Chapter 3 The Gaseous State

CHAPTER ANALYSIS

FOCUS

- Relatively straight forward chapter
- 4 **key** concepts

EXAM

- Mostly calculations type of question

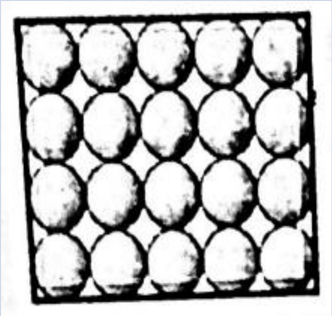
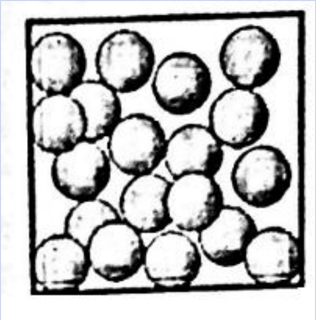
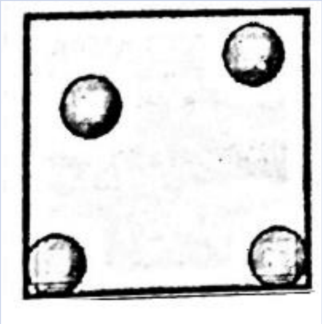
WEIGHTAGE

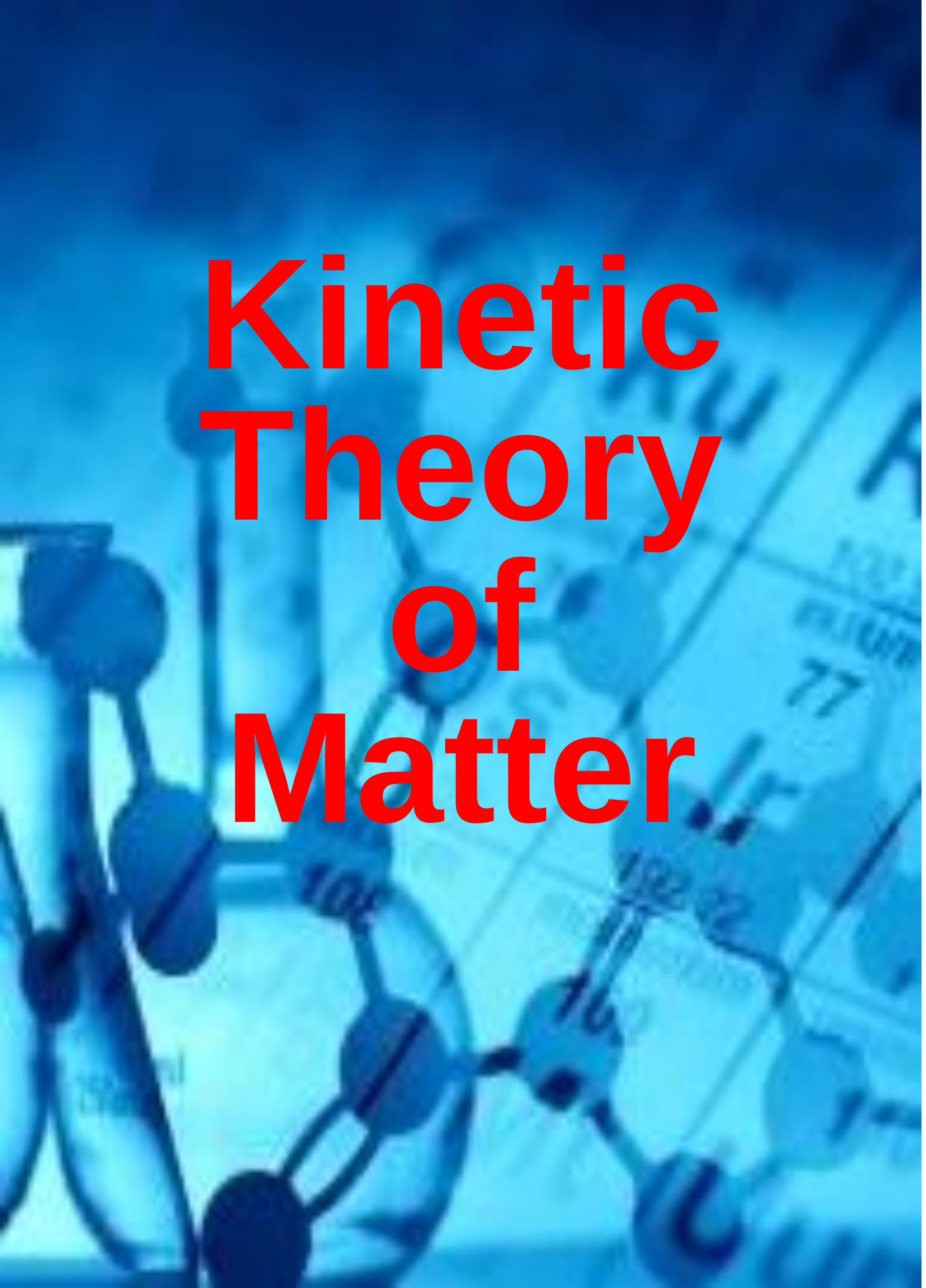
- Light weightage

KEY CONCEPT

Kinetic Theory of Matter
Ideal Gas Law
Real Gas & Deviation from Ideal Behaviour
Partial Pressure of Gas

Kinetic Theory of Matter

	Solid	Liquid	Gas
Model			
Arrangement of Particles	Ordered arrangement	Disordered	Random
Separation between Particles	Closely packed. Particles are in contact.	Closely packed. Particles are still in contact, slightly further as compared to solid state.	Far apart. Particles are no longer in contact.
Forces between	Strong	Intermediate	Very Weak
Energy of Particles	Less energy than liquid and gases.	More energy than solid but less energy than gases.	More energy than solid and liquid.
Motion of Particles	Vibrate and rotate about fixed position.	Vibrate, rotate and slide over each other.	Move about rapidly in a random motion.



Kinetic Theory of Matter

	Solid	Liquid	Gas
Volume	Fixed	Fixed	Varies with container
Shape	Definite Shape	Indefinite Shape	Adopts the shape of the container
Density	High	High	Low
Compressibility	Unable to be compressed	Slight	Very easily compressed
Change in State	Gained in energy during state change from solid to liquid.	Gained in energy during state change from liquid to gas.	

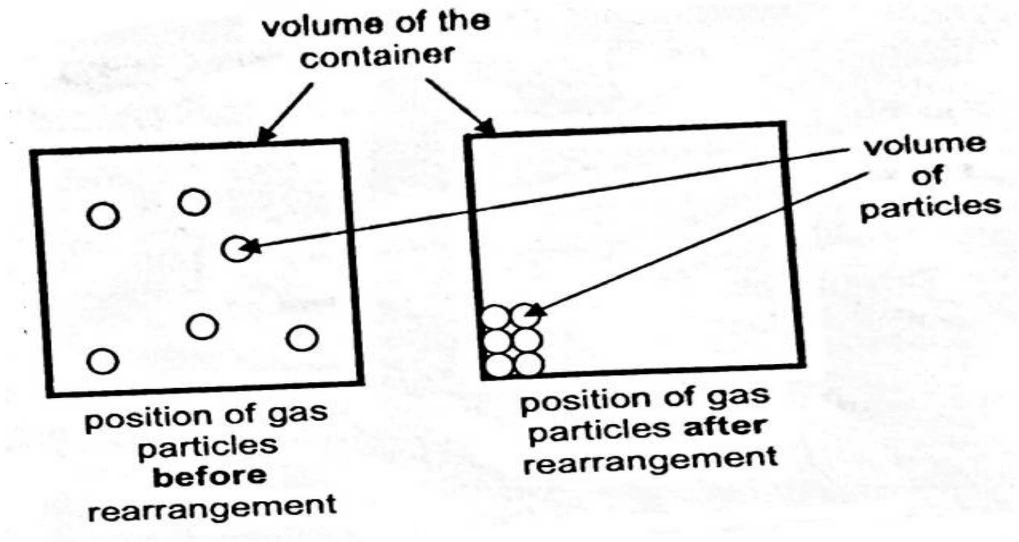
Ideal Gas Law

IDEAL GAS

An ideal gas is a hypothetical gas that obeys the ideal gas equation under all conditions of temperature and pressure.

ASSUMPTION 1

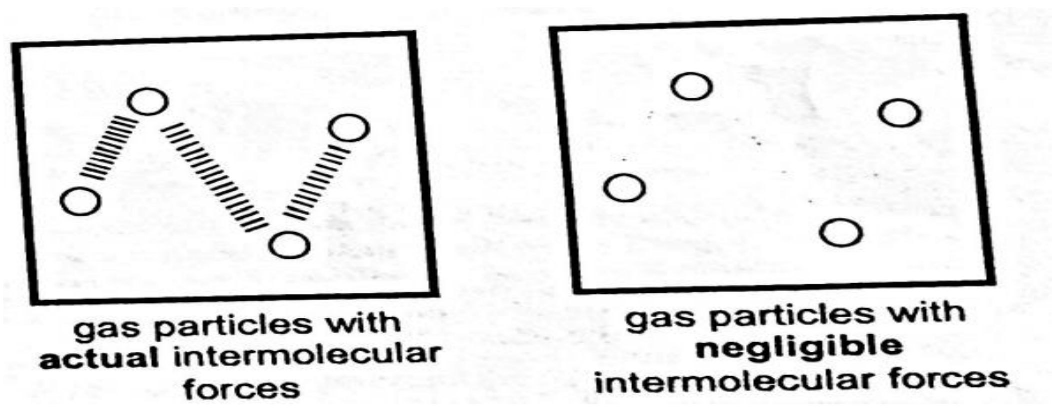
The particles have negligible volume compared to the volume of the container



ASSUMPTION 2

There are negligible intermolecular forces between the particles

- The collisions between particles of an ideal gas are thus perfectly elastic and they behave as rigid spheres

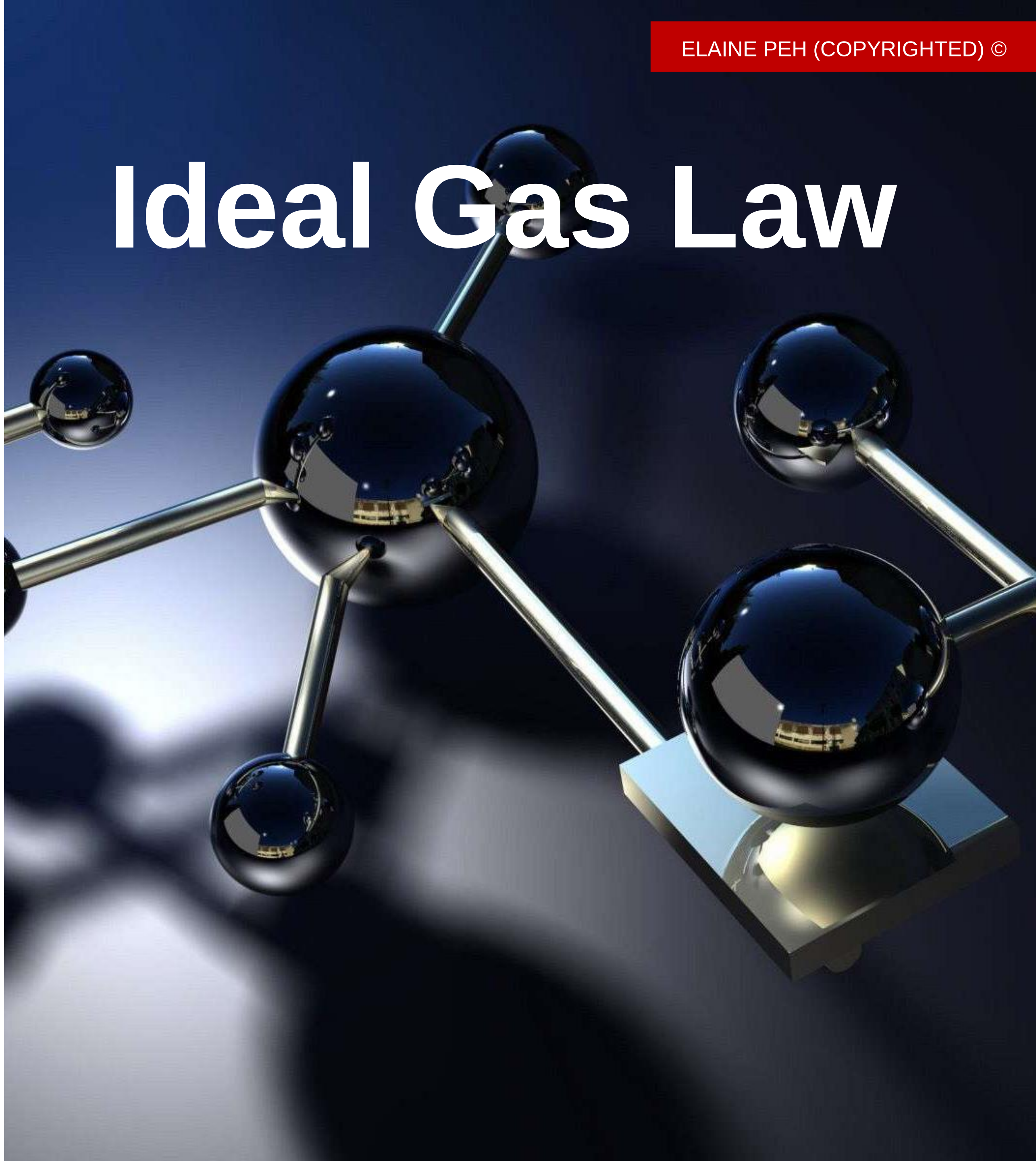


IDEAL GAS EQUATION

$$pV = nRT$$

Symbol	Parameter	Units
p	Pressure	Pa
V	Volume	m^3
n	Amount of gas	mol
R	Molar gas constant	8.31 $J\ K^{-1}\ mol^{-1}$
T	temperature	K

Parameter	Equivalent Values
Volume	1 m^3 = 10^3 dm^3
	1 m^3 = 10^6 cm^3
Pressure	1 bar = 10^5 Pa
	1 atm = 101 325 Pa
Temperature	T (in K) = T (^oC) + 273



Ideal Gas Law

Deriving other Parameters from the Ideal Gas Equation:

(a) Molar Mass (M_r)

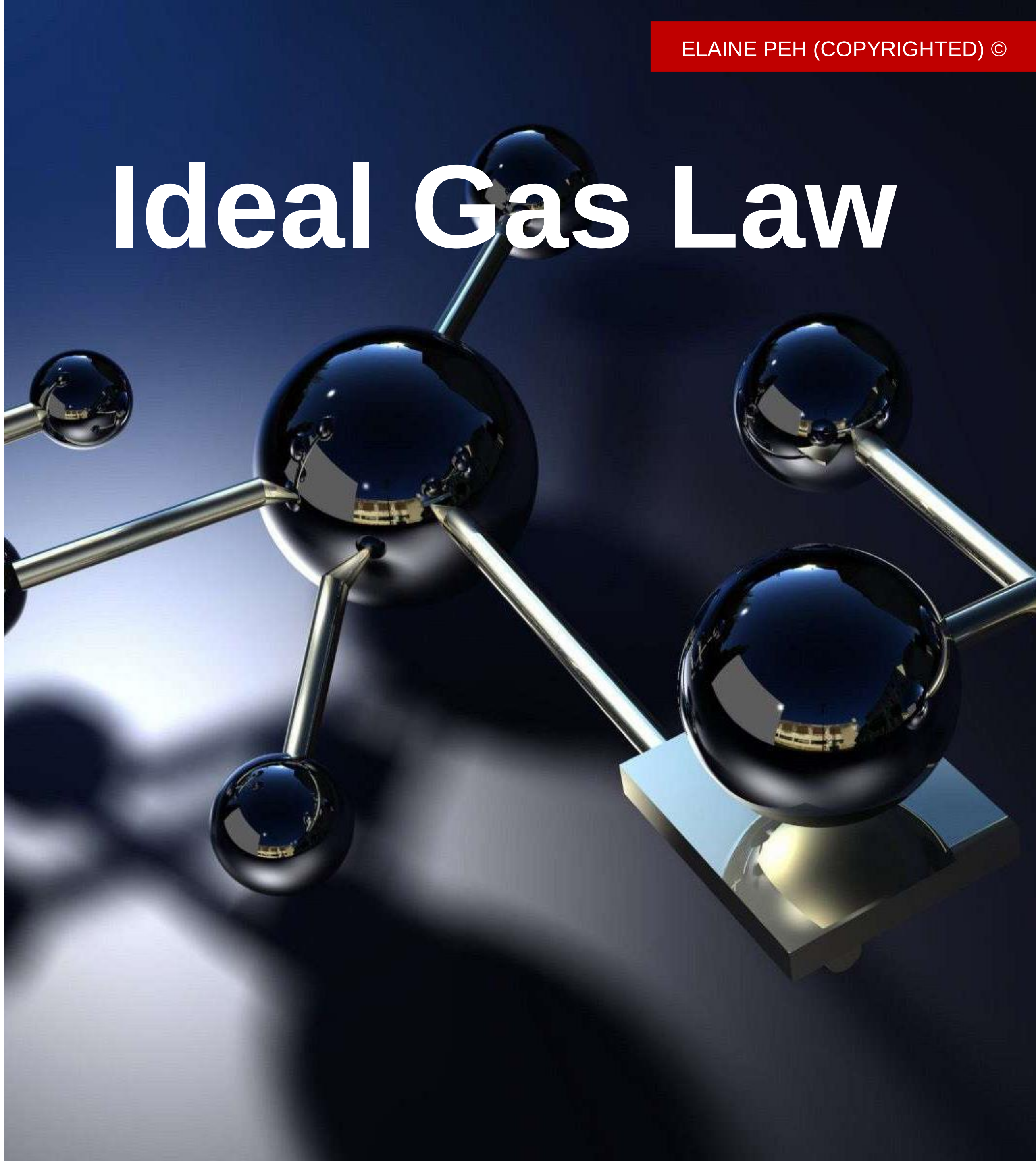
$$M_r = \frac{\text{mass}(RT)}{pV}$$

(b) Density (ρ)

$$\rho = \frac{(p)(M_r)}{RT}$$

(c) Concentration (c)

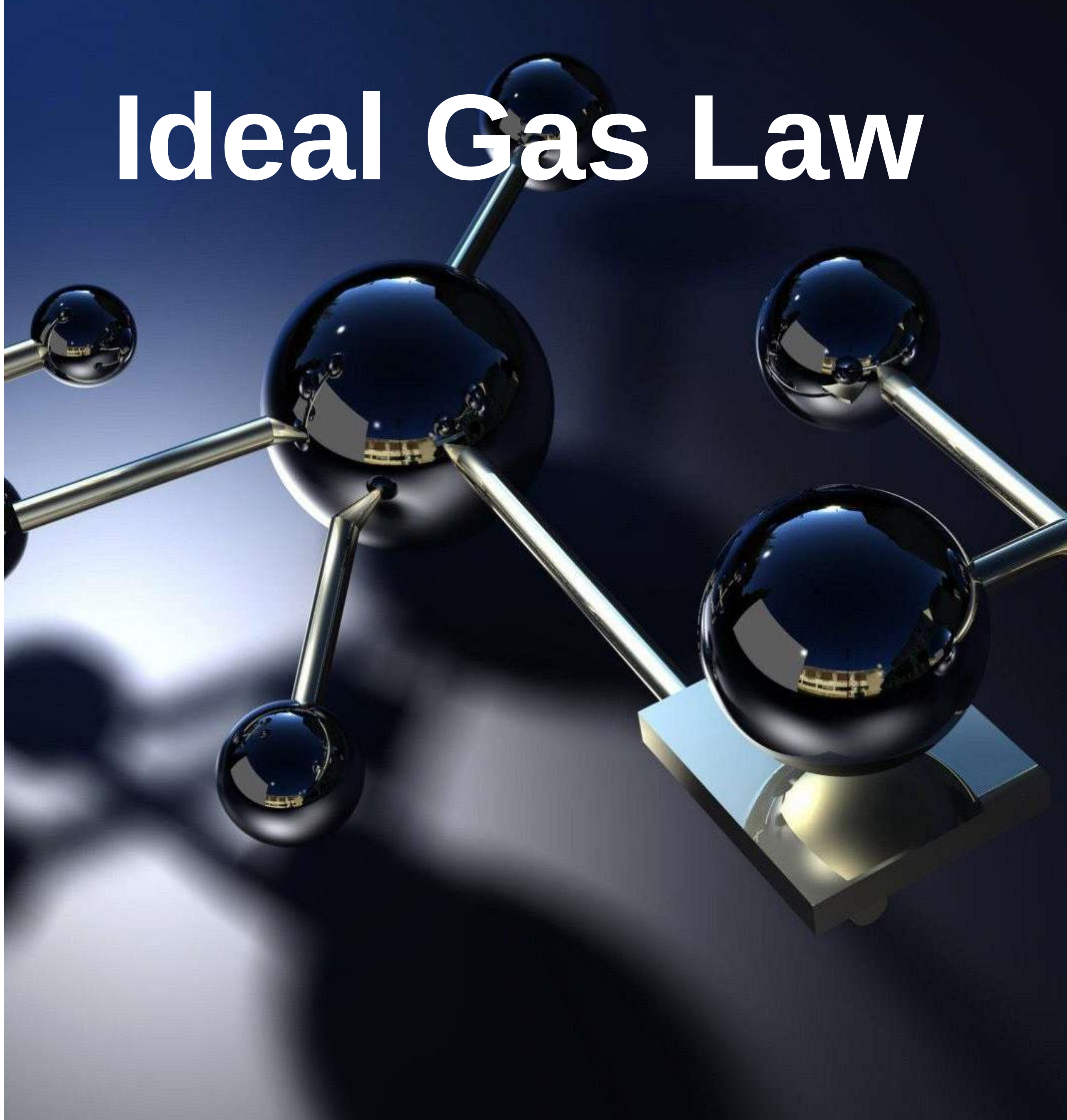
$$c = \frac{p}{RT}$$



Ideal Gas Law

- Gas Law
  - Boyle's Law
  - Charles' Law
  - Avogadro's Law

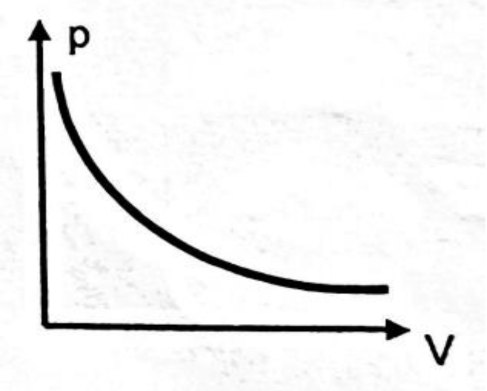
Ideal Gas Law

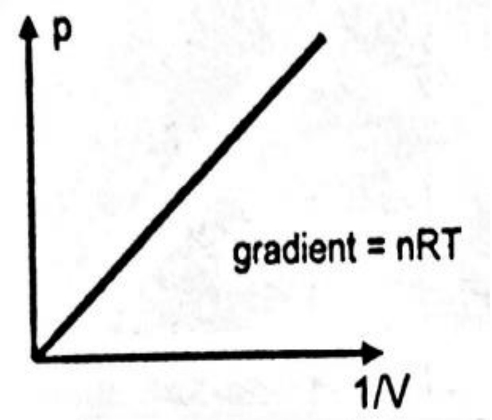


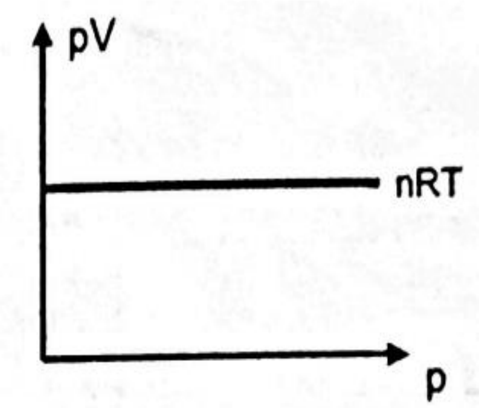
BOYLE'S LAW

At **constant temperature**, the **volume** of a fixed mass of gas (fixed number of moles) is **inversely proportional** to its **pressure**

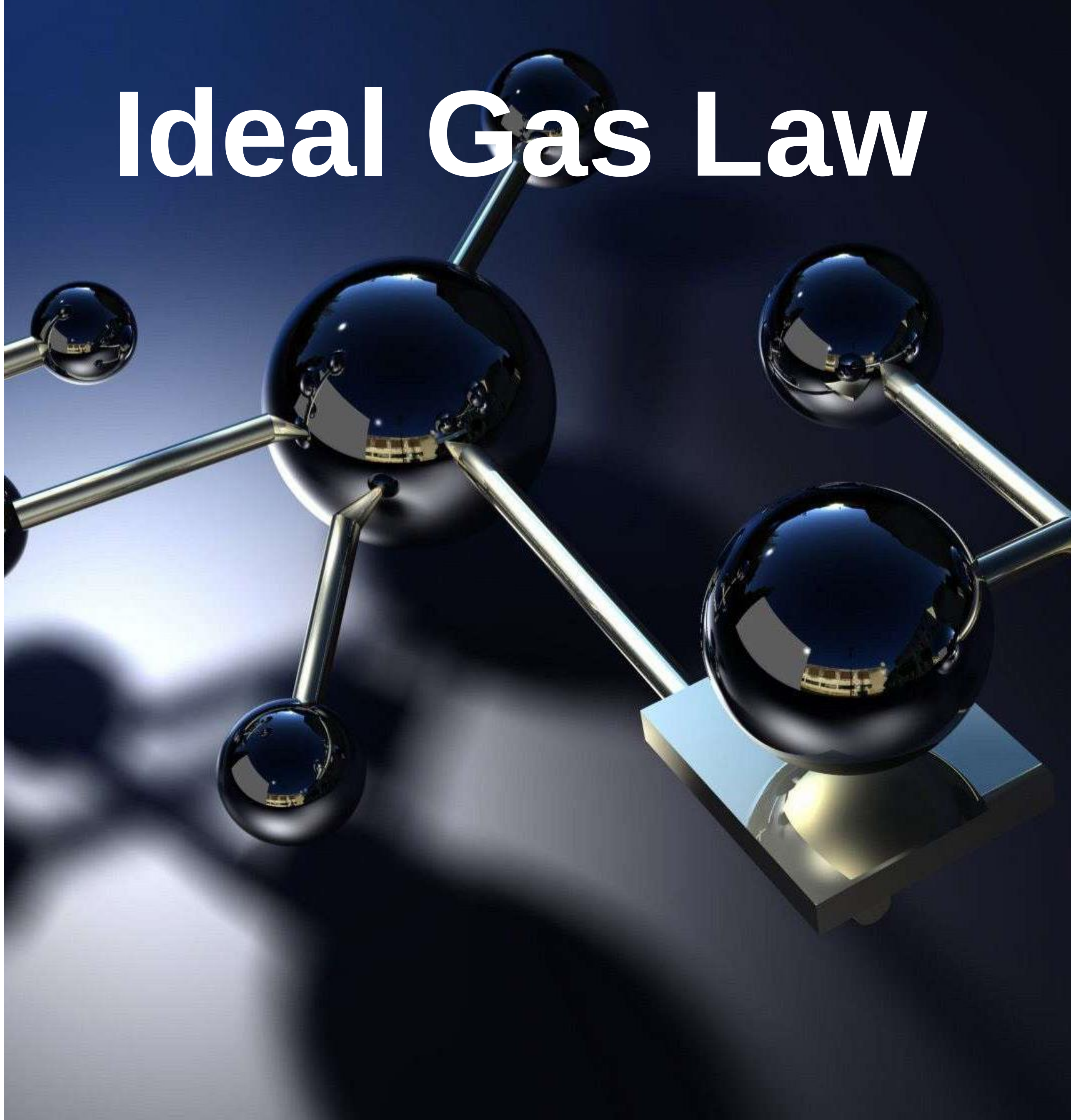
$$V \propto \frac{1}{p}$$







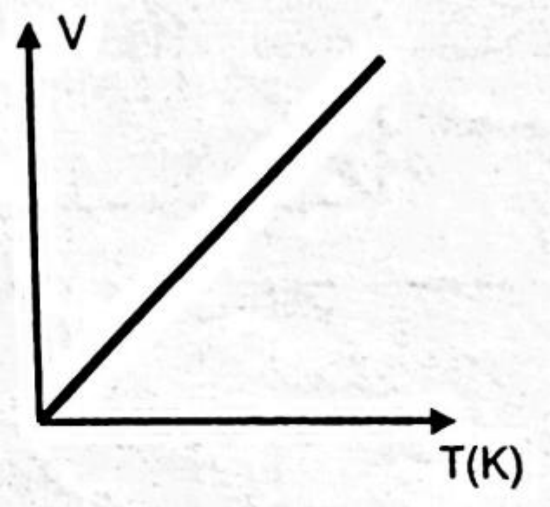
Ideal Gas Law

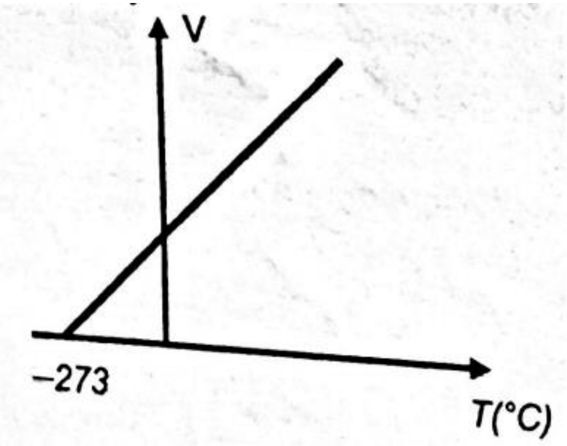


CHARLES' LAW

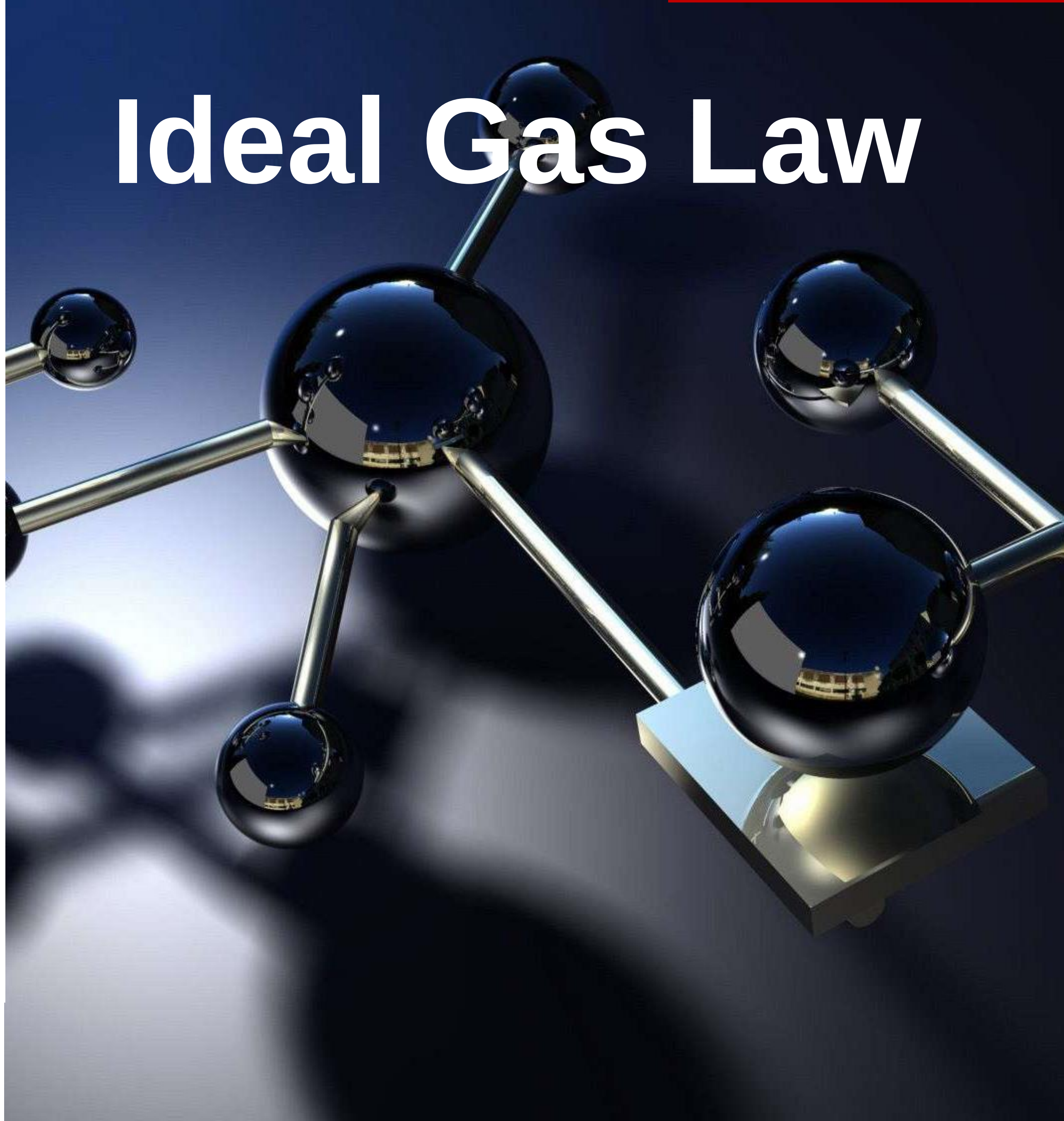
At **constant pressure**, the **volume** of a fixed mass of gas (fixed number of moles) is **directly proportional** to its **absolute temperature (Kelvin)**

$$V \propto T$$





Ideal Gas Law



AVOGADRO'S LAW

At **constant temperature and pressure**, the **volume** of a gas is **directly proportional** to the **number of moles** of gas

$$V \propto n$$

- ➢ *Under s.t.p = 273K (0^{o}C), 1 bar (10,000Pa), 1 mol*
- V = 22.7 dm^3 (Molar Volume @ s.t.p = 22.7 dm^{3}mol^{-1})

- ➢ *Under r.t.p = 293K (20^{o}C), 1 atm (101,325Pa), 1 mol*
- V = 24.0 dm^3 (Molar Volume @ r.t.p = 24.0 dm^{3}mol^{-1})

Real Gas & Deviation from Ideal Behaviour

REAL GAS

In reality, an ideal gas does not exist. Gases that do not obeys the ideal gas equation are known as real gas.

Factors causing the Deviation from Ideal Gas Behaviour

- **Pressure**
- **Temperature**
- **Intermolecular Forces of Attraction Present**

Real Gas & Deviation from Ideal Behaviour

A real gas behaves most like an ideal gas at <u>LOW</u> pressure

<u>PRESSURE</u>

➢ At Low Pressure:

- At **low pressure**, the gas particles are far apart and can be **considered to have negligible volume** compared to the volume of the container (linked to assumption 1)
- At **low pressure**, the **intermolecular attractive forces** between the widely spaced apart gaseous particles **are negligible** (linked to assumption 2)

➢ At High Pressure:

- At **high pressure**, the **gas particles are packed closer together** and hence **occupies a significant volume** as compared to the volume of the container (linked to assumption 1)
- At **high pressure**, the **gas particles are closer together** hence **the intermolecular attractive forces** between the closely spaced gaseous particles **are significant** (linked to assumption 2)

Real Gas & Deviation from Ideal Behaviour

A real gas behaves most like an ideal gas at <u>HIGH</u> temperature

<u>TEMPERATURE</u>

➢ At Low Temperature:

- At **low temperature**, the **gas particles do not possess enough kinetic energy to overcome the intermolecular attractive forces**, hence **the intermolecular attractive forces are significant** (linked to assumption 2)

➢ At High Temperature:

- At **high temperature**, the **gas particles possess sufficiently high kinetic energy to overcome the intermolecular attractive forces**. Hence the **intermolecular attractive forces** can be considered as **negligible** (linked to assumption 2)

Real Gas & Deviation from Ideal Behaviour

A real gas behaves most like an ideal gas with WEAK intermolecular forces of attraction

INTERMOLECULAR FORCES OF ATTRACTION

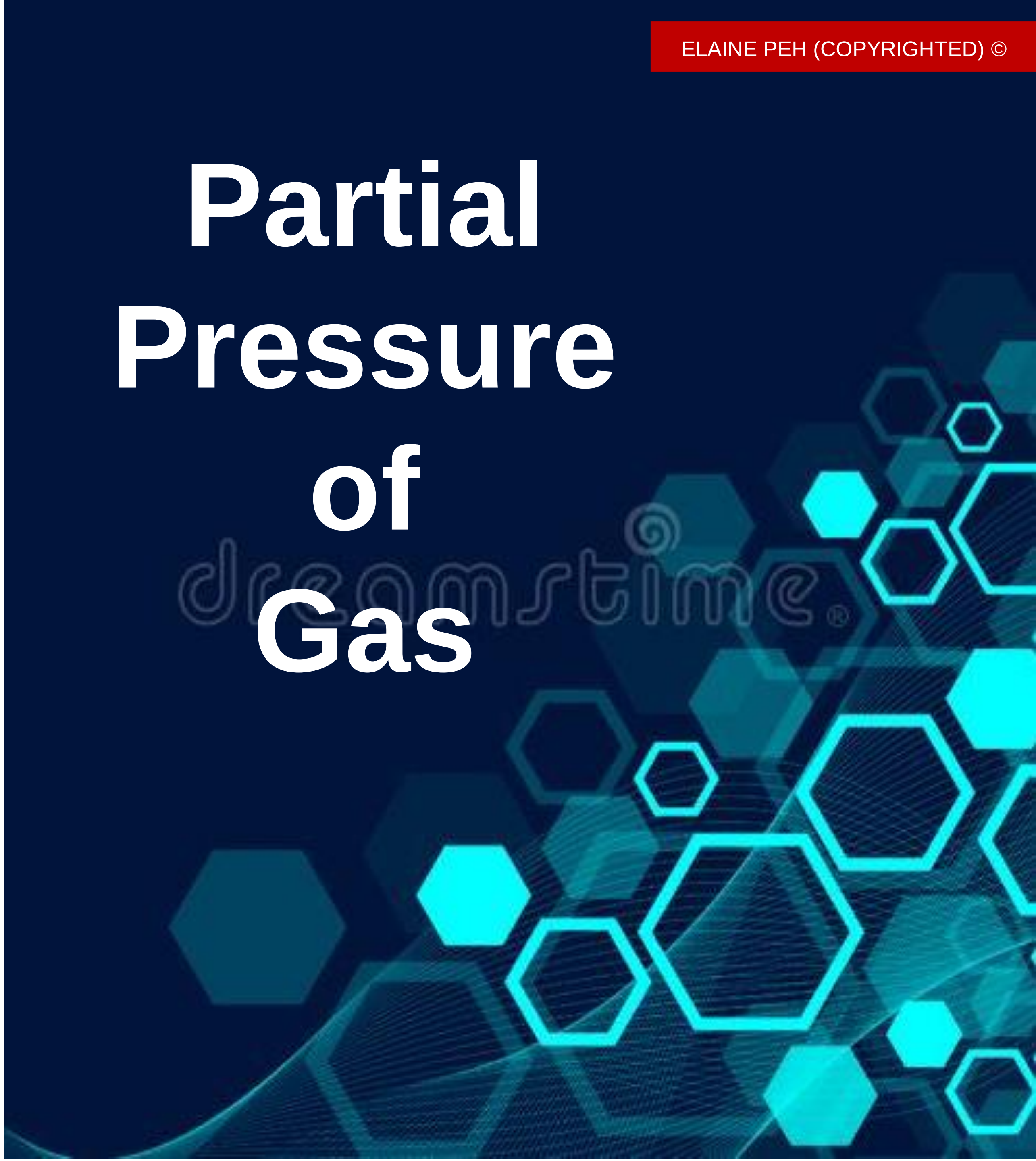
➢ **With Weak Intermolecular Forces:**

- Gases with **weak intermolecular forces of attraction** have **negligible intermolecular attractive force**s between one another (linked to assumption 2)

➢ **With Strong Intermolecular Forces:**

- Gases with **strong intermolecular forces of attraction** tend to have **more significant intermolecular attractive forces** between one another (linked to assumption 2)

Recap: strength of intermolecular forces of attraction in Chapter 2 Chemical Bonding



DALTON'S LAW OF PARTIAL PRESSURE

In a mixture of **non-reacting gases**, the **total pressure** of the mixture is equal to the **sum of the partial pressures** of all the individual gases in the mixture. For a mixture containing gases A, B and C:

$$p_{total} = p_A + p_B + p_C$$

Using Ideal Gas Equation

$$pV = nRT$$

$$n_T \frac{RT}{V} = n_A \frac{RT}{V} + n_B \frac{RT}{V} + n_C \frac{RT}{V}$$

$$n_T = n_A + n_B + n_C$$

Therefore, the **total number of moles** of the non-reacting mixture is equal to the **sum of the individual number of moles** of gases in the mixture.

$$p_A = \frac{n_A}{n_{total}} \times p_{total}$$

Practice Questions

Question: Assuming ideal gas behavior, calculate the pressure of 10 mol of hydrogen gas occupying a volume of 1.50 dm^3 at 27^oC.

Answer: 1.66 x 10^7 Pa

Question: The density of a certain gas at 27^oC and 98.66 kPA is 2530 g m^{-3}. Calculate its molar mass.

Answer: 63.9 g mol^{-1}

Question: An inflated balloon has a volume of 0.55 dm^3 at sea level where the pressure is 1.0 atm and is allowed to rise to a height of 6.5 km, where the pressure is about 0.40 atm. Assuming that the temperature remains constant, what is the final volume of the balloon.

Answer: 1.38 dm^3

Question: A 2.0 dm^3 balloon at 25^oC was placed in a container of ice water at 3.0^oC. If the pressure is held constant, what is the resulting volume of the balloon?

Answer: 1.85 dm^3

Practice Questions

Question: A 6.0 dm^3 of sample at 25^oC and 2.00 atm of pressure contains 0.5 mol of a gas. If an additional 0.25 mol of gas at the same pressure and temperature are added, what is the final total volume of the gas?

Answer: 9.00 dm^3

Question: A 20 L cylinder contains 6 atm of gas at 27 ^oC. What would the pressure of the gas be if the gas was heated to 77 ^oC?

Answer: 7 atm

Question: A sealed balloon was filled with 100 cm^3 of helium at sea level with a pressure of 1.01 x 10^5 Pa and a temperature of 27^oC. it was brought to the top of a mountain where the atmospheric pressure is 8.0 x 10^4 Pa and the ambient temperature is -10^oC. what would be the volume of the balloon at the top of the mountain?

Answer: 1.11 x 10^{-4} m^3

Practice Questions

Question: A weather balloon filled with helium gas has a volume of 2.00×10^3 m^3 at ground level where the atmospheric pressure is 1.00 atm and the temperature is 27^oC. After the balloon rises high above the earth to appoint where the atmospheric pressure is 0.400 atm, its volume increases to 4.00×10^3 m^3. What is the temperature of the atmosphere at this altitude?

Answer: -33^oC

Question: A glass of cola is fizzy because the carbon dioxide has been dissolved in it under pressure. When the cola is poured out of the can, the carbon dioxide is gradually released as bubbles of gas. The cola will eventually go flat, as the concentration of dissolved carbon dioxide decreases to its saturation level. A 500 cm^3 can of cola has 2.0 g of carbon dioxide dissolved in it under pressure. Calculate the volume of carbon dioxide that it released to the atmosphere as it goes flat.
A saturated solution of carbon dioxide at room temperature contains 1.5 g dm^{-3}.

Answer: $683cm^3$

Question: 4 g of methane occupies a volume of 6.25 dm^3 at a particular temperature and pressure. Calculate the volume of the same mass of hydrogen under the same conditions.

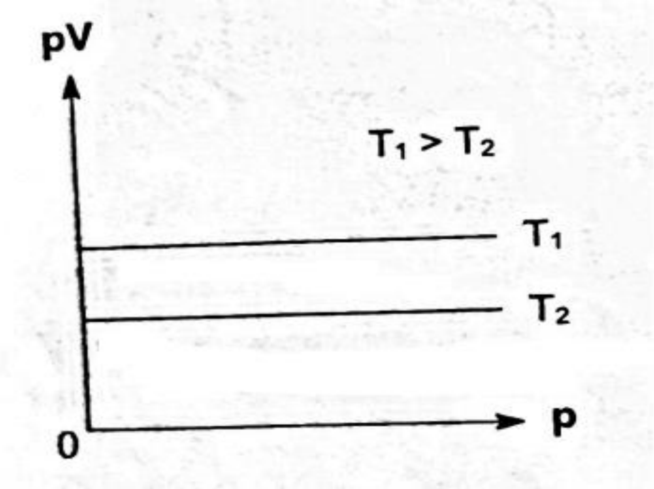
Answer: 0.05 m^3

Practice Questions

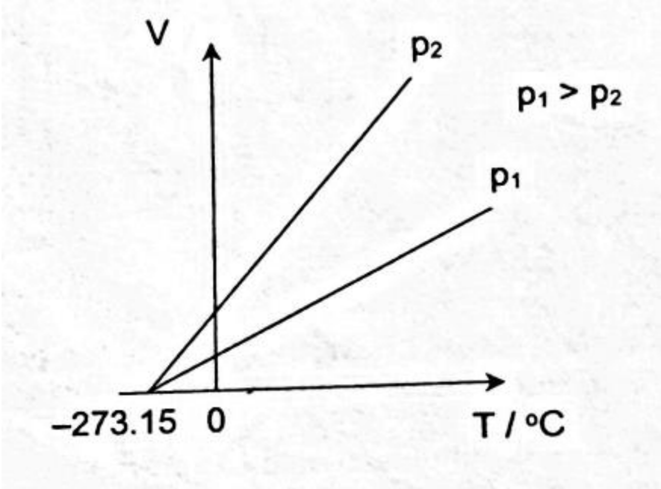
Question: Sketch graphs of
(i) pV against p for n moles of an ideal gas at two constant temperatures T_1 and T_2 in which T_1 is greater than T_2.
(ii) V against T (°C) for n moles of an ideal gas at two constant pressure p_1 and p_2 in which p_1 is greater than p_2.

Answer:

(i)

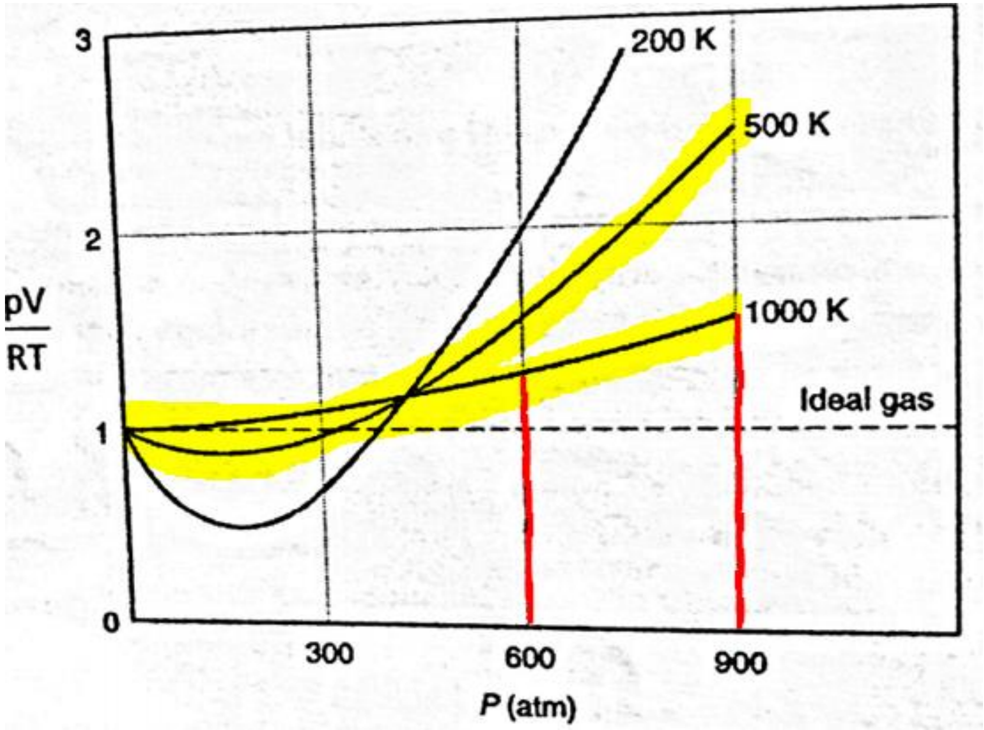


(ii)



Practice Questions

Question: The graph below shows that areal gas deviates more from ideal gas behavior at high pressure and low temperatures. Explain the observation.

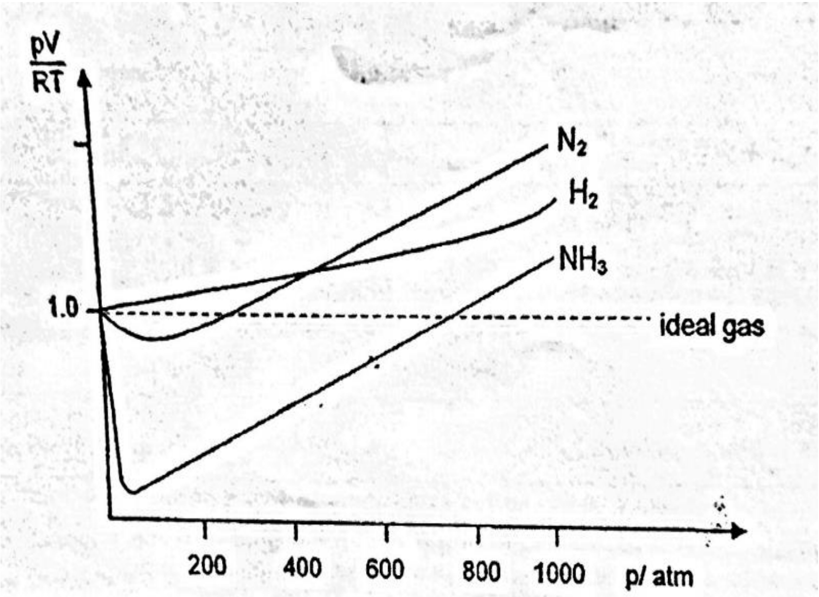


Answer: At higher pressure, particles in a gas are packed closer together. Hence they take up significant volume as compared to the volume of the container and cannot be assumed to be negligible. At the same time, the intermolecular forces of attraction also becomes significant as the particles in the gas are closer to one another, and hence cannot be assumed to be negligible. Therefore, gas particles deviates more from ideal gas at higher pressure.

At lower temperature, the gas particles possess lesser amount of kinetic energy as compared to gas particles at higher temperature. These gas particles are thus unable to overcome the intermolecular forces of attraction, hence the intermolecular forces of attraction cannot be assumed to be negligible. Therefore, gas particles deviates more from ideal gas at lower temperature.

Practice Questions

Question: The graph is drawn at constant temperature. Explain the shape of the graph.



Answer:

NH_3 deviates the most from ideal gas condition as it has strong hydrogen bonding between its molecules as compared to the weaker instantaneous dipole – induce dipole interactions between H_2 and N_2 molecules. Hence NH_3 has the most significant intermolecular forces of attraction present resulting in the greatest deviation.

N_2 deviates more from ideal gas condition as compared to H_2 due to its larger electron cloud size than H_2. With a larger electron cloud size, it is more easily polaries and hence stronger instantaneous dipole – induce dipole interactions are present between N_2 molecules as compared to H_2 molecules. Furthermore a larger electron cloud size also result in N_2 molecules taking up more volume than H_2 molecules. This result in N_2 molecules having more significant intermolecular forces of attraction and volume than H_2 molecules causing N_2 molecules to deviate more from ideal gas behavior as compared to H_2 molecules.

Practice Questions

Question: If there are 2 mol of H_2, 4 mol of O_2 and 6 mol of He in a 5 dm^3 vessel at 27^oC, determine the partial pressure of each gas and the total pressure of the mixture.

Answer:
$p_{hydrogen} = 9.97 \times 10^5$ Pa (3 sf)
$p_{oxygen} = 1.99 \times 10^5$ Pa (3 sf)
$p_{helium} = 2.99 \times 10^5$ Pa (3 sf)
$p_{total} = 5.98 \times 10^5$ Pa (3 sf)

Question: A sample of natural gas contains 8.24 mol of methane, 0.421 mol of ethane and 0.116 mol of propane. If the total pressure of the gases is 1.37 atm, what are the partial pressure of each gas?

Answer:
$p_{methane} = 1.29$ atm (3 sf)
$p_{ethane} = 0.0657$ atm (3 sf)
$p_{propane} = 0.0181$ atm (3 sf)

Practice Questions

Question: Flask X contains 1 dm^3 of helium at 2 kPa pressure and flask Y contains 3 dm^3 of neon at 4 kPa pressure. If the flasks are connected at constant temperature, what is the final pressure?

Answer: 3500 Pa (3 sf)

Question: A small spacecraft of capacity 10 m^3 is connected to another of capacity 30 m^3. Before connection, the pressure inside the smaller craft if 50 kPa and that inside the larger craft is 100 kPa. If all measurements are made at the same temperature, what is the pressure in the combined arrangement after connection?

Answer: 87500 Pa

Question: A 15 dm^3 cylinder containing water vapour at a pressure of 500 kPa is connected to a 5 dm^3 cylinder containing argon at a pressure of 300 kPa. Both cylinders are at temperature of 465 K. Calculate (i) the partial pressure of the two gases, (ii) the total pressure in the joined cylinder and (iii) the final total pressure in the cylinders when the cylinders are cooled to 320 K.

Answer:
(i) 75000 Pa & 375000 Pa
(ii) 450000 Pa
(iii) 51600 Pa

Test yourself!

(a) state the basic assumptions of the kinetic theory as applied to an ideal gas

(b) explain qualitatively in terms of intermolecular forces and molecular size:

i. the conditions necessary for a gas to approach ideal behaviour
ii. the limitations of ideality at very high pressures and very low temperatures

(c) state and use the general gas equation $pV = nRT$ in calculations, including the determination of M_r

(d) use Dalton's Law to determine the partial pressures of gases in a mixture

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