HEAT & THERMODYNAMICS

CONCEPTS

C1 Zeroth law of thermodynamics

This law defines the concept of temperature and thermal equilibrium. When two bodies are in thermal equilibrium, their temperature are equal and vice versa. If bodies A and B are each in thermal equilibrium with a third body C, then A and B are in thermal equilibrium with each other.

C2 Measuring Temperature

Thermometer is used to measure the temperature using the above law. If the thermometric property at temperature at 0^0C, 100^0C and T_c ^0C is X_0, X_{100} and X respectively then $T_C = \frac{X - X_0}{X_{100} - X_0} \times 100^0 C$.

The relation between Celsius (C), Fahrenheit (F) and Kelvin (K) are given by $\frac{C}{5} = \frac{F - 32}{9}$ and K = 273 + C.

<u>**Practice Problems :**</u>

1. **A constant volume gas thermometer shows pressure readings of 50 cm and 90 cm of mercury at 0^0C and 100^0C, respectively. When the pressure reading is 60 cm of mercury, the temperature is**

(a) 25^0C (b) 40^0C (c) 15^0C (d) 12.5^0C

[Answers : (1) (a)]

C3 Thermal Expansion

(i) **Linear Expansion :** $l = l_0 (1 + \alpha\Delta T)$, where l_0 is the initial length and l is final length and α is the coefficient of the linear expansion and ΔT is the change in temperature.

(ii) **Area expansion :** $A = A_0(1 + \beta\Delta T)$, where A_0 is the initial area and A is the final area. Here $\beta = 2\alpha$ (for solid), is coefficient of area expansion.

(iii) **Volume expansion :** $V = V_0 (1 + \gamma\Delta T)$, where V_0 is the initial volume, V is the final volume and $\gamma = 3\alpha$ (for liquid), is the coefficient of volume expansion.

<u>**Practice Problems :**</u>

1. **Two rods of length l_1 and l_2 are made of materials whose coefficients of linear expansion are α_1 and α_2, respectively. The difference between their lengths will be independent of temperature if l_1/l_2 is equal to**

(a) $\frac{\alpha_1}{\alpha_2}$ (b) $\frac{\alpha_2}{\alpha_1}$ (c) $\left(\frac{\alpha_1}{\alpha_2}\right)^{1/2}$ (d) $\left(\frac{\alpha_2}{\alpha_1}\right)^{1/2}$

(b)

2. **A vessel of volume V and linear coefficient of expansion α contains a liquid. The level of liquid does not change on heating. The volume coefficient of real expansion of the liquid is**

(a) $\frac{V + \alpha}{V}$ (b) $\frac{V - \alpha}{V}$ (c) $\frac{V}{V - \alpha}$ (d) 3α

(d)

[Answers : (1) b (2) d]

C4 Effect of temperature on density

$\rho = \frac{\rho_0}{1 + \gamma\Delta T}$ where ρ_0 is the initial density and ρ is the final density

C5 Thermal Stress

When a rod is heated or cooled, it expands or contracts. If it is prevented from the expansion or contraction, then stresses are produced in it corresponding to the thermal strain which are given by Thermal Strain = $\alpha\Delta T$, Thermal Stress = $Y\alpha\Delta T$, Force = $YA\alpha\Delta T$ where α is the coefficient of linear expansion, Y is the young's modulus of elasticity, A is the cross-sectional area of the rod and ΔT is the change in temperature.

Practice Problems :

1. **A steel rod of length 25 cm has a cross-sectional area of 0.8 cm^2. The force required to stretch this rod by the same amount as the expansion produced by heating it through 10^{0}C is (coefficient of linear expansion of steel is $10^{-5}/^0$C and Young's modulus of steel is 2×10^{10} N/m^2)**

(a) **40 N** **(b)** **80 N** **(c)** **120 N** **(d)** **160 N**

[Answers : (1) d]

C6 Ideal Gas

An ideal gas is one for which the pressure P, volume V, and temperature T are related by

$$PV = nRT \text{ or } P = n_0kT \text{ or } \frac{P}{\rho} = \frac{RT}{M}.$$

Here n : no of moles, R : Gas constant, n_0 : No. of moles per unit volume

k : Boltzmann's constant, ρ : Density of Gas, M : Molar mass of Gas

Practice Problems :

1. **A vessel contains 1 mole of O_2 gas (molar mass 32) at a temperature T. The pressure of the gas is P. An identical vessel containing one mole of He gas (molar mass 4) at a temperature 2T has a pressure of**

(a) **P/8** **(b)** **P** **(c)** **2P** **(d)** **8P**

2. **Two gases A and B having the same temperature T, same pressure P and same volume V are mixed. If the mixture is at the same temperature T and occupies a volume V, the pressure of the mixture is**

(a) **2P** **(b)** **P** **(c)** **P/2** **(d)** **4P**

[Answers : (1) c (2) a]

C7 Kinetic Interpretation of Pressure

The pressure exerted by an ideal gas, in terms of the speed of its molecules is

$$\mathbf{p = \frac{mv^2_{rms}}{3V} = \frac{1}{3}\rho v^2_{r.m.s}} \qquad \left(\rho = \frac{\mathbf{m}}{\mathbf{V}}\right)$$

where v_{rms} is the root-means-square speed of the molecules of the gas. Here m is the mass of the gas.

Hence $v_{r.m.s.} = \sqrt{\frac{3P}{\rho}} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3kT}{m}}$. There is another two speeds of the gas molecules according to

Maxwell Speed Distribution :

Average speed, $$v_{avg} = \sqrt{\frac{8RT}{\pi M}} = \sqrt{\frac{8kT}{\pi m}}$$

Most probable Speed (the speed at which the number of molecules is maximum)

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

Here $v_{rms} > v_{avg} > v_{mp}$.

Practice Problems :

1. **The temperature of an ideal gas is increased from 120 K to 480 K. If at 120 K the root mean square velocity of the gas molecules is v, at 480 K it becomes**

   (a) 4v (b) 2v (c) v/2 (d) v/4

2. **At room temperature the rms speed of the molecules of a certain diatomic gas is found to be 1930 m/s. The gas is**

   (a) H_2 (b) F_2 (c) O_2 (d) Cl_2

3. **If the rms velocity of oxygen molecule at certain temperature is 0.5 km/s, the rms velocity for hydrogen molecule at the same temperature will be**

   (a) 2 km/s (b) 4 km/s (c) 9 km/s (d) 16 km/s

[Answers : (1) b (2) a (3) a]

C8 Specific Heat Capacity and Calorimetry

Heat capacity per unit mass is known as specific heat capacity i.e., $\mathbf{s = \frac{dQ}{mdT}} \Rightarrow \int \mathbf{dQ = m\int sdT}$. If s is constant then $Q = ms(T_f - T_i)$.

Principle of Calorimetry : Heat lost = heat gained.

C9 Heat of Transformation

The amount of energy required per unit mass to change the phase (but not the temperature) of a particular material is its heat of transformation L. Thus. Q = Lm.

Practice Problems :

1. **One gm of ice at 0^0C is added to 5 gm of water at 10^0C. If the latent heat is 80 cal/gm, the final temperature of the mixture is**

   (a) 5^0C (b) 0^0C (c) -5^0C (d) None of the above

2. **200 gm of a solid ball at 20^0C is dropped in an equal amount of water at 80^0C. The resulting temperature is 60^0C. This means that specific heat of solid is**

   (a) One fourth of water (b) One half of water

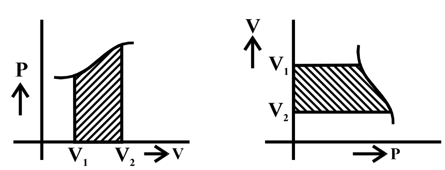
   (c) Twice of water (d) Four times of water

[Answers : (1) b (2) b]

C10 Thermodynamic Work Done

The work performed by a system at pressure P expands from volume V_1 to V_2 is given by $W = \int_{V_1}^{V_2} PdV$.

Here P may be a constant or change during the volume change. The work done equals the area under the curve on a P-V diagram as shown in figure.



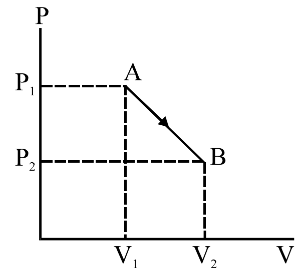
The work done in **cyclic process** (a process in which the thermodynamic variables periodically return to their original values) is equal to the area enclosed by the cycle.

Positive Work : If the cycle is clockwise on P – V and anticlockwise on V – P.

Negative Work : If the cycle is anticlockwise on P – V and clockwise on V – P.

Practice Problems :

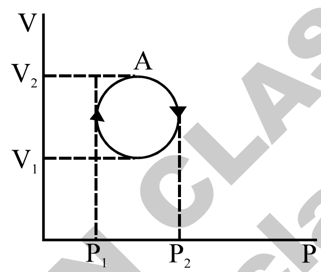
1. The work performed for the process shown in figure is



(a) $\frac{1}{2}(P_1 + P_2)(V_2 - V_1)$ (b) $\frac{1}{2}(P_1 - P_2)(V_2 - V_1)$

(c) $\frac{1}{2}(P_1 - P_2)(V_2 + V_1)$ (d) $\frac{1}{2}(P_1 + P_2)(V_2 + V_1)$

2. The amount of heat involved for the cyclic process shown in figure is



(a) $\frac{\pi}{4}(P_2 - P_1)(V_2 - V_1)$ (b) $-\frac{\pi}{4}(P_2 - P_1)(V_2 - V_1)$

(c) $-\frac{\pi}{4}(P_2 + P_1)(V_2 - V_1)$ (d) $-\frac{\pi}{4}(P_2 + P_1)(V_2 + V_1)$

[Answers : (1) a (2) b]

C11 Internal Energy

For an ideal gas, it is the sum of all types of kinetic energy associated with gas molecules. Remember the following points for internal energy of an ideal gas :

1. Internal energy at temperature T for an ideal gas of n moles is $U = n\frac{f}{2}RT$

   where f is the degrees of freedom of gas. The value of f for monoatomic gas is (He, Ne etc.) 3 whereas for diatomic gas (O_2, H_2, N_2 etc) is 5

2. Internal energy for mixture of gaseous is $U = n_1\frac{f_1}{2}RT + n_2\frac{f_2}{2}RT + ...$

3. The change in internal energy, $dU = nC_VdT$ for any thermodynamic process.

   Here C_V is the molar heat capacity at constant volume which equals to $\frac{f}{2}R$.

4. Internal energy is state dependent function and hence for a cyclic process, dU = 0.

Practice Problems :

1. A gas mixture consists of 2 moles of oxygen and 4 moles of argon at temperature T. Neglecting all vibrational modes, the internal energy of the system is

(a) 5RT (b) 11RT (c) 13RT (d) 17RT

[Answers : (1) b]

C12 First Law of Thermodynamics : This law is based on conservation of energy and in mathematical form the law is given by dQ = dU + dW

Heat and work are path dependent whereas internal energy is a state dependent.

Signs for heat and work in thermodynamics

(a) When heat is added to a system or absorbed by system, Q is positive

(b) When heat is transferred out of the system or rejected by system Q is negative

(c) When work is done by the system W is positive

(d) When work is done on the system W is negative.

C13 Molar Heat Capacity

Now we define the molar heat capacity of two special thermodynamic process :

(i) Molar heat capacity at constant volume (C_V) : It is defined as the heat required to raise the temperature by 1K of 1 mole of gas at constant volume. Mathematically

$$C_V = \frac{(dQ)_V}{ndT} \Rightarrow (dQ)_V = nC_V dT$$

Here $(dQ)_V$ is the required heat for this process i.e. for isochoric process.

(ii) Molar heat capacity at constant pressure (C_P) : It is defined as the heat required to raise the temperature by 1 K of 1 mole of gas at constant pressure. Mathematically

$$C_P = \frac{(dQ)_P}{ndT} \Rightarrow (dQ)_P = nC_P dT$$

Here $(dQ)_P$ is the required heat for this process i.e. for isobaric process to raise the temperature by dT on n moles of gas.

Remember the following points :

(i) C_P is always greater than C_V

(ii) $C_P - C_V = R$ for ideal gas

(iii) The ratio $\frac{C_P}{C_V}$ is known as adiabatic exponent (γ)

(iv) $C_V = \frac{R}{\gamma - 1}$ and $C_P = \frac{R\gamma}{\gamma - 1}$

(v) In terms of degree of freedom (f) $C_V = \frac{f}{2}R$, $C_P = \left(1 + \frac{f}{2}\right)R$ and $\gamma = \left(1 + \frac{2}{f}\right)$

(vi) C_V for mixture of gases $C_V = \frac{n_1 C_{V_1} + n_2 C_{V_2} + n_3 C_{V_3} + ...}{n_1 + n_2 + n_3}$

(vii) γ for mixture of gases $\frac{n}{\gamma - 1} = \frac{n_1}{\gamma_1 - 1} + \frac{n_2}{\gamma_2 - 1} + ...$ Here $n = n_1 + n_2 + n_3 + ...$

(viii) Molecular weight of mixture of gases $\frac{m_1 + m_2 + ...}{M} = \frac{m_1}{M_1} + \frac{m_2}{M_2} + ...$

Practice Problems :

1. **If one mole of a monatomic gas (γ = 5/3) is mixed with one mole of diatomic gas (γ = 7/5), the value of γ for the mixture is :**

(a) 1.4 (b) 1.5 (c) 1.53 (d) 1.67

[Answers : (1) b]

C14 Application of the First Law of Thermodynamics

(i) Isochoric Process (Constant Volume Process) : $W = 0$, $Q = \Delta U$

(ii) Isobaric Process (Constant Pressure Process) : $W = P(V_2 - V_1) = nR(T_2 - T_1)$

$Q = nC_p(T_2 - T_1)$

(iii) Isothermal Process (Constant Temperature Process)

$$\Delta U = 0, Q = W = nRT \ln\frac{V_2}{V_1} = nRT\ln\frac{\rho_1}{\rho_2} = nRT\ln\frac{P_1}{P_2}.$$

(iv) Adiabatic Process

PV^{γ} = constant, $TV^{\gamma-1}$ = constant, $P^{1-\gamma}T^{\gamma}$ = constant.

For this process Q = 0, $\Delta U = \frac{nR}{\gamma - 1}(T_2 - T_1) = \frac{1}{\gamma-1}(P_2V_2 - P_1V_1)$ and $W = -\Delta U$

(v) Cyclic Process

There is process in which, after certain interchanges of heat and work, the system is restored to its initial state, named as cyclic process. In this case $\Delta U = 0$ and $Q = W$

(vi) Free expansions

These are adiabatic process in which no transfer of heat occurs between the system and its environment and no work is done on or by the system. Thus, $Q = W = 0$ and hence from the first law thermodynamics $\Delta U = 0$.

Practice Problems :

1. **A monatomic gas (γ = 5/3) is suddenly compressed to (1/8) of its initial volume adiabatically, then the pressure of the gas will change to :**

(a) 24/5 (b) 8 (c) 40/3 (d) 32

2. **In an adiabatic change, the pressure P and temperature T of a diatomic gas are related by the relation $P \propto T^C$ where c equals**

(a) 5/3 (b) 2/5 (c) 3/5 (d) 7/2

3. **One mole of an ideal gas requires 207 J heat to raise the temperature by 10 K when heated at constant pressure. If the same gas is heated at constant volume to raise the temperature by the same 10 K, the heat required is : [R = 8.3 J/mol K]**

(a) 198.7 J (b) 29 J (c) 215.3 J (d) 124 J

4. **When an ideal diatomic gas is heated at constant pressure, the fraction of the heat energy supplied which increases the internal energy of the gas is**

(a) (2/5) (b) (3/5) (c) (3/7) (d) (5/7)

[Answers : (1) d (2) d (3) d (4) d]

C15 Efficiency of a Themodynamic Cycle

The efficiency of a thermodynamic cycle is defined as

$$\eta = \frac{W_{net}}{Q_{in}}$$

where W_{net} is the net work done by the cycle, and Q_{in} is total heat input of the cycle.

Practice Problems :

1. An ideal gas is taken through a cyclic thermodynamic process through four steps. The amount of heat involves in these steps are Q_1 = 5960J, Q_2 = –5585J, Q_3 = –2980J and Q_4 = 3645J respectively. The corresponding quantities of work involved are W_1 = 2200 J, W_2 = –825J, W_3 = –1100 J, and W_4 respectively. The value of W_4 is

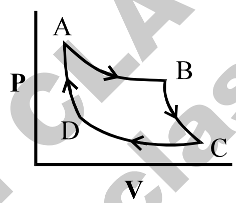
(a) 265 J (b) 575 J (c) 765 J (d) 975 J

2. In the above problem, the efficiency of the cycle is

(a) 10.82 % (b) 7.65 % (c) 8.55 % (d) 9.75 %

[Answers : (1) c (2) a]

C16 Carnot Cycle : This cycle consists of four processes given in the figure : (i) AB is isothermal expansion at temperature T_1 (ii) BC is adiabatic expansion (iii) CD is isothermal compression at temperature T_2 (iv) DA is adiabatic compression.



The efficiency of the cycle is $1 - T_2/T_1$, where $T_2 < T_1$.

1. A Carnot engine working between 300 K and 600 K has a work output of 800 J per cycle. The amount of heat energy supplied to the engine from the source in each cycle is

(a) 800 J (b) 1600 J (c) 3500 J (d) 6400 J

[Answers : (1) b]

C17 Second Law of Thermodynamics

(i) Kelvin Planck Statement : No process is possible whose sole result is the absorption of heat from a reservoir and the conversion of the heat into work.

(ii) Clausius' Statement : No process is possible whose sole result is the transfer of heat from a colder object to a hotter object. According to this law no engine has the efficiency equals to 1, it is always less than 1

C18 Entropy : Entropy is a measure of disorder of the molecular motion of a system. The greater the disorder, the greater is the entropy. The change in entropy is given by $dS = \frac{dQ}{T}$.

C19 Heat Transfer

There are three mechanisms for heat transfer : Conduction, Convection and Radiation.

Conduction : Conduction occurs in solids. If the ends of a rod of thermal conductivity k is kept at the temperature T_1 and T_2 then heat flowing per unit time through the rod is given by $(T_1 - T_2)/R$, where R is the thermal resistance of the rod. If the length of the rod is l and cross-sectional area A then $R = l/kA$.

Practice Problems :

1. **Two ends of rods of length L and radius r of the same material are kept at the same temperature. Which of the following rods conducts most heat**

   (a) **L = 50 cm, r = 1 cm** (b) **L = 100 cm, r = 2 cm**

   (c) **L = 25 cm, r = 0.5 cm** (d) **L = 75 cm, r = 1.5 cm**

2. **Heat is flowing through two cylindrical rods of the same material. The diameter of the rods are in the ratio 1 : 2 and their lengths are in the ratio 2 : 1. If the temperature difference between their ends is the same, then the ratio of the amounts of heat conducted through them per unit time will be**

   (a) **1 : 1** (b) **2 : 1** (c) **1 : 4** (d) **1 : 8**

[Answers : (1) b (2) d]

Convection : It occurs in fluids.

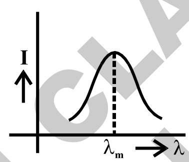
Heat Radiation : Heat radiation is electro-magnetic energy transfer in the form of electromagnetic waves (infrared waves) through any medium. Heat radiation has the same character as the electromagnetic wave. This transfer does not require any material medium. The surface of any material medium emits heat radiations if its temperature is above 0 K.

Black Body

A perfect black body is one which absorbs all the radiations (from $\lambda = 0$ to $\lambda = \infty$) incident on it.

Black Body Radiation

The graph is plotted between intensity of heat radiation I and wave length λ of heat radiation emitted by the black body as shown in figure



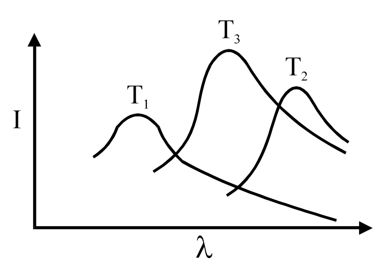
There is particular wavelength λ_m at which the intensity of emitted heat radiation is maximum, this wave length is relates with the temperature of the black body using the following law $\lambda_m T = b$ = constant. This law is known as **Wien's Displacement law.** Here b is known as Wien's constant having value 0.29 cm-K.

Practice Problems :

1. **The intensity of radiation emitted by the Sun has its maximum value at a wavelength of 510 nm and that emitted by the North Star has the maximum value at 350 nm. If these stars behave like black bodies, then the ratio of the surface temperature of the Sun and the North Star is**

   (a) **1.46** (b) **0.69** (c) **1.21** (d) **0.83**

2. **The plots of intensity versus wavelength for three black bodies at temperatures T_1, T_2 and T_3 respectively are as shown in figure. Their temperature are such that**



   (a) $T_1 > T_2 > T_3$ (b) $T_1 > T_3 > T_2$ (c) $T_2 > T_3 > T_1$ (d) $T_3 > T_2 > T_1$

[Answers : (1) b (2) b]

Stefan's Boltzmann Law

The energy of heat radiation emitted per unit time E is directly proportional to the fourth power of absolute temperature of the body i.e., $E = e\sigma(T^4 - T_0^4)$

where e is the emissivity of the surface defined as the ratio of emissive power of the surface to the emissive power of black body surface at the same temperature. Its value lies between 0 and 1. For black body e = 1. σ is known as Stefan's constants, its numerical value is 5.68×10^{-8} Wm^{-2} K^{-4}. T_0 is the surrounding temperature in which body is placed. If A is the surface area of the body, then the rate of heat emitted by the body is

$$\frac{dQ}{dt} = e\sigma A(T^4 - T_0^4)$$

As dQ = msdT then the rate of cooling if $T > T_0$

$$\frac{dT}{dt} = -\frac{e\sigma A}{ms}(T^4 - T_0^4)$$

If $T_0 = 0$ or $T >> T_0$ then $\frac{dQ}{dt} = e\sigma T^4$ and $\frac{dT}{dt} = -\frac{e\sigma A}{ms}T^4$

Newton's Law of Cooling

When the temperature difference between the body and is surrounding is not very large, i.e. $T - T_0 = \Delta T$ is small then the rate of cooling is given by $\frac{dT}{dt} = -k(T - T_0)$. This law is known as **Newton's Law of Cooling** which is derived from **Stefan's Law.** There is another way to express the **Newton's Law Cooling**

$$\left[\frac{T_1 - T_2}{t}\right] = K\left[\left(\frac{T_1 + T_2}{2}\right) - T_0\right]$$

Here T_1 : Initial temperature of the body, T_2 : Temperature of the body after time t

T_0 : Surrounding temperature, K : A constant

Practice Problems :

1. A spherical black body with a radius of 12 cm radiates 450 W power at 500 K. If the radius were halved and the temperature doubled, the power radiates in watt would be

(a) 225 (b) 450 (c) 900 (d) 1800

2. A sphere, a cube and a thin circular plate all made of the same mass and finish are heated to a temperature of 200^0C; which of these objects will cool slowest when left in air at room temperature

(a) The sphere (b) The cube

(c) The circular plate (d) All will cool at the same rate

3. A ball A has twice the diameter as another ball B of the same material and with same surface finish. A and B are both heated to the same temperature and allowed to cool radiatively; then

(a) Rate of cooling of A is same as that of B

(b) Rate of cooling of A is twice that of B

(c) Rate of cooling of A is half that of B

(d) Rate of cooling of A is four times that of B

4. The temperature of a body is increased from 27^0C to 127^0C. The radiation emitted by it increases by a factor of

(a) (256/81) (b) (15/9) (c) (4/3) (d) (12/27)

5. A liquid cools in 6 minutes from 80^0C to 60^0C. Take the temperature of surrounding to be 30^0C and assume that Newton's law of cooling is applicable throughout the process. Its temperature after 10 minutes is

(a) 48.2^0C (b) 42.8^0C (c) 37.5^0C (d) 32.5^0C

[Answers : (1) d (2) a (3) c (4) a (5) b]

1. For an ideal gas :

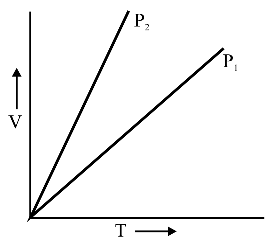
(a) The change in internal energy in a constant pressure process from temperature T_1 to $T_2 = nC_V(T_2 - T_1)$ where C_V is the molar specific heat at constant volume and n the number of moles of the gas.

(b) The change in internal energy of the gas and the work done by the gas are equal in magnitude in an adiabatic process.

(c) The internal energy does not change in isothermal process.

(d) all are coorect

2. For V versus T curves at constant pressure P_1 and P_2 for an ideal gas are shown in fig.



(a) $P_1 > P_2$ (b) $P_1 < P_2$

(c) $P_1 = P_2$ (d) $P_1 \geq P_2$

3. A black body emits

(a) Radiation of all wavelengths

(b) No radiations

(c) Radiations of only one wavelength

(d) Radiations of selected wavelength

4. Ice starts freezing in a lake with water at 0^0C when the atmospheric temperature is -10^0C. If the time taken for 1 cm of ice to be formed is 12 minutes the time taken for the thickness of the ice to change from 1 cm to 2 cm will be

(a) 12 minutes

(b) Less than 12 minutes

(c) More than 12 minutes but less than 24 minutes

(d) More than 24 minutes

5. A wall has two layers A and B, each made of a different material. Both the layers have the same thickness. The thermal conductivity of the material of A is twice that of B; if under thermal equilibrium the temperature difference across the wall is 36^0C, the temperature difference accross the layer A is

(a) 6^0C (b) 12^0C

(c) 18^0C (d) 24^0C

6. Two identical objects A and B are at temperature T_A and T_B respectively. Both objects are placed in a room with perfectly absorbing walls maintained at a temperature $T(T_A > T > T_B)$. The objects A and B attain the temperature T eventually. Select the correct statements from the following

(a) Each object continues to emit and absorb radiation even after attaining the temperature T

(b) A loses more heat by radiation than it absorbs, while B absorbs more radiation than it emits, until they attain the temperature T

(c) Both A and B only absorb radiation, but do not emit it, until they attain the temperature T.

(d) both (a) and (b) are correct

7. An air bubble of volume 1.0 cm^3 rises from the bottom of a lake 40 m deep at a temperature of 12^0C. To what volume does it grow when it reaches the surface, which is at a temperature of 35^0C ?

(a) 1.0 cm^3 (b) 2.5 cm^3

(c) 1.75 cm^3 (d) none of these

8. Let the specific heat capacity of a gas at constant volume and at constant pressure is $C_P^* \text{ and } C_V^*$ then $C_P^* - C_V^*$ equals to

(a) R (b) R/M

(c) MR (d) $\sqrt{M}R$

Here M is the molecular weight of the gas.

9. For which process the molar heat capacity is zero ?

(a) Isochoric process

(b) Adiabatic process

(c) Isothermal process

(d) Isobaric process

10. Which of the following quantity is path independent ?

(a) internal energy

(b) work done

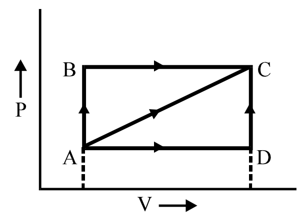
(c) amount of heat

(d) molar heat capacity of gases

FINAL STEP EXERCISE

1. Steam at 100^0C passed into 1.1 kg of water contained in a calorimeter of water equivalent 0.02 kg at 15^0C till the temperature of the calorimeter and its content rises to 80^0C. If the enthalpy of vaporization of water at 100^0C is 2.26 kJ/g, the mass of steam condensed is
   (a) 0.130 kg (b) 0.065 kg
   (c) 0.260 kg (d) 0.33 kg

2. A thermodynamical process is shown in fig. with $P_A = 3 \times 10^4$ Pa; $V_A = 2 \times 10^{-3}$ m^3; $P_B = 8 \times 10^4$ N/m^2; $V_D = 5 \times 10^{-3}$ m^3. In the processes AB and BC, 600 J and 200 J of heat is added to the system respectively. The change in internal energy of the system in process AC would be



   (a) 560 J (b) 800 J
   (c) 600 J (d) 640

3. Two samples of air A and B having same composition and initially at the same temperature and pressure are compressed from a volume V to V/2, the sample A isothermally and the sample B adiabatically. The final pressure of
   (a) A is greater than B
   (b) A is lesser than B
   (c) A is equal to that of B
   (d) A is twice that of B

4. Two identical containers A and B with frictionless pistons contain the same ideal gas at the same temperature and the same volume V. The mass of the gas in A is m_A, and that in B is m_B. The gas in each cylinder is now allowed to expand isothermally to the same final volume 2V. The changes in the pressure in A and B are found to be ΔP and 1.5 ΔP respectively. Then
   (a) $4m_A = 9m_B$ (b) $2m_A = 3m_B$
   (c) $3m_A = 2m_B$ (d) $9m_A = 4m_B$

5. The initial pressure and volume of a gas are P_i and V_i. The gas after expansion attains final volume V_f. Let W_1, W_2 and W_3 are the corresponding work done under isothermal, adiabatic and isobaric pressure. Then
   (a) $W_1 = W_2 = W_3$ (b) $W_2 > W_1 > W_3$
   (c) $W_1 > W_2 > W_3$ (d) $W_3 > W_1 > W_2$

6. A cylinder of radius R made of a material of thermal conductivity K_1 is surrounded by a cylindrical shell of inner radius R and outer radius 2R made of a material of thermal conductivity K_2. The two ends of the combined system are maintained at two different temperature. There is no loss of heat across the cylindrical surface and the system is in steady state. The effective thermal conductivity of the system is
   (a) $K_1 + K_2$ (b) $(K_1 + 3K_2)/4$
   (c) $K_1K_2/(K_1 + K_2)$ (d) $(3K_1 + K_2)/4$

7. One end of a copper rod of length 1.0 m and area of cross-section 10^{-3}m^2 is immersed in boiling water and the other end in ice. If the coefficient of thermal conductivity of copper is 92 cal/m s C^0 and the latent heat of ice is 8×10^4 cal/kg, then the amount of ice which will melt in one minute is
   (a) 9.2×10^{-3} kg (b) 8×10^3 kg
   (c) 6.9×10^{-3} kg (d) 5.4×10^{-3} kg

8. A cylindrical pipe consists of a material of thermal conductivity k having length L, and the inner and outer radii are R_1 and R_2, respectively. The pipe conducts heat radially outward at a constant rate dQ/dt. The temperature difference between the inner and outer radii is
   (a) $\frac{1}{(2\pi l)K}\frac{dQ}{dt}\ln\left|\frac{R_1}{R_2}\right|$
   (b) $\frac{1}{(3\pi l)K}\frac{dQ}{dt}\ln\left|\frac{R_1}{R_2}\right|$
   (c) $\frac{1}{(2\pi l)K}\frac{dQ}{dt}\ln\left|\frac{R_2}{R_1}\right|$
   (d) $\frac{1}{(4\pi l)K}\frac{dQ}{dt}\ln\left|\frac{R_2}{R_1}\right|$

9. A source of power P is placed at the centre of a spherical shell of coefficient of thermal conductivity k with inner radius r_1 and outer radius r_2. The temperature difference between inner surface and outer surface is
   (a) $\frac{P(r_1^2 + r_2^2)}{4\pi k r_1 r_2}$ (b) $\frac{P(r_2 - r_1)}{4\pi k r_1 r_2}$
   (c) $\frac{P(r_2 + r_1)}{6\pi k r_1 r_2}$ (d) $\frac{P(r_1 + r_2)}{4\pi k r_1 r_2}$

10. On a cold water winter day, the atmospheric temperature is – θ (on Celsius scale) which is below 0^0C. A cylindrical drum of height h made of a bad conductor is completely filled with water at 0^0C and is kept outside without any lid. Thermal conductivity of ice is K and its latent heat of fusion is L. Neglect expansion of water on freezing. The time taken for the whole mass of water to freeze is
   (a) $\frac{\rho L h^2}{2K\theta}$ (b) $\frac{\rho L h^2}{3K\theta}$
   (c) $\frac{\rho L h^2}{4K\theta}$ (d) $\frac{\rho L h^2}{5K\theta}$

ANSWERS (INITIAL STEP EXERCISE)

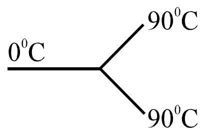
1.	d	6.	d
2.	a	7.	d
3.	a	8.	b
4.	d	9.	b
5.	b	10.	a

ANSWERS (FINAL STEP EXERCISE)

1.	a	6.	b
2.	a	7.	c
3.	b	8.	c
4.	c	9.	b
5.	d	10.	a

TEST YOURSELF

1. Three rods made of the same material and having the same cross-section have been joined as shown in the figure. Each rod is of the same length. The left and right ends are kept 0^0C and 90^0C respectively. The temperature of the junction of the three rods will be



(a) 45^0C (b) 60^0C
(c) 30^0C (d) 20^0C

2. 10 g of ice cubes at 0^0C are released in a tumbler (water equivalent 55 g) at 40^0C. Assuming that negligible heat is taken from the surroundings, the temperature of the water in the tumbler becomes nearly (L = 80 cal g^{-1}),
(a) 31^0C (b) 22^0C
(c) 19^0C (d) 15^0C

3. The maximum energy in the thermal radiations from a hot source occurs at a wavelength of 11×10^{-5} cm. According to Wien's law, the temperature of the source (on kelvin scale) will be n times the temperature of another source (on kelvin scale) for which the wavelength at maximum energy is 5.5×10^{-5} cm. The value of n is
(a) 2 (b) 4
(c) 0.5 (d) 1

4. For hydrogen gas $C_p - C_v = a$ and for oxygen gas $C_p - C_v = b$. The relation between a and b is
(a) a = 16 b (b) $a = \frac{b}{16}$
(c) a = 4b (d) a = b

5. An ideal gas A and a real gas B have their volumes increased from V to 2V under isothermal conditions. The increase in internal energy
(a) will be the same in both A and B
(b) will be zero in both cases
(c) of B will be more than that of A
(d) of A will be more than that of B

6. A diatomic gas initially at 18^0C is compressed adiabatically to one-eight of its initial volume. The temperature after compression will be
(a) 18^0C (b) 887^0C
(c) 891^0C (d) none of these

7. If the temperature of a black body increases from 7^0C to 287^0C, then the rate of energy radiation increases by
(a) $\left(\frac{287}{7}\right)^4$ (b) 16
(c) 4 (d) 2

8. If a gas has f degrees of freedom, the ratio C_p/C_v of the gas is
(a) $\frac{1+f}{2}$ (b) $1+\frac{f}{2}$
(c) $\frac{1}{2}+f$ (d) $1+\frac{2}{f}$

9. For a gas, the difference between the two specific heats is 4150 J $kg^{-1}K^{-1}$ and the ratio of the two specific heats is 1.4. What is the specific heat of the gas at constant volume in units of J $kg^{-1}K^{-1}$?
(a) 8475 (b) 5186
(c) 1660 (d) 10375

10. Two rods of the same length and material transfer a given amount of heat in 12 seconds when they are joined end to end. But when they are joined lengthwise, they will transfer the same amount of heat, in the same conditions, in
(a) 24 s (b) 3 s
(c) 1.5 s (d) 48 s

ANSWERS

1.	b	6.	d
2.	b	7.	b
3.	a	8.	d
4.	d	9.	d
5.	b	10.	d