Secondary School Physics Notes

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Detailed Notes

10. The Gas Laws

10.1 Measurement of Gas Pressure

- **Pressure:** Force per unit area exerted by gas molecules colliding with the container walls.
  - **Formula:** P = F/A
  - **Unit:** Pascal (Pa), which is N/m². Other units include atmospheres (atm), millimeters of mercury (mmHg), and bar.
- **Instruments for Measuring Gas Pressure:**
  - **Manometer:** A U-shaped tube containing a liquid (often mercury or water) used to measure the pressure difference between a gas and the atmosphere, or between two gases.
  - **Barometer:** Specifically used to measure atmospheric pressure. (e.g., Fortin barometer, Aneroid barometer).

10.2 Boyle's Law and its Applications

- **Boyle's Law:** For a fixed mass of gas at constant temperature, the pressure of the gas is inversely proportional to its volume.

- Mathematical Relation: $P \propto \frac{1}{V}$ or

  $PV = \text{constant}$

- Equation: $P_1V_1 = P_2V_2$

- **Applications:**
  - **Syringes/Pumps:** When the plunger is pulled, volume increases, pressure decreases, drawing liquid in.
  - **Deep Sea Diving:** Air in the lungs compresses as a diver descends due to increasing pressure.
  - **Aerosol Cans:** Gas is highly compressed in the can.

10.3 Charles' Law and its Applications

- **Charles' Law:** For a fixed mass of gas at constant pressure, the volume of the gas is directly proportional to its absolute temperature (temperature in Kelvin).

  - Mathematical Relation: $V \propto T$ or $\frac{V}{T} = \text{constant}$
  - Equation: $\frac{V_1}{T_1} = \frac{V_2}{T_2}$ (where T is in Kelvin)

- **Applications:**
  - **Hot Air Balloons:** Heating the air inside the balloon increases its volume, making it less dense than the surrounding air, causing it to rise.
  - **Tires:** Air in tires expands when heated during driving, increasing the tire volume and pressure.

10.4 Pressure Law (Gay-Lussac's Law)

- **Pressure Law:** For a fixed mass of gas at constant volume, the pressure of the gas is directly proportional to its absolute temperature.

  - Mathematical Relation: $P \propto T$ or $\frac{P}{T} = \text{constant}$
  - Equation: $\frac{P_1}{T_1} = \frac{P_2}{T_2}$ (where T is in Kelvin)

- **Applications:**
  - **Pressure Cookers:** Sealing food in a container and heating it increases the pressure inside, allowing food to cook faster at a higher temperature.
  - **Gas Cylinders:** Gas cylinders can explode if heated due to the rapid increase in pressure.

10.5 General Gas Law (Combined Gas Law)

- **General Gas Law:** Combines Boyle's, Charles', and Pressure Laws. For a fixed mass of gas, the ratio of the product of pressure and volume to its absolute temperature is constant.
    - Equation: $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$ (where T is in Kelvin)
    - This law is used when none of the three variables (P, V, T) are held constant.

10.6 Kinetic Molecular Theory and Gas Laws

- **Kinetic Molecular Theory (KMT) of Gases:** A model that explains the macroscopic properties of gases in terms of the motion of their microscopic particles.
    - **Postulates:**
        1. Gases consist of a large number of tiny particles (atoms or molecules) in constant, random motion.
        2. The volume of the particles themselves is negligible compared to the volume of the container.
        3. Collisions between particles and with the container walls are perfectly elastic (no energy loss).
        4. There are no attractive or repulsive forces between particles.
        5. The average kinetic energy of the particles is directly proportional to the absolute temperature.
- **How KMT Explains Gas Laws:**
    - **Boyle's Law:** Decreasing volume increases particle collisions with walls, hence increasing pressure.
    - **Charles' Law:** Increasing temperature increases particle speed, leading to more forceful collisions. To maintain constant pressure, volume must increase.
    - **Pressure Law:** Increasing temperature increases particle speed and collision force. If volume is constant, this leads to increased pressure.

10.7 Summary

- Gas pressure is due to molecular collisions.
- Boyle's Law: $PV = constant$ (constant T).
- Charles' Law: $\frac{V}{T} = constant$ (constant P).
- Pressure Law: $\frac{P}{T} = constant$ (constant V).
- General Gas Law: $\frac{PV}{T} = constant$.
- Kinetic Molecular Theory explains gas laws based on particle motion.

16. Pressure in Fluids

16.1 Concept of Pressure

- **Definition:** Pressure is defined as the force acting perpendicularly on a unit area.
  - **Formula:** P = F/A
  - **Unit:** Pascal (Pa), which is equivalent to Newton per square metre (N/m^2). Other common units include kPa (kilopascal), psi (pounds per square inch), atmosphere (atm), and bar.
- **Properties of Pressure in Fluids:**
  - Acts in all directions.
  - Increases with depth.
  - Transmitted equally throughout an enclosed fluid (Pascal's Principle).

16.2 Pressure in Liquids

- **Pressure due to a Liquid Column:** The pressure exerted by a column of liquid at a certain depth is given by:
  - **Formula:** P = pgh, where:
    - P = pressure (Pa)
    - ***p*(rho)** = density of the liquid (kg/m^3)
    - **g** = acceleration due to gravity (approx. 9.8 or 10 m/s^2)
    - **h** = depth of the liquid column (m)
- **Factors Affecting Liquid Pressure:**
  - **Depth:** Pressure increases with increasing depth.
  - **Density of Liquid:** Denser liquids exert greater pressure at the same depth.
  - **Acceleration due to Gravity:** Increases with higher 'g'.
- **Pressure in Connected Vessels (Hydrostatic Paradox):** The pressure at the same horizontal level in a continuous fluid at rest is the same, regardless of the shape or volume of the container above that level.

16.3 Atmospheric Pressure

- **Definition:** The pressure exerted by the weight of the air column above the Earth's surface.
- **Standard Atmospheric Pressure:** Approximately 1.013 × 10^5 Pa or 1 atm.
- **Measurement:** Measured using a barometer (e.g., mercury barometer, aneroid barometer).
- **Effects of Atmospheric Pressure:**
    - Drinking straws (sucking reduces pressure in straw, atmospheric pressure pushes liquid up).
    - Suction cups.
    - Weather patterns (high and low pressure systems).
    - Our bodies are adapted to atmospheric pressure.

16.4 Pascal's Principle

- **Principle:** When pressure is applied to an enclosed fluid, the pressure change is transmitted undiminished to every portion of the fluid and to the walls of the containing vessel.
- **Applications:**
    - **Hydraulic Systems:** Used in brakes, car lifts, hydraulic jacks, excavators. A small force applied to a small piston creates a large force on a large piston, demonstrating force multiplication.

- Formula: $\frac{F_1}{A_1} = \frac{F_2}{A_2}$

16.5 Determination of Relative Density of Liquids

- **Relative Density (Specific Gravity):** The ratio of the density of a substance to the density of water (at 4°C). It is a unitless quantity.

- Formula: Relative Density = $\frac{\text{Density of liquid}}{\text{Density of water}}$

- **Methods of Determination:**
    - **Using a Hydrometer:** A calibrated instrument that floats at different depths in liquids of different densities. It sinks lower in less dense liquids.
    - **Using a Specific Gravity Bottle (Pycnometer):** A bottle of known volume used to find the mass of a liquid and then calculate its density, which is compared to the density of water.
    - **Using U-tube Manometer:** If two immiscible liquids are in a U-tube, their heights are inversely proportional to their densities at equilibrium. p1h1 = p2h2.

16.6 Summary

- Pressure is force per unit area.
- Pressure in liquids increases with depth and density (P = pgh).
- Atmospheric pressure is the weight of the air column.
- Pascal's Principle states that pressure applied to an enclosed fluid is transmitted equally.
- Relative density compares a liquid's density to water's density.