CHAPTER 10

Thermal Properties of Matter

1. Heat given to a body which raises its temperature by 1°C is **[2002]**
(a) water equivalent
(b) thermal capacity
(c) specific heat
(d) temperature gradient

2. Infrared radiation is detected by **[2002]**
(a) spectrometer (b) pyrometer
(c) nanometer (d) photometer

3. Which of the following is more close to a black body? **[2002]**
(a) black board paint
(b) green leaves
(c) black holes
(d) red roses

4. If mass-energy equivalence is taken into account, when water is cooled to form ice, the mass of water should **[2002]**
(a) increase
(b) remain unchanged
(c) decrease
(d) first increase then decrease

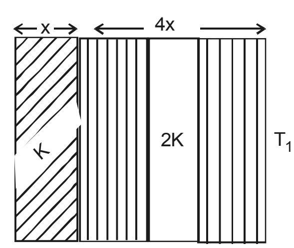
5. Two spheres of the same material have radii 1 m and 4 m and temperatures 4000 K and 2000 K respectively. The ratio of the energy radiated per second by the first sphere to that by the second is **[2002]**
(a) 1 : 1 (b) 16 : 1
(c) 4 : 1 (d) 1 : 9.

6. The earth radiates in the infra-red region of the spectrum. The spectrum is correctly given by **[2003]**
(a) Rayleigh Jeans law
(b) Planck's law of radiation
(c) Stefan's law of radiation
(d) Wien's law

7. According to Newton's law of cooling, the rate of cooling of a body is proportional to $(\Delta\theta)^n$, where $\Delta\theta$ is the difference of the temperature of the body and the surroundings, and n is equal to **[2003]**
(a) two (b) three
(c) four (d) one

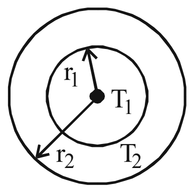
8. If the temperature of the sun were to increase from T to $2T$ and its radius from R to $2R$, then the ratio of the radiant energy received on earth to what it was previously will be **[2004]**
(a) 32 (b) 16
(c) 4 (d) 64

9. The temperature of the two outer surfaces of a composite slab, consisting of two materials having coefficients of thermal conductivity K and $2K$ and thickness x and $4x$, respectively, are 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 **[2004]**



(a) $\frac{2}{3}$ (b) $\frac{1}{2}$
(c) 1 (d) $\frac{1}{3}$

10. The figure shows a system of two concentric spheres of radii r_1 and r_2 are kept at temperatures T_1 and T_2, respectively. The radial rate of flow of heat in a substance between the two concentric spheres is proportional to **[2005]**



(a) $\ln\left(\frac{r_2}{r_1}\right)$ (b) $\frac{(r_2 - r_1)}{(r_1 r_2)}$

(c) $(r_2 - r_1)$ (d) $\frac{r_1 r_2}{(r_2 - r_1)}$

11. Assuming the Sun to be a spherical body of radius R at a temperature of TK, evaluate the total radiant powerd incident of Earth at a distance r from the Sun **[2006]**

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

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

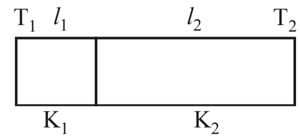
where r_0 is the radius of the Earth and σ is Stefan's constant.

12. Two rigid boxes containing different ideal gases are placed on a table. Box A contains one mole of nitrogen at temperature T_0, while Box contains one mole of helium at temperature $\left(\frac{7}{3}\right) T_0$. The boxes are then put into thermal contact with each other, and heat flows between them until the gases reach a common final temperature (ignore the heat capacity of boxes). Then, the final temperature of the gases, T_f in terms of T_0 is **[2006]**

(a) $T_f = \frac{3}{7} T_0$ (b) $T_f = \frac{7}{3} T_0$

(c) $T_f = \frac{3}{2} T_0$ (d) $T_f = \frac{5}{2} T_0$

13. 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 length l_1 and l_2 and thermal conductivities K_1 and K_2 respectively. The temperature at the interface of the two section is **[2007]**



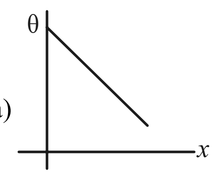
(a) $\frac{(K_1 l_1 T_1 + K_2 l_2 T_2)}{(K_1 l_1 + K_2 l_2)}$

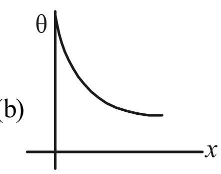
(b) $\frac{(K_2 l_2 T_1 + K_1 l_1 T_2)}{(K_1 l_1 + K_2 l_2)}$

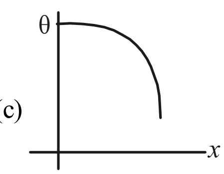
(c) $\frac{(K_2 l_1 T_1 + K_1 l_2 T_2)}{(K_2 l_1 + K_1 l_2)}$

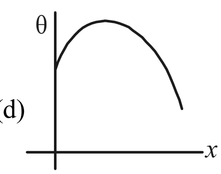
(d) $\frac{(K_1 l_2 T_1 + K_2 l_1 T_2)}{(K_1 l_2 + K_2 l_1)}$

14. 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? **[2009]**

(a) 

(b) 

(c) 

(d) 

15. 100g of water is heated from 30°C to 50°C. Ignoring the slight expansion of the water, the change in its internal energy is (specific heat of water is 4184 J/kg/K): **[2011]**

(a) 8.4 kJ (b) 84 kJ

(c) 2.1 kJ (d) 4.2 kJ

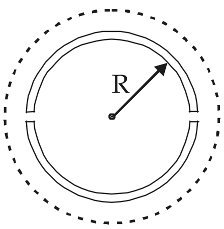
16. The specific heat capacity of a metal at low temperature (T) is given as

$$C_p (kJK^{-1}kg^{-1}) = 32\left(\frac{T}{400}\right)^3$$

A 100 gram vessel of this metal is to be cooled from 20ºK to 4ºK by a special refrigerator operating at room temperature (27°C). The amount of work required to cool the vessel is **[2011 RS]**

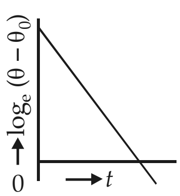
(a) greater than 0.148 kJ
(b) between 0.148 kJ and 0.028 kJ
(c) less than 0.028 kJ
(d) equal to 0.002 kJ

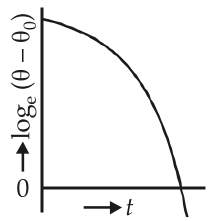
17. A wooden wheel of radius R is made of two semicircular part (see figure). The two parts are held together by a ring made of a metal strip of cross sectional area S and length L. L is slightly less than $2\pi R$. To fit the ring on the wheel, it is heated so that its temperature rises by ΔT and it just steps over the wheel. As it cools down to surrounding temperature, it presses the semicircular parts together. If the coefficient of linear expansion of the metal is α, and its Young's modulus is Y, the force that one part of the wheel applies on the other part is : **[2012]**

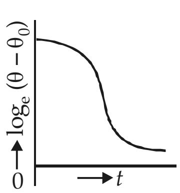


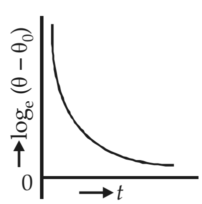
(a) $2\pi SY\alpha\Delta T$ (b) $SY\alpha\Delta T$
(c) $\pi SY\alpha\Delta T$ (d) $2SY\alpha\Delta T$

18. A liquid in a beaker has temperature $\theta(t)$ at time t and θ_0 is temperature of surroundings, then according to Newton's law of cooling the correct graph between $\log_e(\theta - \theta_0)$ and t is : **[2012]**

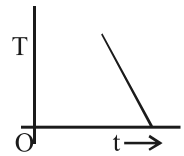
(a) 

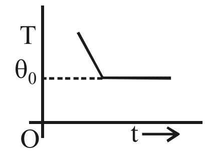
(b) 

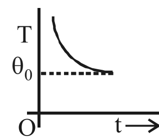
(c) 

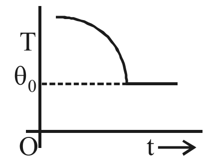
(d) 

19. 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 **[2013]**

(a) 

(b) 

(c) 

(d) 

20. Three rods of Copper, Brass and Steel are welded together to form a Y shaped structure. Area of cross - section of each rod = 4 cm^2. End of copper rod is maintained at 100ºC where as ends of brass and steel are kept at 0ºC. Lengths of the copper, brass and steel rods are 46, 13 and 12 cms respectively. The rods are thermally insulated from surroundings excepts at ends. Thermal conductivities of copper, brass and steel are 0.92, 0.26 and 0.12 CGS units respectively. Rate of heat flow through copper rod is: **[2014]**

(a) 1.2 cal/s (b) 2.4 cal/s
(c) 4.8 cal/s (d) 6.0 cal/s

21. Consider a spherical shell of radius R at temperature T. The black body radiation inside it can be considered as an ideal gas of photons with internal energy per unit volume $u = \frac{U}{V} \propto T^4$ and pressure $p = \frac{1}{3}\left(\frac{U}{V}\right)$. If the shell now undergoes an adiabatic expansion the relation between T and R is : **[2015]**

(a) $T \propto \frac{1}{R}$ (b) $T \propto \frac{1}{R^3}$
(c) $T \propto e^{-R}$ (d) $T \propto e^{-3R}$

22. A pendulum clock loses 12 s a day if the temperature is 40°C and gains 4 s a day if the temperature is 20°C. The temperature at which the clock will show correct time, and the co-efficient of linear expansion (α) of the metal of the pendulum shaft are respectively : **[2016]**

(a) 30°C; $\alpha = 1.85 \times 10^{-3}$/°C
(b) 55°C; $\alpha = 1.85 \times 10^{-2}$/°C
(c) 25°C; $\alpha = 1.85 \times 10^{-5}$/°C
(d) 60°C; $\alpha = 1.85 \times 10^{-4}$/°C

23. A copper ball of mass 100 gm is at a temperature T. It is dropped in a copper calorimeter of mass 100 gm, filled with 170 gm of water at room temperature. Subsequently, the temperature of the system is found to be 75°C. T is given by (Given : room temperature = 30° C, specific heat of copper = 0.1 cal/gm°C **[2017]**

(1) 1250°C (2) 825°C

(3) 800°C (4) 885° C

24. An external pressure P is applied on a cube at 0°C so that it is equally compressed from all sides. K is the bulk modulus of the material of the cube and α is its coefficient of linear expansion. Suppose we want to bring the cube to its original size by heating. The temperature should be raised by : **[2017]**

(1) $\frac{3\alpha}{PK}$ (2) $3PK\alpha$

(3) $\frac{P}{3\alpha K}$ (4) $\frac{P}{\alpha K}$

Answer Key

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
(b)	(b)	(a)	(c)	(a)	(d)	(d)	(d)	(d)	(d)	(b)	(c)	(d)	(a)	(a)
16	17	18	19	20	21	22	23	24						
(d)	(d)	(a)	(c)	(c)	(a)	(c)	(d)	(c)						

SOLUTIONS

1. **(b)** Heat required for raising the temperature of the whole body by 1°C is called the thermal capacity of the body.

2. **(b)** Pyrometer is used to detect infra-red radiation.

3. **(a)** Black board paint is quite approximately equal to black bodies.

4. **(c)** When water is cooled to form ice, energy is released from water in the form of heat. As energy is equivalent to mass, therefore, when water is cooled to ice, its mass decreases.

5. **(a)** The energy radiated per second is given by $E = e\sigma T^4 A$

For same material e is same. σ is stefan's constant

$$\therefore \frac{F_1}{F_2} = \frac{T_1^4 A_1}{T_2^4 A_2} = \frac{T_1^4 4\pi r_1^2}{T_2^4 4\pi r_2^2}$$

$$= \frac{(4000)^4 \times 1^2}{(2000)^4 \times 4^2} = \frac{1}{1}$$

6. **(d)** Wein's law correctly explains the spectrum

7. **(d)** According to Newton's law of cooling

$$-\frac{dQ}{dt} \propto (\Delta\theta)$$

8. **(d)** $E = \sigma A T^4$; $A \propto R^2$ $\therefore E \propto R^2 T^4$

$$\therefore \frac{E_2}{E_1} = \frac{R_2^2 T_2^4}{R_1^2 T_1^4}$$

put $R_2 = 2R, R_1 = R$; $T_2 = 2T, T_1 = T$

$$\Rightarrow \frac{E_2}{E_1} = \frac{(2R)^2 (2T)^4}{R^2 T^4} = 64$$

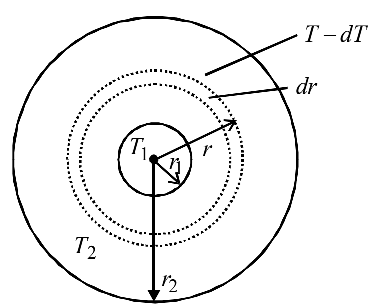
9. **(d)** The thermal resistance is given by

$$\frac{x}{KA} + \frac{4x}{2KA} = \frac{x}{KA} + \frac{2x}{KA} = \frac{3x}{KA}$$

$$\therefore \frac{dQ}{dt} = \frac{\Delta T}{\frac{3x}{KA}} = \frac{(T_2 - T_1)KA}{3x}$$

$$= \frac{1}{3}\left\{\frac{A(T_2 - T_1)K}{x}\right\} \quad \therefore f = \frac{1}{3}$$

10. **(d)**



Consider a shell of thickness (dr) and of radiius (r) and let the temperature of inner and outer surfaces of this shell be T and $(T - dT)$ respectively.

$\frac{dQ}{dt}$ = rate of flow of heat through it

$$= \frac{KA[(T-dT)-T]}{dr} = \frac{-KAdT}{dr}$$

$$= -4\pi Kr^2 \frac{dT}{dr} \qquad (\because\ A = 4\pi r^2)$$

To measure the radial rate of heat flow, integration technique is used, since the area of the surface through which heat will flow is not constant.

$$\text{Then, } \left(\frac{dQ}{dt}\right)\int_{r_1}^{r_2} \frac{1}{r^2} dr = -4\pi K \int_{T_1}^{T_2} dT$$

$$\frac{dQ}{dt}\left[\frac{1}{r_1} - \frac{1}{r_2}\right] = -4\pi K\left[T_2 - T_1\right]$$

$$\text{or } \frac{dQ}{dt} = \frac{-4\pi K r_1 r_2 (T_2 - T_1)}{(r_2 - r_1)}$$

$$\therefore \quad \frac{dQ}{dt} \propto \frac{r_1\, r_2}{(r_2 - r_1)}$$

11. (b) Total power radiated by Sun = $\sigma T^4 \times 4\pi R^2$

The intensity of power at earth's surface

$$= \frac{\sigma T^4 \times 4\pi R^2}{4\pi r^2}$$

Total power received by Earth

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

12. (c) Heat lost by He = Heat gained by N_2

$$n_1 C_{v_1} \Delta T_1 = n_2 C_{v_2} \Delta T_2$$

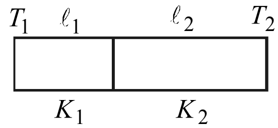
$$\frac{3}{2}R\left[\frac{7}{3}T_0 - T_f\right] = \frac{5}{2}R\left[T_f - T_0\right]$$

$$7T_0 - 3T_f = 5T_f - 5T_0$$

$$\Rightarrow 12T_0 = 8T_f \Rightarrow T_f = \frac{12}{8}T_0$$

$$\Rightarrow T_f = \frac{3}{2}T_0.$$

13. (d) Let T be the temperature of the interface. As the two sections are in series, the rate of flow of heat in them will be equal.



$$\therefore \quad \frac{K_1 A(T_1 - T)}{\ell_1} = \frac{K_2 A(T - T_2)}{\ell_2},$$

where A is the area of cross-section.

or, $\quad K_1 A(T_1 - T)\ell_2 = K_2 A(T - T_2)\ell_1$

or, $\quad K_1 T_1 \ell_2 - K_1 T \ell_2 = K_2 T \ell_1 - K_2 T_2 \ell_1$

or, $\quad (K_2\ell_1 + K_1\ell_2)T = K_1 T_1 \ell_2 + K_2 T_2 \ell_1$

$$\therefore T = \frac{K_1 T_1 \ell_2 + K_2 T_2 \ell_1}{K_2 \ell_1 + K_1 \ell_2}$$

$$= \frac{K_1 \ell_2 T_1 + K_2 \ell_1 T_2}{K_1 \ell_2 + K_2 \ell_1}.$$

14. (a) The heat flow rate is given by

$$\frac{dQ}{dt} = \frac{kA(\theta_1 - \theta)}{x}$$

$$\Rightarrow \theta_1 - \theta = \frac{x}{kA}\frac{dQ}{dt} \;\Rightarrow\; \theta = \theta_1 - \frac{x}{kA}\frac{dQ}{dt}$$

where θ_1 is the temperature of hot end and θ is temperature at a distance x from hot end.

The above equation can be graphically represented by option (a).

15. (a) $\Delta U = \Delta Q = mc\Delta T$

$= 100 \times 10^{-3} \times 4184\,(50 - 30) \approx 8.4$ kJ

16. (d) Required work = energy released

Here, $Q = \int mc\, dT$

$$= \int_{20}^{4} 0.1 \times 32 \times \left(\frac{T^3}{400^3}\right) dT \;\approx 0.002 \text{ kJ}.$$

Therefore, required work = 0.002 kJ

17. (d) The Young modulus is given as

$$Y = \frac{F/S}{\Delta L/L}$$

Here it is given as

$$Y = \frac{F}{S2\pi\Delta R} \times 2\pi R \quad \{L = 2\pi R\}$$

$$\text{or} \quad Y = \frac{FR}{S.\Delta R} \qquad \ldots(i)$$

The coefficient of linear expansion is given as $\alpha = \dfrac{\Delta R}{R\Delta T}$

$$\Rightarrow \frac{\Delta R}{R} = \alpha.\Delta T \Rightarrow \frac{R}{\Delta R} = \frac{1}{\alpha\Delta T} \quad \ldots\text{(ii)}$$

From equation (i) and (ii)

$$Y = \frac{F}{S.\alpha\Delta T} \Rightarrow F = Y.S.\alpha\Delta T$$

$\therefore$ The ring is pressing the wheel from both sides, Thus

$$F_{net} = 2F = 2YS\alpha\Delta T$$

18. (a) Newton's law of cooling

$$\frac{d\theta}{dt} = -k(\theta - \theta_0)$$

$$\Rightarrow \frac{d\theta}{(\theta - \theta_0)} = -kdt$$

Integrating

$$\Rightarrow \log(\theta - \theta_0) = -kt + c$$

Which represents an equation of straight line.

Thus the option (a) is correct.

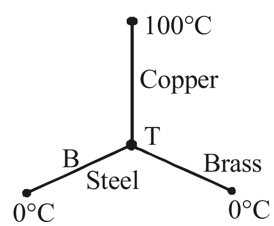
19. (c) According to Newton's law of cooling, the temperature goes on decreasing with time non-linearly.

20. (c) Rate of heat flow is given by,

$$Q = \frac{KA(\theta_1 - \theta_2)}{l}$$

Where, K = coefficient of thermal conductivity

l = length of rod and A = area of cross-section of rod



If the junction temperature is T, then

$$Q_{Copper} = Q_{Brass} + Q_{Steel}$$

$$\frac{0.92 \times 4(100 - T)}{46} = \frac{0.26 \times 4 \times (T - 0)}{13} + \frac{0.12 \times 4 \times (T - 0)}{12}$$

$\Rightarrow$ $200 - 2T = 2T + T$

$\Rightarrow$ $T = 40°C$

$$\therefore \quad Q_{Copper} = \frac{0.92 \times 4 \times 60}{46} = 4.8 \text{ cal/s}$$

21. (a) As, $P = \dfrac{1}{3}\left(\dfrac{U}{V}\right)$

But $\dfrac{U}{V} = KT^4$

So, $P = \dfrac{1}{3}KT^4$

or $\dfrac{uRT}{V} = \dfrac{1}{3}KT^4$ [As PV = u RT]

$$\frac{4}{3}\pi R^3 T^3 = \text{constant}$$

Therefore, $T \propto \dfrac{1}{R}$

22. (c) Time lost/gained per day $= \dfrac{1}{2} \propto \Delta\theta \times 86400$ second

$$12 = \frac{1}{2}\alpha(40 - \theta) \times 86400 \quad \ldots\text{(i)}$$

$$4 = \frac{1}{2}\alpha(\theta - 20) \times 86400 \quad \ldots\text{(ii)}$$

On dividing we get, $3 = \dfrac{40 - \theta}{\theta - 20}$

$3\theta - 60 = 40 - \theta$

$4\theta = 100 \Rightarrow \theta = 25°C$

23. (d) According to principle of calorimetry,

Heat lost = Heat gain

$$100 \times 0.1(-75) = 100 \times 0.1 \times 45 + 170 \times 1 \times 45$$

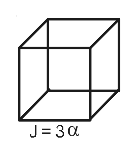
$$10 - 750 = 450 + 7650$$

$$10 = 1200 + 7650 = 8850$$

$$T = 885°C$$

24. (c) As we know, Bulk modulus

$$K = \frac{\Delta P}{\left(\dfrac{-\Delta V}{V}\right)} \Rightarrow \frac{\Delta V}{V} = \frac{P}{K}$$



$$V = V_0(1 + \gamma\Delta t)$$

$$\frac{\Delta V}{V_0} = \gamma\Delta t$$

$$\therefore \quad \frac{P}{K} = \gamma\Delta t \Rightarrow \Delta t = \frac{P}{\gamma K} = \frac{P}{3\alpha K}$$