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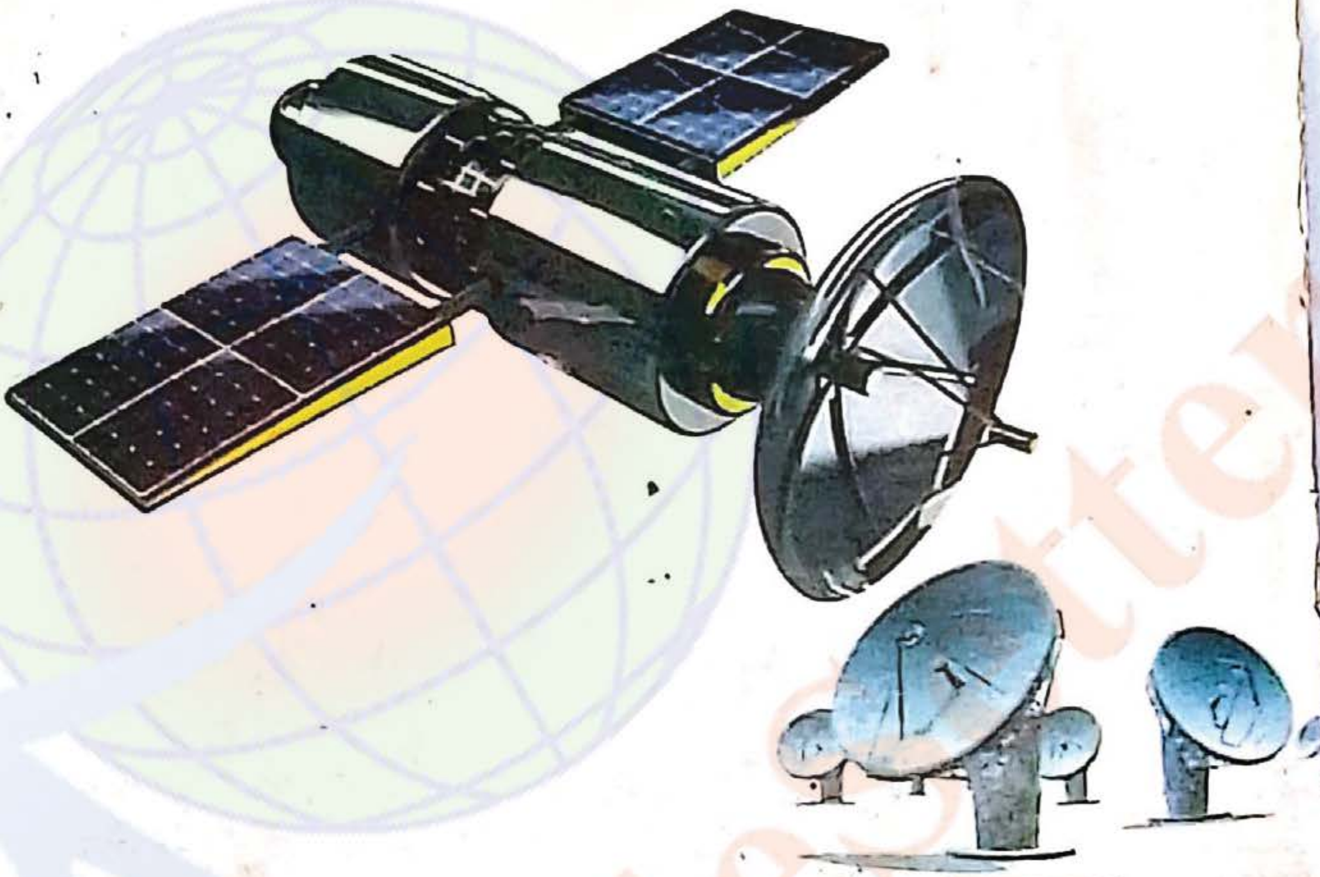

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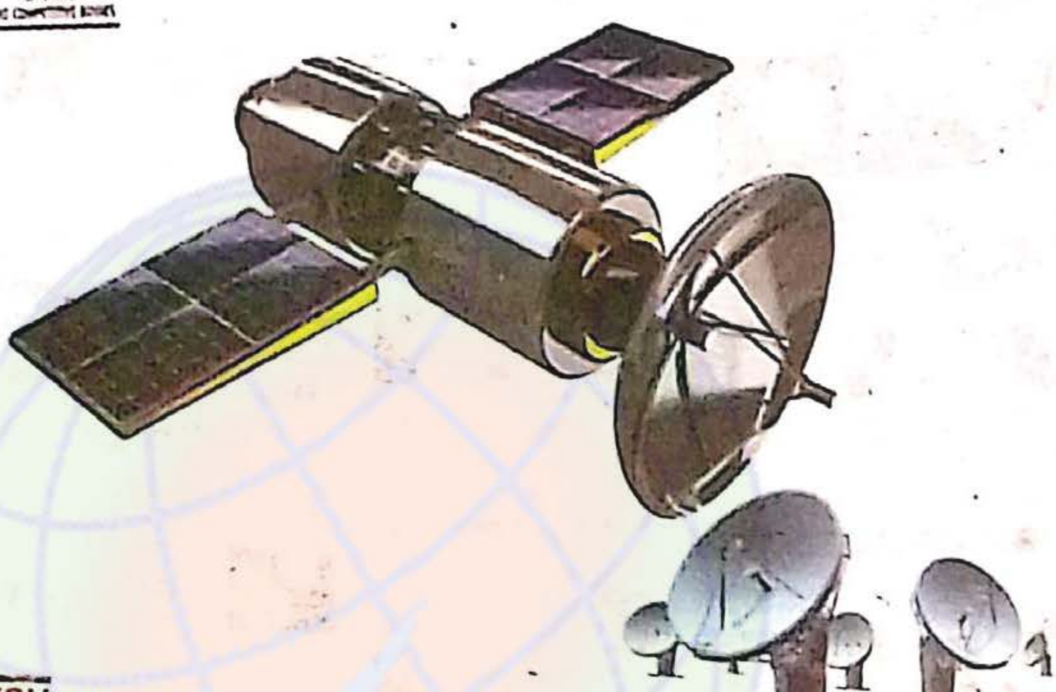

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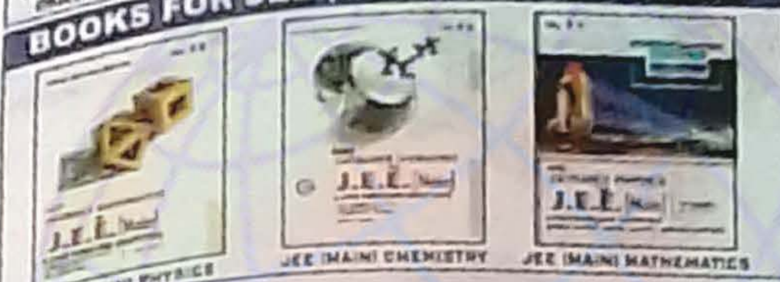

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HEAT AND THERMODYNAMICS

KINETIC THEORY OF GASES

8.1

Comprehensive Review

1. Solids, liquids and gases

1.1. The intermolecular separation for the solids is the least and that for the gases is the largest.

1.2. In solids, the position of the molecule is fixed.

1.3. In liquids, the molecules can move within the volume of the liquid.

1.4. In gases, the molecules are free to roam about within the volume of the container.

1.5. The intermolecular potential energy is minimum for the solids and maximum for the gases.

1.6. Solids possess definite shape. The liquids acquire the shape of the container, but their volume may be less than that of the container. The gases occupy whole of the available volume of the container.

1.7. The molecular kinetic energy is minimum for the solids and maximum for the gases.

1.8. Intermolecular force is minimum for the gases and maximum for the solids.

1.9. The gases can be easily compressed as compared to solids and liquids.

1.10. Both liquids and gases flow. Therefore they are called fluids.

1.11. Density of solids is much larger as compared to liquids and gases.

1.12. Coefficient of thermal expansion is much larger for gases as compared to that for solids and liquids.

2. Brownian Motion

Random motion of the particles suspended in the liquid or fluids is called Brownian motion. For Brownian motion, the suspended particles should be extremely small in size.

Brownian motion of the suspended particles is due to the continuous collision of the molecules on the suspended particles. The force exerted due to collision from different directions, makes the particles move in irregular manner.

2.1. Brownian motion increases with the rise in temperature.

2.2. Brownian motion is faster with smaller particles.

2.3. Brownian motion is faster for low viscosity fluids.

2.4. Brownian motion is faster for low density fluids.

3. Ideal gas or perfect gas

3.1. The molecules of the ideal gas are point masses, with zero volume.

3.2. There is no intermolecular force between the molecules of ideal gas.

3.3. There is no intermolecular potential energy for the molecules of ideal gas.

3.4. The molecules of ideal gas possess only the kinetic energy.

3.5. The ideal gas can not be converted into liquids or solids. That is, the ideal gas cannot be liquified or solidified.

* This is the consequence of the absence of intermolecular force.

3.6. The change in internal energy with volume is zero for the ideal gas, provided the temperature remains constant. That is :

$$\left[\frac{\partial U}{\partial V}\right]_T = 0$$

It is called Joule's law.

Or the internal energy of the ideal gas is independent of volume.

3.7. The internal energy of the ideal gas depends on temperature alone.

3.8. The ideal gases strictly obey the gas equation, Boyle's law, Charle's law etc. at all temperatures and pressures.

3.9. The coefficient of cubical expansion of ideal gas is equal to $\frac{1}{273}$ per kelvin.

3.10. The coefficient of pressure variation with temperature for ideal gas is equal to $\frac{1}{273}$ per kelvin.

3.11. The specific heat of ideal gases does not depend on temperature.

3.12. No gas in the universe is ideal. Gases such as H_2, N_2, O_2 etc. behave very similar to ideal gases.

3.13. Monoatomic inert gases also behave like ideal gases.

3.14. The behaviour of real gases at high temperature and low pressure is very similar to that of the ideal gases.

4. Ideal gas equation

The equation which relates all the macroscopic variables [pressure (p), volume (V), temperature (T)] of an ideal gas is called ideal gas equation. It is given by :

$$pV = nRT,$$

where R is molar gas constant and n is number of moles of the given sample of the gas.

4.1. For one mole, the gas equation is

$$pV = RT$$

4.2. For one gram of gas, we write

$$pV = rT,$$

where r is specific gas constant, given by $r = \frac{R}{M}$. Here M is molecular weight of the gas.

4.3. The values of gas constant are :

$$R = 8{\cdot}4 \text{ J/mol K}$$

Also, $R = 2$ cal/mol K.

5. Avogadro's hypothesis

5.1. Equal volumes of all gases at the same temperature and pressure contain the same number of molecules.

5.2. One mole of every gas at NTP has same volume equal to 22·4 litres.

5.3. One mole of every gas contains same number of molecules called Avogadro's number $N_A = 6{\cdot}023 \times 10^{23}$

5.4. Avogadro's number is also equal to the number of atoms in 12g of carbon-12 atom.

6. Real gases

6.1. The gases actually found in nature are called real gases.

6.2. The molecules of the real gas have finite volume.

6.3. There is intermolecular attraction or repulsion between the molecules of the real gas.

6.4. The intermolecular force is attractive at larger intermolecular separation and repulsive, when the molecules are too close to each other.

6.5. The molecules of the real gas have intermolecular potential energy as well as kinetic energy.

6.6. Real gases can be liquefied as well as solidified.

6.7. The internal energy of real gases depends on volume, pressure as well as temperature.

6.8. Real gases do not obey Boyle's law at all temperatures.

6.9. The real gases obey the Boyle's law only at a particular temperature called the Boyle's temperature (T_B).

6.10. $T_B = a/Rb$, where a & b are van der Waal constants.

6.11. The Boyle's law equation for real gases can be written as

$$pV = A + Bp + Cp^2 + Dp^3 + \dots$$

where $A > B > C > D > \dots$

Here A, B, C, D ... etc are called viral coefficients.

6.12. Real gases do not obey the gas equation

$$pV = nRT.$$

They obey the van der Waal gas equation.

6.13. The deviation of the real gases from the ideal gas behaviour is due to the finite molecular size and intermolecular attraction.

7. van der Waal gas equation

7.1. The real gases obey this equation at high pressure and low temperature.

7.2. The gas equation is

$$\left(p + \frac{an^2}{V^2}\right)(V - nb) = nRT,$$

where $\frac{an^2}{V^2}$ is pressure correction and nb is volume correction.

7.3. Value of 'a' depends on the intermolecular force and nature of the gas.

7.4. The unit of 'a' is Jm^3/mol^2 and its dimensional formula is : ML^5T^{-2}.

7.5. The unit of 'b' is m^3/mol and its dimensional formula is $M^0L^3T^0$.

7.6. The value of 'b' depends on the size of the molecules.

7.7. The 'b' is also called hidden volume of the gas that is, practically $(V - b)$ volume is available to the molecules of the real gas to move about.

7.8. $(V - b)$ is also called effective volume of the gas.

7.9. 'b' is approximately 4 times the actual volume of all the molecules of the gas sample. That is, $b = 4 \times$ No. of molecules $\times$ Volume of each molecule.

8. Relation between pV and p for the real gases. (Here T_B stands for Boyle's temperature)

(i) For $T < T_B$, we find pV first decreases and then increases with the rise in pressure.

(ii) For $T = T_B$, we find pV is independent of pressure.

(iii) For $T > T_B$, the value of pV first increases and then decreases with the rise in pressure.

9. Specific heat

Specific heat of real gases varies directly with temperature. That is

$$C_V \propto T$$

9.1. Internal energy of real gas depends on volume as well as temperature.

9.2. The change in internal energy of one mole of real gas is given by :

$$\Delta U = C_V \Delta T + \frac{a}{V^2} \Delta V$$

9.3. The real gases do not obey the Joule's law. That is,

$$\left[\frac{\partial U}{\partial V}\right]_T \neq 0.$$

10. Gram mole and kilogram mole

Molecular weight expressed in grams is called gram mole (g mol). And the molecular weight expressed in kilograms is called kilogram mole (kg mol).

For example, one gram mole of hyd... (H_2) gas is 2 gram and one kilogram mo... hydrogen gas (H_2) is 2 kg.

10.1. Mass of 1 mole of gas is equal to molecular weight in grams.

10.2. 1 kg mol = 1000 g mole.

10.3. Thus, in 2 kg hydrogen gas (H_2), amount of substance is 1000 moles.

11. Molar Volume

The volume of 1 mole of gas is known as molar volume. The unit of molar volume is m^3/mol. Sometimes it may be expressed in l... per mole (l/mol).

11.1. $1l = 10^{-3}m^3$

11.2. Volume of 1mole of every gas at N... is 22·4 litres.

12. Molar mass and Molecular Weight

The mass of 1 mole of substance is ca... molar mass.

12.1. The numerical value of the molar ma... in grams is called molecular weight.

12.2. Molar mass = $N_A \times$ mass of o... molecule.

13. NTP or STP

NTP stands for normal temperature a... pressure.

STP stands for standard temperature a... pressure.

Both NTP and STP carry the same meaning. They refer to a temperature of 273K or 0°C and 1 atm pressure.

13.1. 1 atm pressure = 76 cm of Hg pressure $\equiv 1{\cdot}01 \times 10^5$ Pa.

14. Absolute zero

The absolute zero refers to zero of the kelvin scale. That is absolute zero = 0 K = − 273°C.

14.1. Exact value of absolute zero i... −273·15°C.

14.2. At the absolute zero all molecular motion ceases.

14.3. The volume of ideal gas becomes zero at the absolute zero.

14.4. The pressure of ideal gas becomes zero at the absolute zero.

14.5. The molecular energy or internal energy of the ideal gas becomes zero at the absolute zero.

14.6. All real gases get liquefied before reaching the absolute zero.

14.7. The internal energy of the real gases (after liquefaction) at the absolute zero is not zero. It is called zero point energy or Fermi energy.

15. Postulates of the kinetic theory of gases :

(i) **Nature of molecules**

(a) The molecules of each gas are identical but different from that of other gases.

(b) Molecules of a gas are point masses.

(c) Molecules are rigid and perfectly elastic spheres.

(ii) **Motion of molecules**

Molecules of the gases move randomly in all directions with all possible velocities.

(iii) **Collisions**

(a) The molecules of the gas continuously collide with one another as well as with the walls of the containing vessel.

(b) The molecular collisions are perfectly elastic.

(c) The total energy of the molecules remains constant during collisions.

(d) Molecules move with constant velocity along a straight line during the two collisions.

(e) The time spent in a collisions (10^{-8} s) is very very small as compared to that between the two collisions.

(f) The number of collisions per second does not change with time, provided physical conditions such as pressure and temperature do not change.

(g) Collisions cause no change in the density of the gas in any part of the sample.

(iv) **Intermolecular forces**

(a) There is no intermolecular force (strictly applicable to perfect gas).

(b) Gravitational attraction between the molecules is negligible and so it is not taken into account.

(v) **Pressure**

(a) Continuous collisions of the molecules with the walls of the containing vessel cause pressure on the walls.

(b) Continuous collisions of the molecules also cause pressure at all points within the gas.

15.1. General Characteristics of the real gas, in connection with the kinetic theory of gases :

(1) The size of the molecules is negligible as compared to the average intermolecular separation, which is of the order of 10^{-9} m.

(2) The volume of the molecules is negligible as compared to the volume of the gas sample. For one mole of the gas at NTP, the volume of all the molecules added together may be around 0·014% of the volume of the gas as a whole.

(3) The time of collision of the molecules is of the order of 10^{-8}s. The time elapsed between two collisions is very very large as compared to the time of collisions.

(4) In actual gases or real gases, there is intermolecular force. It is attractive when the molecules are far apart and is repulsive when the molecules are too close to each other.

(5) Continuous collisions of the molecules with the walls cause pressure of the gas.

16. Critical state of gas

The point on the p–V diagram at which we can not distinguish between the gaseous and liquid state of the substance is called **critical point.**

16.1. At the critical point, the density of gas is equal to the density of the liquid.

16.2. At the critical point, the gas and liquid co-exist.

16.3. The temperature, pressure and volume of the gas at critical point are called critical temperature (T_c), critical pressure (p_c) and critical volume (V_c) respectively. Their values are as follows :

$$T_c = \frac{8a}{27Rb} = \frac{8}{27}T_B$$

$$p_c = \frac{a}{27b^2}$$

$$V_c = 3b$$

Here a and b are the van der Waal's constants and T_B is the Boyle's temperature.

16.4. $\frac{p_c V_c}{T_c} = \frac{3}{8}R$

Also, $a = \frac{27R^2T_c^2}{64p_c}$ and $b = \frac{RT_c}{8p_c}$

16.5. Critical temperatures :

For O_2, $T_c = -118°C$

For N_2, $T_c = -147°C$

For CO_2, $T_c = 31\cdot1°C$

For steam, $T_c = 365°C$

For H_2, $T_c = -240°C$.

16.6. **Critical pressures**

For O_2, $P_c = 49\cdot7$ atm

For CO_2, $P_c = 73\cdot8$ bar

16.7. The gaseous state of matter, above the critical temperature, is called gas and that below the critical temperature is called vapour.

16.8. A gas cannot be liquefied by applying pressure alone. That is, gas can be liquefied if its temperature is above the critical temperature.

16.9. Only vapours can be liquefied.

16.10. Gases obey the gas laws (Boyle's law, Charle's law, Gay Lussac's law, gas equation). Also unsaturated vapours obey the gas laws, but saturated vapours do not obey the gas laws.

16.11. At the critical temperature, the surface tension of the liquid is zero and the intermolecular forces for liquids and gases become equal.

16.12. Saturated vapours can coexist with their liquid. Gases can not co-exist with their liquid.

17. Degrees of freedom

The number of ways in which a gas molecule can absorb energy is called degrees of freedom.

The degrees of freedom can be of following three types :

(i) Degrees of freedom of translational motion (f_t).

(ii) Degrees of freedom of rotatory motion (f_r).

(iii) Degrees of freedom of vibrational motion (f_v).

17.1. Total degrees of freedom are given by :

$$f = f_t + f_r + f_v$$

The f_t are present at all temperatures. The f_r are present at ordinary temperatures. And f_v are present only at high temperatures.

17.2. Formula for degrees of freedom

The degrees of freedom can be calculated by using the relation :

$$f = 3N - k$$

Here N = number of atoms in the molecule and k is the number of links or constraints.

17.3. Degrees of freedom of monoatomic gases :

(i) Examples of the monoatomic gases are

He, Ne, Ar, Kr, Xe, Rn

(ii) For monoatomic gases, there is only translatory motion.

That is,

$$f_r = f_v = 0.$$

(iii) Using the relation :

$f = 3N - k$, for the monoatomic gas we find $N = 1$ and $k = 0$. Hence $f =$ ... They correspond to translatory motion alone.

17.4. Degrees of freedom for the diatomic gases :

(i) Examples of diatomic gases are

H_2, N_2, O_2, Cl_2 etc.

(ii) Using the relation

$f = 3N - k$, we find for the diatomic gas : $N = 2$ and $k = 1$.

Hence $f = 3 \times 2 - 1 = 5$.

17.5. Out of 5 degrees of freedom for diatomic gases, 3 correspond to translatory motion and 2 correspond to rotatory motion. That is $f_t = 3$ and $f_r = 2$. There are no degrees of freedom corresponding to the vibratory motion. That is, $f_v = 0$.

17.6. At very low temperatures (≈ 70 K), the degrees of freedom corresponding to the rotatory motion are absent. Hence, the diatomic gas possesses only 3 degrees of freedom. At high temperatures (250 K to 750 K) diatomic gases exhibit 5 degrees of freedom.

17.7. Degrees of freedom for triatomic gases :

(i) Examples of triatomic gases are : SO_2, CO_2, H_2O, O_3 etc.

(ii) The number of degrees of freedom depends on the structure of the molecule.

(a) For linear triatomic molecule $k = 2$, hence :

$$f = 3N - k = 3 \times 3 - 2 = 7.$$

(b) For non-linear triatomic molecule $k = 3$, hence :

$$f = 3N - k = 3 \times 3 - 3 = 6.$$

17.8. CO_2 is a linear molecule with 7 degrees of freedom. O_3 is a triangular molecule with 6 degrees of freedom. H_2O is a nonlinear molecule with 6 degrees of freedom.

18. Maxwell's law of equipartition of energy

This law states that the kinetic energy is equally distributed among all the degrees of freedom. And, the energy associated with each degree of freedom $= \frac{1}{2} k_B T$, where T is the absolute temperature and k_B is the Boltzmann constant, the gas constant for one molecule of gas.

18.1. Kinetic energy of a molecule having f degrees of freedom is given by:

$$U_k \text{ (molecule)} = \frac{f}{2} k_B T.$$

18.2. Total kinetic energy of 1 mole of gas with f degrees of freedom is given by :

$$U_k = N_A\left[\frac{f}{2} k_B T\right] = \frac{f}{2} N_A k_B T = \frac{f}{2} RT,$$

where N_A is the Avogadros number.

18.3. The relation $U_k = \frac{f}{2} RT$ is not strictly applicable at low temperatures.

19. Molar Specific heat at constant volume of a gas

If C_V be the specific heat at constant volume, then using the relation $\Delta Q = n C_V \Delta T$, we find that heat absorbed by 1 mole ($n = 1$) of gas in raising the temperature of the gas by ΔT is given by :

$$\Delta Q = 1 \times C_V \times \Delta T = C_V \Delta T.$$

Also, ΔQ = increase in kinetic energy

$$= \frac{f}{2} R(T + \Delta T) - \frac{f}{2} RT.$$

$$= \frac{f}{2} R\Delta T$$

Hence $\frac{f}{2} R\Delta T = C_V \Delta T$

That is, $C_V = \frac{f}{2} R$

20. Molar specific heat at constant pressure is given by :

$$C_P = C_V + R$$

$$C_P = \frac{f}{2} R + R$$

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

21. The ratio of C_P and C_V is called adiabatic constant or thermodynamic constant. It is denoted by γ. That is :

$$\gamma = \frac{C_P}{C_V}$$

21.1. In general ,

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

$$= 1 + \frac{2}{f}.$$

21.2. Also, γ is equal to the ratio of bulk modulus of gas under adiabatic conditions (B_a) to that under isothermal conditions (B_T). That is,

$$\gamma = \frac{B_a}{B_T}$$

21.3. Again, γ is also related to the slope of the indicator diagrams as follows :

$$\gamma = \frac{\text{Slope of adiabatic } p - V \text{ diagram}}{\text{Slope of isothermal } p - V \text{ diagram}}$$

22. Other relations for C_V and C_P

22.1. $C_V = \frac{f}{2} R$

Since $\gamma = 1 + \frac{2}{f}$.

Hence $f = \frac{2}{\gamma - 1}$

Hence $C_V = \frac{R}{\gamma - 1}$

22.2. According to Dulong–Petit law, for solids :

$$C_V = 3R$$

22.3. According to Debye law, for solids :

$$C_V \propto T^3$$

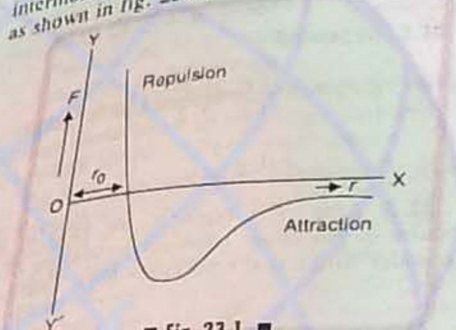
22.4. $C_P = \frac{\gamma}{\gamma - 1} R$

22.5. $C_V = \left(\frac{\partial Q}{\partial T}\right)_V$

22.6. $C_P = \left(\frac{\partial Q}{\partial T}\right)_P$

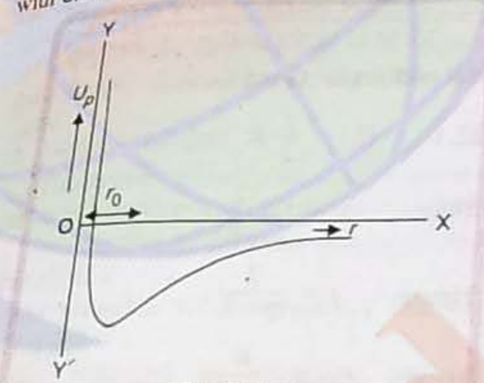
23. Interatomic and intermolecular forces and potential energy

23.1. Both the interatomic as well as intermolecular forces (F) vary with distance (r) as shown in fig. 23.1.



■ Fig. 23.1. ■

23.2. Fig. 23.2 shows the variation of interatomic or intermolecular potential energy (U_p) with distance.



■ Fig. 23.2. ■

23.3. The interatomic or intermolecular force is repulsive for small values of r and it is attractive for large values of r.

23.4. The interatomic or intermolecular force is zero at a certain distance $r = r_0$. This is the **equilibrium state.** And under normal conditions r_0 is the intermolecular or interatomic distance.

23.5. The potential energy at $r = r_0$ is minimum. That is, the intermolecular or interatomic potential energy is minimum in the state of equilibrium.

23.6. The r_0 may be assumed as the diameter of the atom or that of the molecule as the case may be.

For $r < r_0$, the interatomic or intermole... force is +VE (repulsive) and for $r > r_0$ ... -VE (attractive).

23.7. The intermolecular or interatomic ... (F) and the corresponding potential energy ... are related as follows :

$$F = -\frac{dU_p}{dr}$$

23.8. Both the interatomic and intermole... forces as well as potential energy are zero ... infinite separation.

23.9. The nature of variation is same ... for the interatomic as well as intermolecular fo... and potential energy.

23.10. The interatomic as well ... intermolecular potential energy varies inver... as sixth power of distance. That is,

$$U_p \propto \frac{1}{r^6}$$

23.11. The interatomic forces depend ... on the separation (r) between the atoms. But ... intermolecular forces depend both on the separa... (r) and the orientation of the molecules.

Value of r_0 is more for molecules as compa... to that for the atoms. That is,

r_0(molecules) > r_0 (atoms)

23.12. For $r > r_0$, an atom can attract o... one other atom. But in case of molecules, ... molecule can attract more than one molecule ... its surroundings.

24. Gas laws

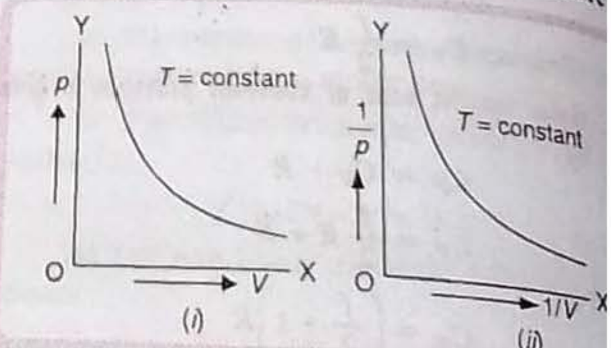
24.1. Boyle's law

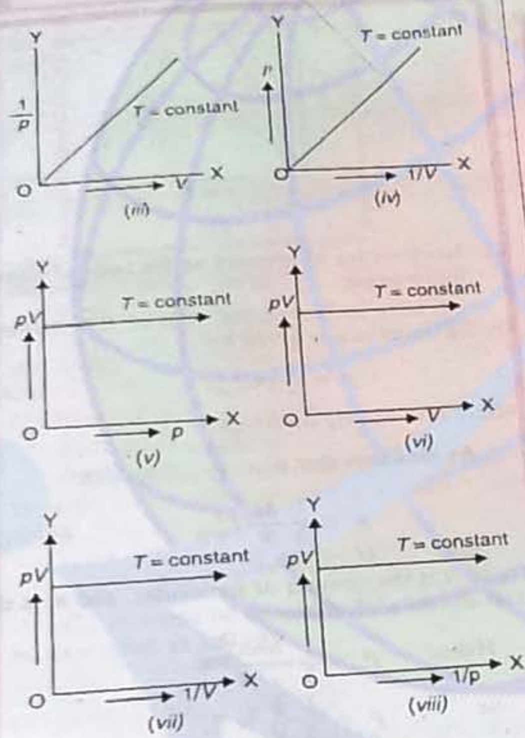
At constant temperature for a given mass ... ideal gas, the volume of gas is inversely proportional to its pressure.

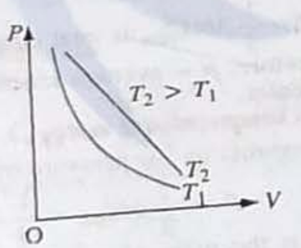
$$V \propto \frac{1}{p} \quad \text{or} \quad pV = \text{Constant}$$

The curve between pressure and volume ... constant temperature is known as isotherm.

24.2. p-V graphs at constant temperature







(ix)

24.3. Charle's law

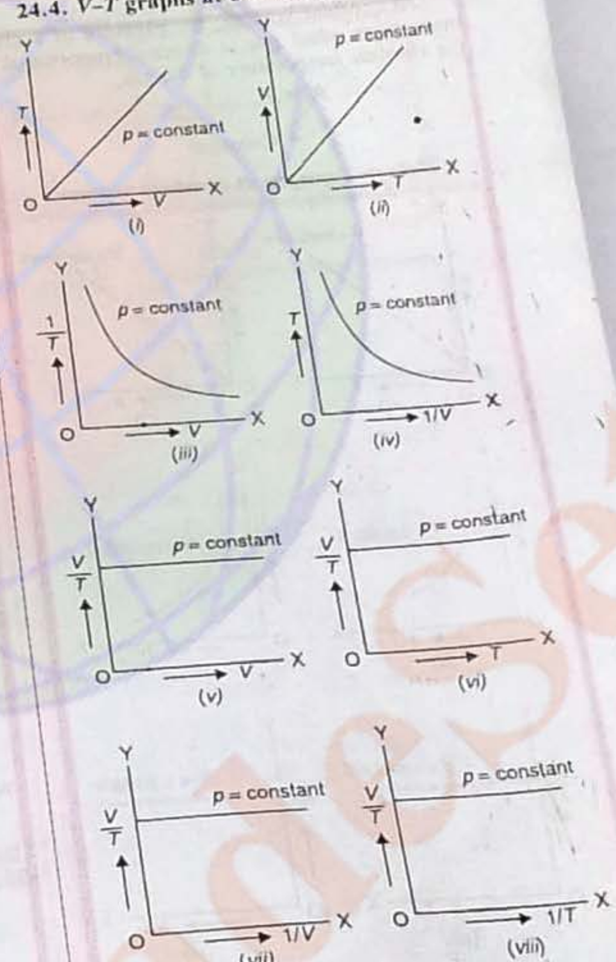
At constant pressure, volume of a given mass of gas is directly proportional to its absolute temperature.

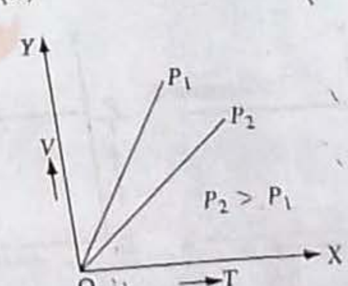
$$V \propto T$$

or $$\frac{V}{T} = \text{Constant}$$

The curves between volume and temperature at constant pressure are called Isobars.

24.4. V–T graphs at constant pressure :





(ix)

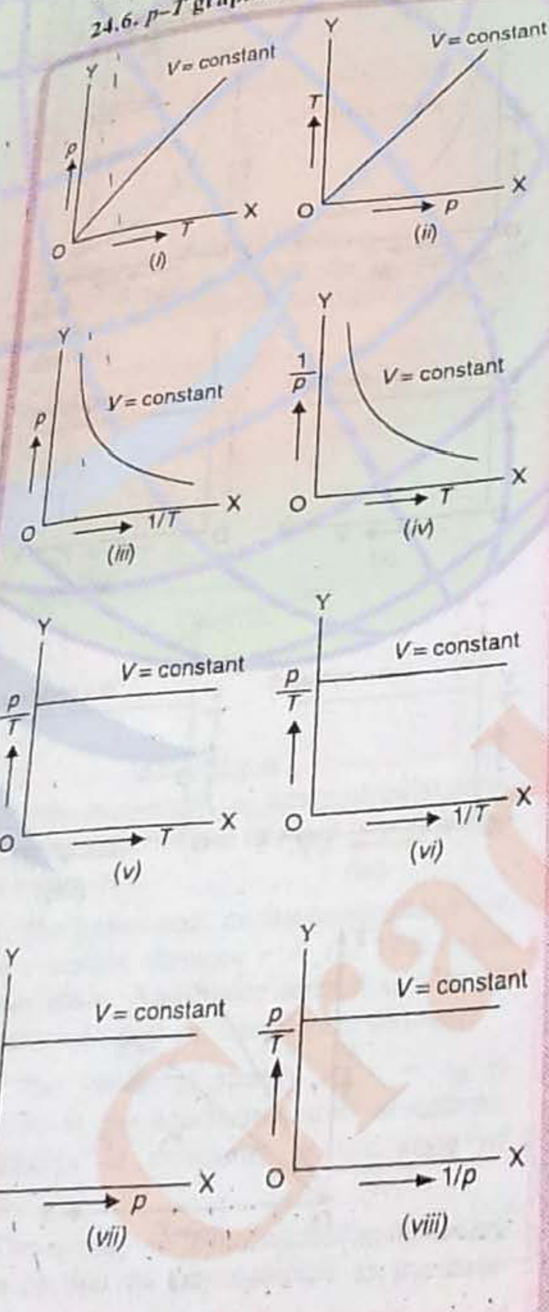
24.5. Gay Lussac's law

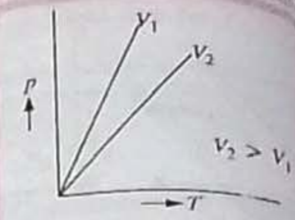
At constant volume, the pressure of a given mass of an ideal gas is directly proportional to the absolute temperature of the gas.

$$p \propto T$$

or $\frac{p}{T}$ = Constant

24.6. p–T graphs at constant volume :





(ix)

25. Interpretation of pressure on the basis of k... theory of gas :

Pressure exerted on the walls of the co... by the molecules is given by

$$p = \frac{1}{3}\rho C_{rms}^2,$$

where ρ is density of the gas.

As we know that $\rho = \frac{M}{V}$, therefore

$$p = \frac{1}{3}\frac{M}{V}C_{rms}^2$$

Also, $M = Nm$,

where N is the number of molecules, and m is ... mass of one molecule.

Hence $p = \frac{1}{3}\frac{NmC_{rms}^2}{V}$

or $p = \frac{2}{3}\frac{1}{V}\times E$,

where $E = \frac{1}{2}NmC_{rms}^2$ is total kinetic energy.

Therefore, $p \propto$ average kinetic energy of the molecules.

26. Kinetic interpretation of energy

The expression for pressure of a gas is :

$$p = \frac{1}{3}\rho C_{rms}^2 = \frac{1}{3}\frac{M}{V}C_{rms}^2$$

If M is the mass of one mole and V be volume of one mole, then from the gas equati... we find :

$$pV = RT,$$

where R is the gas constant for one mol... gas.

Here $pV = RT = \frac{1}{3}MC_{rms}^2$

or $T = \frac{1}{3}\frac{M}{R}C_{rms}^2$ or $T \propto C_{rms}^2$

That is, the temperature of the gas is dire... proportional to the square of the rms velocity... the gas molecules.

26.1. In other words, If C_{1rms} and C_{2rms} be the rms speeds at temperatures T_1 and T_2 respectively, then :

$$\frac{T_1}{T_2} = \frac{C_{1rms}^2}{C_{2rms}^2} \text{ Or } \frac{C_{1rms}}{C_{2rms}} = \sqrt{\frac{T_1}{T_2}}$$

This is called kinetic interpretation of temperature.

$$k_{av} = \frac{1}{2} m C_{rms}^2 = \frac{3}{2} k_b T,$$

where k_b is Boltzmann constant, the gas constant for one molecule of the gas.

Therefore average kinetic energy $\propto T$

Here, average kinetic energy includes only the energy of random translational motion and does not include any orderly motion.

27. Different speeds of gas molecules

27.1. Average speed

The arithmetic mean of the speeds of molecules in a gas at a given temperature is called average speed.

$$C_{av} = \frac{C_1 + C_2 + C_3 + \ldots}{N}$$

C_{av} in terms of temperature and pressure can be expressed as follows :

$$C_{av} = \sqrt{\frac{8}{\pi}\frac{RT}{M}} \quad \ldots(1)$$

We know that molecular mass $M = N_A m$ and $\frac{R}{N_A} = k_b$, therefore

$$C_{av} = \sqrt{\frac{8}{\pi}\frac{k_b T}{m}} \quad \ldots(2)$$

Also, we know that $M = \rho V$ and $pV = k_b T$

$$C_{av} = \sqrt{\frac{8}{\pi}\frac{p}{\rho}} \quad \ldots(3)$$

27.2. Root mean square speed

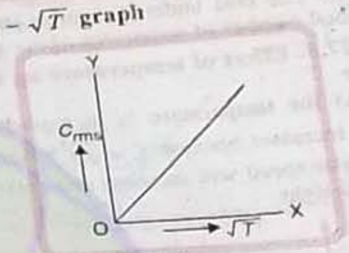
The square root of mean of squares of speed of different molecules is called root mean square speed.

$$C_{rms} = \sqrt{\frac{C_1^2 + C_2^2 + C_3^2 + \ldots}{N}}$$

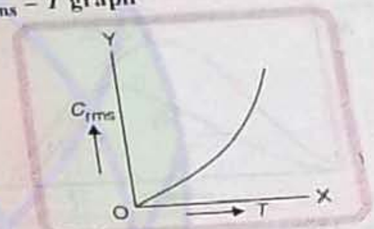
In terms of pressure and temperature

$$C_{rms} = \sqrt{3\frac{RT}{M}} = \sqrt{3\frac{k_b T}{m}} = \sqrt{3\frac{p}{\rho}}$$

(ii) $C_{rms} - \sqrt{T}$ graph



(iii) $C_{rms} - T$ graph



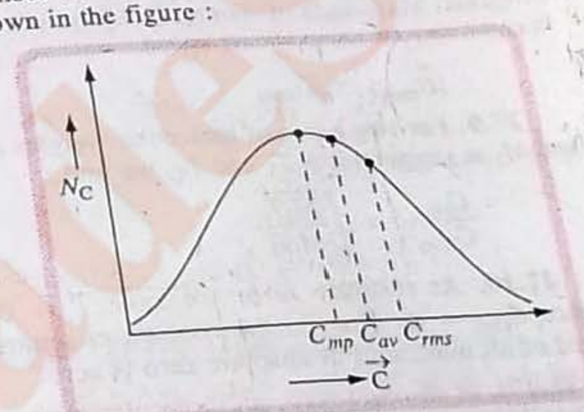
27.3. Most probable speed

The speed possessed by maximum number of molecules in a gas at constant temperature is called most probable speed.

$$C_{mp} = \sqrt{2\frac{RT}{M}} = \sqrt{2\frac{k_b T}{m}} = \sqrt{2\frac{p}{\rho}}$$

27.4. Maxwell distribution of molecular speeds

This distribution gives the number of molecules N_c with speeds within a speed interval ΔC. The number of molecules plotted against velocity is shown in the figure :



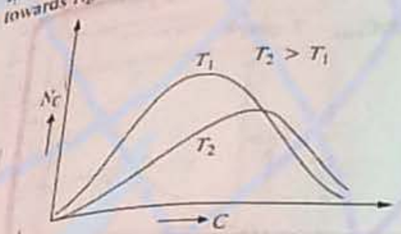
(a) The distribution function depends only on the absolute temperature.

(b) There is only small fraction of molecules having very small and very large value of velocities.

(c) The area under the curve ($N_c - C$) gives the total number of molecules of the gas.

27.5. Effect of temperature on distribution curve

As the temperature is increased, molecular speed increases because $C \propto \sqrt{T}$. Hence average molecular speed will increase and curve will shift towards right.



27.6. Mean velocity of the gas molecules is zero. That is, mean speed is not equal to mean velocity! Because, for finding mean velocity, the direction also need to be taken into account. Due to the random directions of motion, the direction of velocity of different molecules is also random. Hence mean velocity is zero.

Thus : $|\vec{C}_m| \neq C_m$

27.7. Magnitude of most probable velocity is equal to most probable speed.

$$|\vec{C}_{mp}| = C_{mp}$$

27.8. Magnitude of root mean square velocity is equal to root mean square speed.

$$|\vec{C}_{rms}| = C_{rms}$$

27.9. For two gases of molecular weights M_1 and M_2 at temperatures T_1 and T_2, we find :

$$\frac{C_{1rms}}{C_{2rms}} = \sqrt{\frac{M_2 T_1}{M_1 T_2}}$$

27.10. At absolute zero, we have $T = 0$. Hence $C_{rms} = 0$. That is, the root mean square speed of all molecules at absolute zero is zero.

That is, at absolute zero, all molecular motion ceases.

27.11. Since $T \propto C_{rms}^2$ and C_{rms}^2 cannot be -VE. Hence the absolute temperature or kelvin temperature can never be –VE.

27.12. Root mean square velocity of molecules of a gas depends on the temperature alone. And, does not depend on the volume or pressure of the gas, because :

(i) When pressure changes at constant temperature, p/ρ = constant.

(ii) When volume changes at constant temperature, pV = constant.

$$\text{Hence } C_{rms} = \sqrt{\frac{3p}{\rho}} = \sqrt{\frac{3pV}{M}} = \text{constant}$$

27.13. If C be the speed of sound in the gas, then

$$C = \sqrt{\frac{\gamma p}{\rho}},$$

where $\gamma = C_V/C_P$ = the ratio of molar specific heats at constant volume and constant pressure respectively.

$$\text{Also, } C_{rms} = \sqrt{\frac{3p}{\rho}}$$

$$\text{Hence } C_{rms} = \sqrt{\frac{3}{\gamma}}C$$

28. Mean free path

The average distance travelled by a molecule between the two collisions is called mean free path. It is denoted by λ.

28.1. The mean free path of a gas molecule is given by :

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

where d = diameter of moleculer and n = number of molecules per unit volume. It is also called the number density of the molecules.

28.2. If m be the mass of each molecule, then

$$\lambda = \frac{1}{\sqrt{2}\pi d^2 n} = \frac{m}{\sqrt{2}\pi d^2 nm}$$

But $mn = \rho$ = density of gas. Hence

$$\lambda = \frac{m}{\sqrt{2}\pi d^2 \rho}$$

28.3. Other expressions for mean free path

For viscous liquids, we have :

$$\lambda = \frac{2\eta}{\rho C}$$

where η = coefficient of viscosity, ρ = density of gas and C = average speed of the molecules.

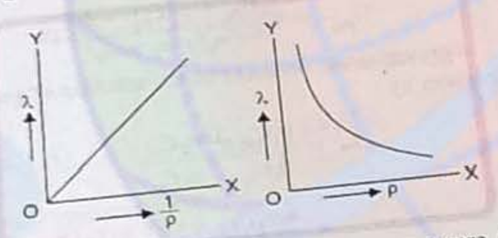
28.4. For diffusion of gases, we find :

$$\lambda = \frac{3D}{C},$$

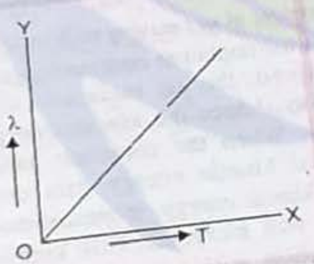
where D = coefficient of viscosity and C = average speed of the molecules.

29. Factors that influence the mean free path (λ)

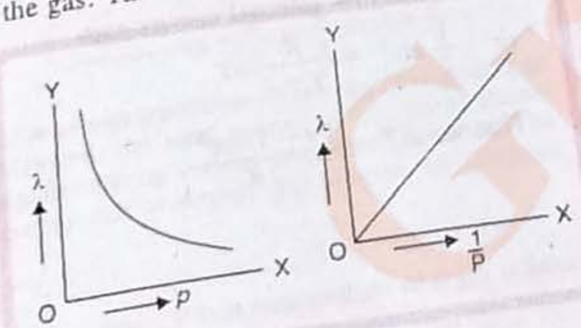
29.1. λ varies inversely as the density ρ of the gas. That is, $\lambda \propto 1/\rho$.



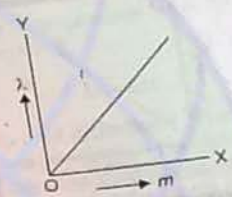
29.2. λ varies directly as the temperature (T) of the gas. That is, $\lambda \propto T$.



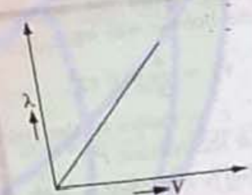
29.3. λ varies inversely as the pressure (p) of the gas. That is, $\lambda \propto 1/p$.



29.4. λ varies directly as the mass (m) of molecule. That is, $\lambda \propto m$.



29.5. λ increases with the increase in volume. That is, $\lambda \propto V$.



30. Cause of changes in mean free path.

30.1. At constant temperature of the gas λ decreases with the increase in pressure because the volume of the gas decreases.

30.2. At constant pressure, the λ increases with the increase in temperature because the volume increases.

31. Average kinetic energy of the molecules

The average kinetic energy of one mole of ideal gas is :

$$U_k = \frac{3}{2} RT$$

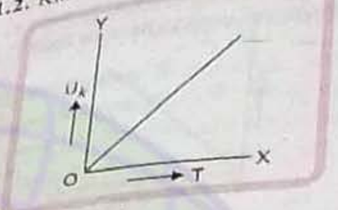
The mean kinetic energy of the molecule of an ideal gas is :

$$U_{k\,(\text{molecule})} = \frac{3}{2} k_b T,$$

where k_b = Boltzmann's constant.

31.1. The above relations are not true for the real gases, as in such case the energy depends on the number of atoms in each molecule of the gas. *The above relations are true for monoatomic real gases.*

31.2. Kinetic energy–Temperature graph



32. Bubble rising in a lake

An air bubble rises from the bottom to the surface of a lake. Let the increase in the radius of bubble be β times the original radius. The volume of the bubble will be :

$$V_2 = \frac{4}{3}\pi(\beta r)^3$$

Here r = radius of the bubble.

Pressure at the bottom P_1

= Atmospheric Pressure + $\rho gh = p_0 + \rho gh$

Pressure at the surface of water P_2

= Atmospheric pressure = p_0

Thus, according to Boyle's law, $P_1V_1 = P_2V_2$

$$(p_0 + \rho gh)\frac{4}{3}\pi r^3 = p_0\left[\frac{4}{3}\pi(\beta r)^3\right]$$

That is, $\beta^3 = 1 + \frac{\rho gh}{p_0}$

Hence, h (depth of lake) $= \frac{p_0}{\rho g}(\beta^3 - 1)$

33. Parameters for mixture of gases

(a) Internal energy of mixture

When three gases of internal energy U_1, U_2 and U_3 are mixed, the net internal energy of the mixture is :

$$U = U_1 + U_2 + U_3$$

(b) Equivalent Molar mass of mixture

If n_1 moles of a gas of molar mass M_1 are mixed with a gas of molar mass M_2 and n_2 moles, then :

Equivalent molar mass $= \frac{n_1M_1 + n_2M_2}{n_1 + n_2}$

(c) Specific heat of mixture

If n_1 moles of specific heat C_{v_1}, n_2 mo... specific heat C_{v_2} and n_3 moles of specific he... are mixed, then the specific heat of the mix...

$$C_{v_m} = \frac{n_1C_{v_1} + n_2C_{v_2} + n_3C_{v_3}}{n_1 + n_2 + n_3}$$

The same is true for C_p. That is,

$$C_{p_m} = \frac{n_1C_{p_1} + n_2C_{p_2} + n_3C_{p_3}}{n_1 + n_2 + n_3}$$

(d) Adiabatic constant of the mixture of ... is given by :

$$\gamma_m = \frac{n_1C_{p_1} + n_2C_{p_2}}{n_1C_{v_1} + n_2C_{v_2}}$$

$$= \frac{n_1\gamma_1(\gamma_2 - 1) + n_2\gamma_2(\gamma_1 - 1)}{n_1(\gamma_2 - 1) + n_2(\gamma_1 - 1)}$$

$$= 1 + \frac{R}{C_{v_m}} = \frac{C_{p_m}}{C_{v_m}}$$

34. A container of gas moving with constant spe...

When the container containing gas mov... constant speed, the gas molecules are mov... ordered way, hence the kinetic energy is ... distributed. When the container suddenly ... this ordered kinetic energy gets conver... disordered kinetic energy. It means, the temp... of the gas will increase. This kinetic en... orderly motion will be converted into ... energy of the random motion of the mole... the system. Therefore,

(K.E.) = Internal energy gain

or $\frac{1}{2}mv^2 = \frac{R}{\gamma - 1}\Delta T$

That is, $\Delta T = \frac{(\gamma - 1)mv^2}{2R}$

Memory Tips

1. R.M.S. velocity is related to density by the relation :

$$C_{rms} = \sqrt{\frac{3p}{\rho}} = \sqrt{\frac{3RT}{M}}$$

2. $$C_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_bT}{m}}$$

3. For two different gases :

$$\frac{C_{rms1}}{C_{rms2}} = \sqrt{\frac{T_1M_2}{T_2M_1}}$$

4. Average speed of n molecules moving with speeds $C_1, C_2, \ldots, C_n$ is :

$$\overline{C} = \frac{C_1 + C_2 + \ldots + C_n}{n} = \sqrt{\frac{8RT}{\pi m}}$$

5. Most probable speed :

$$C_{mp} = \sqrt{\frac{2RT}{M}}$$

6. $C_{rms} : \overline{C} : C_{mp} = \sqrt{3} : \sqrt{2 \cdot 5} : \sqrt{2}$
$= 1 \cdot 73 : 1 \cdot 6 : 1 \cdot 41$

7. The relation between degree of freedom of gas and ratio of specific heats is :

$\gamma = 1 + \frac{2}{f}$, where $\gamma = \frac{C_p}{C_v}$, f is degree of freedom.

8. γ
 - Monoatomic → $1 + \frac{2}{3} = \frac{5}{3}$
 - Diatomic → $1 + \frac{2}{5} = \frac{7}{5}$
 - Triatomic → $1 + \frac{2}{6} = \frac{4}{3}$ or $1 + \frac{2}{7} = \frac{9}{7}$

9. **Law of equipartition of energy :** According to Maxwell, the total energy of the gas is shared equally among various degrees of freedom. The energy per molecule per degree of freedom $= \frac{1}{2}kT$.

10. **Boyle's law :** When temperature of a gas is kept constant, then $p \propto \frac{1}{V}$ or PV = constant

11. **Charle's law :** If pressure of a gas is kept constant, then $V \propto T$

or $\frac{V}{T}$ = constant

12. **Graham's law of diffusion :** When two gases at the same temperature and pressure are allowed to diffuse, then rate of diffusion of each gas is inversely proportional to the square root of density of the gas.

13. Ideal gas obeys the gas equation $pV = nRT$.

14. Real gases do not obey the gas equation $pV = nRT$. On the other hand, they obey the vander Waal equation :

$$\left(p + \frac{an^2}{V^2}\right)(V - nb) = nRT$$

15. Gases obey this equation at high pressure and low temperature.

16. The Boyle's law equation for real gases can be written as :

$$pV = A + Bp + Cp^2 + Dp^3,$$

where $A > B > C > D > \ldots$

Here A, B, C, D ... etc. are called viral coefficients.

17. At the Boyle's temperature viral coefficient B is zero.

Therefore, $B = C = D = \ldots = 0$

Hence $pV = A = RT$.

18. The deviation of the real gases from the ideal gas behaviour is due to the finite molecular size and intermolecular attraction.

19. **Pressure of gas :**

$$p = \frac{1}{3}\rho C_{rms}^2 = \frac{1}{3}\frac{M}{V}C_{rms}^2 = \frac{2}{3} \times \frac{1}{V} \times E$$

That is, $p \propto$ average kinetic energy of all the molecules.

20. Kinetic energy of gas (kinetic theory of gas)

$$K = \frac{1}{3}\frac{M}{V}C_{rms}^2$$

$\Rightarrow \quad K \propto C_{rms}^2 \quad$ or $\quad K \propto T$

21. The average kinetic energy of one mole of ideal gas is :

$$U_K = \frac{3}{2}RT$$

The mean kinetic energy of the molecule of an ideal gas is :

$$U_{K(\text{molecule})} = \frac{3}{2} k_B T$$

22. Molar specific heat at constant volume :

$$\Delta Q = nC_v \Delta T$$

$$\Rightarrow \quad C_v = \frac{\Delta Q}{n\Delta T}$$

23. C_v is related to degree of freedom as :

$$C_v = \frac{f}{2} R$$

24. Molar specific heat at constant pressure :

$$\therefore \quad C_p = C_v + R$$

$$\text{or} \quad C_p = \left(\frac{f}{2} + 1\right) R$$

25. $\gamma = \frac{C_p}{C_v}$. It is also related to degree of freedom as

$$\gamma = 1 + \frac{2}{f}$$

26. Also γ is equal to the ratio of bulk modulus of gas under adiabatic condition (B_a) to that under isothermal conditions (B_T). That is

$$\gamma = \frac{B_a}{B_T}$$

$$\text{or} \quad \gamma = \frac{\text{Slope of adiabatic } p - V \text{ diagram}}{\text{Slope of isothermal } p - V \text{ diagram}}$$

Multiple Choice Questions

Basic Concepts

1. Two gases at the same temperature *T*, pressure *P* and volume *V* are mixed. The mixture has volume V and temperature T. What is the pressure of the mixture ?
   (A) $P/2$ (B) P
   (C) $2P$ (D) $4P$.
2. A cylinder contains 2 kg of air at a pressure 10^5 Pa. If 2 kg more air is pumped into it, keeping the temperature constant, the pressure will be
   (A) 10^5 Pa (B) 2×10^5 Pa
   (C) $0{\cdot}5 \times 10^5$ Pa (D) 10^{10} Pa
3. Hydrogen and nitrogen are at the same temperature. The molecules of which one of them will have more average kinetic energy ?
   (A) Hydrogen (B) Nitrogen
   (C) Both have equal amount of energy
   (D) Depends upon actual value of temperature.
4. At constant pressure the rms velocity '*c*' is related to density '*d*' as
   (A) $c \propto d$ (B) $c \propto 1/d$
   (C) $c \propto \sqrt{d}$ (D) $c \propto 1/\sqrt{d}$.
5. A gas is compressed at constant temperature. Its molecules gain
   (A) speed (B) kinetic energy
   (C) internal energy (D) None of the above.
6. The rms speed of the molecules of a gas at a pressure 10^5 Pa and temperature 0°C is $0{\cdot}5$ km s^{-1}. If the pressure is kept constant but temperature is raised to 819°C, the velocity will become
   (A) 1 km s^{-1} (B) $1{\cdot}5$ km s^{-1}
   (C) 2 km s^{-1} (D) 5 km s^{-1}.
7. Which of the following is NOT a component of internal energy of a body ?
   (A) Gravitational potential energy
   (B) Potential energy of the intermolecular force field
   (C) Kinetic energy of protons in the nucleus
   (D) Kinetic energy of individual atoms.
8. Which of the following laws can be the basis of separating a mixture of gases ?
   (A) Avogadro's law
   (B) Graham's law of diffusion
   (C) Boyle's law
   (D) Charle's law.
9. A gas molecule of mass *m* is incident normally on the wall of the containing vessel with velocity *u*. After the collision the momentum of the molecule will be
   (A) zero (B) $\frac{1}{2}mu$
   (C) mu (D) $2\,mu$.
10. The molecular motion ceases at
    (A) 273 K (B) 273°C
    (C) − 273 K (D) − 273°C.
11. The energy associated with each degree of freedom of a gas molecule is
    (A) Zero (B) $\frac{1}{2}kT$
    (C) kT (D) $\frac{3}{2}kT$.
12. A closed bottle containing water is opened on the moon. What will happen ?
    (A) The water will freeze
    (B) The water will boil
    (C) The water will remain as before
    (D) The water will decompose into H_2 and O_2.
13. The expression for pressure of gas and the gas equation shows that the absolute temperature of a gas is proportional to the average
    (A) sum of vibrational, translational and rotational kinetic energies of molecules
    (B) translational kinetic energy of molecules
    (C) rotational kinetic energy of molecules
    (D) vibrational kinetic energy of molecules.
14. The number of degrees of freedom for translatory motion are
    (A) same for all types of molecules
    (B) less for multiatomic molecules
    (C) more for multiatomic molecules
    (D) dependent on the nature of translatory motion.
15. Which law of thermodynamics suggests a tendency for equalisation of temperature throughout the system ?
    (A) Zeroth law (B) First law
    (C) Second law (D) Third law.

Answers

1. (C)	2. (B)	3. (C)	4. (A)	5. (D)	6. (A)	7. (A)	8. (B)	9. (C)	10. (D)
11. (B)	12. (B)	13. (B)	14. (A)	15. (A)					

16. A man is climbing up a spiral type stair case. His degrees of freedom are
(A) 1 (B) 2
(C) 3 (D) more than 3.

17. If energy of an isolated system is not distributed equally among all the degrees of freedom, it tends to
(A) maximise it (B) minimise it
(C) equalise the distribution
(D) continue in that state.

18. The degrees of freedom of system are equal to the number of
(A) molecules in it
(B) its possible independent modes of motion
(C) the actual modes of motion at a particular instant
(D) atoms in it.

19. The monoatomic molecules have only three degrees of freedom because they can possess
(A) only translatory motion
(B) only rotatory motion
(C) both translatory and rotatory motion
(D) translatory, rotatory as well as vibratory motion.

20. A system consists of N particles, which have independent k relations among one another. The number of degrees of freedom of the system is given by
(A) $3N - k$ (B) $3N + k$
(C) $3Nk$ (D) $3N/k$.

21. Given that R is the molar gas constant and N is the Avogadro's number, then R/N gives
(A) Planck's constant
(B) Boltzmann's constant
(C) Stefan's constant
(D) None of the above.

22. The increase in the mass of the gas in a container increases its pressure. Increase in which of the following causes it ?
(A) Only the momentum of molecules
(B) Only the frequency of collision of molecules
(C) Both momentum and frequency of collision of molecules
(D) Neither momentum nor frequency of collision of molecules.

23. Gases deviate from perfect gas behaviour because their molecules
(A) are polyatomic
(B) do not attract each other
(C) interact with each other through inter-molecular forces
(D) are of very small size.

24. When does a gas behave like perfect ga...
(A) At high pressure and high temper...
(B) At low pressure and low temper...
(C) At high pressure and low temper...
(D) At low pressure and high temper...

25. 300 cm^3 of a gas at 27°C is cooled to ... constant pressure. The final volume is
(A) 300 cm^3 (B) 270 cm^3
(C) 150 cm^3 (D) 135 cm^3

26. One mole of a gas at a pressure 2... temperature 27°C is heated till both ... and volume are doubled. What is the tem... of the gas ?
(A) 300 K (B) 600 K
(C) 900 K (D) 1200 K.

27. One mole of monoatomic gas (γ = 5/3) is ... with one mole of diatomic gas γ = 7/5 ... value of γ for the mixture is
(A) 4 (B) 3
(C) 2 (D) 1·5

28. What is the value of pV/T for one mole of ... gas ?
(A) 8.4 cal mol^{-1} K^{-1} (B) 4.2 cal mol^{-1} ...
(C) 2 cal mol^{-1} K^{-1} (D) None of the ...

29. Which of the following states of matter ... two specific heats ?
(A) Solid (B) Gas
(C) Liquid (D) Fluid.

30. One mole of monoatomic gas and one ... diatomic gas are mixed together. What is the ... specific heat at constant volume for the mix...
(A) $\frac{3}{2}R$ (B) $2R$
(C) $\frac{5}{2}R$ (D) $3R$.

31. The rms speed of hydrogen at 27°C is v. ... will be the rms speed of oxygen at 300 K ?
(A) $4v$ (B) $2v$
(C) $v/2$ (D) $v/4$.

32. What happens to the mean free path of the ... molecules when air is drawn out of an encl... at constant temperature for reducing the pre... inside it ?
(A) Decreases (B) Increases
(C) Remains unchanged
(D) Depends on temperature.

33. Four students were asked to estimate the va... of C_p and C_v in cal/molK for the given sam... of gas. Their observations are listed below. Wh... of them is most reliable ?

Answers

16. (C)	17. (C)	18. (B)	19. (A)	20. (A)	21. (B)	22. (B)	23. (C)	24. (D)	25. ...
26. (D)	27. (D)	28. (C)	29. (B)	30. (B)	31. (D)	32. (B)			

(A) 5·1 and 4·2 (B) 7 and 5
(C) 7·6 and 8·6 (D) 7 and 3.

34. For a certain gas the ratio of specific heats is 3/2. What is the value of C_p for it ?
(A) R (B) $2R$
(C) $3R$ (D) $5R$.

35. The mean rotational kinetic energy of a diatomic molecule at temperature T is
(A) $\frac{1}{2}kT$ (B) kT
(C) $2kT$ (D) $\frac{5}{2}kT$.

36. For the same rise in temperature of two moles of gas at constant pressure the heat required for triatomic gas is k times that required for monoatomic gas. What is the value of k ?
(A) $\frac{3}{2}$ (B) $\frac{5}{2}$
(C) $\frac{8}{3}$ (D) $\frac{8}{5}$.

37. Supposing the distance between the atoms of a diatomic gas to be constant, its specific heat at constant volume per mole (gram mole) is
(A) $\frac{5}{2}R$ (B) $\frac{3}{2}R$
(C) R (D) $\frac{1}{2}R$.

38. A sealed container with negligible thermal coefficient of expansion contains helium (a monoatomic gas). When it is heated from 300 to 600 K, the average kinetic energy of the helium atom is
(A) halved (B) left unchanged
(C) doubled (D) becomes $\sqrt{2}$ times

39. The temperature of an ideal gas is increased from 27°C to 927°C. The root mean square speed of its molecules becomes
(A) twice (B) half
(C) four times (D) one fourth.

40. A sample of an ideal gas occupies a volume V at a pressure p and absolute temperature T. The mass of each molecule is m. Which of the following expressions gives the density of the gas ?
(A) mkT (B) pm/kT
(C) p/kTV (D) p/kT.

41. When the volume of a gas is reduced at constant temperature, the pressure exerted by the gas on the walls of the container increases because
(A) each molecule hits the walls with greater speed
(B) each molecule loses more energy when it strikes the wall.
(C) each molecule loses momentum when it strikes the wall.
(D) the number of molecules striking the wall per unit time increases.

42. The cause of diffusion of gases is
(A) temperature difference
(B) pressure difference
(C) peltier effect
(D) concentration gradient of molecules.

43. The temperature of an ideal gas enclosed in a chamber is raised from 300 K to 600 K. The pressure becomes two fold because the
(A) mean molecular velocity becomes $\sqrt{2}$ fold
(B) root-mean square velocity becomes $\sqrt{2}$ fold
(C) number of molecules striking the wall per unit time becomes 2-fold
(D) energy transfer to walls per unit time becomes 2-fold.

44. The ratio (C_p/C_v) of the specific heats at a constant pressure and constant volume of any perfect gas
(A) cannot be greater than 5/4
(B) cannot be greater than 3/2
(C) cannot be greater than 5/3
(D) can have any value.

45. A gas at a pressure p is contained in a vessel. If the masses of all the molecules are halved and their velocities are doubled, then the resulting pressure of the gas will be
(A) $p/4$ (B) $p/2$
(C) p (D) $2p$

46. We have a sample of gas characterised by p, V and T and another sample of gas characterised by $2p$, $V/4$ and $2T$. What is the ratio of the molecules in the first and second samples ?
(A) 2 (B) 4
(C) 8 (D) 16

47. In order to double the average separation between the molecules of a sample of gas at constant temperature the pressure should be reduced by a factor
(A) $\frac{1}{2}$ (B) $\frac{1}{4}$
(C) $\frac{1}{8}$ (D) $\frac{1}{16}$

Answers

33. (B)	34. (C)	35. (B)	36. (D)	37. (A)	38. (C)	39. (A)	40. (B)	41. (D)	42. (D)
43. (B)	44. (C)	45. (D)	46. (B)	47. (C)					

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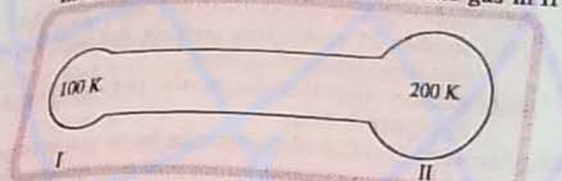
48. A sample of oxygen have the same mass, volume and pressure as another sample of hydrogen. The ratio of their temperature will be : $T_{(oxygen)}/T_{(hydrogen)}$ =
(A) 4 (B) 8
(C) 16 (D) 32

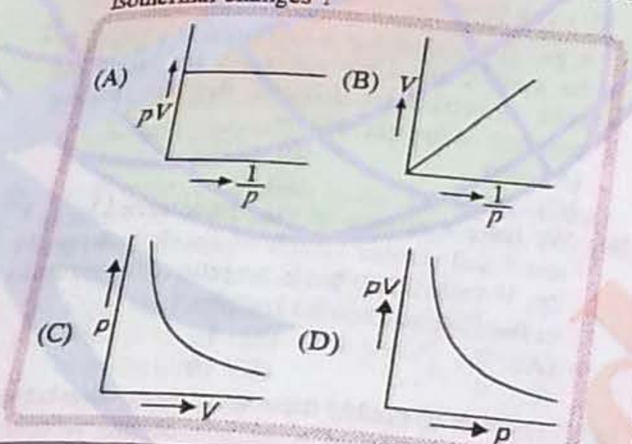
49. A mixture of two gases is contained in a vessel. The gas–I is monoatomic and gas–II is diatomic and ratio of their molecular masses $M_1/M_2 = 1/4$. What is the ratio of the root mean square speeds of the molecules of two gases ?
(A) 2 (B) 4
(C) 8 (D) 16

50. Figure shows two flasks connected to each other. The volume of the flask I is twice that of flask II. The system is filled with an ideal gas at temperature 100 K and 200 K respectively. If the mass of the gas in I be m, then what is the mass of the gas in II ?



(A) m (B) $m/2$
(C) $m/4$ (D) $m/8$

51. Which of the following curves is not correct for isothermal changes ?



Questions From Competitive Exams

52. The value of C_v for one mole of Neon gas is
(A) (1/2) R (B) (3/2) R
(C) (5/2) R (D) (7/2) R.
(M.P.C.E.E.T. 2000)

53. If γ be the ratio of specific heats of a gas, the number of degrees of freedom of a molecule of the gas is
(A) $\frac{25}{2}(\gamma - 1)$ (B) $\frac{3\gamma - 1}{2\gamma - 1}$
(C) $\frac{2}{\gamma - 1}$ (D) $\frac{9}{2}(\gamma - 1)$
(C.B.S.E.

54. The speeds of 5 molecules of gas (in arb. units) are as follows
2, 3, 4, 5, 6
The root mean square speed for these molecules
(A) 2·91 (B) 4·00
(C) 3·52 (D) 4·24.
(M.P.P.M.T.

55. Oxygen and hydrogen are at the same temperature T. The ratio of the mean kinetic energy of oxygen molecules to that of hydrogen molecules will be
(A) 16 : 1 (B) 1 : 1
(C) 4 : 1 (D) 1 : 4.
(M.P.P.M.T. 2

56. For a diatomic gas
(A) $C_v = \frac{7}{2}R$ (B) $C_p = \frac{2}{7}R$
(C) $C_p = \frac{5}{2}R$ (D) $C_v = \frac{5}{2}R$.
(I.I.I.T. Alla. 20

57. An isochoric process is one which takes place at
(A) constant internal energy
(B) constant entropy
(C) constant volume
(D) constant pressure. (I.I.I.T. Alla. 20

58. 10 c.c. each of oxygen and hydrogen are kept in separate flasks. What is the number of molecules present in the gases ?
(A) each have same number of molecules
(B) don't have same number of molecules
(C) can't be predicted
(D) none.
(I.I.I.T. Hyd. 200

59. According to kinetic theory of gases, Root Mean Square (R.M.S.) velocity of a gas is directly proportional to
(A) $\sqrt{T}$ (B) T^2
(C) T (D) $1/\sqrt{T}$.
(I.I.I.T. Hyd. 200

60. If one mole of a monoatomic gas is mixed with one mole of a diatomic gas, the value of γ for the mixture is

Answers

48. (C) 49. (A) 50. (C) 51. (D) 52. (B) 53. (C) 54. (D) 55. (B) 56. (D) 57. (C)
58. (C) 59. (A)

(A) 1·40 (B) 1·50
(C) 1·53 (D) 3·07.

(I.I.T. Hyd. 2000)

61. According to kinetic theory of gases, molecules of a gas behave like
(A) inelastic spheres
(B) perfectly elastic rigid sphere
(C) perfectly elastic non-rigid spheres
(D) inelastic non-rigid spheres.

(C.E.T. J & K. 2000)

62. The average kinetic energy of hydrogen molecules at 300 K is E. At the same temperature, the average kinetic energy of oxygen molecules will be
(A) $E/4$ (B) $E/16$
(C) E (D) $4E$.

(J.I.P.M.E.R. 2000)

63. Pressure of a gas at constant volume is proportional to
(A) total energy of gas
(B) average P.E. of molecules
(C) average K.E. of molecules
(D) total internal energy of gas.

(A.F.M.C. 2001)

64. Rate of diffusion is
(A) faster in solids than in liquids and gases
(B) faster in liquids than in solids and gases
(C) equal to solids, liquids and gases
(D) faster in gases than in liquids and solids.

(A.F.M.C. 2001)

65. Which of the following is the *correct* relation ?
(A) $C_p + C_v = R$ (B) $C_p - C_v = R$
(C) $\dfrac{C_p}{C_v} = R$ (D) $\dfrac{C_v}{C_p} = R$.

(B.V.T. M.B.B.S. 2001)

66. The root-mean-square velocity for an ideal gas is (where the symbols have their usual meanings)
(A) $v_{rms} = \sqrt{\dfrac{3MT}{R}}$ (B) $v_{rms} = \sqrt{\dfrac{3RT}{M}}$
(C) $v_{rms} = \sqrt{\dfrac{3RM}{T}}$ (D) $v_{rms} = \sqrt{3RMT}$.

(M.P.C.E.E.T. 2001)

67. The equation for the adiabatic change in a gas is PV^γ = a constant, where γ stands for [where C_p and C_v represent the principal specific heats of the gas]
(A) C_v/C_p (B) $C_p - C_v$
(C) $C_v - C_p$ (D) C_p/C_v
(E) $C_p . C_v$

(Kerala P.M.T. 2001)

68. Triple point of water is
(A) 273·16°F (B) 273·16 K
(C) 273·16°C (D) 273·16.

(U.P.C.P.M.T. 2002)

69. If R is gas constant for 1 gram mole, C_P and C_V are specific heat for a gas then
(A) $C_P - C_V = R$ (B) $C_P - C_V < R$
(C) $C_P - C_V = 0$ (D) $C_P - C_V > R$.

(U.P.C.P.M.T. 2002)

70. Under constant temperature, graph between P and $1/V$ is a
(A) parabola (B) hyperbola
(C) straight line (D) circle.

(U.P. C.P.M.T. 2002)

71. The relationship between pressure and the density of a gas expressed by Boyle's law, $P = KD$ holds true
(A) for any gas under any conditions
(B) for some gases under any conditions
(C) only if the temperature is kept constant
(D) only if the density is constant.

(U.P. C.P.M.T. 2002)

72. The equation of state of some gases can be expressed as
$$\left(P + \frac{a}{V^2}\right) = \frac{R\theta}{V}.$$
where P is the pressure, V the volume, θ the absolute temperature and a and R are constants. The dimensional formula of a is
(A) ML^5T^{-2} (B) $M^{-1}L^5T^{-2}$
(C) $ML^{-1}T^{-2}$ (D) $ML^{-5}T^2$.

(U.P.S.E.A.T. 2002)

73. For an ideal gas of diatomic molecules
(A) $C_p = \dfrac{5}{2}R$ (B) $C_v = \dfrac{3}{2}R$
(C) $C_p - C_v = 2R$ (D) $C_p = \dfrac{7}{2}R$.

(U.P.S.E.A.T. 2002)

74. Two gases are at absolute temperatures 300 K and 350 K respectively. Ratio of average kinetic energy of their molecules is
(A) 7 : 6 (B) 6 : 7
(C) 36 : 49 (D) 49 : 36.

(D.C.E. 2002)

75. If a gas has n degrees of freedom, ratio of specific heats of gas is
(A) $\dfrac{1+n}{2}$ (B) $1 + \dfrac{1}{n}$
(C) $1 + \dfrac{n}{2}$ (D) $1 + \dfrac{2}{n}$. (D.C.E. 2002)

Answers

60. (C) **61.** (B) **62.** (C) **63.** (C) **64.** (D) **65.** (B) **66.** (B) **67.** (D) **68.** (B) **69.** (A)
70. (C) **71.** (C) **72.** (A) **73.** (D) **74.** (B) **75.** (D)

76. At what temperature is r.m.s. speed of air molecules double of that at N.T.P. ?
(A) 819°C (B) 719°C
(C) 909°C (D) None of these.
(J & K C.E.T. 2002)

77. A gas at a pressure p is contained in a vessel. If the masses of all the molecules are halved and their velocities are doubled, then the resulting pressure of the gas will be
(A) $p/4$ (B) $p/2$
(C) p (D) $2p$ (C.P.M.T. 2000)

78. We have a sample of gas characterised by p, V and T and another sample of gas characterised by $2p$, $V/4$ and $2T$. What is the ratio of the molecules in the first and second samples ?
(A) 2 (B) 4
(C) 8 (D) 16 (C.B.S.E. 2000)

79. In order to double the average separation between the molecules of a sample of gas at constant temperature, the pressure should be reduced by a factor
(A) $\frac{1}{2}$ (B) $\frac{1}{4}$
(C) $\frac{1}{8}$ (D) $\frac{1}{16}$ (C.B.S.E. 2000)

80. A sample of oxygen has the same mass, volume and pressure as another sample of hydrogen. The ratio of their temperature will be $(T_{(oxygen)}/T_{(hydrogen)})$
(A) 4 (B) 8
(C) 16 (D) 32 (C.B.S.E. 2001)

81. A mixture of two gases is contained in a vessel. The gas I is monoatomic and gas II is diatomic and ratio of their molecular masses $M_1/M_2 = 1/4$. What is the ratio of the root mean square speeds of the molecules of two gases ?
(A) 2 (B) 4
(C) 8 (D) 16
(H.P.P.M.T. 2000)

82. What is the unit pV in the gas equation $pV = RT$?
(A) Nm (B) J
(C) $Jk^{-1} mol^{-1}$ (D) None of these.
(H.P.P.M.T. 2000)

83. The dimension of 'a' in van der Waal Gas equation

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

(A) $[ML^3T^{-2}]$ (B) $[ML^5T^{-2}]$
(C) $[ML^2T^{-1}]$ (D) $[ML^5T^{-3}]$
(C.P.M.T.

84. In the gas equation, for one mole of ...

$$\left(P + \frac{a}{V^2}\right)(V - b) = RT, \text{ dimension ...}$$

(A) $[ML^4T^{-2}]$ (B) $[ML^2T^{-2}]$
(C) $[L^3]$ (D) None of these
(J & K C.E.T. ...

85. A gas for which $\gamma = 1 \cdot 5$, is suddenly com... to $\frac{1}{4}$ th of the initial volume. Then the r... the final to the initial pressure is
(A) 1 : 16 (B) 1 : 8
(C) 1 : 4 (D) 8 : 1
(E.A.M.C.E.T. 2...

86. We have a jar A filled with gas chara... by parameters P, V, T and another jar B... with a gas with parameters $2P$, $\frac{V}{4}$, $2T$, ... the symbols have their usual meanings... ratio of the numbers of molecules of jar... those of jar B is
(A) 1 : 1 (B) 1 : 2
(C) 2 : 1 (D) 4 : 1
(A.I.I.M.S. 1...

87. The number of molecules per unit volum... vessel containing a gas at absolute temper... T, in terms of the pressure P and Boltzm... constant is
(A) $\frac{Pk}{T}$ (B) $\frac{P}{kT}$
(C) PkT (D) $\frac{k}{PT}$
(E.A.M.C.E.T. 19...

88. A real gas can be approximated to an idea... at
(A) Low density (B) High pressure
(C) High density (D) Low temperatur...
(E.A.M.C.E.T. 19...

89. If the volume of the gas is to be increased ... times, then
(A) temperature and pressure must be do...
(B) at constant P the temperature mu... increased by 4 times
(C) at constant T the pressure must be inc... by four times
(D) it cannot be increased
(E.A.M.C.E.T. 1...

90. Th... pr... (... (... (... (...

91.

92.

93

Answers

76. (A)	77. (D)	78. (B)	79. (C)	80. (C)	81. (A)	82. (C)	83. (B)	84. (C)	85
86. (D)	87. (B)	88. (A)	89. (B)						

90. The graph between temperature in °C and pressure of a perfect gas is
(A) a hyperbola
(B) a straight line passing through origin
(C) a straight line parallel to pressure
(D) a straight line with a +ve intercept on pressure axis intercepting temperature axis at − 273°C (N.C.E.R.T. 1995)

91. The difference between C_P and C_V
(A) is equal to R
(B) is equal to $2R$
(C) is equal to $\frac{R}{2}$
(D) depends upon the atomicity of gas molecules. (E.A.M.C.E.T. 1995)

92. In gases of diatomic molecules, the ratio of the two specific heats of gases $\frac{C_P}{C_V}$ is
(A) 1·66 (B) 1·40
(C) 1·33 (D) 1·00. (E.A.M.C.E.T. 1995)

93. Two vessels having equal volume contain molecular hydrogen at one atmosphere and helium at two atmospheres respectively. If both samples are at the same temperature, the mean velocity of hydrogen molecules is
(A) equal to that of helium
(B) twice that of helium
(C) half that of helium
(D) $\sqrt{2}$ times that of helium (M.P.P.M.T. 1999)

94. In kinetic theory of gases; one assumes that the collisions between the molecules are
(A) perfectly elastic
(B) perfectly inelastic
(C) partly inelastic
(D) may be perfectly elastic or perfectly inelastic depending on nature of gas. (C.P.M.T. 1992)

95. If the r.m.s. velocity of the molecules of a gas in a container be doubled, then pressure of gas will
(A) become 4 times of its previous value
(B) become 2 times of its previous value
(C) remain same
(D) become 1/4 of its previous value (C.P.M.T. 1992)

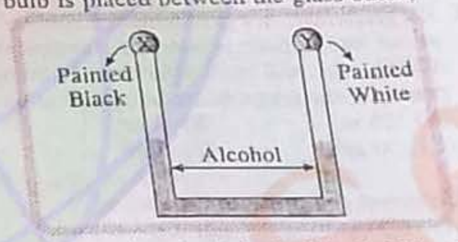
96. At a given temperature which of the following gases possesses maximum r.m.s. velocity ?
(A) hydrogen (B) oxygen
(C) nitrogen (D) carbon dioxide (C.P.M.T. 1992)

97. The temperature of gas is produced by
(A) the potential energy of its molecules
(B) the kinetic energy of its molecules
(C) the attractive force between its molecules
(D) the repulsive force between its molecules (C.P.M.T. 1992)

98. Pressure exerted by a gas is
(A) independent of density of the gas
(B) inversely proportional to the density of the gas
(C) directly proportional to the square of the density of the gas
(D) directly proportional to the density of the gas (C.P.M.T. 1992)

99. A polyatomic gas with n degrees of freedom has a mean energy per molecule given by
(A) $\frac{nkT}{N}$ (B) $\frac{nkT}{2N}$
(C) $\frac{nkT}{2}$ (D) $\frac{3kT}{2}$ (C.B.S.E. 1992)

100. The figure below shows a U-tube attached at its ends to two glass bulbs, one coated with black paint and the other polished. The tube is partly filled with alcohol. When a 100-watt bulb is placed between the glass bulbs,



(A) the level of alcohol in X falls while that in Y rises
(B) level of alcohol in X rises while that of Y falls
(C) the level falls in both
(D) there is no change in the levels of alcohol in the two limbs. (H.P.P.M.T. 1995)

101. A diatomic gas molecules has translation, rotational and vibrational degrees of freedom, then the ratio $\frac{C_p}{C_v}$ is
(A) 1·29 (B) 1·33
(C) 1·4 (D) 1·6. (Punjab P.M.T. 2002)

Answers

90. (D) 91. (A) 92. (B) 93. (A) 94. (A) 95. (A) 96. (A) 97. (B) 98. (B) 99. (C)
100. (A) 101. (A)

102. Helium at 27°C has volume 8 litre, it is suddenly compressed to a volume 1 litre. The temperature of the gas will be $\left(\gamma = \frac{5}{3}\right)$

(A) 1327°C (B) 1200°C
(C) 108°C (D) 927°C.

(Punjab P.M.T. 2002)

103. A fixed mass of gas at constant pressure occupies a volume V. The gas undergoes a rise in temperature so that the root mean square velocity of the molecule is doubled. The new volume will be

(A) $V/2$ (B) $V/\sqrt{2}$
(C) $2V$ (D) $4V$.

(Haryana C.E.E.T. 2002)

104. The temperature of the ideal gas is increased form 27°C to 927°C. The root mean square speed of its molecules becomes

(A) half (B) twice
(C) four times (D) one-fourth.

(A.M.U. (Med.) 2002)

105. At which of the following temperature would the molecules of a gas have twice the average kinetic energy they have at 20°C ?

(A) 313°C (B) 373°C
(C) 393°C (D) 586°C.

(A.M.U. (Engg.) 2002)

106. If a given mass of a gas occupies a volume 100 m^3 at one atmospheric pressure and temperature of 100°C, what will be its volume at 4 atmospheric pressure, the temperature being the same ?

(A) 25 m^3 (B) 0 m^3
(C) 50 m^3 (D) 5 m^3.

(A.M.U. (Engg.) 2002)

107. Universal gas constant is equal to

(A) C_p/C_V (B) $C_p - C_V$
(C) $C_p + C_V$ (D) C_V/C_p.

(Orissa J.E.E. 2003)

108. In the relation $n = \frac{PV}{RT}$, n = ?

(A) Number of molecules
(B) Atomic number
(C) Mass number
(D) Number of moles.

(Raj. P.E.T. 2003)

109. At absolute temperature, the translational kinetic energy of the molecules

(A) becomes zero (B) becomes maximum
(C) becomes minimum
(D) remains constant.

(Raj. P.E.T. 2003)

110. On colliding in a closed container, the molecules

(A) transfer momentum to the walls.
(B) momentum becomes zero.
(C) move in opposite directions.
(D) perform brownian motion.

(Raj. P.E.T. ...)

111. The average energy of molecules having ... degree of freedom is

(A) $\frac{3kT}{2}$ (B) $\frac{kT}{2}$
(C) $\frac{3}{4}kT$ (D) kT.

(Raj. P.E.T. ...)

112. A gaseous mixture consists of 16g of ... and 16 g of oxygen. The ratio C_p/C_v of ... mixture is

(A) 1·4 (B) 1·54
(C) 1·59 (D) 1·62

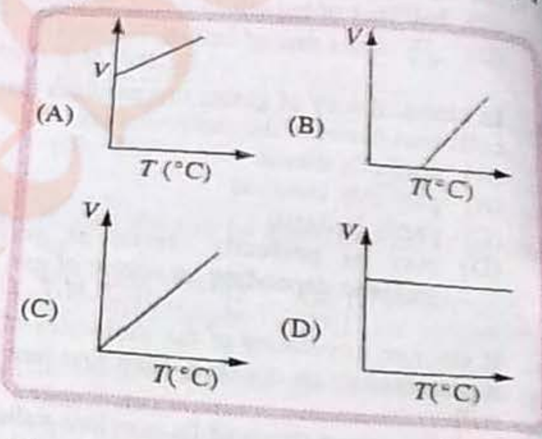
(A.I.E.E.E. ...)

113. A tyre kept outside in sunlight bursts off ... sometime because of

(A) increase in pressure
(B) increase in volume
(C) both (A) and (B)
(D) none of these.

(A.F.M.C. 20...)

114. Volume-temperature graph at atmospheric pressure for a monoatomic-gas (V in m^3, T in °C) is



(D.C.E. 200...)

115. The gas having average speed four times ... that of SO_2 (molecular mass 64) is

(A) He (molecular mass 4)
(B) O_2 (molecular mass 32)
(C) H_2 (molecular mass 2)
(D) CH_4 (molecular mass 16)

(D.C.E. 200...)

Answers

102. (D) 103. (D) 104. (B) 105. (A) 106. (A) 107. (B) 108. (D) 109. (A) 110. (C) 111. (C)
112. (D) 113. (A) 114. (C) 115. (A)

116. In isothermal process, which of the following is not true ?
(A) temperature remains constant
(B) internal energy does not change
(C) no heat enters or leaves the system
(D) none *(B.H.U. 2005)*

117. A perfect gas is found to obey the relation $PV^{1/2}$ = constant during an adiabatic process. If such a gas is initially at a temperature T, is compressed to half of its initial volume then its final temperature will be
(A) $2T$ (B) $4T$
(C) $(2)^{1/2}\,T$ (D) $2(2)^{1/2}T$. *(B.H.U. 2005)*

118. The value of PV/T for one mole of an ideal gas is nearly equal to
(A) 2 J mol^{-1} K^{-1} (B) 8·3 cal mol^{-1} K^{-1}
(C) 4·2 J mol^{-1} K^{-1} (D) 2 cal mol^{-1} K^{-1}
(E) 4 cal mol^{-1} K^{-1}. *(Kerala P.E.T 2005)*

119. Equation of a gas in terms of pressure (P), absolute temperature (T) and density (d) is
(A) $\frac{P_1}{T_1 d_1} = \frac{P_2}{T_2 d_2}$ (B) $\frac{P_1 T_1}{d_1} = \frac{P_2 T_2}{d_2}$
(C) $\frac{P_1 d_2}{T_1} = \frac{P_2 d_1}{T_1}$ (D) $\frac{P_1 d_1}{T_1} = \frac{P_2 d_2}{T_2}$ *(E.A.M.C.E.T. 2005)*

120. What is the mass of 2 litres of nitrogen at 22·4 atmospheric pressure and 273 K ?
(A) 28 g (B) 14 × 22·4 g
(C) 56 g (D) None of these *(J &K C.E.T. 2005)*

121. In Boyle's law what remains constant ?
(A) PV (B) TV
(C) $\frac{V}{T}$ (D) $\frac{P}{T}$ *(U.P.C.P.M.T. 2005)*

122. When the temperature of a gas is increased the kinetic energy of the molecules
(A) remains unaffected
(B) increases
(C) decreases
(D) may increase or decrease *(U.P.C.P.M.T. 2005)*

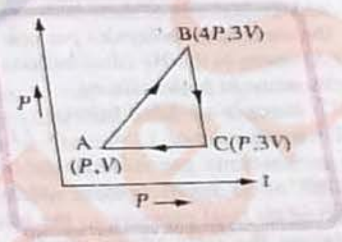
123. A real gas behaves like an ideal gas at which pressure (P) and temperature (T) ?
(A) low P, high T (B) high P, high T
(C) low P, low T (D) high P, low T *(U.P.C.P.M.T. 2005)*

124. The temperature of H_2 at which the rms velocity of its molecules is seven times the rms velocity of the molecules of nitrogen at 300 K is
(A) 2100 K (B) 1700 K
(C) 1350 K (D) 1050 K. *(V.G.E.T -M.A.H.E- Manipal 2005)*

125. Gas exerts pressure on the walls of the container because
(A) gas has weight
(B) gas molecules have momentum
(C) gas molecules collide with each other
(D) gas molecules collide with the walls of the container *(V.G.E.T -M.A.H.E- Manipal 2005)*

126. If at NTP velocity of sound in a gas is 1150 m/s, then the rms velocity of gas molecules at NTP is
(Given R = 8·3 joule/ mol/ K
C_p = 4·8 cal/ mol/ K)
(A) 1600 m/s (B) 1532·19 m/s
(C) 160 m/s (D) zero *(V.G.E.T -M.A.H.E- Manipal 2005)*

127. A sample of ideal monoatomic gas is taken round the cycle $ABCA$ as shown in the figure. The work done during the cycle is



(A) 3 PV (B) zero
(C) 9 PV (D) 6 PV *(Punjab C.E.T. 2005)*

128. An ideal monoatomic gas at 27°C is compressed adiabatically to 8/27 times of its present volume. The increase in temperature of the gas is
(A) 375°C (B) 402°C
(C) 175°C (D) 475°C *(Punjab C.E.T. 2005)*

129. Two perfect gases at absolute temperatures T_1 and T_2 are mixed. There is no loss of energy.

Answers

116. (C) 117. (C) 118. (D) 119. (A) 120. (A) 121. (A) 122. (B) 123. (A) 124. (D) 125. (D)
126. (B) 127. (A) 128. (A)

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