The length of mercury column at 30°C is l_0. Suppose the length of the mercury column, if it were at 0°C, is l_0. Then,

$$l_\theta = l_0\,[1 + \frac{1}{3}\gamma\,(30°C)]. \quad \ldots \text{(ii)}$$

By (i) and (ii),

$$l_0[1 + \frac{1}{3}\gamma\,(30°C)] = 75\text{ cm}[1 + \alpha(30°C)]$$

or,

$$l_0 = 75\text{ cm}\frac{[1 + \alpha(30°C)]}{[1 + \frac{1}{3}\gamma\,(30°C)]}$$

$$= 75\text{ cm}\,[1 + (\alpha - \frac{\gamma}{3})\,(30°C)]$$

$$= 74{\cdot}89\text{ cm}.$$

□

QUESTIONS FOR SHORT ANSWER

1. If two bodies are in thermal equilibrium in one frame, will they be in thermal equilibrium in all frames ?
2. Does the temperature of a body depend on the frame from which it is observed ?
3. It is heard sometimes that mercury is used in defining the temperature scale because it expands uniformly with the temperature. If the temperature scale is not yet defined, is it logical to say that a substance expands uniformly with the temperature ?
4. In defining the ideal gas temperature scale, it is assumed that the pressure of the gas at constant volume is proportional to the temperature T. How can we verify whether this is true or not ? Are we using the kinetic theory of gases ? Are we using the experimental result that the pressure is proportional to temperature ?
5. Can the bulb of a thermometer be made of an adiabatic wall ?
6. Why do marine animals live deep inside a lake when the surface of the lake freezes ?
7. The length of a brass rod is found to be smaller on a hot summer day than on a cold winter day as measured by the same aluminium scale. Do we conclude that brass shrinks on heating ?
8. If mercury and glass had equal coefficient of volume expansion, could we make a mercury thermometer in a glass tube ?
9. The density of water at 4°C is supposed to be 1000 kg/m^3. Is it same at the sea level and at a high altitude ?
10. A tightly closed metal lid of a glass bottle can be opened more easily if it is put in hot water for some time. Explain.
11. If an automobile engine is overheated, it is cooled by putting water on it. It is advised that the water should be put slowly with engine running. Explain the reason.
12. Is it possible for two bodies to be in thermal equilibrium if they are not in contact ?
13. A spherical shell is heated. The volume changes according to the equation $V_\theta = V_0\,(1 + \gamma\theta)$. Does the volume refer to the volume enclosed by the shell or the volume of the material making up the shell ?

OBJECTIVE I

1. A system X is neither in thermal equilibrium with Y nor with Z. The systems Y and Z
   (a) must be in thermal equilibrium
   (b) cannot be in thermal equilibrium
   (c) may be in thermal equilibrium.
2. Which of the curves in figure (23-Q1) represents the relation between Celsius and Fahrenheit temperatures ?

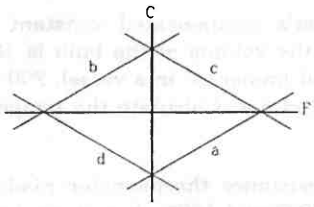

Figure 23-Q1

3. Which of the following pairs may give equal numerical values of the temperature of a body ?
   (a) Fahrenheit and kelvin (b) Celsius and kelvin
   (c) kelvin and platinum.
4. For a constant volume gas thermometer, one should fill the gas at
   (a) low temperature and low pressure
   (b) low temperature and high pressure
   (c) high temperature and low pressure
   (d) high temperature and high pressure.
5. Consider the following statements.
   (A) The coefficient of linear expansion has dimension K^{-1}.
   (B) The coefficient of volume expansion has dimension K^{-1}.
   (a) A and B are both correct.
   (b) A is correct but B is wrong.

(c) B is correct but A is wrong.
(d) A and B are both wrong.

6. A metal sheet with a circular hole is heated. The hole
(a) gets larger (b) gets smaller
(c) remains of the same size (d) gets deformed.

7. Two identical rectangular strips, one of copper and the other of steel, are rivetted together to form a bimetallic strip ($\alpha_{copper} > \alpha_{steel}$). On heating, this strip will
(a) remain straight
(b) bend with copper on convex side
(c) bend with steel on convex side
(d) get twisted.

8. If the temperature of a uniform rod is slightly increased by Δt, its moment of inertia I about a perpendicular bisector increases by
(a) zero (b) $\alpha I \Delta t$ (c) $2\alpha I \Delta t$ (d) $3\alpha I \Delta t$.

9. If the temperature of a uniform rod is slightly increased by Δt, its moment of inertia I about a line parallel to itself will increase by
(a) zero (b) $\alpha I \Delta t$ (c) $2\alpha I \Delta t$ (d) $3\alpha I \Delta t$.

10. The temperature of water at the surface of a deep lake is 2°C. The temperature expected at the bottom is
(a) 0°C (b) 2°C (c) 4°C (d) 6°C.

11. An aluminium sphere is dipped into water at 10°C. If the temperature is increased, the force of buoyancy
(a) will increase (b) will decrease
(c) will remain constant
(d) may increase or decrease depending on the radius of the sphere.

OBJECTIVE II

1. A spinning wheel is brought in contact with an identical wheel spinning at identical speed. The wheels slow down under the action of friction. Which of the following energies of the first wheel decrease ?
(a) kinetic (b) total (c) mechanical (d) internal.

2. A spinning wheel A is brought in contact with another wheel B initially at rest. Because of the friction at contact, the second wheel also starts spinning. Which of the following energies of the wheel B increase ?
(a) kinetic (b) total (c) mechanical (d) internal.

3. A body A is placed on a railway platform and an identical body B in a moving train. Which of the following energies of B are greater than those of A as seen from the ground ?
(a) kinetic (b) total (c) mechanical (d) internal.

4. In which of the following pairs of temperature scales, the size of a degree is identical ?
(a) mercury scale and ideal gas scale
(b) Celsius scale and mercury scale
(c) Celsius scale and ideal gas scale
(d) ideal gas scale and absolute scale.

5. A solid object is placed in water contained in an adiabatic container for some time. The temperature of water falls during the period and there is no appreciable change in the shape of the object. The temperature of the solid object
(a) must have increased (b) must have decreased
(c) may have increased
(d) may have remained constant.

6. As the temperature is increased, the time period of a pendulum
(a) increases proportionately with temperature
(b) increases (c) decreases
(d) remains constant.

EXERCISES

1. The steam point and the ice point of a mercury thermometer are marked as 80° and 20°. What will be the temperature in centigrade mercury scale when this thermometer reads 32° ?

2. A constant volume thermometer registers a pressure of $1{\cdot}500 \times 10^4$ Pa at the triple point of water and a pressure of $2{\cdot}050 \times 10^4$ Pa at the normal boiling point. What is the temperature at the normal boiling point ?

3. A gas thermometer measures the temperature from the variation of pressure of a sample of gas. If the pressure measured at the melting point of lead is 2·20 times the pressure measured at the triple point of water, find the melting point of lead.

4. The pressure measured by a constant volume gas thermometer is 40 kPa at the triple point of water. What will be the pressure measured at the boiling point of water (100°C) ?

5. The pressure of the gas in a constant volume gas thermometer is 70 kPa at the ice point. Find the pressure at the steam point.

6. The pressures of the gas in a constant volume gas thermometer are 80 cm, 90 cm and 100 cm of mercury at the ice point, the steam point and in a heated wax bath respectively. Find the temperature of the wax bath.

7. In a Callender's compensated constant pressure air thermometer, the volume of the bulb is 1800 cc. When the bulb is kept immersed in a vessel, 200 cc of mercury has to be poured out. Calculate the temperature of the vessel.

8. A platinum resistance thermometer reads 0° when its resistance is 80 Ω and 100° when its resistance is 90 Ω. Find the temperature at the platinum scale at which the resistance is 86 Ω.

9. A resistance thermometer reads $R = 20{\cdot}0\ \Omega$, $27{\cdot}5\ \Omega$, and $50{\cdot}0\ \Omega$ at the ice point (0°C), the steam point (100°C) and the zinc point (420°C) respectively. Assuming that the resistance varies with temperature as $R_\theta = R_0(1 + \alpha\theta + \beta\theta^2)$, find the values of R_0, α and β. Here θ represents the temperature on Celsius scale.

10. A concrete slab has a length of 10 m on a winter night when the temperature is 0°C. Find the length of the slab on a summer day when the temperature is 35°C. The coefficient of linear expansion of concrete is $1{\cdot}0 \times 10^{-5}$/°C.

11. A metre scale made of steel is calibrated at 20°C to give correct reading. Find the distance between 50 cm mark and 51 cm mark if the scale is used at 10°C. Coefficient of linear expansion of steel is $1{\cdot}1 \times 10^{-5}$/°C.

12. A railway track (made of iron) is laid in winter when the average temperature is 18°C. The track consists of sections of 12·0 m placed one after the other. How much gap should be left between two such sections so that there is no compression during summer when the maximum temperature goes to 48°C? Coefficient of linear expansion of iron = 11×10^{-6}/°C.

13. A circular hole of diameter 2·00 cm is made in an aluminium plate at 0°C. What will be the diameter at 100°C? α for aluminium = $2{\cdot}3 \times 10^{-5}$/°C.

14. Two metre scales, one of steel and the other of aluminium, agree at 20°C. Calculate the ratio aluminium-centimetre/steel-centimetre at (a) 0°C, (b) 40°C and (c) 100°C. α for steel = $1{\cdot}1 \times 10^{-5}$/°C and for aluminium = $2{\cdot}3 \times 10^{-5}$/°C.

15. A metre scale is made up of steel and measures correct length at 16°C. What will be the percentage error if this scale is used (a) on a summer day when the temperature is 46°C and (b) on a winter day when the temperature is 6°C? Coefficient of linear expansion of steel = 11×10^{-6}/°C.

16. A metre scale made of steel reads accurately at 20°C. In a sensitive experiment, distances accurate upto 0·055 mm in 1 m are required. Find the range of temperature in which the experiment can be performed with this metre scale. Coefficient of linear expansion of steel = 11×10^{-6}/°C.

17. The density of water at 0°C is 0·998 g/cm^3 and at 4°C is 1·000 g/cm^3. Calculate the average coefficient of volume expansion of water in the temperature range 0 to 4°C.

18. Find the ratio of the lengths of an iron rod and an aluminium rod for which the difference in the lengths is independent of temperature. Coefficients of linear expansion of iron and aluminium are 12×10^{-6}/°C and 23×10^{-6}/°C respectively.

19. A pendulum clock gives correct time at 20°C at a place where $g = 9{\cdot}800$ m/s^2. The pendulum consists of a light steel rod connected to a heavy ball. It is taken to a different place where $g = 9{\cdot}788$ m/s^2. At what temperature will it give correct time? Coefficient of linear expansion of steel = 12×10^{-6}/°C.

20. An aluminium plate fixed in a horizontal position has a hole of diameter 2·000 cm. A steel sphere of diameter 2·005 cm rests on this hole. All the lengths refer to a temperature of 10°C. The temperature of the entire system is slowly increased. At what temperature will the ball fall down? Coefficient of linear expansion of aluminium is 23×10^{-6}/°C and that of steel is 11×10^{-6}/°C.

21. A glass window is to be fit in an aluminium frame. The temperature on the working day is 40°C and the glass window measures exactly 20 cm × 30 cm. What should be the size of the aluminium frame so that there is no stress on the glass in winter even if the temperature drops to 0°C? Coefficients of linear expansion for glass and aluminium are $9{\cdot}0 \times 10^{-6}$/°C and 24×10^{-6}/°C respectively.

22. The volume of a glass vessel is 1000 cc at 20°C. What volume of mercury should be poured into it at this temperature so that the volume of the remaining space does not change with temperature? Coefficients of cubical expansion of mercury and glass are $1{\cdot}8 \times 10^{-4}$/°C and $9{\cdot}0 \times 10^{-6}$/°C respectively.

23. An aluminium can of cylindrical shape contains 500 cm^3 of water. The area of the inner cross-section of the can is 125 cm^2. All measurements refer to 10°C. Find the rise in the water level if the temperature increases to 80°C. The coefficient of linear expansion of aluminium = 23×10^{-6}/°C and the average coefficient of volume expansion of water = $3{\cdot}2 \times 10^{-4}$/°C respectively.

24. A glass vessel measures exactly 10 cm × 10 cm × 10 cm at 0°C. It is filled completely with mercury at this temperature. When the temperature is raised to 10°C, 1·6 cm^3 of mercury overflows. Calculate the coefficient of volume expansion of mercury. Coefficient of linear expansion of glass = $6{\cdot}5 \times 10^{-6}$/°C.

25. The densities of wood and benzene at 0°C are 880 kg/m^3 and 900 kg/m^3 respectively. The coefficients of volume expansion are $1{\cdot}2 \times 10^{-3}$/°C for wood and $1{\cdot}5 \times 10^{-3}$/°C for benzene. At what temperature will a piece of wood just sink in benzene?

26. A steel rod of length 1 m rests on a smooth horizontal base. If it is heated from 0°C to 100°C, what is the longitudinal strain developed?

27. A steel rod is clamped at its two ends and rests on a fixed horizontal base. The rod is unstrained at 20°C. Find the longitudinal strain developed in the rod if the temperature rises to 50°C. Coefficient of linear expansion of steel = $1{\cdot}2 \times 10^{-5}$/°C.

28. A steel wire of cross-sectional area 0·5 mm^2 is held between two fixed supports. If the wire is just taut at 20°C, determine the tension when the temperature falls to 0°C. Coefficient of linear expansion of steel is $1{\cdot}2 \times 10^{-5}$/°C and its Young's modulus is $2{\cdot}0 \times 10^{11}$ N/m^2.

29. A steel rod is rigidly clamped at its two ends. The rod is under zero tension at 20°C. If the temperature rises to 100°C, what force will the rod exert on one of the

clamps. Area of cross-section of the rod = 2·00 mm^2. Coefficient of linear expansion of steel = 12·0 × 10^{-6}/°C and Young's modulus of steel = 2·00 × 10^{11} N/m^2.

30. Two steel rods and an aluminium rod of equal length l_o and equal cross-section are joined rigidly at their ends as shown in the figure below. All the rods are in a state of zero tension at 0°C. Find the length of the system when the temperature is raised to θ. Coefficient of linear expansion of aluminium and steel are α_a and α_s respectively. Young's modulus of aluminium is Y_a and of steel is Y_s.

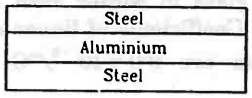

Figure 23-E1

31. A steel ball initially at a pressure of 1·0 × 10^5 Pa is heated from 20°C to 120°C keeping its volume constant. Find the pressure inside the ball. Coefficient of linear expansion of steel = 12 × 10^{-6}/°C and bulk modulus of steel = 1·6 × 10^{11} N/m^2.

32. Show that moment of inertia of a solid body of any shape changes with temperature as $I = I_0(1 + 2\alpha\theta)$, where I_0 is the moment of inertia at 0°C and α is the coefficient of linear expansion of the solid.

33. A torsional pendulum consists of a solid disc connected to a thin wire (α = 2·4 × 10^{-5}/°C) at its centre. Find the percentage change in the time period between peak winter (5°C) and peak summer (45°C).

34. A circular disc made of iron is rotated about its axis at a constant velocity ω. Calculate the percentage change in the linear speed of a particle of the rim as the disc is slowly heated from 20°C to 50°C keeping the angular velocity constant. Coefficient of linear expansion of iron = 1·2 × 10^{-5}/°C.

□

ANSWERS

OBJECTIVE I

1. (c) 2. (a) 3. (a) 4. (c) 5. (a) 6. (a)
7. (b) 8. (c) 9. (c) 10. (c) 11. (b)

OBJECTIVE II

1. (a), (c) 2. all 3. (a), (b), (c)
4. (c), (d) 5. (a) 6. (b)

EXERCISES

1. 20°C
2. 373·3 K
3. 601 K
4. 55 kPa
5. 96 kPa
6. 200°C
7. 307 K
8. 60°
9. 20·0 Ω, 3·8 × 10^{-3}/°C, – 5·6 × 10^{-7}/°C^2
10. 10·0035 m
11. 1·00011 cm
12. 0·4 cm
13. 2·0046 cm
14. (a) 0·99977 (b) 1·00025 (c) 1·00096
15. (a) 0·033% (b) – 0·011%
16. 15°C to 25°C
17. – 5 × 10^{-4}/°C
18. 23 : 12
19. – 82°C
20. 219°C
21. 20·012 cm × 30·018 cm
22. 50 cc
23. 0·089 cm
24. 1·8 × 10^{-4}/°C
25. 83°C
26. zero
27. – 3·6 × 10^{-4}
28. 24 N
29. 384 N
30. $l_o\left[1 + \frac{\alpha_a Y_a + 2\alpha_s Y_s}{Y_a + 2Y_s}\theta\right]$
31. 5·8 × 10^8 Pa
33. 9·6 × 10^{-2}
34. 3·6 × 10^{-2}

□

$$T_2 = 0{\cdot}99\ T_1$$

and hence,

$$p_2 = 0{\cdot}99\ p_1$$

$= 0{\cdot}99 \times 800$ mm of mercury $= 792$ mm of mercury.

The vapour is still saturated and hence, its pressure is 25 mm of mercury. The total pressure at the reduced temperature is

$$p = (792 + 25) \text{ mm of mercury}$$
$$= 817 \text{ mm of mercury.}$$

22. *Calculate the mass of* 1 litre *of moist air at* 27°C *when the barometer reads* 753·6 mm of mercury *and the dew point is* 16·1°C. *Saturation vapour pressure of water at* 16·1°C = 13·6 mm of mercury, *density of air at STP* = 0·001293 g/cc, *density of saturated water vapour at STP* = 0·000808 g/cc.

Solution : We have $pV = \frac{m}{M} RT$

or, $$\rho = \frac{m}{V} = \frac{Mp}{RT}. \quad \ldots \text{(i)}$$

The dew point is 16·1°C and the saturation vapour pressure is 13·6 mm of mercury at the dew point. This means that the present vapour pressure is 13·6 mm of mercury.

At this pressure and temperature, the density of vapour will be

$$\rho = \frac{Mp}{RT}$$

$$= \frac{(18 \text{ g/mol})(13{\cdot}6 \times 10^{-3} \text{ m})(13600 \text{ kg/m}^3)(9{\cdot}8 \text{ m/s}^2)}{(8{\cdot}3 \text{ J/mol-K})(300 \text{ K})}$$

$= 13{\cdot}1$ g/m^3.

Thus, 1 litre of moist air at 27°C contains 0·0131 g of vapour.

The pressure of dry air at 27°C is 753·6 mm – 13·6 mm = 740 mm of mercury. The density of air at STP is 0·001293 g/cc. The density at 27°C is given by equation (i),

$$\frac{\rho_1}{\rho_2} = \frac{p_1/T_1}{p_2/T_2}$$

or, $$\rho_2 = \frac{p_2 T_1}{T_2 p_1} \rho_1$$

$$= \frac{740 \times 273}{300 \times 760} \times 0{\cdot}001293 \text{ g/cc.}$$

$$= {\cdot}001457 \text{ g/cc.}$$

Thus, 1 litre of moist air contains 1·145 g of dry air. The mass of 1 litre of moist air is 1·1457 g + 0·0131 g = 1·159 g.

□

QUESTIONS FOR SHORT ANSWER

1. When we place a gas cylinder on a van and the van moves, does the kinetic energy of the molecules increase ? Does the temperature increase ?
2. While gas from a cooking gas cylinder is used, the pressure does not fall appreciably till the last few minutes. Why ?
3. Do you expect the gas in a cooking gas cylinder to obey the ideal gas equation ?
4. Can we define the temperature of vacuum ? The temperature of a single molecule ?
5. Comment on the following statement. The temperature of all the molecules in a sample of a gas is the same.
6. Consider a gas of neutrons. Do you expect it to behave much better as an ideal gas as compared to hydrogen gas at the same pressure and temperature ?
7. A gas is kept in a rigid cubical container. If a load of 10 kg is put on the top of the container, does the pressure increase ?
8. If it were possible for a gas in a container to reach the temperature 0 K, its pressure would be zero. Would the molecules not collide with the walls ? Would they not transfer momentum to the walls ?
9. It is said that the assumptions of kinetic theory are good for gases having low densities. Suppose a container is so evacuated that only one molecule is left in it. Which of the assumptions of kinetic theory will not be valid for such a situation ? Can we assign a temperature to this gas ?
10. A gas is kept in an enclosure. The pressure of the gas is reduced by pumping out some gas. Will the temperature of the gas decrease by Charles' law ?
11. Explain why cooking is faster in a pressure cooker.
12. If the molecules were not allowed to collide among themselves, would you expect more evaporation or less evaporation ?
13. Is it possible to boil water at room temperature, say 30°C ? If we touch a flask containing water boiling at this temperature, will it be hot ?
14. When you come out of a river after a dip, you feel cold. Explain.

OBJECTIVE I

1. Which of the following parameters is the same for molecules of all gases at a given temperature?
(a) mass (b) speed
(c) momentum (d) kinetic energy.

2. A gas behaves more closely as an ideal gas at
(a) low pressure and low temperature
(b) low pressure and high temperature
(c) high pressure and low temperature
(d) high pressure and high temperature.

3. The pressure of an ideal gas is written as $p = \frac{2E}{3V}$. Here E refers to
(a) translational kinetic energy
(b) rotational kinetic energy
(c) vibrational kinetic energy
(d) total kinetic energy.

4. The energy of a given sample of an ideal gas depends only on its
(a) volume (b) pressure (c) density (d) temperature.

5. Which of the following gases has maximum rms speed at a given temperature?
(a) hydrogen (b) nitrogen
(c) oxygen (d) carbon dioxide.

6. Figure 24-Q1 shows graphs of pressure vs. density for an ideal gas at two temperatures T_1 and T_2.
(a) $T_1 > T_2$ (b) $T_1 = T_2$
(c) $T_1 < T_2$ (d) any of the three is possible.

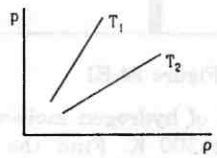

Figure 24-Q1

7. The mean square speed of the molecules of a gas at absolute temperature T is proportional to
(a) $\frac{1}{T}$ (b) $\sqrt{T}$ (c) T (d) T^2.

8. Suppose a container is evacuated to leave just one molecule of a gas in it. Let v_a and v_{rms} represent the average speed and the rms speed of the gas.
(a) $v_a > v_{rms}$. (b) $v_a < v_{rms}$.
(c) $v_a = v_{rms}$. (d) v_{rms} is undefined.

9. The rms speed of oxygen at room temperature is about 500 m/s. The rms speed of hydrogen at the same temperature is about
(a) 125 m/s (b) 2000 m/s (c) 8000 m/s (d) 31 m/s.

10. The pressure of a gas kept in an isothermal container is 200 kPa. If half the gas is removed from it, the pressure will be
(a) 100 kPa (b) 200 kPa (c) 400 kPa (d) 800 kPa.

11. The rms speed of oxygen molecules in a gas is v. If the temerature is doubled and the oxygen molecules dissociate into oxygen atoms, the rms speed will become
(a) v (b) $v\sqrt{2}$ (c) $2v$ (d) $4v$.

12. The quantity $\frac{pV}{kT}$ represents
(a) mass of the gas
(b) kinetic energy of the gas
(c) number of moles of the gas
(d) number of molecules in the gas.

13. The process on an ideal gas, shown in figure (24-Q2), is
(a) isothermal (b) isobaric (c) isochoric (d) none of these.

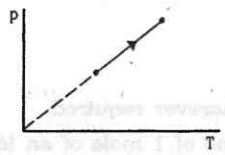

Figure 24-Q2

14. There is some liquid in a closed bottle. The amount of liquid is continuously decreasing. The vapour in the remaining part
(a) must be saturated (b) must be unsaturated
(c) may be saturated (d) there will be no vapour.

15. There is some liquid in a closed bottle. The amount of liquid remains constant as time passes. The vapour in the remaining part
(a) must be saturated (b) must be unsaturated
(c) may be unsaturated (d) there will be no vapour.

16. Vapour is injected at a uniform rate in a closed vessel which was initially evacuated. The pressure in the vessel
(a) increases continuously
(b) decreases continuously
(c) first increases and then decreases
(d) first increases and then becomes constant.

17. A vessel A has volume V and a vessel B has volume $2V$. Both contain some water which has a constant volume. The pressure in the space above water is p_a for vessel A and p_b for vessel B.
(a) $p_a = p_b$. (b) $p_a = 2p_b$.
(c) $p_b = 2p_a$. (d) $p_b = 4p_a$.

OBJECTIVE II

1. Consider a collision between an oxygen molecule and a hydrogen molecule in a mixture of oxygen and hydrogen kept at room temperature. Which of the following are possible?
(a) The kinetic energies of both the molecules increase.
(b) The kinetic energies of both the molecules decrease.

(c) The kinetic energy of the oxygen molecule increases and that of the hydrogen molecule decreases.
(d) The kinetic energy of the hydrogen molecule increases and that of the oxygen molecule decreases.

2. Consider a mixture of oxygen and hydrogen kept at room temperature. As compared to a hydrogen molecule an oxygen molecule hits the wall
(a) with greater average speed
(b) with smaller average speed
(c) with greater average kinetic energy
(d) with smaller average kinetic energy.

3. Which of the following quantities is zero on an average for the molecules of an ideal gas in equilibrium ?
(a) kinetic energy (b) momentum
(c) density (d) speed.

4. Keeping the number of moles, volume and temperature the same, which of the following are the same for all ideal gases ?
(a) rms speed of a molecule (b) density
(c) pressure
(d) average magnitude of momentum.

5. The average momentum of a molecule in a sample of an ideal gas depends on
(a) temperature (b) number of moles
(c) volume (d) none of these.

6. Which of the following quantities is the same for all ideal gases at the same temperature ?
(a) the kinetic energy of 1 mole
(b) the kinetic energy of 1 g
(c) the number of molecules in 1 mole
(d) the number of molecules in 1 g

7. Consider the quantity $\frac{MkT}{pV}$ of an ideal gas where M is the mass of the gas. It depends on the
(a) temperature of the gas (b) volume of the gas
(c) pressure of the gas (d) nature of the gas.

EXERCISES

Use $R = 8{\cdot}3$ J/mol–K wherever required.

1. Calculate the volume of 1 mole of an ideal gas at STP.
2. Find the number of molecules of an ideal gas in a volume of $1{\cdot}000\ cm^3$ at STP.
3. Find the number of molecules in $1\ cm^3$ of an ideal gas at 0°C and at a pressure of 10^{-5} mm of mercury.
4. Calculate the mass of $1\ cm^3$ of oxygen kept at STP.
5. Equal masses of air are sealed in two vessels, one of volume V_0 and the other of volume $2V_0$. If the first vessel is maintained at a temperature 300 K and the other at 600 K, find the ratio of the pressures in the two vessels.
6. An electric bulb of volume 250 cc was sealed during manufacturing at a pressure of 10^{-3} mm of mercury at 27°C. Compute the number of air molecules contained in the bulb. Avogadro constant $= 6 \times 10^{23}$ per mol, density of mercury $= 13600\ kg/m^3$ and $g = 10\ m/s^2$.
7. A gas cylinder has walls that can bear a maximum pressure of $1{\cdot}0 \times 10^6$ Pa. It contains a gas at $8{\cdot}0 \times 10^5$ Pa and 300 K. The cylinder is steadily heated. Neglecting any change in the volume, calculate the temperature at which the cylinder will break.
8. 2 g of hydrogen is sealed in a vessel of volume $0{\cdot}02\ m^3$ and is maintained at 300 K. Calculate the pressure in the vessel.
9. The density of an ideal gas is $1{\cdot}25 \times 10^{-3}\ g/cm^3$ at STP. Calculate the molecular weight of the gas.
10. The temperature and pressure at Simla are 15·0°C and 72·0 cm of mercury and at Kalka these are 35·0°C and 76·0 cm of mercury. Find the ratio of air density at Kalka to the air density at Simla.
11. Figure (24-E1) shows a cylindrical tube with adiabatic walls and fitted with a diathermic separator. The separator can be slid in the tube by an external mechanism. An ideal gas is injected in the two sides at equal pressures and equal temperatures. The separator remains in equilibrium at the middle. It is now slid to a position where it divides the tube in the ratio of 1:3. Find the ratio of the pressures in the two parts of the vessel.

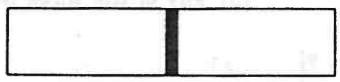

Figure 24-E1

12. Find the rms speed of hydrogen molecules in a sample of hydrogen gas at 300 K. Find the temperature at which the rms speed is double the speed calculated in the previous part.
13. A sample of 0·177 g of an ideal gas occupies $1000\ cm^3$ at STP. Calculate the rms speed of the gas molecules.
14. The average translational kinetic energy of air molecules is 0·040 eV (1 eV $= 1{\cdot}6 \times 10^{-19}$ J). Calculate the temperature of the air. Boltzmann constant $k = 1{\cdot}38 \times 10^{-23}$ J/K.
15. Consider a sample of oxygen at 300 K. Find the average time taken by a molecule to travel a distance equal to the diameter of the earth.
16. Find the average magnitude of linear momentum of a helium molecule in a sample of helium gas at 0°C. Mass of a helium molecule $= 6{\cdot}64 \times 10^{-27}$ kg and Boltzmann constant $= 1{\cdot}38 \times 10^{-23}$ J/K.
17. The mean speed of the molecules of a hydrogen sample equals the mean speed of the molecules of a helium sample. Calculate the ratio of the temperature of the hydrogen sample to the temperature of the helium sample.
18. At what temperature the mean speed of the molecules of hydrogen gas equals the escape speed from the earth ?

19. Find the ratio of the mean speed of hydrogen molecules to the mean speed of nitrogen molecules in a sample containing a mixture of the two gases.

20. Figure (24-E2) shows a vessel partitioned by a fixed diathermic separator. Different ideal gases are filled in the two parts. The rms speed of the molecules in the left part equals the mean speed of the molecules in the right part. Calculate the ratio of the mass of a molecule in the left part to the mass of a molecule in the right part.

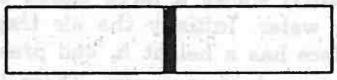

Figure 24-E2

21. Estimate the number of collisions per second suffered by a molecule in a sample of hydrogen at STP. The mean free path (average distance covered by a molecule between successive collisions) = $1{\cdot}38 \times 10^{-5}$ cm.

22. Hydrogen gas is contained in a closed vessel at 1 atm (100 kPa) and 300 K. (a) Calculate the mean speed of the molecules. (b) Suppose the molecules strike the wall with this speed making an average angle of 45° with it. How many molecules strike each square metre of the wall per second?

23. Air is pumped into an automobile tyre's tube upto a pressure of 200 kPa in the morning when the air temperature is 20°C. During the day the temperature rises to 40°C and the tube expands by 2%. Calculate the pressure of the air in the tube at this temperature.

24. Oxygen is filled in a closed metal jar of volume $1{\cdot}0 \times 10^{-3}$ m^3 at a pressure of $1{\cdot}5 \times 10^5$ Pa and temperature 400 K. The jar has a small leak in it. The atomospheric pressure is $1{\cdot}0 \times 10^5$ Pa and the atmospheric temperature is 300 K. Find the mass of the gas that leaks out by the time the pressure and the temperature inside the jar equalise with the surrounding.

25. An air bubble of radius 2·0 mm is formed at the bottom of a 3·3 m deep river. Calculate the radius of the bubble as it comes to the surface. Atmospheric pressure = $1{\cdot}0 \times 10^5$ Pa and density of water = 1000 kg/m^3.

26. Air is pumped into the tubes of a cycle rickshaw at a pressure of 2 atm. The volume of each tube at this pressure is 0·002 m^3. One of the tubes gets punctured and the volume of the tube reduces to 0·0005 m^3. How many moles of air have leaked out? Assume that the temperature remains constant at 300 K and that the air behaves as an ideal gas.

27. 0·040 g of He is kept in a closed container initially at 100·0°C. The container is now heated. Neglecting the expansion of the container, calculate the temperature at which the internal energy is increased by 12 J.

28. During an experiment, an ideal gas is found to obey an additional law pV^2 = constant. The gas is initially at a temperature T and volume V. Find the temperature when it expands to a volume $2V$.

29. A vessel contains 1·60 g of oxygen and 2·80 g of nitrogen. The temperature is maintained at 300 K and the volume of the vessel is 0·166 m^3. Find the pressure of the mixture.

30. A vertical cylinder of height 100 cm contains air at a constant temperature. The top is closed by a frictionless light piston. The atmospheric pressure is equal to 75 cm of mercury. Mercury is slowly poured over the piston. Find the maximum height of the mercury column that can be put on the piston.

31. Figure (24-E3) shows two vessels A and B with rigid walls containing ideal gases. The pressure, temperature and the volume are p_A, T_A, V in the vessel A and p_B, T_B, V in the vessel B. The vessels are now connected through a small tube. Show that the pressure p and the temperature T satisfy

$$\frac{p}{T} = \frac{1}{2}\left(\frac{p_A}{T_A} + \frac{p_B}{T_B}\right)$$

when equilibrium is achieved.

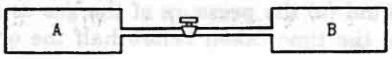

Figure 24-E3

32. A container of volume 50 cc contains air (mean molecular weight = 28·8 g) and is open to atmosphere where the pressure is 100 kPa. The container is kept in a bath containing melting ice (0°C). (a) Find the mass of the air in the container when thermal equilibrium is reached. (b) The container is now placed in another bath containing boiling water (100°C). Find the mass of air in the container. (c) The container is now closed and placed in the melting-ice bath. Find the pressure of the air when thermal equilibrium is reached.

33. A uniform tube closed at one end, contains a pallet of mercury 10 cm long. When the tube is kept vertically with the closed end upward, the length of the air column trapped is 20 cm. Find the length of the air column trapped when the tube is inverted so that the closed end goes down. Atmospheric pressure = 75 cm of mercury.

34. A glass tube, sealed at both ends, is 100 cm long. It lies horizontally with the middle 10 cm containing mercury. The two ends of the tube contain air at 27°C and at a pressure 76 cm of mercury. The air column on one side is maintained at 0°C and the other side is maintained at 127°C. Calculate the length of the air column on the cooler side. Neglect the changes in the volume of mercury and of the glass.

35. An ideal gas is trapped between a mercury column and the closed end of a narrow vertical tube of uniform base containing the column. The upper end of the tube is open to the atmosphere. The atmospheric pressure equals 76 cm of mercury. The lengths of the mercury column and the trapped air column are 20 cm and 43 cm respectively. What will be the length of the air column when the tube is tilted slowly in a vertical plane through an angle of 60°? Assume the temperature to remain constant.

36. Figure (24-E4) shows a cylindrical tube of length 30 cm which is partitioned by a tight-fitting separator. The separator is very weakly conducting and can freely slide along the tube. Ideal gases are filled in the two parts of the vessel. In the beginning, the temperatures in the parts A and B are 400 K and 100 K respectively. The separator slides to a momentary equilibrium position shown in the figure. Find the final equilibrium position of the separator, reached after a long time.

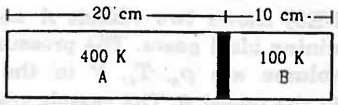

Figure 24-E4

37. A vessel of volume V_0 contains an ideal gas at pressure p_0 and temperature T. Gas is continuously pumped out of this vessel at a constant volume-rate $dV/dt = r$ keeping the temperature constant. The pressure of the gas being taken out equals the pressure inside the vessel. Find (a) the pressure of the gas as a function of time, (b) the time taken before half the original gas is pumped out.

38. One mole of an ideal gas undergoes a process

$$p = \frac{p_0}{1 + (V/V_0)^2}$$

where p_0 and V_0 are constants. Find the temperature of the gas when $V = V_0$.

39. Show that the internal energy of the air (treated as an ideal gas) contained in a room remains constant as the temperature changes between day and night. Assume that the atmospheric pressure around remains constant and the air in the room maintains this pressure by communicating with the surrounding through the windows etc.

40. Figure (24-E5) shows a cylindrical tube of radius 5 cm and length 20 cm. It is closed by a tight-fitting cork. The friction coefficient between the cork and the tube is 0·20. The tube contains an ideal gas at a pressure of 1 atm and a temperature of 300 K. The tube is slowly heated and it is found that the cork pops out when the temperature reaches 600 K. Let dN denote the magnitude of the normal contact force exerted by a small length dl of the cork along the periphery (see the figure). Assuming that the temperature of the gas is uniform at any instant, calculate $\frac{dN}{dl}$.

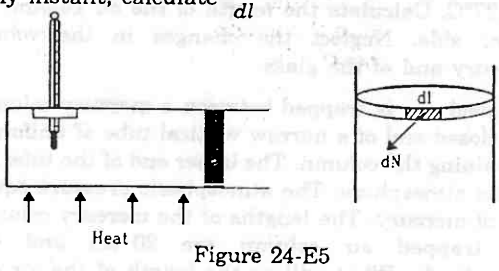

Figure 24-E5

41. Figure (24-E6) shows a cylindrical tube of cross-sectional area A fitted with two frictionless pistons. The pistons are connected to each other by a metallic wire. Initially, the temperature of the gas is T_0 and its pressure is p_0 which equals the atmospheric pressure. (a) What is the tension in the wire? (b) What will be the tension if the temperature is increased to $2T_0$?

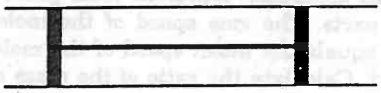

Figure 24-E6

42. Figure (24-E7) shows a large closed cylindrical tank containing water. Initially the air trapped above the water surface has a height h_0 and pressure $2p_0$ where p_0 is the atmospheric pressure. There is a hole in the wall of the tank at a depth h_1 below the top from which water comes out. A long vertical tube is connected as shown. (a) Find the height h_2 of the water in the long tube above the top initially. (b) Find the speed with which water comes out of the hole. (c) Find the height of the water in the long tube above the top when the water stops coming out of the hole.

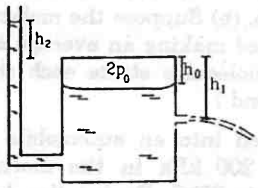

Figure 24-E7

43. An ideal gas is kept in a long cylindrical vessel fitted with a frictionless piston of cross-sectional area 10 cm^2 and weight 1 kg (figure 24-E8). The vessel itself is kept in a big chamber containing air at atmospheric pressure 100 kPa. The length of the gas column is 20 cm. If the chamber is now completely evacuated by an exhaust pump, what will be the length of the gas column? Assume the temperature to remain constant throughout the process.

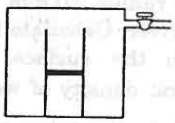

Figure 24-E8

44. An ideal gas is kept in a long cylindrical vessel fitted with a frictionless piston of cross-sectional area 10 cm^2 and weight 1 kg. The length of the gas column in the vessel is 20 cm. The atmospheric pressure is 100 kPa. The vessel is now taken into a spaceship revolving round the earth as a satellite. The air pressure in the spaceship is maintained at 100 kPa. Find the length of the gas column in the cylinder.

45. Two glass bulbs of equal volume are connected by a narrow tube and are filled with a gas at 0°C at a pressure of 76 cm of mercury. One of the bulbs is then placed in melting ice and the other is placed in a water bath maintained at 62°C. What is the new value of the

pressure inside the bulbs ? The volume of the connecting tube is negligible.

46. The weather report reads, "Temperature 20°C : Relative humidity 100%". What is the dew point ?

47. The condition of air in a closed room is described as follows. Temperature = 25°C, relative humidity = 60%, pressure = 104 kPa. If all the water vapour is removed from the room without changing the temperature, what will be the new pressure ? The saturation vapour pressure at 25°C = 3·2 kPa.

48. The temperature and the dew point in an open room are 20°C and 10°C. If the room temperature drops to 15°C, what will be the new dew point ?

49. Pure water vapour is trapped in a vessel of volume 10 cm^3. The relative humidity is 40%. The vapour is compressed slowly and isothermally. Find the volume of the vapour at which it will start condensing.

50. A barometer tube is 80 cm long (above the mercury reservoir). It reads 76 cm on a particular day. A small amount of water is introduced in the tube and the reading drops to 75·4 cm. Find the relative humidity in the space above the mercury column if the saturation vapour pressure at the room temperature is 1·0 cm.

51. Using figure (24.6) of the text, find the boiling point of methyl alcohol at 1 atm (760 mm of mercury) and at 0·5 atm.

52. The human body has an average temperature of 98 °F. Assume that the vapour pressure of the blood in the veins behaves like that of pure water. Find the minimum atmospheric pressure which is necessary to prevent the blood from boiling. Use figure (24.6) of the text for the vapour pressures.

53. A glass contains some water at room temperature 20°C. Refrigerated water is added to it slowly. When the temperature of the glass reaches 10°C, small droplets condense on the outer surface. Calculate the relative humidity in the room. The boiling point of water at a pressure of 17·5 mm of mercury is 20°C and at 8·9 mm of mercury it is 10°C.

54. 50 m^3 of saturated vapour is cooled down from 30°C to 20°C. Find the mass of the water condensed. The absolute humidity of saturated water vapour is 30 g/m^3 at 30°C and 16 g/m^3 at 20°C.

55. A barometer correctly reads the atmospheric pressure as 76 cm of mercury. Water droplets are slowly introduced into the barometer tube by a dropper. The height of the mercury column first decreases and then becomes constant. If the saturation vapour pressure at the atmospheric temperature is 0·80 cm of mercury, find the height of the mercury column when it reaches its minimum value.

56. 50 cc of oxygen is collected in an inverted gas jar over water. The atmospheric pressure is 99·4 kPa and the room temperature is 27°C. The water level in the jar is same as the level outside. The saturation vapour pressure at 27°C is 3·4 kPa. Calculate the number of moles of oxygen collected in the jar.

57. A faulty barometer contains certain amount of air and saturated water vapour. It reads 74·0 cm when the atmospheric pressure is 76·0 cm of mercury and reads 72·10 cm when the atmospheric pressure is 74·0 cm of mercury. Saturation vapour pressure at the air temperature = 1·0 cm of mercury. Find the length of the barometer tube above the mercury level in the reservoir.

58. On a winter day, the outside temperature is 0°C and relative humidity 40%. The air from outside comes into a room and is heated to 20°C. What is the relative humidity in the room ? The saturation vapour pressure at 0°C is 4·6 mm of mercury and at 20°C it is 18 mm of mercury.

59. The temperature and humidity of air are 27°C and 50% on a particular day. Calculate the amount of vapour that should be added to 1 cubic metre of air to saturate it. The saturation vapour pressure at 27°C = 3600 Pa.

60. The temperature and relative humidity in a room are 300 K and 20% respectively. The volume of the room is 50 m^3. The saturation vapour pressure at 300 K is 3·3 kPa. Calculate the mass of the water vapour present in the room.

61. The temperature and the relative humidity are 300 K and 20% in a room of volume 50 m^3. The floor is washed with water, 500 g of water sticking on the floor. Assuming no communication with the surrounding, find the relative humidity when the floor dries. The changes in temperature and pressure may be neglected. Saturation vapour pressure at 300 K = 3·3 kPa.

62. A bucket full of water is placed in a room at 15°C with initial relative humidity 40%. The volume of the room is 50 m^3. (a) How much water will evaporate ? (b) If the room temperature is increased by 5°C how much more water will evaporate ? The saturation vapour pressure of water at 15°C and 20°C are 1·6 kPa and 2·4 kPa respectively.

□

ANSWERS

OBJECTIVE I

1. (d)	2. (b)	3. (a)	4. (d)	5. (a)	6. (a)
7. (c)	8. (c)	9. (b)	10. (a)	11. (c)	12. (d)
13. (c)	14. (b)	15. (a)	16. (d)	17. (a)	

OBJECTICE II

1. (c), (d)	2. (b)	3. (b)
4. (c)	5. (d)	6. (a), (c)
7. (d)		

EXERCISES

1. 2-24 x 10^{-2} m^3
2. 2-685 x 10^{19}
3. 3-53 x 10^{11}
4. 1-43 mg
5. 1 : 1
6. 8-0 x 10^{15}
7. 375 K
8. 1-24 x 10^5 Pa
9. 28-3 g/mol
10. 0-987
11. 3: 1
12. 1930 m/s, 1200 K
13. 1300 m/s
14. 310 K
15. 8 0 hour
16. 8-0 x 10 kg-m/s
17. 1:2
18. 11800 K
19. 3-74
20. 1−18
21. 1*23 x 10^{10}
22. (a) 1780 m/s (b) v_2 x 10^{28}
23. 209 kPa
24. 0-16 g
25. 2-2 mm
26. 0-14
27. 196°C
28. **T/2**
29. 2250 N/m^2
30. 25 cm
32. (a) 0 058 g (b) 0 04 68 g (c) 73'0 kPa
33. 15 cm
34. 36*5 cm
35. 48 cm
36. 10 cm from the left end
37. (a) $p = p_0 e^{-Y'/V}$ (b) $\frac{V_0}{}$ - $\frac{\wedge}{}$
40. 1'25 x 10 * N/m
41. (a) zero (b) $p_0 A$
42. (a (b) 2
    (c) - h,
43. 2-2 m
44. 22 cm
45. 84 cm of mercury
46. 20°C
47. 102 kPa
48. 10°C
49. 4-0 cm^3
50. 60%
51. 65°C, 48°C
52. 50 mm of mercury
53. 51%
54. 700 g
55. 75-2 cm
56. 1-93 x 10^{-3}
57. 91-1 cm
58. 9-5%
59. 13 g
60. 238 g
61. 62%
62. (a) 361 g (b) 296 g