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Q1. **What is temperature for which of the reading on Celsius and Fahrenheit scale are same?**

Q2. **Define specific heat. Write its SI unit.**

Q3. **What is latent heat?**

Q4. **When a Centigrade thermometer is taken from the melting ice to a warm liquid, the mercury level rises to $(2/5)^{th}$ of the distance between the lower and the upper fixed points. Find the temperature of liquid in °C and K.**

Q5. **A faulty thermometer has its fixed points marked as 5 °C and 95 °C. The temperature of a body as measured by the faulty thermometer is 59 °C. Find the correct temperature of the body on Celsius scale.**

Q6. **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.**

Q7. **Two absolute scales *A* and *B* have triple points of water defined to be 200 *A* and 350 *B*. What is the relation between T_A and T_B?**

Q8. **(a) The triple-point of water is a standard fixed point in modern thermometry. Why? What is wrong in taking the melting point of ice and the boiling point of water as standard fixed points (as was originally done in the Celsius scale)?**

(b) There were two fixed points in the original Celsius scale as men mentioned above which were assigned the number 0 °C and 100 °C 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 the temperature of the triple-point of water on an absolute scale whose unit interval size is equal to that of the Fahrenheit scale?

Q9. **The electrical resistance in ohms of a certain thermometer varies with temperature according to the approximate law:**

$$R = R_0 [1 + \alpha (T - T_0)]$$

The resistance is 101.6 Ω at the triple-point of water 273.16 K, and 165.5 Ω at the normal melting point of lead (600.5 K). What is the temperature when the resistance is 123.4 Ω?

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S1. Let x be the temperature, which has the same reading on Celsius and Fahrenheit scales.

Then, $C = F = x$

From the relation: $\frac{C}{5} = \frac{F-32}{9}$

$$\frac{x}{5} = \frac{x-32}{9}$$

or $x = -40°$

S2. The specific heat of the material of substance may be defined as the amount of heat required to raise the temperature of the unit mass of substance through 1 °C.

S.I. unit of specific heat J kg^{-1} K^{-1}.

S3. The latent heat of substance may be defined as quantity of heat required to change the unit mass of the substance completely from its one state to another state at constant temperature.

S4. The lower fixed point of Centigrade thermometer

$$= 0\,°C;$$

Upper fixed point of Centigrade thermometer

$$= 100\,°C$$

If C is temperature of the warm liquid, then

$$C = \frac{2}{5} \times (100 - 0) = 40\,°C$$

The temperature of liquid on absolute scale

$$= 273.15 + 40 = \mathbf{313.15\ K}.$$

S5. Let θ_0 be the lower fixed point of the faulty thermometer and n be the number of divisions between its lower and the upper fixed points. If a temperature C on Celsius scale corresponds to temperature θ_0 on the scale of faulty thermometer, then

$$\frac{C-0}{100} = \frac{\theta-\theta_0}{n} \quad \ldots \text{(i)}$$

Here, $\theta_0 = 5\,°C$; $n = 95 - 5 = 90$ and $\theta = 59\,°C$

Therefore, the equation (i) becomes

$$\frac{C-0}{100} = \frac{59-5}{95-5}$$

or $$C = \frac{54}{90} \times 100$$

or $$C = 60\,°C.$$

S6. Kelvin and Celsius scales are related as:

$$T_C = T_K - 273.15 \quad \ldots \text{(i)}$$

Celsius and Fahrenheit scales are related as:

$$T_F = \frac{9}{5} T_C + 32 \quad \ldots \text{(ii)}$$

For neon:

$$T_K = 24.57\text{ K}$$

$\therefore$ $$T_C = 24.57 - 273.15 = -248.58°C$$

$$T_F = \frac{9}{5} T_C + 32$$

$$= \frac{9}{5}(-248.58) + 32$$

$$= -415.44°F$$

For carbon dioxide:

$$T_K = 216.55\text{ K}$$

$\therefore$ $$T_C = 216.55 - 273.15 = -56.60°C$$

$$T_F = \frac{9}{5} T_C + 32$$

$$= \frac{9}{5}(-56.60) + 32$$

$$= -69.88°C.$$

S7. Triple point of water on absolute scale A, $T_1 = 200\,A$

Triple point of water on absolute scale B, $T_2 = 350\,B$

Triple point of water on Kelvin scale, $T_K = 273.15\,K$

The temperature 273.15 K on Kelvin scale is equivalent to 200 A on absolute scale A.

$$T_1 = T_K$$

$$200\,A = 273.15\,K$$

$\therefore$ $$A = \frac{273.15}{200}$$

The temperature 273.15 K on Kelvin scale is equivalent to 350 B on absolute scale B.

$$T_2 = T_K$$

$$350\,B = 273.15$$

$$\therefore \quad B = \frac{273.15}{350}$$

T_A is triple point of water on scale A.

T_B is triple point of water on scale B.

$$\therefore \quad \frac{273.15}{200} \times T_A = \frac{273.15}{350} \times T_B$$

$$T_A = \frac{200}{350} T_B$$

Therefore, the ratio $T_A : T_B$ is given as 4 : 7.

S8. (a) The triple point of water has a unique value of 273.16 K. At particular values of volume and pressure, the triple point of water is always 273.16 K. The melting point of ice and boiling point of water do not have particular values because these points depend on pressure and temperature.

(b) The absolute zero or 0 K is the other fixed point on the Kelvin absolute scale.

(c) The temperature 273.16 K is the triple point of water. It is not the melting point of ice. The temperature 0 °C on Celsius scale is the melting point of ice. Its corresponding value on Kelvin scale is 273.15 K.

Hence, absolute temperature (Kelvin scale) T, is related to temperature t_c, on Celsius scale as:

$$t_c = T - 273.15$$

(d) Let T_F be the temperature on Fahrenheit scale and T_K be the temperature on absolute scale. Both the temperatures can be related as:

$$\frac{T_F - 32}{180} = \frac{T_K - 273.15}{100} \qquad \text{... (i)}$$

Let T_{F1} be the temperature on Fahrenheit scale and T_{K1} be the temperature on absolute scale. Both the temperatures can be related as:

$$\frac{T_{F1} - 32}{180} = \frac{T_{K1} - 273.15}{100} \qquad \text{... (ii)}$$

It is given that:

$$T_{K1} - T_K = 1\,K$$

Subtracting equation (i) from equation (ii), we get:

$$\frac{T_{F1} - T_F}{180} = \frac{T_{K1} - T_K}{100} = \frac{1}{100}$$

$$T_{F1} - T_F = \frac{1 \times 180}{100} = \frac{9}{5}$$

Triple point of water = 273.16 K

$\therefore$ Triple point of water on absolute scale = $273.16 \times \frac{9}{5} = 491.69$.

S9. It is given that:

$$R = R_0 [1 + \alpha (T - T_0)] \quad \dots (i)$$

Where,

R_0 and T_0 are the initial resistance and temperature respectively

R and T are the final resistance and temperature respectively α is a constant

At the triple point of water, $T_0 = 273.15$ K

Resistance of lead, $R_0 = 101.6\,\Omega$

At normal melting point of lead, $T = 600.5$ K

Resistance of lead, $R = 165.5\,\Omega$

Substituting these values in equation (i), we get:

$$R = R_0 [1 + \alpha (T - T_0)]$$

$$165.5 = 101.6 [1 + \alpha (600.5 - 273.15)]$$

$$1.629 = 1 + \alpha (327.35)$$

$$\therefore \quad \alpha = \frac{0.629}{327.35} = 1.92 \times 10^{-3}\ K^{-1}$$

For resistance, $R_1 = 123.4\,\Omega$

$$R_1 = R_0 [1 + \alpha (T - T_0)]$$

Where, T is the temperature when the resistance of lead is $123.4\,\Omega$

$$123.4 = 101.6 [1 + 1.92 \times 10^{-3} (T - 273.15)]$$

$$1.214 = 1 + 1.92 \times 10^{-3} (T - 273.15)]$$

$$\frac{0.214}{1.92 \times 10^{-3}} = T - 273.15$$

$$\therefore \quad T = 384.61\ K.$$

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Q1. A substance absorbs heat Q_1 in going from one state to another and releases Q_2 in coming from the second state to the first state. How much work is done by the substance and what is the change in the internal energy of the substance?

Q2. Is the specific heat of sand greater than that water?

Q3. Do water and ice have the same specific heats?

Q4. Why are telephone wires often given snag?

Q5. Why a small space is left between the two rails on a railway track?

Q6. The top of a lake is frozen. Air in contact is at –15 °C. What do you expect the maximum temperature of water (a) in contact with the lower surface of ice and (b) at the bottom of the lake?

Q7. Is the value of temperature coefficient always positive.

Q8. Are coefficients of thermal expansion constant for given solid?

Q9. Of metal and alloy, which has greater value of temperature coefficient ?

Q10. Do the values of coefficients of expansion differ, when the lengths are measured in cgs system or in SI?

Q11. Why do two layers of a cloth of equal thickness provide warmer covering than a single layer of cloth of double the thickness?

Q12. A blacksmith fixes iron ring on the rim of the wooden wheel of a bullock cart. The diameter of the rim and the iron ring are 5.243 m and 5.231 m respectively at 27°C. To what temperature should the ring be heated so as to fit the rim of the wheel?

Q13. What is the coefficient of linear, superficial and cubical expansion?

Q14. What is relation among α, β and γ?

Q15. Why is clock pendulum made of invar?

Q16. Pendulum clocks generally go fast in winter and slow in summer. Why?

Q17. What is wrong in taking the melting point of ice and the boiling point of water as standard fixed points (as was originally done in the Celsius scale)?

Q18. Two thermometer are constructed in the same way, except that one has a spherical bulb and the other a cylindrical bulb. Which will respond quickly to temperature changes?

Q19. How much the temperature of a brass rod should be increased, so as to increase its length by 1%? Given that a for brass = 0.00002 $^{\circ}C^{-1}$.

Q20. How the fishes can survive in the extreme winter, when ponds and lakes are frozen?

Q21. A specific gravity bottle is marked with its volume along with a temperature value. Why?

Q22. A circular piece is cut from flat metal sheet. The sheet is, then, placed in a surface. Will the size of hole become larger or smaller? Explain.

Q23. A steel tape is calibrated at 20 °C. On a cool day, when the temperature is – 15 °C, what will be the percentage error in the tape? For steel, $\alpha = 1.1 \times 10^{-5}\ ^{\circ}C^{-1}$.

Q24. An iron scale is correct at 0 °C and the length of a zinc rod as measured by the scale is 100 cm, when both of the scale and the rod are at 0 °C. What will be the length of the rod as measured by an iron scale, when both of them are at 100 °C? Given, α for iron = $12 \times 10^{-6}\ ^{\circ}C^{-1}$ and for zinc = $26 \times 10^{-6}\ ^{\circ}C^{-1}$.

Q25. It is required to prepare a steel meter scale, such that the millimeter intervals are to be accurate within 0.0005 mm at a certain temperature. Determine the maximum temperature variation allowable during the rulings of millimeter marks. Given, α for steel = $1.322 \times 10^{-5}\ ^{\circ}C^{-1}$.

Q26. A brass rod of length 40 cm is join copper rod of length 50 cm. The two rods are of the same thickness and at initial temperature of 40 °C. When change in length of the combined rod, when the same is to 280 °C. Coefficients of linear expansion of brass $1.9 \times 10^{-5}\ ^{\circ}C^{-1}$ and are $1.7 \times 10^{-5}\ ^{\circ}C^{-1}$ respectively.

Q27. A circular sheet of copper of radius 35 cm is at 20 °C. On heating, its area increases by 14.5 cm^2. If coefficient of linear expansion of copper is $1.7 \times 10^{-5}\ ^{\circ}C^{-1}$, find the temperature to which the sheet was heated.

Q28. Two rods *A* and *B* are of equal length. Each rod has its ends at temperatures T_1 and T_2. What are the conditions that will ensure equal rates of flow of heat through the roads *A* and *B*?

Q29. Given below are observations on molar specific heats at room temperature of some common gases.

Gas	Hydrogen	Nitrogen	Oxygen	Nitric oxide	Carbon monoxide	Chlorine
Molar specific heat (Cv) (cal mol^{-1} K^{-1})	4.87	4.97	5.02	4.99	5.01	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. Explain this difference. What can you infer from the somewhat larger (than the rest) value for chlorine?

Q30. Show that the coefficient of area expansions, $(\Delta A/A)/\Delta T$, of a rectangular sheet of the solid is twice its linear expansivity, α_1.

Q31. A steel beam is 5 m long at a temperature of 20 °C. On a hot day, the temperature rises to 40 °C.

(a) What is the change in the length of the beam due to thermal expansion?

(b) Suppose that the ends of the beam are initially in contact with rigid vertical support. How much force will the expanded beam exert on the support, if it has a cross-sectional area of 60 cm^2. Given, coefficient of linear expansion of steel = $1.2 \times 10^{-5}\ C^{-1}$ and Young's modulus of steel = $2.0 \times 10^{11}\ N m^{-2}$.

Q32. (a) The ratio of thermal conductivities of two different metal is 5 : 3. In order to have the same thermal resistance in these metals of equal thickness, what should be the ratio of their lengths?

(b) How much the temperature of a brass rod should be increased, so as to increase its length by 2%? Given that a for brass = 0.00005 $^{\circ}C^{-1}$.

Q33. Draw the energy- distribution graph of a black body. List some salient features.

Q34. The coefficient of volume expansion of mercury is $5.4 \times 10^{-4}\ ^{\circ}C^{-1}$. What is the fractional change in its density for a 80 $^{\circ}$C rise in temperature?

Q35. Two ideal gas thermometers *A* and *B* use oxygen and hydrogen respectively. The following observations are made:

Temperature	Pressure thermometer *A*	Pressure thermometer *B*
Triple-point of water	1.250×10^5 Pa	0.200×10^5 Pa
Normal melting point of sulphur	1.797×10^5 Pa	0.287×10^5 Pa

What is the absolute temperature of normal melting point of sulphur as read by thermometers *A* and *B?*

What do you think is the reason behind the slight difference in answers of thermometers *A* and *B?* (The thermometers are not faulty). What further procedure is needed in the experiment to reduce the discrepancy between the two readings?

Q36. A brass wire 1.8 m long at 27 °C is held taut with little tension between two rigid supports. If the wire is cooled to a temperature of – 39 °C, what is the tension developed in the wire, if its diameter is 2.0 mm? Co-efficient of linear expansion of brass = $2.0 \times 10^{-5}\ ^{\circ}C^{-1}$; Young's modulus of brass = 0.91×10^{11} Pa.

Q37. 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 = $1.20 \times 10^{-5}\ ^{\circ}C^{-1}$.

Q38. Two rods of the same area of cross-section, but of lengths l_1 and l_2 and conductivities K_1 and K_2 are joined in series. Show that the combination is equivalent of a material of conductivity $K = \dfrac{l_1 + l_2}{\left(\dfrac{l_1}{K_1}\right) + \left(\dfrac{l_2}{K_2}\right)}$

Q39. Define thermal conduction. Write a relation for rate of flow of heat energy by conduction. Use it to find equivalent resistance when two rods are places in series or parallel.

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S1. Work done $W = Q_1 - Q_2, \Delta U = 0.$

S2. No, the specific heat of sand is less than that of water. It may be noted that the values of the specific heat of water is maximum.

S3. No, water and ice do not have the same values of the specified heat.

For water, $c = 1 \text{ cal g}^{-1} \text{ °C}^{-1}$

And for ice, $c = 0.5 \text{ cal g}^{-1} \text{ °C}^{-1}$

S4. The telephone wires are given snag, so that the wires may contract safely in winter. In case no snag is given, a large tension will develop in the wires, when temperature falls in winter. The tension developed in the wires is so large that the wires may even break.

S5. The solids expand on heating. A small gap is left between the rails so as to allow the expansion of the rails in summer. In case the space is not left, the rails will bend.

S6. (a) 0 °C (b) 4 °C.

S7. It has positive value for metals and alloys. For semiconductors and insulators, the value of α is negative.

S8. The coefficients of expansion of a solid change with temperature.

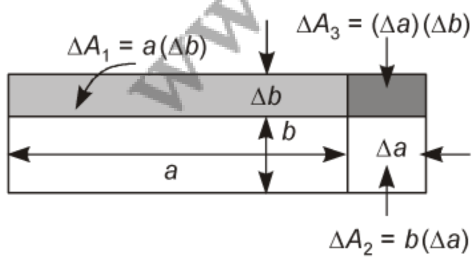
S9. The value of α is more for metal than that for alloys.

For example, α for copper (metal) = 1.7×10^{-5} °C^{-1} and α for invar (alloy) = 6.7×10^{-7} °C^{-1}

S10. No. Because coefficients is the ratio of length energy or volume of the body due to not affected, in cgs or SI form.

S11. The air enclosed between two layers of cloths prevents the transmission of heat from our body to outside.

S12. Given, $T_1 = 27$ °C; $L_{T1} = 5.231$ m; $L_{T2} = 5.243$ m



So, $$L_{T2} = L_{T1}[1 + \alpha_1 (T_2 - T_1)]$$

$$5.243\text{ m} = 5.231\text{ m}[1 + 1.20 \times 10^{-5}\text{ K}^{-1}(T_2 - 27°\text{C})]$$

or $$T_2 = 218°\text{C}.$$

S13. **Coefficient of linear expansion:** The coefficient of linear expansion of the material of a solid is defined as the increase in its length per unit length per unit rise in its temperature.

Coefficient of *Superficial expansion:* The coefficient of superficial expansion of the material of a solid is defined as the increase its surface area per unit surface area per unit rise in its temperature.

Coefficient of *Cubical expansion:* The coefficient of cubical expansion of the material of a solid is defined as the increase in its volume per unit rise in its temperature.

S14. The relation among α, β and γ

$$\alpha = \frac{\beta}{2} = \frac{\gamma}{3}.$$

S15. It is because, invar (alloy of nickel and steel) has extremely small coefficient expansion. Therefore, the length of clock pendulum made of invar does not change appreciably with change of season. As such, the clock keeps correct time in comparison to clock, which make use of pendulum made of other metals.

S16. The time period of a pendulum is given by

$$t = 2\pi\sqrt{\frac{l}{g}},$$

where l is the length of the pendulum. Thus, t is directly proportional to $\sqrt{l}$. In summer, t will increase with increase in temperature; while in winter, t will decrease with fall in temperature. Likewise, pendulum clocks go fast in winter and slow in summer.

S17. The melting point of ice and the boiling point of water change with change in the value of pressure. Further, melting point of ice and the boiling point of water also change, if some impurities are dissolved in water.

S18. For the given volume, a sphere has minimum surface area. Therefore, the thermometer whose bulb is cylindrical will respond quickly to temperature, as its bulb will attain the temperature of the body quickly due greater surface area of the bulb.

S19. Given, $$\frac{l' - l}{l} = 1\%$$

$$= \frac{1}{100} = 0.01$$

Now, $l' - l = l\alpha\Delta T$

or $\dfrac{l' - l}{l} = \alpha\,\Delta T$

$$\alpha\Delta T = 0.01$$

or $\Delta T = \dfrac{0.01}{\alpha}$

$$= \frac{0.01}{0.00002} = \mathbf{500\ ^{o}C}.$$

S20. When it is extreme cold, the temperature of water in ponds and lakes starts falling. On getting colder, water becomes denser and it goes down. To replace it, the warmer water from below rises up. However, it happens so, till the temperature of water at the bottom of the pond becomes 4 °C. It is because, the density of water is maximum at 4 °C. Now, as the temperature lower further, ice is formed at the surface of the pond with water below it. In this manner, the fishes can survive in the extreme winter, when pond and lakes are frozen.

S21. It is because, glass (material of S.G. bottle) expands with increase in temperature. Therefore, at different temperature, the S.G. bottle will hold different volume of a liquid. So as to give a definite meaning to its volume capacity, the volume capacity is marked along with the corresponding temperature.

S22. The size of the whole will increase. To understand it, think of the piece of metal removed from the hole, rather than of the hole itself. This piece would expand on heating. This piece will fit into the hole only, if the hole has also increased in size. Another way to analyse the situation is that if we draw a circle on the metal sheet, the radius of the circle will increase.

S23. Here, $\Delta T = -15 - 20 = -35\ ^{o}C$; $\alpha = 1.1 \times 10^{-5}\ ^{o}C^{-1}$

Let u be the size of 1 cm interval at 20 °C and u' at 15 °C.

Then $u' = u(1 + \alpha\Delta T)$

or $u' - u = u\,\alpha\Delta T$

or $\dfrac{u' - u}{u} = \alpha\Delta T$

$$= 1.1 \times 10^{-5} \times (-35) = -3.85 \times 10^{-4}$$

Therefore, % error in the tape at – 15 °C

$$= \frac{u' - u}{u} \times 100 = -3.85 \times 10^{-4} \times 100 = \mathbf{-0.0385\%}.$$

S24. The iron scale is correct at 0 °C. Let u be the size of one cm interval of the iron scale at 0 °C and u', at 100 °C.

Then, $u' = u(1 + \alpha\Delta T)$

Here, $u = 1$ cm; $\alpha = 12 \times 10^{-6}\ ^oC$ and $\Delta T = 100\ ^oC$

$$u' = 1 \times (1 + 12 \times 10^{-6} \times 100) = 1.0012 \text{ cm}$$

At 100 °C, length of the zinc rod will be

$$l' = l(1 + \alpha\Delta T)$$

or $$l' = 100\ (1 + 26 \times 10^{-6} \times 100)$$

$$= \mathbf{100.26\ cm}$$

Therefore, length of the zinc rod as measured by iron scale at 100 °C

$$= \frac{l'}{u'} = \frac{100.26}{1.0012} = \mathbf{100.14\ cm}.$$

S25. Let ΔT be the variation in temperature, which increase size of 1 mm interval to 1 + 0.0005 *i.e.*, 1.0005 mm.

Here, $u = 1$ mm ; $u' = 1.0005$ mm

Now, $u' = u\ (1 + \alpha\Delta T)$

$\therefore$ $1.0005 = 1 \times (1 + 1.322 \times 10^{-5} \times \Delta T)$

or $$\Delta T = \frac{1.0005 - 1}{1.322 \times 10^{-5}}$$

or $\Delta T = \mathbf{37.8\ ^oC}$.

S26. **For brass rod:** $\alpha_1 = 1.9 \times 10^{-5}\ ^oC^{-1}$; $l_1 = 40$ cm; $\Delta T_1 = 280 - 40 = 240\ ^oC$

The length of the brass rod at 280 °C is given by

$$l_1' = l_1\ (1 + \alpha_1\Delta T_1)$$

$$= 40 \times (1 + 1.9 \times 10^{-5} \times 240) = 40.18\ 24$$

For copper rod: $\alpha_2 = 1.7 \times 10^{-5}\ ^oC^{-1}$;

$$l_2 = 50 \text{ cm}; \quad \Delta T_2 = 280 - 40 = 240\ ^oC$$

The length of the steel rod at 280 °C is given by

$$l_2' = l_2\ (1 + \alpha_2\Delta T_2)$$

$$= 50 \times (1 + 1.7 \times 10^{-5} \times 240) = 50.2040 \text{ cm}$$

Therefore, the length of the combined rod at 280 °C,

$$l_1' + l_2' = 40.1824 + 50.2040 = 90.3864 \text{ cm}$$

As the length of the combined rod at 40 °C is 50 + 40 *i.e.*, 90 cm

The change in length of the combined rod at 280 °C

$$= 90.3864 - 90 = \mathbf{0.3864\ cm.}$$

S27. Here,

$$S = \pi \times 35^2 = 3{,}848.45 \text{ cm}^2;$$

$$\Delta S = 14.5 \text{ cm}^2;$$

$$\theta_1 = 20\,^{\circ}\text{C};$$

$$\beta = 2\,\alpha = 2 \times 1.7 \times 10^{-5} = 3.4 \times 10^{-5}\,^{\circ}\text{C}^{-1}$$

Now,

$$\Delta S = S\beta\Delta T$$

or

$$\Delta T = \frac{\Delta S}{S\beta}$$

$$\Delta T = \frac{14.5}{3{,}848.45 \times 3.4 \times 10^{-5}} = 110.82\,^{\circ}\text{C}$$

If θ_2 is the temperature to which the copper sheet was heated, then

$$\theta_2 = \theta_1 + \Delta T = 20 + 110.82 = \mathbf{130.82\,^{\circ}C}.$$

S28. As

$$\frac{\Delta Q_1}{\Delta t} = \frac{\Delta Q_2}{\Delta t}$$

$$K_1 A_1 \frac{(T_2 - T_1)}{\Delta x_1} = K_2 A_2 \frac{(T_2 - T_1)}{\Delta x_2}$$

As rods have equal length,

$$\Delta x_1 = \Delta x_2$$

$$K_1 A_1 = K_2 A_2 \quad \text{or} \quad \frac{A_1}{A_2} = \frac{K_2}{K_1}.$$

i.e., ratio of cross sectional area of the two rods must be in the inverse ratio of their thermal conductivities.

S29. The gases listed in the given table are diatomic. Besides the translational degree of freedom, they have other degrees of freedom (modes of motion).

Heat must be supplied to increase the temperature of these gases. This increases the average energy of all the modes of motion. Hence, the molar specific heat of diatomic gases is more than that of monatomic gases.

If only rotational mode of motion is considered, then the molar specific heat of a diatomic

$$\text{gas} = \frac{5}{2}R$$

$$= \frac{5}{2} \times 1.98 = 4.95 \text{ cal mol}^{-1}\text{K}^{-1}$$

With the exception of chlorine, all the observations in the given table agree with $\left(\frac{5}{2}R\right)$.

This is because at room temperature, chlorine also has vibrational modes of motion besides rotational and translational modes of motion.

S30. Consider a rectangular sheet of the solid material of length a and breadth b (see figure). When the temperature increases by ΔT, a increases by $\Delta a = \alpha_1 a\Delta T$ and b increases by $\Delta b = \alpha_1 b\Delta T$. From figure, the increase in area

$$\Delta A = \Delta A_1 + \Delta A_2 + \Delta A_3$$

$$\Delta A = a\,\Delta b + b\,\Delta a + (\Delta a)\,(\Delta b)$$

$$= a\,\alpha_1\,b\,\Delta T + b\,\alpha_1\,a\,\Delta T + (\alpha_1)^2\,ab\,(\Delta T)^2$$

$$= \alpha_1\,ab\,\Delta T\,(2 + \alpha_1\,\Delta T) = \alpha_1\,A\,\Delta T\,(2 + \alpha_1\,\Delta T)$$

Since $\alpha_1 \simeq 10^{-5}\,K^{-1}$, from Table 11.1, the product $\alpha_1\,\Delta T$ for fractional temperature is small in comparision with 2 and may be neglected.

Hence,

$$\left(\frac{\Delta A}{A}\right)\frac{1}{\Delta T} \simeq \alpha_1.$$

S31. (a) Given, $l_1 = 5$ m; $\Delta T = 40 - 20 = 20\,^oC$;

$$\alpha = 1.2 \times 10^{-5}\,^oC^{-1}$$

If l_2 length of the beam at 40 °C, then

$$l_2 = l_1\,(1 + \alpha\,\Delta T) = 5 \times (1 + 1.2 \times 10^{-5} \times 20)$$

$$= 5 \times (1 + 2.4 \times 10^{-4}) = 5.0012 \text{ m}$$

Therefore, increase in length of the beam,

$$\Delta l = l_2 - l_1$$

$$= 5.0012 - 5 = 0.0012 \text{ m} = \mathbf{1.2\ mm}.$$

(b) Given, $Y = 2.0 \times 10^{11}$ N m^{-2}; $a = 60$ cm$^2 = 60 \times 10^{-4}$ m^2

Now, Young's modulus of the material of the beam is given by

$$Y = \frac{F/a}{\Delta l/l_1} = \frac{F \times l_1}{a \times \Delta l}$$

or

$$F = \frac{Y a\,\Delta l}{l_1}$$

$$= \frac{2.0 \times 10^{11} \times 60 \times 10^{-4} \times 0.0012}{5}$$

$$= \mathbf{2.88 \times 10^5\ N}.$$

S32. (a) Thermal resistance,

$$R_{M_1} = \frac{l_1}{K_1 A_1}$$

and $$R_{M_2} = \frac{l_2}{K_2 A_2}$$

Since $$R_{M_1} = R_{M_2} \quad \Rightarrow \quad \frac{l_1}{K_1 A_1} = \frac{l_2}{K_2 A_2}$$

or $$\frac{l_1}{K_1} = \frac{l_2}{K_2}$$ [∵ They have equal thickness]

∴ $$\frac{l_1}{l_2} = \frac{K_1}{K_2} = \frac{5}{3}.$$

(b) Given, $$\frac{l' - l}{l} = 2\%$$

$$= \frac{2}{100} = 0.02$$

Now, $$l' - l = l\alpha\Delta T$$

or $$\frac{l' - l}{l} = \alpha\,\Delta T$$

$$\alpha\Delta T = 0.02$$

or $$\Delta T = \frac{0.02}{\alpha}$$

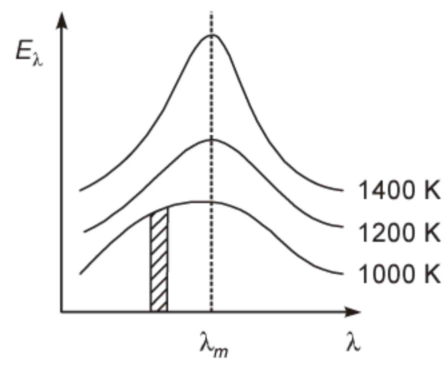
$$= \frac{0.02}{0.00005} = \mathbf{400\ ^\circ C}.$$

S33. (a) At a given temperature with increase in wavelength, the energy radiated increases and the decreases.

(b) As the temperature increases, there is a shift in the wavelength towards lesser values corresponding to maximum intense wavelength as given by

$$\lambda_m T = \text{constant } (2.89 \times 10^{-3}\ \text{m K}).$$

(c) Area below the graph in a specified wavelength range is a measure of the radiant energy in that wavelength range.



S34. Given, $\gamma = 5.4 \times 10^{-4}\ ^\circ C^{-1}$; $\Delta T = 80\ ^\circ C$

Let there be m grams of mercury and its initial volume be V. Suppose that the volume of the mercury V' after a rise of temperature of $80\ ^\circ C$. Then,

$$V' = V(1 + \gamma\Delta T)$$

$$= V(1 + 5.4 \times 10^{-4} \times 80)$$

or $$V' = 1.0432\,V$$

Initial density of the mercury,

$$\rho = \frac{m}{V}$$

Final density of the mercury,

$$\rho' = \frac{m}{V'} = \frac{m}{1.0432\,V} = \frac{\rho}{1.0432}$$

$$\rho' = \mathbf{0.9586}\,\rho.$$

Therefore, fractional change in the value of density of mercury,

$$\frac{\rho - \rho'}{\rho} = \frac{\rho - 0.9586\rho}{\rho} = \mathbf{0.0414}.$$

S35. Triple point of water, $T = 273.16$ K.

At this temperature, pressure in thermometer A,

$$P_A = 1.250 \times 10^5\,\text{Pa}$$

Let T_1 be the normal melting point of sulphur.

At this temperature, pressure in thermometer A,

$$P_1 = 1.797 \times 10^5\,\text{Pa}$$

According to Charles' law, we have the relation:

$$PT = \text{Constant}$$

$$P_1 T_1 = P_2 T_2$$

$$\frac{P_A}{T} = \frac{P_1}{T_1}$$

$$\therefore \quad T_1 = \frac{P_1 T}{P_A} = \frac{1.797 \times 10^5 \times 273.16}{1.250 \times 10^5} = 392.69\,\text{K}$$

Therefore, the absolute temperature of the normal melting point of sulphur as read by thermometer A is 392.69 K.

At triple point 273.16 K, the pressure in thermometer B,

$$P_B = 0.200 \times 10^5\,\text{Pa}$$

At temperature T_1, the pressure in thermometer B,

$$P_2 = 0.287 \times 10^5 \text{ Pa}$$

According to Charles' law, we can write the relation:

$$\frac{P_B}{T} = \frac{P_1}{T_1}$$

$$\frac{0.200 \times 10^5}{273.16} = \frac{2.287 \times 10^5}{T_1}$$

$$\therefore \quad T_1 = \frac{0.287 \times 10^5}{0.200 \times 10^5} \times 273.16 = 391.98 \text{ K.}$$

Therefore, the absolute temperature of the normal melting point of sulphur as read by thermometer B is 391.98 K.

The oxygen and hydrogen gas present in thermometers A and B respectively are not perfect ideal gases. Hence, there is a slight difference between the readings of thermometers A and B.

To reduce the discrepancy between the two readings, the experiment should be carried under low pressure conditions. At low pressure, these gases behave as perfect ideal gases.

S36. Initial temperature, $T_1 = 27°C$

Length of the brass wire at T_1, $l = 1.8$ m

Final temperature, $T_2 = -39\,°C$

Diameter of the wire, $d = 2.0 \text{ mm} = 2 \times 10^{-3}$ m

Tension developed in the wire $= F$

Coefficient of linear expansion of brass,

$$\alpha = 2.0 \times 10^{-5}\,°C^{-1}$$

Young's modulus of brass, $Y = 0.91 \times 10^{11}$ Pa

Young's modulus is given by the relation:

$$Y = \frac{\text{Stress}}{\text{Strain}} = \frac{\frac{F}{A}}{\frac{\Delta L}{L}}$$

$$\Delta L = \frac{F \times L}{A \times Y} \qquad \ldots \text{(i)}$$

Where,

A = Area of cross-section of the wire.

ΔL = Change in the length, given by the relation:

$$\Delta L = \alpha L\,(T_2 - T_1) \qquad \ldots \text{(ii)}$$

Equating equations (i) and (ii), we get:

$$\alpha L(T_2 - T_1) = \frac{FL}{\pi\left(\frac{d}{2}\right)^2 \times Y}$$

$$F = \alpha(T_2 - T_1)\pi Y\left(\frac{d}{2}\right)^2$$

$$F = 2 \times 10^{-5} \times (-39 - 27) \times 3.14 \times 0.91 \times 10^{11} \times \left(\frac{2 \times 10^{-3}}{2}\right)^2$$

$$= -3.8 \times 10^2 \text{ N.}$$

(The negative sign indicates that the tension is directed inward.)

Hence, the tension developed in the wire is 3.8×10^2 N.

S37. Length of the steel tape at temperature $T = 27\,°C$, $l = 1$ m = 100 cm

At temperature $T_1 = 45\,°C$, the length of the steel rod, $l_1 = 63$ cm

Coefficient of linear expansion of steel, $\alpha = 1.20 \times 10^{-5}\,°C^{-1}$

Let l_2 be the actual length of the steel rod and l' be the length of the steel tape at 45°C.

$$l' = l + \alpha l(T_1 - T)$$

$\therefore$
$$l' = 100 + 1.20 \times 10^{-5} \times 100(45 - 27)$$
$$= 100.0216 \text{ cm}$$

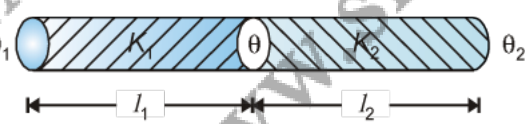
Hence, the actual length of the steel rod measured by the steel tape at 45°C can be calculated as:

$$l_2 = \frac{100.0216}{100} \times 63 = 63.0136 \text{ cm}$$

Therefore, the actual length of the rod at 45.0°C is 63.0136 cm. Its length at 27.0°C is 63.0 cm.

S38. Given two rods lengths l_1 and l_2 and conductivities of rod K_1 and K_2.

Since they are in series, the rate of flow of heat energy is the same. But the sum of the difference in temperature is the difference across their free ends.



$\therefore$
$$(\theta_1 - \theta) + (\theta - \theta_2) = (\theta_1 - \theta_2)$$

i.e.,
$$\frac{Q}{t}\cdot\frac{l_1}{K_1 . A} + \frac{Q}{t}\cdot\frac{l_2}{K_2 . A} = \frac{Q}{t}\cdot\frac{(l_1 + l_2)}{K_{eq} . A}$$

$$\frac{l_1}{K_1} + \frac{l_2}{K_2} = \frac{l_1 + l_2}{K_{eq}} \qquad \therefore\ K_{eq} = \frac{l_1 + l_2}{\left(\frac{l_1}{K_1}\right) + \left(\frac{l_2}{K_2}\right)}.$$

S39. ***Conduction:*** Transfer of heat by the collision among the molecules with their neighbours is called conduction. Rate of heat transfer is given by,

$$\frac{Q}{t} = \frac{KAd\theta}{dl},$$

where K is called thermal conductivity.

Thermal conductivity is defined as heat energy transferred in unit time from unit area having a difference in temperature of unity over unit length. It is expressed in $J\,s^{-1}\,m^{-1}\,{}^{o}C^{-1}$ or $W\,m^{-1}\,K^{-1}$.

When rods are arranged in series, $\frac{Q}{t}$ is same in both and the sum of the difference in temperature across their ends is the difference at the open ends.

i.e., $$(\theta_1 - \theta) + (\theta - \theta_2) = (\theta_1 - \theta_2)$$

Using $\frac{Q}{t} = \frac{d\theta}{R_{N\text{th}}}$ we get

$$\left(\frac{Q}{t}\right) R_1 + \left(\frac{Q}{t}\right) R_2 = \left(\frac{Q}{t}\right) R_{N\,\text{th}}$$

When rods are arranged in parallel and the difference in temperature will be the same, then

$$\left(\frac{Q}{t}\right)_N = \left(\frac{Q}{t}\right)_1 + \left(\frac{Q}{t}\right)_2$$

i.e., $$\frac{d\theta}{R_N} = \frac{d\theta}{R_1} + \frac{d\theta}{R_2}$$

$$\boldsymbol{\frac{1}{R_N} = \frac{1}{R_1} + \frac{1}{R_2}}.$$

Date: 14/10/2021

Q1. What is the basic principal of a thermometer?

Q2. State whether the following characteristics of a metal washer increase, decrease or remain the same, when the washer is heated?

(a) internal diameter (b) volume

(c) mass (d) density

Q3. A metal ball is heated through a certain temperature. Out of mass, radius, surface area and volume, which will undergo largest percentage increase and which on the least?

Q4. Why is it cooler at the top of mountains?

Q5. Why a thick glass tumbler cracks, when boiling water is poured in it.

Q6. Iron rims are heated red hot before planting on cart wheels. Why?

Q7. Even when no heat is exchanged by the contents of a thermos flask, the contents get heated up by constant shaking. Why?

Q8. Distinguish radiation and convection methods of heat transfer.

Q9. Write the salient features of heat radiations.

Q10. Answer the following questions based on the *P-T* phase diagram of carbon dioxide:

(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?

Q11. Answer the following questions based on the *P–T* phase diagram of CO_2:

(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 given 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?

Date: 14/10/2021

S1. The variation of any physical property of the substance with temperature form the principal of the thermometer.

S2. (a) increases (b) increases

(c) remains the same (d) decreases

S3. There will be no change in mass. The volume will undergo largest percentage increase; while the radius, minimum. It is because, volume of the spherical ball depends on cube of its radius.

S4. Atmosphere is less dense at higher altitudes. So, the radiated energy from surface of earth escapes at higher altitudes. So, it is comparatively cooler at high mountains.

S5. When boiling water is poured into a thick tumbler, its inner surface expands. However, due to low thermal conductivity of glass, the expansion of outer surface of the tumbler is quite small. Due to uneven expansion of the outer and inner surfaces, the tumbler breaks.

S6. The radius of iron to be put on the cart wheel is always a little smaller than the radius of the wheel. When the iron rim is heated red hot, its size becomes greater than that of wheel and it easily slips on the wheel. When the rim is allowed to cool, it returns to its original size and fits firmly on the wheel.

S7. On shaking, there comes friction between the molecules and the surface and so the heat increases.

S8.

Radiation	*Convection*
(1) No material medium is required.	(1) Requires medium.
(2) Fastest method.	(2) Decided by various parameters like wind, temperature etc.
(3) Depends on the nature of the surface and fourth power of temperature.	(3) Always rises up from hot region.

S9. Heat radiations

(a) can travel through vacuum.

(b) travel with a velocity of 3×10^8 m/sec.

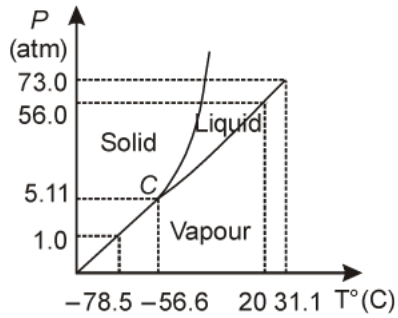
(c) travel in straight lines.

(d) obey the laws of reflection.

(e) does not heat the medium on its way.

(f) reduce their intensity with square of the distance from source.

S10. The *P-T* phase diagram for CO_2 is shown in the following figure.



(a) *C* is the triple point of the CO_2 phase diagram. This means that at the temperature and pressure corresponding to this point (*i.e.*, at – 56.6 °C and 5.11 atm), the solid, liquid, and vaporous phases of CO_2 co-exist in equilibrium.

(b) The fusion and boiling points of CO_2 decrease with a decrease in pressure.

(c) The critical temperature and critical pressure of CO_2 are 31.1 °C and 73 atm respectively.

(d) Even if it is compressed to a pressure greater than 73 atm, CO_2 will not liquefy above the critical temperature.

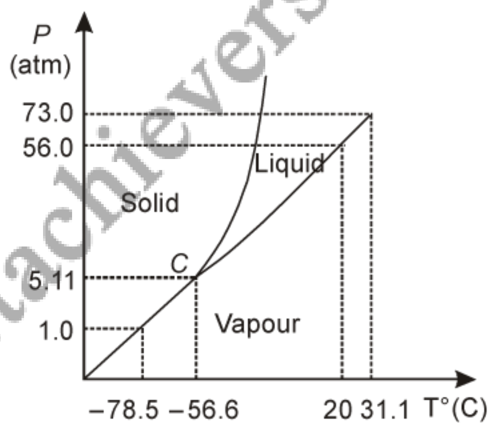
It can be concluded from the *P-T* phase diagram of CO_2 that:

(i) CO_2 is gaseous at – 70°C, under 1 atm pressure

(ii) CO_2 is solid at – 60°C, under 10 atm pressure

(iii) CO_2 is liquid at 15°C, under 56 atm pressure

S11. The *P-T* phase diagram for CO_2 is shown in the following figure.



(a) No, at 1 atm pressure and at – 60°C, CO_2 lies to the left of – 56.6 °C (triple point C). Hence, it lies in the region of vaporous and solid phases.

Thus, CO_2 condenses into the solid state directly, without going through the liquid state.

(b) It condenses to solid directly. At 4 atm pressure, CO_2 lies below 5.11 atm (triple point C) Hence, it lies in the region of vaporous and solid phases. Thus, it condenses into the solid state directly, without passing through the liquid state.

(c) The fusion and boiling points are given by the intersection point where this parallel line cuts the fusion and vaporisation curves. When the temperature of a mass of solid CO_2 (at 10 atm pressure and at – 65°C) is increased, it changes to the liquid phase and then to the vaporous phase. It forms a line parallel to the temperature axis at 10 atm. The fusion and boiling points are given by the intersection point where this parallel line cuts the fusion and vaporisation curves.

(d) It departs from ideal gas behaviour as pressure increases. If CO_2 is heated to 70 °C and compressed isothermally, then it will not exhibit any transition to the liquid state. This is because 70 °C is higher than the critical temperature of CO_2. It will remain in the vapour state, but will depart from its ideal behaviour as pressure increases.

Date: 14/10/2021

Q1. A substance absorbs heat Q_1 in going from one state to another and releases Q_2 in coming from the second state to the first state. How much work is done by the substance and what is the change in the internal energy of the substance?

Q2. Is the specific heat of sand greater than that water?

Q3. Do water and ice have the same specific heats?

Q4. Why are telephone wires often given snag?

Q5. Why a small space is left between the two rails on a railway track?

Q6. The top of a lake is frozen. Air in contact is at –15 °C. What do you expect the maximum temperature of water (a) in contact with the lower surface of ice and (b) at the bottom of the lake?

Q7. Is the value of temperature coefficient always positive.

Q8. Are coefficients of thermal expansion constant for given solid?

Q9. Of metal and alloy, which has greater value of temperature coefficient ?

Q10. Do the values of coefficients of expansion differ, when the lengths are measured in cgs system or in SI?

Q11. Why do two layers of a cloth of equal thickness provide warmer covering than a single layer of cloth of double the thickness?

Q12. A blacksmith fixes iron ring on the rim of the wooden wheel of a bullock cart. The diameter of the rim and the iron ring are 5.243 m and 5.231 m respectively at 27°C. To what temperature should the ring be heated so as to fit the rim of the wheel?

Q13. What is the coefficient of linear, superficial and cubical expansion?

Q14. What is relation among α, β and γ?

Q15. Why is clock pendulum made of invar?

Q16. Pendulum clocks generally go fast in winter and slow in summer. Why?

Q17. What is wrong in taking the melting point of ice and the boiling point of water as standard fixed points (as was originally done in the Celsius scale)?

Q18. Two thermometer are constructed in the same way, except that one has a spherical bulb and the other a cylindrical bulb. Which will respond quickly to temperature changes?

Q19. How much the temperature of a brass rod should be increased, so as to increase its length by 1%? Given that a for brass = $0.00002\ ^{\circ}C^{-1}$.

Q20. How the fishes can survive in the extreme winter, when ponds and lakes are frozen?

Q21. A specific gravity bottle is marked with its volume along with a temperature value. Why?

Q22. A circular piece is cut from flat metal sheet. The sheet is, then, placed in a surface. Will the size of hole become larger or smaller? Explain.

Q23. A steel tape is calibrated at 20 °C. On a cool day, when the temperature is – 15 °C, what will be the percentage error in the tape? For steel, $\alpha = 1.1 \times 10^{-5}\ ^\circ C^{-1}$.

Q24. An iron scale is correct at 0 °C and the length of a zinc rod as measured by the scale is 100 cm, when both of the scale and the rod are at 0 °C. What will be the length of the rod as measured by an iron scale, when both of them are at 100 °C? Given, α for iron = $12 \times 10^{-6}\ ^\circ C^{-1}$ and for zinc = $26 \times 10^{-6}\ ^\circ C^{-1}$.

Q25. It is required to prepare a steel meter scale, such that the millimeter intervals are to be accurate within 0.0005 mm at a certain temperature. Determine the maximum temperature variation allowable during the rulings of millimeter marks. Given, α for steel = $1.322 \times 10^{-5}\ ^\circ C^{-1}$.

Q26. A brass rod of length 40 cm is join copper rod of length 50 cm. The two rods are of the same thickness and at initial temperature of 40 °C. When change in length of the combined rod, when the same is to 280 °C. Coefficients of linear expansion of brass $1.9 \times 10^{-5}\ ^\circ C^{-1}$ and are $1.7 \times 10^{-5}\ ^\circ C^{-1}$ respectively.

Q27. A circular sheet of copper of radius 35 cm is at 20 °C. On heating, its area increases by 14.5 cm^2. If coefficient of linear expansion of copper is $1.7 \times 10^{-5}\ ^\circ C^{-1}$, find the temperature to which the sheet was heated.

Q28. Two rods *A* and *B* are of equal length. Each rod has its ends at temperatures T_1 and T_2. What are the conditions that will ensure equal rates of flow of heat through the roads *A* and *B*?

Q29. Given below are observations on molar specific heats at room temperature of some common gases.

Gas	Hydrogen	Nitrogen	Oxygen	Nitric oxide	Carbon monoxide	Chlorine
Molar specific heat (Cv) (cal mol^{-1} K^{-1})	4.87	4.97	5.02	4.99	5.01	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. Explain this difference. What can you infer from the somewhat larger (than the rest) value for chlorine?

Q30. Show that the coefficient of area expansions, $(\Delta A/A)/\Delta T$, of a rectangular sheet of the solid is twice its linear expansivity, α_1.

Q31. A steel beam is 5 m long at a temperature of 20 °C. On a hot day, the temperature rises to 40 °C.

(a) What is the change in the length of the beam due to thermal expansion?

(b) Suppose that the ends of the beam are initially in contact with rigid vertical support. How much force will the expanded beam exert on the support, if it has a cross-sectional area of 60 cm^2. Given, coefficient of linear expansion of steel = $1.2 \times 10^{-5}\ C^{-1}$ and Young's modulus of steel = $2.0 \times 10^{11}\ N m^{-2}$.

Q32. (a) The ratio of thermal conductivities of two different metal is 5 : 3. In order to have the same thermal resistance in these metals of equal thickness, what should be the ratio of their lengths?

(b) How much the temperature of a brass rod should be increased, so as to increase its length by 2%? Given that a for brass = 0.00005 $^\circ C^{-1}$.

Q33. Draw the energy- distribution graph of a black body. List some salient features.

Q34. The coefficient of volume expansion of mercury is $5.4 \times 10^{-4}\ ^\circ C^{-1}$. What is the fractional change in its density for a 80 $^\circ$C rise in temperature?

Q35. Two ideal gas thermometers *A* and *B* use oxygen and hydrogen respectively. The following observations are made:

Temperature	Pressure thermometer *A*	Pressure thermometer *B*
Triple-point of water	1.250×10^5 Pa	0.200×10^5 Pa
Normal melting point of sulphur	1.797×10^5 Pa	0.287×10^5 Pa

What is the absolute temperature of normal melting point of sulphur as read by thermometers *A* and *B?*

What do you think is the reason behind the slight difference in answers of thermometers *A* and *B?* (The thermometers are not faulty). What further procedure is needed in the experiment to reduce the discrepancy between the two readings?

Q36. A brass wire 1.8 m long at 27 °C is held taut with little tension between two rigid supports. If the wire is cooled to a temperature of – 39 °C, what is the tension developed in the wire, if its diameter is 2.0 mm? Co-efficient of linear expansion of brass = $2.0 \times 10^{-5}\ ^\circ C^{-1}$; Young's modulus of brass = 0.91×10^{11} Pa.

Q37. 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 = $1.20 \times 10^{-5}\ ^\circ C^{-1}$.

Q38. Two rods of the same area of cross-section, but of lengths l_1 and l_2 and conductivities K_1 and K_2 are joined in series. Show that the combination is equivalent of a material of conductivity $K = \dfrac{l_1 + l_2}{\left(\dfrac{l_1}{K_1}\right) + \left(\dfrac{l_2}{K_2}\right)}$

Q39. Define thermal conduction. Write a relation for rate of flow of heat energy by conduction. Use it to find equivalent resistance when two rods are places in series or parallel.

Date: 14/10/2021

S1. Work done $W = Q_1 - Q_2, \Delta U = 0.$

S2. No, the specific heat of sand is less than that of water. It may be noted that the values of the specific heat of water is maximum.

S3. No, water and ice do not have the same values of the specified heat.

For water, $c = 1\text{ cal g}^{-1}\,°\text{C}^{-1}$

And for ice, $c = 0.5\text{ cal g}^{-1}\,°\text{C}^{-1}$

S4. The telephone wires are given snag, so that the wires may contract safely in winter. In case no snag is given, a large tension will develop in the wires, when temperature falls in winter. The tension developed in the wires is so large that the wires may even break.

S5. The solids expand on heating. A small gap is left between the rails so as to allow the expansion of the rails in summer. In case the space is not left, the rails will bend.

S6. (a) 0 °C (b) 4 °C.

S7. It has positive value for metals and alloys. For semiconductors and insulators, the value of α is negative.

S8. The coefficients of expansion of a solid change with temperature.

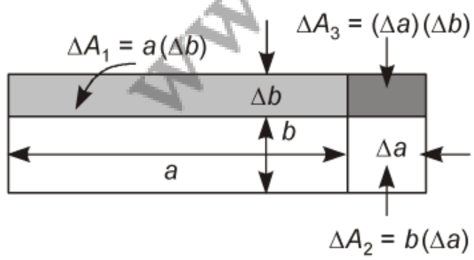
S9. The value of α is more for metal than that for alloys.

For example, α for copper (metal) = $1.7 \times 10^{-5}\,°\text{C}^{-1}$ and α for invar (alloy) = $6.7 \times 10^{-7}\,°\text{C}^{-1}$

S10. No. Because coefficients is the ratio of length energy or volume of the body due to not affected, in cgs or SI form.

S11. The air enclosed between two layers of cloths prevents the transmission of heat from our body to outside.

S12. Given, $T_1 = 27\,°\text{C}$; $L_{T1} = 5.231$ m; $L_{T2} = 5.243$ m



So, $$L_{T2} = L_{T1} [1 + \alpha_1 (T_2 - T_1)]$$

$$5.243 \text{ m} = 5.231 \text{ m} [1 + 1.20 \times 10^{-5} \text{K}^{-1} (T_2 - 27°\text{C})]$$

or $$T_2 = 218°\text{C}.$$

S13. **Coefficient of linear expansion:** The coefficient of linear expansion of the material of a solid is defined as the increase in its length per unit length per unit rise in its temperature.

Coefficient of *Superficial expansion:* The coefficient of superficial expansion of the material of a solid is defined as the increase its surface area per unit surface area per unit rise in its temperature.

Coefficient of *Cubical expansion:* The coefficient of cubical expansion of the material of a solid is defined as the increase in its volume per unit rise in its temperature.

S14. The relation among α, β and γ

$$\alpha = \frac{\beta}{2} = \frac{\gamma}{3}.$$

S15. It is because, invar (alloy of nickel and steel) has extremely small coefficient expansion. Therefore, the length of clock pendulum made of invar does not change appreciably with change of season. As such, the clock keeps correct time in comparison to clock, which make use of pendulum made of other metals.

S16. The time period of a pendulum is given by

$$t = 2\pi\sqrt{\frac{l}{g}},$$

where l is the length of the pendulum. Thus, t is directly proportional to $\sqrt{l}$. In summer, t will increase with increase in temperature; while in winter, t will decrease with fall in temperature. Likewise, pendulum clocks go fast in winter and slow in summer.

S17. The melting point of ice and the boiling point of water change with change in the value of pressure. Further, melting point of ice and the boiling point of water also change, if some impurities are dissolved in water.

S18. For the given volume, a sphere has minimum surface area. Therefore, the thermometer whose bulb is cylindrical will respond quickly to temperature, as its bulb will attain the temperature of the body quickly due greater surface area of the bulb.

S19. Given, $$\frac{l' - l}{l} = 1\%$$

$$= \frac{1}{100} = 0.01$$

Now, $l' - l = l\alpha\Delta T$

or $\frac{l' - l}{l} = \alpha\,\Delta T$

$\alpha\Delta T = 0.01$

or $\Delta T = \frac{0.01}{\alpha}$

$= \frac{0.01}{0.00002} = \mathbf{500\ ^{o}C}$.

S20. When it is extreme cold, the temperature of water in ponds and lakes starts falling. On getting colder, water becomes denser and it goes down. To replace it, the warmer water from below rises up. However, it happens so, till the temperature of water at the bottom of the pond becomes 4 °C. It is because, the density of water is maximum at 4 °C. Now, as the temperature lower further, ice is formed at the surface of the pond with water below it. In this manner, the fishes can survive in the extreme winter, when pond and lakes are frozen.

S21. It is because, glass (material of S.G. bottle) expands with increase in temperature. Therefore, at different temperature, the S.G. bottle will hold different volume of a liquid. So as to give a definite meaning to its volume capacity, the volume capacity is marked along with the corresponding temperature.

S22. The size of the whole will increase. To understand it, think of the piece of metal removed from the hole, rather than of the hole itself. This piece would expand on heating. This piece will fit into the hole only, if the hole has also increased in size. Another way to analyse the situation is that if we draw a circle on the metal sheet, the radius of the circle will increase.

S23. Here, $\Delta T = -15 - 20 = -35\ ^{o}C$; $\alpha = 1.1 \times 10^{-5}\ ^{o}C^{-1}$

Let u be the size of 1 cm interval at 20 °C and u' at 15 °C.

Then $u' = u(1 + \alpha\Delta T)$

or $u' - u = u\,\alpha\Delta T$

or $\frac{u' - u}{u} = \alpha\Delta T$

$= 1.1 \times 10^{-5} \times (-35) = -3.85 \times 10^{-4}$

Therefore, % error in the tape at – 15 °C

$= \frac{u' - u}{u} \times 100 = -3.85 \times 10^{-4} \times 100 = \mathbf{-0.0385\%}$.

S24. The iron scale is correct at 0 °C. Let u be the size of one cm interval of the iron scale at 0 °C and u', at 100 °C.

Then, $u' = u(1 + \alpha\Delta T)$

Here, $u = 1$ cm; $\alpha = 12 \times 10^{-6}\ ^{o}C$ and $\Delta T = 100\ ^{o}C$

$$u' = 1 \times (1 + 12 \times 10^{-6} \times 100) = 1.0012 \text{ cm}$$

At 100 °C, length of the zinc rod will be

$$l' = l(1 + \alpha \Delta T)$$

or $$l' = 100\,(1 + 26 \times 10^{-6} \times 100)$$

$$= \mathbf{100.26\ cm}$$

Therefore, length of the zinc rod as measured by iron scale at 100 °C

$$= \frac{l'}{u'} = \frac{100.26}{1.0012} = \mathbf{100.14\ cm}.$$

S25. Let ΔT be the variation in temperature, which increase size of 1 mm interval to 1 + 0.0005 *i.e.*, 1.0005 mm.

Here, $u = 1$ mm ; $u' = 1.0005$ mm

Now, $$u' = u\,(1 + \alpha \Delta T)$$

$\therefore$ $$1.0005 = 1 \times (1 + 1.322 \times 10^{-5} \times \Delta T)$$

or $$\Delta T = \frac{1.0005 - 1}{1.322 \times 10^{-5}}$$

or $$\Delta T = \mathbf{37.8\ ^{o}C}.$$

S26. **For brass rod:** $\alpha_1 = 1.9 \times 10^{-5}\ ^{o}C^{-1}$; $l_1 = 40$ cm; $\Delta T_1 = 280 - 40 = 240\ ^{o}C$

The length of the brass rod at 280 °C is given by

$$l_1' = l_1\,(1 + \alpha_1 \Delta T_1)$$

$$= 40 \times (1 + 1.9 \times 10^{-5} \times 240) = 40.18\ 24$$

For copper rod: $\alpha_2 = 1.7 \times 10^{-5}\ ^{o}C^{-1}$;

$$l_2 = 50 \text{ cm}; \quad \Delta T_2 = 280 - 40 = 240\ ^{o}C$$

The length of the steel rod at 280 °C is given by

$$l_2' = l_2\,(1 + \alpha_2 \Delta T_2)$$

$$= 50 \times (1 + 1.7 \times 10^{-5} \times 240) = 50.2040 \text{ cm}$$

Therefore, the length of the combined rod at 280 °C,

$$l_1' + l_2' = 40.1824 + 50.2040 = 90.3864 \text{ cm}$$

As the length of the combined rod at 40 °C is 50 + 40 *i.e.*, 90 cm

The change in length of the combined rod at 280 °C

$$= 90.3864 - 90 = \mathbf{0.3864\ cm.}$$

S27. Here,

$$S = \pi \times 35^2 = 3,848.45 \text{ cm}^2;$$

$$\Delta S = 14.5 \text{ cm}^2;$$

$$\theta_1 = 20\,^{\circ}\text{C};$$

$$\beta = 2\,\alpha = 2 \times 1.7 \times 10^{-5} = 3.4 \times 10^{-5}\,^{\circ}\text{C}^{-1}$$

Now,

$$\Delta S = S\,\beta\,\Delta T$$

or

$$\Delta T = \frac{\Delta S}{S\beta}$$

$$\Delta T = \frac{14.5}{3,848.45 \times 3.4 \times 10^{-5}} = 110.82\,^{\circ}\text{C}$$

If θ_2 is the temperature to which the copper sheet was heated, then

$$\theta_2 = \theta_1 + \Delta T = 20 + 110.82 = \mathbf{130.82\,^{\circ}C}.$$

S28. As

$$\frac{\Delta Q_1}{\Delta t} = \frac{\Delta Q_2}{\Delta t}$$

$$K_1 A_1 \frac{(T_2 - T_1)}{\Delta x_1} = K_2 A_2 \frac{(T_2 - T_1)}{\Delta x_2}$$

As rods have equal length,

$$\Delta x_1 = \Delta x_2$$

$$K_1 A_1 = K_2 A_2 \quad \text{or} \quad \frac{A_1}{A_2} = \frac{K_2}{K_1}.$$

i.e., ratio of cross sectional area of the two rods must be in the inverse ratio of their thermal conductivities.

S29. The gases listed in the given table are diatomic. Besides the translational degree of freedom, they have other degrees of freedom (modes of motion).

Heat must be supplied to increase the temperature of these gases. This increases the average energy of all the modes of motion. Hence, the molar specific heat of diatomic gases is more than that of monatomic gases.

If only rotational mode of motion is considered, then the molar specific heat of a diatomic

$$\text{gas} = \frac{5}{2}R$$

$$= \frac{5}{2} \times 1.98 = 4.95 \text{ cal mol}^{-1}\text{K}^{-1}$$

With the exception of chlorine, all the observations in the given table agree with $\left(\frac{5}{2}R\right)$.

This is because at room temperature, chlorine also has vibrational modes of motion besides rotational and translational modes of motion.

S30. Consider a rectangular sheet of the solid material of length a and breadth b (see figure). When the temperature increases by ΔT, a increases by $\Delta a = \alpha_1 a\Delta T$ and b increases by $\Delta b = \alpha_1 b\Delta T$. From figure, the increase in area

$$\Delta A = \Delta A_1 + \Delta A_2 + \Delta A_3$$

$$\Delta A = a\,\Delta b + b\,\Delta a + (\Delta a)\,(\Delta b)$$

$$= a\,\alpha_1\,b\,\Delta T + b\,\alpha_1\,a\,\Delta T + (\alpha_1)^2\,ab\,(\Delta T)^2$$

$$= \alpha_1\,ab\,\Delta T\,(2 + \alpha_1\,\Delta T) = \alpha_1\,A\,\Delta T\,(2 + \alpha_1\,\Delta T)$$

Since $\alpha_1 \simeq 10^{-5}\,K^{-1}$, from Table 11.1, the product $\alpha_1\,\Delta T$ for fractional temperature is small in comparision with 2 and may be neglected.

Hence,

$$\left(\frac{\Delta A}{A}\right)\frac{1}{\Delta T} \simeq \alpha_1.$$

S31. (a) Given, $l_1 = 5$ m; $\Delta T = 40 - 20 = 20\,^{o}C$;

$$\alpha = 1.2 \times 10^{-5}\,^{o}C^{-1}$$

If l_2 length of the beam at 40 °C, then

$$l_2 = l_1\,(1 + \alpha\,\Delta T) = 5 \times (1 + 1.2 \times 10^{-5} \times 20)$$

$$= 5 \times (1 + 2.4 \times 10^{-4}) = 5.0012 \text{ m}$$

Therefore, increase in length of the beam,

$$\Delta l = l_2 - l_1$$

$$= 5.0012 - 5 = 0.0012 \text{ m} = \mathbf{1.2\ mm}.$$

(b) Given, $Y = 2.0 \times 10^{11}$ N m^{-2}; $a = 60$ cm$^2 = 60 \times 10^{-4}$ m^2

Now, Young's modulus of the material of the beam is given by

$$Y = \frac{F/a}{\Delta l/l_1} = \frac{F \times l_1}{a \times \Delta l}$$

or

$$F = \frac{Ya\,\Delta l}{l_1}$$

$$= \frac{2.0 \times 10^{11} \times 60 \times 10^{-4} \times 0.0012}{5}$$

$$= \mathbf{2.88 \times 10^5\ N}.$$

S32. (a) Thermal resistance,

$$R_{M_1} = \frac{l_1}{K_1 A_1}$$

and
$$R_{M_2} = \frac{l_2}{K_2 A_2}$$

Since
$$R_{M_1} = R_{M_2} \quad \Rightarrow \quad \frac{l_1}{K_1 A_1} = \frac{l_2}{K_2 A_2}$$

or
$$\frac{l_1}{K_1} = \frac{l_2}{K_2}$$ [$\because$ They have equal thickness]

$$\therefore \quad \frac{l_1}{l_2} = \frac{K_1}{K_2} = \frac{5}{3}.$$

(b) Given,
$$\frac{l' - l}{l} = 2\%$$

$$= \frac{2}{100} = 0.02$$

Now,
$$l' - l = l\alpha\Delta T$$

or
$$\frac{l' - l}{l} = \alpha\,\Delta T$$

$$\alpha\Delta T = 0.02$$

or
$$\Delta T = \frac{0.02}{\alpha}$$

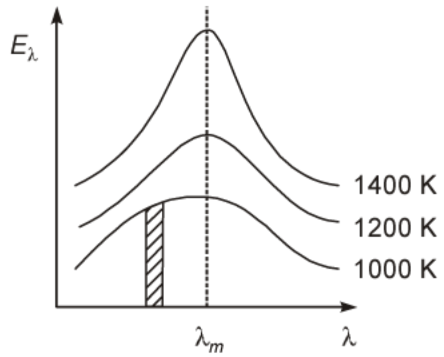
$$= \frac{0.02}{0.00005} = \mathbf{400\ ^\circ C}.$$

S33. (a) At a given temperature with increase in wavelength, the energy radiated increases and the decreases.

(b) As the temperature increases, there is a shift in the wavelength towards lesser values corresponding to maximum intense wavelength as given by

$$\lambda_m T = \text{constant } (2.89 \times 10^{-3}\ \text{m K}).$$

(c) Area below the graph in a specified wavelength range is a measure of the radiant energy in that wavelength range.



S34. Given, $\gamma = 5.4 \times 10^{-4}\ ^\circ C^{-1}$; $\Delta T = 80\ ^\circ C$

Let there be m grams of mercury and its initial volume be V. Suppose that the volume of the mercury V' after a rise of temperature of $80\ ^\circ C$. Then,

$$V' = V(1 + \gamma\Delta T)$$

$$= V(1 + 5.4 \times 10^{-4} \times 80)$$

or $$V' = 1.0432\text{ V}$$

Initial density of the mercury,

$$\rho = \frac{m}{V}$$

Final density of the mercury,

$$\rho' = \frac{m}{V'} = \frac{m}{1.0432\text{ V}} = \frac{\rho}{1.0432}$$

$$\rho' = \mathbf{0.9586}\ \rho.$$

Therefore, fractional change in the value of density of mercury,

$$\frac{\rho - \rho'}{\rho} = \frac{\rho - 0.9586\rho}{\rho} = \mathbf{0.0414}.$$

S35. Triple point of water, $T = 273.16$ K.

At this temperature, pressure in thermometer *A*,

$$P_A = 1.250 \times 10^5\text{ Pa}$$

Let T_1 be the normal melting point of sulphur.

At this temperature, pressure in thermometer *A*,

$$P_1 = 1.797 \times 10^5\text{ Pa}$$

According to Charles' law, we have the relation:

$$PT = \text{Constant}$$

$$P_1 T_1 = P_2 T_2$$

$$\frac{P_A}{T} = \frac{P_1}{T_1}$$

$\therefore$ $$T_1 = \frac{P_1 T}{P_A} = \frac{1.797 \times 10^5 \times 273.16}{1.250 \times 10^5} = 392.69\text{ K}$$

Therefore, the absolute temperature of the normal melting point of sulphur as read by thermometer *A* is 392.69 K.

At triple point 273.16 K, the pressure in thermometer *B*,

$$P_B = 0.200 \times 10^5\text{ Pa}$$

At temperature T_1, the pressure in thermometer B,

$$P_2 = 0.287 \times 10^5 \text{ Pa}$$

According to Charles' law, we can write the relation:

$$\frac{P_B}{T} = \frac{P_1}{T_1}$$

$$\frac{0.200 \times 10^5}{273.16} = \frac{2.287 \times 10^5}{T_1}$$

$\therefore$ $$T_1 = \frac{0.287 \times 10^5}{0.200 \times 10^5} \times 273.16 = 391.98 \text{ K}.$$

Therefore, the absolute temperature of the normal melting point of sulphur as read by thermometer B is 391.98 K.

The oxygen and hydrogen gas present in thermometers A and B respectively are not perfect ideal gases. Hence, there is a slight difference between the readings of thermometers A and B.

To reduce the discrepancy between the two readings, the experiment should be carried under low pressure conditions. At low pressure, these gases behave as perfect ideal gases.

S36. Initial temperature, $T_1 = 27°\text{C}$

Length of the brass wire at T_1, $l = 1.8$ m

Final temperature, $T_2 = -39\,°\text{C}$

Diameter of the wire, $d = 2.0 \text{ mm} = 2 \times 10^{-3}$ m

Tension developed in the wire $= F$

Coefficient of linear expansion of brass,

$$\alpha = 2.0 \times 10^{-5}\,°\text{C}^{-1}$$

Young's modulus of brass, $Y = 0.91 \times 10^{11}$ Pa

Young's modulus is given by the relation:

$$Y = \frac{\text{Stress}}{\text{Strain}} = \frac{\frac{F}{A}}{\frac{\Delta L}{L}}$$

$$\Delta L = \frac{F \times L}{A \times Y} \quad \text{... (i)}$$

Where,

A = Area of cross-section of the wire.

ΔL = Change in the length, given by the relation:

$$\Delta L = \alpha L\,(T_2 - T_1) \quad \text{... (ii)}$$

Equating equations (i) and (ii), we get:

$$\alpha L(T_2 - T_1) = \frac{FL}{\pi\left(\frac{d}{2}\right)^2 \times Y}$$

$$F = \alpha(T_2 - T_1)\,\pi Y\left(\frac{d}{2}\right)^2$$

$$F = 2\times10^{-5}\times(-39-27)\times3.14\times0.91\times10^{11}\times\left(\frac{2\times10^{-3}}{2}\right)^2$$

$$= -3.8\times10^2\ \text{N}.$$

(The negative sign indicates that the tension is directed inward.)

Hence, the tension developed in the wire is 3.8×10^2 N.

S37. Length of the steel tape at temperature $T = 27\,°C$, $l = 1\ \text{m} = 100\ \text{cm}$

At temperature $T_1 = 45\,°C$, the length of the steel rod, $l_1 = 63\ \text{cm}$

Coefficient of linear expansion of steel, $\alpha = 1.20\times10^{-5}\ °C^{-1}$

Let l_2 be the actual length of the steel rod and l' be the length of the steel tape at 45°C.

$$l' = l + \alpha l(T_1 - T)$$

$\therefore$ $$l' = 100 + 1.20\times10^{-5}\times100\,(45-27)$$

$$= 100.0216\ \text{cm}$$

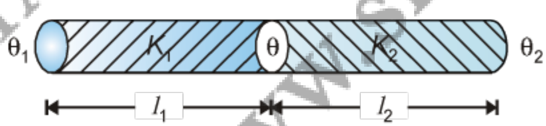
Hence, the actual length of the steel rod measured by the steel tape at 45°C can be calculated as:

$$l_2 = \frac{100.0216}{100}\times63 = 63.0136\ \text{cm}$$

Therefore, the actual length of the rod at 45.0°C is 63.0136 cm. Its length at 27.0°C is 63.0 cm.

S38. Given two rods lengths l_1 and l_2 and conductivities of rod K_1 and K_2.

Since they are in series, the rate of flow of heat energy is the same. But the sum of the difference in temperature is the difference across their free ends.



$\therefore$ $$(\theta_1 - \theta) + (\theta - \theta_2) = (\theta_1 - \theta_2)$$

i.e., $$\frac{Q}{t}\cdot\frac{l_1}{K_1 . A} + \frac{Q}{t}\cdot\frac{l_2}{K_2 . A} = \frac{Q}{t}\cdot\frac{(l_1 + l_2)}{K_{eq} . A}$$

$$\frac{l_1}{K_1} + \frac{l_2}{K_2} = \frac{l_1 + l_2}{K_{eq}} \qquad \therefore\ K_{eq} = \frac{l_1 + l_2}{\left(\frac{l_1}{K_1}\right) + \left(\frac{l_2}{K_2}\right)}.$$

S39. ***Conduction:*** Transfer of heat by the collision among the molecules with their neighbours is called conduction. Rate of heat transfer is given by,

$$\frac{Q}{t} = \frac{KAd\theta}{dl},$$

where K is called thermal conductivity.

Thermal conductivity is defined as heat energy transferred in unit time from unit area having a difference in temperature of unity over unit length. It is expressed in $J\,s^{-1}\,m^{-1}\,{}^{o}C^{-1}$ or $W\,m^{-1}\,K^{-1}$.

When rods are arranged in series, $\frac{Q}{t}$ is same in both and the sum of the difference in temperature across their ends is the difference at the open ends.

i.e., $$(\theta_1 - \theta) + (\theta - \theta_2) = (\theta_1 - \theta_2)$$

Using $\frac{Q}{t} = \frac{d\theta}{R_{N\text{th}}}$ we get

$$\left(\frac{Q}{t}\right) R_1 + \left(\frac{Q}{t}\right) R_2 = \left(\frac{Q}{t}\right) R_{N\text{ th}}$$

When rods are arranged in parallel and the difference in temperature will be the same, then

$$\left(\frac{Q}{t}\right)_N = \left(\frac{Q}{t}\right)_1 + \left(\frac{Q}{t}\right)_2$$

i.e., $$\frac{d\theta}{R_N} = \frac{d\theta}{R_1} + \frac{d\theta}{R_2}$$

$$\boldsymbol{\frac{1}{R_N} = \frac{1}{R_1} + \frac{1}{R_2}}.$$

Date: 14/10/2021

Q1. Draw graph showing energy emitted versus wavelength for a black body at different temperature.

Q2. What would be the effect on the r.m.s. velocity of gas molecules if the temperature of the gas is increased by a factor of 4?

Q3. If a drop of water falls on a hot plate, it takes long time to evaporate. Why?

Q4. What is radiation of heat?

Q5. What is convection of heat?

Q6. What is conduction of heat?

Q7. A slab consists of two parallel layers of two different materials of the same thickness, having thermal conductivities K_1 and K_2. What is the equivalent thermal conductivity of the slab?

Q8. A black metal foil is warmed by radiation from a sphere at temperature T at a distance d, If the power received is P, find the power received when both the temperature and distance are doubled.

Q9. Define coefficient of thermal conductivity.

Q10. Which is the only way of heat transfer through a solid?

Q11. Why are steam pipes wrapped with insulating material?

Q12. Why do lamp black and platinum black serve as perfect body only for absorption of heat radiation?

Q13. A blanket, which keeps us warm in the winter, also able to protect ice from melting. Explain.

Q14. A glass rod can even melted by holding it close the flame, while a copper rod held even at a distance comes too hot to hold. Explain, why?

Q15. On a winter night you feel warmer, when clouds cover the sky than when the sky is clear. Why?

Q16. Pieces of copper and glass are heated to the same temperature. Why does a piece of copper feel hotter on munching?

Q17. State Wien's law. Write the S.I. unit of Wien's constant.

Q18. Stainless steel cooking pans are preferred with extra copper bottom. Why?

Q19. A piece of paper wrapped tightly on a wooden is found to get charred, when held over a flame compared a similar piece of paper when wrapped around a brass rod.

Q20. Temperature of a perfect black body is 2000 K and area of its radiating surface is 2×10^{-4} m^2. Find the energy radiated by the black body in 15 minutes. Stefan's constant = 5.7×10^{-8} W m^{-2} K^{-4}.

Q21. Place a safety pin on a sheet of white paper. Hold the sheet over a burning candle, until the paper becomes yellow and cherry. On removing the pin, its white trace is observed on the paper. Explain, why?

Q22. Heat is generated continuously in an electric heater but its temperature remains constant after some time. Why?

Q23. Tea in a thermos flask remains hot for a long time. Why?

Q24. On a hot day, a car is in sunlight with all the windows closed. After some time, it is found that the inside of the car is considerably warmer than air outside. Explain, why?

Q25. The inside if the glass window 2 mm thick and one square meter in area is at a temperature of 15 °C and the temperature outside is – 5 °C. Calculate the rate at which heat escaping from the room by conduction through the glass. K of glass is 0.002 cal $cm^{-1}\ s^{-1}\ °C^{-1}$.

Q26. When 0.15 kg of ice of 0°C mixed with 0.30 kg of water at 50°C in a container, the resulting temperature is 6.7°C. Calculate the heat of fusion of ice. (s_{water} = 4186 J $kg^{-1}\ K^{-1}$)

Q27. Calculate the temperature (in *K*) at which a perfect black radiates at the rate of 5.67 watt cm^{-2}. Given, $\sigma = 5.67 \times 10^{-8}$ watt $m^{-2}\ K^{-4}$.

Q28. Wavelength corresponding to E_{max} for the moon is 14 microns. Estimate the temperature of the moon, if $b = 2.884 \times 10^{-3}$ m K.

Q29. 2 kg water at 80°C is mixed with 3 kg water at 20°C. Assuming no heat losses, find the final temperature of the mixture.

Q30. Calculate the heat of combustion of coal, when 10 gm of coal, on burning raises the temperature of 2 kg of water from 20°C to 55°C.

Q31. A copper block of mass 2.5 kg is heated in a furnace to a temperature of 500 °C and then placed on a large ice block. What is the maximum amount of ice that can melt? (Specific heat of copper = 0.39 J $g^{-1}\ K^{-1}$; heat of fusion of water = 335 J g^{-1}).

Q32. A glass tube of length 133 cm and of uniform cross-section is to be filled with mercury, so that the volume of the tube unoccupied by mercury remains the same at all temperature. If coefficients of cubical expansion for glass and mercury are respectively $2.6 \times 10^{-5}\ °C^{-1}$ and $18.2 \times 10^{-5}\ °C^{-1}$, calculate the length of mercury column.

Q33. A metal rod of length 20 cm and diameter 2 cm is covered with non-conducting substance. One of its ends is maintained at 100 °C, while the other end is put in ice at 0 °C. It is found that 25 g of ice melts in 5 minutes. Calculate the coefficient of thermal conductivity of the metal. Given, specific latent heat of ice = 80 cal $g^{-1}\ °C^{-1}$.

Q34. (a) The surface temperature of a hot body is 1,227 °C. Find the wavelength at which it radiates maximum energy. Given, Wien's constant = 0.2898 cm K.

(b) A spherical black body with a radius 12 cm radiates 450 W power at 500 K. If the radius were halved and the temperature doubled, what be the power radiated?

Q35. A slab of stone of area 0.36 m^2 and thickness 0.1 m is exposed on the lower surface to steam at 100 °C. A block of ice at 0 °C rests on the upper surface of the slab. In one hour, 4.8 kg of ice is melted. Calculate the thermal conductivity of stone.

Q36. A brass rod 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 °C, if the original lengths are at 40.0 °C? 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 = $2.0 \times 10^{-5} K^{-1}$, steel = $1.2 \times 10^{-5} K^{-1}$).

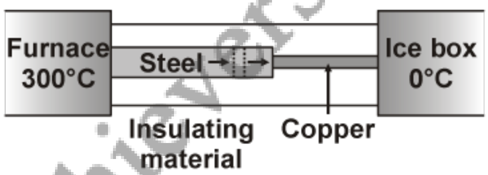
Q37. The only possibility of heat flow in a thermos flask is through its cork, which is 75 cm^2 in area and 5 cm thick. Its thermal conductivity is 0.0075 cal cm^{-1} s^{-1} $^oC^{-1}$. How long will 500 g of ice at 0 ^oC in thermos flask will take to melt into water at 0 ^oC? The outside temperature is 40 ^oC and latent heat of fusion of ice is 80 cal g^{-1} $^oC^{-1}$.

Q38. Define Coefficient of Thermal Conductivity and derive its SI unit. Calculate the rate of loss of heat through a glass window of area 1000 cm^2 and thickness 0.4 cm when temperature inside is 37 ^oC and outside is -5 ^oC. Coefficient of thermal conductivity of glass is 2.2×10^{-3} cal s^{-1} cm^{-1} k^{-1}.

Q39. A copper tube (length 3 m, inner diameter 1.5 cm, outer diameter 1.7 cm) passes through a vat of rapidly circulating water maintained at 20 ^oC. Steam at 100 ^oC passes through the tube. What is the heat flow rate from steam into the vat? How much steam is condensed in each minute? For copper, K = 420 W m^{-1} $^oC^{-1}$ and latent of steam = 537 cal g^{-1}.

Q40. 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 caused, 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}.

Q41. What is the temperature of the steel-copper junction in the steady state of the system shown in figure. Length of the steel rod = 15.0 cm, length of the copper rod = 10.0 cm, temperature of the furnace = 300°C, temperature of the other end = 0°C. The area of cross section of the steel rod is twice that of the copper rod. (Thermal conductivity of steel = 50.2 J s^{-1} m^{-1})



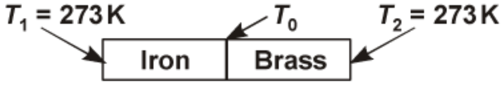
Q42. Calculate the heat required to convert 3 kg of ice at – 12°C kept in a calorimeter to steam at 100°C at atmospheric pressure. Given specific heat capacity of ice = 2100 J kg^{-1} K^{-1}, specific heat capacity of water = 4186 J kg^{-1} K^{-1}, latent heat of fusion of ice = 3.35×10^5 J kg^{-1} and latent heat of steam = 2.256×10^6 J kg^{-1}.

Q43. An iron bar (L_1 = 0.1 m, A_1 = 0.02 m^2, K_1 = 79 W m^{-1} K^{-1}) and a brass bar (L_2 = 0.1 m, A_2 = 0.02 m^2, K_2 = 109 W m^{-1} K^{-1}) are soldered end to end as shown in figure. The free ends of the iron bar and brass bar are maintained at 373 K and 273 K respectively. Obtain expressions for and hence compute

(a) the temperature of the junction of the two bars,

(b) the equivalent thermal conductivity of the compound bar, and

(c) the heat current through the compound bar.

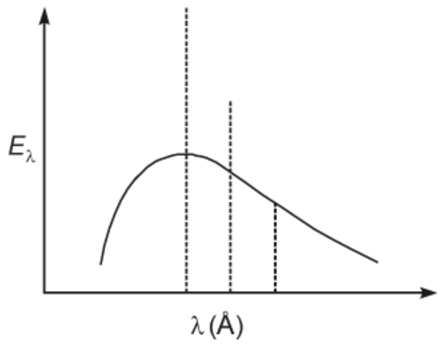


Q44. (a) A hole is drilled in a copper sheet. The diameter of the hole is 4.24 cm at 27.0 °C. What is the change in the diameter of the hole when the sheet is heated to 227 °C? Coefficient of linear expansion of copper = $1.70 \times 10^{-5}\ K^{-1}$.

(b) The inside if the glass window 2 mm thick and one square meter in area is at a temperature of 15 °C and the temperature outside is – 5 °C. Calculate the rate at which heat escaping from the room by conduction through the glass. K of glass is $0.002\ cal\ cm^{-1}\ s^{-1}\ {}^{o}C^{-1}$.

Date: 14/10/2021

S1.



S2. ∴ $v_{r.m.s.} = \sqrt{T}$

so, $v_{r.m.s.}$ is doubled.

S3. The vapour formed at the instant of landing of the drop acts as an insulator and prevents the heat being passed on to the water above. So it takes time to evaporate.

S4. ***Radiation:*** The energy emitted by a body in the form of radiation by virtue of its temperature is called thermal radiation.

S5. ***Convection:*** It is the process in which heat is transferred from one point to another point by actual movement of the material particles from a region of high temperature to region of lower temperature.

S6. ***Conduction:*** It is the process by which heat is transmitted from one point to another through a substance in the direction of fall of temperature without the actual motion of the particles of the substance themselves.

S7. $\dfrac{2K_1K_2}{K_1 + K_2}$

S8. Power radiated $(P) \propto \dfrac{T^4}{d^2}$.

$$P' = \frac{(2T)^4}{(2d)^2} = \frac{16T^4}{4d^2} = \frac{4T^4}{d^2} = 4P.$$

S9. The coefficient of thermal conductivity of a material may be defined as the quantity of heat energy that flows in unit time between the opposite faces of a cube of unit side made of that material, the face being kept at one degree difference of temperature

S10. Conduction.

S11. So as to minimize the loss of heat due to radiation.

S12. A body coated with lamp black (or platinum black) absorbs the heat radiation of all the wavelength falling on it. But when such a body is heated, it does not radiate heat radiation of all the wavelength. Hence, a body coated with lamp black or platinum black serves as a perfect black body only for absorption of heat radiation.

S13. A blanket only prevents the flow of heat due to the air piped in the pores. In winter, it keeps us warm as heat cannot flow from our body to the surroundings. On the other hand, ice can saved from melting, as heat cannot flow from the surrounding to the ice.

S14. The thermal conductivity of glass is quite small as compared to that of copper. When glass is heated in a flame, lay a small amount of heat is conducted to the other end of the rod. Therefore, one may hold the glass rod, till it may even melt. In case of copper rod, the other end of the rod becomes too hot hold due to high value of the thermal conductivity of copper.

S15. The surface of earth absorbs sun rays during day time and gets heated. At night, the earth radiates heat but the clouds reflect the heat radiation back to the earth. Therefore, on a cloudy night, the heat radiation are reflected back to the surface of earth. However, when the sky is clear, the heat radiation escape the surface of the earth. For this reason, the cloudy night are warmer than the nights, when the sky is clear.

S16. When we touch the hot piece of copper, heat readily flows from the piece of copper to our fingers, whereas it dose not happen so in case of the piece of glass. It is because, copper a better conductor of heat than glass.

S17. According to Wien's law, the wavelength λ_m for which the emittance of a black body is maximum, is inversely proportional to its absolute temperature. $\lambda_m T$ = constant.

This constant is written as b and has a value of 0.288 cmK in the CGS units and 2.88×10^{-3} mK in the S.I. units.

S18. The coefficient of thermal conductivity of copper is quite large as compared to that of steel. When a cooking pan is heated with extra copper bottom, it will allow more heat to flow into the pan, when placed over flame. It will result in faster cooking of the food.

S19. When a piece of paper is wrapped tightly on a wooden rod and is held over flame, the heat received from the same does not wholly pass to the wooden rod. It is because; wood is bad conductor of heat. As sufficient amount of heat is left with the paper, it gets charred.

On the other hand, when a piece of paper is wrapped on a brass rod and is held over the flame, the heat from the flame immediately flows to the brass rod. It is because, brass is a good conductor of heat. Due to this fact, the paper does not get charred in this case.

S20. Here, $T = 2{,}000$ K; $A = 2 \times 10^{-4}$ m^2;

t = 15 minutes = $15 \times 60 = 900$ s;

and $\sigma = 5.7 \times 10^{-8}$ W m^{-2} K^{-4}

According to Stefan's law, energy radiated by the area A of the body in time t,

$$E = A(\sigma T^4)t$$

$$= 2 \times 10^{-4} \times 5.7 \times 10^{-8} \times (2,000)^4 \times 900 = \mathbf{1.64 \times 10^5\ J}.$$

S21. The heat from the candle flame is taken up by the safety pin, before it can cause the charring of the portion of the paper just below it. It is because, steel (material of pin) is very good conductor of heat. However, the remaining part of the paper becomes yellow and charrs.

S22. When heat is generated continuously in an heater, its temperature continuously rises. The temperature of the electric heater in the beginning due to the reason that the rate of production of heat is greater that the rate at which heat is lost to the surroundings. At a particular temperature of the heater, the rate of production of heat in the heater become equal to the rate at which is lost to the surroundings. Then, the temperature of the heater becomes constant.

S23. Thermos flask is a double walled glass bottle and the space between the two walls is evacuated. When hot tea is poured into the flask, heat cannot be conducted away due to vacuum between the two walls. Further, the walls of the flask are highly polished. Due to this, the outer surface of the inner wall can radiate only a very little amount of heat. On the other hand, the highly polished inner surface of the outer wall reflects back the heat radiate by the outer surface of the inner wall. Due to this, tea remains hot in the flask for a very long time.

S24. Glass possesses the property of selective absorption of heat radiation. Further, it transmits about 50% of heat radiation coming from a hot source like the sun is more or less opaque to the radiation from moderately hot bodies (at about 100 °C or so). Due to this, when a car is left in the sun, heat radiation from the sun get into the car but as the temperature inside the car is moderate, they can not escape through its windows. Thus, glass windows of the car trap the sun rays and because of this, inside of the car becomes considerably warmer.

S25. Here,

$$d = 2\ \text{mm} = 0.2\ \text{cm}; \quad A = 1\ \text{m}^2 = 10^4\ \text{cm}^2;$$

$$T_1 = 15\ °\text{C}; \quad T_2 = -5\ °\text{C}; \quad K = 0.002\ \text{cal cm}^{-1}\ \text{s}^{-1}\ °\text{C}^{-1}$$

Now,

$$\frac{dQ}{dt} = \frac{KA(T_1 - T_2)}{d}$$

$$= \frac{0.002 \times 10^4 \times [15 - (-5)]}{0.2} = \mathbf{2,000\ cal\ s^{-1}}.$$

S26.

Heat lost by water $= ms_w\,(\theta_f - \theta_i)_w$

$= (0.30\ \text{kg})\,(4186\ \text{J kg}^{-1}\,\text{K}^{-1})\,(50.0°\text{C} - 6.7°\text{C})$

$= 54376.14\ \text{J}$

Heat required to melt ice $= m_2 L_f = (0.15\ \text{kg})\,L_f$

Heat required to raise temperature of ice water to final temperature

$= m_1 s_w\,(\theta_f - \theta_i)_f$

$= (0.15\ \text{kg})\,(4186\ \text{J kg}^{-1}\,\text{K}^{-1})\,(6.7°\text{C} - 0°\text{C})$

$= 4206.93\ \text{J}$

$$\text{Heat lost} = \text{heat gained}$$

$$54376.14 \text{ J} = (0.15 \text{ kg}) L_f + 4206.93 \text{ J}$$

$$L_f = 3.34105 \text{ J kg}^{-1}.$$

S27. Here, $E = 5.67 \text{ watt cm}^{-2} = 5.67 \times 10^4 \text{ watt m}^{-2}$;

$$\sigma = 5.67 \times 10^{-8} \text{ watt m}^{-2} \text{ K}^{-4}$$

According to Stefan's law, we have

$$E = \sigma T^4$$

$$T = \left(\frac{E}{\sigma}\right)^{1/4} = \left(\frac{5.67 \times 10^4}{5.67 \times 10^{-8}}\right)^{1/4} = (10^{12})^{1/4}$$

$$= 10^3 = \mathbf{1{,}000\ K}.$$

S28. Here, $\lambda_m = 14 \text{ microns} = 14 \times 10^{-6} \text{ m}$;

$$b = 2.884 \times 10^{-3} \text{ m K}$$

From Wien's displacement law, we have

$$T = \frac{b}{\lambda_m} = \frac{2.884 \times 10^{-3}}{14 \times 10^{-6}} = \mathbf{206\ K}.$$

S29. Given $m_1 = 2 \text{ kg}$; $T_1 = 80\ °\text{C}$; $m_2 = 3 \text{ Kg}$ and $T_2 = 20\ °\text{C}$

$$\text{Heat lost} = \text{heat gain}$$

$$m_1 (80 - t) = m_2 (t - 20)$$

$$2(80 - t) = 3(t - 20)$$

$\Rightarrow$ $t = 44°\text{C}.$

S30. $m = 2 \text{ kg}$, $\Delta\theta = 35° \text{ C}$

$$\text{Heat produced} = ms\Delta\theta$$

$$= 2 \times 4186 \times 35$$

$$= \mathbf{293020\ J}.$$

S31. Mass of the copper block, $m = 2.5 \text{ kg} = 2500 \text{ g}$

Rise in the temperature of the copper block, $\Delta\theta = 500\ °\text{C}$

Specific heat of copper, $C = 0.39 \text{ J g}^{-1}\ °\text{C}^{-1}$

Heat of fusion of water, $L = 335\ \text{J g}^{-1}$

The maximum heat the copper block can lose, $Q = mC\Delta\theta$

$$= 2500 \times 0.39 \times 500$$

$$= 487500\ \text{J}$$

Let m_1 g be the amount of ice that melts when the copper block is placed on the ice block.

The heat gained by the melted ice, $Q = m_1 L$

$$\therefore \qquad m_1 = \frac{Q}{L} = \frac{487500}{335} = 1455.22\ \text{g}$$

Hence, the maximum amount of ice that can melt is 1.45 kg.

S32. Let a be area of cross-section of the glass tube.

Here, length of the glass tube, $L_{\text{glass}} = 133$ cm

$$\gamma_{\text{glass}} = 2.6 \times 10^{-5}\ ^{\circ}\text{C}^{-1}; \quad \gamma_{\text{mercury}} = 18.2 \times 10^{-5}\ ^{\circ}\text{C}^{-1}$$

Let L_{mercury} be the length of the mercury thread in tube.

Then $\qquad V_{\text{glass}} = 133 \times a \quad$ and $\quad V_{\text{mercury}} = L_{\text{mercury}}.$

The volume of the tube unoccupied by mercury w_1 same at all temperature, if increase in the volume tube is equal to increase in the volume of mercury.

$$V_{\text{glass}} \times \gamma_{\text{glass}} \times \Delta T = V_{\text{mercury}} \times \gamma_{\text{mercury}} \times \Delta T$$

or $\qquad 133 \times a \times 2.6 \times 10^{-5} = L_{\text{mercury}} \times a \times 18.2 \times 10^{-5}$

or $\qquad L_{\text{mercury}} = \dfrac{133 \times 2.6 \times 10^{-5}}{18.2 \times 10^{-5}} = \mathbf{19\ cm}.$

S33. Here, $T_1 = 100\ ^{\circ}\text{C}$; $T_2 = 0\ ^{\circ}\text{C}$; $t = 5$ minutes $= 5 \times 60 = 300\text{s}$; $d = 20$ cm; and diameter of the metal rod, $D = 2$ cm.

Therefore, area of cross-section of the rod,

$$A = \frac{\pi D^2}{4} = \frac{\pi \times (2)^2}{4} = \pi\ \text{cm}^2.$$

Let K be the coefficient of thermal conductivity of the material of the rod. Then, amount of heat flowing from the rod into the ice.

$$Q = \frac{KA(T_1 - T_2)t}{d} = \frac{K \times \pi \times (100 - 0) \times 300}{20}$$

or $\qquad Q = 4{,}712.4\ K$ cal $\qquad \ldots$ (i)

Also, $\qquad$ mass of ice melted, $m = 25$ g;

Specific latent heat of ice, $L = 80 \text{ cal g}^{-1}\,{}^{o}\text{C}^{-1}$

Therefore, heat required to melt the ice,

$$Q = mL = 25 \times 80$$

or $$Q = 2{,}000 \text{ cal} \quad \dots \text{(ii)}$$

From the equations (i) and (ii), we have

$$4{,}712.4\,K = 2{,}000$$

or $$K = \frac{2{,}000}{4{,}712.4} = \mathbf{0.424 \text{ cal s}^{-1}\text{ cm}^{-1}\,{}^{o}\text{C}^{-1}}.$$

S34. (a) Here, Wien's constant, $b = 0.2898$ cm K; $T = 1{,}227 + 273 = 1{,}500$ K

According to Wien's displacement law, we have

$$\lambda_m T = b$$

or $$\lambda_m = \frac{b}{T} = \frac{0.2898}{1{,}500} = 19{,}320 \times 10^{-8} \text{ cm} = \mathbf{19{,}320\ \text{Å}}.$$

(b) We know that power radiated,

$$E = A\sigma T^4 = 4\pi r^2 \sigma T^4$$

Initially, $r = 12$ cm $= 0.12$ m; $T = 500$ K and $E = 450$ W

$$\therefore \quad 450 = 4\pi \times (0.12)^2 \times \sigma \times (500)^4 \quad \dots \text{(i)}$$

Finally, $r = \frac{0.12}{2} = 0.06$ m; $T = 500 \times 2 = 1{,}000$ K

If E is power radiated then

$$E = 4\pi \times (0.06)^2 \times \sigma \times (1{,}000)^4 \quad \dots \text{(ii)}$$

Dividing the equation (ii) and (i), we have

$$\frac{E}{450} = \frac{4\pi \times (0.06)^2 \times \sigma \times (1{,}000)^4}{4\pi \times (0.12)^2 \times \sigma \times (500)^4} = 4$$

or $$E = 4 \times 450 = \mathbf{1{,}800\ W}.$$

S35. Here, $A = 0.36$ m^2; $d = 0.1$ m; $T_1 - T_2 = 100 - 0 = 100\,^{o}$C; $t = 1$ h $= 3{,}600$ s

Mass of ice melted, $M = 4.8$ kg

We know, latent heat of ice, $L = 336 \times 10^3 \text{ J kg}^{-1}$

Therefore, heat required to melt the ice,

$$Q = ML = 4.8 \times 336 \times 10^3$$

or $$Q = 1.613 \times 10^6 \text{ J} \quad \ldots \text{(i)}$$

Now, $$Q = \frac{KA(T_1 - T_2)}{d} \times t$$

$$= \frac{K \times 0.36 \times 100 \times 3{,}600}{0.1}$$

or $$Q = 1.296 \times 10^6 \text{ K} \quad \ldots \text{(ii)}$$

From the equations (i) and (ii), we have

$$1.296 \times 10^6 \text{ K} = 1.613 \times 10^6$$

$$K = \mathbf{1.245 \text{ W m}^{-1} \text{ °C}^{-1}}.$$

S36. Given, Initial temperature, $T_1 = 40\,°C$

Final temperature, $T_2 = 250\,°C$

Change in temperature, $\Delta T = T_2 - T_1 = 210\,°C$

Length of the brass rod at T_1, $l_1 = 50$ cm

Diameter of the brass rod at T_1, $d_1 = 3.0$ mm

Length of the steel rod at T_2, $l_2 = 50$ cm

Diameter of the steel rod at T_2, $d_2 = 3.0$ mm

Coefficient of linear expansion of brass,

$$\alpha_1 = 2.0 \times 10^{-5} \text{K}^{-1}$$

Coefficient of linear expansion of steel,

$$\alpha_2 = 1.2 \times 10^{-5} \text{K}^{-1}$$

For the expansion in the brass rod, we have:

$$\frac{\text{Change in length } (\Delta l_1)}{\text{Original length } (l_1)} = \alpha_1 \Delta T$$

$$\therefore \quad \Delta l_1 = 50 \ (2.0 \times 10^{-5}) \times 210$$

$$= 0.2205 \text{ cm}.$$

For the expansion in the steel rod, we have:

$$\frac{\text{Change in length } (\Delta l_2)}{\text{Original length } (l_2)} = \alpha_2 \Delta T$$

$\therefore \quad \Delta l_2 = 50\ (1.2 \times 10^{-5}) \times 210$

$= 0.126$ cm.

Total change in the lengths of brass and steel,

$$\Delta l = \Delta l_1 + \Delta l_2$$

$$= 0.2205 + 0.126$$

$$= 0.346 \text{ cm}$$

Total change in the length of the combined rod = 0.346 cm

Since the rod expands freely from both ends, no thermal stress is developed at the junction.

S37. Here, $A = 75$ cm^2; $d = 5$ cm, $K = 0.0075$ cal cm^{-1} s^{-1} ^{o}C^{-1}

$T_1 = 40\,^{o}$C; $T_2 = 0\,^{o}$C; $L = 80$ cal g^{-1} ^{o}C^{-1}

Here, mass of ice to be melted, $M = 500$ g

Heat required to melt the ice,

$$Q = ML = 500 \times 80 = 4 \times 10^4 \text{ cal} \quad \ldots \text{(i)}$$

Suppose that the amount of heat required to melt the ice flow into the flask in time t. Then,

$$Q = \frac{KA(T_1 - T_2)t}{d}$$

$$= \frac{0.0075 \times 75 \times (40 - 0)t}{5}$$

or $$Q = 4.5\,t \quad \ldots \text{(ii)}$$

From the equation (i) and (ii), we have

$$4.5\,t = 4 \times 10^4$$

or $t = 8{,}888.9$ s = **2.47 h**.

S38. Thermal conductivity is defined as heat energy transferred in unit time from unit area having a difference in temperature of unity over unit length. It is expressed in J s^{-1} m^{-1} ^{o}C^{-1} or Wm^{-1} K^{-1}. It is given by

$$K = \left(\frac{Q}{t}\right) \cdot \frac{dl}{Ad\theta}$$

And is expressed in S.I. system as $\frac{\text{joule}}{\text{sec}} = \frac{\text{metre}}{(\text{metre})^2 K}$ *i.e.*, J s^{-1} m^{-1} K^{-1}

or W m^{-1} K^{-1}

$$A = 1000 \text{ cm}^{-2} = 10^{-1} \text{ m}^2;$$

$$l = 0.4 \times 10^{-2} \text{ m},$$

$$d\theta = 37 - (-5) = 42\,^{o}C$$

$$K = 2.2 \times 10^{-3} \times 4.2 \times 10^{2}\ J\,s^{-1}\,m^{-1}\,K^{-1}$$

$$\frac{Q}{t} = K\,\frac{Ad\theta}{l}$$

$$= \frac{2.2 \times 10^{-3} \times 4.2 \times 10^{2} \times 10^{-1} \times 42}{0.4 \times 10^{-2}} = \mathbf{970.2\ J/sec}.$$

S39. Here, $K = 420\ W\,m^{-1}\,^{o}C^{-1}$; $T_1 - T_2 = 100 - 20 = 80\,^{o}C$

$$d = 1.7 - 1.5 = 0.2\ cm = 2 \times 10^{-3}\ m$$

Mean diameter of the copper tube,

$$D = \frac{1.5 + 1.7}{2} = 1.6\ cm = 1.6 \times 10^{-2}\ m$$

Length of the copper tube, $l = 3$ m

Therefore, surface area of the copper tube,

$$A = 2\,\pi r l = 2\pi \times \frac{1.6 \times 10^{-2}}{2} \times 3 = 0.1508\ m^2$$

Now, $$\frac{dQ}{dt} = \frac{KA(T_1 - T_2)}{d}$$

$$= \frac{420 \times 0.1508 \times 80}{2 \times 10^{-3}}$$

$$= 2.533 \times 10^{6}\ J = \frac{2.533 \times 10^{6}}{4.2}$$

$$= 6.03 \times 10^{5}\ cal\ s^{-1}$$

Let M be the mass of steam condensed per second.

Then $ML = 6.03 \times 10^{5}$

or $M \times 537 = 6.03 \times 10^{5}$

or $M = 1{,}122.9\ g = \mathbf{1.123\ kg}$.

S40. Initial temperature of the body of the child,

$$T_1 = 101\ °F$$

Final temperature of the body of the child,

$$T_2 = 98\ °F$$

Change in temperature, $\Delta T = \left[(101-98)\times\frac{5}{9}\right]$°C

Time taken to reduce the temperature,

$$t = 20 \text{ min}$$

Mass of the child, $m = 30 \text{ kg} = 30 \times 10^3 \text{ g}$

Specific heat of the human body = Specific heat of water = c

= 1000 cal/kg/°C

Latent heat of evaporation of water,

$$L = 580 \text{ cal g}^{-1}$$

The heat lost by the child is given as:

$$\Delta\theta = mc\Delta T$$

$$= 30 \times 1000 \times (101 - 98) \times \frac{5}{9}$$

$$= 50000 \text{ cal.}$$

Let m_1 be the mass of the water evaporated from the child's body in 20 min.

Loss of heat through water is given by:

$$\Delta\theta = m_1 L$$

$$\therefore \quad m_1 = \frac{\Delta\theta}{L} = \frac{50000}{580} = 86.2 \text{ g}$$

$\therefore$ Average rate of extra evaporation caused by the drug

$$= \frac{m_1}{t} = \frac{86.2}{20} = 4.3 \text{ g/min}.$$

S41. The insulating material around the rods reduces heat loss from the sides of the rods. Therefore, heat flows only along the length of the rods. Consider any cross section of the rod. In the steady state, heat flowing into the element must equal the heat flowing out of it; otherwise there would be a net gain or loss of heat by the element and its temperature would not be steady. Thus in the steady state, rate of heat flowing across a cross section of the rod is the same at every point along the length of the combined steel-copper rod. Let T be the temperature of the steel-copper junction in the steady state. Then,

$$\frac{K_1 A_1 \, 300\, T}{L_1} = \frac{K_2 A_2 \, T - 0}{L_2} \qquad \left[\because \ \frac{\Delta Q}{\Delta t} = \frac{KA\Delta T}{L}\right]$$

where 1 and 2 refer to the steel and copper rod respectively. For $A_1 = 2A_2$, $L_1 = 15.0$ cm, $L_2 = 10.0$ cm, $K_1 = 50.2 \text{ J s}^{-1}\text{ m}^{-1}\text{ K}^{-1}$, $K_2 = 385 \text{ J s}^{-1}\text{ m}^{-1}\text{ K}^{-1}$, we have

$$\frac{50.2 \times 2(300 - T)}{15} = \frac{385\,T}{10}$$

which gives $T = 44.4$ °C.

S42. We have, Mass of the ice, $m = 3$ kg

specific heat capacity of ice, $s_{ice} = 2100\ \text{J kg}^{-1}\text{K}^{-1}$

specific heat capacity of water, $s_{water} = 4186\ \text{J kg}^{-1}\text{K}^{-1}$

latent heat of fusion of ice, $L_{f\,ice} = 3.35 \times 10^5\ \text{J kg}^{-1}$

latent heat of steam, $L_{steam} = 2.256 \times 10^6\ \text{J kg}^{-1}$

Now, Q = heat required to convert 3 kg of ice at –12°C to steam at 100°C,

Q_1 = heat required to convert ice at – 12°C to ice at 0°C.

$= m\, s_{ice}\, \Delta T_1 = (3\text{ kg})\,(2100\ \text{J kg}^{-1}\text{K}^{-1})\,[0 - (-12)]°\text{C} = 75600\ \text{J}$

Q_2 = heat required to melt ice at 0 °C to water at 0 °C

$= m\, L_{f\,ice} = (3\text{ kg})\,(3.35 \times 10^5\ \text{J kg}^{-1}) = 1005000\ \text{J}$

Q_3 = heat required to convert water at 0°C to water at 100°C.

$= m s_w \Delta T_2 = (3\text{ kg})\,(4186\text{J kg}^{-1}\text{K}^{-1})\,(100°\text{C}) = 1255800\ \text{J}$

Q_4 = heat required to convert water at 100 °C to steam at 100 °C.

$= m\, L_{steam} = (3\text{ kg})\,(2.256 \times 10^6\ \text{J kg}^{-1}) = 6768000\ \text{J}$

So, $Q = Q_1 + Q_2 + Q_3 + Q_4$

$= 75600\ \text{J} + 1005000\ \text{J} + 1255800\ \text{J} + 6768000\ \text{J} = 9.1 \times 10^6\ \text{J}.$

S43. Given, $L_1 = L_2 = L = 0.1$ m, $A_1 = A_2 = A = 0.02\ \text{m}^2$, $K_1 = 79\ \text{W m}^{-1}\text{K}^{-1}$, $K_2 = 109\ \text{W m}^{-1}\text{K}^{-1}$, $T_1 = 373$ K, and $T_2 = 273$ K.

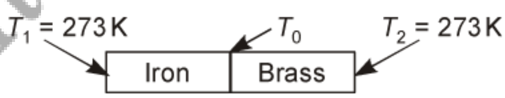
Under steady state condition, the heat current (H_1) through iron bar is equal to the heat current (H_2) through brass bar.

So, $H = H_1 = H_2$

$$= \frac{K_1 A_1 (T_1 - T_0)}{L_1} = \frac{K_2 A_2 (T_0 - T_2)}{L_2}$$

For $A_1 = A_2 = A$ and $L_1 = L_2 = L$, this equation leads to

$$K_1 (T_1 - T_0) = K_2 (T_0 - T_2)$$



Thus the junction temperature $T0$ of the two bars is

$$T_0 = \frac{(K_1 A_1 + K_2 A_2)}{(K_1 + K_2)}$$

Using this equation, the heat current H through either bar is

$$H = \frac{K_1 A (T_1 - T_0)}{L} = \frac{K_2 A (T_0 - T_2)}{L}$$

$$= \left(\frac{K_1 K_2}{K_1 + K_2}\right) \frac{A (T_1 - T_0)}{L} = \frac{A (T_1 - T_2)}{L\left(\dfrac{1}{K_1} + \dfrac{1}{K_2}\right)}$$

Using these equations, the heat current H_2 through the compound bar of length $L_1 + L_2 = 2L$ and the equivalent thermal conductivity K_2, of the compound bar are given by

$$H' = \frac{K'A(T_1 - T_2)}{2L} = H \; ; \qquad K = \frac{2K_1K_2}{K_1 + K_2}$$

(a)
$$T_0 = \frac{(K_1T_1 + K_2T_2)}{(K_1 + K_2)}$$

$$= \frac{(79\ \text{W m}^{-1}\text{K}^{-1})(373\ \text{K}) + (109\ \text{W m}^{-1}\text{K}^{-1})(273\ \text{K})}{79\ \text{W m}^{-1}\text{K}^{-1} + 109\ \text{W m}^{-1}\text{K}^{-1}} = 315\ \text{K}.$$

(b)
$$K' = \frac{2K_1K_2}{K_1 + K_2}$$

$$= \frac{2 \times (79\ \text{W m}^{-1}\text{K}^{-1}) \times (109\ \text{W m}^{-1}\text{K}^{-1})}{79\ \text{W m}^{-1}\text{K}^{-1} + 109\ \text{W m}^{-1}\text{K}^{-1}} = 91.6\ \text{W m}^{-1}\text{K}^{-1}.$$

(c)
$$H' = H = \frac{K'A(T_1 - T_2)}{2L}$$

$$= \frac{(91.6\ \text{W m}^{-1}\text{K}^{-1}) \times (0.02\ \text{m}^2) \times (373\ \text{K} - 273\ \text{K})}{2 \times (0.1\ \text{m})} = 916.1\ \text{W}.$$

S44. (a) Initial temperature, $T_1 = 27.0\ °\text{C}$

Diameter of the hole at T_1, $d_1 = 4.24\ \text{cm}$

Final temperature, $T_2 = 227\ °\text{C}$

Diameter of the hole at $T_2 = d_2$

Co-efficient of linear expansion of copper, $\alpha_{Cu} = 1.70 \times 10^{-5}\ \text{K}^{-1}$

For co-efficient of superficial expansion β, and change in temperature ΔT, we have the relation:

$$\frac{\text{Change in area } (\Delta A)}{\text{Original area } (A)} = \beta \Delta T$$

$$\frac{\left(\pi \dfrac{d_2^2}{4} - \pi \dfrac{d_1^2}{4}\right)}{\left(\pi \dfrac{d_1^2}{4}\right)} = \frac{\Delta A}{A}$$

$$\therefore \quad \frac{\Delta A}{A} = \frac{d_2^2 - d_1^2}{d_1^2}$$

But $\beta = 2\alpha$

$$\therefore \quad \frac{d_2^2 - d_1^2}{d_1^2} = 2\alpha \Delta T$$

$$\frac{d_2^2}{d_1^2} - 1 = 2\alpha(T_2 - T_1)$$

$$\frac{d_2^2}{(4.24)^2} = 2 \times 1.7 \times 10^{-5}(227 - 27) + 1$$

$$d_2^2 = 17.98 \times 1.0068 = 18.1$$

$\therefore$ $$d_2 = 4.2544 \text{ cm}$$

Change in diameter = $d_2 - d_1 = 4.2544 - 4.24 = 0.0144$ cm.

Hence, the diameter increases by 1.44×10^{-2} cm.

(b) Here, $d = 2$ mm $= 0.2$ cm; $A = 1 \text{ m}^2 = 10^4 \text{ cm}^2$;

$T_1 = 15\ ^\circ\text{C}$; $T_2 = -5\ ^\circ\text{C}$; $K = 0.002 \text{ cal cm}^{-1} \text{ s}^{-1}\ ^\circ\text{C}^{-1}$

Now, $$\frac{dQ}{dt} = \frac{KA(T_1 - T_2)}{d}$$

$$= \frac{0.002 \times 10^4 \times [15 - (-5)]}{0.2} = \mathbf{2{,}000 \text{ cal s}^{-1}}.$$

Date: 14/10/2021

Q1. The pipes which have to convey steam from a boiler, must have loops. Explain.

Q2. What is principal of Calorimetry?

Q3. A 200 gram copper calorimeter contain 150 gram of oil at 20 °C. To the oil is added 80 gram of aluminium at 300 °C. What will be the temperature of the system after equilibrium is established. Given that specific heat of copper = 0.3906 J g^{-1} °C, specific heat of aluminium = 0.882 J g^{-1} °C^{-1} and specific heat of oil = 1.554 J g^{-1} °C^{-1}.

Q4. Steam at 100 °C is passes over 1000 g of ice at 0 °C. After sometime, 600g of ice at 0 °C is left and 450 g of water at 0 °C is formed. Calculate the specific latent heat of vaporization of steam. Specific heat capacity of water = 42,000 J kg^{-1} °C and specific latent heat of fusion of ice = 336×10^3 J kg^{-1}.

Q5. An electric heater of power 1,000 W raises the temperature of 5 kg of a liquid from 25 °C to 31 °C in 2 minutes. Calculate heat capacity of the liquid and its specific heat.

Q6. Determine the resulting temperature, when 150 gram of ice at 0 °C is mixed with 300 gram of water at 50 °C. Given, latent heat of fusion of ice = 336 J g^{-1}.

Q7. When a piece of metal weighting 48.3 kg at 10.7 °C is immersed in a current of steam at 100 °C, 0.762 kg of steam is condensed on it. Calculate the specific heat of the metal. Latent heat of vaporization = $2{,}268 \times 10^3$ J kg^{-1}.

Q8. 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} K^{-1}.

Q9. What is meant by monochromatic emittance, emissive power, emissivity and monochromatic absorbance?

Q10. What is a black body ? How was such a body designed by Fery?

Q11. The temperature of 100 g 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. Take specific heat of water = 4.2×10^3 J kg^{-1} °C^{-1} and latent heat of vaporization = 2268×10^3 J kg^{-1}.

Q12. In an experiment on the specific heat of a metal, a 0.16 kg block of metal at 210 °C is dropped in a copper calorimeter of water equivalent 0.03 kg containing 0.12 kg of the water at 30 °C. The final temperature of the mixture is 48 °C. Calculate the specific heat of the metal.

Q13. A sphere of aluminium of 0.047 kg placed for sufficient time in a vessel containing boiling water, so that the sphere is at 100°C. It is then immediately transfered to 0.14 kg copper calorimeter containing 0.25 kg of water at 20°C. The temperature of water rises and attains a steady state at 23°C. Calculate the specific heat capacity of aluminium.

Q14. 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} K^{-1}; Heat of vaporisation of water = 2256×10^3 J kg^{-1}.

Date: 14/10/2021

S1. When the hot oil passes through the pipelines, the pipes expand. The loops in the pipelines take up the extra length, when the pipe get heated.

S2. The heat lost by the hot body must be equal to the heat of gained by the cold body it is principle of calorimetry

Heat lost = Heat gained.

S3. Let θ be the equilibrium temperature.

Heat lost by the piece of aluminium,

$$Q = M_1 c_1 (\theta_1 - \theta)$$

Given, $M_1 = 80\,g$; $c_1 = 0.882\,J\,g^{-1}\,{}^oC^{-1}$; $\theta_1 = 300\,{}^oC$

$\therefore$ $Q = 80 \times 0.882 \times (300 - \theta)$ …(i)

$= 70.56\,(300 - \theta)$

$$Q = M_2 c_2 (\theta - \theta_2) + m c (\theta - \theta_2)$$

$$= (M_2 c_2 + m c)\,(\theta - \theta_2)$$

Here, $M_2 = 150\,g$; $m = 200\,g$; $c_2 = 1.554\,J\,g^{-1}\,{}^oC^{-1}$;

$c = 0.3906\,J\,g^{-1}\,{}^oC^{-1}$; $\theta_2 = 20\,{}^oC$

$\therefore$ $Q = (150 \times 1.554 + 200 \times 0.3906)\,(\theta - 20)$

or $Q = 311.22\,(\theta - 20)$ …(ii)

From the equation (i) and (ii), we get

$$311.22\,(\theta - 20) = 70.56\,(300 - \theta)$$

$\Rightarrow$ $311.22\,\theta - 6224.4 = 12168 - 70.56\,\theta$

or $\theta = \mathbf{48.18\,{}^oC}$.

S4. Given, Initial mass of ice, $M_1 = 1000\,g = 1\,kg$

Mass of ice left, $M_2 = 600\,g = 0.6\,kg$

and Mass of water formed, $M = 450\,g = 0.45\,kg$

Therefore, mass of steam passed,

$$m = (M_2 + M) - M_1 = (0.6 + 0.45) - 1 = 0.05\,kg$$

Latent heat of ice, $L = 336 \times 10^3\,J\,kg^{-1}$

Specific heat of water, $c = 4.200 \text{ J kg}^{-1} \text{°C}^{-1}$

Let L be the latent heat of steam

Heat lost by water,

$$Q = mL + m \times c \times (100 - 0) = m(L + 100c)$$

or $$Q = 0.05 \times (L + 100 \times 4{,}200) \quad \ldots\text{(i)}$$

Now, mass of ice melted, $M_1 - M_2 = 1 - 0.6 = 0.4$ kg

Heat gained by ice.

$$Q = (M_1 - M_2)L = 0.4 \times 336 \times 10^3 \quad \ldots\text{(ii)}$$

From the Eq. (i) and (ii), we have

$$0.05 \times (L + 100 \times 4{,}200) = 0.4 \times 336 \times 10^3$$

or $$L = \mathbf{2{,}268 \times 10^3 \text{ J kg}^{-1}}.$$

S5. Here, heat energy supplied by the electric heater,

$$Q = P \times t = 1{,}000 \times (2 \times 60) = 1.2 \times 10^5 \text{ J} \quad \ldots\text{(i)}$$

Let c be the specific heat of the liquid. Then,

$$Q = Mc\Delta T$$

Here, $M = 5$ kg; $\Delta T = 31 - 25 = 6$ °C

$$Q = 5 \times c \times 6 = 30c \quad \ldots\text{(ii)}$$

From the equation (i) and (ii), we have

$$30c = 1.2 \times 10^5 = 4{,}000 \text{ J kg}^{-1} \text{°C}^{-1}$$

Now, heat capacity of the liquid,

$$c = 4.0 \times 10^3 \text{ Kg}^{-1} \text{°C}^{-1}$$

$$Mc = 5 \times 4000 = \mathbf{2 \times 10^4 \text{ J °C}^{-1}}.$$

S6. Here, Mass of water, $M_1 = 300$ g;

Temperature of water, $\theta_1 = 50$ °C;

Mass of ice, $M_2 = 150$ g

and Latent heat ice, $L = 336 \text{ J g}^{-1}$

We know, Specific heat of water = 4.2 J g^{-1}

Let θ be the resultant temperature.

Heat lost by water, $Q = M_1 c_1 (\theta_1 - \theta) = 300 \times 4.2 \times (50 - \theta) \quad \ldots\text{(i)}$

Heat gained by ice. $Q = M_2 L + M_2 c_1 (\theta - 0) = M_2 (L + c_1 \theta)$

or $$Q = 150 \times (336 + 4.2\,\theta) \qquad \ldots\text{(ii)}$$

From the Eq. (i) and (ii), we have

$$300 \times 4.2 \times (50 - \theta) = 150 \times (336 + 4.2\,\theta)$$

or $$\theta = \mathbf{6.67\ ^{o}C}.$$

S7. Let c be specific heat of the metal and m, the mass of steam condensed.

When the steam is condensed on the metal, the final temperature will be 100 ^{o}C.

Here, Mass of the metal, $M = 48.3$ kg;

$\theta_1 = 10.7\,^{o}$C; $\theta_2 = 100\,^{o}$C;

Mass of steam condensed $m = 0.762$ kg;

$L = 2{,}268 \times 10^3$ J kg^{-1}

Heat gained by the metal,

$$Q = Mc\,(\theta_2 - \theta_1) = 48.3 \times c \times (100 - 10.7) \qquad \ldots\text{(i)}$$

Heat lost by steam,

$$Q = mL = 0.762 \times 2{,}268 \times 10^3 \qquad \ldots\text{(ii)}$$

From the Eq. (i) and (ii), we have

$$48.3 \times c \times (100 - 10.7) = 0.762 \times 2{,}268 \times 10^3$$

or $$c = \mathbf{400.68\ J\ kg^{-1}\ ^{o}C^{-1}}.$$

S8. Power of the drilling machine, $P = 10 \times 10^3$ W

Mass of the aluminum block, = 8.0 Kg

Time for which the machine is used, = 2.5min = 150 sec

Specific heat of aluminium, $c = 0.91$ J g^{-1} K^{-1}

Rise in the temperature of the block after drilling = δT

Total energy of the drilling machine = Pt

$$= 10 \times 10^3 \times 150$$

$$= 1.5 \times 10^6 \text{ J}$$

It is given that only 50% of the power is useful.

Useful energy,

$$\Delta Q = \frac{50}{100} \times 1.5 \times 10^6 = 7.5 \times 10^5 \text{ J}$$

But $\Delta Q = mc\Delta T$

$$\Delta T = \frac{\Delta Q}{mc}$$

$$= \frac{7.5 \times 10^5}{8 \times 10^3 \times 0.91} = 103\,°C.$$

Therefore, in 2.5 minutes of drilling, the rise in the **103 °C**.

S9. (a) Monochromatic emittance or spectral emissive power of a body corresponding to particular wave length λ at a particular temperature is defined as the amount of radiant energy emitted per unit time per unit surface area of the body within wavelength interval around λ *i.e.*, between $\left(\lambda - \frac{1}{2}\right)$ and $\left(\lambda + \frac{1}{2}\right)$.

It is represented by e_λ.

If we consider a small wavelength interval *d* around λ *i.e.*, between $(\lambda - d\lambda/2)$ and $(\lambda + d\lambda/2)$, then the amount of energy radiated per unit time per unit area of the body in the wave length interval d will be given by $e_\lambda \, d\lambda$.

(b) The total emittance or emissive power of a body at a certain temperature is defined as the total amount of thermal energy emitted per unit time per unit area of the body for all possible wavelengths. It is represented by *e*.

As the wavelength of radiation emitted range from 0 to ∞, obviously,

$$e = \int_0^\infty e_\lambda \, dA,$$

e is measured in joule sec^{-1} $metre^{-2}$ or Wm^{-2}.

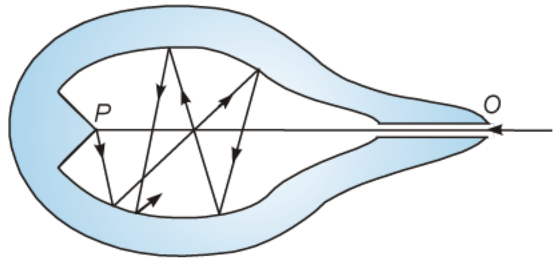
(c) Emissivity of a body at a given temperature is defined as the ratio of the total emissive power of the body (*e*) to the total emissive power of a perfectly black (*E*) at that temperature. It is represented by '*E*'. Thus

$$E = \frac{e}{\in} \quad \text{or} \quad e = \in E.$$

(d) Monochromatic absorbance or special absorptive power of a body corresponding to a certain wavelength λ is defined as the ratio of the amount of heat energy absorbed in a certain time to the total heat energy incident upon it in the same time, both in the unit wavelength interval around the wavelength λ, *i.e.*, between $\left(\lambda - \frac{1}{2}\right)$ and $\left(\lambda + \frac{1}{2}\right)$. It is represented by α_λ.

S10. A perfectly black body is that which absorbs completely the radiations of all wavelengths incident on it.

As a perfectly black body neither reflects nor transmits any radiation, therefore the absorbance or absorbing power of a perfectly black body in unity.



We know that the colour of an opaque body is the colour (*i.e.*, wavelength) of radiation reflected by it. As a black body whatever be the colour of radiation incident on it.

When a perfectly black body is heated to a suitable high temperature, it emits radiations of all possible wavelength. The radiations given out by a perfectly back body are called plain body radiations or full radiations or total radiations.

It consists of a hollow double walled metallic sphere having a narrow opening *O* on the side and a conical projection *P* inside just opposite to it. The inside of the sphere is coated with lamp black. Any radiation entering the sphere through the opening *O* suffer multiple reflections at its inner walls and about 97% of it is absorbed by lamp black at each reflection. Therefore, after a few reflections, almost entire radiation is absorbed. The projection help in avoiding any direct reflection which even otherwise is hardly possible because of the small size of the opening *O*. When this body is placed in a bath at fixed temperature, the heat radiations come out of the hole. The opening thus acts as a black body radiator. It should be remembered that only the opening (and not the walls) acts as a black body radiator.

S11. Here, mass of water, M = 100 g = 0.1 kg; θ_1 = 24 °C; θ_2 = 90 °C; $c = 4.2 \times 10^3$ J kg °C^{-1}; $L = 2{,}268 \times 10^3$ J kg^{-1}.

Let m be the required mass of the steam.

Heat gained by water,

$$Q = Mc \times (\theta_2 - \theta_1) = 0.1 \times 4.2 \times 10^3 \times (90 - 24)$$

or $$Q = 27.72 \times 10^3 \qquad \ldots(i)$$

Heat lost by steam,

$$Q = mL + mc(100 - 90) = m(L + 10c)$$
$$= m(2{,}268 \times 10^3 + 10 \times 4.2 \times 10^3)$$

or $$Q = 2{,}310 \times 10^3 \text{ m} \qquad \ldots(ii)$$

From the equations (i) and (ii), we have

$$2310 \times 10^3\, m = 27.72 \times 10^3$$

or $$m = 0.012 \text{ kg} = \mathbf{12\ g}.$$

S12. Here, mass of metal block, M_1 =0.16 kg; temperature of metal block, θ_1 = 210 °C; temperature of calorimeter, θ = 48 °C; water equivalent of calorimeter, w = 0.03 kg; and mass of water in the calorimeter = 0.12 kg

Let c_1 (J kg^{-1} °C^{-1}) be the specific heat of the metal block

Then, heat lost by the metal block.

$$= M_1 c_1 \times (\theta_1 - \theta)$$
$$= 0.16 \times c_1 \times (210 - 48) = 25.92\, c_1$$

Also, specific heat of water;

$$c_2 = 4.2 \times 10^3 \text{ kg}^{-1}\ {}^\circ\text{C}^{-1}$$

Then, heat gained by water and calorimeter

$$= (M_2 + w) \times c_2 \times (\theta - \theta_2)$$

$$= (0.12 + 0.03) \times 4.2 \times 10^3 \times (48 - 30)$$

$$= 0.15 \times 4.2 \times 10^3 \times 18 = 11.34 \times 10^3 \text{ J}$$

Now, heat lost = heat gained

$\therefore$ $$25.92\, c_1 = 11.34 \times 10^3$$

Or $$c_1 = \frac{11.34 \times 10^3}{25.92} = \mathbf{437.5\ J\ kg^{-1}\ {}^oC^{-1}}.$$

Note: The specific heat of water is 4.2×10^3 J kg^{-1} ^{o}C^{-1} in SI and cal g^{-1} ^{o}C^{-1} in c.g.s system.

S13. In solving this example we shall use the fact that at a steady state, heat given by an aluminium sphere will be equal to the heat absorbed by the water and calorimeter. This is also called law of calorimetry

Heat lost by the hot body = Heat gained by the cold body

Mass of aluminium sphere (m_1) = 0.047 kg

Initial temp. of aluminium sphere = 100 °C

Final temp. = 23 °C

Change in temp (ΔT) = (100°C – 23°C) = 77°C

Let specific heat capacity of aluminium be s_{Al}.

The amount of heat lost by the aluminium sphere

$$= m_1 s_{Al} \Delta T = 0.047\text{kg} \times s_{Al} \times 77°\text{C}$$

Mass of water (m_2) = 0.25 kg

Mass of calorimeter (m_3) = 0.14 kg

Initial temp. of water and calorimeter = 20°C

Final temp. of the mixture = 23°C

Change in temp. (ΔT_2) = 23°C – 20°C = 3°C

Specific heat capacity of water (s_w) = 4.18×10^3 J kg^{-1} K^{-1}

Specific heat capacity of copper calorimeter

$$= 0.386 \times 10^3 \text{ J kg}^{-1} \text{K}^{-1}$$

The amount of heat gained by water and calorimeter

$$= m_2 sw\, \Delta T_2 + m_3\, s_{cu} \Delta T_2$$

$$= (m_2 s_w + m_3 s_{cu})\, (\Delta T_2)$$

$$= 0.25 \text{ kg} \times 4.18 \times 10^3 \text{ J kg}^{-1} \text{K}^{-1}$$

$$+ 0.14 \text{ kg} \times 0.386 \times 10^3 \text{ J kg}^{-1} \text{K}^{-1})\, (23°\text{C} - 20°\text{C})$$

In the steady state heat lost by the aluminium sphere = heat gained by water + heat gained by calorimeter.

So, $0.047 \text{ kg} \times s_{Al} \times 77°C$

$$= (0.25 \text{ kg} \times 4.18 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1} + 0.14 \text{ kg} \times 0.386 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1})(3°C)$$

$$s_{Al} = 0.911 \text{ kJ kg}^{-1} \text{ K}^{-1}.$$

S14. Base area of the boiler, $A = 0.15 \text{ m}^2$

Thickness of the boiler, $l = 1.0 \text{ cm} = 0.01 \text{ m}$

Boiling rate of water, $R = 6.0 \text{ kg/min}$

Mass, $m = 6 \text{ kg}$

Time, $t = 1 \text{ min} = 60 \text{ s}$

Thermal conductivity of brass, $K = 109 \text{ J s}^{-1} \text{ m}^{-1} \text{ K}^{-1}$

Heat of vaporisation, $L = 2256 \times 10^3 \text{ J kg}^{-1}$

The amount of heat flowing into water through the brass base of the boiler is given by:

$$\theta = \frac{KA(T_1 - T_2)t}{l} \quad \text{... (i)}$$

Where,

T_1 = Temperature of the flame in contact with the boiler

T_2 = Boiling point of water = 100°C

Heat required for boiling the water:

$$\theta = mL \quad \text{... (ii)}$$

Equating equations (i) and (ii), we get:

$$\therefore \quad mL = \frac{KA(T_1 - T_2)t}{l}$$

$$T_1 - T_2 = \frac{mLl}{KAt}$$

$$= \frac{6 \times 2256 \times 10^3 \times 0.01}{109 \times 0.15 \times 60} = 137.98 \text{ °C}$$

Therefore, the temperature of the part of the flame in contact with the boiler is 137.98 °C.