IDX G10 PHYSICS H

Study Guide Issue 1

By Hayley, Edited by Edward

Contents:

13-1 Atomic Theory of Matter

- **Atomic Theory of Matter**: Matter is made up of atoms
  - Brownian motion: pollen grains in water moved randomly as liquid molecules collided into them (kinetic theory)
- Atomic mass unit (u): 1u = 1/12 mass of C-12 = 1.6605×10^{-27} kg
- Diameter of an atom ≈ 10^{-10} m (calculated by Albert Einstein)
- Intermolecular force
- Three phases of matter
  - Crystalline solid: strong attractive force, atoms oscillate about a fixed position
  - Liquid: weaker force, moving more rapidly
  - Gas: weak force, high speeds, molecules do not stay close together

13-2 Temperature and Thermometers

- Definitions
  - (1) Temperature (T) is a measure of how hot or cold something is.
  - (2) Temperature measures the **average kinetic energy** of the particles in the object.
- Property changes based on temperature:
  - Volume (most materials expand when heated)
  - Color radiated by objects (e.g., fire turns red -> blue -> white)
  - Electrical resistance (usually increases with increasing temperature))
- Two fixed points: **freezing point and boiling point of water** (at atmospheric pressure)
- Temperature Scales:
  - Celsius (°C) scale = centigrade scale
    - Freezing point of water: 0°C
    - Boiling point of water: 100°C
  - Kelvin (K) scale = absolute scale (SI unit)
    - Absolute zero = 0K = -273.15°C, the temperature at which all thermal motion is the minimum in the classical description of thermodynamics
    - Change in 1K = change in 1°C
    - **T (K) = T(°C) + 273**
  - Fahrenheit (°F) scale
    - Freezing point of water: 32°F
    - Boiling point of water: 212°F
    - $\mathbf{T_F = 9/5T_C + 32}$
    - $\mathbf{T_C = 5/9(T_F - 32)}$
    - Change in 1°C = change in 1.8°F
- Types of Thermometers
  - Liquid in glass thermometer (principle: thermal expansion)
    - Liquid expands more than the glass, the liquid level rises in the tube
    - Liquid: mercury (better for high T), colored alcohol (better for low T)
  - **Bimetallic strip**
    - Binding together 2 dissimilar metals whose rate of expansion are different.
    - When T increases, the bimetallic strip bends toward the metal with a lower expansion rate.
    - **Thermostat**: a device for keeping a steady T.
  - **Thermistor thermometer** (very precise)

        - The probe consists of a thermistor, which is a semiconductor device with a resistance that is very sensitive to the change of T.
        - T↑, R↓(resistance), I↑(current), larger reading on the meter.

13-3 Thermal Equilibrium and the Zeroth Law of Thermodynamics

- **Thermal equilibrium**: If two bodies of different temperature are placed close together, thermal energy will be transferred from one to the other, and the two objects will eventually reach the same temperature (high T to low T).
- **Zeroth law of thermodynamics**: If two systems are in thermal equilibrium with a third system, they are also in thermal equilibrium with each other.

13-4 Thermal Expansion

- **Thermal expansion**: as the temperature of an object (solid, liquid, gas) increases, volume increases.
- The particles in a substance increase their spacing, but do not expand themselves
- Linear Expansion (change of T not too large) —> **only for solids**
    - $\Delta L = \alpha L_0 \Delta T$
    - $L = L_0 (1+\alpha\Delta T)$
- Volume thermal expansion
    - $\Delta V = \beta V_0 \Delta T$
    - $V = V_0(1+\beta\Delta T)$
    - For solids that are isotropic (having the same properties in all direction): $\beta \approx 3\alpha$
        - Pure metals
- **Anomalous Behavior** of Water Below 4℃
    - If water at 0℃ is heated, it decreases in volume until it reaches 4℃.
    - Above 4 ℃, water expands in volume as temperature increases.
    - Water has its greatest density at 4℃.
    - When temperature is between 0℃ and 4℃, the number of hydrogen bonds increases if temperature decreases. The hydrogen bonds will increase the volume of the water.

13-5 The Gas Law and the Absolute Temperature

- Atmospheric pressure (P_A): At sea level, the pressure of the atmosphere on average is $\mathbf{1.013 \times 10^5\ N/m^2}$
    - Pascal (Pa): $1Pa = 1N/m^2$

- Atmosphere (atm): 1 atm = 1.013×10^5 N/m^2 = 101.3 kPa
- Bar: 1 bar = 1.00×10^5 N/m^2
- Gauge pressure (P_G)
  - Most pressure gauges only register pressure above atmospheric pressure.
- **Absolute pressure (P)**
  - Sum of the atmospheric pressure and the gauge pressure.
  - $P = P_A + P_G$
- Gas Laws
  - **Equation of state**: The relation between the volume (V), the pressure (P), the temperature (T) and the mass (m) of a gas.
  - **Equilibrium state of a system**: when the variables that describe the system (such as T and P) are the same throughout the system and are not changing in time.
  - Conditions for gas laws to be accurate: the gas is close to an ideal gas.
    - **Gas is not too dense, P is not too high**
    - **Gas is not close to the liquefaction/boiling point (T not too low).**

- Boyle's Law: P-V law
  - Mass and temperature are constant: P and V change
  - When adding pressure onto a gas, it's compressed and gets smaller → P increases, V decreases (inverse proportion)
  - **PV = constant or $P_1V_1 = P_2V_2$ (P is absolute pressure, atm or Pa; P and V have the same units for both sides)**
- Charles's Law: V-T Law
  - Mass and pressure is constant: V and T change
  - When gas is heated → particles move more randomly and faster → takes up more space → volume is larger
  - **V/T = constant or $V_1/T_1 = V_2/T_2$ (T: Kelvin; V has the same units for both sides)**
- Gay-Lussac's Law: P-T Law
  - Mass and volume is constant: P and T change
  - When gas is heated → particles move more randomly and faster → exert more F on the walls → pressure is larger
  - **P/T is constant or $P_1/T_1 = P_2/T_2$ (P has the same units for both sides; T: Kelvin)**
- General Gas Law $$\frac{PV}{T} = c \Rightarrow \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

13-6 & 7 The Ideal Gas Law

- Molar mass and mole
    - One mole (mol): The amount of substance that contains as many atoms or molecules as there are in precisely 12 grams of carbon-12

$$n(mol) = \frac{mass\ (grams)}{molar\ mass\ (g/mol)}$$

    - The number of moles (n)
- Ideal Gas Law Equation
    - **PV = nRT** (P: Pa; V: m^3; T: K; n: mol)
    - R: universal gas constant
    - **R = 8.314 J/mol·K= 8.314 Pa·m^3/ mol·K (SI unit)**
- Ideal Gas
    - A gas in which the molecules do not exert forces on each other except when colliding.
- STP
    - Standard conditions or standard temperature and pressure.
    - T = 273 K (0℃)
    - **P = 1.00 atm = 1.013 × 10^5 Pa = 101.3 kPa**
        - **Volume of one mol at STP = 22.4 L**
- **Molar Volume (V_m)**
    - The volume occupied by one mole of a substance at a given T and P.
    - Molar volume (m^3/mol) = molar mass (g/mol) / molar density (g/m^3)

$$V_m = \frac{M}{\rho}$$

13-8 Ideal Gas Law in Terms of Molecules: Avogadro's Number

- Avogadro's Hypothesis: Equal volumes of gas at the same pressure and temperature contain equal numbers of molecules.
- **Avogadro's number (N_A) = 6.02 × 10^{23} molecules/mol**
- **N (number of molecules) = nN_A**
- Ideal gas law in terms of molecules:
    - **PV = nRT = NkT**
    - **k: Boltzmann's constant = 1.38 × 10^{-23} J/K**