arride learning

HEAT TRANSFER

Contents

Syllabus

Blackbody radiation : absorptive and emissive powers ; Kirchhoff's law ; Wine's displacement law, Stefan's law.

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HEAT TRANSFER

(A) ***Conduction :*** Due to vibration and collision of medium particles.

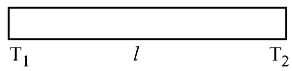
(i) ***Steady State :*** In this state heat absorption stops and temperature gradient throughout the rod becomes constant i.e. $\frac{dT}{dx}$ = constant.

(ii) ***Before steady state :*** Temp of rod at any point changes

Note : If specific heat of any substance is zero, it can be considered always in steady state.

1. ***Ohm's law for Thermal Conduction in Steady State :***

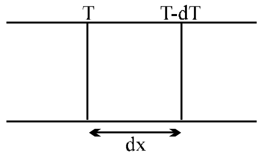
Let the two ends of rod of length l is maintained at temp T_1 and T_2($T_1 > T_2$)



Thermal current $\frac{dQ}{dT} = \frac{T_1 - T_2}{R_{Th}}$

Where thermal resistance $R_{Th} = \frac{1\;1}{K\;A}$

2. ***Differential form of Ohm's Law***



$\frac{dQ}{dT} = KA\frac{dT}{dx}$ $\frac{dT}{dx}$ = temperature gradient

(B) ***Convection :*** Heat transfer due to movement of medium particles.

(C) ***Radiation:*** Every body radiates electromagnetic radiation of all possible wavelength at all temp>0 K.

1. ***Stefan's Law :*** Rate of heat emitted by a body at temp T K from per unit area $E = \sigma T^4$ J/sec/m^2

Radiation power $\frac{dQ}{dT} = P = \sigma A T^4$ watt

If a body is placed in a surrounding of temperature T_S

$\frac{dQ}{dT} = \sigma A\,(T^4 - T_s^{\,4})$

valid only for black body

Emissivity or emmisive power $e = \frac{\text{heat from general body}}{\text{heat from black body}}$

If temp of body falls by dT in time dt

$$\frac{dT}{dt} = \frac{eA\sigma}{mS}(T^4 - T_s^4)$$ (dT/dt = rate of cooling)

2. ***Newton's law of cooling***

$$\frac{dT}{dt} \alpha \ (T - T_s)$$

3. ***Average form of Newtons law of cooling***

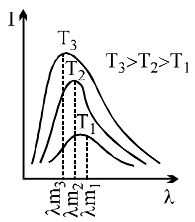
If a body cools from T_1 to T_2 in time δt

$$\frac{T_1 - T_2}{\delta t} = \frac{K}{mS}\left(\frac{T_1 + T_2}{2} - T_s\right)$$ (used generally in objective questions)

$$\frac{dT}{dt} = \frac{K}{mS}(T - T_s)$$ (for better results use this generally in subjective)

4. ***Wein's black body radiation***

At every temperature (>0K) a body radiates energy radiations of all wavelengths. According to Wein's displacement law if the wavelength corresponding to maximum energy is $\lambda_{m.}$



then $\lambda_m T = b$ where b = is a constant (Wein's constant)

T = temperature of body

EXERCISE # 1

PART - I : OBJECTIVE QUESTIONS

*** Marked Questions are having more than one correct option.**

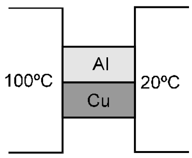
SECTION (A) : THERMAL CONDUCTION IN LINEAR CONDUCTORS AT STEADY STATE

A-1. A wall has two layers A and B, each made of different material. Both the layers have the same thickness. The thermal conductivity for A is twice that of B. Under steady state, the temperature difference across the whole wall is 36°C. Then the temperature difference across the layer A is

(A) 6°C (B) 12°C (C) 18°C (D) 24°C

A-2. Two metal cubes with 3 cm-edges of copper and aluminium are arranged as shown in figure (K_{CU} =385 W/m-K, K_{AL} = 209 W/m-K)

(a) The total thermal current from one reservoir to the other is :



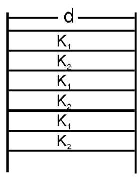
(A) 1.42×10^3 W (B) 2.53×10^3 W

(C) 1.53×10^4 W (D) 2.53×10^4 W

(b) The ratio of the thermal current carried by the copper cube to that carried by the aluminium cube is:

(A) 1.79 (B) 1.69 (C) 1.54 (D) 1.84

A-3. A wall consists of alternating blocks with length 'd' and coefficient of thermal conductivity k_1 and k_2. The cross sectional area of the blocks are the same. The equivalent coefficient of thermal conductivity of the wall between left and right is :-



(A) $K_1 + K_2$ (B) $\frac{(K_1+K_2)}{2}$ (C) $\frac{K_1 K_2}{K_1+K_2}$ (D) $\frac{2 K_1 K_2}{K_1+K_2}$

A-4. A boiler is made of a copper plate 2.4 mm thick with an inside coating of a 0.2 mm thick layer of tin. The surface area exposed to gases at 700°C is 400 cm². The amount of steam that could be generated per hour at atmospheric pressure is (K_{cu} = 0.9 and K_{tin} = 0.15 cal/cm/s/°C and L_{steam} = 540 cal/g)

(A) 5000 Kg (B) 1000 kg (C) 4000 kg (D) 200 kg

A-5. A lake surface is exposed to an atmosphere where the temperature is < 0°C. If the thickness of the ice layer formed on the surface grows from 2 cm to 4 cm in 1 hour, The atmospheric temperature, T_a will be- (Thermal conductivity of ice K = 4×10^{-3} cal/cm/s/°C; density of ice = 0.9 gm/cc. Latent heat of fusion of ice = 80 cal/gm. Neglect the change of density during the state change. Assume that the water below the ice has 0º temperature every where)

(A) – 20 °C (B) 0 °C (C) – 30 °C (D) – 15 °C

SECTION (B) : THERMAL CONDUCTION IN NONLINEAR CONDUCTORS AT STEADY STATE

B-1. Heat flows radially outward through a spherical shell of outside radius R_2 and inner radius R_1. The temperature of inner surface of shell is θ_1 and that of outer is θ_2. The radial distance from centre of shell where the temperature is just half way between θ_1 and θ_2 is :

(A) $\frac{R_1+R_2}{2}$ (B) $\frac{R_1 R_2}{R_1+R_2}$ (C) $\frac{2R_1 R_2}{R_1+R_2}$ (D) $R_1 + \frac{R_2}{2}$

SECTION (C) : RADIATION, STEFEN'S LAW AND WEIN'S LAW

C-1*. Assume transmitivity $t \to 0$ for all the cases :

(A) bad absorber is bad emitter (B) bad absorber is good reflector

(C) bad reflector is good emitter (D) bad emitter is good absorber

C-2*. A hollow and a solid sphere of same material and having identical outer surface are heated under identical condition to the same temperature at the same time (both have same e, a) :

(A) in the beginning both will emit equal amount of radiation per unit time

(B) in the beginning both will absorb equal amount of radiation per unit time

(C) both spheres will have same rate of fall of temperature (dT/dt)

(D) both spheres will have equal temperatures at any moment

C-3. A metallic sphere having radius 0.08 m and mass m = 10kg is heated to a temperature of 227°C and suspended inside a box whose walls are at a temperature of 27°C. The maximum rate at which its temperature will fall is :-

(Take e = 1, Stefan's constant $\sigma = 5.8 \times 10^{-8}\ Wm^{-2}\ K^{-4}$ and specific heat of the metal s = 90 cal/kg/deg J = 4.2 Joules/Calorie)

(A) .055 °C/sec (B) .066 °C/sec (C) .044 °C/sec (D) 0.03 °C/sec

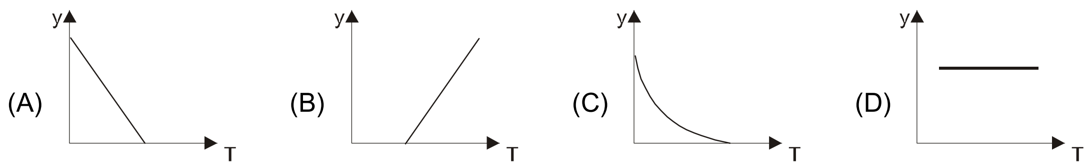
SECTION (D) : NEWTON'S LAW OF COOLING

D-1. Which of the law can be understood in terms of Stefan's law

(A) Wien's displacement law (B) Kirchoff's law

(C) Newton's law of cooling (D) Planck's law

D-2. A hot liquid is kept in a big room. Rate of cooling of liquid (represented as y) is plotted against its temperature T. Which of the following curves may represent the plot ?

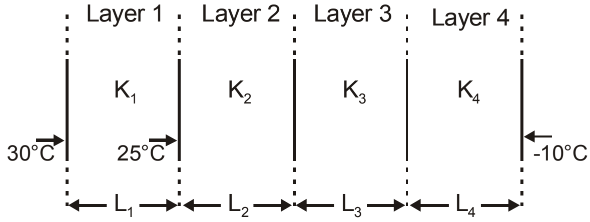


PART - II : MISCELLANEOUS OBJECTIVE QUESTIONS

Comprehensions Type :

Comprehension # 1

Figure shows in cross section a wall consisting of four layers with thermal conductivities K_1 = 0.06 W/mK; K_3 = 0.04 W/mK and K_4 = 0.10 W/mK. The layer thicknesses are L_1 = 1.5 cm ; L_3 = 2.8 cm and L_4 = 3.5 cm. The temperature of interfaces is as shown in figure. Energy transfer through the wall is steady.



1. The temperature of the interface between layers 3 and 4 is :
(A) – 1°C (B) – 3°C (C) 2°C (D) 0°C

2. The temperature of the interface between layers 2 and 3 is :
(A) 11°C (B) 8°C (C) 7.2°C (D) 5.4°C

3. If layer thickness L_2 is 1.4 cm, then its thermal conductivity K_2 will have value (in W/mK) :
(A) 2×10^{-2} (B) 2×10^{-3} (C) 4×10^{-2} (D) 4×10^{-3}

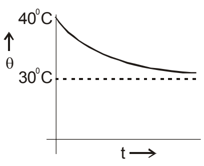
Comprehension # 2

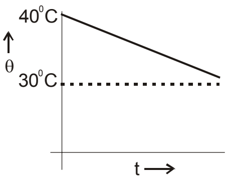
A body cools in a surrounding of constant temperature 30 ºC. Its heat capacity is 2J/ºC. Initial temperature of the body is 40ºC . Assume Newton's law of cooling is valid. The body cools to 38ºC in 10 minutes.

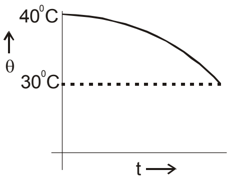
4. In further 10 minutes it will cool from 38ºC to :

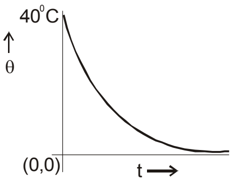
(A) 36ºC (B) 36.4ºC (C) 37ºC (D) 37.5ºC

5. The temperature of the body in ºC denoted by θ the variation of θ versus time t is best denoted as

(A)


(B)


(C)


(D)


6. When the body temperature has reached 38 ºC, it is heated again so that it reaches to 40ºC in 10 minutes .The total heat required from a heater by the body is:

(A) 3.6J (B) 0.364J (C) 8 J (D) 4 J

Assertion/Reason :

7. **STATEMENT-1 :** Two solid cylindrical rods of identical size and different thermal conductivities K_1 and K_2 are connected in series. Then the equivalent thermal conductivity of two rod system is less than the value of thermal conductivity of either rod.

STATEMENT-2 : For two cylindrical rods of identical size and different thermal conductivities K_1 and K_2 respectively connected in series, the equivalent thermal conductivity K is given by

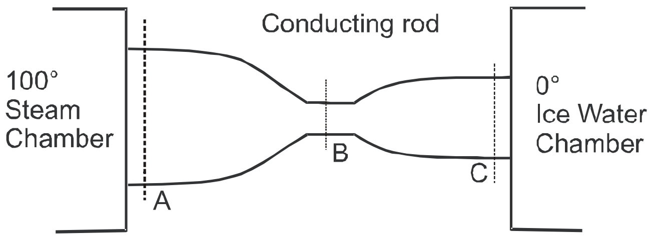
$$\frac{2}{K} = \frac{1}{K_1} + \frac{1}{K_2}$$

(A) Statement-1 is True, Statement-2 is True; Statement-2 **is** a correct explanation for Statement-1
(B) Statement-1 is True, Statement-2 is True; Statement-2 **is NOT** a correct explanation for Statement-1
(C) Statement-1 is True, Statement-2 is False
(D) Statement-1 is False, Statement-2 is True.

8. **STATEMENT-1 :** As the temperature of the blackbody increases, the wavelength at which the spectral intensity (E_λ) is maximum decreases.
STATEMENT-2 : The wavelength at which the spectral intensity will be maximum for a black body is proportional to the fourth power of its absolute temperature.
(A) Statement-1 is True, Statement-2 is True; Statement-2 **is** a correct explanation for Statement-1
(B) Statement-1 is True, Statement-2 is True; Statement-2 **is NOT** a correct explanation for Statement-1
(C) Statement-1 is True, Statement-2 is False
(D) Statement-1 is False, Statement-2 is True.

Match The Column :

9. A copper rod (initially at room temperature 20°C) of non-uniform cross section is placed between a steam chamber at 100°C and ice-water chamber at 0°C.



(A) Initially rate of heat flow $\left(\frac{dQ}{dt}\right)$ will be — (p) maximum at section A

(B) At steady state rate of heat flow $\left(\frac{dQ}{dt}\right)$ will be — (q) maximum at section B

(C) At steady state temperature gradient $\left|\left(\frac{dT}{dx}\right)\right|$ will be — (r) minimum at section A

(D) At steady state rate of change of temperature $\left(\frac{dT}{dt}\right)$ at a certain point will be — (s) minimum at section B

(t) same for all section

10. Match the statements in column-I with the statements in column-II.

Column-I	Column-II
(A) For a perfect black body	(p) Absorption of radiation occurs
(B) For a perfectly polished white body	(q) Emission of radiation occurs
(C) When radiation from air is incident on a perfectly transparent medium of greater refractive index	(r) Reflection of radiation will always occur
(D) When radiation moves from a transparent medium of greater refractive index to air	(s) Transmission (refraction) of radiation will always occur

(All conditions are for temperature T > 0 K.)

True / False :

11. State true / false

(i) Two spheres of the same material have radii 1 m and 4 m and temperatures 4000 K and 2000 K respectively. The energy radiated per second is same for both the spheres.

(ii) Increase in roughness of a body surface, increases its absorptivity.

(iii) Usually a black buffalo will have more emissive power than a white cow at the same temperature. (True)

Fill in the Blanks :

12. Fill in the blanks :

(i) It is known that the temperature in the room is +20 ^{0}C when the outdoor temperature is –20 ^{0}C, and +10 ^{0}C when the outdoor temperature is –40 ^{0}C. Assuming Newton's law of cooling to be valid, the temperature of the radiator in the room is ________.

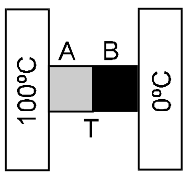
(ii) The absolute temperature of a blackbody is increased by 1%. The amount of radiation emitted by it increases by_____.

(iii) The earth receives at its surface radiation from the sun at the rate of 1400 Wm^{-2}. The distance of the centre of the sun from the surface of the earth is 1.5×10^{11} m and the radius of the sun is 7×10^8 m. Treating the sun as a black body, it follows from the above data that its surface temperature is .... K.

(iv) A point source of heat of power P is placed at the centre of a spherical shell of mean radius R. The material of the shell has thermal conductivity K. If the temperature difference between the outer and inner surface of the shell is not to exceed T, the thickness of the shell should not exceed ....

(v) A solid copper sphere (density ρ and specific heat c) of radius r at an initial temperature 200 K is suspended inside a chamber whose walls are at almost 0 K. The time required for the temperature of the sphere to drop to 100 K is .... (Assume sphere as a black body)

(vi) Two metal cubes A and B of same size are arranged as shown in figure. The extreme ends of the combination are maintained at the indicated temperatures. The arrangement is thermally insulated. The coefficient of thermal conductivity of A and B are 300 W/m° C and 200 W/m° C respectively. After steady state is reached the temperature T of the interface will be ______.



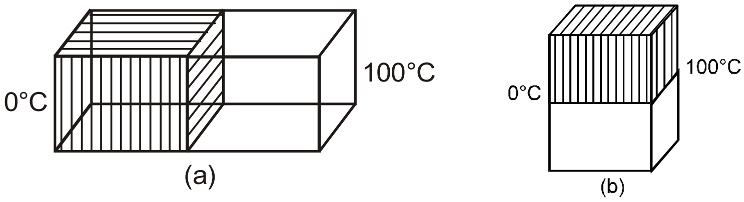
EXERCISE # 2

PART - I : MIXED OBJECTIVE

** Marked Questions are having more than one correct option.*

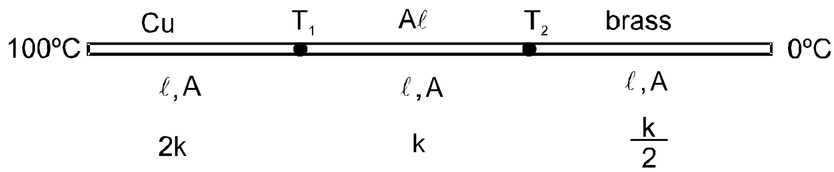
Single choice type :

1. Two identical square rods of metal are welded end to end as shown in figure (a). Assume that 10 cal of heat flows through the rods in 2 min. Now the rods are welded as shown in figure, (b). The time it would take for 10 cal to flow through the rods now, is



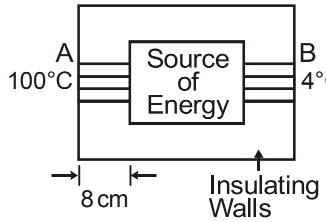
(A) 0.75 min (B) 0.5 min (C) 1.5 min (D) 1 min

2. Three metal rods made of copper, aluminium and brass, each 20 cm long and 4 cm in diameter, are placed end to end with aluminium between the other two. The free ends of copper and brass are maintained at 100 and 0°C respectively. Assume that the thermal conductivity of copper is twice that of aluminium and four times that of brass. The approximately equilibrium temperatures of the copper-aluminium and aluminium-brass junctions are respectively.



(A) 68 °C and 75 °C (B) 75 °C and 68 °C (C) 57 °C and 86 °C (D) 86 °C and 57 °C

3. A closed cubical box is made of a perfectly insulating material walls of thickness 8 cm and the only way for heat to enter or leave the box is through two solid metallic cylindrical plugs, each of cross-sectional area 12 cm^2 and length 8 cm, fixed in the opposite walls of the box. The outer surface A on one plug is maintained at 100°C while the outer surface B of the other plug is maintained at 4°C. The thermal conductivity of the material of each plug is 0.5 cal/°C/cm. A source of energy generating 36 cal/s is enclosed inside the box. Assuming the temperature to be the same at all points on the inner surface, the equilibrium temperature of the inner surface of the box is



(A) 62 °C (B) 46 °C (C) 76 °C (D) 52 °C

4. Two models of a windowpane are made. In one model, two identical glass panes of thickness 3 mm are separated with an air gap of 3 mm. This composite system is fixed in the window of a room. The other model consists of a single glass pane of thickness 6 mm, the temperature difference being the same as for the first model. The ratio of the heat flow for the double pane to that for the single pane is ($K_{glass} = 2.5 \times 10^{-4}$ cal/s.m. °C and $K_{air} = 6.2 \times 10^{-6}$ cal/s.m.°C)

(A) 1/20 (B) 1/70 (C) 31/1312 (D) 31/656

5. A spherical solid black body of radius 'r' radiates power 'H' and its rate of cooling is 'C'. If density is constant then which of the following is/are true.

(A) $H \propto r$ and $c \propto r^2$ (B) $H \propto r^2$ and $c \propto \frac{1}{r}$ (C) $H \propto r$ and $c \propto \frac{1}{r^2}$ (D) $H \propto r^2$ and $c \propto r^2$

More than one choice type

6.* Two bodies A and B have thermal emissivities of 0.01 and 0.81 respectively. The surface areas of the two bodies are the same. The two bodies emit total radiant power at the same rate. The wavelength λ_B corresponding to maximum spectral radiancy in the radiation from B is shifted from the wavelength corresponding to maximum spectral radiancy in the radiation from A by 1.00 μm. If the temperature of A is 5802 K,

(A) the temperature of B is 1934 K (B) $\lambda_B = 1.5\ \mu$m

(C) the temperature of B is 11604 K (D) the temperature of B is 2901 K

7.* The solar constant is the amount of heat energy received per second per unit area of a perfectly black surface placed at a mean distance of the Earth from the Sun, in the absence of Earth's atmosphere, the surface being held perpendicular to the direction of Sun's rays. Its value is 1388 W/m^2 .
If the solar constant for the earth is 's'. The surface temperature of the sun is TK. The sun subtends a small angle 'θ' at the earth. Then correct options is/are :–

(A) $s \propto T^2$ (B) $s \propto T^4$ (C) $s \propto \theta^2$ (D) $s \propto \theta$

8*. A heated body emits radiation which has maximum intensity at frequency ν_m. If the temperature of the body is doubled:

(A) the maximum intensity radiation will be at frequency 2 ν_m

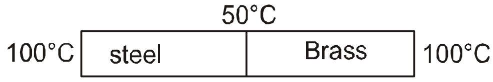
(B) the maximum intensity radiation will be at frequency ν_m.

(C) the total emitted power will increase by a factor 16

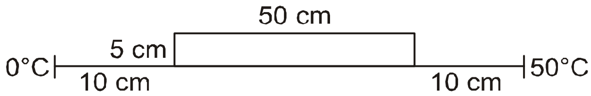
(D) the total emitted power will increase by a factor 2.

PART - II : SUBJECTIVE QUESTIONS

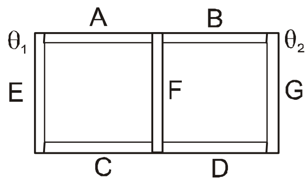
1. Figure shows a steel rod joined to a brass rod. Each of the rods has length of 31 cm and area of cross-section 0.20 cm^2. The junction is maintained at a constant temperature 50°C and the two ends are maintained at 100°C. Calculate the amount of heat taken out from the cold junction in 10 minutes after the steady state is reached. The thermal conductivities are K_{steel} = 46 W/m–°C and K_{brass} = 109 W/m–°C.



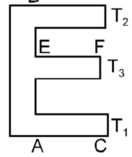
2. Consider the situation shown in figure. The frame is made of the same material and has a uniform cross-sectional area everywhere. If amount of heat flowing per second through a cross-section of the bent part is 60 J. Calculate the amount of total heat taken out per second from the end at 50°C.



3. Seven rods A, B, C, D, E, F and G are joined as shown in figure. All the rods have equal cross-sectional area A and length l. The thermal conductivities of the rods are $K_A = 2K_C = 3K_B = 6K_D = K_0$. The rod E is kept at a constant temperature θ_1 and the rod G is kept at a constant temperature $\theta_2(\theta_2 > \theta_1)$. (a) Show that the rod F has a uniform temperature $\theta = (3\theta_1 + \theta_2)/4$. (b) Find the rate of heat flow from the source which maintains the temperature θ_2.

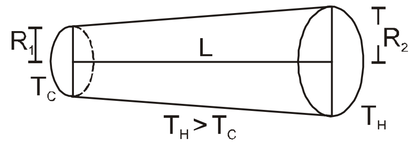


4. Four thin identical rods AB, AC, BD and EF made of the same material are joined as shown. The free-ends C, D and F are maintained at temperatures T_1, T_2 and T_3 respectively. Assuming that there is no loss of heat to the surroundings, find the temperature at joint E when the steady state is attained.

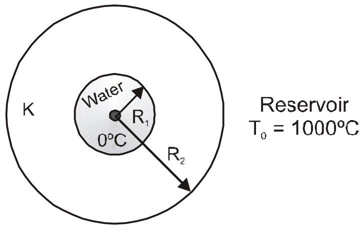


5. One end of copper rod of uniform cross-section and of length 1.45 m is in contact with ice at 0ºC and the other end with water at 100°C. Find the position of point along its length where a temperature of 200°C should be maintained so that in steady state the mass of ice melting is equal to that of steam produced in the same interval of time [Assume that the whole system is insulated from surroundings]. (take L_v = 540 cal/g L_f = 80 cal/g)

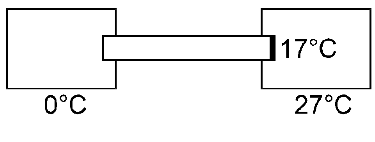
6. Find the rate of heat flow through a cross-section of the rod shown in figure ($T_H > T_C$). Thermal conductivity of the material of the rod is K.



7. A hollow spherical conducting shell of inner radius $R_1 = 0.25$ m and outer radius $R_2 = 0.50$ m is placed inside a heat reservoir of temperature T_0 = 1000 ºC. The shell is initially filled with water at 0ºC. The thermal conductivity of the material is $k = \frac{10^2}{4\pi}$ W/m-K and its heat capacity is negligible. Find the time required to raise the temperature of water to 100ºC. Take specific heat of water s = 4.2 kJ/kg.°C , density of water $d_w = 1000$ kg/m³ , $\pi = \frac{22}{7}$



8. A cylindrical rod of length 1 m is fitted between a large ice chamber at 0°C and an evacuated chamber maintained at 27°C as shown in figure. Only small portions of the rod are inside the chambers and the rest is thermally insulated from the surrounding. The cross-section going into the evacuated chamber is blackened so that it completely absorbs any radiation falling on it. The temperature of the blackened end is 17°C when steady state is reached. Stefan constant $\sigma = 6 \times 10^{-8}$ W/m²–K⁴. Find the thermal conductivity of the material of the rod. ($29^4 = 707281$)



9. A spherical tungsten piece of radius 1.0 cm is suspended in an evacuated chamber maintained at 300 K. The piece is maintained at 1000 K by heating it electrically. Find the rate at which the electrical energy must be supplied. The emissivity of tungsten is 0.30 and the stefan constant σ is 6.0×10^{-8} W/m²–K⁴.

10. A solid aluminium sphere and a solid copper sphere of twice the radius of aluminium are heated to the same temperature and are allowed to cool under identical surrounding temperatures. Assume that the emissivity of both the sphere is the same. Find the initial ratio of (a) the rate of heat loss from the aluminium sphere to the rate of heat loss from the copper sphere and (b) the rate of fall of temperature of the aluminium sphere to the rate of fall of temperature of the copper sphere. The specific heat capacity of aluminium = 900 J/kg–°C and that of copper = 390 J/kg–°C. The density of copper = 3.4 times the density of aluminium.

11. A hot body placed in a surrounding of temperature T_0. Its temperature at t = 0 is T_1. The specific heat capacity of the body is s and its mass is m. Assuming Newton's law of cooling to be valid, find (a) the maximum heat that the body can lose and (b) the time starting from t = 0 in which it will lose 50% of this maximum heat.

12. Find the total time elapsed for a hollow copper sphere of inner radius 3 cm outer radius 6 cm, density $\rho = 9 \times 10^3$ kg/m^3, specific heat $s = 4 \times 10^3$ J/kg K and emissivity e = 0.4 to cool from 727°C to 227°C when the surrounding temperature is 0 K.(for inner surface e = 1 Stefan's constant $\sigma = 5.6 \times 10^{-8}$ W/m^2 K^4)

13. A metal ball of mass 2 kg is heated by means of a 40 W heater in a room at 25°C. The temperature of the ball becomes steady at 60°C. (a) Find the rate of loss of heat to the surrounding when the ball is at 60°C. (b) Assuming Newton's law of cooling, calculate the rate of loss of heat to the surrounding when the ball is at 39°C. (c) Assume that the temperature of the ball rises uniformly from 25°C to 39°C in 2 minutes. Find the total loss of heat to the surrounding during this period. (d) Calculate the specific heat capacity of the metal.

14. A metal block of heat capacity 90 J/°C placed in a room at 25°C is heated electrically. The heater is switched off when the temperature reaches 35°C. The temperature of the block rises at the rate of 2°C/s just after the heater is switched on and falls at the rate of 0.2 °C/s just after the heater is switched off. Assume Newton's law of cooling to hold. (a) Find the power of the heater. (b) Find the power radiated by the block just after the heater is switched off. (c) Find the power radiated by the block when the temperature of the block is 30°C. (d) Assuming that the power radiated at 30°C respresents the average value in the heating process, find the time for which the heater was kept on.

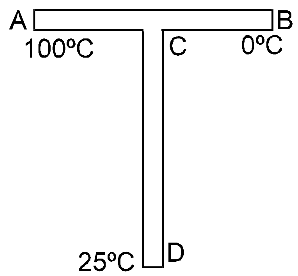
15. A hollow metallic sphere of radius 20 cm surrounds a concentric metallic sphere of radius 5 cm. The space between the two spheres is filled with a nonmetallic material. The inner and outer spheres are maintained at 50°C and 10°C respectively and it is found that 160 π Joule of heat passes from the inner sphere to the outer sphere per second. Find the thermal conductivity of the material between the spheres.

16. A hollow tube has a length *l*, inner radius R_1 and outer radius R_2. The material has thermal conductivity K. Find the heat flowing through the walls of the tube per second if the inside of the tube is maintained at temperature T_1 and the outside is maintained at T_2 [assume $T_2 > T_1$]

17. A uniform slab of dimension 10cm × 10cm × 1cm is kept between two heat reservoirs at temperatures 10ºC and 90ºC. The larger surface areas touch the reservoirs. The thermal conductivity of the material is 0.80 W/m–ºC. Find the amount of heat flowing through the slab per second.

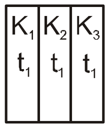
18. One end of a steel rod (K = 42 J/m–s–ºC) of length 1.0 m is kept in ice at 0ºC and the other end is kept in boiling water at 100ºC. The area of cross–section of the rod is 0.04cm^2. Assuming no heat loss to the atmosphere, find the mass of the ice melting per second. Latent heat of fusion of ice = 3.36×10^5 J/kg.

19. A rod CD of thermal resistance 5.0 K/W is joined at the middle of an identical rod AB as shown in figure. The ends A, B and D are maintained at 100ºC, 0ºC and 25ºC respectively. Find the heat current in CD.



20. A semicircular rod is joined at its ends to a straight rod of the same material and same cross-sectional area. The straight rod forms a diameter of the other rod. The junctions are maintained at different temperatures. Find the ratio of the heat transferred through a cross-section of the semicircular rod to the heat transferred through a cross-section of the straight rod in a given time.

21. Three slabs of same surface area but different conductivities k_1, k_2, k_3 and different thickness t_1, t_2, t_3 are placed in close contact. After steady state this combination behaves as a single slab. Find its effective thermal conductivity.



22. A metal rod of cross-sectional area 1.0 cm^2 is being heated at one end. At one time, the temperature gradient is 5.0°C/cm at cross-section A and is 2.6 °C/cm at cross-section B. Calculate the rate at which the temperature is increasing in the part AB of the rod. The heat capacity of the part AB = 0.40 J/°C, thermal conductivity of the material of the rod = 200 W/m–°C. Neglect any loss of heat to the atmosphere.

23. When q_1 joules of radiation is incident on a body it reflects and transmits total of q_2 joules. Find the emissivity of the body.

24. A blackbody of surface area 1 cm^2 is placed inside an enclosure. The enclosure has a constant temperature 27ºC and the blackbody is maintained at 327ºC by heating it electrically. What electric power is needed to maintain the temperature? $\sigma = 6.0 \times 10^{-8}$ W/m^2–K^4.

25. Estimate the temperature at which a body may appear blue or red. The values of λ_{mean} for these are 5000 and 7500 Å respectively. [Given Wein's constant b = 0.3 cm K]

26. The temperature of a hot liquid in a container of negligible heat capacity falls at the rate of 3 K/min due to heat emission to the surroundings, just before it begins to solidify. The temperature then remains constant for 30 min, by which time the liquid has all solidified. Find the ratio of specific heat capacity of liquid to specific latent heat of fusion.

27. A liquid cools from 70ºC to 60ºC in 5 minutes. Find the time in which it will further cool down to 50 ºC, if its surrounding is held at a constant temperature of 30ºC.

PART-I IIT-JEE (PREVIOUS YEARS PROBLEMS)

*** Marked Questions are having more than one correct option.**

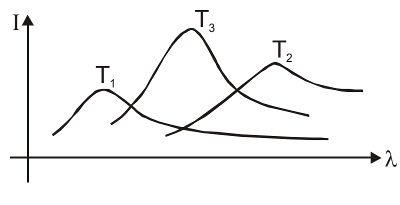
1. A double-pane window used for insulating a room thermally from outside consists of two glass sheets each of area 1 m^2 and thickness 0.01 m separated by a 0.05 m thick stagnant air space. In the steady state, the room-glass interface and the glass-outdoor interface are at constant temperatures of 27º C and 0º C respectively. Calculate the rate of heat flow through the window pane. Also find the temperatures of other interfaces. Given, thermal conductivities of glass and air as 0.8 and 0.08 $Wm^{-1} K^{-1}$ respectively. **[JEE '97, 5]**

2. A solid body X of heat capacity C is kept in an atmosphere whose temperature is T_A = 300 K. At time t = 0 the temperature of X is T_0 = 400 K. It cools according to Newton's law of cooling. At time t_1 the temperature is found to be 350 K. At this time (t_1), the body X is connected to a large box Y at atmospheric temperature T_A, through a conducting rod of length L, cross-sectional area A and thermal conductivity K. The heat capacity of Y is so large that any variation in its temperature may be neglected. The cross-Sectional area A of the connecting rod is small compared to the surface area of X. Find the temperature of X at time t = 3 t_1. **[JEE '98, 8]**

3. A black body is at a temperature of 2800 K. The energy of radiation emitted by this object with wavelength between 499 nm and 500 nm is U_1, between 999 nm and 1000 nm is U_2 and between 1499 nm and 1500 nm is U_3. The Wien constant b = 2.88 × 10^6 nm K. Then **[JEE 98, 2]**
(A) $U_1 = 0$ (B) $U_3 = 0$ (C) $U_1 > U_2$ (D) $U_2 > U_1$

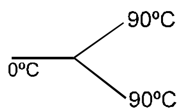
4. A composite body consists of two rectangular plates of the same dimensions but different thermal conductivities K_A and K_B. This body is used to transfer heat between two objects maintained at different temperatures. The composite body can be placed such that the flow of heat takes place either parallel to the interface or perpendicular to it. Calculate the effective thermal conductivities $K_{||}$ and $K_{\perp}$ of the composite body for the parallel and perpendicular orientations. Which orientation will have more thermal conductivity? **[REE 2000, 6]**

5. The plots of intensity vs. wavelength for three black bodies at temperatures T_1, T_2 and T_3 respectively are as shown. Their temperatures are such that-



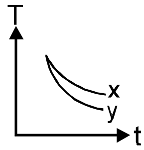
(A) $T_1 > T_2 > T_3$ (B) $T_1 > T_3 > T_2$ (C) $T_2 > T_3 > T_1$ (D) $T_3 > T_2 > T_1$

6. Three rods made of the same material and having the same cross-section have joined as shown in the fig. Each rod is of same length. The left and right ends are kept at 0°C and 90°C respectively. The temperature of the junction of the three rods will be : **[JEE (Scr.) 2001, 1/35]**



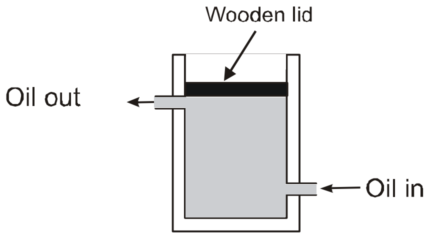
(A) 45°C (B) 60°C (C) 30°C (D) 20°C

7. The temperature of bodies X and Y vary with time as shown in the figure. If emissivity of bodies X and Y are e_X & e_Y and absorptive powers are A_X and A_Y, (assume other conditions are identical for both):then: **[JEE (Scr.) 2003, 3/84, –1]**



(A) $e_Y > e_X$, $A_Y > A_X$ (B) $e_Y < e_X$, $A_Y < A_X$
(C) $e_Y > e_X$, $A_Y < A_X$ (D) $e_Y < e_X$, $A_Y > A_X$

8. A container open at the top is made of a perfectly insulating material. A wooden lid of thickness 5×10^{-3} m closes the top tightly. Heated oil at temperature T is flowing continuously through the container as shown in the figure. The outer surface of the wooden lid attains a constant temperature of 127°C when the surroundings are at 27°C. Calculate **[JEE (Main) 2003' 2 + 2/60]**



(i) the radiation loss (in $Js^{-1}\,m^{-2}$) from the lid and

(ii) the temperature T (in °C) of the oil. The thermal conductivity and emissivity of wood are 0.149 $Wm^{-1}\,K^{-1}$ and 0.6 respectively. The value of the Stefan's constant

$\sigma = \frac{17}{3} \times 10^{-8}$ $Wm^{-2}\,K^{-4}$ (Neglect heat loss by convection and give answers correct to the nearest whole number).

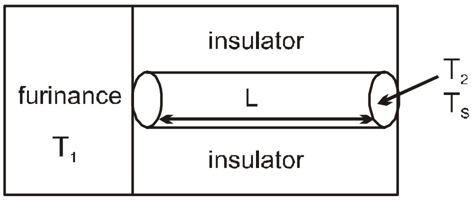
9. Two containers, one is having ice at 0°C and other containing boiling water at 100°C are connected by two identical rods. When rods are in parallel the rate of heat transfer is Q_1 and when rods are in series, the rate of heat transfer is Q_2. Then Q_2/Q_1 will be : **[JEE(Scr.) 2004' 3/84, –1]**

(A) 2 : 1 (B) 1 : 2 (C) 4 : 1 (D) 1 : 4

10. Three discs of same material A, B, C of radii 2 cm, 4 cm and 6 cm respectively are coated with carbon black. Their wavelengths corresponding to maximum spectral radiancy are 300, 400 and 500 nm respectively then maximum power will be emitted by **[JEE(Scr.) 2004' 3/84, –1]**

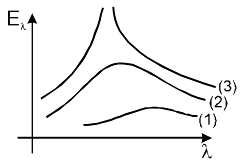
(A) A (B) B (C) C (D) same for all

11. One end of a rod of length L and cross-sectional area A is kept in a furnace of temperature T_1. The other end of the rod is kept at a temperature T_2. The thermal conductivity of the material of the rod is K and emissivity of the rod is e. It is given that $T_2 = T_s + \Delta T$, where $\Delta T << T_S$, T_s being the temperature of the surrounding. If $\Delta T \propto (T_1 - T_S)$, find the proportionality constant. Consider that heat is lost only by radiation at the end where the temperature of the rod is T_2. **[JEE (Main) 2004 ; 4/60 marks]**



12. Three graphs marked as 1, 2, 3 representing the variation of maximum emissive power and wavelength of radiation of the sun, a welding arc and a tungsten filament. Which of the following combination is correct

[JEE(Scr.)-2005, 3/84, –1]



(A) 1- bulb, 2 $\rightarrow$ welding arc, 3 $\rightarrow$ sun
(B) 2- bulb, 3 $\rightarrow$ welding arc, 1 $\rightarrow$ sun
(C) 3- bulb, 1 $\rightarrow$ welding arc, 2 $\rightarrow$ sun
(D) 2- bulb, 1 $\rightarrow$ welding arc, 3 $\rightarrow$ sun

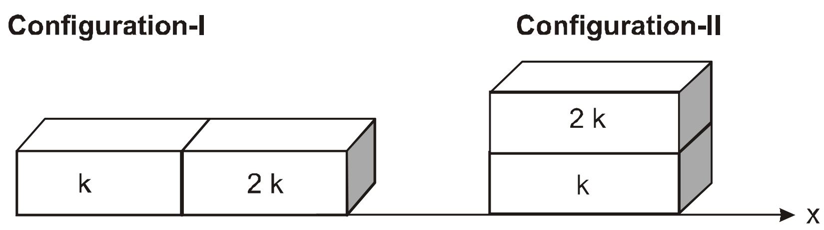
13. In which of the following phenomenon heat convection does not take place **[JEE (Scr.) 2005, 3/84 , –1]**

(A) land and sea breeze
(B) boiling of water
(C) heating of glass surface due to filament of the bulb
(D) air around the furnace

14. A metal rod AB of length 10 *x* has its one end A in ice at 0ºC and the other end B in water at 100ºC. If a point P on the rod is maintained at 400ºC, then it is found that equal amounts of water and ice evaporate and melt per unit time. The latent heat of evaporation of water is 540 cal/g and latent heat of melting of ice is 80 cal/g. If the point P is at a distance of λx from the ice end A, find the value of λ. [Neglect any heat loss to the surrounding] **[JEE, 2009, 4,/160, –1]**

15. Two spherical bodies A (radius 6 cm) and B (radius 18 cm) are at temperature T_1 and T_2 respectively. The maximum intensity in the emission spectrum of A is at 500 nm and in that of B is at 1500 nm. Considering them to be black bodies, what will be the ratio of the rate of total energy radiated by A to that of B ? **[JEE, 2010, 3,/163]**

16. Two rectangular blocks, having identical dimensions, can be arranged either in configuration I or in configuration II as shown in the figure. One of the blocks has thermal conductivity k and the other 2k. The temperature difference between the ends along the x-axis is the same in both the configuration. It takes 9 s to transport a certain amount of heat from the hot end to the cold end in the configuration I. The time to transport the same amount of heat in the configuration II is : **[JEE Advanced 2013]**



(A) 2.0 s (B) 3.0 s (C) 4.5 s (D) 6.0 s

PART-II AIEEE (PREVIOUS YEARS PROBLEMS)

1. Infrared radiations are detected by **[AIEEE-2002, 4/300]**

(1) spectrometer (2) pyrometer (3) nanometer (4) photometer

2. Which of the following is more close to a black body ? **[AIEEE-2002, 4/300]**

(1) Black board paint (2) Green leaves

(3) Black holes (4) Red roses

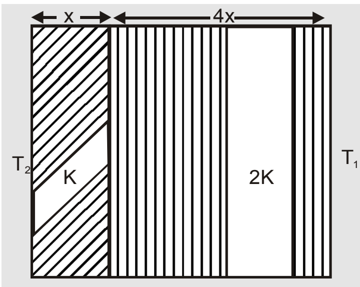
3. Which of the following radiations has the least wavelength ? **[AIEEE-2003, 4/300]**

(1) γ-rays (2) β-rays (3) α-rays (4) X-rays

4. If the termpreature of the sun were to increase from T to 2T and its radius from R to 2R, then the ratio of the radiant energy received on earth to what it was previously will be- **[AIEEE-2004, 4/300]**

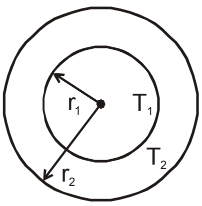
(1) 4 (2) 16 (3) 32 (4) 64

5. The temperature of the two outer surfaces of a composite slab, consisting of two materials K and 2K and thickness x and 4x, respectively, and T_2 and T_1($T_2 > T_1$). The rate of heat transfer through the slab, in a steady state is $\left(\frac{A(T_2 - T_1)K}{x}\right)f$ with f equal to– **[AIEEE-2004, 4/300]**



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

6. The figure shows a system of two concentric spheres of radii r_1 and r_2 and kept at temperature T_1 and T_2, respectively. The radical rate of flow of heat in a substance between the two concentric spheres is proportional to : **[AIEEE-2005, 4/300]**

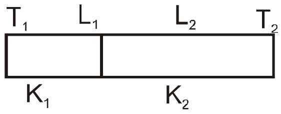


(1) $\frac{(r_2 - r_1)}{(r_1 r_2)}$ (2) $\ln\frac{(r_2)}{(r_1)}$ (3) $\frac{r_1 r_2}{(r_2 - r_1)}$ (4) $(r_2 - r_1)$

7. Assuming the sun to be a spherical body of radius R at a temperature of T K, evaluate the total radiant power, incident on Earth, at a distance r from the Sun. (earth radius = r_0) **[AIEEE-2006; 3/180]**

(1) $\frac{R^2\sigma T^4}{r^2}$ (2) $\frac{4\pi r_0^2 R^2\sigma T^4}{r^2}$ (3) $\frac{\pi r_0^2 R^2\sigma T^4}{r^2}$ (4) $\frac{r_0^2 R^2\sigma T^4}{4\pi r^2}$

8. One end of a thermally insulated rod is kept at a temperature T_1 and the other at T_2. The rod is composed of two sections of lengths L_1 and L_2 and thermal conductivities k_1 and k_2 respectively. The temperature at the interface of the sections is

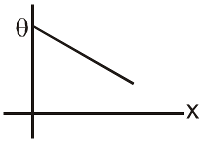


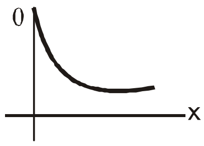
[AIEEE-2007; 3/120]

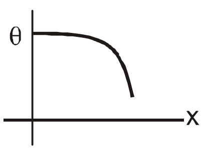
(1) $\frac{(K_2L_2T_1 + K_1L_1T_2)}{(K_1L_1 + K_2L_2)}$ (2) $\frac{(K_2L_1T_1 + K_1L_2T_2)}{(K_2L_1 + K_1L_2)}$

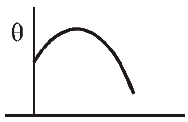
(3) $\frac{(K_1L_2T_1 + K_2L_1T_2)}{(K_1L_2 + K_2L_1)}$ (4) $\frac{(K_1L_1T_1 + K_2L_2T_2)}{(K_1L_1 + K_2L_2)}$

9. A long metallic bar is carrying heat from one of its ends to the other end under steady-state. The variation of temperature θ along the length x of the bar from its hot end is best described by which of the following figures **[AIEEE-2009, 4/144]**

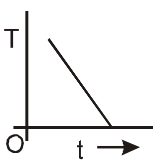
(1)


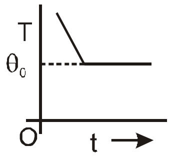
(2)


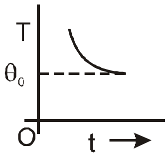
(3)


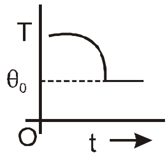
(4)


10. If a piece of metal is heated to temperature θ and then allowed to cool in a room which is at temperature θ_0, the graph between the temperature T of the metal and time t will be closest to : **[JEE Mains 2013]**

(1)


(2)


(3)


(4)


EXERCISE # 4

NCERT QUESTIONS

1. A 'thermacole' icebox is a cheap and efficient method for storing small quantities of cooked food in summer in particular. A cubical icebox of side 30 cm has a thickness of 5.0 cm. If 4.0 kg of ice is put in the box, estimate the amount of ice remaining after 6 h. The outside temperature is 45 oC, and co-efficient of thermal conductivity of thermacole is 0.01 J s^{-1} m^{-1} $^oC^{-1}$. [Heat of fusion of water = 335 x 103 J kg^{-1}].

2. A brass boiler has a base area of 0.15 m^2 and thickness 1.0 cm. It boils water at the rate of 6.0 kg/min when placed on a gas stove. Estimate the temperature of the part of the flame in contact with the boiler. Thermal conductivity of brass = 109 J s^{-1} m^{-1} $^oC^{-1}$. [Heat of vaporization of water = 2256 x 10^3 J kg^{-1}].

3. Explain why :
(a) a body with large reflectivity is a poor emitter
(b) a brass tumbler feels much colder that a wooden tray on a chilly day
(c) an optical pyrometer (for measuring high temperatures) calibrated for an ideal black body radiation gives too low a value for the temperature of a red hot iron piece in the open, but gives a correct value for the temperature when the same piece is in the furnace
(d) the earth without its atmosphere would be inhospitably cold
(e) heating systems based on circulation of steam are more efficient in warming a building than those based on circulation of hot water

4. A body cools from 80 ^oC to 50 ^oC in 5 minutes. Calculate the time it takes to cool from 60 ^oC to 30 ^oC. The temperature of the surroundings is 20 ^oC.

5. The triple points of neon and carbon dioxide are 24.57 K and 216.55 K respectively Express these temperatures on the Celsius and Fahrenheit scales.

6. Two absolute scale *A* and *B* have triple points of water defined ot be 200 A and 350 B. What is the relation betwwen T_A and T_B ?

7. The electrical resistance in ohms of acertain thermometer varies with temperature according to the approximate law : $R = R_o [1 + 5 \times 10^{-3} (T - T_o)]$
The resistance is 101.6 W at the triple-point of water, and 165.5 W at the normalmelting point of lead (600.5 K). What is the temperature when the resistance is 123.4 W ?

8. Answer the following :
(a) The trople- point of water is a standard fixed point in modern thermometry. Why ? What is wrong intaking the melting point of ice and the boiling point of water as standard fixed points (as was originally done inthe Celsius scale)?
(b) There were two fixed point in the original Celsius scale as mentioned above which were *assigned* the number 0 ^oC and 100 ^oC respectively. On the absolute scale, one of the fixed points is the triple-point of water, which on the kelvin absolute scale is assigned the number 273.16 K. What is the other fixed point on this (Kelvin) scale ?
(c) The absolute temperature (Kelvin scale) *T* is related to the temperature t_c on the Celsius scale by

$$t_c = T - 273.15$$

Why do we have 273.15 in this relation, and not 273.16 ?
(d) What is thetemperature of the triple-point of water on an absolute scale whose unit interval size is equal to that of Fahrenheit scale ?

9. Two ideal gas thermometers *A* and *B* use oxygen and hydrogen respectively. The follwing observations are made :

Temperature	**Pressure thermometer A**	**Pressure thermometer B**
Triple-point of water	1.250 105 Pa	0.200 105 Pa
Normal melting point of sulphur	1.797 105 Pa	0.287 105 Pa

(a) What is the absolute temperature of normal melting point of sulphur as read by thermometers *A* and *B* ?
(b) What do you think is the reason for the slightly different answers from *A* and *B* ? (The thermometers are not faulty). What further procedure is needed in the experiment to reduce the discrepancy between the two readings?

10. A steel tape 1 m long is correctly calibrated for a temperature of 27.0 °C. The length of a steel rod measured by this tape is found to be 63.0 cm on a hot day when the temperature is 45.0 °C. What is the actual length of the steel rod on that day ? What is the length of the same steel rod on a day when the temperature is 27.0 °C ? Coefficient of linear expansion of steel = 1.20×10^{-5} $°C^{-1}$.

11. A hole is drilled in a copper sheet. The diameter of the hole is 4.24 cm at 27.0 ºC. What is the change in the diameter of the hole when the sheet is heated to 227 ºC? Coefficient of linear expansion of copper =1.77×10^{-5} $^{o}K^{-1}$.

12. A brass wire 1.8 m long at 27 ºC is held taut with little tension between two rigid supports. If the wire is cooled to a temperature of -39 ºC, what is the tension developed in the wire, if its diameter is 2.0 mm ? Co - efficient of linear expansion of brass = 2.0×10^{-5} $^{o}C^{-1}$; Young's modulus of brass = 0.91×10^{11} Pa.

13. A brass or d of length 50 cm and diameter 3.0 mm is joined to a steel rod of the same length and diameter. What is the change in length of the combined rod at 250 ºC, if the original lengths are at 40.0 ºC? Is there a 'thermal stress' developed at the junction ? The ends of the rod are free to expand (Co-efficient of linear expansion of brass = 2.0 x 10-5 $^{o}C^{-1}$, steel = 1.2×10^{-5} $^{o}C^{-1}$).

14. The coefficient of volume expansion of glycerin is 49×10^{-5} $^{o}C^{-1}$. What is the fractional change in its density for a 30 ºC rise in temperature ?

15. A 10 kW drilling machine is used to drill a bore in a small aluminium block of mass 8.0 kg. How much is the rise in temperature of the block in 2.5 minutes, assuming 50% of power is used up in heating the machine itself or lost to the surroundings. Specific heat of aluminium = 0.91 J g^{-1} $^{o}C^{-1}$.

16. A copper block of mass 2.5 kg is heated in a furnace to a temperature of 500 ºC and then placed on a large ice block. What is the maximum amount of ice the can melt ? (Specific heat of copper = 0.39 J g^{-1o} C^{-1}; heat of fusion of water = 335 J g^{-1}).

17. In an experiment on the specific heat of a metal, a 0.20 kg block of the metal at 150 ºC is dropped in a copper calorimeter (of water equivalent 0.025 kg) containing 150 cm^3 of water at 27 ºC. The final temperature is 40 ºC. Compute the specific heat of the metal. If heat losses to the surroundings are not negligible, is your answer greater of smaller than the actual value for specific heat of the metal ?

18. In an experiment, the specific heats of some inert gases (at ordinary temperatures are measured to be as follows :
Try to discover a regularity in the data and explain it on the basis of kinetic theory.

19. Given below are observations on molar specific heats at room temperature of some common gases.

Gas	Molar specific heat (C_v) (cal mol^{-1} K^{-1})
Hydrogen	4.87
Nitrogen	4.97
Oxygen	5.02
Nitric oxide	4.99
Carbon monoxide	5.01
Chlorine	6.17

The measured molar specific heats of these gases are markedly different from those for monatomic gases. [Typically, molar specific heat of a monatomic gas is 2.92 cal/mol K, as you must have worked out in 12.16.] Explain this difference. What can you infer from the somewhat larger (then the rest) value for chlorine ?

20. Answer the following questions bases on the *P–T* phase diagram of carbon dioxide [Fig. 12.11 (b)] :

(a) At what temperature and pressure can the solid, liquid and vapour phases of CO_2 co-exist in equilibrium ?

(b) What is the effect of decrease of pressure on the fusion and boiling point of CO_2 ?

(c) What are the critical temperature and pressure for CO_2 ? What is their significance ?

(d) Is CO_2 solid, liquid or gas at (a) –70 °C under 1 atm, (b) –60 °C under 10 atm, (c) 15 °C under 56 atm ?

21. Answer the following questions based on the *P–T* phase diagram of CO_2 [Fig. 12.11 (b)] :

(a) CO_2 at 1 atm pressure and temperature –60 °C is compressed isothermally. Does it go through a liquid phase ?

(b) What happens when CO_2 at 4 atm pressure is cooled from room temperature at constant pressure ?

(c) Describe qualitatively the changes in a give mass of solid CO_2 at 10 atm pressure and temperature –65 °C as it is heated up to room temperature at constant pressure.

(d) CO_2 is heated to a temperature 70 °C and compressed isothermally. What changes in its properties do you expect to observe ?

22. A child running a temperature of 101 °F is given an antipyrin (i.e. a medicine that lowers fever) which causes an increase in the rate of evaporation of sweat from his body. If the fever is brought down to 98 °F in 20 min, what is the average rate of extra evaporation causes, by the drug. Assume the evaporation mechanism to be the only way by which heat is lost. The mass of the child is 30 kg. The specific heat of human body is approximately the same as that of water, and latent heat of evaporation of water at that temperature is about 580 cal g^{-1}.

ANSWERS

Exercise # 1

PART-I

A-1. (B) **A-2.** (A) **A-3.** (B) **A-4.** (C) **A-5.** (C) **B-1.** (C) **C-1*.** (ABC)

C-2*. (AB) **C-3.** (B) **D-1.** (C) **D-2.** (B)

PART-II

1. (B) **2.** (A) **3.** (A) **4.** (B) **5.** (A) **6.** (C) **7.** (D)

8. (C) **9.** (A) – p, s ; (B) – t ; (C) – q , r ; (D) – t **10.** (A) – p, q ; (B) – r ; (C) – s ; (D) – r

11. True **12.** **(i) 60 ^{0}C** **(ii) 4%** **(iii) 5803** **(iv)** $\frac{4\pi KTR^2}{P}$ **(v)** 1.71 ρrc **(vi) 60°C**

Exercise # 2

PART-I

1. (B) **2.** (D) **3.** (C) **4.** (D) **5.** (B) **6.*** (AB) **7.*** (BC)

8.* (AC)

PART-II

1. 300 J **2.** 132 J **3.** **(b)** $\frac{3K_0A(\theta_2-\theta_1)}{8l}$ **4.** $\frac{1}{7}(2T_1+2T_2+3T_3)$

5. 10 cm from the end in contact with water at 100°C **6.** $\frac{K\pi R_1R_2(T_H-T_C)}{L}$ **7.** $5500\ \ell n\ \frac{10}{9}$

8. 3.6 W/m–°C **9.** 22 W **10.** (a) 1 : 4 (b) 2.9 : 1 **11.** (a) $ms(T_1-T_0)$ (b) $\frac{\ln\ 2}{k}$

12. 6.56×10^4 sec **13.** (a) 40 W (b) 16W (c) 960 J (d) 137.1 J/kg–K

14. (a) 180 W (b) 18 W (c) 9 W (d) $\frac{100}{19}$ s **15.** 15 W/m–°C

16. $\frac{2\pi K\ell(T_2-T_1)}{\ln(R_2/R_1)}$ **17.** 64 J **18.** 5×10^{-5} g/s **19.** 4.0 W **20.** 2 : π **21.** $\frac{t_1+t_2+t_3}{\frac{t_1}{k_1}+\frac{t_2}{k_2}+\frac{t_3}{k_3}}$

22. 12 °C/s **23.** $\frac{q_1-q_2}{q_1}$ **24.** 0.73 W. **25.** 6×10^3 K; 4×10^3 K **26.** $\frac{1}{90}$ **27.** 7 minutes.

Exercise # 3

PART-I

1. 41.5 W , $\theta_1 = 26.48^\circ C$, $\theta_2 = 0.52^\circ C$

2. $T_2 = 300 + 50 \exp.\left[-2\ell n 2 - \frac{2kAt_1}{LC}\right]$

3. (D)

4. $K_\perp = \frac{2K_AK_B}{K_A + K_B}$ $K_\parallel = \left(\frac{K_A + K_B}{2}\right)$

5. (B)

6. (B) **7.** (A) **8.** 595 $Js^{-1} m^{-2}$, 147 °C. **9.** (D) **10.** (B)

11. Required proportionality constant = $\left(\frac{4e\sigma\ell T_s^3}{K} + 1\right)^{-1}$

12. (A) **13.** (C)

14. $\lambda = 9$ **15.** 9 **16.** (A)

PART-II

1. (2) **2.** (1) **3.** (1) **4.** (4) **5.** (4) **6.** (3) **7.** (3)

8. (3) **9.** (1) **18.** (3)

Exercise # 4

1. 3.7 kg.

2. 238 °C

4. 10 min

5. Neon : –248.58 °C = –415.44 °F;
CO_2 : –56.60 °C = –69.88 °F
(use t_F=+32)

6. $T_A = (4 / 7)\ T_B$

7. 384.8 K

8. (a) Triple- point has a *unique* temperature; fusion point and boiling point temperatures depend on pressure; (b) The other fixed point is the absolute zero itself; (c) Triple-point is 0.01 °C; (d) 491.69.

9. (a) T_A = 392.69 K, T_B = 391.98 K; (b) The discrepancy arises because the gases are not perfectly ideal. To reduce the discrepancy, readings should be taken for lower and lower pressure and the plot between temperature measured versus absolute pressure of the gas at triple point should be extrapolated to obtain temperature in the limit pressure tends to zero, when the gases approach ideal gas behavior.

10. Actual length of the rod at 45.0 °C = 63.0 + 0.0136 = 63.0136 cm. (However, we should say that change in length up to three significant figures is 0.0136 cm, but the total length is 63.0 cm, up to three significant places. Length of the same rod at 27.0 °C = 63.0 cm.

11. The diameter increases by an amount == 1.44 x 10-2 cm.

12. 3.8×10^2 N

13. Since the ends of the combined rod are not clamped, each rod expands freely.
$\Delta\ell_{brass}$ = 0.21 cm, $\Delta\ell_{steel}$ = 0.126 cm = 0.13 cm
Total change in length = .034 cm. No 'thermal stress' is developed at the junction since the rods freely expand.

14. 0.0147 = 1.5×10^{-2}.

15. 103 °C

16. 1.5 kg

17. 0.43 J g^{-1} K^{-1} ; smaller

18. The product of atomic mass and specific heat (molar specific heat) of monatomic gases nearly equals (3/2) R, as predicted by kinetic theory. See Chapter 11.

19. The gases are diatomic, and have other degrees of freedom (i.e. have other modes of motion) possible besides the translational degrees of freedom. To raise the temperature of the gas by a certain amount, heat is to be supplied to increase the average energy of all the modes. Consequently, molar specific heat of diatomic gases is more that to monatomic gases. It can be shown that if only rotational modes of motion are considered, the molar specific heat of diatomic gases is nearly (5/2) R which agrees with the observations for all the gases listed in the table, except chlorine. The higher value of molar specific heat of chlorine indicates that besides rotational modes, vibrational modes are also present in chlorine at room temperature. See Chapter 11.

20. (a) At the triple point temperature = –56.6 °C and pressure = 5.11 atm.
(b) Both the boiling point and freezing point of CO_2 decrease if pressure decreases.
(c) The critical temperature and pressure of CO_2 are 31.1 °C and 73.0 atm respectively. Above this temperature, CO_2 will not liquefy even if compressed to high pressures.
(d) (a) vapour ; (b) solid ; (c) liquid.

21. (a) No, vapour condenses to solid directly.
(b) It condenses to solid directly without passing through the liquid phase.
(c) It turns to liquid phase and then to vapour phase. The fusion and boiling points are where the horizontal line on *P-T* diagram at the constant pressure of 10 atm intersects the fusion and vaporization curves.
(d) It will not exhibit any clear transition to the liquid phase, but will depart more and more from ideal gas behavior as its pressure increases.

22. 4.3 g / min.