fo/u fopkjr Hkh# tu] ugh vkjEHk dke] foifr n[k NkM rjr e/;e eu dj ';keA
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STUDY PACKAGE

Subject : PHYSICS

Topic : KINETIC THEORY OF GASES & THERMODYNAMICS

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SHORT REVISIONS

Kinetic Theory Of Gases

1. Assumption of kinetic theory of gases

(1) A gas consist of particles called molecules which move randomly in all directions.
(2) These molecules obey Newton's law of motion.
(3) Size of molecule negligible in comparison to average separation between the molecules.
(4) The forces on molecule are negligible except at the time of collision.
(5) All collision between molecules or between molecules and wall are pefectly elastic. Time of collision is very small.
(6) For large number of molecules the density and distribution of molecules with different velocities are independent of position, direction and time.

2. Pressure of an ideal gas

$$P = \frac{1}{3}\rho\overline{v}^2 = \frac{1}{3}\rho\overline{v}^2_{rms}$$

Here $\overline{v}$ = mean square speed

v_{rms} = root mean square speed
ρ = density of gas

$$P = \frac{2}{3}\left(\frac{1}{2}\rho v^2_{rms}\right)$$

$$P = \frac{2}{3}E$$

$$E = \frac{3}{2}P$$

So total K.E. $K = \frac{3}{2}PV$

3. R.M.S. velocity – depends on tempearture only for any gas.

$$V_{rms} = \frac{\sqrt{v_1^2 + v_2^2 + v_3^2 + ...+v_n^2}}{n}$$

$$P = \frac{1}{3}\rho v^2_{rms}$$

$$v_{rms} = \sqrt{\frac{3P}{\rho}} = \sqrt{\frac{3RT}{M}}$$

4. Most Probable velocity – velocity which maximum number of molecules may have

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

5. Average velocity

$$v_{avg} = \frac{\vec{v}_1 + \vec{v}_2 + ... + \vec{v}_n}{n} = 0$$

6. Average speed

$$v_{avg} = \frac{|\vec{v}_1| + |\vec{v}_2| + |\vec{v}_3| + ...+|\vec{v}_n|.}{n} = \sqrt{\frac{8RT}{\pi M}}$$

7. Ideal gas equation

PV= nRT (container form of gas law/ pressure volume form)

$P = \left(\frac{\rho}{M}\right)RT$ (open atmosphere / pressure density form)

8. Graham's law of diffusion :–

When two gases at the same pressure and tempearture 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

$r \propto v_{rms}$ where r = rate of diffusion

so, $$\frac{r_1}{r_2} = \sqrt{\frac{\rho_2}{\rho_1}}$$

9. Degree of Freedom (f) – No. of ways in which a gas molecule can distribute its energy

10. Law of equipartition of energy : – Energy in each degree of freedom = 1/2 KT joules

If degree of freedom is f. Energy = $\frac{f}{2}$ KT joules.

$$U = \frac{f}{2} KTnN_A = \frac{f}{2} nRT$$

11. Degree of freedom(f) in different gas molecules

Molecules	Translational	Rotational
Monoatomic	3	0
Diatomic	3	2
Polyatomic	3	2 (linear molecule) 3 (non-linear molecule)

Translational energy for all type of molecules = $\frac{3}{2}$ **(nRT)**

Law of Thermodynamics

1. Zeroth law of thermodynamics :– If two bodies A and B are in thermal equilibrium and A and C are also in thermal equilibrium.Then B and C are also in thermal equilibrium.

2. First law of Thermodynamics:– Energy conservation for gaseous system.

Heat supplied to the gas = Increment in internal energy + work done by the gas.

$\Delta Q = \Delta U + \Delta W$ ΔQ is +ve for heat supplied

in differential form $dQ = dU + dW$ ΔQ is –ve for heat rejected

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and $dQ = nCdT$ $\quad$ C = molar specific heat

$C = C_P$ (constant pressure) ; $C = C_V$ = (constant volume)

$$dU = \frac{f}{2}\,nRdT$$

$$dW = \int_{v_1}^{v_2} P\,dv$$ (P = pressure of the gas of which work is to be calculated)

ΔW = +ve for work done by gas (in expansion of gas)

ΔW = –ve for work done on the gas (in contraction of gas)

Molar specific heat for a given process $C = \frac{f}{2}R + \frac{R\,PdV}{PdV + VdP} = C_V + \frac{R\,PdV}{PdV + VdP}$

Process	**C**	**Monoatomic**	**Diatomic**	**Polyatomic**
V= constant	$C_V = (f/2)R$	(3/2)R	(5/2)R	3R
P = constant	$C_P = \frac{f+2}{2}R$	(5/2)R	(7/2)R	4R

Mayor's Relation $\quad C_P = C_V + R$

Note :– C of a gas depends on the process of that gas, which can be infinite in types.

Ratio of specific heat :– $\gamma = \frac{C_P}{C_V} = \frac{f+2}{f}$

- monoatomic → 5/3 = 1.67
- diatomic → 7/5 = 1.4
- polyatomic → 4/3 = 1.33

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

$C_V = \frac{R}{\gamma - 1}$; $C_P = \frac{\gamma R}{\gamma - 1}$

<u>Isochoric Process (V= constant)</u>

$dV = 0 \Rightarrow dW = 0$

By FLT $\quad dQ = dU = nC_V\,dT$

$$Q = \int_{T_1}^{T_2} nC_v\,dT = nC_v(T_2 - T_1)$$

* Be careful if $\Delta V = 0$ then not necessarily an Isochoric Process.

<u>Isobaric Process (P = constant)</u>

$dP = 0$

By FLT $\quad dQ = dU + dW$

$n_{Cp}(T_2 - T_1) = (\frac{f}{2})nR(T_2 - T_1) + nR(T_2 - T_1)$

$$W = nR(T_2 - T_1)$$

* If $\Delta P = 0$ then not necessarily an Isobaric Process.

Isothermal Process (T = constant)

$dT = 0$, $dU = 0$

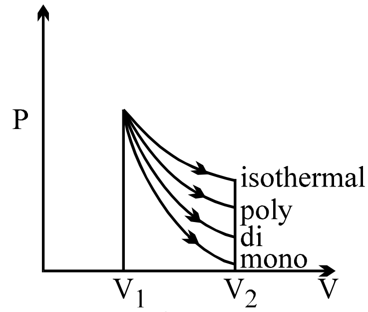
$$Q = W = (nRT)\int_{v_1}^{v_2} dV/V$$

$$W = nRT\, ln\frac{V_2}{V_1} = nRT\, ln\frac{P_1}{P_2}$$ $\left(\frac{V_2}{V_1} = \frac{P_1}{P_2} = \text{compression ratio}\right)$

Adiabatic Process dQ = 0 but if ΔQ = 0, it is not necessaserily adibatic.

dW = –dU By FLT

$$W = \int_{T_1}^{T_2} \frac{nRdT}{\gamma - 1} = \frac{nR(T_1 - T_2)}{\gamma - 1} = \frac{P_1V_1 - P_2V_2}{\gamma - 1}$$



So PdV + VdP = (γ–1) ....(ii)

For Adiabatic Process PV^{γ} = constant

Work done is least for monoatomic gas

$$\left|\frac{dP}{dV}\right|_{adiabatic} = \gamma \left|\frac{dP}{dV}\right|_{isothermal}$$

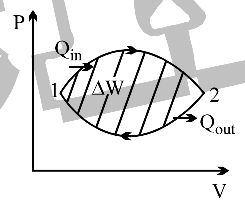
Polytropic process

PV^n= constant

$$P = \frac{K}{V^n} \Rightarrow \frac{dP}{dV} = n\left|\frac{K}{V^{n+1}}\right| \quad ; \qquad C = \frac{R}{\gamma - 1} + \frac{R}{1-n}$$

So C is constant for polytropic process

Efficiency of a cyclic process



ΔU = 0

so ΔQ = ΔW

Efficiency $\eta = \frac{\text{work done by gas}}{\text{heat input}}$

$$\eta = \frac{W}{Q_{in}} = 1 - \frac{Q_{out}}{Q_{in}}$$

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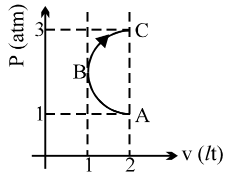
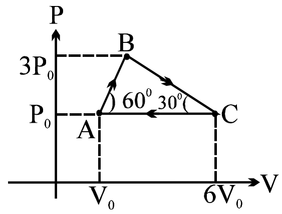
EXERCISE – I



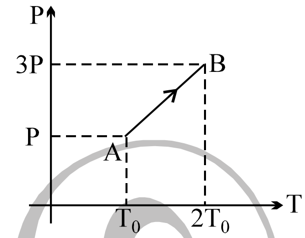
Q.1 In the P-V diagram shown in figure, ABC is a semicircle. Find the workdone in the process ABC.



Q.2 Two moles of an ideal monoatomic gas undergone a cyclic process ABCA as shown in figure. Find the ratio of temperatures at B and A .

Q.3 The average degrees of freedom per molecules for a gas is 6. The gas performs 25 J of work when it expands at constant pressure. Find the heat absorbed by the gas .

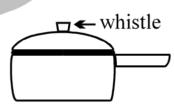
Q.4 1 mole of an ideal gas at initial temperature T was cooled isochorically till the gas pressure decreased n times. Then by an isobaric process, the gas was restored to the initial temperature T. Find the net heat absorbed by the gas in the whole process.

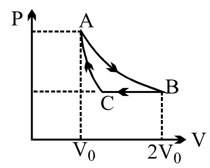


Q.5 Pressure versus temperature graph of an ideal gas is shown. Density of gas at point A is ρ_0. Find the density of gas at B.

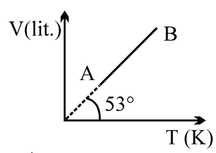
Q.6 PV-diagram of a monoatomic ideal gas is a straight line passing through origin. Find the molar heat capacity in the process.

Q.7 An empty pressure cooker of volume 10 litres contains air at atmospheric pressure 10^5 Pa and temperature of 27°C. It contains a whistle which has area of 0.1 cm^2 and weight of 100 gm. What should be the temperature of air inside so that the whistle is just lifted up?

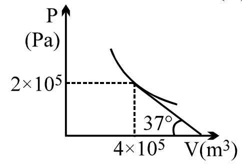




Q.8 In a cycle ABCA consisting of isothermal expansion AB, isobaric compression BC and adiabatic compression CA, find the efficiency of cycle (Given : $T_A = T_B = 400$ K, $\gamma = 1.5$)



Q.9 V-T curve for 2 moles of a gas is straight line as shown in the graph here. Find the pressure of gas at A.



Q.10 P-V graph for an ideal gas undergoing polytropic process PV^m = constant is shown here.Find the value of m.

Q.11 Air at temperature of 400 K and atmospheric pressure is filled in a balloon of volume 1 m^3. If surrounding air is at temperature of 300 K, find the ratio of Buoyant force on balloon and weight of air inside

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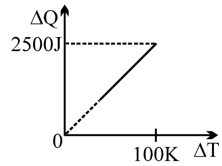
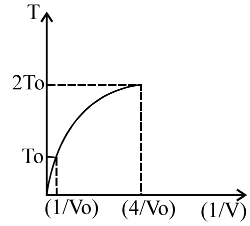
Q.12 One mole of a gas mixture is heated under constant pressure, and heat required ΔQ is plotted against temperature difference acquired. Find the value of γ for mixture.



Q.13 Ideal diatomic gas is taken through a process $\Delta Q = 2\Delta U$. Find the molar heat capacity for the process (where ΔQ is the heat supplied and ΔU is change in internal energy)

Q.14 A gas is undergoing an adiabatic process. At a certain stage A, the values of volume and temperature $\equiv (V_0, T_0)$ and the magnitude of the slope of V-T curve is m. Find the value of C_P and C_V.

Q.15 Figure shows a parabolic graph between T and $\frac{1}{V}$ for a mixture of a gas undergoing an adiabatic process. What is the ratio of V_{rms} and speed of sound in the mixture?



Q.16 The height of mercury is a faulty barometer is 75 cm and the tube above mercury having air is 10 cm long. The correct barometer reading is 76 cm. If the faulty barometer reads 74 cm, find the true barometer reading.

Q.17 A piston divides a closed gas cylinder into two parts. Initially the piston is kept pressed such that one part has a pressure P and volume 5V and the other part has pressure 8P and volume V. The piston is now left free. Find the new pressures and volumes for the adiabatic and isothermal processes. For this gas $\gamma = 1.5$.

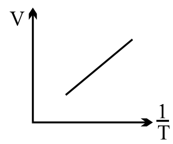
Q.18 A closed vessel of volume V_0 contains oxygen at a pressure P_0 and temperature T_0. Another closed vessel of the same volume V_0 contains helium at a pressure of P_0 and temperature $T_0/2$. Find the ratio of the masses of oxygen to the helium.

Q.19 A gas undergoes a process in which the pressure and volume are related by VP^n = constant. Find the bulk modulus of the gas.

Q.20 An ideal gas has a molar heat capacity C_V at constant volume. Find the molar heat capacity of this gas as a function of volume, if the gas undergoes the process : $T = T_0 e^{\alpha V}$.

Q.21 A standing wave of frequency 1000 Hz in a column of methane at 27°C produces nodes which are 20.4 cm apart. Find the ratio of heat capacity of methane at constant pressure to that at constant volume (Take gas constant, $R = 8.31\ J{\cdot}K^{-1}mol^{-1}$)

Q.22 One mole of an ideal monoatomic gas undergoes a process as shown in the figure. Find the molar specific heat of the gas in the process.



Q.23 One mole of an ideal gas is compressed from 0.5 lit to 0.25 lit. During the compression, 23.04×10^2 J of work is done on the gas and heat is removed to keep the temperature of the gas constant at all times. Find the temperature of the gas. (Take universal gas constant $R = 8.31\ J\ mol^{-1}K^{-1}$)

Q.24 A mixture of 4 gm helium and 28 gm of nitrogen in enclosed in a vessel of constant volume 300°K. Find the quantity of heat absorbed by the mixture to doubled the root mean velocity of its molecules. (R = Universal gas constant)

Q.25 The pressure of an ideal gas changes with volumes as P = aV where 'a' is a constant. One moles of this gas is expanded to 3 times its original volume V_0. Find
(i) the heat transferred in the process.
(ii) the heat capacity of the gas.

Q.26 If heat is added at constant volume, 6300 J of heat are required to raise the temperature of an ideal gas by 150 K. If instead, heat is added at constant pressure, 8800 joules are required for the same temperature change. When the temperature of the gas changes by 300 K. Determine the change is the internal energy of the gas.

Q.27 70 calorie of heat is required to raise the temperature of 2 mole of an ideal gas at constant pressure from 40°C to 45°C. Find the amount of heat required to raise the temperature of the same gas through the same range at constant volume (R = 2 cal/mol-K)

Q.28 The volume of one mole of an ideal gas with specific heat ratio γ is varied according to the law $V = \frac{a}{T^2}$, where a is a constant. Find the amount of heat obtained by the gas in this process if the gas temperature is increased by ΔT.

Q.29 Find the molecular mass of a gas if the specific heats of the gas are C_P=0.2 cal/gm°C and C_V = 0.15 cal/gm°C. [Take R = 2 cal/mole°C]

Q.30 Examine the following plots and predict whether in (i) $P_1 < P_2$ and $T_1 > T_2$, in (ii) $T_1 = T_2 < T_3$, in (iii) $V_1 > V_2$, in (iv) $P_1 > P_2$ or otherwise.

(i) (ii) (iii) (iv)

List of recommended questions from I.E. Irodov.

2.1 to 2.7, 2.10 to 2.13, 2.17, 2.27, 2.29 to 2.35, 2.37 to 2.40,
2.43, 2.46, 2.48, 2.49, 2.63 to 2.73, 2.116, 2.120, 2.122, 2.127

