Class 11 Physics · Chapter 12: Kinetic Theory

Answer key and marking scheme · 20 marks · about 40 minutes · based on NCERT

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1. A vacuum chamber at 300 K holds 2.5×10^{16} gas molecules per cubic metre. The pressure in the chamber is about ($k_B = 1.38 \times 10^{-23}$ J K^{-1}) [1]

(a) 3.5×10^{-7} Pa (b) 1.0×10^{-4} Pa
(c) 6.2×10^{19} Pa (d) 9.3×10^{-6} Pa

Answer: (b) $P = nk_BT = 2.5 \times 10^{16} \times 1.38 \times 10^{-23} \times 300 = 1.04 \times 10^{-4}$ Pa. Leaving out T gives 3.5×10^{-7}; using R for k_B gives 6.2×10^{19}; using 27 for T gives 9.3×10^{-6}.

2. The pressure of a gas is doubled while its temperature is kept constant. The mean free path of its molecules [1]

(a) doubles (b) stays the same
(c) becomes four times (d) becomes half

Answer: (d) $l = k_BT/(\sqrt{2}\,\pi d^2 P)$. At constant T, $l \propto 1/P$, so doubling P halves l: the number density doubles and a molecule meets others twice as often.

3. A sample of a real gas follows $PV = \mu RT$ most closely when it is kept at [1]

(a) high pressure and low temperature (b) low pressure and high temperature
(c) high pressure and high temperature (d) low pressure and low temperature

Answer: (b) Real gases approach ideal behaviour at low pressures and high temperatures, where the molecules are far apart and their interactions negligible. High pressure or low temperature brings them close enough for intermolecular forces to matter.

4. For a monatomic ideal gas, the ratio $\gamma = C_p/C_v$ is [1]

(a) $\frac{5}{3}$ (b) $\frac{7}{5}$
(c) $\frac{4}{3}$ (d) $\frac{9}{7}$

Answer: (a) $C_v = (3/2)R$ and $C_p = C_v + R = (5/2)R$, so $\gamma = 5/3$. 7/5 is the rigid diatomic value.

5. In a vessel at a fixed temperature, the rms speed of hydrogen molecules (molar mass 2 g mol^{-1}) is four times the rms speed of the molecules of a gas X in the same vessel. The molar mass of X is [1]

(a) 8 g mol^{-1} (b) 16 g mol^{-1}
(c) 32 g mol^{-1} (d) 64 g mol^{-1}

Answer: (c) $v_{rms} = \sqrt{(3k_BT/m)}$, so at the same T, $v_{rms} \propto 1/\sqrt{M}$. $v_H/v_X = \sqrt{(M_X/2)} = 4$ gives $M_X = 2 \times 16 = 32$ g mol^{-1}. Taking $v \propto 1/M$ gives 8, a slip.

6. Molecules of a gas at room temperature move at a few hundred metres per second, yet the smell of a perfume opened at one end of a classroom takes minutes to reach the other end. Explain. [2]

The molecules have a finite size, so each molecule collides with others again and again; between collisions it travels only a mean free path, of the order of 10^{-7} m. After every collision its direction changes at random, so it moves along a zig-zag path and its net displacement grows very slowly, though its speed is large. The perfume therefore spreads slowly by diffusion.

- molecules collide incessantly because of their finite size; short mean free path (1)
- random zig-zag path gives a slow net drift (diffusion) despite high speed (1)

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7. State the law of equipartition of energy. A CO molecule at moderate temperature has one mode of vibration. Find its average energy at temperature T. [2]

Law: in thermal equilibrium at absolute temperature T, the total energy is distributed equally among all possible energy modes, each mode having average energy $\frac{1}{2}k_{BT}$. CO: 3 translational terms + 2 rotational terms + 2 vibrational terms (kinetic and potential) = 7 squared terms, so the average energy is $7 \times \frac{1}{2}k_{BT} = (7/2)k_{BT}$.

- statement of the law: $\frac{1}{2}k_{BT}$ for each mode (1)
- 3 + 2 + 2 = 7 terms, average energy $(7/2)k_{BT}$ (1)

8. Three molecules have speeds 2, 4 and 6 m s^{-1}. Calculate $\langle v^2 \rangle$ and $(\langle v \rangle)^2$, and state what the result shows. [2]

$\langle v \rangle = (2 + 4 + 6)/3 = 4$ m s^{-1}, so $(\langle v \rangle)^2 = 16$ m^2 s^{-2}. $\langle v^2 \rangle = (4 + 16 + 36)/3 = 56/3 = 18.7$ m^2 s^{-2}. The two differ: the average of a squared quantity is not necessarily the square of the average, so v_{rms} (4.32 m s^{-1}) is not the mean speed.

- $(\langle v \rangle)^2 = 16$ m^2 s^{-2} (0.5)
- $\langle v^2 \rangle = 18.7$ m^2 s^{-2} (1)
- conclusion: $\langle v^2 \rangle \neq (\langle v \rangle)^2$ (0.5)

9. A gas at 300 K and 1.0×10^5 Pa has density 1.28 kg m^{-3}. (a) Find its molar mass and suggest which common gas it could be. (b) What would its density be at 600 K and the same pressure? ($R = 8.31$ J mol^{-1} K^{-1}) [3]

(a) From $P = \rho RT/M_0$, $M_0 = \rho RT/P = 1.28 \times 8.31 \times 300/(1.0 \times 10^5) = 0.0319$ kg $mol^{-1} \approx 32$ g mol^{-1}, the molar mass of oxygen, so the gas could be O_2. (b) At fixed P, $\rho = PM_0/(RT) \propto 1/T$; doubling T halves the density: $\rho = 0.64$ kg m^{-3}.

- $P = \rho RT/M_0$ used (1)
- $M_0 \approx 0.032$ kg mol^{-1}, oxygen (1)
- $\rho \propto 1/T$ at fixed P, 0.64 kg m^{-3} (1)

10. The mean free path of the molecules of a gas at 300 K and 1.0 atm is 1.0×10^{-7} m. Find the mean free path (a) at 300 K and 0.50 atm, (b) at 600 K and 1.0 atm, (c) after the gas, sealed in a rigid vessel at 300 K and 1.0 atm, is heated to 600 K. [3]

$l = 1/(\sqrt{2}\, n\pi d^2)$ and $P = nk_{BT}$ give $l = k_{BT}/(\sqrt{2}\, \pi d^2 P)$. (a) T fixed, P halved: l doubles to 2.0×10^{-7} m. (b) P fixed, T doubled: $l \propto T$, so 2.0×10^{-7} m. (c) Rigid sealed vessel: n is unchanged (the pressure rises with T), so l stays 1.0×10^{-7} m.

- (a) 2.0×10^{-7} m (1)
- (b) 2.0×10^{-7} m (1)
- (c) unchanged, 1.0×10^{-7} m, since n is fixed (1)

11. At what temperature will the rms speed of oxygen molecules be double its value at 27 °C? What is the average kinetic energy of an oxygen molecule at that temperature? ($k_B = 1.38 \times 10^{-23}$ J K^{-1}) [3]

$v_{rms} \propto \sqrt{T}$, so doubling v_{rms} needs T to become 4 times: $T = 4 \times 300 = 1200$ K, i.e. 927 °C. Average kinetic energy $= (3/2)k_{BT} = 1.5 \times 1.38 \times 10^{-23} \times 1200 = 2.48 \times 10^{-20}$ J.

- $v_{rms} \propto \sqrt{T}$ (1)
- T = 1200 K (927 °C) (1)
- $(3/2)k_{BT} = 2.48 \times 10^{-20}$ J (1)

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