Kinetic Theory

Case Study Based Questions

Read the following passages and answer the questions that follow:

1. According to this law, for any system in thermal equilibrium, the total energy is equally distributed among its various degree of freedom. And each degree of freedom is associated
with energy 1/2 KT. (where $K = 1.3 \times 10^{-23}$ J/K,
T= absolute temperature of the system).
At a given temperature T; all ideal gas molecules no matter what their mass have the same average translational kinetic energy; namely, 3/2 KT.
When measure the temperature of a gas, we are also measuring the average translational kinetic energy of its molecules.
At the same temperature, gases with different degrees of freedom (e.g. He and H) will have different average energy or internal energy namely f/2 KT (f is different for different gases).

(A) Relation between pressure P and average kinetic energy E per unit volume of a gas is:

(a) $P = \frac{2E}{3}$ (b) $P = \frac{E}{3}$

(c) $P = \frac{3E}{2}$ (d) $P = 3E$

(B) At 0 K, which of the following properties of a gas will be zero?

(a) Kinetic energy
(b) Potential energy
(c) Vibrational energy
(d) Density

(C) The root mean square velocity of a gas molecule of mass m at a given temperature is proportional to:

(b) m
(a) mo

(c) $\sqrt{m}$ (d) $m^{-\frac{1}{2}}$

(D) An ant is walking on the horizontal surface. The number of degrees of freedom of an ant will be:

(a) 1

(b) 2

(c) 3

(d) 6

(E) The number of degrees of freedom for a diatomic gas molecule is:

(a) 2

(b) 3

(c) 5

(d) 6

Ans. (A)

(a) $P = \frac{2E}{3}$

Explanation:

Kinetic Energy $= \frac{3RT}{2}$

$\Rightarrow \quad K.E. = \frac{3PV}{2}$

Since, PV = nRT, here n = 1 mole

Therefore, $\quad P = \frac{2E}{3V}$, (E = Kinetic Energy)

As per question,

$$\frac{E}{V} = E \qquad \text{(As volume = 1)}$$

So, $\quad P = \frac{2E}{3}$

(B) (a) Kinetic Energy

Explanation: At 0 K, all molecular motion stops, so kinetic energy becomes zero.

(C) (d) m½

Explanation: $V_{rms} = \sqrt{\frac{3K_3T}{m}}$, *i.e.* $v_{rms} \propto m^{-\frac{1}{2}}$

(D) (b) 2

Explanation: As the ant can move on a plane, it has 2 degrees of freedom.

(E) (c) 5

Explanation: A diatomic molecule has

3 degrees of freedom due to translatory motion and 2 degrees of freedom due to rotatory motion.

2. Cooking utensils are made of metal which has low specific heat capacity so that they need less heat to raise up the temperature. Handles of cooking utensils are made of substances with high specific heat capacities so that their temperature won't become too high even if it a absorbs large amount of heat.

(A) A gas occupies a volume of 400 cm^3 at 0°C and 780 mm of Hg. How many litres of volume will the gas occupy at 80 degree Celsius and 780 mm of Hg?
(B) At very low pressure and high temperature, the real gas behaves like an ideal gas. Why?
(C) A tank of volume 0.3 m^3 contains 2 moles of Helium gas at 200°C. Assuming the helium behaves as an ideal gas, what will be the total internal energy of the system?

Ans. (A) According to the question,
V_1 = 400 cm^3
T_1 =0°C=0+273 = 273 K
T_2 = 80°C=80+273 = 353 K
You need to find V_2.
Here, only the temperature is changing, the pressure remains constant. Using Charle's law,

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Putting the above values in the Charle's law, we get,

$$\frac{400}{273} = \frac{V_2}{353}$$

$$V_2 = 400 \times \frac{353}{273}$$

$$V_2 = 517.21\ cm^3$$

Since, $1\ cm^3 = 0.001$ litres,

Then, 517.21 cubic cm

$$= 517.21 \times 10^3$$

$$= 0.517\ L$$

(B) An ideal gas is one which has zero volume of molecule and no intermolecular forces.

Now:

(1) At very low pressure, the volume of gas is large, so that the volume of molecule is negligible compared to volume of gas.

(2) At very high temperatures, the kinetic energy of molecules is very large and effect of intermolecular forces can be neglected. Hence, real gases behave as an ideal gas at low pressure and high temperature.

(C) n = No. of moles = 2

T = Temperature = 273 +20 = 293 K

R = Universal Gas constant = 8.31 J/mole/K

Total energy of the system $E = \frac{3}{2} nRT$

$$E = \frac{3}{2} \times n \times 8.31 \times 293$$

$$E = 7.30 \times 10^3\ J$$