Thermal Properties of Matter

Case Study Based Questions

Read the following passages and answer the questions that follow:

1. Even in its solid form, glass exhibits the molecular structure of a stiff liquid. For this reason, glass at room temperature is sometimes referred to as a supercooled liquid. As it is heated, glass gradually begins to behave more and more like a liquid until, at temperatures above 2000°F (1093°C), it will flow easily, with a consistency similar to honey. The temperatures at which glass is worked in a kiln are usually between 1000-1700°F (538-927°C). Within this range, a wide variety of effects may be achieved by using a variety of processes.

(A) Boiling water is used to dip a centigrade and a Fahrenheit thermometer. The temperature of the water is reduced until the thermometer reads 140°F. What is the temperature drop as measured according to the centigrade thermometer?

(B) Why do the ends of a glass tube become rounded on heating?

(C) The coolant used in a nuclear plant should have high specific heat. Why?

Ans. (A) Here, F = 140°

Using,

$$\frac{F-32}{9}=\frac{C}{5}$$

$$\frac{140-32}{9}=\frac{C}{5}$$

$$C = 60°C$$

So, fall in temperature in °C is,

$$100 - 60 = 40°C$$

(B) When glass is heated, it melts. The surface of this liquid tends to have a minimum area. For a given volume, the surface area is minimum for a sphere. This is why the ends of a glass tube become rounded on heating.

(C) So that, it absorbs more heat with a compa- ratively small change in temperature and extracts a large amount of heat.

2. Many solids are made up of crystals, regular shapes composed of molecules joined to one another as though on springs. A spring that is pulled back, just before it is released, is an example of potential energy, or the energy that an object possesses by virtue of its position. For a crystalline solid at room temperature, potential energy and spacing between molecules are relatively low. But as temperature increases and the solid expands, the space between molecules increases, as does the potential energy in the solid.

(A) The length of a copper rod of 88 cm and an aluminium rod of unknown length increases independently of temperature increase. Aluminium rod has a length of

(α_{Cu} = 1.7 × 10^{-5} K^{-1}, α_{Al} = 2.2 × 10^{-5} K^{-1}):

(a) 68 cm

(b) 6.8 cm

(c) 113.9 cm

(d) 88 cm

(B) The linear expansion coefficients of brass and steel rods are α_1, and α_2, respectively. Brass and steel rods have lengths of l_4, and l_2, respectively. Which of the following relationships holds true if (l_2-l_1) remains constant at all temperatures?

(a) $\alpha_1^2 l_2 = \alpha_2^2 l_1$ **(b)** $\alpha_1 l_1 = \alpha_2 l_2$

(c) $\alpha_1 l_2 = \alpha_2 l_1$ **(d)** $\alpha_1 l_2^2 = \alpha_2 l_1^2$

(C) Glycerin has a coefficient of volume expansion of 5 x 10-4 K-^{1}. The fractional change in density of glycerin for a temperature increase of 40°C is:

(a) 0.025

(b) 0.010

(c) 0.015
(d) 0.020
(D) Water has a density of 998 kg/m^3 at 20°C and 992 kg/m^3 at 40°C, water's coefficient of volume expansion is:
(a) 3 x 10- /°C
(b) 5 x 10-4/°C
(c) 7 x 10-4/°C
(d) 2 × 10-4/°C
(E) A uniform metallic rod rotates about its perpendicular bisector with constant angular speed. If it is heated uniformly to raise, its temperature slightly:
(a) Its speed of rotation increases.
(b) Its speed of rotation decreases.
(c) Its speed of rotation remains the same.
(d) Its speed increases because its moment of inertia increases

Ans. (A) (a) 68 cm

Explanation: As $\alpha_{cu} l_{cu} = \alpha_{Al} l_{Al}$

$$1.7 \times 10^{-5} \times 88 \text{ cm} = 2.2 \times 10^{-5} \times l_{Al}$$

$$l_{Al} = \frac{1.7 \times 88}{2.2}$$

$$= 68 \text{ cm}$$

(B) (b) α1l1 = α2l2
Explanation:
Linear expansion of brass = α_1
Linear expansion of steel = α_2
Length of brass rod = l_1
Length of steel rod = l_2
On increasing the temperature of the rods by ΔT, new lengths would be,

$$l'_1 = l_1(1 + \alpha_1 \Delta T)$$

$$l'_2 = l_2(1 + \alpha_2 \Delta T)$$

On subtracting the above both equations,

$$l'_2 - l'_1 = (l_2 - l_2)(l_2\alpha_2 - l_1\alpha_1)\Delta T$$

$$l'_2 - l'_1 = l_2 - l_1$$

For all temperatures

$$(l'_2\alpha_2 - l'_1\alpha_1) = 0$$

or, $$l_1\alpha_1 = l_2\alpha_2$$

(C) (d) 0.020

Explanation: Let Po and p, be densities of glycerin at 0°C and T°C respectively. Then P_T = Po (1-YΔT)

where, y is the coefficient of volume expansion of glycerin and ΔT is a rise in temperature.

$$\frac{\rho_T}{\rho_0} = 1 - \gamma\Delta T$$

or $$\gamma\Delta T = 1 - \frac{\rho_T}{\rho_0}$$

Thus, $$\frac{\rho_0 - \rho_T}{\rho_0} = \gamma\Delta T$$

Here, $\gamma = 5 \times 10^{-4}\ K^{-1}$ and $\Delta T = 40°C$

The fractional change in the density of glycerin,

$$\frac{\rho_0 - \rho_T}{\rho_0} = \gamma\Delta T$$

$$= (5 \times 10^{-4})(40K) = 0.020$$

(D) (a) 3 x 10-4/°C

Explanation: Here,

$$\rho_{T_2} = \frac{\rho_{T_1}}{(1+\gamma\Delta T)} = \frac{\rho_{T_1}}{(1+\gamma(T_2 - T_1)}$$

Here, $T_1 = 20°C, T_2 = 40°C$

$\rho_{20°C} = 998 kg / m^3, \rho_{40°C} = 992 \ kg/m^3$

$$992 = \frac{998}{1+\gamma(40-20)}$$

$$992 = \frac{998}{1+20\gamma}$$

$$992(1 + 20\gamma) = 998$$

$$1+20\gamma = \frac{998}{992}$$

$$20\gamma = \frac{998}{992} - 1 = \frac{6}{992}$$

$$\gamma = \frac{6}{992} \times \frac{1}{20} = 3\times10^{-4} / °C$$

(E) (b) its speed of rotation decreases.

Explanation: On heating a uniform metallic rod, its length will increase, so moment of inertia of rod increased from I_1, to I_2 Now, from the law of conservation of angular momentum,

$$I_1\omega_1 = I_2\omega_2$$

As $I_1 < I_2, \omega_1 > \omega_2,$

So, angular speed decreased.

3. At high doses, radiation therapy kills cancer cells or slows their growth by damaging their DNA. Cancer cells whose DNA is damaged beyond repair stop dividing or die. When the damaged cells die, they are broken down and removed by the body. Radiation therapy does not kill cancer cells right away. It takes days or weeks of treatment before DNA is damaged enough for cancer cells to die. Then, cancer cells keep dying for weeks or months after radiation therapy ends.

(A) Consider a physical body which absorbs all incident electromagnetic radiation and whose temperature is 57.60 K. The energy of radiation emitted by a body at wavelength 250 nm is λ_2, the energy at wavelength 500 nm is 22, and the energy at wavelength 1000 nm is λ_3, b = 2.88 x 10^6 nm K is Wien's constant. What's the link between λ_1, and λ_2?

(B) What is Fery's black body?

(C) Explain that different temperature causes variation in wavelength and intensity of blackbody radiation.

Ans. (A) Given Temperature, T1, = 5760 K Since its given that energy of radiation emitted by the body at wavelength 250 nm for λ2, at wavelength 500 nm for λ1, and that of 1000 nm for λ3. According to Wein's law,

$$\lambda_m T = b$$

$$\lambda_m = \frac{b}{T}$$

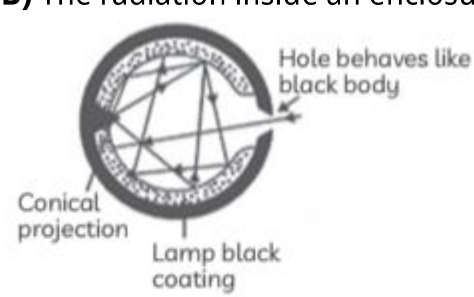
$$\lambda_m = \frac{2.88 \times 10^6}{5760 \text{ K}}$$

$$\lambda_m = 500 \text{ K}$$

A is wavelength corresponding to maximum energy.

So, $\lambda_2 > \lambda 1$

(B) The radiation inside an enclosure whose.



Most of the energy entering through hole is absorbed (99%).
(C) At a certain temperature as wavelength increases, intensity corresponding to those wavelengths also increases, achieves a maximum value and again starts to decrease. It means at a given temperature; spectral emissive power is maximum for a particular wavelength. Spectrum of black body is a continuous spectrum. As temperature increases, wavelengths corresponding to maximum intensity shift towards lower wavelengths. Wavelength corresponding to maximum intensity is inversely proportional to absolute temperature.

4. A body emits radiation at a given temperature and frequency exactly as well as it absorbs the same radiation. This was proved by Kirchhoff. the essential point is that if we suppose a particular body can absorb better than it emits, then in a room full of objects all at the same temperature, it will absorb radiation from the other bodies better than it radiates energy back
to them. This means it will get hotter, and the rest of the room will grow colder, contradicting the second law of thermodynamics.
(A) The temperature of boiler is 2324°C and the intensity of its radiation spectrum is near 12000. If the maximum intensity in a star's spectrum is near 4800, then the star's surface temperature is:
(a) 8400°C
(b) 7200°C
(c) 6219.5°C
(d) 5900°C
(B) A black body at 27°C emits 10 J of energy per second. If the temperature of the black body is raised to 327°C, the energy emitted per second will be:
(a) 20 J
(b) 40 J
(c) 80 J
(d) 160 J
(C) A black body's initial temperature is 727°C. The temperature at which the
total radiant energy from this black body doubles is:
(a) 971 K
(b) 1189 K
(c) 2001 K

(d) 1458 K

(D) In one minute, a cup of coffee cools from 80°C to 60°C. The temperature outside is 30°C. How long will it take to cool from 60°C to 50°C?

(a) 60 sec

(b) 48 sec

(c) 52 sec

(d) 3 min

(E) A black body at 200 K emits the most energy at a wavelength of 14 m. When its temperature is raised to 1000 K, what wavelength emits the most energy?

(a) 2.8 μm

(c) 4.2 μm

(b) 2.4 μm

(d) 5.6 μm

Ans. (A) (c) 6219.5°C

Explanation: According to Wien's displace- ment law,

λ_{max} is inversely proportional to temperature (in Kelvin),

$$\frac{\lambda_1}{\lambda_2} = \frac{T_2}{T_1}$$

$$\frac{12000}{4800} = \frac{T_2}{(2324+273)}$$

$$T_2 = 6492.5K$$

So, $T_2 = 6492.5 - 273$

$$= 6219.5°C$$

$$T_2 \approx 6219°C$$

(B) (d) 160 J

Explanation: Given that; Initial temperature,

T_1 = 27°C

T_1 = 27+ 273

T_1 = 300 K

Final temperature,

T_2 = 327°C

T_2 = 327 +273

T_2 = 600 K

Initial energy radiated, E_1= 10 J
Final energy emitted, E_2= ?
By Applying Stefan's law

$$E \propto T^4$$
$$E = KT^4$$
$$2\frac{1}{4} = K \text{ (constant)}$$
$$\frac{E_1}{T_1^4} = \frac{E_2}{T_2^4}$$
$$\frac{100}{(300)^4} = \frac{E_2}{(600)^4}$$
$$E_2 = 160 \text{ J}$$

(C) (b) 1189 K

Explanation: Radiant Energy = σT^2

$$\text{Energy} = \sigma(1000)^4$$
$$E_2 = 2E_1$$
$$\text{Then, } \sigma T_2^4 = 2 \times \sigma(1000)^4$$
$$T_2 = 2\frac{1}{4} \times 1000$$
$$T_2 = 1189 \text{ K}$$

(D) (b) 48 sec

Explanation: As,

$$\frac{\Delta T}{\text{time}} = K\left(\frac{t_1 + t_2}{2} - t_0\right)$$
$$\frac{80-60}{60} = K\left(\frac{80+60}{2} - 30\right)$$
$$\frac{1}{3} = K(40)$$
$$K = \frac{1}{120}$$
$$\frac{60-50}{\text{time}} = \frac{1}{120}\left(\frac{60+50}{2} - 30\right)$$
$$= 48 \text{ sec.}$$
$$\text{Time} = 48 \text{ sec.}$$

(E) (a) 2.8 μm

Explanation: From Wien's displacement law,

$$\lambda \times T = \text{Constant.}$$

So, $1000 \times \lambda = 200 \times 14$

$$\Rightarrow \quad \lambda = \frac{200 \times 14}{1000}$$

$$= 2.8\ \mu m$$