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Kinetic Theory of Gases — JEE (Main) Pattern Topic Test

FREE SAMPLE TEST · PHYSICS · PATTERN OF JEE (MAIN)

DURATION	MAXIMUM MARKS	QUESTIONS	NAME / ROLL NO.
60 minutes	100	25 (20 + 5)	

GENERAL INSTRUCTIONS

1. This question paper has two sections, A and B. All 25 questions are compulsory.
2. Section A has TWENTY (20) multiple-choice questions. Each has FOUR options, (1), (2), (3) and (4), of which ONLY ONE is correct.
3. Section B has FIVE (05) questions whose answer is a numerical value. Enter the value rounded off to the nearest integer.
4. Marking scheme for both sections: +4 for a correct answer, −1 for an incorrect answer, 0 if the question is not attempted.
5. Treat all gases as ideal; R = 8.314 J/mol K unless stated otherwise. Use of a calculator, log tables or any other aid is not allowed.
6. The answer key and worked solutions are at the end of this booklet. Attempt the paper in 60 minutes before you look at them.

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Topics covered: Equation of state of a perfect gas · Kinetic theory of gas pressure · Kinetic interpretation of temperature · RMS speed of gas molecules · Degrees of freedom · Law of equipartition of energy · Specific heat capacities of gases · Mean free path · Avogadro's number · Work done in compressing a gas

SECTION A (Q1–20) · Multiple choice · +4 / 0 / −1

Each question has FOUR options. ONLY ONE of them is correct.

1. The temperature at which the rms speed of oxygen molecules equals the rms speed of hydrogen molecules at 300 K is

(1) 1200 K

(2) 19 200 K

(3) 2400 K

(4) 4800 K

2. A gas at a pressure of 1.0×10^5 Pa has a density of 1.2 kg/m³. The rms speed of its molecules is

(1) 289 m/s

(2) 408 m/s

(3) 500 m/s

(4) 250 m/s

3. The average translational kinetic energy of a molecule of a gas at 27 °C is about ($k = 1.38 \times 10^{-23}$ J/K)

(1) 4.14×10^{-21} J

(2) 6.21×10^{-21} J

(3) 5.59×10^{-22} J

(4) 1.04×10^{-20} J

4. At a high temperature, the molecules of a diatomic gas also vibrate. Counting this vibrational mode as well, the ratio of specific heats γ of the gas is

(1) 7/5

(2) 9/7

(3) 4/3

(4) 5/3

5. A mixture contains 2 moles of a monoatomic ideal gas and 3 moles of a diatomic ideal gas (rigid molecules). The ratio of specific heats γ of the mixture is

(1) 3/2

(2) 29/21

(3) 31/21

(4) 7/5

6. Nitrogen molecules have a diameter of about 3×10^{-10} m. The mean free path of nitrogen molecules at 300 K and 1.0×10^5 Pa is about ($k = 1.38 \times 10^{-23}$ J/K)

(1) 1×10^{-9} m

(2) 1×10^{-5} m

(3) 3×10^{-8} m

(4) 1×10^{-7} m

7. For the molecules of an ideal gas in equilibrium, the ratio of the rms speed to the most probable speed is

(1) $\sqrt{(3/2)}$

(2) $\sqrt{(8/3\pi)}$

(3) $\sqrt{(3\pi/8)}$

(4) $\sqrt{2}$

8. Five molecules have speeds of 1, 2, 3, 4 and 5 km/s. Their average speed and rms speed are

(1) 3 km/s and 3 km/s

(2) 3 km/s and $\sqrt{55}$ km/s

(3) $\sqrt{11}$ km/s and 3 km/s

(4) 3 km/s and $\sqrt{11}$ km/s

9. A rigid container holds an ideal gas at 27 °C and a pressure of 2 atm. Half of the gas leaks out, and the temperature of the remaining gas becomes 127 °C. Its pressure is now

(1) 4/3 atm

(2) 8/3 atm

(3) 3/2 atm

(4) 1 atm

10. The number of molecules in 1 cm^3 of an ideal gas at 273 K and 1.0×10^5 Pa is about ($k = 1.38 \times 10^{-23}$ J/K)

(1) 2.7×10^{19}

(2) 6.0×10^{23}

(3) 2.7×10^{22}

(4) 2.7×10^{16}

11. Every second, 2×10^{22} nitrogen molecules (mass 4.65×10^{-26} kg each), moving at 500 m/s, strike an area of 1 cm^2 of a wall at 60° to the normal and rebound elastically. The pressure they exert on the wall is about

(1) 9.3×10^3 Pa

(2) 8.1×10^3 Pa

(3) 4.65×10^3 Pa

(4) 2.3×10^3 Pa

12. The total internal energy of 2 moles of oxygen (rigid diatomic molecules) at 300 K is about (R = 8.314 J/mol K)

(1) 7.48 kJ

(2) 17.5 kJ

(3) 4.99 kJ

(4) 12.5 kJ

13. For a certain ideal gas, the difference between its specific heats (per unit mass) at constant pressure and at constant volume is 297 J/kg K. The gas could be (R = 8.314 J/mol K)

(1) helium

(2) oxygen

(3) nitrogen

(4) carbon dioxide

14. Match List-I (gas) with List-II (ratio of specific heats γ).
List-I: (A) Helium (B) Nitrogen, rigid molecules (C) Water vapour, rigid non-linear molecules (D) Oxygen at a high temperature, with vibration
List-II: (I) 9/7 (II) 4/3 (III) 7/5 (IV) 5/3
Choose the correct answer from the options given below:

(1) (A)-(IV), (B)-(III), (C)-(II), (D)-(I)
(2) (A)-(IV), (B)-(II), (C)-(III), (D)-(I)
(3) (A)-(III), (B)-(IV), (C)-(II), (D)-(I)
(4) (A)-(IV), (B)-(III), (C)-(I), (D)-(II)

15. The escape speed from the Earth is 11.2 km/s. The temperature at which the rms speed of hydrogen molecules equals this speed is about (R = 8.314 J/mol K)

(1) 1.0×10^4 K
(2) 1.6×10^5 K
(3) 5.0×10^3 K
(4) 3.0×10^4 K

16. Statement I: At a constant temperature, the mean free path of the molecules of a gas is inversely proportional to its pressure.
Statement II: The mean free path of gas molecules does not depend on the size of the molecules.
In the light of the above statements, choose the correct answer from the options given below:

(1) Both Statement I and Statement II are true
(2) Statement I is true but Statement II is false
(3) Statement I is false but Statement II is true
(4) Both Statement I and Statement II are false

17. The density of nitrogen (molar mass 28 g/mol) at 27 °C and a pressure of 2 atm (1 atm = 1.013×10^5 Pa) is about

(1) 1.14 kg/m³
(2) 2.27 kg/m³
(3) 4.55 kg/m³
(4) 0.57 kg/m³

18. For a diatomic ideal gas with rigid molecules, the fraction of its total internal energy that is rotational kinetic energy is

(1) 3/5
(2) 1/3
(3) 2/5
(4) 2/3

19. An ideal gas is compressed at a constant pressure of 2×10^5 Pa from 5 L to 2 L, and then, at constant volume, its pressure is raised to 6×10^5 Pa. The total work done on the gas is

(1) 1800 J
(2) 600 J
(3) 1200 J
(4) zero

20. The rms speed of the molecules of a gas at 27 °C is to be doubled. The gas must be heated to

(1) 54 °C

(2) 327 °C

(3) 927 °C

(4) 1200 °C

SECTION B (Q21–25) · Numerical value · +4 / 0 / −1

The answer to each question is a NUMERICAL VALUE. Enter it rounded off to the nearest integer.

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21. The rms speed (in m/s) of helium atoms (molar mass 4 g/mol) at 27 °C is _____ (to the nearest integer; R = 8.314 J/mol K).

Answer: _____

22. A mixture contains 1 mole of helium and 1 mole of hydrogen (rigid diatomic molecules). Its molar heat capacity at constant pressure (in J/mol K) is _____ (to the nearest integer; R = 8.3 J/mol K).

Answer: _____

23. A vessel of volume 8.3 L holds an ideal gas at 300 K and 1.0×10^5 Pa. The number of molecules in it is $x \times 10^{21}$. The value of x is _____ (R = 8.3 J/mol K, Avogadro's number 6×10^{23} per mol).

Answer: _____

24. The mean free path of air molecules at atmospheric pressure and room temperature is about 0.1 μm. If the pressure is reduced to 1/1000 of atmospheric pressure at the same temperature, the mean free path becomes (in μm) _____.

Answer: _____

25. A monoatomic ideal gas is at a pressure of 1.5×10^5 Pa. The total translational kinetic energy of its molecules per cubic metre (in kJ) is _____.

Answer: _____

END OF THE QUESTION PAPER

ANSWER KEY

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
(4)	(3)	(2)	(2)	(3)	(4)	(1)	(4)	(1)	(1)

Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20
(3)	(4)	(3)	(1)	(1)	(2)	(2)	(3)	(2)	(3)

Q21	Q22	Q23	Q24	Q25
1368	25	200	100	225

WORKED SOLUTIONS

Q1. Answer (4). $v_rms = \sqrt{(3RT/M)}$, so equal speeds need T/M equal: $T_{O_2} = 300 \times 32/2 = 4800$ K.

Q2. Answer (3). $P = \frac{1}{3}\rho v_rms^2$, so $v_rms = \sqrt{(3P/\rho)} = \sqrt{(3 \times 10^5/1.2)} = \sqrt{(2.5 \times 10^5)} = 500$ m/s.

Q3. Answer (2). $(3/2)kT = 1.5 \times 1.38 \times 10^{-23} \times 300 = 6.21 \times 10^{-21}$ J, the same for every gas at this temperature.

Q4. Answer (2). 3 translational and 2 rotational degrees of freedom give (5/2)kT; a vibration has kinetic and potential energy, adding kT. So $C_v = (7/2)R$, $C_p = (9/2)R$ and $\gamma = 9/7$.

Q5. Answer (3). C_v of the mixture = $(2 \times 3R/2 + 3 \times 5R/2)/5 = (3 + 7.5)R/5 = 2.1R$; $C_p = C_v + R = 3.1R$. $\gamma = 3.1/2.1 = 31/21 \approx 1.48$.

Q6. Answer (4). $\lambda = kT/(\sqrt{2}\pi d^2 P) = (1.38 \times 10^{-23} \times 300)/(1.414 \times 3.142 \times 9 \times 10^{-20} \times 10^5) \approx 1.0 \times 10^{-7}$ m, a few hundred molecular diameters.

Q7. Answer (1). $v_rms = \sqrt{(3kT/m)}$, $v_avg = \sqrt{(8kT/\pi m)}$ and $v_mp = \sqrt{(2kT/m)}$, so $v_mp < v_avg < v_rms$ and $v_rms/v_mp = \sqrt{(3/2)} \approx 1.22$.

Q8. Answer (4). Average = 15/5 = 3 km/s. Mean square = (1 + 4 + 9 + 16 + 25)/5 = 11, so $v_rms = \sqrt{11} \approx 3.32$ km/s, larger than the average as always.

Q9. Answer (1). At constant volume $P \propto nT$: $P = 2 \times (1/2) \times (400/300) = 4/3$ atm. Using Celsius temperatures (127/27) gives a wrong answer.

Q10. Answer (1). $N = PV/(kT) = 10^5 \times 10^{-6}/(1.38 \times 10^{-23} \times 273) \approx 2.65 \times 10^{19}$. (Equivalently, 1 cm³ is about 1/22 700 of a mole.)

Q11. Answer (3). Each molecule reverses its normal component: $\Delta p = 2mv \cos 60° = 2 \times 4.65 \times 10^{-26} \times 500 \times 0.5 = 2.325 \times 10^{-23}$ kg m/s. Force = $2 \times 10^{22} \times 2.325 \times 10^{-23} = 0.465$ N on 10^{-4} m²: 4.65×10^3 Pa. Using cos 30° gives 8.1×10^3 Pa.

Q12. Answer (4). Each molecule has 5 degrees of freedom, each with ½kT: $U = (5/2)nRT = 2.5 \times 2 \times 8.314 \times 300 \approx 12\,470$ J ≈ 12.5 kJ (7.48 kJ counts only the translational part).

Q13. Answer (3). Per mole $C_p - C_v = R$, so per kilogram $c_p - c_v = R/M$. $M = 8.314/297 = 0.028$ kg/mol: nitrogen (helium 0.004, oxygen 0.032, CO_2 0.044).

Q14. Answer (1). $\gamma = 1 + 2/f$. Helium: f = 3, 5/3. Rigid N_2: f = 5, 7/5. Rigid non-linear H_2O: 3 translational + 3 rotational, f = 6, 4/3. Vibrating O_2: f = 7, 9/7.

Q15. Answer (1). $T = Mv^2/(3R) = 2 \times 10^{-3} \times (1.12 \times 10^4)^2/(3 \times 8.314) \approx 1.0 \times 10^4$ K. (Some molecules in the fast tail escape at much lower temperatures, which is why the Earth has lost its hydrogen.)

Q16. Answer (2). $\lambda = kT/(\sqrt{2}\pi d^2 P)$. At constant T, $\lambda \propto 1/P$: Statement I is true. $\lambda \propto 1/d^2$: larger molecules collide more often, so Statement II is false.

Q17. Answer (2). $PV = (m/M)RT$ gives $\rho = PM/(RT) = 2 \times 1.013 \times 10^5 \times 0.028/(8.314 \times 300) \approx 2.27$ kg/m³.

Q18. Answer (3). Of the 5 degrees of freedom, each with ½kT, 3 are translational and 2 rotational. The rotational share is 2/5.

Q19. Answer (2). Work done on the gas is $-\int P\,dV$. At constant pressure: $2 \times 10^5 \times (5 - 2) \times 10^{-3} = 600$ J. At constant volume no work is done, however much the pressure rises. Total 600 J (1800 J wrongly uses the final pressure).

Q20. Answer (3). $v_r ms \propto \sqrt{T}$, so T must become four times 300 K: 1200 K = 927 °C. Doubling the Celsius temperature (54 °C) is wrong; 327 °C (600 K) only multiplies the speed by √2.

Q21. Answer 1368. $v_r ms = \sqrt{(3RT/M)} = \sqrt{(3 \times 8.314 \times 300/0.004)} = \sqrt{(1.871 \times 10^6)} \approx 1367.7$ m/s, i.e. 1368.

Q22. Answer 25. C_p of the mixture = (5R/2 + 7R/2)/2 = 3R = 24.9 J/mol K, i.e. 25.

Q23. Answer 200. $n = PV/(RT) = 10^5 \times 8.3 \times 10^{-3}/(8.3 \times 300) = 1/3$ mol, so $N = 6 \times 10^{23}/3 = 2 \times 10^{23} = 200 \times 10^{21}$.

Q24. Answer 100. At constant temperature $\lambda \propto 1/P$ (fewer molecules per unit volume), so $\lambda = 0.1 \times 1000 = 100$ µm.

Q25. Answer 225. $P = (2/3)E/V$, where E/V is the translational kinetic energy per unit volume. $E/V = 1.5P = 2.25 \times 10^5$ J/m³ = 225 kJ/m³.

All questions are original and © Master Testing Agency. Free to download and use for personal practice; not for resale. Every answer in this paper was checked independently by computer: molecular speeds from the Maxwell distribution integrated numerically, specific heats by sharing the energy over the degrees of freedom, and the force on a wall from the momentum change of each molecule.