Chapter

13

Kinetic Theory of Gases

Gas

In gases the intermolecular forces are very weak and its molecule may fly apart in all directions. So the gas is characterized by the following properties.

(i) It has no shape and size and can be obtained in a vessel of any shape or size.

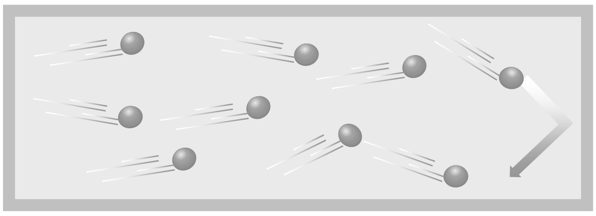
(ii) It expands indefinitely and uniformly to fill the available space.

(iii) It exerts pressure on its surroundings.

(iv) Intermolecular forces in a gas are minimum.

(v) They can easily compressed and expand.

Assumption of Ideal Gases (or Kinetic Theory of Gases)



Kinetic theory of gases relates the macroscopic properties of gases (such as pressure, temperature *etc.*) to the microscopic properties of the gas molecules (such as speed, momentum, kinetic energy of molecule *etc.*)

Actually it attempts to develop a model of the molecular behaviour which should result in the observed behaviour of an ideal gas. It is based on following assumptions :

(1) Every gas consists of extremely small particles known as molecules. The molecules of a given gas are all identical but are different than those of another gas.

(2) The molecules of a gas are identical, spherical, rigid and perfectly elastic point masses.

(3) Their size is negligible in comparison to intermolecular distance ($10^{-9}\ m$)

(4) The volume of molecules is negligible in comparison to the volume of gas. (The volume of molecules is only 0.014% of the volume of the gas).

(5) Molecules of a gas keep on moving randomly in all possible direction with all possible velocities.

(6) The speed of gas molecules lie between zero and infinity

(7) The gas molecules keep on colliding among themselves as well as with the walls of containing vessel. These collisions are perfectly elastic.

(8) The time spent in a collision between two molecules is negligible in comparison to time between two successive collisions.

(9) The number of collisions per unit volume in a gas remains constant.

(10) No attractive or repulsive force acts between gas molecules.

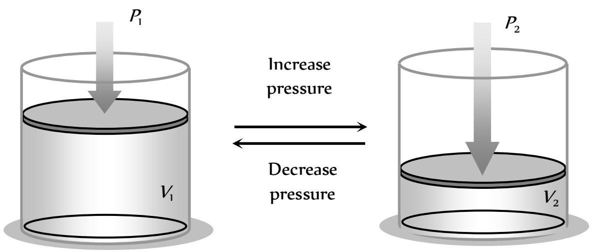
(11) Gravitational attraction among the molecules is ineffective due to extremely small masses and very high speed of molecules.

(12) Molecules constantly collide with the walls of container due to which their momentum changes. The change in momentum is transferred to the walls of the container. Consequently pressure is exerted by gas molecules on the walls of container.

(13) The density of gas is constant at all points of the container.

Gas Laws

(1) **Boyle's law :** For a given mass of an ideal gas at constant temperature, the volume of a gas is inversely proportional to its pressure.



i.e. $V \propto \frac{1}{P}$ or $PV = \text{constant} \Rightarrow P_1V_1 = P_2V_2$

Fig. 13.1

(i) $PV = P\left(\frac{m}{\rho}\right) = \text{constant} \Rightarrow \frac{P}{\rho} = \text{constant}$ or $\frac{P_1}{\rho_1} = \frac{P_2}{\rho_2}$

(As volume $= \frac{m}{\rho(\text{Density of the gas})}$ and m = constant)

(ii) $PV = P\left(\frac{N}{n}\right) = \text{constant} \Rightarrow \frac{P}{n} = \text{constant}$ or $\frac{P_1}{n_1} = \frac{P_2}{n_2}$

(iii) As number of molecules per unit volume $n = \frac{N}{V}$

$\Rightarrow V = \frac{N}{n}$ also N = constant

(iv) Graphical representation : If m and T are constant

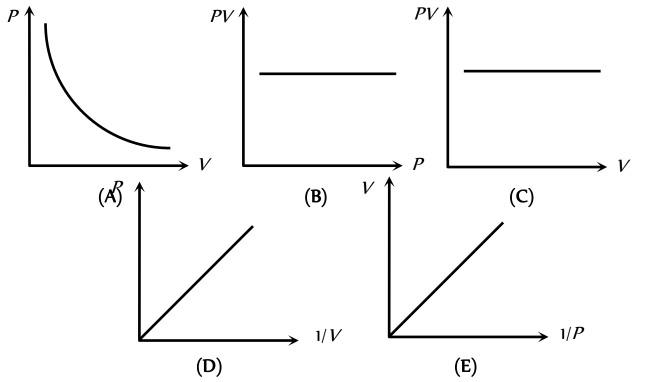


Fig. 13.2

(2) **Charle's law :** If the pressure remaining constant, the volume of the given mass of a gas is directly proportional to its absolute temperature.

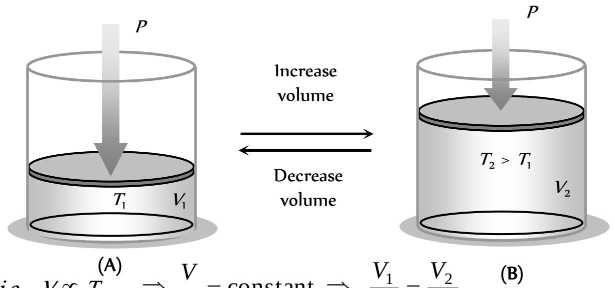


Fig. 13.3

i.e., $V \propto T \Rightarrow \frac{V}{T} = \text{constant} \Rightarrow \frac{V_1}{T_1} = \frac{V_2}{T_2}$

(i) $\frac{V}{T} = \frac{m}{\rho T} = \text{constant}$ (As volume $V = \frac{m}{\rho}$)

or $\rho T = \text{constant} \Rightarrow \rho_1 T_1 = \rho_2 T_2$

(ii) If the pressure remains constant, the volume of the given mass of a gas increases or decreases by $\frac{1}{273.15}$ of its volume at $0°C$ for each $1°C$ rise or fall in temperature.

$$V_t = V_0\left(1 + \frac{1}{273.15}t\right).$$

This is Charle's law for centigrade scale.

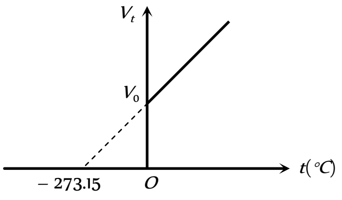
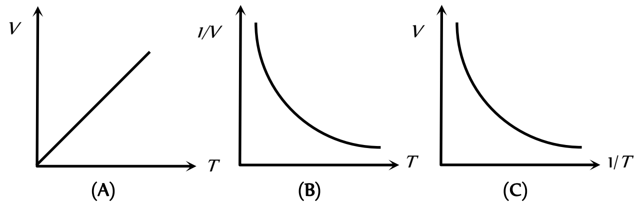


Fig. 13.4

(v) Graphical representation: If m and P are constant



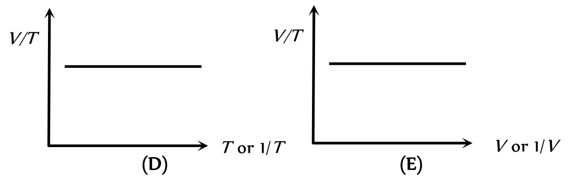


Fig. 13.5

(3) **Gay-Lussac's law or pressure law :** The volume remaining constant, the pressure of a given mass of a gas is directly proportional to its absolute temperature.

$P \propto T$ or $\frac{P}{T} = \text{constant} \Rightarrow \frac{P_1}{T_1} = \frac{P_2}{T_2}$

(i) The volume remaining constant, the pressure of a given mass of a gas increases or decreases by $\frac{1}{273.15}$ of its pressure at $0°C$ for each $1°C$ rise or fall in temperature.

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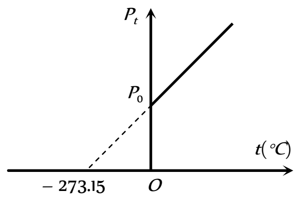


Fig. 13.5

(ii) **Graphical representation :** If m and V are constants

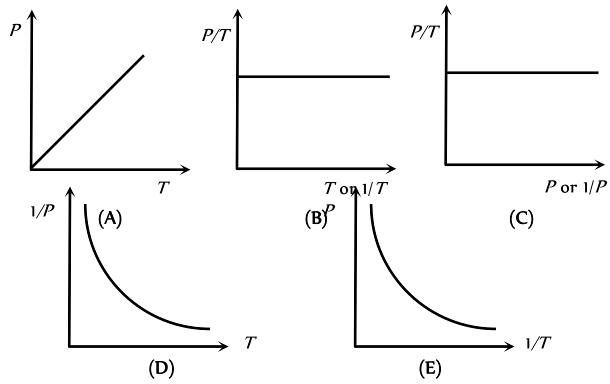


Fig. 13.6

(4) **Avogadro's law :** Equal volume of all the gases under similar conditions of temperature and pressure contain equal number of molecules *i.e.* $N_1 = N_2$.

(5) **Grahm's law of diffusion :** When two gases at the same pressure and temperature are allowed to diffuse into each other, the rate of diffusion of each gas is inversely proportional to the square root of the density of the gas *i.e.* $r \propto \frac{1}{\sqrt{\rho}} \propto \frac{1}{\sqrt{M}}$ (M is the molecular weight of the gas) $\Rightarrow$

$$\frac{r_1}{r_2} = \sqrt{\frac{\rho_2}{\rho_1}} = \sqrt{\frac{M_2}{M_1}}$$

If V is the volume of gas diffused in t *sec* then

$$r = \frac{V}{t} \Rightarrow \frac{r_1}{r_2} = \frac{V_1}{V_2} \times \frac{t_2}{t_1}$$

(6) **Dalton's law of partial pressure :** The total pressure exerted by a mixture of non-reacting gases occupying a vessel is equal to the sum of the

individual pressures which each gases exert if it alone occupied the same volume at a given temperature.

For n gases $P = P_1 + P_2 + P_3 + ... P_n$

where P = Pressure exerted by mixture and $P_1, P_2, P_3, ... P_n$ = Partial pressure of component gases.

Equation of State or Ideal Gas Equation

The equation which relates the pressure (P) volume (V) and temperature (T) of the given state of an ideal gas is known as ideal gas equation or equation of state.

For 1 mole of gas $\dfrac{PV}{T} = R$ (constant) $\Rightarrow PV = RT$

where R = universal gas constant.

Table 13.1 : Different forms of gas equation

Quantity of gas	Equation	Constant
1 mole gas	$PV = RT$	R = universal gas constant
μ mole gas	$PV = \mu RT$	
1 molecule of gas	$PV = \left(\dfrac{R}{N_A}\right)T = kT$	k = Boltzmann's constant
N molecules of gas	$PV = NkT$	
1 *gm* of gas	$PV = \left(\dfrac{R}{M}\right)T = rT$	r = Specific gas constant
m gm of gas	$PV = mrT$	

(1) **Universal gas constant (R) :** Universal gas constant signifies the work done by (or on) a gas per mole per kelvin.

$$R = \frac{PV}{\mu T} = \frac{\text{Pressure} \times \text{Volume}}{\mu \times \text{Temperature}} = \frac{\text{Work done}}{\mu \times \text{Temperature}}$$

(i) At S.T.P. the value of universal gas constant is same for all gases $R = 8.31 \dfrac{J}{mole \times kelvin} = 1.98 \dfrac{cal}{mole \times kelvin} \simeq 2 \dfrac{cal}{mol \times kelvin}$

$$= 0.8221 \frac{litre \times atm}{mole \times kelvin}.$$

(ii) Dimension : $[ML^2T^{-2}\theta^{-1}]$

(2) **Boltzman's constant (k) :** It is represented by per mole gas constant *i.e.,* $k = \dfrac{R}{N} = \dfrac{8.31}{6.023 \times 10^{23}} = 1.38 \times 10^{-23}\ J/K$

It's dimension : $[ML^2T^{-2}\theta^{-1}]$

(3) **Specific gas constant (r) :** It is represented by per gram gas constant *i.e.,* $r = \dfrac{R}{M}$. It's unit is $\dfrac{Joule}{gm \times kelvin}$ and dimension $[L^2T^{-2}\theta^{-1}]$

Since the value of M is different for different gases. Hence the value of r is different for different gases. *e.g.* It is maximum for hydrogen $r_{H_2} = \dfrac{R}{2}$

Real Gases

(1) The gases actually found in nature are called real gases.

(2) They do not obeys gas Laws.

(3) For exactly one mole of an ideal gas $\dfrac{PV}{RT} = 1$. Plotting the experimentally determined value of $\dfrac{PV}{RT}$ for exactly one mole of various real gases as a function of pressure P, shows a deviation from identity.

(4) The quantity $\dfrac{PV}{RT}$ is called the compressibility factor and should be unit for an ideal gas.

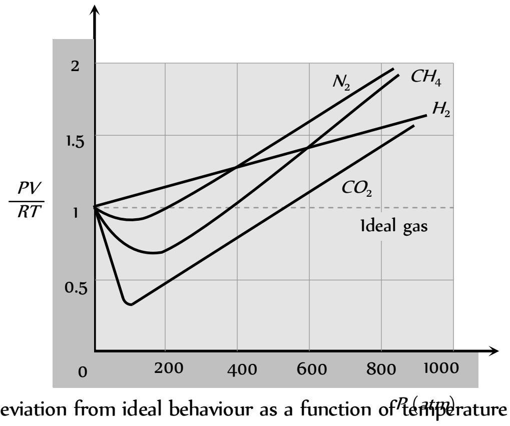


Fig. 13.7

(5) Deviation from ideal behaviour as a function of temperature

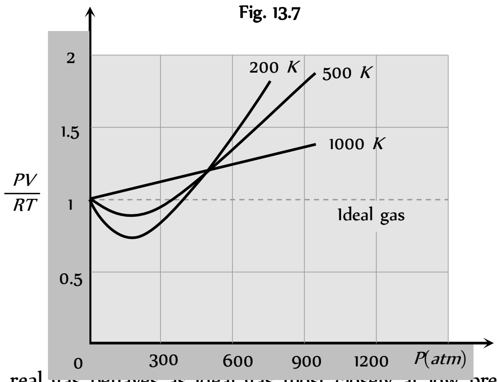


Fig. 13.8

(6) A real gas behaves as ideal gas most closely at low pressure and high temperature. Also can actual gas can be liquefied most easily which deviates most from ideal gas behaviour at low temperature and high pressure.

(7) **Equation of state for real gases :** It is given by Vander Waal's with two correction in ideal gas equation. The it know as Vander Waal's gas equation.

(i) **Volume correction :** Due to finite size of molecule, a certain portion of volume of a gas is covered by the molecules themselves. Therefore the space available for the free motion of molecules of gas will be slightly less than the volume V of a gas. Hence the effective volume becomes ($V - b$).

(ii) **Pressure correction :** Due to intermolecular force in real gases, molecule do not exert that force on the wall which they would have exerted in the absence of intermolecular force. Therefore the observed pressure P of the gas will be less than that present in the absence of intermolecular force. Hence the effective pressure becomes $\left(P + \dfrac{a}{V^2}\right)$.

(iii) **Vander Waal's gas equations**

For 1 *mole* of gas $\left(P + \dfrac{a}{V^2}\right)(V - b) = RT$

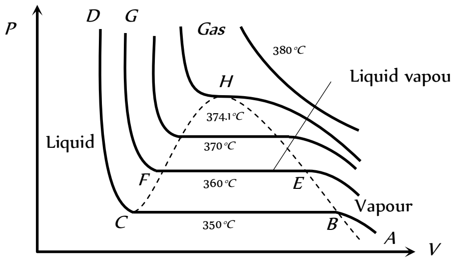
For μ *moles* of gas $\left(P + \frac{a\mu^2}{V^2}\right)(V - \mu b) = \mu RT$

Here a and b are constant called Vander Waal's constant.

Dimension : $[a] = [ML^5T^{-2}]$ and $[b] = [L^3]$

Units : $a = N \times m^4$ and $b = m^3$.

(8) **Andrews curves** : The pressure (P) versus volume (V) curves for actual gases are called Andrews curves.



Andrews curve for water

Fig. 13.9

(i) At 350°C, part AB represents vapour phase of water, in this part Boyle's law is obeyed $\left(P \propto \frac{1}{V}\right)$. Part BC represents the co-existence of vapour and liquid phases. At point C, vapours completely change to liquid phase. Part CD is parallel to pressure axis which shows that compressibility of the water is negligible.

(ii) At 360°C portion representing the co-existence of liquid vapour phase is shorter.

(iii) At 370°C this portion is further decreased.

(iv) At 374.1°C, it reduces to point (H) called critical point and the temperature 374.1°C is called critical temperature (T_c) of water.

(v) The phase of water (at 380°C) above the critical temperature is called gaseous phase.

(9) **Critical temperature, pressure and volume :** The point on the P-V curve at which the matter gets converted from gaseous state to liquid state is known as critical point. At this point the difference between the liquid and vapour vanishes *i.e.* the densities of liquid and vapour become equal.

(i) **Critical temperature** (T_c) **:** The maximum temperature below which a gas can be liquefied by pressure alone is called critical temperature and is characteristic of the gas. A gas cannot be liquefied if its temperature is more than critical temperature.

CO_2 (31.1°C), O_2(–118°C), N_2 (–147.1°C) and H_2O (374.1°C)

(ii) **Critical pressure** (P_c) **:** The minimum pressure necessary to liquify a gas at critical temperature is defined as critical pressure CO_2 (73.87 *bar*) and O_2 (49.7*atm*)

(iii) **Critical volume** (V_c) **:** The volume of 1 mole of gas at critical pressure and critical temperature is defined as critical volume CO_2 (95 $\times 10^{-6}$ m^3)

(iv) **Relation between Vander Waal's constants and T_c, P_c, V_c**

$$T_c = \frac{8a}{27Rb},\ P_c = \frac{a}{27b^2},\ V_c = 3b\ ,$$

$$a = \frac{27R^2}{64}\frac{T_c^2}{P_c},\ b = \frac{R}{8}\left(\frac{T_c}{P_c}\right) \text{ and } \frac{P_cV_c}{T_c} = \frac{3}{8}R$$

Pressure of an Ideal Gas

Consider an ideal gas (consisting of N molecules each of mass m) enclosed in a cubical box of side L.

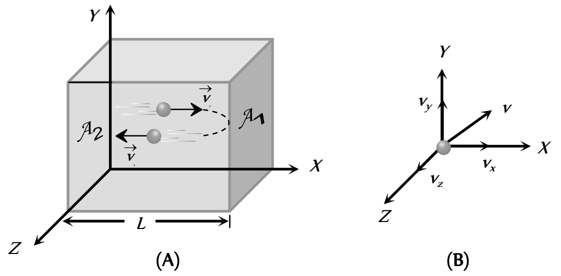


Fig. 13.10

(1) **Instantaneous velocity :** Any molecule of gas moves with velocity $\vec{v}$ in any direction

where $\vec{v} = v_x\hat{i} + v_y\hat{j} + v_z\hat{k} \Rightarrow v = \sqrt{v_x^2 + v_y^2 + v_z^2}$. Due to random motion of molecule $v_x = v_y = v_z \Rightarrow v^2 = 3v_x^2 = 3v_y^2 = 3v_z^2$

(2) **Time during collision :** Time between two successive collision with the wall A_1.

$$\Delta t = \frac{\text{Distance travelled by molecule between two successive collision}}{\text{Velocity of molecule}}$$

$$= \frac{2L}{v_x}$$

(3) **Collision frequency** (n) **:** It means the number of collision per second. Hence $n = \frac{1}{\Delta t} = \frac{v_x}{2L}$

(4) **Change in momentum :** This molecule collides with the shaded wall (A_1) with velocity v_x and rebounds with velocity $-v_x$.

The change in momentum of the molecule

$$\Delta p = (-mv_x) - (mv_x) = -2mv_x$$

As the momentum remains conserved in a collision, the change in momentum of the wall A_1 is $\Delta p = 2mv_x$

After rebound this molecule travel toward opposite wall A_2 with velocity $-v_x$, collide to it and again rebound with velocity v_x towards wall A_1.

(5) **Force on wall :** Force exerted by a single molecule on shaded wall is equal to rate at which the momentum is transferred to the wall by this molecule.

i.e. $F_{\text{Single molecule}} = \frac{\Delta p}{\Delta t} = \frac{2mv_x}{(2L/v_x)} = \frac{mv_x^2}{L}$

The total force on the wall A_1 due to all the molecules

$$F_x = \frac{m}{L}\sum v_x^2 = \frac{m}{M}(v_{x_1}^2 + v_{x_2}^2 + v_{x_3}^2 + ...) = \frac{mN}{L}\overline{v_x^2}$$

$\overline{v_x^2}$ = mean square of x component of the velocity.

(6) **Pressure :** Now pressure is defined as force per unit area, hence pressure on shaded wall $P_x = \frac{F_x}{A} = \frac{mN}{AL}\overline{v_x^2} = \frac{mN}{V}\overline{v_x^2}$

For any molecule, the mean square velocity $\overline{v^2} = \overline{v_x^2} + \overline{v_y^2} + \overline{v_z^2}$; by symmetry $\overline{v_x^2} = \overline{v_y^2} = \overline{v_z^2} \Rightarrow \overline{v_x^2} = \overline{v_y^2} = \overline{v_z^2} = \frac{\overline{v^2}}{3}$

Total pressure inside the container

$$P = \frac{1}{3}\frac{mN}{V}\overline{v^2} = \frac{1}{3}\frac{m\,N}{V}v_{rms}^2 \qquad \text{(where } v_{rms} = \sqrt{\overline{v^2}}\text{)}$$

(7) **Relation between pressure and kinetic energy :** As we know

$$P = \frac{1}{3}\frac{mN}{V}v_{rms}^2 = \frac{1}{3}\frac{M}{V}v_{rms}^2 \Rightarrow P = \frac{1}{3}\rho v_{rms}^2 \quad \text{... (i)}$$

[As $M = mN$ = Total mass of the gas and $\rho = \dfrac{M}{V}$]

$\therefore$ K.E. per unit volume $E = \dfrac{1}{2}\left(\dfrac{M}{V}\right)v_{rms}^2 = \dfrac{1}{2}\rho v_{rms}^2$ ...(ii)

From (i) and (ii), we get $P = \dfrac{2}{3}E$

i.e. the pressure exerted by an ideal gas is numerically equal to the two third of the mean kinetic energy of translation per unit volume of the gas.

(8) **Effect of mass, volume and temperature on pressure :**

$$P = \frac{1}{3}\frac{mN}{V}v_{rms}^2 \quad \text{or} \quad P \propto \frac{(mN)T}{V} \quad [\text{As } v_{rms}^2 \propto T\ ]$$

(i) If volume and temperature of a gas are constant $P \propto mN$ *i.e.* Pressure ∝ (Mass of gas).

i.e. if mass of gas is increased, number of molecules and hence number of collision per second increases *i.e.* pressure will increase.

(ii) If mass and temperature of a gas are constant. $P \propto (1/V)$, *i.e.*, if volume decreases, number of collisions per second will increase due to lesser effective distance between the walls resulting in greater pressure.

(iii) If mass and volume of gas are constant, $P \propto (v_{rms})^2 \propto T$

i.e., if temperature increases, the mean square speed of gas molecules will increase and as gas molecules are moving faster, they will collide with the walls more often with greater momentum resulting in greater pressure.

Various Speeds of Gas Molecules

The motion of molecules in a gas is characterised by any of the following three speeds.

(1) **Root mean square speed :** It is defined as the square root of mean of squares of the speed of different molecules

i.e. $v_{rms} = \sqrt{\dfrac{v_1^2 + v_2^2 + v_3^2 + v_4^2 + ...}{N}} = \sqrt{\overline{v^2}}$

(i) From the expression of pressure $P = \dfrac{1}{3}\rho v_{rms}^2$

$$\Rightarrow v_{rms} = \sqrt{\frac{3P}{\rho}} = \sqrt{\frac{3PV}{\text{Mass of gas}}} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3kT}{m}}$$

where $\rho = \dfrac{\text{Mass of gas}}{V}$ = Density of the gas, $M = \mu \times$ (mass of gas), $pV = \mu RT$, $R = kN_A$, k = Boltzmann's constant,

$m = \dfrac{M}{N_A}$ = mass of each molecule.

(ii) With rise in temperature *rms* speed of gas molecules increases as $v_{rms} \propto \sqrt{T}$.

(iii) With increase in molecular weight *rms* speed of gas molecule decreases as $v_{rms} \propto \dfrac{1}{\sqrt{M}}$. *e.g.*, *rms* speed of hydrogen molecules is four times that of oxygen molecules at the same temperature.

(iv) *rms* speed of gas molecules is of the order of *km/s* *e.g.*, at NTP for hydrogen gas

$$(v_{rms}) = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3 \times 8.31 \times 273}{2 \times 10^3}} = 1840\, m/s\,.$$

(v) *rms* speed of gas molecules is $\sqrt{\dfrac{3}{\gamma}}$ times that of speed of sound in gas, as $v_{rms} = \sqrt{\dfrac{3RT}{M}}$ and $v_s = \sqrt{\dfrac{\gamma RT}{M}} \Rightarrow v_{rms} = \sqrt{\dfrac{3}{\gamma}}v_s$

(vi) *rms* speed of gas molecules does not depends on the pressure of gas (if temperature remains constant) because $P \propto \rho$ (Boyle's law) if pressure is increased *n* times then density will also increases by *n* times but v_{rms} remains constant.

(vii) Moon has no atmosphere because v_{rms} of gas molecules is more than escape velocity (v_e).

A planet or satellite will have atmosphere only if $v_{rms} < v_e$

(viii) At $T = 0$; $v_{rms} = 0$ *i.e.* the *rms* speed of molecules of a gas is zero at 0 *K*. This temperature is called absolute zero.

(2) **Most probable speed :** The particles of a gas have a range of speeds. This is defined as the speed which is possessed by maximum fraction of total number of molecules of the gas. *e.g.*, if speeds of 10 molecules of a gas are 1, 2, 2, 3, 3, 3, 4, 5, 6, 6 *km/s*, then the most probable speed is 3 *km/s*, as maximum fraction of total molecules possess this speed.

Most probable speed $v_{mp} = \sqrt{\dfrac{2P}{\rho}} = \sqrt{\dfrac{2RT}{M}} = \sqrt{\dfrac{2kT}{m}}$

(3) **Average speed :** It is the arithmetic mean of the speeds of molecules in a gas at given temperature.

$$v_{av} = \frac{v_1 + v_2 + v_3 + v_4 + ...}{N}$$

and according to kinetic theory of gases

Average speed $v_{av} = \sqrt{\dfrac{8P}{\pi\rho}} = \sqrt{\dfrac{8}{\pi}\dfrac{RT}{M}} = \sqrt{\dfrac{8}{\pi}\dfrac{kT}{m}}$

Maxwell's Law (or the Distribution of Molecular Speeds)

(1) The v_{rms} gives us a general idea of molecular speeds in a gas at a given temperature. This doesn't mean that the speed of each molecule is v_{rms}. Many of the molecules have speed less than v_{rms} and many have speeds greater than v_{rms}.

(2) Maxwell derived as equation given the distribution of molecules in different speed as follow

$$dN = 4\pi N\left(\frac{m}{2\pi kT}\right)^{3/2} v^2 e^{-\frac{mv^2}{2kT}}dv$$

where *dN* = Number of molecules with speeds between *v* and *v* + *dv*.

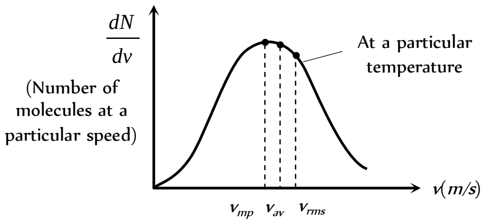


Fig. 13.11

(3) Graph between $\frac{dN}{dv}$ (number of molecules at a particular speed) and v (speed of these molecules). From the graph it is seen that $\frac{dN}{dv}$ is maximum at most probable speed.

This graph also represent that $v_{rms} > v_{av} > v_{mp}$

(Order remember trick RAM)

$$\Rightarrow \sqrt{\frac{3RT}{M}} > \sqrt{\frac{8RT}{\pi M}} > \sqrt{\frac{2RT}{M}} \Rightarrow$$

$$1.77\sqrt{\frac{RT}{M}} > 1.6\sqrt{\frac{RT}{M}} > 1.41\sqrt{\frac{RT}{M}}$$

Area bonded by this curve with speed axis represents the number of molecules corresponds to that velocity range. This curve is asymmetric curve.

Effect of temperature on velocity distribution : With temperature rise the $\frac{dN}{dv}$ vs v. Curve shift towards right and becomes broader.

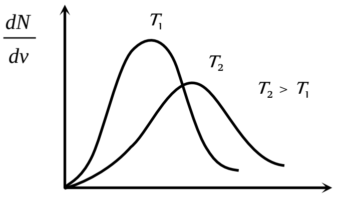


Fig. 13.12

(Because with temperature rise average molecular speed increases).

Mean Free Path

(1) The distance travelled by a gas molecule between two successive collisions is known as free path.

$$\lambda = \frac{\text{Total distance travelled by a gas molecule between successive collisions}}{\text{Total number of collisions}}$$

During two successive collisions, a molecule of a gas moves in a straight line with constant velocity and

Let $\lambda_1, \lambda_2, \lambda_3.....$ be the distance travelled by a gas molecule during n collisions respectively, then the mean free path of a gas molecule is given by

$$\lambda = \frac{\lambda_1 + \lambda_2 + \lambda_3 + ... + \lambda_n}{n}$$

(2) $\lambda = \frac{1}{\sqrt{2}\pi n d^2}$

where d = Diameter of the molecule,

n = Number of molecules per unit volume

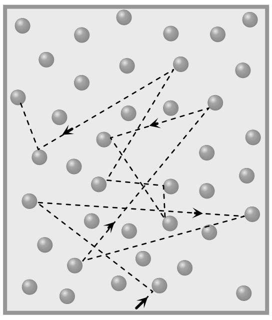


Fig. 13.13

(3) As $PV = \mu\ RT = \mu\ NkT \Rightarrow \frac{N}{V} = \frac{P}{kT} = n =$ Number of molecule per unit volume so $\lambda = \frac{1}{\sqrt{2}}\frac{kT}{\pi d^2 P}$.

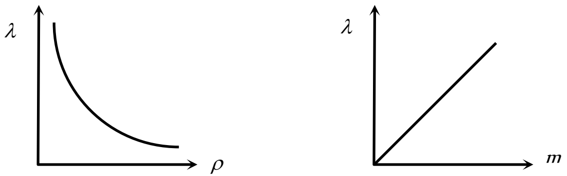
(4) From $\lambda = \frac{1}{\sqrt{2}\pi n d^2} = \frac{m}{\sqrt{2}\pi (mn) d^2} = \frac{m}{\sqrt{2}\pi d^2 \rho}$

[As m = Mass each molecule, mn = Mass per unit volume = Density = ρ]

(5) If average speed of molecule is v then $\lambda = v \times \frac{t}{N} = v \times T$

[As N = Number of collision in time t, T = time interval between two collisions].

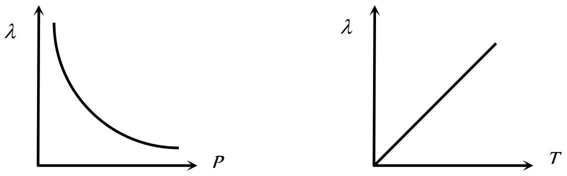
(i) As $\lambda \propto \frac{1}{\rho}$ and $\lambda \propto m$ *i.e.* the mean free path is inversely proportional to the density of a gas and directly proportional to the mass of each molecule.



(A) (B)

Fig. 13.14

(ii) As $\lambda = \frac{1}{\sqrt{2}}\frac{kT}{\pi d^2 P}$. For constant volume and hence constant number density n of gas molecules, $\frac{P}{T}$ is constant so that λ will not depend on P and T. But if volume of given mass of a gas is allowed to change with P or T then $\lambda \propto T$ at constant pressure and $\lambda \propto \frac{1}{P}$ at constant temperature.



(A) (B)

Fig. 13.15

Degree of Freedom

The term degree of freedom of a system refers to the possible independent motions, systems can have. or

The total number of independent modes (ways) in which a system can possess energy is called the degree of freedom (f).

The independent motions can be translational, rotational or vibrational or any combination of these.

So the degree of freedom are of three types :

(i) Translational degree of freedom

(ii) Rotational degree of freedom

(iii) Vibrational degree of freedom

General expression for degree of freedom

$f = 3A - B$; where A = Number of independent particles,

B = Number of independent restriction

(1) **Monoatomic gas :** Molecule of monoatomic gas can move in any direction in space so it can have three independent motions and hence 3 degrees of freedom (all translational)

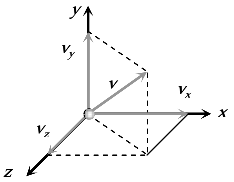


Fig. 13.16

(2) **Diatomic gas :** Molecules of diatomic gas are made up of two atoms joined rigidly to one another through a bond. This cannot only move bodily, but also rotate about one of the three co-ordinate axes. However its moment of inertia about the axis joining the two atoms is negligible compared to that about the other two axes.

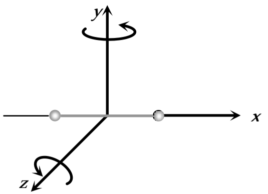


Fig. 13.17

Hence it can have only two rotational motion. Thus a diatomic molecule has 5 degree of freedom : 3 translational and 2 rotational.

(3) **Triatomic gas (Non-linear) :** A non-linear molecule can rotate about any of three co-ordinate axes. Hence it has 6 degrees of freedom : 3 translational and 3 rotational.

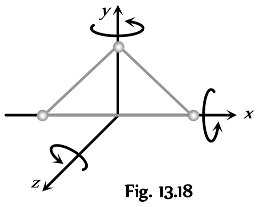
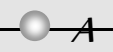
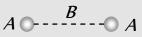
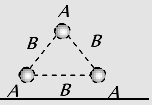
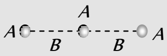


Fig. 13.18

Table 13.2 ; Degree of freedom for different gases

Atomicity of gas	Example	A	B	$f = 3A - B$	Figure
Monoatomic	*He, Ne, Ar*	1	0	$f = 3$	
Diatomic	H_2, O_2, N_2, Cl_2 *etc.*	2	1	$f = 5$	
Triatomic non linear	H_2O	3	3	$f = 6$	
Triatomic linear	CO_2, $BeCl_2$	3	2	$f = 7$	

The above degrees of freedom are shown at room temperature. Further at high temperature, in case of diatomic or polyatomic molecules, the atoms with in the molecule may also vibrate with respect to each other. In such cases, the molecule will have an additional degrees of freedom, due to vibrational motion.

An object which vibrates in one dimension has two additional degree of freedom. One for the potential energy and one for the kinetic energy of vibration.

A diatomic molecule that is free to vibrate (in addition to translation and rotation) will have $7\,(2+3+2)$ degrees of freedom.

Kinetic Energy of Ideal Gas

In ideal gases, the molecules are considered as point particles. For point particles, there is no internal excitation, no vibration and no rotation. The point particles can have only translational motion and thus only translational energy. For an ideal gas the internal energy can only be tranlational kinetic energy.

Hence kinetic energy (or internal energy) of 1 mole ideal gas

$$E = \frac{1}{2}Mv_{rms}^2 = \frac{1}{2}M \times \frac{3RT}{M} = \frac{3}{2}RT$$

Table 13.3 : Various Translational kinetic energies

Quantity of gas	Kinetic energy
1 mole gas	$\frac{3}{2}RT$; R = Universal gas constant
μ mole gas	$\frac{3}{2}\mu RT$
1 molecule	$\frac{3}{2}kT$; k = Boltzmann's constant
N molecule	$\frac{3}{2}NkT$
1 *gm* gas	$\frac{3}{2}rT$; r = Specific gas constant
m gm gas	$\frac{3}{2}mrT$

(1) Kinetic energy per molecule of gas does not depends upon the mass of the molecule but only depends upon the temperature of the gas. As $E = \frac{3}{2}kT$ or $E \propto T$ *i.e.* molecules of different gases say *He*, H_2 and O_2 *etc.* at same temperature will have same translational kinetic energy though their *r.m.s.* speed are different.

(2) For two gases at the same temperature $m_1(v_{rms})_1^2 = m_2(v_{rms})_2^2$

(3) Kinetic energy per mole of gas depends only upon the temperature of gas.

(4) Kinetic energy per *gram* of gas depend upon the temperature as well as molecular weight (or mass of one molecule) of the gas.

$$E_{gram} = \frac{3}{2}\frac{k}{m}T \Rightarrow E_{gram} \propto \frac{T}{m}$$

(5) From the above expressions it is clear that higher the temperature of the gas, more will be the average kinetic energy possessed by the gas molecules at $T = 0$, $E = 0$ *i.e.* at absolute zero the molecular motion stops.

Law of Equipartition of Energy

According to this law, for any system in thermal equilibrium, the total energy is equally distributed among its various degree of freedom. And each degree of freedom is associated with energy $\frac{1}{2}kT$ (where $k = 1.38 \times 10^{-23}\ J/K$, T = absolute temperature of the system).

(1) At a given temperature T, all ideal gas molecules no matter what their mass have the same average translational kinetic energy; namely, $\frac{3}{2}kT$. When measure the temperature of a gas, we are also measuring the average translational kinetic energy of it' s molecules.

(2) At same temperature gases with different degrees of freedom (*e.g.*, *He* and H_2) will have different average energy or internal energy namely $\frac{f}{2}kT$. (f is different for different gases)

(3) Different energies of a system of degree of freedom f are as follows

(i) Total energy associated with each molecule = $\frac{f}{2}kT$

(ii) Total energy associated with N molecules = $\frac{f}{2}NkT$

(iii) Total energy associated with μ mole = $\frac{f}{2}RT$

(iv) Total energy associated with μ molen = $\frac{f}{2}\mu RT$

(v) Total energy associated with each gram = $\frac{f}{2}rT$

(iv) Total energy associated with m gram = $\frac{f}{2}mrT$

Specific Heat (C_P and C_V) of a Gas

The specific heat of gas can have many values, but out of them following two values are very important

(1) **Specific heat at constant volume (C_v) :** The specific heat of a gas at constant volume is defined as the quantity of heat required to raise the temperature of unit mass of gas through 1°*C* or 1 *K* when its volume is kept constant, *i.e.*, $c_V = \frac{(\Delta Q)_V}{m\Delta T}$

If instead of unit mass, 1 mole of gas is considered, the specific heat is called molar specific heat at constant volume and is represented by capital C_v.

$$C_V = Mc_V = \frac{M(\Delta Q)_V}{m\Delta T} = \frac{1}{\mu}\frac{(\Delta Q)_V}{\Delta T} \qquad \left[\text{As } \mu = \frac{m}{M}\right]$$

(2) **Specific heat at constant from (C_p) :** The specific heat of a gas at constant pressure is defined as the quantity of heat required to raise the temperature of unit mass of gas through 1 *K* when its pressure is kept constant, *i.e.*, $c_P = \frac{(\Delta Q)_P}{m\Delta T}$

If instead of unit mass, 1 mole of gas is considered, the specific heat is called molar specific heat at constant pressure and is represented by C_p.

$$C_p = MC_p = \frac{M(\Delta Q)_p}{m\Delta T} = \frac{1}{\mu}\frac{(\Delta Q)_p}{\Delta T} \qquad \left[\text{As } \mu = \frac{m}{M}\right]$$

Mayer's Formula

(1) Out of two principle specific heats of a gas, C_p is more than C_v because in case of C_v, volume of gas is kept constant and heat is required only for raising the temperature of one gram mole of the gas through 1°*C* or 1 *K*. Hence no heat, what so ever, is spent in expansion of the gas.

It means that heat supplied to the gas increases its internal energy only *i.e.* $(\Delta Q)_V = \Delta U = \mu C_V \Delta T$ .....(i)

(2) While in case of C_p the heat is used in two ways

(i) In increasing the temperature of the gas by ΔT

(ii) In doing work, due to expansion at constant pressure (ΔW)

So $(\Delta Q)_P = \Delta U + \Delta W = \mu C_P \Delta T$ .....(ii)

From equation (i) and (ii) $\mu C_P \Delta T - \mu C_V \Delta T = \Delta W$

$$\Rightarrow \quad \mu \Delta T(C_P - C_V) = P\Delta V \Rightarrow \quad C_P - C_V = \frac{P\Delta V}{\mu \Delta T} = R$$

[For constant pressure, $\Delta W = P\Delta V$ also from $PV = \mu RT$,

$P\Delta V = \mu R\Delta T$]

This relation is called Mayer's formula and shows that $C_P > C_V$ *i.e.* molar specific heat at constant pressure is greater than that at constant volume.

Specific Heat in Terms of Degree of Freedom

(1) **C_v :** For a gas at temperature *T*, the internal energy $U = \frac{f}{2}\mu RT \Rightarrow$ Change in energy $\Delta U = \frac{f}{2}\mu R\Delta T$ ... (i)

Also, as we know for any gas heat supplied at constant volume $(\Delta Q)_V = \mu C_V \Delta T = \Delta U$ ... (ii)

From equation (i) and (ii) $C_V = \frac{1}{2}fR$

(2) **C_p :** From the Mayer's formula $C_p - C_v = R$

$$\Rightarrow \quad C_P = C_V + R = \frac{f}{2}R + R = \left(\frac{f}{2} + 1\right)R$$

(3) **Ratio of C_p and C_v (γ) :** $\gamma = \frac{C_P}{C_V} = \frac{\left(\frac{f}{2}+1\right)R}{\frac{f}{2}R} = 1 + \frac{2}{f}$

(i) Value of γ is different for monoatomic, diatomic and triatomic gases. $\gamma_{mono} = \frac{5}{3} = 1.6, \gamma_{di} = \frac{7}{5} = 1.4, \gamma_{tri} = \frac{4}{3} = 1.33$

(ii) Value of γ is always more than 1. So we can say that always $C_p > C_v$.

Gaseous Mixture

If two non-reactive gases are enclosed in a vessel of volume *V*. In the mixture μ_1 moles of one gas are mixed with μ_2 moles of another gas. If N_A is Avogadro's number then

Number of molecules of first gas $N_1 = \mu_1 N_A$

and number of molecules of second gas $N_2 = \mu_2 N_A$

(1) Total mole fraction $\mu = (\mu_1 + \mu_2)$.

(2) If M_1 is the molecular weight of first gas and M_2 that of second gas.

Then molecular weight of mixture $M = \frac{\mu_1 M_1 + \mu_2 M_2}{\mu_1 + \mu_2}$

(3) Specific heat of the mixture at constant volume will be

$$C_{V_{mix}} = \frac{\mu_1 C_{V_1} + \mu_2 C_{V_2}}{\mu_1 + \mu_2} = \frac{\frac{m_1}{M_1}C_{V_1} + \frac{m_2}{M_2}C_{V_2}}{\frac{m_1}{M_1} + \frac{m_2}{M_2}}$$

(4) Specific heat of the mixture at constant pressure will be

$$C_{P_{mix}} = \frac{\mu_1 C_{P_1} + \mu_2 C_{P_2}}{\mu_1 + \mu_2} = \frac{\mu_1\left(\frac{\gamma_1}{\gamma_1 - 1}\right)R + \mu_2\left(\frac{\gamma_2}{\gamma_2 - 1}\right)R}{\mu_1 + \mu_2}$$

$$= \frac{R}{\mu_1 + \mu_2}\left[\mu_1\left(\frac{\gamma_1}{\gamma_1 - 1}\right) + \mu_2\left(\frac{\gamma_2}{\gamma_2 - 1}\right)\right]$$

$$= \frac{R}{\frac{m_1}{M_1} + \frac{m_2}{M_2}}\left[\frac{m_1}{M_1}\left(\frac{\gamma_1}{\gamma_1 - 1}\right) + \frac{m_2}{M_2}\left(\frac{\gamma_2}{\gamma_2 - 1}\right)\right]$$

(5) $\gamma_{\text{mixture}} = \frac{C_{P_{mix}}}{C_{V_{mix}}} = \frac{\frac{(\mu_1 C_{P_1} + \mu_2 C_{P_2})}{\mu_1 + \mu_2}}{\frac{(\mu_1 C_{V_1} + \mu_2 C_{V_2})}{\mu_1 + \mu_2}}$

$$= \frac{\mu_1 C_{P_1} + \mu_2 C_{P_2}}{\mu_1 C_{V_1} + \mu_2 C_{V_2}} = \frac{\left\{\mu_1\left(\frac{\gamma_1}{\gamma_1-1}\right)R + \mu_2\left(\frac{\gamma_2}{\gamma_2-1}\right)R\right\}}{\left\{\mu_1\left(\frac{R}{\gamma_1-1}\right) + \mu_2\left(\frac{R}{\gamma_2-1}\right)\right\}}$$

$$\therefore\ \gamma_{\text{mixture}} = \frac{\frac{\mu_1\gamma_1}{\gamma_1-1} + \frac{\mu_2\gamma_2}{\gamma_2-1}}{\frac{\mu_1}{\gamma_1-1} + \frac{\mu_2}{\gamma_2-1}} = \frac{\mu_1\gamma_1(\gamma_2-1) + \mu_2\gamma_2(\gamma_1-1)}{\mu_1(\gamma_2-1) + \mu_2(\gamma_1-1)}$$

Tips & Tricks

✍ The cooking gas cylinder contains L.P.G. (Liquid Petroleum gas) which is saturated. And as pressure of saturated vapours is independent of volume (at constant temperature). the pressure of gas coming out of the cylinder remains constant till the cylinder becomes empty.

✍ If the number of molecules in a gas increases, then the temperature, kinetic energy and pressure of the gas increases because $P \propto n$, $T \propto n$ and kinetic energy $\propto T \propto n$.

✍ At constant volume if T increases then $\bar{v}$, v_{rms}, P and collision frequency increases.

✍ If two gases are filled in vessel then nothing can be predicted about the pressure of gases. However their mean molecular energies will be same but their *rms* velocities will be different.

✍ The average distance between two gas molecules at NTP is 10^{-9} *m*.

✍ The space available for a single gas molecule at NTP is 37.2×10^{-2} *m*.

✍ The molecules of gases will escape out from a planet if the temperature of planet $T \le \frac{Mv_e^2}{3R}$; where v_e = escape velocity from the planet, R = universal, gas constant and M = Molecular mass of the gas.

✍ As f (degree of freedom) increases then $C_P \uparrow$, $C_V \uparrow$ and $\gamma \uparrow$.

✍ The number of molecules present in 1 *gm mole* of a gas is defined as Avogadro number (N_A).

$$N_A = 6.023 \times 10^{23} \text{ per } gm\ mole = 6.023 \times 10^{26} \text{ per } kg\ mole.$$

At S.T.P. or N.T.P. (T = 273 K and P = 1 *atm*) 22.4 *litre* of each gas has 6.023×10^{23} molecule

✍ One mole of any gas at S.T.P. occupy 22.4 *litre* of volume

e.g. 32 *gm* oxygen, 28 *gm* nitrogen and 2*gm* hydrogen occupy the same volume at S.T.P.

✍ For any gas 1 *mole* = *M gram* = 22.4 *litre* = 6.023×10^{23} molecule.

✍ $v_{rms} : v_{av} : v_{mp} = \sqrt{3} : \sqrt{\frac{8}{\pi}} : \sqrt{2} = \sqrt{3} : \sqrt{2.5} : \sqrt{2}$

✍ For oxygen gas molecules v_{rms} = 461 *m/s*, v_{av} = 424.7 *m/s* and v_{rms} = 376.4 *m/s*

✍ An atom in a solid though has no degree of freedom for translational and rotational motion, due to vibration along 3 axes has 3 × 2 = 6 degrees of freedom (and not like an ideal gas molecule). When a diatomic or polyatomic gas dissociates into atoms it behaves as monoatomic gas whose degree of freedom are changed accordingly

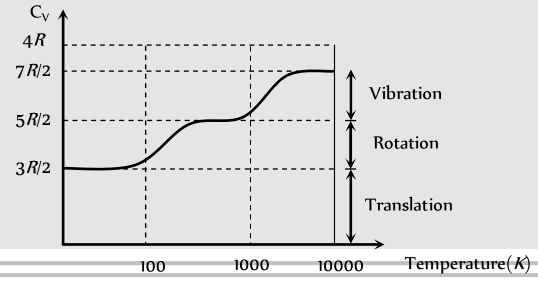
✍ In General a polyatmic molecule has 3 translational, 3 rotational degree of freedom and a certain number of vibration mode f_{vib}. Hence $\gamma_{poly} = \frac{4 + f_{vib}}{3 + f_{vib}}$.

✍ Only average translational kinetic energy of a gas contributes to its temperature. Two gases with the same average translational kinetic energy have the same temperature even if one has grater rotational energy and thus greater internal energy.

✍ Unsaturated vapours obey gas laws while saturated vapours don't.

✍ For real gases effective volume is considered as $(V - \mu b)$ where $b = 4N_A\left(\frac{4}{3}\pi r^3\right)$; r = radius of each molecule and N_A = avogrado number.

✍ Variation of degree of freedom of a diatomic gas (H_2) with temperature. At very low temperature only translation is possible. as the temperature increases rotational motion can begin. At still higher temperatures vibratory motion can begin.



Ordinary Thinking

Objective Questions

Gas Laws

1. The temperature of a gas at pressure P and volume V is 27°*C*. Keeping its volume constant if its temperature is raised to 927°*C*, then its pressure will be [MP PMT 1985]

(a) 2 P (b) 3 P

(c) 4 P (d) 6 P

2. 4 moles of an ideal gas is at 0°*C*. At constant pressure it is heated to double its volume, then its final temperature will be

(a) 0°*C* (b) 273°*C*

(c) 546°*C* (d) 136.5°*C*

3. Every gas (real gas) behaves as an ideal gas [CPMT 1997; RPMT 2000; MP PET 2001]

(a) At high temperature and low pressure
(b) At low temperature and high pressure
(c) At normal temperature and pressure
(d) None of the above

4. Boyle's law holds for an ideal gas during [AFMC 1994; KCET 1999]

(a) Isobaric changes (b) Isothermal changes
(c) Isochoric changes (d) Isotonic changes

5. S.I. unit of universal gas constant is [MNR 1988; MP PMT 1994; UPSEAT 1999]

(a) $cal/^{\circ}C$ (b) J/mol
(c) $J\,mol^{-1}\,K^{-1}$ (d) J/kg

6. Molecules of a gas behave like [J & K CET 2000]

(a) Inelastic rigid sphere
(b) Perfectly elastic non-rigid sphere
(c) Perfectly elastic rigid sphere
(d) Inelastic non-rigid sphere

Ordinary Thinking

Objective Questions

Communication

1. In short wave communication waves of which of the following frequencies will be reflected back by the ionospheric layer, having electron density 10^{11} per *m* [AIIMS 2003]
   (a) 2 *MHz* (b) 10 *MHz*
   (c) 12 *MHz* (d) 18 *MHz*

2. In an amplitude modulated wave for audio frequency of 500 *cycle/second*, the appropriate carrier frequency will be [AMU 1996]
   (a) 50 *cycles/sec* (b) 100 *cycles/sec*
   (c) 500 *cycles/sec* (d) 50,000 *cycles/sec*

3. AM is used for broadcasting because
   (a) It is more noise immune than other modulation systems
   (b) It requires less transmitting power compared with other systems
   (c) Its use avoids receiver complexity
   (d) No other modulation system can provide the necessary bandwidth faithful transmission

4. Range of frequencies allotted for commercial FM radio broadcast is
   (a) 88 to 108 *MHz* (b) 88 to 108 *kHz*
   (c) 8 to 88 *MHz* (d) 88 to 108 *GHz*

5. The velocity factor of a transmission line *x*. If dielectric constant of the medium is 2.6, the value of *x* is [AFMC 1995]
   (a) 0.26 (b) 0.62
   (c) 2.6 (d) 6.2

6. The process of superimposing signal frequency (*i.e.* audio wave) on the carrier wave is known as [AIIMS 1987]
   (a) Transmission (b) Reception
   (c) Modulation (d) Detection

7. Long distance short-wave radio broadcasting uses [AFMC 1996]
   (a) Ground wave (b) Ionospheric wave
   (c) Direct wave (d) Sky wave

8. A step index fibre has a relative refractive index of 0.88%. What is the critical angle at the corecladding interface [Manipal 2003]
   (a) 60° (b) 75°
   (c) 45° (d) None of these

9. The characteristic impedance of a coaxial cable is of the order of
   (a) 50 Ω (b) 200 Ω
   (c) 270 Ω (d) None of these

10. In which frequency range, space waves are normally propagated
    (a) HF (b) VHF
    (c) UHF (d) SHF

11. If μ_1 and μ_2 are the refractive indices of the materials of core and cladding of an optical fibre, then the loss of light due to its leakage can be minimised by having [BVP 2003]
    (a) $\mu_1 > \mu_2$ (b) $\mu_1 < \mu_2$
    (c) $\mu_1 = \mu_2$ (d) None of these

12. Through which mode of propagation, the radio waves can be sent from one place to another [JIPMER 2003]
    (a) Ground wave propagation
    (b) Sky wave propagation
    (c) Space wave propagation
    (d) All of them

13. A laser beam of pulse power 10^{12} *watt* is focussed on an object are 10^{-4} *cm*. The energy flux in *watt/ cm* at the point of focus is
    (a) 10^{20} (b) 10^{16}
    (c) 10^{8} (d) 10^{4}

14. The carrier frequency generated by a tank circuit containing 1 *nF* capacitor and 10 μH inductor is [AFMC 2003]
    (a) 1592 *Hz* (b) 1592 *MHz*
    (c) 1592 *kHz* (d) 159.2 *Hz*

15. Broadcasting antennas are generally [AFMC 2003]
    (a) Omnidirectional type (b) Vertical type
    (c) Horizontal type (d) None of these

16. For television broadcasting, the frequency employed is normally
    (a) 30-300 *MHz* (b) 30-300 *GHz*
    (c) 30-300 *KHz* (d) 30-300 *Hz*

17. The radio waves of frequency 300 *MHz* to 3000 *MHz* belong to
    (a) High frequency band [MNR 1997]
    (b) Very high frequency band
    (c) Ultra high frequency band
    (d) Super high frequency band

18. An antenna behaves as resonant circuit only when its length is
    (a) $\frac{\lambda}{2}$
    (b) $\frac{\lambda}{4}$
    (c) λ
    (d) $\frac{\lambda}{2}$ or integral multiple of $\frac{\lambda}{2}$

19. Maximum useable frequency (MUF) in *F*-region layer is *x*, when the critical frequency is 60 *MHz* and the angle of incidence is 70°. Then *x* is [Himachal PMT 2003]
    (a) 150 *MHz* (b) 170 *MHz*
    (c) 175 *MHz* (d) 190 *MHz*

20. The electromagnetic waves of frequency 2 *MHz* to 30 *MHz* are
    (a) In ground wave propagation
    (b) In sky wave propagation
    (c) In microwave propagation
    (d) In satellite communication [CPMT 2003]

21. A laser is a coherent source because it contains [JIPMER 2003]
    (a) Many wavelengths [EAMCET 2002]
    (b) Uncoordinated wave of a particular wavelength

(c) Coordinated wave of many wavelengths

(d) Coordinated waves of a particular wavelength

22. The attenuation in optical fibre is mainly due to

[AFMC 2003]

(a) Absorption

(b) Scattering

(c) Neither absorption nor scattering

(d) Both (a) and (b)

23. The maximum distance upto which TV transmission from a TV tower of height h can be received is proportional to

[AIIMS 2003]

(a) $h^{1/2}$ (b) h

(c) $h^{3/2}$ (d) h^2

24. A laser beam is used for carrying out surgery because it

[AIIMS 2003]

(a) Is highly monochromatic (b) Is highly coherent

(c) Is highly directional (d) Can be sharply focussed

25. Laser beams are used to measure long distances because

[DCE 2002, 03]

(a) They are monochromatic

(b) They are highly polarised

(c) They are coherent

(d) They have high degree of parallelism

26. An oscillator is producing FM waves of frequency 2 *kHz* with a variation of 10 *kHz*. What is the modulating index

[DCE 2004]

(a) 0.20 (b) 5.0

(c) 0.67 (d) 1.5

27. The maximum peak to peak voltage of an AM wire is 24 *mV* and the minimum peak to peak voltage is 8 *mV*. The modulation factor is

(a) 10% (b) 20%

(c) 25% (d) 50%

28. Sinusoidal carrier voltage of frequency 1.5 *MHz* and amplitude 50 *V* is amplitude modulated by sinusoidal voltage of frequency 10 *kHz* producing 50% modulation. The lower and upper side-band frequencies in *kHz* are

(a) 1490, 1510 (b) 1510, 1490

(c) $\frac{1}{1490}, \frac{1}{1510}$ (d) $\frac{1}{1510}, \frac{1}{1490}$

29. What is the modulation index of an over modulated wave

(a) 1 (b) Zero

(c) < 1 (d) > 1

30. Basically, the product modulator is

(a) An amplifier (b) A mixer

(c) A frequency separator (d) A phase separator

31. If f_a and f_f represent the carrier wave frequencies for amplitude and frequency modulations respectively, then

(a) $f_a > f_f$ (b) $f_a < f_f$

(c) $f_a \approx f_f$ (d) $f_a \geq f_f$

32. Which of the following is the disadvantage of FM over AM

(a) Larger band width requirement

(b) Larger noise

(c) Higher modulation power

(d) Low efficiency

33. If a number of sine waves with modulation indices n_1, n_2, n_3 .... modulate a carrier wave, then total modulation index (n) of the wave is

(a) $n_1 + n_2 .... + 2(n_1 + n_2.....)$

(b) $\sqrt{n_1 - n_2 + n_3..........}$

(c) $\sqrt{n_1^2 + n_2^2 + n_3^2.........}$

(d) None of these

34. An AM wave has 1800 *watt* of total power content, For 100% modulation the carrier should have power content equal to

(a) 1000 *watt* (b) 1200 *watt*

(c) 1500 *watt* (d) 1600 *watt*

35. The frequency of a FM transmitter without signal input is called

(a) Lower side band frequency

(b) Upper side band frequency

(c) Resting frequency

(d) None of these

36. What type of modulation is employed in India for radio transmission

(a) Amplitude modulation (b) Frequency modulation

(c) Pulse modulation (d) None of these

37. When the modulating frequency is doubled, the modulation index is halved and the modulating voltage remains constant, the modulation system is

(a) Amplitude modulation (b) Phase modulation

(c) Frequency modulation (d) All of the above

38. An antenna is a device

(a) That converts electromagnetic energy into radio frequency signal

(b) That converts radio frequency signal into electromagnetic energy

(c) That converts guided electromagnetic waves into free space electromagnetic waves and vice-versa

(d) None of these

39. While tuning in a certain broadcast station with a receiver, we are actually

(a) Varying the local oscillator frequency

(b) Varying the frequency of the radio signal to be picked up

(c) Tuning the antenna

(d) None of these

40. Indicate which one of the following system is digital

(a) Pulse position modulation

(b) Pulse code modulation

(c) Pulse width modulation

(d) Pulse amplitude modulation

41. In a communication system, noise is most likely to affect the signal

(a) At the transmitter

(b) In the channel or in the transmission line

(c) In the information source

(d) At the receiver

42. The waves used in telecommunication are

(a) IR (b) UV

(c) Microwave (d) Cosmic rays

43. In an FM system a 7 *kHz* signal modulates 108 *MHz* carrier so that frequency deviation is 50 *kHz*. The carrier swing is

(a) 7.143 (b) 8

(c) 0.71 (d) 350

44. Consider telecommunication through optical fibres. Which of the following statements is not true [AIEEE 2003]

(a) Optical fibres may have homogeneous core with a suitable cladding

(b) Optical fibres can be of graded refractive index

(c) Optical fibres are subject to electromagnetic interference from outside

(d) Optical fibres have extremely low transmission loss

45. The phenomenon by which light travels in an optical fibres is

(a) Reflection (b) Refraction

(c) Total internal reflection (d) Transmission

46. Television signals on earth cannot be received at distances greater than 100 *km* from the transmission station. The reason behind this is that [DCE 1995]

(a) The receiver antenna is unable to detect the signal at a distance greater than 100 *km*

(b) The TV programme consists of both audio and video signals

(c) The TV signals are less powerful than radio signals

(d) The surface of earth is curved like a sphere

47. Advantage of optical fibre [DCE 2005]

(a) High bandwidth and EM interference

(b) Low bandwidth and EM interference

(c) High band width, low transmission capacity and no EM interference

(d) High bandwidth, high data transmission capacity and no EM interference

48. In frequency modulation [Kerala PMT 2005]

(a) The amplitude of modulated wave varies as frequency of carrier wave

(b) The frequency of modulated wave varies as amplitude of modulating wave

(c) The amplitude of modulated wave varies as amplitude of carrier wave

(d) The frequency of modulated wave varies as frequency of modulating wave

(e) The frequency of modulated wave varies as frequency of carrier wave

49. Audio signal cannot be transmitted because

[Kerala PMT 2005]

(a) The signal has more noise

(b) The signal cannot be amplified for distance communication

(c) The transmitting antenna length is very small to design

(d) The transmitting antenna length is very large and impracticable

(e) The signal is not a radio signal

50. In which of the following remote sensing technique is not used

(a) Forest density (b) Pollution

(c) Wetland mapping (d) Medical treatment

51. For sky wave propagation of a 10 *MHz* signal, what should be the minimum electron density in ionosphere

[AIIMS 2005]

(a) $\sim 1.2 \times 10^{12}\ m^{3}$ (b) $\sim 10^{6}\ m^{3}$

(c) $\sim 10^{14}\ m^{3}$ (d) $\sim 10^{22}\ m^{3}$

52. What should be the maximum acceptance angle at the aircore interface of an optical fibre if n_1 and n_2 are the refractive indices of the core and the cladding, respectively

[AIIMS 2005]

(a) $\sin^{-1}(n_2 / n_1)$ (b) $\sin^{-1}\sqrt{n_1^2 - n_2^2}$

(c) $\left[\tan^{-1}\dfrac{n_2}{n_1}\right]$ (d) $\left[\tan^{-1}\dfrac{n_1}{n_2}\right]$

[DCE 2001]

Critical Thinking

Objective Questions

1. A sky wave with a frequency 55 *MHz* is incident on *D*-region of earth's atmosphere at 45°. The angle of refraction is (electron density for *D*-region is 400 $electron/cm^3$)

[Haryana PMT 2003]

(a) 60° (b) 45°

(c) 30° (d) 15°

2. In a diode AM-detector, the output circuit consist of $R = 1k\Omega$ and $C = 10\ pF$. A carrier signal of 100 *kHz* is to be detected. Is it good

(a) Yes

(b) No

(c) Information is not sufficient

(d) None of these

3. Consider an optical communication system operating at $\lambda \sim 800\ nm$. Suppose, only 1% of the optical source frequency is the available channel bandwidth for optical communication. How many channels can be accommodated for transmitting audio signals requiring a bandwidth of 8 *kHz*

(a) 4.8×10^{8} (b) 48

(c) 6.2×10^{8} (d) 4.8×10^{5}

4. A photodetector is made from a semiconductor $In_{0.53}Ga_{0.47}As$ with $E_g = 0.73\ eV$. What is the maximum wavelength, which it can detect

(a) 1000 *nm* (b) 1703 *nm*

(c) 500 *nm* (d) 173 *nm*

5. A transmitter supplies 9 *kW* to the aerial when unmodulated. The power radiated when modulated to 40% is

(a) 5 *kW* (b) 9.72 *kW*

(c) 10 *kW* (d) 12 *kW*

6. The antenna current of an AM transmitter is 8 *A* when only carrier is sent but increases to 8.96 *A* when the carrier is sinusoidally modulated. The percentage modulation is

(a) 50% (b) 60%

(c) 65% (d) 71%

7. The total power content of an AM wave is 1500 *W*. For 100% modulation, the power transmitted by the carrier is

(a) 500 *W* (b) 700 *W*

(c) 750 *W* (d) 1000 *W*

8. The total power content of an AM wave is 900 *W*. For 100% modulation, the power transmitted by each side band is

(a) 50 *W* (b) 100 *W*

(c) 150 *W* (d) 200 *W*

9. The modulation index of an FM carrier having a carrier swing of 200 *kHz* and a modulating signal 10 *kHz* is

(a) 5 (b) 10

(c) 20 (d) 25

10. A 500 *Hz* modulating voltage fed into an FM generator produces a frequency deviation of 2.25 *kHz*. If amplitude of the voltage is kept constant but frequency is raised to 6 *kHz* then the new deviation will be

(a) 4.5 *kHz* (b) 54 *kHz*

(c) 27 *kHz* (d) 15 *kHz*

11. The audio signal used to modulate 60 sin $(2\pi \times 10^6\ t)$ is $15\sin 300\pi t$. The depth of modulation is

(a) 50% (b) 40%

(c) 25% (d) 15%

12. The bit rate for a signal, which has a sampling rate of 8 *kHz* and where 16 quantisation levels have been used is

(a) 32000 *bits/sec* (b) 16000 *bits/sec*

(c) 64000 *bits/sec* (d) 72000 *bits/sec*

13. An amplitude modulated wave is modulated to 50%. What is the saving in power if carrier as well as one of the side bands are suppressed

(a) 70% (b) 65.4%

(c) 94.4% (d) 25.5%

14. In AM, the centpercent modulation is achieved when

(a) Carrier amplitude = signal amplitude

(b) Carrier amplitude ≠ signal amplitude

(c) Carrier frequency = signal frequency

(d) Carrier frequency ≠ signal frequency

Assertion & Reason

For AIIMS Aspirants

Read the assertion and reason carefully to mark the correct option out of the options given below:

(a) If both assertion and reason are true and the reason is the correct explanation of the assertion.
(b) If both assertion and reason are true but reason is not the correct explanation of the assertion.
(c) If assertion is true but reason is false.
(d) If the assertion and reason both are false.
(e) If assertion is false but reason is true.

1. Assertion : Diode lasers are used as optical sources in optical communication.

Reason : Diode lasers consume less energy. [AIIMS 2005]

2. Assertion : Television signals are received through sky-wave propagation.

Reason : The ionosphere reflects electromagnetic waves of frequencies greater than a certain critical frequency. [AIIMS 2005]

3. Assertion : In high latitude one sees colourful curtains of light hanging down from high altitudes.

Reason : The high energy charged particles from the sun are deflected to polar regions by the magnetic field of the earth. [AIIMS 2003]

4. Assertion : Short wave bands are used for transmission of radio waves to a large distance.

Reason : Short waves are reflected by ionosphere [AIIMS 1994]

5. Assertion : The electrical conductivity of earth's atmosphere decreases with altitude.

Reason : The high energy particles (*i.e.* γ-rays and cosmic rays) coming from outer space and entering our earth's atmosphere cause ionisation of the atoms of the gases present there and the pressure of gases decreases with increase in altitude.

6. Assertion : The electromagnetic waves of shorter wavelength can travel longer distances on earth's surface than those of longer wavelengths.

Reason : Shorter the wavelength, the larger is the velocity of wave propagation.

7. Assertion : The surface wave propagation is used for medium wave band and for television broadcasting.

Reason : The surface waves travel directly from transmitting antenna to receiver antenna through atmosphere.

8. Assertion : The television broadcasting becomes weaker with increasing distance.

Reason : The power transmitted from TV transmitter varies inversely as the distance of the receiver

9. Assertion : Microwave propagation is better than the sky wave propagation.

Reason : Microwaves have frequencies 100 to 300 *GHz*, which have very good directional properties.

10. Assertion : Satellite is an ideal platform for remote sensing.

Reason : Satellite in polar orbit can provide global coverage or continuous coverage of the fixed area in geostationary configuration.

11. Assertion : Fax is a modulating and demodulating device.

Reason : It is necessary for exact reproduction of a document.

12. Assertion : A dish antenna is highly directional.

Reason : This is because a dipole antenna is omni directional.

Answers

Communication

1	a	2	d	3	c	4	a	5	b
6	c	7	c	8	d	9	c	10	c
11	a	12	d	13	b	14	c	15	b
16	a	17	c	18	d	19	c	20	b
21	d	22	d	23	a	24	d	25	d
26	b	27	d	28	a	29	d	30	b
31	b	32	a	33	c	34	b	35	c
36	a	37	c	38	c	39	a	40	b
41	b	42	c	43	a	44	c	45	c
46	d	47	d	48	b	49	d	50	d
51	a	52	b						

Critical Thinking Questions

1	b	2	b	3	a	4	b	5	b
6	d	7	d	8	c	9	b	10	b
11	c	12	a	13	c	14	a		

Assertion & Reason

For AIIMS Aspirants

Read the assertion and reason carefully to mark the correct option out of the options given below:

(a) *If both assertion and reason are true and the reason is the correct explanation of the assertion.*
(b) *If both assertion and reason are true but reason is not the correct explanation of the assertion.*
(c) *If assertion is true but reason is false.*
(d) *If the assertion and reason both are false.*
(e) *If assertion is false but reason is true.*

1. Assertion : In pressure-temperature (P-T) phase diagram of water, the slope of the melting curve is found to be negative.

Reason : Ice contracts on melting to water.

[AIIMS 2005]

2. Assertion : For gas atom the number of degrees of freedom is 3.

Reason : $\frac{C_P}{C_V} = \gamma$ [AIIMS 2000]

3. Assertion : A gas have a unique value of specific heat.

Reason : Specific heat is defined as the amount of heat required to raise the temperature of unit mass of the substance through unit degree.

4. Assertion : A gas can be liquified at any temperature by increase of pressure alone.

Reason : On increasing pressure the temperature of gas decreases.

5. Assertion : Equal masses of helium and oxygen gases are given equal quantities of heat. There will be a greater rise in the temperature of helium compared to that of oxygen.

Reason : The molecular weight of oxygen is more than the molecular weight of helium.

6. Assertion : Absolute zero is the temperature corresponding to zero energy.

Reason : The temperature at which no molecular motion cease is called absolute zero temperature.

7. Assertion : The ratio of specific heat gas at constant pressure and specific heat at constant volume for a diatomic gas is more than that for a monatomic gas.

Reason : The molecules of a monatomic gas have more degree of freedom than those of a diatomic gas.

8. Assertion : At room temperature, water does not sublimate from water to steam.

Reason : The critical point of water is much above the room temperature.

9. Assertion : Specific heat of a gas at constant pressure (C) is greater than its specific heat at constant volume (C).

Reason : At constant pressure, some heat is spent in expansion of the gas.

10. Assertion : The internal energy of a real gas is function of both, temperature and volume.

Reason : Internal kinetic energy depends on temperature and internal potential energy depends on volume.

11. Assertion : For an ideal gas, at constant temperature, the product of the pressure and volume is constant.

Reason : The mean square velocity of the molecules is inversely proportional to mass. [AIIMS 1998]

12. Assertion : If a gas container in motion is suddenly stopped, the temperature of the gas rises.

Reason : The kinetic energy of ordered mechanical motion is converted in to the kinetic energy of random motion of gas molecules.

13. Assertion : Internal energy of an ideal gas does not depend upon volume of the gas

Reason : Internal energy of ideal gas depends on temperature of gas.

14. Assertion : At low density, variables of gases P, V and T follows the equation $PV = \mu RT$

Reason : At low density real gases are more closely to ideal gases

15. Assertion : Maxwell speed distribution graph is symmetric about most probable speed

Reason : *rms* speed of ideal gas, depends upon it's type (monoatomic, diatomic and polyatomic)

Answers

Gas Laws

1	c	2	b	3	a	4	b	5	c
6	c	7	c	8	c	9	a	10	d
11	a	12	d	13	b	14	d	15	c
16	b	17	c	18	a	19	a	20	d
21	c	22	b	23	a	24	a	25	a
26	a	27	c	28	a	29	c	30	c
31	d	32	c	33	a	34	d	35	a
36	a	37	c	38	a	39	a	40	c
41	d	42	b	43	a	44	c	45	a
46	a	47	d	48	d	49	c	50	d
51	c	52	c	53	c	54	b	55	d
56	c	57	c	58	a	59	d	60	a
61	d	62	c	63	d	64	d	65	c
66	b	67	a	68	d	69	d	70	c
71	c	72	c	73	d	74	b	75	c
76	c	77	c	78	a	79	c	80	c
81	b	82	a	83	c	84	b	85	c
86	d	87	c	88	c	89	b	90	a
91	b	92	a	93	a	94	d	95	a
96	c	97	a	98	a	99	c	100	c

Speed of Gas

1	b	2	a	3	c	4	c	5	a
6	a	7	d	8	d	9	a	10	a
11	c	12	d	13	b	14	c	15	a

16	a	17	a	18	d	19	c	20	a
21	d	22	c	23	c	24	a	25	d
26	a	27	b	28	d	29	a	30	b
31	c	32	b	33	d	34	c	35	a
36	b	37	a	38	c	39	d	40	a
41	d	42	a	43	c	44	b	45	b
46	c	47	c	48	b	49	b	50	a
51	b	52	b	53	b	54	d	55	a
56	a	57	c	58	b	59	d	60	a
61	c	62	b	63	b	64	d	65	a
66	b	67	b	68	a				

Degree of Freedom and Specific Heat

1	a	2	c	3	a	4	a	5	c
6	d	7	c	8	b	9	d	10	d
11	c	12	a	13	b	14	d	15	a
16	a	17	a	18	a	19	b	20	a
21	c	22	b	23	c	24	d	25	b
26	d	27	d	28	a	29	b	30	d
31	a	32	c	33	a	34	c	35	a
36	d	37	a	38	a	39	b	40	c
41	b	42	b	43	b	44	d	45	b
46	c	47	c	48	d				

Pressure and Energy

1	c	2	b	3	c	4	d	5	d
6	d	7	d	8	a	9	a	10	b
11	d	12	c	13	c	14	a	15	d
16	d	17	b	18	b	19	c	20	a
21	c	22	b	23	b	24	c	25	a
26	b	27	d	28	d	29	c	30	d
31	a	32	a	33	c	34	c	35	d
36	c	37	a	38	b	39	ac	40	d
41	d	42	b	43	a	44	a	45	a
46	b	47	a	48	a	49	d	50	a
51	c	52	c	53	d	54	c	55	b
56	c	57	d	58	d	59	c	60	c
61	a	62	c	63	c	64	a		

Critical Thinking Questions

1	d	2	d	3	a	4	b	5	a
6	acd	7	b	8	b	9	cd	10	b
11	b	12	bc	13	d	14	d	15	a
16	c	17	d	18	b	19	d	20	d
21	a	22	c	23	b	24	a	25	c
26	c	27	c	28	c	29	d	30	d
31	d	32	b	33	a	34	a	35	d
36	c	37	c	38	d				

Graphical Questions

1	d	2	b	3	c	4	c	5	c
6	c	7	a	8	b	9	a	10	c
11	b	12	c	13	c	14	a	15	b
16	b	17	a	18	a	19	b	20	c
21	a	22	c	23	b	24	b	25	a

Assertion and Reason

1	a	2	b	3	e	4	d	5	b
6	e	7	d	8	a	9	a	10	a
11	b	12	a	13	b	14	a	15	d

Answers and Solutions

Gas Laws

1. (c) Using Charle's law $\frac{P_1}{P_2}=\frac{T_1}{T_2}$

or $P_2=\frac{P_1T_2}{T_1}=\frac{P(273+927)}{(273+27)}=4P.$

2. (b) $\frac{V_1}{V_2}=\frac{T_1}{T_2}\Rightarrow T_2=2\times T_1=2\times(273+0)=546K$

$\Rightarrow T_2=273\times 2=546K\Rightarrow 273^{\circ}C\Rightarrow 273^{\circ}C$

Kinetic Theory of Gases

SET Self Evaluation Test -13

1. An ideal gas has an initial pressure of 3 pressure units and an initial volume of 4 volume units. The table gives the final pressure and volume of the gas (in those same units) in four, processes. Which processes start and end on the same isotherm

	A	B	C	D
P	5	4	12	6
V	7	6	1	3

(a) A
(b) B
(c) C
(d) D

2. Suppose ideal gas equation follows $VP^3 =$ constant. Initial temperature and volume of the gas are T and V respectively. If gas expand to $27V$ then its temperature will be come

(a) T (b) $9T$
(c) $27T$ (d) $T/9$

3. One mole of a monoatomic ideal gas is mixed with one mole of a diatomic ideal gas. The molar specific heat of the mixture at constant volume is

(a) 8 (b) $\frac{3}{2}R$
(c) $2R$ (d) $2.5\ R$

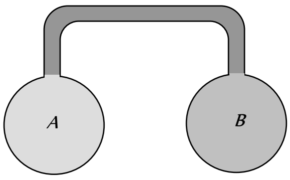
4. When the temperature of a gas is raised from 27°C to 90°C, the percentage increase in the *r.m.s.* velocity of the molecules will be

(a) 10% (b) 15%
(c) 20% (d) 17.5%

5. A gas is enclosed in a closed pot. On keeping this pot in a train moving with high speed, the temperature of the gas

(a) Will increase
(b) Will decrease
(c) Will remain the same
(d) Will change according to the nature of the gas

6. Two spherical vessel of equal volume, are connected by *a n* arrow tube. The apparatus contains an ideal gas at one atmosphere and 300*K*. Now if one vessel is immersed in a bath of constant temperature 600*K* and the other in a bath of constant temperature 300*K*. Then the common pressure will be



(a) 1 *atm*
(b) $\frac{4}{5}$ *atm*
(c) $\frac{4}{3}$ *atm*
(d) $\frac{3}{4}$ *atm*

7. The *r.m.s.* velocity of a gas at a certain temperature is $\sqrt{2}$ times than that of the oxygen molecules at that temperature. The gas can be

(a) H_2 (b) He
(c) CH_4 (d) SO_2

8. At what temperature, the mean kinetic energy of O_2 will be the same for H_2 molecules at – 73°C

(a) 127°C (b) 527°C
(c) – 73°C (d) – 173°C

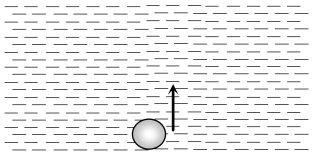
9. The volume of a gas at pressure $21 \times 10^4\ N/m^2$ and temperature 27°C is 83 *litres*. If R = 8.3 *J/mol/K*, then the quantity of gas in *gm-mole* will be

(a) 15 (b) 42
(c) 7 (d) 14

10. The pressure and temperature of an ideal gas in a closed vessel are 720 *kPa* and 40°C respectively. If $\frac{1}{4}$th of the gas is released from the vessel and the temperature of the remaining gas is raised to 353°C, the final pressure of the gas is **[EAMCET (Med.) 2000]**

(a) 1440 *kPa* (b) 1080 *kPa*
(c) 720 *kPa* (d) 540 *kPa*

11. An air bubble doubles its radius on raising from the bottom of water reservoir to be the surface of water in it. If the atmospheric pressure is equal to 10 *m* of water, the height of water in the reservoir is **[EAMCET Med.1999]**



(a) 10 *m*
(b) 20 *m*
(c) 70 *m*
(d) 80 *m*

12. If the *r.m.s.* velocity of a gas at a given temperature (Kelvin scale) is 300 *m/sec*. What will be the *r.m.s.* velocity of a gas having twice the molecular weight and half the temperature on Kelvin scale =

(a) 300 *m/sec* (b) 600 *m/sec*
(c) 75 *m/sec* (d) 150 *m/sec*

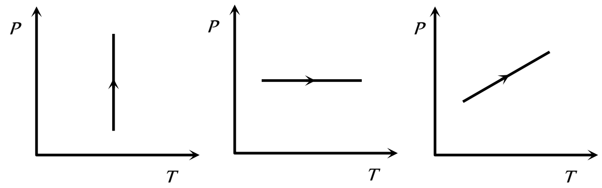
13. The ratio of two specific heats $\frac{C_P}{C_V}$ of CO is

(a) 1.33 (b) 1.40
(c) 1.29 (d) 1.66

14. The energy of a *gas/litre* is 300 joules, then its pressure will be

(a) $3 \times 10^5\ N/m^2$ (b) $6 \times 10^5\ N/m^2$
(c) $10^5\ N/m^2$ (d) $2 \times 10^5\ N/m^2$

15. Pressure versus temperature graphs of an ideal gas are as shown in figure. Choose the wrong statement



(a) Density of gas is increasing in graph (i)
(b) Density of gas is decreasing in graph (ii)
(c) Density of gas is constant in graph (iii)
(d) None of these

16. If pressure of CO_2 (real gas) in a container is given by $P = \frac{RT}{2V - b} - \frac{a}{4b^2}$ then mass of the gas in container is

(a) 11 *gm* (b) 22 *gm*

(c) 33 *gm* (d) 44 *gm*

17. A cylinder of fixed capacity 44.8 *litre.* contains a monatomic gas at standard temperature and pressure. The amount of heat required to cylinder by 10°*C* will be.

(*R*= universal gas constant)

(a) *R* (b) 10*R*

(c) 20*R* (d) 30*R*

18. A pressure cooker contains air at 1 *atm* and 30°*C*. If the safety value of the cooler blows when the inside pressure ≥ 3 *atm*, then the maximum temperature of the air, inside the cooker can be

(a) 90°*C* (b) 636°*C*

(c) 909°*C* (d) 363°*C*

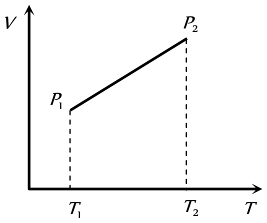
19. One mole of an ideal monatomic gas requires 210 *J* heat to raise the temperature by 10 *K*, when heated at constant temperature. If the same gas is heated at constant volume to raise the temperature by 10 *K* then heat required is

[Pb. PET 2000]

(a) 238 *J* (b) 126 *J*

(c) 210 *J* (d) 350 *J*

20. From the following *V-T* diagram we can conclude



(a) $P_1 = P_2$

(b) $P_1 > P_2$

(c) $P_1 < P_2$

(d) None of these

21. A cylinder contains 10 *kg* of gas at pressure of $10^7\ N/m^2$. The quantity of gas taken out of the cylinder, if final pressure is $2.5 \times 10^6\ N/m^2$, will be (Temperature of gas is constant)

[EAMCET 1998; Pb. PMT 1999; 2003; DPMT 199, 2003]

(a) 15.2 *kg* (b) 3.7 *kg*

(c) Zero (d) 7.5 *kg*

22. Certain amount of an ideal gas are contained in a closed vessel. The vessel is moving with a constant velocity *v*. The molecular mass of gas is *M*. The rise in temperature of the gas when the vessel is suddenly stopped is $(\gamma = C_P / C_V)$

(a) $\frac{Mv^2}{2R(\gamma + 1)}$ (b) $\frac{Mv^2(\gamma - 1)}{2R}$

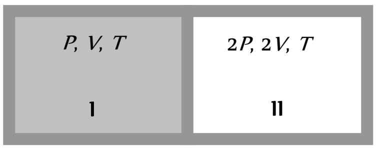
(c) $\frac{Mv^2}{2R(\gamma + 1)}$ (d) $\frac{Mv^2}{2R(\gamma + 1)}$

23. Air is filled at 60°*C* in a vessel of open mouth. The vessel is heated to a temperature *T* so that 1/4th part of air escapes. Assuming the volume of the vessel remaining constant, the value of *T* is

(a) 80°*C* (b) 444°*C*

(c) 333°*C* (d) 171°*C*

24. A partition divides a container having insulated walls into two compartments I and II. the same gas fills the two compartments. The ratio of the number of molecules in compartments I and II is



(a) 1 : 6

(b) 6 : 1

(c) 4 : 1

(d) 1 : 4

25. Considering the gases to be ideal, the value of $\gamma = \frac{C_P}{C_V}$ for a gaseous mixture consisting of = 3 moles of carbon dioxide and 2 moles of oxygen will be $(\gamma_{O_2} = 1.4, \gamma_{CO_2} = 1.3)$

[UPSEAT 2000; Pb. PET 2004]

(a) 1.37 (b) 1.34

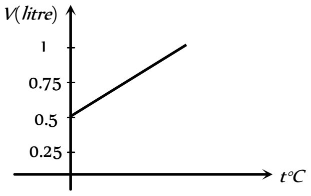
(c) 1.55 (d) 1.63

26. A jar has a mixture of hydrogen and oxygen gas in the ratio of 1 : 5. The ratio of mean kinetic energies of hydrogen and oxygen molecules is [CPMT 1977]

(a) 1 : 16 (b) 1 : 4

(c) 1 : 5 (d) 1 : 1

27. Graph between volume and temperature for a gas is shown in figure. If α = volume coefficient of gas = $\frac{1}{273}$ *per* °*C*, then what is the volume of gas at a temperature of 819°*C*



(a) $1 \times 10^{-3}\ m^3$

(b) $2 \times 10^{-3}\ m^3$

(c) $3 \times 10^{-3}\ m^3$

(d) $4 \times 10^{-3}\ m^3$

Answers and Solutions

(SET -13)

1. (c) For same isotherm ; *T* → constant

$$\therefore\ P \propto \frac{1}{V} \Rightarrow P_1V_1 = P_2V_2$$

2. (b) VP^3 = constant = $k \Rightarrow P = \frac{k}{V^{1/3}}$

Also $PV = \mu RT \Rightarrow \frac{k}{V^{1/3}}.V = \mu RT \Rightarrow V^{2/3} = \frac{\mu RT}{k}$

Hence $\left(\frac{V_1}{V_2}\right)^{2/3} = \frac{T_1}{T_2} \Rightarrow \left(\frac{V}{27V}\right)^{2/3} = \frac{T}{T_2} \Rightarrow T_2 = 9\,T$

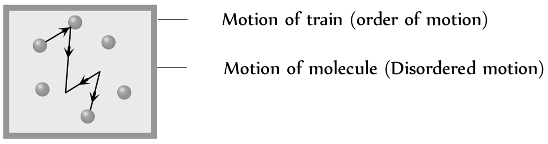
3. (c) $(C_V)_{mix} = \frac{\mu_1 C_{V_1} + \mu_2 C_{V_2}}{\mu_1 + \mu_2} = \frac{1 \times \frac{3}{2}R + 1 \times \frac{5}{2}R}{1 + 1} = 2R$

$$\left((C_V)_{mono} = \frac{3}{2}R,\ (C_V)_{di} = \frac{5}{2}R\right)$$

4. (a) $v_{rms} = \sqrt{\frac{3RT}{M}} \Rightarrow \frac{v_2}{v_1} = \sqrt{\frac{T_2}{T_1}} = \sqrt{\frac{(273+90)}{(273+30)}} = 1.1$

% increase $= \left(\frac{v_2}{v_1} - 1\right) \times 100 = 0.1 \times 100 = 10\%$

5. (c) Temperature of the gas is concerned only with it's disordered motion. It is no way concerned with it's ordered motion.



6. (c) $\mu = \mu_1 + \mu_2$

$$\frac{P(2V)}{RT_1} = \frac{P'v}{RT_1} + \frac{P'V}{RT_2} \Rightarrow \frac{2P}{RT_1} = \frac{P'}{R}\left[\frac{T_2 + T_1}{T_1 T_2}\right]$$

$$P' = \frac{2PT_2}{(T_1 + T_2)} = \frac{2 \times 1 \times 600}{(300 + 600)} = \frac{4}{3} atm$$

7. (c) $v_{rms} \propto \frac{1}{\sqrt{M}} \Rightarrow \frac{v_1}{v_2} = \sqrt{\frac{M_2}{M_1}}$

$\therefore \frac{1}{\sqrt{2}} = \sqrt{\frac{M_2}{32}} \Rightarrow M_2 = 16.$ Hence the gas is CH_4.

8. (c) Mean kinetic energy of molecule depends upon temperature only. For O_2 it is same as that of H_2 at the same temperature of $-73°C$.

9. (c) $PV = \mu RT \Rightarrow \mu = \frac{PV}{RT} = \frac{21 \times 10^4 \times 83 \times 10^{-3}}{8.3 \times 300} = 7$

10. (b) $P_1 = 720kpa, \ T_1 = 40°C = 273 + 40 = 313K$

$$P \propto mT \Rightarrow \frac{P_2}{P_1} = \frac{m_2}{m_1}\frac{T_2}{T_1} = \frac{3}{4} \times \frac{626}{313} = 1.5$$

$\Rightarrow P_2 = 1.5P_1 = 1.5 \times 720 = 1080kPa$

11. (c) According to Boyle's law $(P_1V_1)_{\text{bottom}} = (P_2V_2)_{\text{top}}$

$(10 + h) \times \frac{4}{3}\pi r_1^3 = 10 \times \frac{4}{3}\pi r_2^3$ but $r_2 = 2r_1$

$\therefore (10 + h)r_1^3 = 10 \times 8r_1^3 \Rightarrow 10 + h = 80 \ \therefore h = 70m$

12. (d) $v_{rms} = \sqrt{\frac{3RT}{M}} \Rightarrow v_{rms} \propto \sqrt{\frac{T}{M}}$

$\frac{v_2}{v_1} = \sqrt{\frac{M_1}{M_2} \times \frac{T_2}{T_1}} = \sqrt{\frac{1}{2} \times \frac{1}{2}} \Rightarrow v_2 = \frac{v_1}{2} = \frac{300}{2} =$150m/sec

13. (bc) Co is diatomic gas, for diatomic gas

$$C_P = \frac{7}{2}R \text{ and } C_V = \frac{5}{2}R \Rightarrow \gamma_{di} = \frac{C_P}{C_V} = \frac{7R/2}{5R/2} = 1.4$$

14. (d) Energy $= 300\ J/litre = 300 \times 10^3\ J/m^3$

$$P = \frac{2}{3}E = \frac{2 \times 300 \times 10^3}{3} = 2 \times 10^5\ N/m^2$$

15. (c) $\rho = \frac{PM}{RT}$

Density ρ remains constant when P/T or volume remains constant.

In graph (i) Pressure is increasing at constant temperature hence volume is decreasing so density is increasing. Graphs (ii) and (iii) volume is increasing hence, density is decreasing. Note that volume would had been constant in case the straight line in graph (iii) had passed through origin.

16. (b) Vander wall's gas equation for μ mole of real gas

$$\left(P + \frac{\mu^2 a}{V^2}\right)(V - \mu b) = \mu RT \Rightarrow P = \frac{\mu RT}{V - \mu b} - \frac{\mu^2 a}{V^2}$$

on comparing the given equation with this standard equation

we get $\mu = \frac{1}{2}$. Hence $\mu = \frac{m}{M} \Rightarrow$ mass of gas

$$m = \mu m = \frac{1}{2} \times 44 = 22gm.$$

17. (d) As we know 1 *mol* of any ideal gas at *STP* occupies a volume of 22.4 *litres.*

Hence number of moles of gas $\mu = \frac{44.8}{22.4} = 2$

Since the volume of cylinder is fixed,

Hence $(\Delta Q)_V = \mu \omega \Delta T$

$= 2 \times \frac{3}{2}R \times 10 = 30R \qquad \left(\because (C_V)_{mono} = \frac{3}{2}R\right)$

18. (b) Since volume is constant,

Hence $\frac{P_1}{P_2} = \frac{T_1}{T_2} \Rightarrow \frac{1}{3} = \frac{(273 + 30)}{T_2}$

$\Rightarrow T_2 = 909K = 636°C$

19. (b) $(\Delta Q)_P = \mu C_P \Delta T$ and $(\Delta Q)_V = \mu C_V \Delta T$

$$\Rightarrow \frac{(\Delta Q)_V}{(\Delta Q)_P} = \frac{C_V}{C_P} = \frac{\frac{3}{2}R}{\frac{5}{2}R} = \frac{3}{5}$$

$$\left[\because (C_V)_{mono} = \frac{3}{2}R, (C_P)_{mono} = \frac{5}{2}R\right]$$

$$\Rightarrow (\Delta Q)_V = \frac{3}{5} \times (\Delta Q)_P = \frac{3}{5} \times 210 = 126\ J$$

20. (b) In case of given graph, V and T are related as $V = aT - b$, where a and b are constants.

From ideal gas equation, $PV = \mu RT$

We find $P = \frac{\mu RT}{aT - b} = \frac{\mu R}{a - b/T}$

Since $T_2 > T_1$ therefore $P_2 < P_1$.

21. (d) $PV = mrT \Rightarrow P \propto m \qquad [\because V, r, T \rightarrow \text{constant}]$

$\Rightarrow \frac{m_1}{m_2} = \frac{P_1}{P_2} \Rightarrow \frac{10}{m_2} = \frac{10^7}{2.5 \times 10^6} \Rightarrow m_2 = 2.5\ kg.$

Hence mass of the gas taken out of the cylinder

$$= 10 - 2.5 = 7.5kg.$$

22. (b) If m is the total mass of the gas then its kinetic energy $= \frac{1}{2}mv^2$

When the vessel is suddenly stopped then total kinetic energy will increase the temperature of the gas. Hence

$$\frac{1}{2}mv^2 = \mu C_v \Delta T = \frac{m}{M} C_v \Delta T \qquad [\text{As } C_v = \frac{R}{\gamma - 1}]$$

$$\Rightarrow \frac{m}{M}\frac{R}{\gamma - 1}\Delta T = \frac{1}{2}mv^2 \Rightarrow \Delta T = \frac{Mv^2(\gamma - 1)}{2R}.$$

23. (d) For open mouth vessel, pressure is constant.

Volume is also given constant

Hence from $PV = \mu RT = \left(\frac{m}{M}\right)RT \Rightarrow T \propto \frac{1}{m} \Rightarrow \frac{T_1}{T_2} = \frac{m_2}{m_1}$

$\because$ $\frac{1}{4}th$ part escapes, so remaining mass in the vessel

$$m_2 = \frac{3}{4}m_1 \Rightarrow \frac{(273 + 60)}{T} = \frac{3/4\, m_1}{m_1}$$

$\Rightarrow T = 444K = 171°C$

24. (d) $n = \frac{PV}{kT}$ Now, $n' = \frac{(2P)(2V)}{kT} = 4\frac{PV}{kT} = 4n$ or $\frac{n}{n'} = \frac{1}{4}$.

25. (b) $$\gamma_{\text{mix}} = \frac{\frac{\mu_1\gamma_1}{\gamma_1 - 1} + \frac{\mu_2\gamma_2}{\gamma_2 - 1}}{\frac{\mu_1}{\gamma_1 - 1} + \frac{\mu_2}{\gamma_2 - 1}} = \frac{\frac{3 \times 1.3}{(1.3 - 1)} + \frac{2 \times 1.4}{(1.4 - 1)}}{\frac{3}{(1.3 - 1)} + \frac{2}{(1.4 - 1)}} = 1.33$$

26. (d) In mixture gases will acquire thermal equilibrium (*i.e.*, same temperature) so their kinetic energies will also be same.

27. (b) $V_t = V_0(1 + \alpha t) = 0.5\left(1 + \frac{1}{273} \times 819\right) = 2$ *litre* $= 2 \times 10^{-3}\ m^3$