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STUDY PACKAGE

Subject : PHYSICS

Topic : CALORIMETRY & HEAT TRANSFER

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THERMAL EXPANSION

Definition of Heat :

Heat is a form of energy which is transferred between a system and its surrounding as a result of temperature difference only.

Thermal Expansion : Expansion due to increase in temperature.

1. Type of thermal expansion

	Coefficient of expansion	**For temperature change Δt change in**
(i) Linear	$\alpha = \lim\limits_{\Delta t \to 0} \frac{1}{l_0} \frac{\Delta l}{\Delta t}$	length $\Delta l = l_0 \, \alpha \, \Delta t$
(ii) Superficial	$\beta = \lim\limits_{\Delta t \to 0} \frac{1}{A_0} \frac{\Delta A}{\Delta t}$	Area $\Delta A = A_0 \beta \Delta t$
(iii) Volume	$\gamma = \lim\limits_{\Delta t \to 0} \frac{1}{V_0} \frac{\Delta V}{\Delta t}$	volume $\Delta V = V_0 \gamma \Delta t$

(a) For isotropic solids $\alpha_1 = \alpha_2 = \alpha_3 = \alpha$ (let)
so $\beta = 2\alpha$ and $\gamma = 3\alpha$

(b) For anisotropic solids $\beta = \alpha_1 + \alpha_2$ and $\gamma = \alpha_1 + \alpha_2 + \alpha_3$
Here α_1 , α_2 and α_3 are coefficient of linear expansion in X , Y and Z directions.

2. ***Variation in density :*** With increase of temperature volume increases so density decreases and vice-versa.

$$d = \frac{d_0}{(1 + \gamma \Delta t)}$$

For solids values of γ are generally small so we can write $d = d_0 (1 - \gamma \Delta t)$ (using bimomial expansion)

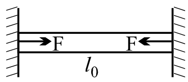
Note :

(i) γ for liquids are in order of 10^{-3}

(ii) For water density increases from 0 to 4°C so γ is –ve (0 to 4° C) and for 4° C to higher temperature γ is +ve. At 4° C density is maximum.

3. ***Thermal Stress :*** A rod of length l_0 is clamped between two fixed walls with distance l_0. If temperature is changed by amount Δt then

stress $= \frac{F}{A}$ (area assumed to be constant)



strain $= \frac{\Delta l}{l_0}$

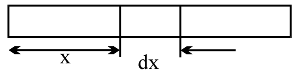
so, $Y = \frac{F/A}{\Delta l / l_0} = \frac{F l_0}{A \Delta l} = \frac{F}{A \alpha \Delta t}$

or $F = Y \, A \, \alpha \, \Delta \, t$

4. *If α is not constant*

(i) (α varies with distance) Let α = ax+b

Total expansion = $\int$ *expansion of length dx* = $\int_0^1 (ax+b)dx\,\Delta t$



(ii) (α varies with tempearture)
Let $\alpha = f(T)$

$$\Delta l = \int_{T_1}^{T_2} \alpha\, l_0\, dT$$

Caution : If α is in °C then put T_1 and T_2 in °C.
similarly if α is in K then put T_1 and T_2 in K.

CALORIMETRY

Quantity of heat transfered and specific heat

The amount of heat needed to incerase the temperature of 1 gm of water from 14.5° C to 15.5°C at STP is 1 calorie

dQ = mcdT

$Q = m\int_{T_1}^{T_2} C\,dT$ (be careful about unit of temperature, use units according to the given units of C)

Heat transfer in phase change

Q = mL L = latent heat of substance in cal/ gm/°C or in Kcal/ kg/ °C
L_{ice} = 80 cal/ gm for ice
L_{steam} = 540 cal/ gm

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.

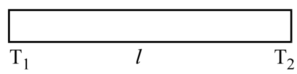
(ii) Before steady state : Temp of rod at any point changes

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($T_1 > T_2$)

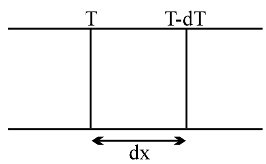
Thermal current $\frac{dQ}{dT} = \frac{T_1 - T_2}{R_{Th}}$



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

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

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

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

If temp difference of body with surrounding is small i.e. $T = T_s$

then, $\frac{dT}{dt} = \frac{4eA\sigma}{mS} T_s^3 (T - T_s)$

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

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

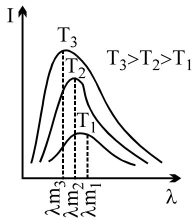
If a body cools from T_1 to T_2 in time δt

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

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

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 λ_m.



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

EXERCISE – I

Q.1 An aluminium container of mass 100 gm contains 200 gm of ice at – 20°C. Heat is added to the system at the rate of 100 cal/s. Find the temperature of the system after 4 minutes (specific heat of ice = 0.5 and L = 80 cal/gm, specific heat of A*l* = 0.2 cal/gm/°C)

Q.2 A U-tube filled with a liquid of volumetric coefficient of 10^{-5}/°C lies in a vertical plane. The height of liquid column in the left vertical limb is 100 cm. The liquid in the left vertical limb is maintained at a temperature = 0°C while the liquid in the right limb is maintained at a temperature = 100°C. Find the difference in levels in the two limbs.

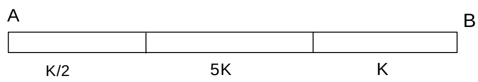
Q.3 A thin walled metal tank of surface area 5 m^2 is filled with water tank and contains an immersion heater dissipating 1 kW. The tank is covered with 4 cm thick layer of insulation whose thermal conductivity is 0.2 W/m/K. The outer face of the insulation is 25°C. Find the temperature of the tank in the steady state

Q.4 A glass flask contains some mercury at room temperature. It is found that at different temperatures the volume of air inside the flask remains the same. If the volume of mercury in the flask is 300 cm^3, then find volume of the flask (given that coefficient of volume expansion of mercury and coefficient of linear expansion of glass are 1.8×10^{-4} (°C)$^{-1}$ and 9×10^{-6} (°C)$^{-1}$ respectively)

Q.5 A clock pendulum made of invar has a period of 0.5 sec at 20°C. If the clock is used in a climate where average temperature is 30°C, aporoximately. How much fast or slow will the clock run in 10^6 sec. ($\alpha_{invar}=1\times10^{-6}$/°C)

Q.6 A pan filled with hot food cools from 50.1 °C to 49.9 °C in 5 sec. How long will it take to cool from 40.1 °C to 39.9°C if room temperature is 30°C?

Q.7 A composite rod made of three rods of equal length and cross-section as shown in the fig. The thermal conductivities of the materials of the rods are K/2, 5K and K respectively. The end A and end B are at constant temperatures. All heat entering the face A goes out of the end B there being no loss of heat from the sides of the bar. Find the effective thermal conductivity of the bar

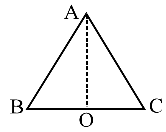


Q.8 An iron bar (Young's modulus = 10^{11} N/m^2 , $\alpha = 10^{-6}$ /°C) 1 m long and 10^{-3} m^2 in area is heated from 0°C to 100°C without being allowed to bend or expand. Find the compressive force developed inside the bar.

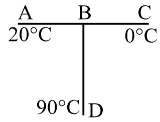
Q.9 A solid copper cube and sphere, both of same mass & emissivity are heated to same initial temperature and kept under identical conditions. What is the ratio of their initial rate of fall of temperature?

Q.10 A cylindrical rod with one end in a stream chamber and other end in ice cause melting of 0.1 gm of ice/sec. If the rod is replaced with another rod of half the length and double the radius of first and thermal conductivity of second rod is 1/4 that of first, find the rate of ice melting in gm/sec

Q.11 Three aluminium rods of equal length form an equilateral triangle ABC. Taking O (mid point of rod BC) as the origin. Find the increase in Y-coordinate of center of mass per unit change in temperature of the system. Assume the length of the each rod is 2m, and $\alpha_{al} = 4\sqrt{3}\times10^{-6}\,/\,°C$



Q.12 Three conducting rods of same material and cross-section are shown in figure. Temperature of A, D and C are maintained at 20°C, 90°C and 0°C. Find the ratio of length BD and BC if there is no heat flow in AB

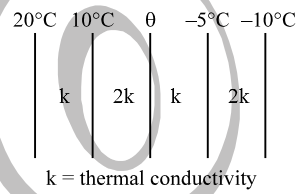


Q.13 If two rods of length L and 2 L having coefficients of linear expansion α and 2α respectively are connected so that total length becomes 3 L, determine the average coefficient of linear expansion of the composite rod.

Q.14 A volume of 120 ml of drink (half alcohol + half water by mass) originally at a temperature of 25°C is cooled by adding 20 gm ice at 0°C. If all the ice melts, find the final temperature of the drink. (density of drink = 0.833 gm/cc, specific heat of alcohol = 0.6 cal/gm/°C)

Q.15 A solid receives heat by radiation over its surface at the rate of 4 kW. The heat convection rate from the surface of solid to the surrounding is 5.2 kW, and heat is generated at a rate of 1.7 kW over the volume of the solid. The rate of change of the average temperature of the solid is $0.5°Cs^{-1}$. Find the heat capacity of the solid.

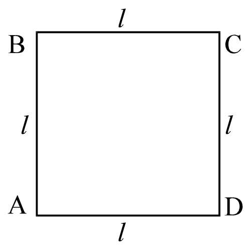
Q.16 The figure shows the face and interface temperature of a composite slab containing of four layers of two materials having identical thickness. Under steady state condition, find the value of temperature θ.



Q.17 Two identical calorimeter A and B contain equal quantity of water at 20°C. A 5 gm piece of metal X of specific heat 0.2 cal g^{-1} $(C°)^{-1}$ is dropped into A and a 5 gm piece of metal Y into B. The equilibrium temperature in A is 22°C and in B 23°C. The initial temperature of both the metals is 40°C. Find the specific heat of metal Y in cal g^{-1} $(C°)^{-1}$.

Q.18 Two spheres of same radius R have their densities in the ratio 8 : 1 and the ratio of their specific heats are 1 : 4. If by radiation their rates of fall of temperature are same, then find the ratio of their rates of losing heat.

Q.19 In the square frame of side l of metallic rods, the corners A and C are maintained at T_1 and T_2 respectively. The rate of heat flow from A to C is ω. If A and D are instead maintained T_1 & T_2 respectivley find, find the total rate of heat flow.



Q.20 A hot liquid contained in a container of negligible heat capacity loses temperature at rate 3 K/min, just before it begins to solidify. The temperature remains constant for 30 min. Find the ratio of specific heat capacity of liquid to specific latent heat of fusion is in K^{-1} (given that rate of losing heat is constant).

Q.21 A thermostatted chamber at small height h above earth's surface maintained at 30°C has a clock fitted in it with an uncompensated pendulum. The clock designer correctly designs it for height h, but for temperature of 20°C. If this chamber is taken to earth's surface, the clock in it would click correct time. Find the coefficient of linear expansion of material of pendulum. (earth's radius is R)

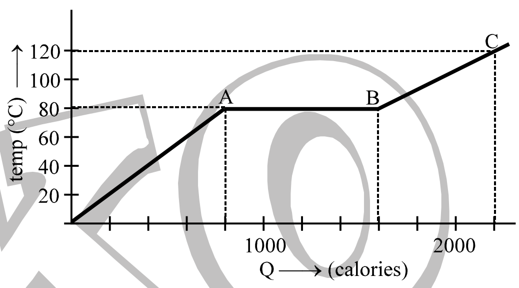
Q.22 The coefficient of volume expansion of mercury is 20 times the coefficient of linear expansion of glass. Find the volume of mercury that must be poured into a glass vessel of volume V so that the volume above mercury may remain constant at all temperature.

Q.23 Two 50 gm ice cubes are dropped into 250 gm of water into a glass. If the water was initially at a temperature of 25°C and the temperature of ice –15°C. Find the final temperature of water. (specific heat of ice = 0.5 cal/gm/°C and L = 80 cal/gm). Find final amount of water and ice.

Q.24 Water is heated from 10°C to 90°C in a residential hot water heater at a rate of 70 litre per minute. Natural gas with a density of 1.2 kg/m^3 is used in the heater, which has a transfer efficiency of 32%. Find the gas consumption rate in cubic meters per hour. (heat combustion for natural gas is 8400 kcal/kg)

Q.25 A metal rod A of 25cm lengths expands by 0.050cm. When its temperature is raised from 0°C to 100°C. Another rod B of a different metal of length 40cm expands by 0.040 cm for the same rise in temperature. A third rod C of 50cm length is made up of pieces of rods A and B placed end to end expands by 0.03 cm on heating from 0°C to 50°C. Find the lengths of each portion of the composite rod.

Q.26 A substance is in the solid form at 0°C. The amount of heat added to this substance and its temperature are plotted in the following graph. If the relative specific heat capacity of the solid substance is 0.5, find from the graph



(i) the mass of the substance ;
(ii) the specific latent heat of the melting process, and
(iii) the specific heat of the substance in the liquid state.

Q.27 One end of copper rod of uniform cross-section and of length 1.5 meters is in contact with melting ice and the other end with boiling water. At what point along its length should a temperature of 200°C 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 the surroundings.

Q.28 Two solids spheres are heated to the same temperature and allowed to cool under identical conditions. Compare: (i) initial rates of fall of temperature, and (ii) initial rates of loss of heat. Assume that all the surfaces have the same emissivity and ratios of their radii of, specific heats and densities are respectively $1 : \alpha$, $1 : \beta$, $1 : \gamma$.

Q.29 A vessel containing 100 gm water at 0°C is suspended in the middle of a room. In 15 minutes the temperature of the water rises by 2°C. When an equal amount of ice is placed in the vessel, it melts in 10 hours. Calculate the specific heat of fusion of ice.

Q.30 The maximum in the energy distribution spectrum of the sun is at 4753 Å and its temperature is 6050K. What will be the temperature of the star whose energy distribution shows a maximum at 9506 Å.

EXERCISE – II

Q.1 A copper calorimeter of mass 100 gm contains 200 gm of a mixture of ice and water. Steam at 100°C under normal pressure is passed into the calorimeter and the temperature of the mixture is allowed to rise to 50°C. If the mass of the calorimeter and its contents is now 330 gm, what was the ratio of ice and water in the beginning? Neglect heat losses.

Given : Specific heat capacity of copper = 0.42×10^3 J $kg^{-1}K^{-1}$,
Specific heat capacity of water = 4.2×10^3 J $kg^{-1}K^{-1}$,
Specific heat of fusion of ice = 3.36×10^5 J kg^{-1}
Latent heat of condensation of steam = 22.5×10^5 Jkg^{-1}

Q.2 An isosceles triangle is formed with a rod of length l_1 and coefficient of linear expansion α_1 for the base and two thin rods each of length l_2 and coefficient of linear expansion α_2 for the two pieces, if the distance between the apex and the midpoint of the base remain unchanged as the temperatures varied show that $\frac{l_1}{l_2} = 2\sqrt{\frac{\alpha_2}{\alpha_1}}$.

Q.3 A solid substance of mass 10 gm at – 10°C was heated to – 2°C (still in the solid state). The heat required was 64 calories. Another 880 calories was required to raise the temperature of the substance (now in the liquid state) to 1°C, while 900 calories was required to raise the temperature from –2°C to 3°C. Calculate the specific heat capacities of the substances in the solid and liquid state in calories per kilogram per kelvin. Show that the latent heat of fusion L is related to the melting point temperature t_m by L = 85400 + 200 t_m.

Q.4 A steel drill making 180 rpm is used to drill a hole in a block of steel. The mass of the steel block and the drill is 180 gm. If the entire mechanical work is used up in producing heat and the rate of raise in temperature of the block and the drill is 0.5 °C/s. Find

(a) the rate of working of the drill in watts, and

(b) the torque required to drive the drill.

Specific heat of steel = 0.1 and J = 4.2 J/cal. Use : $P = \tau\,\omega$

Q.5 A brass rod of mass m = 4.25 kg and a cross sectional area 5 cm^2 increases its length by 0.3 mm upon heating from 0°C. What amount of heat is spent for heating the rod? The coefficient of linear expansion for brass is 2×10^{-5}/K, its specific heat is 0.39 kJ/kg.K and the density of brass is 8.5×10^3 kg/m^3.

Q.6 A submarine made of steel weighing 10^9 g has to take 10^8 g of water in order to submerge when the temperature of the sea is 10°C. How much less water it will have to take in when the sea is at 15°C? (Coefficient of cubic expansion of sea water = 2×10^{-4}/°C, coefficient of linear expansion of steel = 1.2×10^{-5}/°C)

Q.7 A flow calorimeter is used to measure the specific heat of a liquid. Heat is added at a known rate to a stream of the liquid as it passes through the calorimeter at a known rate. Then a measurement of the resulting temperature difference between the inflow and the outflow points of the liquid stream enables us to compute the specific heat of the liquid. A liquid of density 0.2 g/cm^3 flows through a calorimeter at the rate of 10 cm^3/s. Heat is added by means of a 250-W electric heating coil, and a temperature difference of 25°C is established in steady-state conditions between the inflow and the outflow points. Find the specific heat of the liquid.

Q.8 Toluene liquid of volume 300 cm^3 at 0°C is contained in a beaker an another quantity of toluene of volume 110 cm^3 at 100°C is in another beaker. (The combined volume is 410 cm^3). Determine the total volume of the mixture of the toluene liquids when they are mixed together. Given the coefficient of volume expansion $\gamma = 0.001/C$ and all forms of heat losses can be ignored. Also find the final temperature of the mixture.

Q.9 Ice at -20°C is filled upto height h = 10 cm in a uniform cylindrical vessel. Water at temperature θ°C is filled in another identical vessel upto the same height h= 10 cm. Now, water from second vessel is poured into first vessel and it is found that level of upper surface falls through $\Delta h = 0.5$ cm when thermal equilibrium is reached. Neglecting thermal capacity of vessels, change in density of water due to change in temperature and loss of heat due to radiation, calculate initial temperature θ of water.

Given, Density of water, $\rho_w = 1$ gm cm^{-3}
Density of ice, $\rho_i = 0.9$ gm/cm^3
Specific heat of water, $s_w = 1$ cal/gm ^{0}C
Specific heat of ice, $s_i = 0.5$ cal/gm^{0}C
Specific latent heat of ice, L = 80 cal/gm

Q.10 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 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?

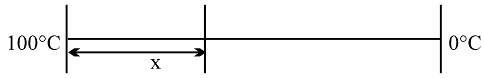
Q.11 Two identical thermally insulated vessels, each containing n mole of an ideal monatomic gas, are interconnected by a rod of length l and cross-sectional area A. Material of the rod has thermal conductivity K and its lateral surface is thermally insulated. If, at initial moment (t = 0), temperature of gas in two vessels is T_1 and T_2 ($< T_1$), neglecting thermal capacity of the rod, calculate difference between temperature of gas in two vessels as a function of time.

Q.12 A highly conducting solid cylinder of radius a and length l is surrounded by a co-axial layer of a material having thermal conductivity K and negligible heat capacity. Temperature of surrounding space (out side the layer) is T_0, which is higher than temperature of the cylinder. If heat capacity per unit volume of cylinder material is s and outer radius of the layer is b, calculate time required to increase temperature of the cylinder from T_1 to T_2. Assume end faces to be thermally insulated.

Q.13 A vertical brick duct(tube) is filled with cast iron. The lower end of the duct is maintained at a temperature T_1 which is greater than the melting point T_m of cast iron and the upper end at a temperature T_2 which is less than the temperature of the melting point of cast iron. It is given that the conductivity of liquid cast iron is equal to k times the conductivity of solid cast iron. Determine the fraction of the duct filled with molten metal.

Q.14 Water is filled in a non-conducting cylindrical vessel of uniform cross-sectional area. Height of water column is h_0 and temperature is 0°C. If the vessel is exposed to an atmosphere having constant temperature of $-\theta$°C (< 0°C) at t = 0, calculate total height h of the column at time t. Assume thermal conductivity of ice to be equal to K. Density of water is ρ_ω and that of ice is ρ_i. Latent heat of fusion of ice is L.

Q.15 A lagged stick of cross section area 1 cm^2 and length 1 m is initially at a temperature of 0°C. It is then kept between 2 reservoirs of tempeature 100°C and 0°C. Specific heat capacity is 10 J/kg°C and linear mass density is 2 kg/m. Find



(a) temperature gradient along the rod in steady state.
(b) total heat absorbed by the rod to reach steady state.

Q.16 A cylindrical block of length 0.4 m an area of cross-section $0.04m^2$ is placed coaxially on a thin metal disc of mass 0.4 kg and of the same cross-section. The upper face of the cylinder is maintained at a constant temperature of 400K and the initial temperature of the disc is 300K. If the thermal conductivity of the material of the cylinder is 10 watt/m-K and the specific heat of the material of the disc in 600 J/kg-K, how long will it take for the temperature of the disc to increase to 350K? Assume, for purposes of calculation, the thermal conductivity of the disc to be very high and the system to be thermally insulated except for the upper face of the cylinder.

Q.17 A copper calorimeter of negligible thermal capacity is filled with a liquid. The mass of the liquid equals 250 gm. A heating element of negligible thermal capacity is immersed in the liquid. It is found that the temperature of the calorimeter and its contents rises from 25°C to 30°C in 5 minutes when a current of 20.5 ampere is passed through it at potential difference of 5 volts. The liquid is thrown off and the heater is again switched on. It is now found that the temperature of the calorimeter alone is constantly maintained at 32°C when the current through the heater is 7A at the potential difference 6 volts. Calculate the specific heat capacity of the liquid. The temperature of the surroundings is 25°C.

Q.18 A solid copper sphere cools at the rate of 2.8°C per minute, when its temperature is 127°C. Find the rate at which another solid copper sphere of twice the radius lose its temperature at 327°C, if in both the cases, the room temperature is maintained at 27°C.

Q.19 A calorimeter contains 100 cm^3 of a liquid of density 0.88 g/cm^3 in which are immersed a thermometer and a small heating coil. The effective water equivalent of calorimeter, thermometer and heater may be taken to be 13 gm. Current of 2 A is passed through the coil. The potential difference across the coil is 6.3 V and the ultimate steady state temperature is 55°C. The current is increased so that the temperature rises slightly above 55°C, and then it is switched off. The calorimeter and the content are found to cool at the rate of 3.6°C/min.
(a) Find the specific heat of the liquid.
(b) The room temperature during the experiment was 10°C. If the room temperature rises to 26°C, find the current required to keep the liquid at 55°C. You may assume that Newton's law is obeyed and the resistance of the heater remains constant.

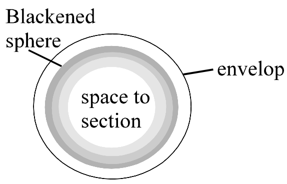
Q.20 End A of a rod AB of length L = 0.5 m and of uniform cross-sectional area is maintained at some constant temperature. The heat conductivity of the rod is k = 17 J/s-m°K. The other end B of this rod is radiating energy into vacuum and the wavelength with maximum energy density emitted from this end is λ_0 = 75000 Å. If the emissivity of the end B is e = 1, determine the temperature of the end A. Assuming that except the ends, the rod is thermally insulated.

Q.21 A wire of length 1.0 m and radius 10^{-3} m is carrying a heavy current and is assumed to radiate as a blackbody. At equilibrium temperature of wire is 900 K while that of the surroundings is 300 K. The resistivity of the material of the wire at 300 K is $\pi^2 \times 10^{-8}$ Ω-m and its temperature coefficient of resistance is 7.8×10^{-3} /°C. Find the current in the wire. [$\sigma \cong 5.68 \times 10^{-8}$ w/m^2K^4].

Q.22 The temperature distribution of solar radiation is more or less same as that of a black body whose maximum emission corresponds to the wavelength 0.483 μm. Find the rate of change of mass due to radiation. [Radius of Sun = 7.0×10^8 m]

Q.23 A black plane surface at a constant high temperature T_h, is parallel to another black plane surface at constant lower temperature T_l. Between the plates is vacuum. In order to reduce the heat flow due to radiation, a heat shield consisting of two thin black plates, thermally isolated from each other, it placed between the warm and the cold surfaces and parallel to these. After some time stationary conditions are obtained. By what factor η is the stationary heat flow reduced due to the presence of the heat shield? Neglect end effects due to the finite size of the surfaces.

Q.24 The shell of a space station is a blackened sphere in which a temperature T = 500K is maintained due to operation of appliances of the station. Find the temperature of the shell if the station is enveloped by a thin spherical black screen of nearly the same radius as the radius of the shell.



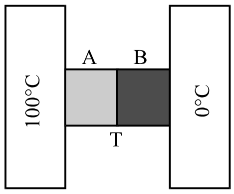
Q.25 A liquid takes 5 minutes to cool from 80°C to 50°C. How much time will it take to cool from 60°C to 30°C ? The temperature of surrounding is 20°C. Use exact method.

Q.26 Find the temperature of equilibrium of a perfectly black disc exposed normally to the Sun's ray on the surface of Earth. Imagine that it has a nonconducting backing so that it can radiate only to hemisphere of space. Assume temperature of surface of Sun = 6200 K, radius of sun = 6.9×10^8 m, distance between the Sun and the Earth = 1.5×10^{11} m. Stefan's constant = 5.7×10^{-8} W/m^2.K^4. What will be the temperature if both sides of the disc are radiate?

EXERCISE – III

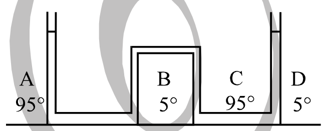
Q.1 The temperature of 100 gm of water is to be raised from 24° C to 90° C by adding steam to it. Calculate the mass of the steam required for this purpose. [JEE '96]

Q.2 Two metal cubes A & 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 coefficients of thermal conductivity of A & 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 ______. [JEE' 96]



Q.3 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 0.05m thick stagnant air space. In the steady state, the room glass interface and the glass outdoor interface are at constant temperatures of 27^0C and 0^0C 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 W $m^{-1}K^{-1}$ respectively. [JEE'97]

Q.4 The apparatus shown in the figure consists of four glass columns connected by horizontal sections. The height of two central columns B & C are 49 cm each. The two outer columns A & D are open to the atmosphere. A & C are maintained at a temperature of 95° C while the columns B & D are maintained at 5° C. The height of the liquid in A & D measured from the base line are 52.8 cm & 51 cm respectively. Determine the coefficient of thermal expansion of the liquid. [JEE '97]



Q.5 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 radiated in watt would be :
(A) 225 (B) 450 (C) 900 (D) 1800

Q.6 Earth receives 1400 W/m^2 of solar power . If all the solar energy falling on a lens of area 0.2 m^2 is focussed on to a block of ice of mass 280 grams, the time taken to melt the ice will be ______ minutes. (Latent heat of fusion of ice = 3.3 x 10^5 J/kg) [JEE '97]

Q.7 A solid body X of heat capacity C is kept in an atmosphere whose temperature is T_A = 300K. At time t = 0, the temperature of X is T_0 = 400K. It cools according to Newton's law of cooling. At time t_1 its temperature is found to be 350K. At this time t_1, the body X is connected to a larger body 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 = $3t_1$. [JEE' 98]

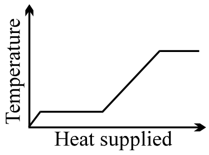
Q.8 A black body is at a temperature of 2880 K. The energy of radiation emitted by this object with wavelength between 499 nm and 500 nm is U_1, between 999 nm and 1000 nm is U_2 and between 1499 nm and 1500 nm is U_3. The Wien constant b = 2.88 × 10^6 nm K. Then [JEE' 98]
(A) $U_1 = 0$ (B) $U_3 = 0$ (C) $U_1 > U_2$ (D) $U_2 > U_1$

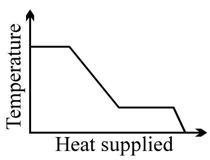
Q.9 A bimetallic strip is formed out of two identical strips one of copper and the other of brass. The coefficient of linear expansion of the two metals are α_C and α_B. On heating, the temperature of the strip goes up by ΔT and the strip bends to form an arc of radius of curvature R. Then R is :

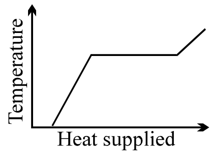
(A) proportional at ΔT (B) inversely proportional to ΔT [JEE' 99]

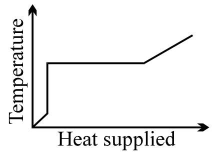
(C) proportional to $|\alpha_B - \alpha_C|$ (D) inversely proportional to $|\alpha_B - \alpha_C|$

Q.10 A block of ice at – 10°C is slowly heated and converted to steam at 100°C. Which of the following curves represents the phenomenon qualitatively? [JEE (Scr) 2000]

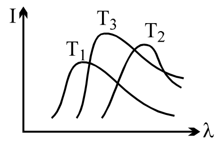
(A) 

(B) 

(C) 

(D) 

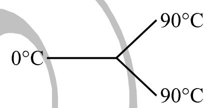
Q.11 The plots of intensity versus wavelength for three black bodies at temperature T_1 , T_2 and T_3 respectively are as shown. Their temperatures are such that [JEE (Scr) 2000]



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

(C) $T_2 > T_3 > T_1$ (C) $T_3 > T_2 > T_1$

Q.12 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 at 0°C and 90°C respectively. The temperature of the junction of the three rods will be [JEE(Scr)2001]



(A) 45°C (B) 60°C (C) 30°C (D) 20°C

Q.13 An ideal black body at room temperature is thrown into a furnace. It is observed that

(A) initially it is the darkest body and at later times the brightest.

(B) it the darkest body at all times

(C) it cannot be distinguished at all times.

(D) initially it is the darkest body and at later times it cannot be distinguished. [JEE(Scr)2002]

Q.14 An ice cube of mass 0.1 kg at 0°C is placed in an isolated container which is at 227°C. The specific heat S of the container varies with temperature T according the empirical relations = A + BT, where A = 100 cal/kg-K and B = 2×10^{-2} cal/kg-K^2. If the final temperature of the container is 27°C, determine the mass of the container. (Latent heat of fusion for water = 8×10^4 cal/kg. Specific heat of water = 10^3 cal/kg-K) [JEE' 2001]

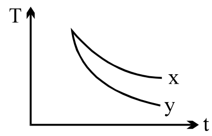
Q.15 Two rods one of aluminium of length l_1 having coefficient of linear expansion α_a, and other steel of length l_2 having coefficient of linear expansion α_s are joined end to end. The expansion in both the rods is same on variation of temperature. Then the value of $\frac{l_1}{l_1 + l_2}$ is [JEE' (Scr) 2003]

(A) $\frac{\alpha_s}{\alpha_a + \alpha_s}$ (B) $\frac{\alpha_s}{\alpha_a - \alpha_s}$ (C) $\frac{\alpha_a + \alpha_s}{\alpha_s}$ (D) None of these

Q.16 2 kg ice at – 20°C is mixed with 5 kg water at 20°C. Then final amount of water in the mixture would be; Given specific heat of ice = 0.5cal/g°C, specific heat of water = 1 cal/g°C, Latent heat of fusion of ice = 80 cal/g. [JEE' (Scr) 2003]

(A) 6 kg (B) 5 kg (C) 4 kg (D) 2 kg

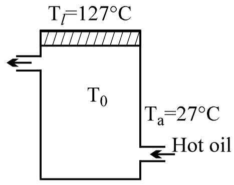
Q.17 If emissivity of bodies X and Y are e_x and e_y and absorptive power are A_x and A_y then [JEE' (Scr) 2003]



(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) $e_y = e_x$; $A_y = A_x$

Q.18 Hot oil is circulated through an insulated container with a wooden lid at the top whose conductivity K = 0.149 J/(m-°C-sec), thickness t = 5 mm, emissivity = 0.6. Temperature of the top of the lid in steady state is at T_l = 127°. If the ambient temperature T_a = 27°C. Calculate



(a) rate of heat loss per unit area due to radiation from the lid.

(b) temperature of the oil. (Given $\sigma = \dfrac{17}{3} \times 10^{-8}$) [JEE' 2003]

Q.19 Three discs A, B, and C having radii 2 m, 4 m and 6 m respectively are coated with carbon black on their outer surfaces. The wavelengths corresponding to maximum intensity are 300 nm, 400 nm and 500 nm respectively. The power radiated by them are Q_A, Q_B and Q_C respectively.

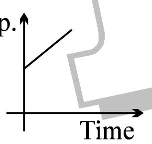
(a) Q_A is maximum (B) Q_B is maximum [JEE' 2004 (Scr.)]

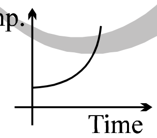
(C) Q_C is maximum (D) $Q_A = Q_B = Q_C$

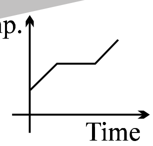
Q.20 Two identical conducting rods are first connected independently to two vessels, one containing water at 100°C and the other containing ice at 0° C. In the second case, the rods are joined end to end and connected to the same vessels. Let q_1 and q_2 g/s be the rate of melting of ice in the two cases respectively. The ratio q_2/q_1 is

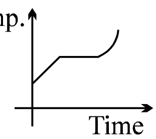
(A) 1/2 (B) 2/1 (C) 4/1 (D) 1/4 [JEE' 2004 (Scr.)]

Q.21 Liquid oxygen at 50 K is heated to 300 K at constant pressure of 1 atm. The rate of heating is constant. Which of the following graphs represents the variation of temperature with time?

(A)


(B)


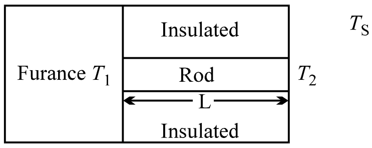
(C)


(D)


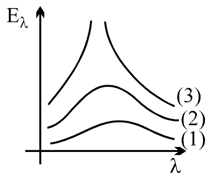
[JEE' 2004 (Scr.)]

Q.22 A cube of coefficient of linear expansion α_s is floating in a bath containing a liquid of coefficient of volume expansion γ_l. When the temperature is raised by ΔT, the depth upto which the cube is submerged in the liquid remains the same. Find the relation between α_s and γ_l, showing all the steps. [JEE 2004]

Q.23 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 surroundings. 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 2004]



Q.24 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



(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 [JEE' 2005 (Scr)]

Q.25 In which of the following phenomenon heat convection does not take place
(A) land and sea breeze
(B) boiling of water
(C) heating of glass surface due to filament of the bulb
(D) air around the furance [JEE' 2005 (Scr)]

Q.26 2 litre water at 27°C is heated by a 1 kW heater in an open container. On an average heat is lost to surroundings at the rate 160 J/s. The time required for the temperature to reach 77°C is
(A) 8 min 20 sec (B) 10 min (C) 7 min (D) 14 min
[JEE' 2005 (Scr)]

Q.27 A spherical body of area A, and emissivity e = 0.6 is kept inside a black body. What is the rate at which energy is radiated per second at temperature T
(A) $0.6\,\sigma AT^4$ (B) $0.4\,\sigma AT^4$ (C) $0.8\,\sigma AT^4$ (D) $1.0\,\sigma AT^4$
[JEE' 2005 (Scr)]

Q.28 1 calorie is the heat required to increased the temperature of 1 gm of water by 1°C from
(A) 13.5°C to 14.5°C at 76 mm of Hg (B) 14.5°C to 15.5°C at 760 mm of Hg
(C) 0°C to 1°C at 760 mm of Hg (D) 3°C to 4°C to 760 mm of Hg
[JEE' 2005 (Scr)]

Q.29 In a dark room with ambient temperature T_0, a black body is kept at a temperature T. Keeping the temperature of the black body constant (at T), sunrays are allowed to fall on the black body through a hole in the roof of the dark room. Assuming that there is no change in the ambient temperature of the room, which of the following statement(s) is/are correct?
(A) The quantity of radiation absorbed by the black body in unit time will increase.
(B) Since emissivity = absorptivity, hence the quantity of radiation emitted by black body in unit time will increase.
(C) Black body radiates more energy in unit time in the visible spectrum.
(D) The reflected energy in unit time by the black body remains same. [JEE 2006]

Q.30 In an insulated vessel, 0.05 kg steam at 373 K and 0.45 kg of ice at 253 K are mixed. Then, find the final temperature of the mixture.
Given, L_{fusion} = 80 cal/g = 336 J/g, $L_{vaporization}$ = 540 cal/g = 2268 J/g,
S_{ice} = 2100 J/kg K = 0.5 cal/gK and S_{water} = 4200 J/kg K = 1 cal /gK [JEE 2006]

ANSWER KEY

EXERCISE –1

Q.1 25.5°C Q.2 0.1 cm Q.3 65°C Q.4 2000 cm^3

Q.5 5 sec slow Q.6 10 sec Q.7 15K/16 Q.8 10, 000 N

Q.9 $\left(\frac{6}{\pi}\right)^{1/3}$ Q.10 0.2 Q.11 4×10^{-6} m/°C

Q.12 7/2 Q.13 5α/3 Q.14 4°C Q.15 1000 J (C°)$^{-1}$

Q.16 5°C Q.17 27/85 Q.18 2 : 1 Q.19 (4/3) ω

Q.20 1/90 Q.21 h/5R Q.22 3V / 20

Q.23 0 °C, 125/4 g ice, 1275/4 g water

Q.24 104.2 Q.25 10cm , 40cm Q.26 (i)0.02kg,(ii) 40,000calkg^{-1},(iii)750calkg^{-1}K^{-1}

Q.27 10.34 cm Q.28 αβγ : 1 ; 1 : α^2 Q.29 80 k cal/kg Q.30 3025 K

EXERCISE – II

Q.1 1 : 1.26 Q.3 800 cal kg^{-1} K^{-1}, 1000 cal kg^{-1} K^{-1}

Q.4 (a) 37.8 J/s (Watts), (b) 2.005 N-m Q.5 25 kJ Q.6 9.02×10^5 gm

Q.7 5000 J/°C kg Q.8 decrease by 0.75 cm^3, 25°C Q.9 45^{0}C

Q.10 $K_{11} > K_\perp$, $K_\parallel = \frac{K_A + K_B}{2}$, $K_\perp = \frac{2K_AK_B}{K_A + K_B}$ Q.11 $(T_1 - T_2)e^{-\left(\frac{4KAt}{3nR\ell}\right)}$

Q.12 $\frac{a^2s}{2K}\log_e\left(\frac{b}{a}\right)\log_e\left(\frac{T_0 - T_1}{T_0 - T_2}\right)$ Q.13 $\frac{l_1}{l} = \frac{k(T_1 - T_m)}{k(T_1 - T_m) + (T_m - T_2)}$

Q.14 $h_0 + \left(1 - \frac{\rho_i}{\rho_w}\right)\sqrt{\frac{2k_i\theta t}{\rho_i L_f}}$ Q.15 (a) –100 °C/m, (b) 1000 J Q.16 166.3 sec

Q.17 21000 Jkg^{-1}K^{-1} Q.18 9.72^{0}C/min Q.19 (a)0.42 cal/gm°C, (b) 1.74A

Q.20 T_A = 423 K Q.21 36 A Q.22 $\frac{dm}{dt} = 5.06 \times 10^9$ kg/s

Q.23 η = 3 Q.24 $T'' = \sqrt[4]{2} \times 500 = 600$ K

Q.25 10 minutes Q.26 T_0 = 420 K, T_0 = 353.6 K

EXERCISE – III

Q.1 12 gm Q.2 60° C Q.3 41.53 Watt; 26.48 ^{0}C ; 0.55^{0}C

Q.4 2×10^{-4} C Q.5 D Q.6 5.5 min

Q.7 $k = \frac{\log_e 2}{t_1}$; $T = 300 + 50 \exp.\left[-\left\{\frac{KA}{LC} + \frac{\log_e 2}{t_1}\right\}2t_1\right]$

Q.8 D Q.9 B, D Q.10 A Q.11 B Q.12 B Q.13 D Q.14 0.5 kg

Q.15 A Q.16 A Q.17 A Q.18 (a) 595 watt/m^2, (b) $T_0 \approx 420$ K Q.19 B

Q.20 D Q.21 C Q.22 $\gamma_l = 2\alpha_s$ Q.23 $\frac{K}{4e\sigma LT_S^3 + K}$ Q.24 A

Q.25 C Q.26 A Q.27 A Q.28 B Q.29 A,B,C,D Q.30 273 K

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