FLUID MECHANICS

Physics Chapter 8

FLUIDS AND BUOYANT FORCE - OBJECTIVES

- **Define** a fluid
- **Distinguish** a gas from a liquid
- **Determine** the magnitude of the buoyant force exerted on a floating object or a submerged object
- **Explain** why some objects float and some objects sink

WHAT DO WE MEAN BY "FLUIDS"?

- **Fluids:**

  "substances that flow"

  "substances take the shape of the container"

- Atoms and molecules are free to move
- An ideal fluid is incompressible, nonviscous, and nonturbulent

- Liquids and Gases

  Liquids –have a definite volume

  Gases – do not

DENSITY AND BUOYANT FORCE

- The concentration of matter of an object is called the **mass density**
  - measured as the mass per unit volume of substance

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

$$\text{mass density} = \frac{\text{mass}}{\text{volume}}$$

The buoyant force is the upward force exerted by a liquid on an object immersed in or floating on the liquid

- Buoyant forces can keep objects afloat

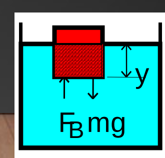
DENSITY AND BUOYANCY

- **Buoyancy** is the apparent loss of weight of an object submerged in a fluid
  - The buoyant force on an object is equal to the weight of the fluid displaces

- **Archimedes' principle** describes the magnitude of a buoyant force
  - Any object completely or partially submerged in a fluid experiences an upward buoyant force equal in magnitude to the weight of the fluid displaced by the object.

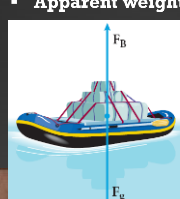
$$F_B = F_g \text{ (displaced fluid)} = m_f g$$

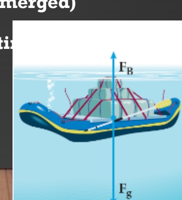
magnitude of buoyant force = weight of fluid displaced



ARCHIMEDES' PRINCIPLE

- The **upward buoyant force (F_B)** is equal in magnitude to the weight of the fluid displaced by the object
  - Weight of displaced fluid = Volume of submerged object x ρ fluid
    - $\mathbf{F_B = \rho_{fluid} V_{fluid}\, g}$ Note: $V_{fluid} = V_{solid}$
    - This "immersed lighter weight" is called **Apparent Weight**
      - **Apparent weight = $F_g - F_B$ (if object submerged)**
      - **= $F_B - F_g$ (if object floati**





APPARENT WEIGHT PROBLEMS

In problems:

- M_f = mass of displaced fluid — f will be for fluid
- M_0 = mass of submerged object — o will be for object
- F_g = m g (newtons)
- $F_B = V_0 \rho_{fluid}\, g$

$$\frac{F_{Object}}{F_{bouyant}} = \frac{\rho_{object}}{\rho_{fluid}}$$

Note: $F_{object} = F_g$

Example Problem:

A small bronze cannon ball has a volume of $4.1\text{x}10^{-2}$ kg/m^3. What is the cannon ball's mass if its apparent weight in sea water is $3.115 \text{ x } 10^3$ N? (Density of sea water is $1.025 \text{ x } 10^3$ kg/m^3)

EXAMPLE CONTINUED

<u>Given:</u>

V_c= $4.51\text{x}10^{-2}$ m^3

App Weight = $3.115\text{x}10^3$ N

P_{sea} = $1.025 \text{ x}10^3$ kg/m^3

M_c=?

<u>Soln:</u>

App Weight = Fg - Fb

Fb = ρsea Vc g

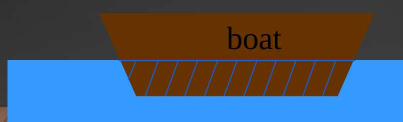
Fg = Mc g

App weight = Mc g - ρsea Vc g

Mc= 364 Kg

PRINCIPLE OF FLOATATION

- For an object to float, it needs to displace a weight of fluid equal to its own weight
- It's the VOLUME of a object – not its weight – that determines the buoyant force
- Things to remember
  - If on object is denser than the fluid in which it is immersed -> it will sink
  - If an object is less dense than the fluid -> it will float



Floating Objects

BUOYANCY QUESTIONS

1. Why are we not crushed from the Atmospheric pressure?

   The reason we are not crushed by our atmosphere inside our bodies is the same as the pressure outside

2. Why do swimmers float better in the ocean than in a lake?

   Because of the salt dissolved in it, seawater is about 2.5% denser, making people (and fish) more buoyant in it.

FLUID PRESSURE - OBJECTIVES

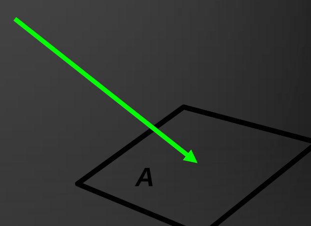
- **Calculate** the pressure exerted by a fluid
- **Calculate** how pressure varies with depth in a fluid

PRESSURE

- **Pressure**
  - Pressure is the amount of force per unit of area

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

$$\text{pressure} = \frac{\text{force}}{\text{area}}$$



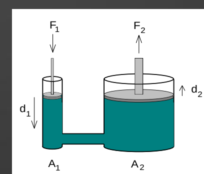
units:
- pascal (Pa) (N/m^2)
- psi (lbs/in^2)
- 1 atm = 1.01×10^5 Pa = 14.7 psi

- Within a fluid the forces are created by molecular collisions

PASCAL'S PRINCIPLE

- Pressure applied to a fluid in a closed container is transmitted equally to every point of the fluid and to the walls of the container
  - This change is in pressure is not diminished even over large volumes

$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

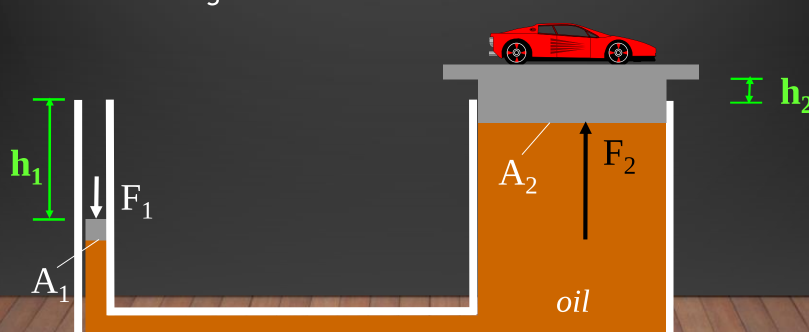


- **Example 1:** You squeeze a tube of toothpaste. The pressure of the toothpaste does not just go up at the place where you are squeezing it. It goes up by the same amount everywhere in the tube.

- **Example 2:** If someone is choking and you do the Heimlich maneuver, you apply a force to his abdomen. The increase in pressure is transmitted to his throat and dislodges the food on which he was choking.

HYDRAULIC PRESS

- Increases the pressure throughout the oil, lifting the car – Uses Pascal's principle
  - This would not work with air, since air is compressible
- The application of a small force at one place can result in the creation of a large force in another



PRESSURE

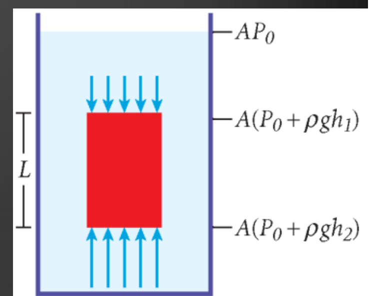
- **Pressure** varies with depth in a fluid
- The pressure in a fluid increases with depth

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

absolute pressure =

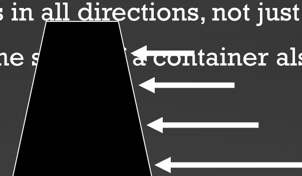
atmospheric pressure +

$$(\text{density} \times \text{free-fall acceleration} \times \text{depth})$$



PRESSURE VS. DEPTH

- Liquids are virtually incompressible
- For an incompressible fluid, the density is the same everywhere, but the pressure is NOT!
- Pressure in a fluid acts in all directions, not just down
  - Pressure against the s a container also increases with depth



Fluid Pressure- Depth

EXAMPLE PROBLEM: PASCAL'S PRINCIPLE

In a hydraulic lift, a 620 N force is exerted on a 0.20m^2 piston in order to support a weight that is placed on a 2.0 m^2 piston. How much pressure is exerted on the narrow piston? How much weight can the wide piston lift? What mass can the wide piston lift?

Given:

Piston 1 Narrow	Piston 2 wide
F1= 620 N	F2 = ?
A1 = .20 m^2	A2 = 2.0 m^2
P1 = ?	M2 = ?

Soln:

Pressure on Narrow Piston

P1 = F1/A1 = 620N/.20m^2

P1 = 3100Pa

Weight wide Piston can lift

$$\frac{F1}{A1} = \frac{F2}{A2}$$

F2 = F1/A1 * A2

F2 = 6200 N

Mass on wide piston

F=ma

m = F/a = 6200n/9.81m/s^2

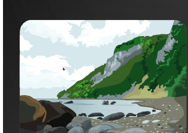
m = 630 kg

EXAMPLE PROBLEM

- Find the atmospheric pressure at an altitude of 1.0x10^3 m if the air density is constant. Assume that the air density is uniformly 1.29 kg/m^3 and P_o = 1.01 x 10^5 Pa

Given:

ρ= 1.29 kg/m^3



h1= 1.0 x 10^3 m

ho = 0

Po = 1.01 x 10^5 Pa

Soln:

P = Po +ρgh   Note: but less pressure

P 1= Po – ρgh

= 1.01 x 10^{5}Pa – (1.29Kg/m^3)(9.81 m/s^2)(1.0x10^{3}m)

P1 = 8.8 x 10^4 Pa

PRESSURE/DENSITY QUESTIONS

Why do snowshoes keep you from sinking into the snow?

The snowshoes greatly increase the area over which your weight is distributed, thereby decreasing the pressure on the snow.

Why don't they make longer snorkels so that people could dive deeper without scuba gear?

The pressure difference just 6 m below water is great enough so that the air in the diver's lungs will be forced through the tube, collapsing his lung. A shorter snorkel might not be fatal, but the pressure differences could prevent him form expanding his lungs (inhaling)

PRESSURE/DENSITY QUESTIONS

Would you rather have a large basketball player wearing sneakers or a petite woman wearing spiked-heeled shoes stomp on your foot with the heel of one shoe?

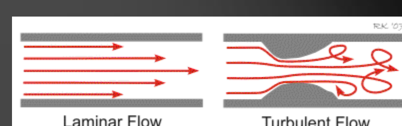
The basketball player's weight is distributed over a larger surface area of the sneaker, the pressure (F/A) that he applies is relatively small. The woman's lesser weight is distributed over the very small cross-sectional area of the spiked heel, so the pressure is high.

FLUIDS IN MOTION - OBJECTIVES

- **Examine** the motion of a fluid using the continuity equation

- **Recognize** the effects of Bernoulli's principle on fluid motion

FLUIDS IN MOTION



- <u>Fluids in motion exhibit 2 types of flow</u>
  - **Laminar (smooth flow)**
    - Each particle of the fluid follows a smooth path
    - The paths of the different particles never cross each other
    - The path taken by the particles is called a *streamline*
  - **Turbulent flow**
    - An irregular flow characterized by small whirlpool like regions
    - Turbulent flow occurs when the particles go above some critical speed

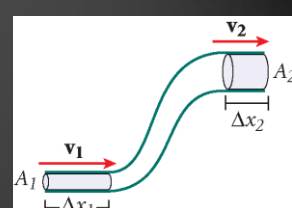
- **Viscosity**- Used to describe the flow rate in a fluid
  - High Viscosity – flows slowly, high of internal friction, thick
    - Honey, Lava
  - Low Viscosity – flows quickly, low internal friction, thin
    - water

FLUIDS IN MOTION

- An **ideal fluid** is a fluid that has no internal friction (non turbulent) or constant viscosity and is incompressible.
  - The ideal fluid model simplifies fluid-flow analysis

FLUID SPEED IN PIPE

- An incompressible fluid, like water, flowing through a pipe will slow down if the pipe gets wider.
  - Here's why: The number of gallons per minute flowing through the little pipe must be the same for the big pipe, otherwise fluid would be disappearing or appearing out of nowhere.

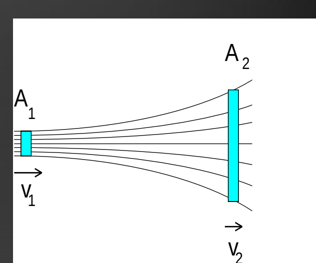


- **Continuity Equation**: In a pipe
  - Amount of fluid leaving (ΔT_1) = amount of fluid entering (ΔT_2)

    $$A_1V_1 = A_2V_2$$

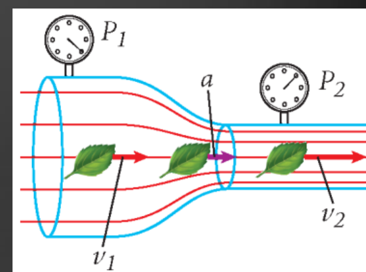
    - A = cross-sectional area
    - V = Velocity

    V x A = Called flow rate



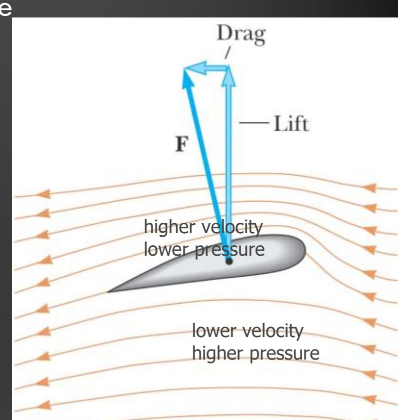
BERNOULLI'S PRINCIPLE

- Bernoulli's principle states that the pressure in a fluid decreases as the fluid's velocity increases
  - Fast moving fluids exert less pressure than slow moving fluids
- Fluids move from area's of high pressure to low pressure
  - Airplane wing
  - Ping Pong Curveball



BERNOULLI'S PRINCIPLE AIRPLANES

- Streamline flow around a moving airplane wing
- Top of wing
  - Faster air
    - Lower pressure
- Bottom of wing
  - Air travels slower
    - Higher pressure
- Fluids move from area's of high pressure to low pressure
  - ***Lift*** is the upward force on the wing from the air
  - ***Drag*** is the resistance
  - The lift depends on the speed of the airplane, the area of the wing, its curvature, and the angle between the wing and the horizontal



CURVING PING PONG BALL

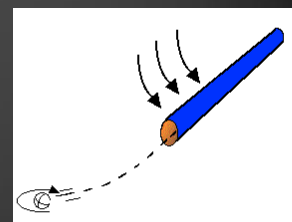
As the ball spins, the surface friction of the ball with the surrounding air drags a thin layer of air with it. This is referred to as the boundary layer.

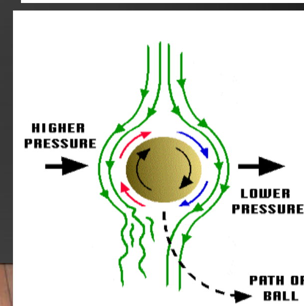
At the same time the ball spins, it is moving forward. On one side of the ball, the boundary layer air is traveling in the same direction as the air stream that is flowing around the ball (the blue arrows).

On the other side, it is traveling in the opposite direction (the red arrows). On the side of the ball where the air stream and boundary layer air are moving opposite to each other friction between the two slows the air stream.

On the opposite side the layers are moving in the same direction and the stream moves faster.

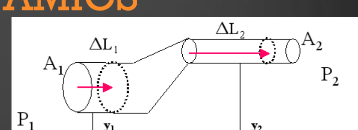
According to Bernoulli's Principle, faster moving air exerts less pressure, so the ball is pushed and it curves to the right for right-handed throws. Left-handed throws produce a curve to the left.



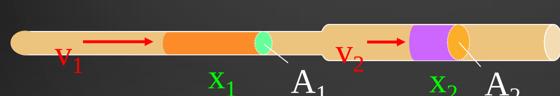


FLUID DYNAMICS

- Fluids flowing from different heights



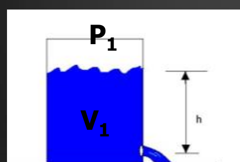
$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$$



- Fluid flowing Horizontal pipe
  - Height is constant
  - $P_1 + ½ \rho V^2_1 = P_2 + ½ \rho V^2_2$

Example:

A camper creates a shower by attaching a tube to the bottom of a hanging bucket that is open to the atmosphere on top. If the water level in the tank is 3.15m above the end of the tube (the shower head), then what is the speed of the water exiting the tube?



$h_1 = 3.15\text{m}$

$h_2 = 0$

P_2

$v_2 = ?$

Soln:

$\cancel{P_1} + \frac{1}{2}\rho \cancel{V^2_1} + \rho g h_1 = \cancel{P2} + \frac{1}{2}\rho v^2_2 + \rho \cancel{g h_2}$

$P_1 = P_2 = P_o$

$h_2 = 0$

$V_1 = 0$ (still, no flow)

$\rho\, g\, h_1 = \frac{1}{2}\, \rho\, v^2_2$

$V^2_2 = 2\, g\, h_1$

$\mathbf{V_2 = 7.86\ m/s}$