP
  - The greater the depth difference (ΔH), the greater ΔP

$$P_2 - P_1 = \rho g \Delta H$$

Derivation of pressures in fluids

Consider a disk of water in a static fluid:





– Applying Newton's 2nd Law to the disk:

$$\vec{F}_{Net} = P_2A\,\hat{j} - P_1A\,\hat{j} - mg\,\hat{j} = 0$$

<u>or</u>

$$P_2A - P_1A = mg$$

– The mass of the disk is: $m = \rho A\Delta y$ so Newton's 2nd Law can be rewritten as

$$P_2A - P_1A = mg = (\rho A\Delta y)g \quad \text{or} \quad P_2 - P_1 = \rho g\Delta y$$

– Note that pressure in a fluid does <u>not</u> depend on:
  - The total mass of the fluid disk
  - The surface area where the force is applied

Atmospheric Pressure

- If the surface of a fluid is exposed to air, the pressure at that surface (P_o) is equal to that of the atmospheric air pressure at that elevation
- At sea level the atmospheric pressure is

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

- The pressure at any depth (H) below the surface of the fluid is given by:

$$P = P_o + \rho gH$$

- This relationship also applies to air pressure at higher altitudes (to the extent that the air density does not change substantially)

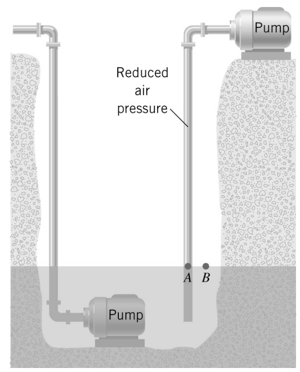
How high can you suck water up using a straw?

(or pumping water uphill)

- In order to draw water (or any fluid) upward you must lower the pressure difference between the pressure inside the "straw" and the outside environment (usually the atmosphere)

1. Is there a limit to how low you can make the pressure inside a straw?

2. How high can you suck water?

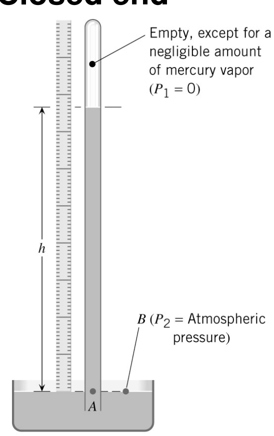


Barometers

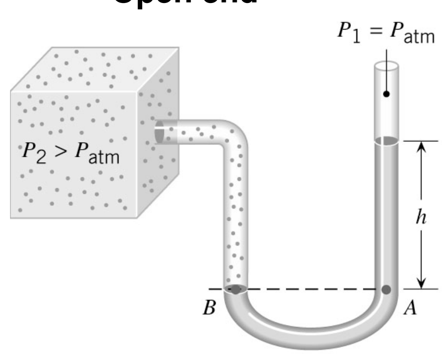
Barometers are devices used to measure air (or atmospheric) pressure

•Types of barometers:

Closed end



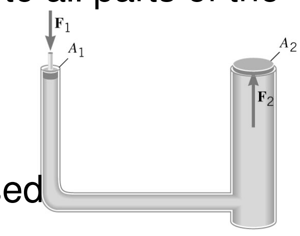
Open end



Pascal's Principle

When pressure is applied to an enclosed fluid, the pressure is transmitted undiminished to all parts of the fluid and the enclosing walls

- The effect of applied pressure is to increase the P_o for the fluid.
- The application of hydraulics is based on this Pascal's Principle:



(a)

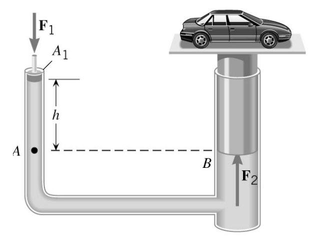
$$P_2 = P_1 + \rho g H$$

or

$$\frac{F_2}{A_2} = \frac{F_1}{A_1} + \rho g H$$

Therefore

$$F_2 = A_2\left(\frac{F_1}{A_1} + \rho g H\right)$$



Archimedes' Principle

When an object is submerged in a fluid, the fluid exerts a buoyant force (F_B) on the object equal to the weight of the fluid displaced by the object:

$$F_B = m_{fluid}g = \rho_{fluid}V_{displaced}g$$

Notes:

- When a submerged object has greater density than the fluid, its weight will be greater than F_B (it will sink)
- When a submerged object has lower density than the fluid, it will partially submerge in the fluid until it reaches a depth where its weight will be the same as F_B (it will float)
- When the submerged object has the same density as the fluid it will neither sink nor float but will remain in equilibrium as long as it is completely submerged

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Equation of Continuity

When a fluid flows, the rate of mass entering a point must be equal to the rate of mass exiting the point:

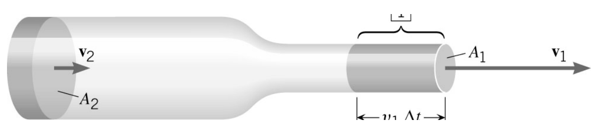
$$\frac{\Delta m_1}{\Delta t} = \frac{\Delta m_2}{\Delta t}$$

Or (since $\Delta m = \rho\Delta V = \rho A\Delta x$ & $\frac{\Delta \vec{x}}{\Delta t} = \vec{v}$)

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$$

Where:

- A is the cross-sectional area of the fluid segment
- Δx is the width of the fluid segment



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Bernoulli's Equation

Bernoulli's Principle: *as speed of fluid increases its pressure drops*

Bernoulli's principle can be extended to Bernoulli's equation for a fluid that is:

- Nonviscous (no friction or interaction with sidewalls)
- Incompressible (liquid does not expand nor compress)

Bernoulli's Equation:

$$P_1 + \rho g y_1 + ½ \rho v_1^2 = P_2 + \rho g y_2 + ½ \rho v_2^2$$

Which can be rewritten as

$$P_2 - P_1 = - \rho g y_1 - ½ \rho v_1^2 + \rho g y_2 + ½ \rho v_2^2$$

Or:

$$P_2 - P_1 = \rho g(y_1 - y_2) + ½ \rho(v_1^2 - v_2^2)$$

Note: the "state" of the fluid is constant at all points:

$$P_1 + \rho g y_1 + ½ \rho v_1^2 = \text{constant}$$