Physics 105

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Chapter -10-
(Fluids)

❖ Section (10.1): Phases of Matter

- The three common phases of matter are **solid**, **liquid** and **gas.**
  - ➢ **Solid:** Maintains a generally **fixed** size and shape.
  - ➢ **Liquid:** Does not maintain a **fixed** shape but has a **fixed** volume.
  - ➢ **Gas:** Has neither a **fixed** shape **nor** a **fixed** volume.
  - ➢ **Fluids:** Refers to both liquids and gases, as they do not maintain a **fixed** shape and have the ability to flow.
  - ➢ **Plasma:** A **fourth,** less common state of matter, consisting of **positive** ions and free **electrons**

❖ Section (10.2): Density and Specific Gravity

- **Density:**

$$Density = \frac{mass}{volume} \longrightarrow \rho = \frac{m}{V}$$ Its unit is kg/m^3 or g/cm^3

✓ ***Example:*** What is the mass of a solid iron wrecking ball of radius 18cm?

✓ ***Solution:***

Volume for a shape $V = \frac{4}{3}\pi\, r^3$

$$= \frac{4}{3} * 3.14 * (0.18\, m)^3$$

$$V = 0.0244\, m^3$$

$$\rho = \frac{m}{V} \longrightarrow m = \rho * V = 7800 * 0.0244 = 190.44\ kg$$

- **Specific gravity:** is defined as the **ratio** of the density of that **substance** to the density of **water**

$$SG = \frac{density\ of\ the\ material}{density\ of\ water\ at\ 4\ c^\circ}$$ $$\rho = 1000\ kg/m^3\ \ at\ 4\ c^\circ$$

✓ ***Example:*** Find the specific gravity of gold, where ρ for gold is $19.3 * 10^3 kg/m^3$, $\rho_{water} = 1 * 10^3 kg/m^3$.

✓ ***Solution:***

$$SG = \frac{\rho_{gold}}{\rho_{water}} = \frac{19.3*10^3}{1*10^3} = 19.3$$

❖ Section (10.3): Pressure in Fluids

- **Pressure** is defined as force per unit area, where the force F is understood to be the magnitude of the force acting perpendicular to the surface area A. pressure is a scalar quantity.

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

➢ The unit of $pressure$ is pascal $= \frac{N}{m^2}$

✓ ***Example:*** A 60 kg person's *two feet* cover an area of $500cm^2$

I. Determine the pressure exerted by the *two feet* on the ground.

II. If the person stands on *one foot*, what will be the pressure on that foot?

✓ ***Solution:***

I. $P = \frac{F}{A} = \frac{mg}{a} = \frac{60*9.8}{0.05} = 11.76 * \ 10^3 \ \frac{N}{m^2} \quad = 11.76 * \ 10^3$ Pascal

II. The area will be the half so the pressure will be as twice. $= 23.52 * \ 10^3$ Pascal

- **Static Fluids** ⟶ **Fluids at rest**

➢ It has two properties:

I. At a point inside the liquid, the <u>pressure</u> is the **same in all directions.**

II. The <u>pressure</u> at any static fluid is always <u>perpendicular</u> to any surface that is in touch with the fluid.

- Calculating the pressure at a depth (h) in liquid, due to the weight of the liquid.

$P = \frac{F}{a} = \frac{mg}{a} = \frac{\rho_{fluid} \ Vg}{A}$ Where $m = \rho_{fluid} \ V$

$P = \frac{\rho_{fluid} \ Vg}{A} = \frac{\rho_{fluid} \ (A \ h) \ g}{A}$ Where $V = A \ h$

$$\boldsymbol{P = \ \rho_{fluid} \ h \ g}$$

- **Fluid pressure** <u>increases</u> with depth below the fluid surface, and the pressure is independent off the area (A)

$$\boldsymbol{\Delta P = \ \rho_{fluid} g \ \Delta \ h}$$

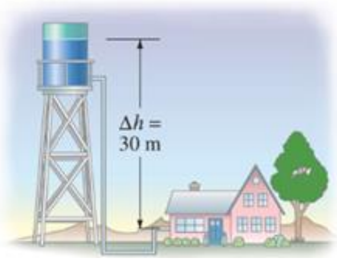
✓ ***Example:*** The surface of the water in a storage tank is 30m above a water faucet in the kitchen of a house, Calculate the difference in water pressure between the faucet and surface of the water in the tank. ($\rho_{water} = 1 * \ 10^3 \ \ kg/\ m^3$)

✓ ***Solution:***

$\Delta P = \ \rho_{fluid} \ g \ \Delta \ h$

$= \ 1 * \ 10^3 \ * 9.8 \ * 30$

$= \ 2.94 \ * \ 10^5 \ \ N\ /\ m^2 \ \ OR \ \ pascal$



❖ Section (10.4): Atmospheric pressure and Gauge pressure

- This concept helps us define a commonly used unit of ***atmospheric pressure:***
  1 atm = 1.013 × 10^5 Pa.

- Another unit of pressure sometimes used (in meteorology and on weather maps) is the bar:
  1 bar = 1 × 10^5 Pa.

✓ ***Example:*** You insert a straw of length into a tall glass of water. You place your finger over the top of the straw, capturing some air above the water but preventing any additional air from getting in or out, and then you lift the straw from the water. You find that the straw retains most of the water. Does the air in the space between your finger and the top of the water have a pressure P that is greater than, equal to, or less than, the atmospheric pressure outside the straw?

✓ ***Solution:***
Consider the forces on the column of water. Atmospheric pressure outside the straw pushes upward on the water at the bottom of the straw, gravity pulls the water downward, and the air pressure inside the top of the straw pushes downward on the water. Since the water is in equilibrium, the upward force due to atmospheric pressure must balance the two downward forces. The only way this is possible is for the air pressure P inside the straw at the top to be less than the atmosphere pressure outside the straw. (When you initially remove the straw from the water glass, a little water may leave the bottom of the straw, thus increasing the volume of trapped air and reducing its density and pressure.) and the portion of water inside the straw is in static equilibrium.

$$\sum F_y = 0$$

$$F_{bottom} - F_{top} - m\,g = 0$$

$$P_{atm}\,A - P\,A - m\,g = 0$$

$$P_{atm}\,A - P\,A - (\rho_{fluid}\,V)g = 0 \qquad \text{where } m = \rho\,V$$

$$P_{atm}\,\cancel{A} - P\,\cancel{A} - \left(\rho_{fluid}\,(\cancel{A}\,h)\right)g = 0 \qquad \text{where } V = A\,h$$

$$\boldsymbol{P_{atm} = P + \rho_{fluid}\,h\,g}$$

- Gauge pressure is the pressure inside the tire <u>above</u> and beyond atmospheric pressure.

$$\boldsymbol{P = P_G + P_{atm}}$$

✓ ***Example:*** If the gauge reading is 220 K Pa. Find the pressure inside the tire. ($P_{atm} = 101.3\ K\ Pa$)

✓ ***Solution:***

$$\boldsymbol{P = P_G + P_{atm}}$$

$$P = 220\ K\ Pa + 101.3\ K\ Pa = 321.3\ K\ Pa = 3.213 * 10^5\ \text{Pa}$$

To convert to **atm**

$$X = \frac{3.213 * \cancel{10^5}}{1.013 * \cancel{10^5}} = 3.171\ \text{atm}$$

To convert to **bar**

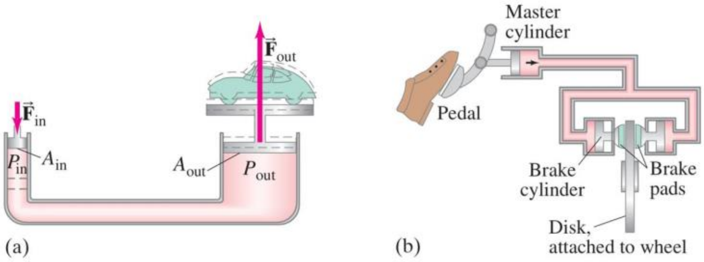
1 **bar** = 1*10^5 **Pa** therefore the pressure inside the tire is 3.123 Bar.

760 mm – Hg = 1 atm

760 tor = 1 atm

❖ Section (10.5): Pascal's principle

- Pascal's principle states that when an external pressure is **applied** to a confined fluid, the pressure at every point within the fluid increases by the same amount.
- ***Applications*** of Pascal's principle:



(a) Hydraulic lift: A device that lifts a car using a small force applied over a larger area.

$$P_{in} = P_{out}$$

$$\frac{F_{in}}{A_{in}} = \frac{F_{out}}{A_{out}} \quad OR \quad \frac{\boldsymbol{F_{out}}}{\boldsymbol{F_{in}}} = \frac{\boldsymbol{A_{out}}}{\boldsymbol{A_{in}}} \longrightarrow \mathbf{1}$$

$\frac{F_{out}}{F_{in}}$ is called the *mechanical advantage of the hydraulic.*

(b) Hydraulic brakes in a car is a type of braking system that uses oil pressure from the brake lever to push the piston.

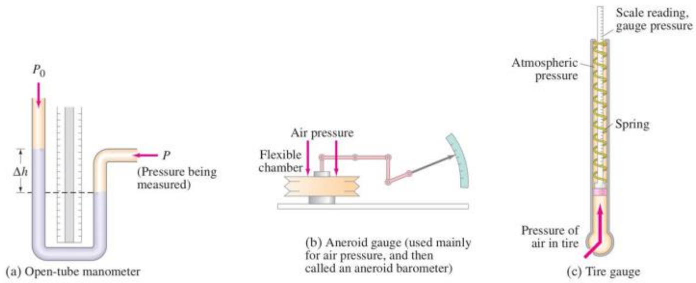
✓ ***Example:*** The weight of the car W= 10000 N , $A_{out} = 20A_{in}$, Find how much force we need to lift the car and keep it in equilibrium.

✓ ***Solution:***

$$\frac{F_{out}}{F_{in}} = \frac{A_{out}}{A_{in}} \longrightarrow \frac{F_{out}}{F_{in}} = 20 \longrightarrow F_{in} = \frac{F_{out}}{20} \longrightarrow F_{in} = \frac{10000}{20} = 500\ N$$

❖ Section (10.6): Measurement of pressure, gauges and barometer

- Many devices have been invented to measure pressure
  - ➢ Such as the open-tube manometer, aneroid gauge, and common tire pressure gauge.



- Atmospheric pressure can be measured with a modified type of mercury manometer, known as a mercury barometer, which has **one end closed**.
- A mercury barometer consists of a column of mercury, and a height of 760 mm corresponds to a pressure equivalent to **atmospheric pressure**.

- ✓ ***Example:*** If water is used instead of mercury, find the height of the water column to balance the atmospheric pressure.
- ✓ ***Solution:***

$$P_{atm} = \rho_{water}\, g\, h = 1.013 * 10^5 \ Pa$$

$$h = \frac{1.013 * 10^5}{(1000) * 9.8} = 0.1.33 * 10^2 \ m = 10.3\, m$$

To check about the height of the mercury barometer.

$$P_{atm} = \rho_{Hg}\, g\, h = 1.013 * 10^5 \ Pa$$

$$h = \frac{1.013 * 10^5}{(13.6 * 10^3) * 9.8} = 0.76005\, m$$

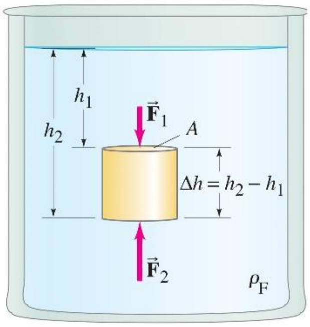
❖ Section (10.7): Buoyancy and Archimedes' Principle

- Buoyant force: The upward force exerted by a fluid on any fully or partially submerged object. It occurs because the pressure in a fluid increase with **<u>depth</u>**.
- The pressure due to liquid at the top surface is:

$$P_1 = \frac{F_1}{A_1} = \rho_f\, g\, h_1 \qquad so \ F_1 = \rho_f\, g\, h_1\, A$$

- The pressure due to liquid at the bottom surface is:

$$P_2 = \frac{F_2}{A_2} = \rho_f\, g\, h_2 \qquad so \ F_2 = \rho_f\, g\, h_2\, A$$



$$\boldsymbol{F_B = \rho_f\, g\, V} \qquad \textbf{Where} \qquad V = A\,\Delta h$$

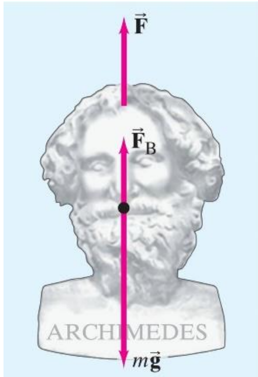
$\boldsymbol{F_B = \rho_f\, g\, V = m_F\, g}$ (is the weight of fluid which takes up a volume equal to the cylinder volume)

- **Archimedes´ principle** states that the buoyant force on an object immersed in a fluid is **equal** to the weight of the fluid displaced by the object.

- ✓ ***Example:*** Consider <u>two identical pails</u> of water filled to the brim. One pail contains <u>only</u> water, the other has a <u>piece of wood</u> floating in it. Which pail has the greater weight?
- ✓ ***Solution:***
  Both pails weigh the same. Recall Archimedes' principle: the wood displaces a volume of water with weight equal to the weight of the wood. Some water will overflow the pail, but Archimedes' principle tells us the spilled water has weight equal to the weight of the wood; so the pails have the same weight.

✓ ***Example:*** A 70 Kg ancient statue lie at the bottom of the sea, It's volume is $3 * 10^4\ cm^3$, How much <u>force is needed to lift it</u> (without acceleration)? Where $\rho_{sea\ water} = 1.025 * 10^3\ \ Kg/m^3$

✓ ***Solution:***



$$\sum F_y = ma = 0$$

$$F + F_B - m\,g = 0$$

$$F = m\,g - F_B \longrightarrow \mathbf{1}$$

$$F_B = \rho_F\ V\ g = (1.025 * 10^3\ Kg/m^3)(3 * 10^4 * 10^{-6}\ m^3)(9.8\ m/s^2)$$

$$F_B = 3.01 * 10^2\ N$$

And $mg = (70) * (9.8) = 686\ N$

$$F = 686N - 3.01 * 10^2 = 385\ N$$

Is the object going to sink or float?

$\boldsymbol{F_R = F_B - m_\circ\, g}$ (where F_R is the resultant force acting on the cylinder, $m_\circ$ is the mass of the object)

$$F_R = \rho_F\ V\ g - \rho_\circ\ V\ g$$

$$F_R = (\rho_F - \rho_\circ)\ V\ g$$

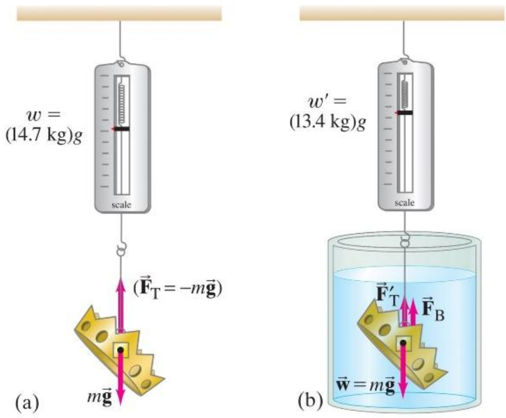
- If $\rho_F > \rho_\circ$ then F_R is upward and the object floats (**partly** submerged object $V_s < V_\circ$)
- If $\rho_F < \rho_\circ$ then F_R is downward and the object floats (**totally** submerged object $V_s = V_\circ$)
- If $\rho_F = \rho_\circ$ then the object will hang in the fluid in equilibrium state.

✓ ***Example:*** The structure of ships is made from iron and steel; despite this, ships float in the sea. Explain this.

✓ ***Solution:***
Ships have evacuated spaces that are filled with compressed air. When we divide the total mass of the ship by its total volume, the resulting density is less than that of seawater, which is why ships float.

✓ ***Example*:** When a crown of mass 14.7 kg is <u>*submerged*</u> in water, an accurate <u>scale reads</u> only 13.4 kg. Is the crown made of gold?

✓ ***Solution:***



To totally submerged:

The sum of forces on the crown is zero.

$$w` = F_T` = w - F_B$$

(w` is called the apparent weight in water)

$$W - w` = F_B$$

$$w = mg = \rho_\circ\ V_\circ\ g$$

$$F_B = \rho_F\ V_F\ g \longrightarrow \mathbf{1}$$

Totally submerged object $V_F = V_\circ$

So $w - w` = F_B = \rho_F\ V_F\ g \longrightarrow \mathbf{2}$

Divide two equations and obtain

$$\frac{w}{w-w`} = \frac{\rho_\circ \not{V} \not{g}}{\rho_F \not{V} \not{g}} \quad \rightarrow \quad \frac{w}{w-w`} = \frac{\rho_\circ}{\rho_F}$$

$$\frac{\rho_\circ}{\rho_F} = \text{specific gravity of the crown}$$

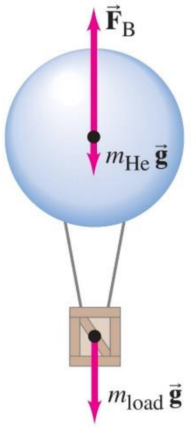
Then $\frac{\rho_\circ}{\rho_F} = \frac{w}{w-w`} = \frac{(14.7\ kg)\ \not{g}}{(14.7-13.4)kg\ \ \not{g}} = \frac{14.7}{1.3} = 11.30$

$$\rho_\circ = 11.3 * \rho_F$$

$$\rho_\circ = 11.3 * 10^3\ kg/m^3$$

This density is for lead **not** for gold, the crown is not for gold

- ✓ ***Example:*** Helium Balloon: What volume V of helium is needed for the balloon to lift a load of 180 kg (including the weight of the empty balloon)?
(Assume the balloon and load are in static equilibrium).



- ✓ ***Solution:***

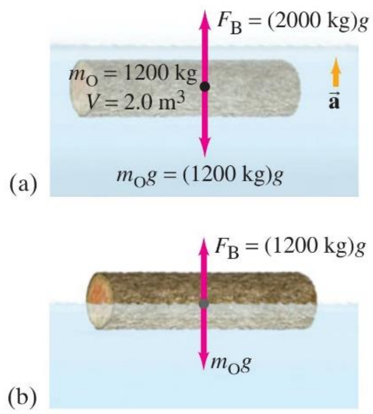
$$F_B - m_{He}\ g - m_L\ g = 0$$

$$\rho_{air} V \not{g} - \rho_{He} V \not{g} - 180 \not{g} = 0$$

$$\rho_{air} V - \rho_{He} V = 180$$

$$V = \frac{180}{\rho_{air} - \rho_{He}} = \frac{180}{1.29 - 0.176} = 161.579\ m^3$$

- ✓ ***Example:*** <u>A piece of wood</u> is floating on water, knowing that $F_B = (1200\ kg)g$, Find the volume of submerged of the object. (*Assume the piece of wood is equilibrium*), $\rho_{water} = 1 * 10^3\ kg/m^3$
- ✓ ***Solution:***



Equilibrium = 0

$$\sum F_y = 0$$

$$F_B - m_\circ\ g = 0$$

$$F_B = m_\circ\ g$$

$$\rho_F V_S\ g = \rho_\circ V_\circ\ g$$

$$\rho_F V_S = \rho_\circ V_\circ$$

$$V_S = \frac{\rho_\circ V_\circ}{\rho_F} \longrightarrow V_S = \frac{m_\circ}{\rho_F}$$

While $m_\circ = 1200\ kg$ *because* $F_B = m_\circ\ g \rightarrow (1200kg) \not{g} = m_\circ \not{g}$

Then $V_s = \frac{1200}{1 * 10^3} = 1.2\ m^3$

And $V_\circ = \frac{m_\circ}{\rho_\circ} = \frac{1200}{0.6 * 10^3} = 2\ m^3$

So $V_S = 0.6\ V_\circ$

The submerged volume of the piece of wood is **60%** of its total volume.

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