# CHAPTER 2: HEAT AND THERMODYNAMICS

## Test Your Concepts-I (Based on Thermometry and Thermal Expansion)

**1.** (a) When the temperature decreases, the length of the ruler also decreases through thermal contraction. Below 20 °C, each centimetre division is actually somewhat shorter than 1 cm, so the steel ruler gives readings that are too long.

(b) At 40 °C, the increase in length of the ruler is

$$\Delta\ell = \ell\alpha\Delta T$$

$$\Rightarrow \Delta\ell = (20)(1.2\times10^{-5})(40-20)$$

$$\Rightarrow \Delta\ell = 0.48\times10^{-2}\text{ cm}$$

So, the actual length of the ruler is,

$$\ell' = \ell + \Delta\ell = 20.0048\text{ cm}$$

**2.** (a) The 88.42 cm mark on aluminium rod is actually at a greater distance from the zero position than indicated because of the increase in temperature $\Delta T = 30$ °C. This increased length is

$$\Delta\ell = \alpha_{A\ell}\ell_{A\ell}\Delta T = (2.55\times10^{-5})(88.42)(30)$$

$$\Rightarrow \Delta\ell = 0.068\text{ cm}$$

(b) At 35 °C the measuring rod at 88.42 cm mark is actually $(88.42+0.068)$ cm $= 88.49$ cm long, as calculated from part (a). It thus measures 88.49 cm length of steel at 35 °C.

**3.** At 30 °C, the copper rod will be of length $\ell(1+\alpha_c\Delta\theta)$, while adjacent 'centimetre' marks on the steel tape will be separated by a distance of $(1)(1+\alpha_s\Delta\theta)$. Therefore, the number of centimetres reading on the tape is

$$\text{Reading (in cm)} = \frac{\ell(1+\alpha_c\Delta\theta)}{(1)(1+\alpha_s\Delta\theta)}$$

$$\Rightarrow \text{Reading (in cm)} = \frac{(90)(1+1.7\times10^{-5}\times20)}{(1)(1+1.2\times10^{-5}\times20)}$$

$$\Rightarrow \text{Reading (in cm)} = 90\left(\frac{1+3.4\times10^{-4}}{1+2.4\times10^{-4}}\right)$$

Since $\frac{1}{1+x} = (1+x)^{-1} \cong 1-x$ for $x \ll 1$, so we get

$$90\left(\frac{1+3.4\times10^{-4}}{1+2.4\times10^{-4}}\right) = 90(1+3.4\times10^{-4})(1-2.4\times10^{-4})$$

So, reading (in cm) is $\approx 90(1+3.4\times10^{-4}-2.4\times10^{-4})$

$\Rightarrow$ Reading (in cm) $= 90 + 0.009 \approx 90.01$ cm

So, the tape will read 90.01 cm

**4.** (i) Let $V_C$ be the volume of the container and $V_L$ be the volume of the liquid. According to the condition given, we have

$$\frac{V_L}{V_C} = \text{constant (i.e., independent of temperature)}$$

$$\Rightarrow \frac{\Delta V_L}{V_L} = \frac{\Delta V_C}{V_C}$$

$$\Rightarrow \gamma\Delta T = \gamma_C\Delta T = (3\alpha)\Delta T$$

For container, coefficient of volume expansion is $\gamma_C = 3\alpha$. Hence

$$\gamma = 3\alpha$$

(ii) If one heating, $H$ does not change, then

$$H = \frac{V}{A} = \text{constant}$$

$$\Rightarrow V \propto A$$

$$\Rightarrow \frac{\Delta V}{V} = \frac{\Delta A}{A}$$

$$\Rightarrow \gamma\Delta T = \beta_C\Delta T$$

$$\Rightarrow \gamma = 2\alpha \qquad \{\because \beta_C = 2\alpha\}$$

(iii) This is exactly same as part (i), so $\gamma = 3\alpha$

**5.** At higher temperatures actual reading is more than the scale reading. The error in the reading is given by

$$\Delta\ell = \text{(scale reading)}\,(\alpha)(\Delta T)$$

$$\Rightarrow \Delta\ell = (60)(1.2\times10^{-5})(27-15) = 0.00864\text{ cm}$$

**6.** Volume expansion of mercury with respect to bulb is

$$\Delta V = V_0(\gamma-3\alpha)t$$

Find area of cross section of capillary is

$$A_f = A_0(1+2\alpha t)$$

Height to which mercury rises in capillary is

$$h = \frac{\Delta V}{A_f} = \frac{V_0(\gamma-3\alpha)t}{A_0(1+2\alpha t)}$$

**7.** The time period of second's pendulum is 2 second. As the temperature increases, the length and hence time period increases and so the clock becomes slow and loses the time. The change in time period is given by

$$\Delta t = \frac{1}{2}t\alpha\Delta T = \left(\frac{1}{2}\right)(2)(1.2\times10^{-5})(30-20)$$

$$\Rightarrow \Delta t = 1.2\times10^{-4}\text{ sec}$$

So, new time period is,

$$t' = t + \Delta t = (2 + 1.2\times10^{-4})$$

$$\Rightarrow t' = 2.00012\text{ sec}$$

So, time lost in one week, i.e., 7 days is

$$\Delta t' = \frac{(1.2\times10^{-4})}{(2.00012)}(7\times24\times3600)$$

$$\Rightarrow \Delta t' = 36.28\text{ s}$$

**8.** Due to drop in temperature, tension increment in the clamped wire is $F = YA\alpha\Delta T$

$$\Rightarrow F = 2.1\times10^{12}\times0.5\times10^{-2}\times1.1\times10^{-5}\times20$$

$$\Rightarrow F = 2.31\times10^{-6}\text{ dyne}$$

**9.** Since, thermal stress is given by

$$\frac{F}{A} = Y\alpha\Delta T$$

$$\Rightarrow \quad F = YA\alpha\Delta T = \left(2\times10^{11}\right)\left(0.8\times10^{-4}\right)\left(10^{-5}\right)(10)$$

$$\Rightarrow \quad F = 1.6\times10^{3}\ \text{N}$$

**10.** Temperature on Kelvin scale are

$$T_K = T_C + 273$$

For $T_C = 4000$ °C, we have

$$T_K = 4000 + 273 = 4273\ \text{K}$$

and for $T_C = 1.5\times10^{7}$ °C, we have

$$T_K = \left(1.5\times10^{7} + 273\right)\ \text{K}$$

Percentage error is given by

$$\%\text{error} = \left(\frac{T_K - T_C}{T_C}\right)\times100\% = \frac{273}{T_C}\times100\%$$

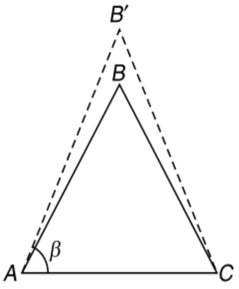
For $T_c = 4000$ °C

$$\%\ \text{Error} = \frac{273}{4000}\times100 = 6.825\%$$

For $T_C = 1.5\times10^{7}$ °C

$$\%\ \text{error} = \frac{273}{1.5\times10^{7}}\times100 = 1.82\times10^{-3}\%$$

**11.** Angle $B'AC = \frac{1}{2}\left[\pi - \left(\frac{\pi}{3} - \theta\right)\right] = \frac{\pi}{3} + \frac{\theta}{2} = \beta$ (say)



Since, $AB' = L_0(1 + 100\alpha)$

Also, $AB'\cos\beta = \frac{L_0}{2} = \frac{AC}{2}$

$$\Rightarrow \quad L_0(1+100\alpha)\cos\left(\frac{\pi}{3} + \frac{\theta}{2}\right) = \frac{L_0}{2}$$

Using approximation, $\sin\left(\frac{\theta}{2}\right) \approx \frac{\theta}{2}$

and $\cos\left(\frac{\theta}{2}\right) \approx 1$, we get

$$\alpha = \frac{\sqrt{3}}{200}\theta$$

**12.** For an ideal gas, we have $PV = nRT$

$$\Rightarrow \quad d(PV) = d(nRT)$$

Since, $P$ is constant, we get $PdV = nRdT$

$$\Rightarrow \quad \frac{dV}{dT} = \frac{nR}{P}$$

Now, by definition, $\gamma = \left(\frac{dV}{V}\right)\frac{1}{dT}$

$$\Rightarrow \quad \gamma = \frac{nR}{PV} = \frac{nR}{nRT} = \frac{1}{T}$$

**13.** Since $\frac{T_C - 32}{212 - 32} = \frac{T_C - 0}{100 - 0}$ ...(1)

For same value on both the scales, we have

$$T_F = T_C = T_0$$

Substituting in equation (1), we get

$$T_0 - 32 = 1.8T_0$$

$$\Rightarrow \quad -0.8T_0 = 32$$

$$\Rightarrow \quad T_0 = -40\ ^\circ\text{F}$$

**14.** (a) Since $L = \text{I}\omega = \left(\frac{1}{2}MR^2\right)\omega$

$$\Rightarrow \quad L = \frac{1}{2}(0.5)(0.030)^2(60) = 0.0135\ \text{kgm}^2\text{s}^{-1}$$

(b) When the cylinder is heated without any mechanical contact, then no external force and hence torque acts on the cylinder, so angular momentum is conserved. Hence,

$$\text{I}\omega = \text{constant}$$

$$\Rightarrow \quad \Delta(\text{I}\omega) = 0$$

$$\Rightarrow \quad \frac{\Delta\omega}{\omega} = -\frac{\Delta\text{I}}{\text{I}} = -\frac{2\Delta R}{R} \qquad \left\{\because \text{I} = \frac{1}{2}MR^2\right\}$$

Since, $\frac{\Delta R}{R} = \alpha\Delta T$

$$\Rightarrow \quad \frac{\Delta\omega}{\omega} = -2(\alpha\Delta T) = -2\times2\times10^{-5}\times80$$

$$\Rightarrow \quad \frac{\Delta\omega}{\omega} = -3.2\times10^{-3}$$

**15.** (a) Since, $\frac{T-0}{100-0} = \frac{15.0 - 12.45}{21.30 - 12.45} = \frac{2.65}{8.85}$

$$\Rightarrow \quad T = \frac{2.65}{8.85}\times100 = 29.94\ ^\circ\text{C}$$

(b) Since, $\frac{T-0}{100-0} = \frac{22.95 - 12.45}{21.30 - 12.45} = \frac{10.5}{8.85}$

$$\Rightarrow \quad T = \frac{10.5}{8.85}\times100 = 118.64\ ^\circ\text{C}$$

**16.** By definition, we have

$$\alpha(T) = \frac{dL}{L_0}\frac{1}{dT}$$

$$\Rightarrow \quad dL = L_0\alpha(T)dT$$

$$\Rightarrow \quad \int_{L_0}^{L} dL = L_0\int_{T_0}^{T}\alpha(T)dT$$

$$\Rightarrow \quad L - L_0 = L_0\int_{T_0}^{T}\alpha(T)dT$$

$$\Rightarrow \quad L = L_0\left[1 + \int_{T_0}^{T}\alpha(T)dT\right]$$

**17.** Since, at all temperatures, we have $\ell_s - \ell_c = 5$ cm ...(1)

$$\Rightarrow \quad \Delta\ell_s - \Delta\ell_c = 0$$

$$\Rightarrow \quad \Delta\ell_s = \Delta\ell_c$$

By definition, we have $\Delta\ell_s = \ell_s\alpha_s\Delta T$ and $\Delta\ell_c = \ell_c\alpha_c\Delta T$

$$\Rightarrow \quad \ell_s\alpha_s = \ell_c\alpha_c$$

$$\Rightarrow \quad \frac{\ell_s}{\ell_c} = \frac{\alpha_c}{\alpha_s} = \frac{17}{11} \qquad \text{...(2)}$$

So, from (1) and (2), we get

$$\ell_s = 14.16 \text{ cm and } \ell_c = 9.16 \text{ cm}$$

**18.** Since $\gamma = \dfrac{\Delta V}{V}\dfrac{1}{\Delta T} = \left(\dfrac{0.12}{100}\right)\dfrac{1}{20}$

$$\Rightarrow \quad \gamma = 6\times 10^{-5}\,(°\text{C})^{-1}$$

Further, we know that $\dfrac{\alpha}{1} = \dfrac{\beta}{2} = \dfrac{\gamma}{3}$

$$\Rightarrow \quad \alpha = \frac{\gamma}{3} = 2\times 10^{-5}\,(°\text{C})^{-1}$$

**19.** Let the distance of centre of mass from suspension point $O$ be $h$, then $h =$ constant

$$\Rightarrow \quad h^2 = l_2^2 - \frac{l_1^2}{4} = \text{constant}$$

$$\Rightarrow \quad \Delta\left(l_2^2\right) - \Delta\left(\frac{l_1^2}{4}\right) = 0$$

$$\Rightarrow \quad 2l_2\Delta l_2 - \frac{1}{4}2l_1\Delta l_1 = 0$$

Since, by definition, $\Delta l = l\alpha\Delta T$

$$\Rightarrow \quad \Delta l_2 = l_2\alpha_2\Delta T \text{ and } \Delta l_1 = l_1\alpha_1\Delta T$$

$$\Rightarrow \quad 2l_2\left(l_2\alpha_2\Delta T\right) = \frac{1}{4}(2l_1)\left(l_1\alpha_1\Delta T\right)$$

$$\Rightarrow \quad l_2^2\alpha_2 = \frac{1}{4}l_1^2\alpha_1$$

$$\Rightarrow \quad \frac{l_1^2}{l_2^2} = 4\left(\frac{\alpha_2}{\alpha_1}\right)$$

$$\Rightarrow \quad l_2 = \frac{l_1}{2}\sqrt{\frac{\alpha_1}{\alpha_2}} = \frac{5}{2}\sqrt{\frac{18}{9}} = 5\sqrt{2} \approx 7 \text{ cm}$$

**20.** Since, $D_T = D_0(1+\alpha\Delta T)$

$$\Rightarrow \quad D_T = 2.54\left(1+2.3\times 10^{-5}\times 100\right) = 2.54(1.0023)$$

$$\Rightarrow \quad D_T = 2.5458 \text{ cm}$$

**21.** Since, $T_K = T_C + 273$ and $T_F = \dfrac{9}{5}T_C + 32$

$$\Rightarrow \quad T_C = T_K - 273.15 \text{ and } T_F = \frac{9}{5}T_C + 32$$

**For Neon**

$$T_C = T_K - 273.15$$

$$\Rightarrow \quad T_C = 24.57 - 273.15 = -248.58 \text{ °C}$$

and $T_F = \dfrac{9}{5}T_C + 32 = \dfrac{9}{5}(-248.58) + 32$

$$\Rightarrow \quad T_F = -447.44 + 32 = -415.44 \text{ °F}$$

**For Carbon dioxide**

$$T_C = T_K - 273.15 = 216.55 - 273.15$$

$$\Rightarrow \quad T_C = -56.60 \text{ °C}$$

and $T_F = \dfrac{9}{5}T_C + 32 = \dfrac{9}{5}(-56.60) + 32$

$$\Rightarrow \quad T_F = -101.88 + 32 = -69.88 \text{ °F}$$

**22. Method-I**

At any temperature $t$, the lengths of the two bars are

$$\ell_1' = \ell_1(1+\alpha_1 t),\ \ell_2' = \ell_2(1+\alpha_2 t) \qquad \ldots(1)$$

From the given conditions,

$$\ell_2' - \ell_1' = \ell \text{ and } \ell_2 - \ell_1 = \ell \qquad \ldots(2)$$

From equations (1) and (2),

$$\ell_2' - \ell_1' = (\ell_2 - \ell_1) + \ell_2\alpha_2 t - \ell_1\alpha_1 t$$

$$\ell_2\alpha_2 = \ell_1\alpha_1 \qquad \ldots(3)$$

$$\frac{\ell_2}{\ell_1} = \frac{\alpha_1}{\alpha_2} \qquad \ldots(4)$$

From equations (2) and (4),

$$\ell_1 = \frac{\ell\alpha_2}{\alpha_2 - \alpha_1},\ \ell_2 = \frac{\ell\alpha_1}{\alpha_2 - \alpha_1}$$

**Method-II**

Since, the separation between the mirrors, $\ell$, is constant. So,

$$\Delta\ell = \Delta(\ell_2 - \ell_1) = 0$$

$$\Rightarrow \quad \Delta\ell_2 - \Delta\ell_1 = 0$$

$$\Rightarrow \quad \Delta\ell_2 = \Delta\ell_1$$

$$\Rightarrow \quad \ell_1\alpha_1\Delta T = \ell_2\alpha_2\Delta T$$

$$\Rightarrow \quad \ell_1\alpha_1 = \ell_2\alpha_2 \qquad \ldots(5)$$

Since, $\ell = \ell_2 - \ell_1$ ...(6)

So, from (5) and (6), on solving, we get

$$\ell_1 = \frac{\ell\alpha_2}{\alpha_2 - \alpha_1} \text{ and } \ell_2 = \frac{\ell\alpha_1}{\alpha_2 - \alpha_1}$$

## Test Your Concepts-II
## (Based on Calorimetry)

**1.** Let $Q$ be the heat required to convert 200 g of water at 40 °C into 100 °C, then

$$Q = mc\Delta T = (200)(1)(100-40) = 12000 \text{ cal}$$

Now, suppose $m_0$ mass of steam converts into water to liberate this much amount of heat, then

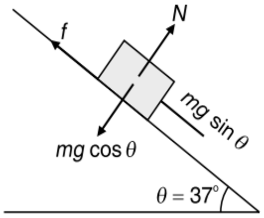
$$m_0 = \frac{Q}{L} = \frac{12000}{539} = 22.26 \text{ g}$$

Since this is less than 30 g, so the temperature of the mixture is 100 °C

Mass of steam in the mixture $= 30 - 22.26 = 7.74$ g

and mass of water in the mixture $= 200 + 22.26 = 222.26$ g

**2.** When the copper cube slides down a rough inclined plane at constant speed, then $f = mg\sin\theta = mg\sin(37°)$



$$(\text{Heat gained}) = (\text{Work done against friction})$$

$$\Rightarrow \quad mc\Delta T = f\Delta r$$

$$\Rightarrow \quad mc\Delta T = mg\sin(37°)\left(\frac{60}{100}\right)$$

$$\Rightarrow \quad 420\Delta T = (10)\left(\frac{3}{5}\right)\left(\frac{3}{5}\right)$$

$$\Rightarrow \quad \Delta T = 8.6\times10^{-3}\ °\text{C}$$

**3.** After time $t$, the mass of water inside pitcher is given by $m = (1000 - 0.1t)$ gram

In a further time $dt$, mass of water vapourised is $dm = (0.1)dt$ and let the temperature of water inside pitcher fall by $dT$.

So, we get $(1000 - 0.1t)(1)(-dT) = (0.1dt)(540)$

$$\Rightarrow \quad \int_0^t \frac{54dt}{1000-0.1t} = -\int_{40}^{30} dT$$

$$\Rightarrow \quad \int_0^t \frac{540dt}{10000-t} = -\int_{40}^{30} dT$$

$$\Rightarrow \quad -540\ln(10000-t)\Big|_0^t = 10$$

$$\Rightarrow \quad \ln\left(\frac{10000-t}{10000}\right) = -\frac{1}{54}$$

$$\Rightarrow \quad 10000 - t = 10000e^{-1/54}$$

$$\Rightarrow \quad t = 10000\left(1-e^{-1/54}\right)\ \text{s} = 10000(1-0.98)\ \text{s}$$

$$\Rightarrow \quad t = (10000)(0.02) = 200\ \text{s}$$

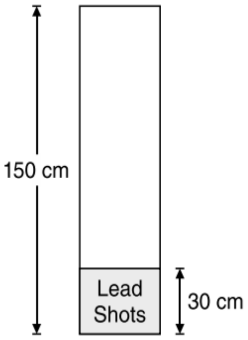
**4.** When inverted, each lead shot falls through an effective height of $(150-30)\ \text{cm} = 120\ \text{cm}$. So,

$$h = 120\ \text{cm} = \frac{120}{100}\ \text{cm}$$

Let the tube has to be inverted $n$ times, then

$$n(mgh) = mc_{\text{lead}}\Delta T$$

$$\Rightarrow \quad n = \frac{c_{\text{lead}}\Delta T}{gh}$$



where $c_{\text{lead}} = (0.031)(4200)\ \text{Jkg}^{-1}\text{K}^{-1}$ and $\Delta T = 2\ °\text{C}$

$$\Rightarrow \quad n = \frac{(0.031)(4200)(2)}{(9.8)\left(\frac{120}{100}\right)} = 22.1$$

So, the number of times the tube has to be inverted end to end is 23.

**5.** Since $\frac{1}{2}\left(\frac{1}{2}mv^2\right) = mc_{\text{bullet}}\Delta T$

and $1\ \text{calg}^{-1}(°\text{C})^{-1} = 4200\ \text{Jkg}^{-1}(°\text{C})^{-1} = 4200\ \text{Jkg}^{-1}\text{K}^{-1}$

$$\Rightarrow \quad \frac{(100)^2}{4} = 0.030\times4200\times\Delta T$$

$$\Rightarrow \quad \Delta T \cong 20\ \text{K or } \Delta T \cong 20\ °\text{C}$$

**6.** Heat supplied is

$$Q = (22)(0.5)(8) + (22)(80) + (22)(1)(16)$$

$$\Rightarrow \quad Q = 88 + 1760 + 352 = 2200\ \text{cal}$$

Heat capacity of body is

$$\text{Heat Capacity} = \frac{2200\ \text{cal}}{44\ °\text{C}} = 50\ \text{cal}(°\text{C})^{-1}$$

Water equivalent of the body is

$$w = \frac{\text{Heat capacity of the body}}{\text{Specific heat of water}}$$

$$\Rightarrow \quad w = \frac{50\ \text{cal}°\text{C}^{-1}}{1\ \text{calg}^{-1}°\text{C}^{-1}} = 50\ \text{g}$$

**7.** $c = \frac{1}{m}\frac{\Delta Q}{\Delta T} = \left(\frac{1}{0.1}\right)\left(\frac{400}{20}\right) = 200\ \text{Jkg}^{-1}(°\text{C})^{-1}$

**8.** The mixture has 1 kg ice at 0 °C and 1 kg steam at 100 °C. Heat required to completely melt ice is

$$Q_1 = 1\times3.36\times10^5\ \text{J}$$

Heat required to raise temperature of water from 0 °C to 100 °C is

$$Q_2 = 1\times4200\times100 = 4.2\times10^5\ \text{J}$$

So, total heat required to melt 1 kg ice at 0 °C to water at 0 °C and then take it to a temperature of 100 °C is

$$Q_{\text{required}} = Q_1 + Q_2 = 7.56\times10^5\ \text{J}$$

If this much entire heat is provided by condensation of steam, then mass $m$ of steam condensed (to give water) would be

$$m = \frac{Q_1+Q_2}{L_v} = \frac{7.56\times10^5}{2.27\times10^6} = 0.333\ \text{kg}$$

$$\Rightarrow \quad m_{\text{water}} = 1333\ \text{g and } m_{\text{steam}} = 667\ \text{g}$$

Hence, final mixture is at 100 °C. The final mixture has 667 g steam and 1333 g water.

**9.** Let $t$ °C be the temperature of the mixture. Then, by Law of Calorimetry, we have

$$\begin{pmatrix}\text{Heat given by}\\ \text{10 g of water}\end{pmatrix} = \begin{pmatrix}\text{Heat taken by}\\ \text{5 g of water}\end{pmatrix}$$

$$\Rightarrow \quad m_1c_{\text{water}}|\Delta t_1| = m_2c_{\text{water}}|\Delta t_2|$$

$$\Rightarrow \quad (10)(70-t) = 5(t-30)$$

$$\Rightarrow \quad t = 36.67\ °\text{C}$$

**10.** By Law of Calorimetry, heat supplied by the block equals heat gained by calorimeter and liquid. Assuming water equivalent of the calorimeter to be $w$, we get

For 200 g of liquid, we have

$$(110)(0.1)(82)=(8)\left[w(1)+(200)c_L\right] \qquad \ldots(1)$$

For 400 g of liquid, we have

$$(110)(0.1)(85.5)=(4.5)\left[w(1)+(400)c_L\right] \qquad \ldots(2)$$

Multiply equation (2) by 8, equation (1) by 4.5 and subtracting, we get

$$110\times0.1(85.5\times8-82\times4.5)=c_L(400\times4.5\times8-200\times4.5\times8)$$

$$\Rightarrow \quad c_L=\frac{3150}{7200}=0.481\ \text{calg}^{-1}{}^\circ\text{C}^{-1}$$

From equation (1), we get

$$w=\frac{902-769.6}{8}=16.55\ \text{g}$$

**11.** Let $s_A$, $s_B$ and $s_C$ be the specific heats of liquid $A$, $B$ and $C$. When $A$ and $B$ are mixed, then

$$\begin{pmatrix}\text{Heat Lost}\\ \text{by } B\end{pmatrix}=\begin{pmatrix}\text{Heat Gained}\\ \text{by } A\end{pmatrix}$$

$$\Rightarrow \quad ms_B(19-16)=ms_A(16-12)$$

$$\Rightarrow \quad 3s_B=4s_A \qquad \ldots(1)$$

When $B$ and $C$ are mixed, then

$$\begin{pmatrix}\text{Heat Lost}\\ \text{by } C\end{pmatrix}=\begin{pmatrix}\text{Heat Gained}\\ \text{by } B\end{pmatrix}$$

$$\Rightarrow \quad ms_C(28-23)=ms_B(23-19)$$

$$\Rightarrow \quad 5s_C=4s_B \qquad \ldots(2)$$

When $A$ and $C$ are mixed, let the equilibrium temperature be $T$, then

$$\begin{pmatrix}\text{Heat Lost}\\ \text{by } C\end{pmatrix}=\begin{pmatrix}\text{Heat Gained}\\ \text{by } A\end{pmatrix}$$

$$\Rightarrow \quad ms_C(28-T)=ms_A(T-12) \qquad \ldots(3)$$

From (1) and (2), we get $s_C=\dfrac{16}{15}s_A$

$$\Rightarrow \quad m\left(\frac{16}{15}s_A\right)(28-T)=ms_A(T-12)$$

$$\Rightarrow \quad 16(28-T)=15(T-12)$$

$$\Rightarrow \quad 448-16T=15T-180$$

$$\Rightarrow \quad 31T=628$$

$$\Rightarrow \quad T=20.25\ {}^\circ\text{C}$$

**12.** 75% of heat is retained by lead and due to this its temperature first rises from 27 °C to 327 °C and then at 327 °C it melts. So, we have

$$\frac{3}{4}\left(\frac{1}{2}mv^2\right)=mc_{\text{lead}}\Delta T+mL_{\text{lead}}$$

$$\Rightarrow \quad \frac{3}{8}v^2=(0.03)(4200)(300)+(6)(4200)$$

$$\Rightarrow \quad v=410\ \text{ms}^{-1}$$

**13.** Let $x$ kg of water be frozen, then amount of heat released is

$$Q_1=\left(x\times4200\times50+x\times3.36\times10^5\right)\ \text{J}$$

$$\Rightarrow \quad Q_1=\left(5.46\times10^5x\right)\ \text{J}$$

The heat required to vapourise $(1-x)$ kg of water from 50 °C is

$$Q_2=(1-x)\times22.5\times10^5\ \text{J}$$

This heat $Q_2$ must be provided by the first part of water. So, we have $Q_2=Q_1$

$$\Rightarrow \quad (1-x)\left(22.5\times10^5\right)=5.46\times10^5x$$

$$\Rightarrow \quad 22.5-22.5x=5.46x$$

$$\Rightarrow \quad x=\frac{22.5}{27.96}=0.805\ \text{kg}$$

**14.** (a) Given $\dfrac{dT}{dt}=0.5\ {}^\circ\text{Cs}^{-1}$

Since, $dQ=mcdT$ i.e., $\dfrac{dQ}{dt}=mc\left(\dfrac{dT}{dt}\right)$

$$\Rightarrow \quad \frac{dQ}{dt}=\left(\frac{180}{1000}\right)(0.10)(4200)(0.5)\ \text{Js}^{-1}$$

$$\Rightarrow \quad \frac{dQ}{dt}=37.8\ \text{W}$$

So, rate of working of drill in watt is 37.8

(b) Since $P=\tau\omega$ and 1 rpm $=\dfrac{2\pi}{60}$ rads$^{-1}$

$$\Rightarrow \quad 37.8=\tau\left(180\times\frac{2\pi}{60}\right)=2\ \text{Nm}$$

**15.** Since $\dfrac{1}{2}\left(\dfrac{1}{2}mv^2\right)=mc_{\text{bullet}}\Delta T$

$$\Rightarrow \quad \frac{v^2}{4}=c_{\text{bullet}}\Delta T$$

where $c_{\text{bullet}}=(0.03)(4200)\ \text{Jkg}^{-1}\text{K}^{-1}$

$$\Rightarrow \quad \frac{(300)^2}{4}=(0.03)(4200)\Delta T$$

$$\Rightarrow \quad \Delta T=178\ {}^\circ\text{C}=178\ \text{K}$$

**16.** Heat supplied in 4 min is

$$Q=100\times4\times60=24000\ \text{cal}$$

$$\Rightarrow \quad 100\times0.215\times(T+20)+200\times0.5\times20+200\times80+200\times1\times T=2400$$

$$\Rightarrow \quad 221.5T=2400-16000-2000=6000$$

$$\Rightarrow \quad T=27.08\ {}^\circ\text{C}$$

**17.** $dQ=mcdT$

$$\Rightarrow \quad \frac{dQ}{dt}=mc\left(\frac{dT}{dt}\right)$$

If heat lost per second to the surroundings is $q$, then

$$135=\left(\frac{5}{1000}\right)c_w(5)+q \qquad \ldots(1)$$

$$\text{Also, } 240=\left(\frac{10}{1000}\right)c_w(5)+q \qquad \ldots(2)$$

From (1) and (2), we get

$$105=\left(\frac{25}{1000}\right)c_w$$

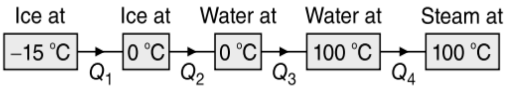
$$\Rightarrow \quad c_w=4200\ \text{Jkg}^{-1}\text{K}^{-1}$$

**18.** $Q_1 = mc_{ice}\left(T_f - T_i\right) = (8)(0.5)[0-(-15)] = 60 \text{ cal}$

$$Q_2 = mL_f = (8)(80) = 640 \text{ cal}$$

$$Q_3 = mc_{\text{water}}\left(T_f - T_i\right) = (8)(1)(100-0) = 800 \text{ cal}$$

$$Q_4 = mL_v = (8)(540) = 4320 \text{ cal}$$



So, net heat required is

$$Q = Q_1 + Q_2 + Q_3 + Q_4 = 5820 \text{ cal}$$

**19.** Heat required to raise temperature of ice to 100 °C is

$$Q_1 = m_1L_1 + m_1c_1\Delta T_1 = 5\times 80 + 5\times 1\times 100$$

$$\Rightarrow \quad Q_1 = 400 + 500 + 900 = 1800 \text{ cal}$$

Heat liberated on condensation of steam is

$$Q_2 = m_2L_2 = 5\times 536 = 2680 \text{ cal}$$

Since, $Q_2 > Q_1$

This simply means that the entire steam is not condensed and hence temperature of mixture will remain at 100 °C

**20.** Let calorimeter contains $x$ gram of ice and $(200-x)$ gram of water.

By Law of Calorimetry, the heat lost by $330-(100+200) = 30$ g of steam equals the heat gained by 100 g calorimeter plus heat gained by $x$ gram ice plus heat gained by $(200-x)$ gram of water

$$\Rightarrow \quad 30L_{steam} + 30s_{water}(100-50) = 100s_{Cu}(50) +$$

$$xL_{ice} + xs_{water}(50) + (200-x)s_{water}(50)$$

$$\Rightarrow \quad x = 88.4 \text{ g}$$

So, the desired ratio is

$$\frac{x}{200-x} = \frac{88.4}{200-88.4} \approx 0.8$$

## Test Your Concepts-III (Based on Kinetic Theory of Gases and Ideal Gas Equation)

**1.** Initially let each bulb contain $n$ moles of the gas, so two bulbs contains $2n$ moles. If the volume of each bulb is $V$ then, at NTP, i.e., $P = 76$ cm of $Hg$ and $T = 273$ K, we have

$$\frac{76\times V}{273} = nR \qquad \ldots(1)$$

Further, $\dfrac{PV}{373} = n_1R$ and $\dfrac{PV}{273} = n_2R$

$$\Rightarrow \quad PV\left(\frac{1}{373} + \frac{1}{273}\right) = (n_1+n_2)R = 2nR \qquad \ldots(2)$$

From (1) and (2), we get

$$P = 87.76 \text{ cm of } Hg$$

**2.** We use $v_{\text{rms}} = \sqrt{\dfrac{3RT}{M}}$

$$\Rightarrow \quad \frac{v_1}{v_2} = \sqrt{\frac{T_1M_2}{T_2M_1}}$$

$$\Rightarrow \quad v_2 = v_1\sqrt{\frac{T_2M_1}{T_1M_2}} = 300\sqrt{\frac{2T_1M_1}{T_1(M_1/2)}}$$

$$\Rightarrow \quad v_2 = 600 \text{ ms}^{-1}$$

**3.** Each electron exerts an impulse of $m_0v$ when it strikes and sticks to the surface. This times the number striking in unit time divided by area is pressure. Hence,

$$P = \frac{10^{15}}{\left(10^{-3}\right)^2}m_0v = 10^{21}m_0v$$

Substituting the given values, we get

$$P = \left(9.1\times 10^{-31}\right)\left(8\times 10^{7}\right)\left(10^{21}\right) = 0.073 \text{ Nm}^{-2}$$

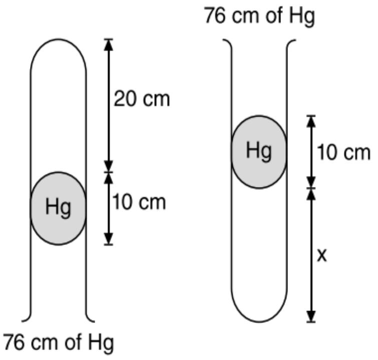
**4.** Since, initial number of moles equals the final number of moles of the gas, so we have

$$n_1 + n_2 = n$$

$$\Rightarrow \quad \frac{p_1V}{T_1} + \frac{p_2V}{T_2} = \frac{p_f(2V)}{T}$$

$$\Rightarrow \quad p_f = \frac{T}{2}\left[\frac{p_1}{T_1} + \frac{p_2}{T_2}\right]$$

**5.** The initial and final states of the tube are shown in Figure (a) and (b) respectively.



(a) (b)

In the initial state, pressure just below the mercury pallet (at the bottom of pallet) is the atmospheric pressure i.e., 76 cm of Hg and at top of the pallet, 10 cm above the bottom is

$$76 - 10 = 66 \text{ cm of Hg}$$

Finally, when the tube is inverted with its open end upwards, then pressure at the top of pallet is atmospheric pressure i.e., 76 cm of Hg but at the bottom of the pallet, the pressure will be

$$76 + 10 = 86 \text{ cm of Hg}$$

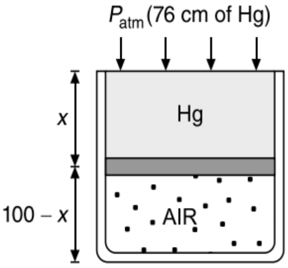
If the length of air column is $x$, then applying Boyle's Law, we get

$$P_1V_1 = P_2V_2$$

$$\Rightarrow \quad (66)(20A) = (86)(xA)$$

where, $A$ is the cross-sectional area of tube

$$\Rightarrow \quad x = 15.35 \text{ cm}$$



**6.** When mercury is poured on the top of the piston, due to increase in pressure, the volume of air will decrease according to Boyle's Law. Since atmospheric pressure is equivalent to the pressure due to a mercury column of height 76 cm, so if final mercury column of height $x$ is poured on the piston, then gas pressure in equilibrium is given by

$$P_f = (76 + x) \text{ cm of Hg}$$

If $A$ be the area of cross section of cylinder, then we have according to Boyle's Law

$$P_1V_1 = P_2V_2$$

$$\Rightarrow \quad (76 \text{ cm})(100A) = (76 + x)(100 - x)A$$

$$\Rightarrow \quad 7600 = 7600 + 24x - x^2$$

$$\Rightarrow \quad x = 24 \text{ cm}$$

**7.** Moment of inertia, $I = 2(mr^2)$

where $m = \dfrac{70 \times 10^{-3}}{2 \times 6.02 \times 10^{23}} = 5.81 \times 10^{-26}$ kg

and $r = \dfrac{2 \times 10^{-10}}{2} = 1 \times 10^{-10}$ m

$$\Rightarrow \quad I = 2(5.81 \times 10^{-26})(1 \times 10^{-10})^2 = 1.16 \times 10^{-45} \text{ kgm}^2$$

Since, $K_R = \dfrac{1}{2}I\omega^2 = \dfrac{1}{2} \times (1.16 \times 10^{-45}) \times (2 \times 10^{12})^2$

$$\Rightarrow \quad K_R = 2.32 \times 10^{-21} \text{ J}$$

### Conceptual Note(s)

At $T = 300$ K, rotational K.E. should be equal to $\dfrac{1}{2}kT$

$$\Rightarrow \quad K_R = \frac{1}{2} \times (1.38 \times 10^{-23}) \times (300) = 2.07 \times 10^{-21} \text{ J}$$

Approximately the same as calculated above.

**8.** Done in Theory.

**9.** Since, initial number of moles equals the final number of moles of the gas, so we have

$$n_1 = n_2$$

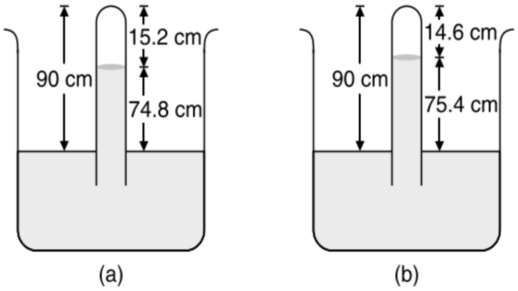
$$\Rightarrow \quad \frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$$

$$\Rightarrow \quad \frac{2 \times 10^5 \times V}{293} = \frac{p \times 1.02V}{313}$$

$$\Rightarrow \quad p = 2.095 \times 10^5 \text{ Nm}^{-2}$$

**10.** Let $A$ be the area of cross section of the tube at 30 °C, volume of air be $V_1 = 15.2$ A cm$^3$. The pressure of air will be $P_1 = 76 - 74.8 = 1.2$ cm of $Hg$.

At 10 °C, $V_2 = 14.6$ A cm$^3$



and $P_2 = (P - 75.4)$ cm of $Hg$

where, $P$ is the true atmospheric pressure

Since, $\dfrac{P_1V_1}{T_1} = \dfrac{P_2V_2}{T_2}$

$$\Rightarrow \quad P = 76.57 \text{ cm of Hg}$$

**11.** Friction force balances the force due to mercury pressure that corresponds to

$$76 - 5 - 69.47 = 1.53 \text{ cm of } Hg$$

Hence, $f_r = PA = P(\pi r^2)$

$$\Rightarrow \quad f_r = (0.0153)(13600)(10)\left[3.14(2 \times 10^{-3})^2\right]$$

$$\Rightarrow \quad f_r = 0.026 \text{ N}$$

**12.** Let the initial pressure of the gas be $P_1$ and the final temperature be $P_2$. Then from Ideal Gas Equation, we have

$$P_1V = n_1RT$$

$$P_2V = n_2RT \text{ where, } T = 273 \text{ K}$$

$$\Rightarrow \quad (P_1 - P_2)V = (n_1 - n_2)RT = \left(\frac{m_1 - m_2}{M}\right)RT$$

$$\Rightarrow \quad (\Delta P)V = \frac{\Delta m}{M}RT \qquad \ldots(1)$$

In the initial condition (at STP), i.e., at $T = 273$ K, we have

$$\frac{RT}{M} = \frac{P_0}{\rho} \qquad \ldots(2)$$

From equations (1) and (2), we get

$$\Delta m = \frac{\rho V \Delta P}{P_0} = \frac{1.2 \times 0.4 \times 0.24}{1} = 0.1152 \text{ kg}$$

$$\Rightarrow \quad \Delta m = 115.2 \text{ g}$$

**13.** Since, $P_{H_2} = \left(\dfrac{30}{2}\right) \times \dfrac{8.314 \times 300}{30 \times 10^{-3}}$

$$\Rightarrow \quad P_{H_2} = 12.471 \times 10^5 \text{ Pa}$$

Also, $P_{O_2} = \dfrac{160}{32} \times \dfrac{8.314 \times 300}{10 \times 10^{-3}}$

$$\Rightarrow \quad P_{O_2} = 12.471 \times 10^5 \text{ Pa}$$

Similarly, $P_{N_2} = \dfrac{70}{28} \times \dfrac{8.314 \times 300}{20 \times 10^{-3}}$

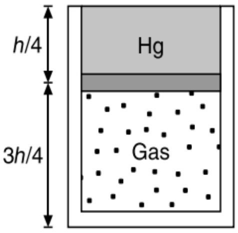
$$\Rightarrow \quad P_{N_2} = 3.118 \times 10^5 \text{ Pa}$$

Hence, $P_{\text{left}} = P_{H_2} = 12.471 \times 10^5$ Pa

$$P_{\text{middle}} = P_{H_2} + P_{O_2} + P_{N_2} = 28.06 \times 10^5 \text{ Pa}$$

and $P_{\text{right}} = P_{H_2} + P_{N_2} = 15.589 \times 10^5$ Pa

**14.** The final state of gas after half of mercury overflows is shown in Figure.



Let this temperature be $T$, then from ideal gas equation applied for initial and final state of gas, we get

$$\frac{P_1V_1}{T_1}=\frac{P_2V_2}{T_2} \qquad \ldots(1)$$

The initial pressure, volume and temperature of gas are

$$P_1=76+\frac{h}{2}=76+76=152 \text{ cm of Hg}$$

$$V_1=A\left(\frac{h}{2}\right)=76A \text{ and } T_1=300 \text{ K}$$

Similarly after heating, the pressure, volume and temperature of gas are

$$P_2=76+\frac{h}{4}=76+38=114 \text{ cm of Hg}$$

$$V_2=A\left(\frac{3h}{4}\right)=114A \text{ and } T_2=?$$

$$\Rightarrow \quad \frac{(152)(76A)}{300}=\frac{(114)(114A)}{T_2} \qquad \{\text{from (1)}\}$$

$$\Rightarrow \quad T_2=337.5 \text{ K}$$

**15.** Since, $P=P_0e^{-\left(\frac{gM}{RT}\right)h}$ {when $T$ =constant}

Since, $PV=RT$

$$\Rightarrow \quad P\left(\frac{M}{\rho}\right)=RT$$

$$\Rightarrow \quad \rho=\frac{PM}{RT}$$

$$\Rightarrow \quad \rho \propto P$$

$$\Rightarrow \quad \rho=\rho_0e^{-\left(\frac{gM}{RT}\right)h}$$

$$\Rightarrow \quad h=-\left(\frac{RT}{gM}\right)\log_e\left(\frac{\rho}{\rho_0}\right)$$

(a) When, $\frac{\rho_0}{\rho}=e$ $\{\because \rho_0>\rho\}$

then, $h=-\frac{RT}{Mg}\log_e\left(e^{-1}\right)=\frac{RT}{Mg}$

$$\Rightarrow \quad h=\frac{(8.31)(273)}{\left(28\times10^{-3}\right)(9.8)}=8.26\times10^3 \text{ m}$$

$$\Rightarrow \quad h=8.26 \text{ km}$$

(b) When, $\frac{\rho}{\rho_0}=0.98$

$$\Rightarrow \quad h=-\frac{RT}{Mg}\log_e(0.98)\approx 0.09 \text{ km}$$

**16.** Centre of gravity of gas is given by $h_c=\frac{\int y\,dm}{\int dm}$

where $dm$ is mass of a layer of width $dy$ at a height $y$. If $A$ be the base area of the vessel, then $dm=(A\,dy)\rho$

Since for uniform $g$ and $T$, we have $\rho=\rho_0e^{-(Mg/RT)y}$

where $\rho_0$ is density at base of the vessel

$$\Rightarrow \quad h_c=\frac{\int_0^{\infty}A\left(\rho_0e^{-(Mg/RT)y}\right)y\,dy}{\int_0^{\infty}A\left(\rho_0{}^{-(Mg/RT)y}\right)dy}$$

$$\Rightarrow \quad h_c=\frac{\left[y\frac{e^{-(Mg/RT)y}}{(-Mg/RT)}-\frac{e^{-(Mg/RT)y}}{(-Mg/RT)^2}\right]_0^{\infty}}{\left[\frac{e^{-(Mg/RT)y}}{-Mg/RT}\right]_0^{\infty}}$$

$$\Rightarrow \quad h_c=\frac{0-(RT/Mg)^2}{(-RT/Mg)}=\frac{RT}{Mg}$$

**17.** Since, $\frac{v_{rms}}{v_{av}}=\sqrt{\frac{3\pi}{8}}$

$$\Rightarrow \quad v_{rms}=\left(\sqrt{\frac{3\pi}{8}}\right)v_{av}=\left(\sqrt{\frac{3\pi}{8}}\right)\left(4.25\times10^2\right)$$

$$\Rightarrow \quad v_{rms}=4.613\times10^2 \text{ ms}^{-1}$$

Average kinetic energy is

$$\frac{1}{2}mv_{\text{rms}}^2=\frac{1}{2}\times\left(5.28\times10^{-26}\right)\left(4.613\times10^2\right)^2$$

$$\Rightarrow \quad \langle KE\rangle=5.62\times10^{-21} \text{ J}$$

**18.** If vessel volume is $V$ then partial pressures of $N_2$ and $CO_2$ are

$$P_{N_2}=\left(\frac{7}{28}\right)\frac{(8.314)(290)}{V}$$

$$\text{and } P_{CO_2}=\left(\frac{11}{44}\right)\frac{(8.314)(290)}{V}$$

Given that $P_1+P_2=10^5$

$$\Rightarrow \quad \frac{8.314}{V}\left(\frac{290}{4}+\frac{290}{4}\right)=10^5$$

$$\Rightarrow \quad V=1.205\times10^{-2} \text{ m}^3$$

So, density of mixture is

$$\rho=\frac{m_1+m_2}{V}=\frac{18\times10^{-3}}{1.205\times10^{-2}}=1.494 \text{ kgm}^{-3}$$

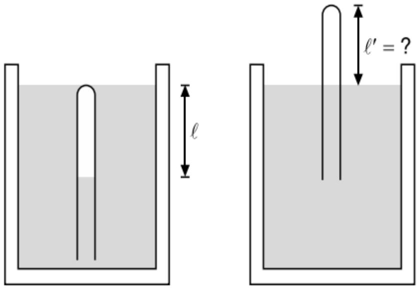
**19.** $P=P_{N_2}+P_N+P_{He}$

$$\Rightarrow \quad P=\left(\frac{1.4\times0.7}{28}+\frac{1.4\times0.3}{14}+\frac{0.4}{4}\right)\frac{RT}{V}$$

$$\Rightarrow \quad P=\frac{(0.035+0.03+0.1)(8.31)(1500)}{5\times10^{-3}}$$

$$\Rightarrow \quad P=4.1\times10^5 \text{ Nm}^{-2}$$

**20.** Since, $P_1V_1 = P_2V_2$



$$\Rightarrow \quad (76+10)\times 10 = 76\times l'$$

$$\Rightarrow \quad l' = 11.315 \text{ cm}$$

Mass of air is $m = \dfrac{PVM}{RT}$

$$\Rightarrow \quad m = \frac{(1.013\times 10^5)\left(\dfrac{11.315}{100}\times 10^{-4}\right)(29\times 10^{-3})}{8.314\times 300}$$

$$\Rightarrow \quad m = 13.32 \text{ mg}$$

**21.** Let $v_i$ for $i = 1, 2, \ldots.. N$ represent the various speeds. Then,

$$v_{av} = \frac{1}{N}\sum_{i=1}^{N} v_i \text{ and } v_{rms}^2 = \frac{1}{N}\sum_{i=1}^{N} v_i^2$$

Let us consider the expression $A = \dfrac{1}{N}\displaystyle\sum_{i=1}^{N}(v_i - v_{av})^2$

where, $A$ is inherently a non-negative quantity.

$$\Rightarrow \quad A = \frac{1}{N}\sum_{i=1}^{N} v_i^2 - \frac{2v_{av}}{N}\sum_{i=1}^{N} v_i + \frac{1}{N}\left(Nv_{av}^2\right)$$

$$\Rightarrow \quad A = v_{rms}^2 - 2v_{av}^2 + v_{av}^2$$

$$\Rightarrow \quad A = v_{rms}^2 - v_{av}^2$$

Since, $A \geq 0$

$$\Rightarrow \quad v_{rms}^2 \geq v_{av}^2$$

$$\Rightarrow \quad v_{rms} \geq v_{av}$$

**22.** At a distance $x$ from open end of the cylinder, we consider an elemental layer of gas width $dx$. If pressure difference across this layer is $dp$, then we have

$$dF = Adp = (dm)x\omega^2 = (\rho Adx)(x\omega^2)$$

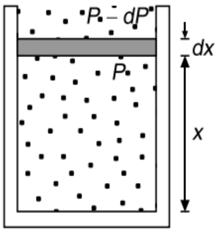
$$\Rightarrow \quad dp = \left(\frac{pM}{RT}\right)(x\omega^2)dx \qquad \left\{\because \rho = \frac{PM}{RT}\right\}$$

$$\Rightarrow \quad \int_{p_0}^{p}\frac{dp}{p} = \frac{M\omega^2}{RT}\int_0^r xdx$$

$$\Rightarrow \quad \ln\left(\frac{p}{p_0}\right) = \frac{M\omega^2 r^2}{2RT}$$

$$\Rightarrow \quad p = p_0 e^{\frac{M\omega^2 r^2}{2RT}}$$

**23.** Consider a gas layer of width $dx$ at a height $x$ above the bottom of container as shown in Figure.



If $P$ is the pressure just below this layer, then just above this layer, we can consider pressure to be $P - dP$, where $dP$ is the pressure due to the gas layer of width $dx$ and is given by

$$dP = -(dx)\rho g \qquad \ldots(1)$$

where, $\rho$ is the density of gas which is constant.

Since, $P = \dfrac{\rho RT}{M}$

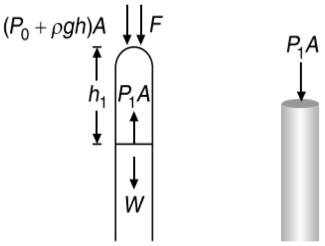
$$\Rightarrow \quad dP = \frac{\rho R}{M}dT \qquad \ldots(2)$$

From equations (1) and (2), we get

$$\frac{\rho R}{M}dT = -(dx)\rho g$$

$$\Rightarrow \quad \text{Temperature Gradient} = \frac{dT}{dx} = -\frac{Mg}{R}$$

**24.** In equilibrium, net downward force on the tube is $F$, $(P_0 + \rho gh)A$, $W$ and upward force is $P_1A$, where $P_1$ is the pressure of air in the tube after submergence.



$$\Rightarrow \quad F + (P_0 + \rho gh)A + W = P_1A$$

$$\Rightarrow \quad F = P_1A - (P_0 + \rho gh)A - W \qquad \ldots(1)$$

Since temperature is constant, so according to Boyle's Law, we have

$$P_0(\ell A) = P_1(h_1 A)$$

$$\Rightarrow \quad P_0\ell = P_1 h_1 \qquad \ldots(2)$$

Further, $P_1 = P_0 + \rho g(h + h_1)$ $\qquad \ldots(3)$

Solving the above three equations, for $F$, $P_1$ and $h_1$, we get

$$F = 8.5\times 10^{-2} \text{ N}$$

**25.** (a) For a layer of width $dy$ at a height $y$, we use

$$dp = -(dy)\rho g = -(dy)\left(\frac{pM}{RT}\right)g$$

$$\Rightarrow \quad \int_{p_0}^{p}\frac{dp}{p} = -\frac{Mg}{RT_0}\int_0^h \frac{dy}{1-ay}$$

$$\Rightarrow \quad \ln\frac{p}{p_0} = \frac{Mg}{RT_0}\ln(1-ah)$$

$$\Rightarrow \quad p = p_0(1-ah)^{Mg/aRT_0}$$

Above relation is valid if $h < \dfrac{1}{a}$

(b) Similarly, we have

$$dp = -(dy)\rho g = -(dy)\left(\frac{pM}{RT}\right)g$$

$$\Rightarrow \int_{p_0}^{p}\frac{dp}{p} = -\frac{Mg}{RT_0}\int_0^h \frac{dy}{(1+ay)}$$

$$\Rightarrow \ln\frac{p}{p_0} = -\frac{Mg}{aRT_0}\ln(1+ah)$$

$$\Rightarrow p = \frac{p_0}{(1+ah)^{Mg/aRT_0}}$$

## Test Your Concepts-IV (Based on Internal Energy, Degrees of Freedom and Molar Specific Heats for Ideal Gases)

**1.** Since $U_{\text{mixture}} = U_1 + U_2$

$$\Rightarrow (n_1+n_2)\left(\frac{3}{2}RT\right) = n_1\left(\frac{3}{2}RT_1\right) + n_2\left(\frac{3}{2}RT_2\right)$$

$$\Rightarrow T = \frac{n_1T_1 + n_2T_2}{n_1+n_2}$$

**2.** Let the gas have $f$ degrees of freedom, then three degrees of freedom are associated with translational motion and the remaining $f-3$ degrees of freedom are associated with rotational motion. So, we have

$$\frac{K_T}{K_R} = \frac{3(nRT/2)}{(f-3)(nRT/2)} = \frac{3}{2}$$

$$\Rightarrow \frac{3}{f-3} = \frac{3}{2}$$

$$\Rightarrow 6 = 3f - 9$$

$$\Rightarrow f = 5$$

$$\Rightarrow U = \left(\frac{nf}{2}\right)RT = \left(1\times\frac{5}{2}\right)(8.3)(100) = 2075\text{ J}$$

**3.** (a) Since, $TKE = U = n\left(\frac{3}{2}RT\right)$

where, $n = 2$ mol and $T = 293$ K, so

$$TKE = \frac{3}{2}(2)(8.31)(293) = 7.3\times10^3\text{ J}$$

(b) The average kinetic energy per molecule is $\frac{3}{2}k_BT$

$$\Rightarrow \frac{1}{2}m\langle v^2\rangle = \frac{1}{2}mv_{rms}^2 = \frac{3}{2}k_BT$$

$$\Rightarrow \frac{1}{2}m\langle v^2\rangle = \frac{3}{2}(1.38\times10^{-23})(293)$$

$$\Rightarrow \frac{1}{2}m\langle v^2\rangle = 6.07\times10^{-21}\text{ J}$$

**4.** (a) An oxygen molecule has three translational degrees of freedom, thus the average translational kinetic energy of an oxygen molecule at 27 °C is

$$E_T = \frac{3}{2}k_BT = \frac{3}{2}\times1.38\times10^{-23}\times300$$

$$\Rightarrow E_T = 6.21\times10^{-21}\text{ Jmole}^{-1}$$

(b) An oxygen molecule has total five degrees of freedom, hence its total kinetic energy is

$$E_T = \frac{5}{2}k_BT = \frac{5}{2}\times1.38\times10^{-23}\times300$$

$$\Rightarrow E_T = 10.35\times10^{-21}\text{ Jmole}^{-1}$$

(c) Total kinetic energy of one mole of oxygen is its internal energy, which can be given as

$$U = \frac{5}{2}nRT = \frac{5}{2}\times1\times8.314\times300$$

$$\Rightarrow U = 6235.5\text{ Jmole}^{-1}$$

**5.** Helium is a monoatomic gas so, internal energy of $n$ moles of the gas is $U = \frac{3}{2}nRT$

$$\Rightarrow \Delta U = \frac{3}{2}nR(\Delta T) = \left(\frac{3}{2}\right)(3)(8.31)(2) = 74.8\text{ J}$$

**6.** Since, the number of moles remains constant, so, we have

$$\Sigma n_{\text{initial}} = \Sigma n_{\text{final}}$$

From ideal gas equation, we get

$$\frac{p_1V}{T_1} + \frac{p_2V}{T_2} = \frac{p_1'V}{T_f} + \frac{p_2'V}{T_f} \qquad \ldots(1)$$

Applying conservation of energy, we get

$$\frac{f}{2}p_1V + \frac{f}{2}p_2V = \frac{f}{2}p_1'V + \frac{f}{2}p_2'V \qquad \ldots(2)$$

$$\Rightarrow p_1' + p_2' = p_1 + p_2$$

From equations (1) and (2), we get

$$\frac{p_1}{T_1} + \frac{p_2}{T_2} = \frac{p_1+p_2}{T_f}$$

$$\Rightarrow T_f = \frac{T_1T_2(p_1+p_2)}{p_1T_2 + p_2T_1}$$

For left and right part of gas, we have

$$\frac{p_1}{T_1} = \frac{p_1'}{T_f} \text{ and } \frac{p_2}{T_2} = \frac{p_2'}{T_f}$$

$$\Rightarrow p_1' = \frac{p_1T_2(p_1+p_2)}{p_1T_2+p_2T_1} \text{ and } p_2' = \frac{p_2T_1(p_1+p_2)}{p_1T_2+p_2T_1}$$

Heat supplied from the left part is $Q = U_i - U_f$

$$\Rightarrow Q = \frac{f}{2}p_1V - \frac{f}{2}p_1'V = \frac{fV}{2}\left(p_1 - \frac{p_1T_2(p_1+p_2)}{p_1T_2+p_2T_1}\right)$$

$$\Rightarrow Q = \frac{fV}{2}\left(\frac{p_1p_2T_2 - p_1p_2T_2}{p_1T_2+p_2T_1}\right)$$

Since the gas is monatomic, so $f = 3$

$$\Rightarrow Q = \frac{3p_1p_2V(T_2-T_1)}{2(p_1T_2+p_2T_1)}$$

**7.** Since, $U_{\text{mixture}} = U_1 + U_2$

$$\Rightarrow (n_1+n_2)C_{V_{mix}}T = n_1C_{V_1}T + n_2C_{V_2}T$$

$$\Rightarrow C_{V_{mix}} = \frac{n_1C_{V_1} + n_2C_{V_2}}{n_1+n_2}$$

Since, for $O_2$, $C_{V_1} = \frac{5R}{2}$ and for $CO_2$, $C_{V_2} = \frac{7R}{2}$. So, we get

$$C_{V_{mix}} = \frac{(2)\left(\frac{5R}{2}\right)+3\left(\frac{7R}{2}\right)}{2+3} = \left(\frac{31}{12}\right)R$$

Since, $C_{P_{mix}} - C_{V_{mix}} = R$

$$\Rightarrow \quad C_{P_{mix}} = \left(\frac{31}{12}+1\right)R = \left(\frac{43}{12}\right)R$$

So, $\gamma_{mix} = \frac{C_{P_{mix}}}{C_{V_{mix}}} = \frac{43}{31} \approx 1.4$

**8.** Rotational kinetic energy of a diatomic molecule is

$$E = 2\left(\frac{1}{2}k_BT\right) = \frac{1}{2}I\omega_{\text{rms}}^2$$

$$\Rightarrow \quad \omega_{\text{rms}} = \sqrt{\frac{2k_BT}{I}}$$

$$\Rightarrow \quad \omega_{\text{rms}} = \sqrt{\frac{2\times1.38\times10^{-23}\times300}{2.1\times10^{-39}}} \approx 2\times10^{9}\ \text{rads}^{-1}$$

**9.** The disordered kinetic energy of the gas converts into the internal energy of its molecules, so

$$\frac{1}{2}mv^2 = nC_V\Delta T = \left(\frac{m}{M}\right)\left(\frac{R}{\gamma-1}\right)\Delta T \qquad \left\{\because\ C_v = \frac{R}{\gamma-1}\right\}$$

$$\Rightarrow \quad v = \sqrt{\frac{2R\Delta T}{M(\gamma-1)}} \qquad \ldots(1)$$

Kinetic Energy of the system is $K = K_{\text{gas jar}} + K_{\text{molecules}}$

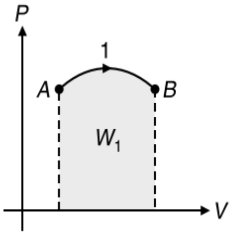
$$\Rightarrow \quad K = \frac{1}{2}Mv^2 + \frac{1}{2}(N_Am)v^2 = \frac{1}{2}Mv^2 + \frac{1}{2}Mv^2$$

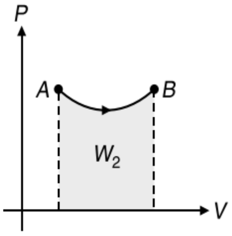
$$\Rightarrow \quad K = \frac{1}{2}(2M)v^2 = Mv^2$$

$$\Rightarrow \quad K = \frac{2R\Delta T}{\gamma-1} \qquad \{\text{from (1)}\}$$

## Test Your Concepts-V (Based on Work Done and First Law of Thermodynamics)

**1.** From FLTD, we have $Q_1 = W_1 + \Delta U_1$ and $Q_2 = W_2 + \Delta U_2$
Since, $U$ is a state function so $\Delta U$ depends only on the initial and final positions. Therefore, $\Delta U_1 = \Delta U_2$





Now, since the area under 1 is greater than area under 2. So $W_1 > W_2$ and hence $Q_1 > Q_2$

**2.** $W = \int_{V_1}^{V_2} PdV = P(V_2 - V_1) = P\left(\frac{\alpha(2T_0)^2}{P} - \frac{\alpha(T_0)^2}{P}\right) = 3\alpha T_0^2$

**3.** For a cyclic process, no change in internal energy takes place, so heat supplied is equal to the work done by the gas in one complete cycle. Hence

$$Q = \Delta U + W = 0 + W = W$$

Also, work done $W$ by the gas equals the positive area enclosed by the ellipse, so

$$Q = \text{Area of ellipse} = \pi ab$$

where, $a$ and $b$ are semi major and semi-minor axis of the ellipse. From the figure, we have

$$2a = 2\times10^5\ \text{Nm}^{-2} \text{ and } 2b = 200\times10^{-6}\ \text{m}^3$$

$$\Rightarrow \quad Q = W = \pi\times1.0\times10^5\times100\times10^{-6}$$

$$\Rightarrow \quad Q = 3.14\times10 = 31.4\ \text{J}$$

**4.** Since work done equals the area enclosed between $PV$ curve and the $V$ axis, so we have

$$W_{AC} = \frac{1}{2}(540)(0.3) + (340)(1) = 421\ \text{kJ}$$

Similarly, we have

$$W_{AD} = 421 + \frac{1}{2}(440)(0.6) = 553\ \text{kJ}$$

**5.** According to FLTD, we have $Q = \Delta U + W$
where, $\Delta U = U_f - U_i$

**For Process 1**

$Q = 35$ J, $W = -15$ J

$\Rightarrow \quad 35 = \Delta U - 15$

$\Rightarrow \quad \Delta U = U_f - U_i = 50$ J

$\Rightarrow \quad -10 - U_i = 50$ J

$\Rightarrow \quad U_i = -60$ J

**For Process 2**

$Q = -15$ J, $\Delta U = -20$ J

$\Rightarrow \quad -15 = -20 + W$

$\Rightarrow \quad W = 5$ J

Since, $\Delta U = U_f - U_i = -20$ J

$\Rightarrow \quad 60 - U_i = -20$ J

$\Rightarrow \quad U_i = 80$ J

**For Process 3**

$W = -20$ J, $\Delta U = 40$ J

$\Rightarrow \quad Q = 40 - 20 = 20$ J

Since, $\Delta U = U_f - U_i = 40$ J

$\Rightarrow \quad U_f - 80 = 40$ J

$\Rightarrow \quad U_f = 120$ J

| Process | $Q$ | $W$ | $U_i$ | $U_f$ | $\Delta U$ |
|---|---|---|---|---|---|
| 1. | 35 | –15 | –60 | –10 | 50 |
| 2. | –15 | 5 | 80 | 60 | –20 |
| 3. | 20 | –20 | 80 | 120 | 40 |

**6.** According to FLTD, we have $Q = \Delta U + W = (U_F - U_I) + W$ where, $U_I$ and $U_F$ are the internal energies in the initial and the final state.

For path $IAF$, $Q = 55$ J and $W = 25$ J.

$$\Rightarrow \quad \Delta U = U_F - U_I = Q - W = 55 - 25 = 30 \text{ J}$$

Now, we know that the internal energy is path independent i.e., it depends only on the initial and final states of the system. *So, internal energy between I and F irrespective of the path followed by the system between I and F is 30 J*

(a) For path $IBF$, $Q = 35$ J and $\Delta U = 30$ J

$$\Rightarrow \quad W = Q - \Delta U = 35 - 30 = 5 \text{ J}$$

i.e., work is being done by the system.

(b) For path $FI$, we have

$$W = -15 \text{ J}, \ \Delta U = U_I - U_F = -30 \text{ J}$$

$$\Rightarrow \quad Q = W + \Delta U = -15 - 30 = -45 \text{ J}$$

i.e., heat is lost by the system.

(c) Given, $U_I = 10$ J and $\Delta U = U_F - U_I$

$$\Rightarrow \quad U_F = \Delta U + U_I = 30 + 10 = 40 \text{ J}$$

(d) The process $BF$ is isochoric, i.e., the volume is constant, so $W = 0$.

$$\Rightarrow \quad Q = \Delta U_{BF} = U_F - U_B = 40 - 20 = 20 \text{ J}$$

The process $IB$ is isobaric (constant pressure). Therefore,

$$Q = Q_{IBF} - Q_{BF} = 35 - 20 = 15 \text{ J}$$

**7.** Change in internal energy of gas

$$\Delta U = \frac{3}{2}(P_B V_B - P_A V_A)$$

$$\Rightarrow \quad \Delta U = \frac{3}{2}(8 \times 10^5 \times 0.8 - 4 \times 10^5 \times 0.5)$$

$$\Rightarrow \quad \Delta U = 6.6 \times 10^5 \text{ J}$$

Work done by gas is equal to area under the $PV$ diagram, so we have

$$W = \frac{1}{2}(12 \times 10^5)(0.3) = 1.8 \times 10^5 \text{ J}$$

By FLTD, we have $Q = \Delta U + W$

$$\Rightarrow \quad Q = 8.4 \times 10^5 \text{ J}$$

**8.** Work done is given by

$$W = \underbrace{(\text{Area } 021)}_{\text{Clockwise}} - \underbrace{(\text{Area } 043)}_{\text{Counter Clockwise}}$$

$$W = \frac{1}{2}(V_2 - V_1)(P_0 - P_1) - \frac{1}{2}(V_4 - V_3)(P_2 - P_0)$$

Since by similarity, we have

$$\frac{V_4 - V_3}{V_2 - V_1} = \frac{P_2 - P_0}{P_0 - P_1}$$

$$\Rightarrow \quad V_4 - V_3 = \left(\frac{P_2 - P_0}{P_0 - P_1}\right)(V_2 - V_1)$$

$$\Rightarrow \quad V_4 - V_3 = \left(\frac{10^5}{2 \times 10^5}\right)(100 \times 10^{-3}) \text{ m}^3$$

$$\Rightarrow \quad V_4 - V_3 = 50 \times 10^{-3} \text{ m}^3$$

$$W = \frac{1}{2}(100 \times 10^{-3})(2 \times 10^5) - \frac{1}{2}(50 \times 10^{-3})(10^5)$$

$$\Rightarrow \quad W = 10^4 - 25 \times 10^2 = 7500 \text{ J}$$

**9.** Work done on the gas is the area bound by the semi-circle given by

$$W = \frac{\pi(1)(1)}{2} = \frac{\pi}{2} \text{ atmlt}$$

**10.** Work done are

$$W_{A \to B} = 8 \times (3 \times 10^5) \times 10^{-3} = 2400 \text{ J}$$

$$W_{B \to C} = 0$$

$$W_{C \to D} = -2 \times 3 \times 10^5 \times 10^{-3} = -600 \text{ J}$$

$$W_{D \to A} = 0$$

Total work is

$$W_{\text{cycle}} = 2400 - 600 = 1800 \text{ J}$$

## Test Your Concepts-VI (Based on Isochoric, Isobaric and Isothermal Processes)

**1.** Since helium is a monatomic gas. Therefore,

$$C_V = \frac{3R}{2} \text{ and } C_P = \frac{5R}{2}$$

(a) At constant volume, we have

$$Q = \Delta U = nC_V \Delta T = (2)\left(\frac{3R}{2}\right)(100)$$

$$\Rightarrow \quad Q = 300R$$

(b) At constant pressure,

$$Q = nC_P \Delta T = (2)\left(\frac{5R}{2}\right)(100)$$

$$\Rightarrow \quad Q = 500R$$

(c) At constant pressure, from FLTD, we have

$$W = Q - \Delta U = nC_P \Delta T - nC_V \Delta T$$

$$\Rightarrow \quad W = nR\Delta T = (2)(R)(100)$$

$$\Rightarrow \quad W = 200R$$

**2.** **Process** $AB$ is an isothermal process with $T =$ constant and $P_B > P_A$.

**For** $P$-$V$ **graph:** $P \propto \frac{1}{V}$ i.e., $P$-$V$ graph is a hyperbola with $P_B > P_A$ and $V_B < V_A$.

**For** $V$-$T$ **graph:** $T =$constant. Therefore, $V$-$T$ graph is a straight line parallel to $V$-axis with $V_B < V_A$.

**For** $\rho$-$T$ **graph:** Since $PV = RT$ where $V = \frac{M}{\rho}$

$$\Rightarrow \quad \rho = \frac{PM}{RT}$$

$$\Rightarrow \quad \rho \propto P$$

As $T$ is constant. Therefore, $\rho$-$T$ graph is a straight line parallel to $\rho$-*axis* with $\rho_B > \rho_A$ as $P_B > P_A$.

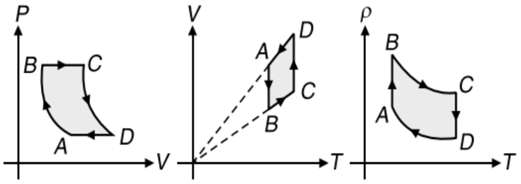
**Process** $BC$ is an isobaric process with $P =$ constant and $T_C > T_B$.

**For $P$-$V$ graph:** As $P$ is constant. Therefore, P-V graph is a straight line parallel to V-axis with $V_C > V_B$ (because $V \propto T$ in an isobaric process).

**For $V$-$T$ graph:** In isobaric process $V \propto T$, i.e., $V$-$T$ graph is a straight line passing through origin, with $T_C > T_B$ and $V_C > V_B$.

**For $\rho$-$T$ graph:** $\rho \propto \frac{1}{T}$ (when $P$ =constant), i.e., $\rho$-$T$ graph is a hyperbola with $T_C > T_B$ and $\rho_C < \rho_B$.

Similarly, we can repeat for the processes $CD$ and $DA$. As they are opposite to $AB$ and $BC$ respectively. The corresponding three graphs are shown below.



3. One mole of gas occupies a volume of 22400 cm$^3$ at 0 °C and at pressure of 1 atm. So, the initial volume of the gas is

$$V_1 = 22400 \text{ cm}^3 = 22400 \times 10^{-6} \text{ m}^3$$

$$\Rightarrow \quad V_1 = 0.0224 \text{ m}^3$$

Since pressure is constant equal to atmospheric pressure $P_0 = 1 \text{ atm} = 10^5 \text{ Nm}^{-2}$, so the final volume $V_2$ is

$$V_2 = V_1\left(\frac{T_2}{T_1}\right) \qquad \left\{\because \frac{V_1}{T_1} = \frac{V_2}{T_2}\right\}$$

where, $T_1 = 0 \text{ °C} = 273 \text{ K}$, $T_2 = 100 \text{ °C} = 373 \text{ K}$

$$\Rightarrow \quad V_2 = 0.0224\left(\frac{373}{273}\right) \text{m}^3 = 0.0306 \text{ m}^3$$

Work done in the process is

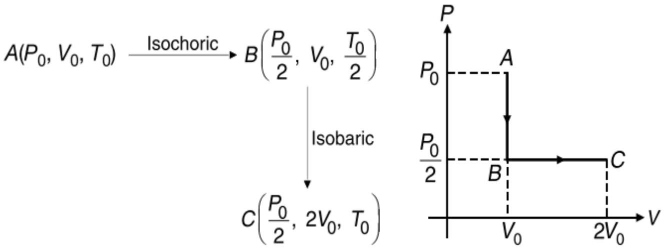
$$W = P(V_2 - V_1) \qquad \{\because P = \text{constant}\}$$

$$\Rightarrow \quad W = 10^5(0.0306 - 0.0224) = 10^5(0.0082)$$

$$\Rightarrow \quad W = 820 \text{ J}$$

i.e., work is done by the gas because the gas is expanding.

4. The most important thing to be observed here is that temperature of final state $C$ (i.e., $T_0$) is equal to the temperature of initial state $A$ (i.e., $T_0$). So, internal energy $\Delta U_{AC} = 0$



Now for the complete process $Q = \Delta U + W$

$$\Rightarrow \quad Q_{\text{net}} = W_{\text{net}} = W_{\text{isochoric}} + W_{\text{isobaric}}$$

But $W_{\text{isochoric}} = 0$

and $W_{\text{isobaric}} = \frac{P_0}{2}(\Delta V_0) = \frac{P_0 V_0}{2} = \frac{nRT_0}{2}$

$$\Rightarrow \quad W_{\text{net}} = \frac{(2)(8.3)(300)}{2} = 2490 \text{ J}$$

5. $W = P\Delta V = nR\Delta T = 1 \times 8.31 \times 72 \cong 600 \text{ J}$

$$\Delta U = Q - W = (500 \times 4.2 - 6 \times 10^2) = 1500 \text{ J}$$

$$\Rightarrow \quad \Delta U = \frac{nR\Delta T}{\gamma - 1}$$

$$\Rightarrow \quad 1500 = \frac{600}{\gamma - 1}$$

$$\Rightarrow \quad \gamma = 1.4$$

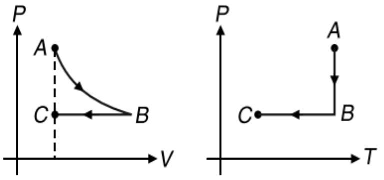
6. At constant pressure work done is

$$W = nR\Delta T = 2 \text{ J}$$

So, heat supplied to diatomic gas is

$$\Delta Q = \frac{7}{2}nR\Delta T = \frac{7}{2} \times 2 = 7 \text{ J}$$

7. (a)



(b) For the process $AB$ (Isothermal),

$$\frac{P_0 V_0}{T_0} = \frac{P_B(2V_0)}{T_0}$$

$$\Rightarrow \quad P_B = \frac{P_0}{2}$$

Since, for isothermal process, $\Delta U = 0$

$$\Rightarrow \quad Q = W + \Delta U = nRT \log_e\left(\frac{V_B}{V_A}\right)$$

$$\Rightarrow \quad Q = 3RT_0 \log_e(2)$$

For the process $BC$ (Isobaric), $\frac{2V_0}{T_0} = \frac{V_0}{T_C}$

$$\Rightarrow \quad T_C = \frac{T_0}{2}$$

For isobaric process,

$$W = nR\Delta T = 3R\left(\frac{T_0}{2} - T_0\right) = -\frac{3}{2}RT_0$$

$$Q = nC_P\Delta T = -\frac{21}{4}RT_0$$

$$\Rightarrow \quad W_{\text{Total}} = 3RT_0 \log_e(2) - \frac{3}{2}RT_0$$

(c) $Q_{\text{Total}} = 3RT_0 \log_e(2) - \frac{21}{4}RT_0$

8. Let spring be displaced by $x$ towards left, then

$$P_0(A\ell_0) = (P_0 + \Delta P)A(\ell_0 - x) \qquad \{\because P_1V_1 = P_2V_2\}$$

$$\Rightarrow \quad \Delta P = \frac{P_0 x}{\ell_0} \qquad \{\text{as } x \text{ is small}\}$$

When the spring is displaced by $x$, then spring force $= -kx$

Net, force against displacement $= -\frac{2P_0 xA}{\ell_0} - kx = -M\omega^2 x$

$$T = 2\pi\sqrt{\frac{M\ell_0}{2P_0 A + k\ell_0}}$$

So, net restoring force is

$$F_{\text{net}} = \begin{pmatrix}\text{Force due to}\\ \text{Excess Pressure}\end{pmatrix} + \begin{pmatrix}\text{Spring}\\ \text{Force}\end{pmatrix}$$

$$\Rightarrow \quad F_{\text{net}} = -(\Delta P)A - kx$$

$$\Rightarrow \quad F_{\text{net}} = -\left(\frac{2P_0 x}{\ell_0}\right)A - kx$$

$$\Rightarrow \quad M\ddot{x} + \left(\frac{2P_0 A}{\ell_0} + k\right)x = 0 \qquad \{\because F_{\text{net}} = M\ddot{x}\}$$

Comparing with standard equation of SHM, i.e., $\ddot{x} + \omega^2 x = 0$, we get

$$\omega = \sqrt{\frac{1}{M}\left(\frac{2P_0 A}{\ell_0} + k\right)}$$

$$\Rightarrow \quad T = 2\pi\sqrt{\frac{M\ell_0}{2P_0 A + k\ell_0}}$$

**9.** Given, mass of piston $M = 5$ kg, cross-sectional area of piston $A = 5\times10^{-3}\ \text{m}^2$, $g = 10\ \text{ms}^{-2}$ and atmospheric pressure $P_0 = 10^5\ \text{Nm}^{-2}$.

Initial pressure of gas in the cylinder is $P = P_0 + \dfrac{Mg}{A}$

$$\Rightarrow \quad P = 10^5 + \frac{5\times10}{5\times10^{-6}} = 1.1\times10^5\ \text{Nm}^{-3}$$

When the piston rises by $x = 0.1$ m at constant pressure, then work done is $W = P_0\Delta V = P_0 A\Delta x$

$$\Rightarrow \quad W = (10^5)(5\times10^{-3})(0.1) = 50\ \text{J}$$

At constant pressure, heat supplied to gas is

$$Q = \Delta U + W = \Delta U + 50$$

Now the piston is clamped, so volume of the gas remains constant during cooling. Hence work done during cooling is zero and $\Delta U' = -\Delta U$ (because the gas is cooled back to initial temperature). So by FLTD, we have

$$Q' = \Delta U' + W' = -\Delta U + 0 = -\Delta U$$

i.e., the heat energy lost during the isochoric cooling process is $Q_{\text{lost}} = |Q'| = \Delta U$

The difference between heat energy added during heating and heat energy lost during cooling is

$$\Delta Q = Q - |Q'| = (\Delta U + 50) - \Delta U = 50\ \text{J}$$

**10.** Let initial pressure is $P_0$ and pressure after first stroke is $P_1$. Then

$$P_1(V + \Delta V) = P_0 V$$

$$\Rightarrow \quad P_1 = \frac{P_0}{\left(1 + \dfrac{\Delta V}{V}\right)}$$

Similarly, if $P_n$ be the pressure after $n$ strokes, then

$$P_n = \frac{P_0}{\left(1 + \dfrac{\Delta V}{V}\right)^n}$$

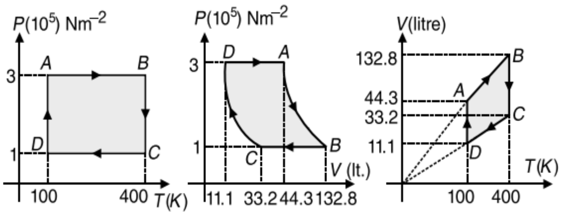
Since, we want that $P_n = \dfrac{P_0}{x}$

$$\Rightarrow \quad \frac{P_n}{P_0} = \frac{1}{x} = \frac{1}{\left(1 + \dfrac{\Delta V}{V}\right)^n}$$

Taking log both sides and solving, we get

$$n = \frac{\log_e(x)}{\log_e\left(1 + \dfrac{\Delta V}{V}\right)}$$

**11.**



**12.** Heat absorbed in an isobaric process is

$$\Delta Q = nC_P\Delta T = \frac{n\gamma R}{\gamma - 1}\Delta T = \frac{\gamma P}{\gamma - 1}(V_2 - V_1)$$

$$\Rightarrow \quad \Delta Q = \frac{1.67}{0.67}\times10^5\times10^{-4} = 24.92\ \text{J}$$

**13.** Since, $(PV)_A = (PV)_C = 3P_0V_0$

$$\Rightarrow \quad T_A = T_C$$

$$\Rightarrow \quad \Delta T = 0$$

$$\Rightarrow \quad \Delta U_{ABC} = 0 \qquad \{\because \Delta U = nC_V\Delta T\}$$

So, $Q_{ABC} = W_{ABC} =$ Area under the graph

$$\Rightarrow \quad Q_{ABC} = W_{ABC} = -2P_0V_0 \qquad \{\because \text{of compression}\}$$

So, heat is released during the process.

Since, $PV = nRT$

$$\Rightarrow \quad \frac{PM}{\rho} = nRT$$

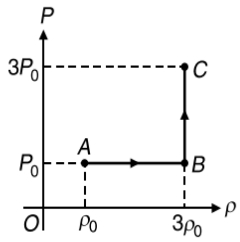
$$\Rightarrow \quad P = \left(\frac{nRT}{M}\right)\rho$$

For $AB$, $P = P_0 =$ constant i.e., $V \propto T$

$$\Rightarrow \quad \rho \propto \frac{1}{T}$$

Also, volume decreases from $3V_0$ to $V_0$, so temperature decreases from $3T_0$ to $T_0$ and hence $\rho$ increases from $\rho_0$ to $3\rho_0$.

For $B$ to $C$, $V =$ constant and $P$ increases from $P_0$ to $3P_0$.



**14.** As the piston is displaced slowly the change in kinetic energy is zero. From Work Energy Theorem, we have

$$W_{\text{atm}} + W_{\text{gas}} + W_{\text{ext}} = \Delta KE = 0 \qquad \ldots(1)$$

where, $W_{\text{atm}} = -\int\limits_{V_0}^{nV_0} P_0 dV = -P_0V_0(n-1)$

Also, $W_{\text{gas}} = \int\limits_{V_0}^{nV_0} PdV = RT\int\limits_{V_0}^{nV_0}\frac{dV}{V}$ $\{\because PV = nRT\}$

$\Rightarrow \quad W_{\text{gas}} = RT\log_e n$

From (1), we get $W_{\text{ext}} = -W_{\text{atm}} - W_{\text{gas}}$

$\Rightarrow \quad W_{\text{ext}} = -(-P_0V_0(n-1) + RT\log_e n)$

$\Rightarrow \quad W_{\text{ext}} = RT((n-1) - \log_e(n))$

**15.** (a) At constant pressure $W = P\Delta V = nR\Delta T$ (as $PV = nRT$)

$\Rightarrow \quad W = nR\Delta T = 2\times 2\times(35-30) = 20$ cal

(b) $\Delta U = Q_p - W$

$\Rightarrow \quad \Delta U = 70 - 20 = 50$ cal

## Test Your Concepts-VII (Based on Adiabatic Process)

**1.** In adiabatic process $\frac{dP}{dV} = -\gamma\left(\frac{P_0}{V_0}\right)$

$\Rightarrow \quad dP = -\gamma\left(\frac{P_0}{V_0}\right)dV$

When the piston is displaced towards right by a small distance $x$, then $dV = Ax$

So, net restoring force is

$$F = (2dP)A = -2\gamma\left(\frac{P_0}{V_0}\right)A^2x$$

Since, $F \propto -x$

Hence the motion of piston is simple harmonic in nature

So, acceleration $a$ is given by

$$a = \frac{F}{m} = -\left(\frac{2\gamma P_0A^2}{V_0m}\right)x$$

$\Rightarrow \quad T = 2\pi\sqrt{\left|\frac{x}{a}\right|} = 2\pi\sqrt{\frac{mV_0}{2\gamma A^2P_0}}$

**2.** In case of isothermal expansion, the work done is given by

$$W_1 = W_{\text{isot}} = nRT\ln\left(\frac{V_2}{V_1}\right)$$

where, $T = 27\ °\text{C} = 273 + 27 = 300\ °\text{K}$, $n = 1$, $\frac{V_2}{V_1} = 2$ and $R = \frac{25}{3}\ \text{Jmol}^{-1}\text{K}^{-1}$

$\Rightarrow \quad W_1 = (25/3)\times 300\times\ln(2)$

$\Rightarrow \quad W_1 = (1)(25/3)(300)(0.7) = 1750$ J

Now the gas is compressed adiabatically to its original volume. Initially at the beginning of adiabatic compression, the temperature of the gas is 300 K and at the end of adiabatic compression, the temperature becomes $T_2$ because the temperature is changed. Now, the initial volume of the gas is $2V_1$ and after compression it again becomes the original volume i.e., $V_1$. For an adiabatic process

$$T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1}$$

$\Rightarrow \quad 300(2V_1)^{\gamma-1} = T_2(V_i)^{\gamma-1}$

$\Rightarrow \quad 300(2)^{1.4-1} = T_2(1)^{1.4-1}$

$\Rightarrow \quad T_2 = 300(2)^{0.4} = (300)(1.3) = 390$ K

Work done during adiabatic process is

$$W_2 = W_{\text{ad}} = \frac{nR}{1-\gamma}(T_2 - T_1)$$

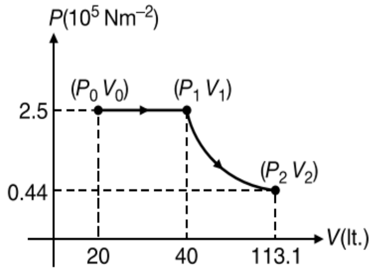
$\Rightarrow \quad W_2 = \frac{(1)(25/3)}{(-0.4)}(390 - 300) = -1875$ J

Total work done is given by

$$W = W_1 + W_2 = 1750 - 1875 = -125\ \text{J}$$

i.e., the work is done on the gas.

**3.** (a)



(b) $P_0 = \frac{nRT_0}{V_0} = \frac{2\times 8.31\times 300}{20\times 10^{-3}}$

$\Rightarrow \quad P_0 = 2.5\times 10^5\ \text{Nm}^{-2}$

$\Rightarrow \quad P_1 = P_0 = 2.5\times 10^5\ \text{Nm}^{-2}$

Also, $V_1 = 2V = 40\times 10^{-3}\ \text{m}^3$

**Process AB:** $V \propto T$

$\Rightarrow \quad T_1 = 2T_0 = 600$ K

**Process BC:** Using $T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1}$, we get

$V_2 = 2\sqrt{2}V_1 = 113.1\times 10^{-3}\ \text{m}^3$

and $P_2 = \frac{nRT_2}{V_2} = \frac{(2)(8.31)(300)}{113.1\times 10^{-3}}$

$P_2 = 0.44\times 10^5\ \text{Nm}^{-2}$

(c) $W_{\text{total}} = W_1 + W_2$

$W_{\text{total}} = P_0(V_1 - V_0) + \frac{nR}{\gamma-1}(T_1 - T_2)$

Substituting the values, we get

$W_{\text{total}} = 12470$ J

**4.** Sudden compression implies adiabatic process, so

$$T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1}$$

$\Rightarrow \quad 300(V_1)^{0.5} = T_2\left(\frac{V_1}{2}\right)^{0.5}$

$\Rightarrow \quad T_2 = 300\sqrt{2} = 423$ K

At the end of adiabatic process, pressure is

$$P_2 = P_1\left(\frac{V_1}{V_1/2}\right)^{1.5} = 2\sqrt{2}P_1 = 2\sqrt{2}\times 10^5\ \text{Pa}$$

Now, for cooling the gas isobarically to 300 K from an initial temperature of $300\sqrt{2}$ K, we have

$$\frac{V_2}{T_2}=\frac{V_3}{T_3}$$

$$\Rightarrow \quad V_3=V_2\left(\frac{T_3}{T_2}\right)=\left(\frac{V_1}{2}\right)\left(\frac{300}{300\sqrt{2}}\right)=\frac{V_1}{2\sqrt{2}}$$

Now the gas is isothermally expanded to its original volume, so we have $V_4=V_1$

Since, $P_3V_3=P_4P_4$

$$\Rightarrow \quad \left(2\sqrt{2}P_1\right)\left(\frac{V_1}{2\sqrt{2}}\right)=P_4V$$

$$\Rightarrow \quad P_4=P_1$$

Work done by gas in first process is

$$W_{\text{adia}}=\frac{P_2V_2-P_1V_1}{1-\gamma}=\frac{\left(2\sqrt{2}P_1\right)\left(\frac{V_1}{2}\right)-P_1V_1}{(-0.5)}$$

$$\Rightarrow \quad W_{\text{adia}}=-\left(\frac{\sqrt{2}-1}{0.5}\right)\left(10^5\right)\left(10^{-3}\right)$$

$$\Rightarrow \quad W_{\text{adia}}=-82\text{ J}$$

Also, $W_{\text{isob}}=P\Delta V=P_2\left(V_3-V_2\right)$

$$\Rightarrow \quad W_{\text{isob}}=\left(2\sqrt{2}P_1\right)\left(\frac{V_1}{2\sqrt{2}}-\frac{V_1}{2}\right)$$

$$\Rightarrow \quad W_{\text{isob}}=P_1V_1\left(1-\sqrt{2}\right)$$

$$\Rightarrow \quad W_{\text{isob}}=\left(1-\sqrt{2}\right)\left(10^5\right)\left(10^{-3}\right)=-41\text{ J}$$

Now, $W_{\text{isot}}=nRT_3\ln\left(\frac{V_4}{V_3}\right)=P_3V_3\ln\left(\frac{V_4}{V_3}\right)$

$$\Rightarrow \quad W_{\text{isot}}=\left(2\sqrt{2}P_1\right)\left(\frac{V_1}{2\sqrt{2}}\right)\ln\left(\frac{V_1}{V_1/2\sqrt{2}}\right)$$

$$\Rightarrow \quad W_{\text{isot}}=P_1V_1\ln\left(2\sqrt{2}\right)=P_1V_1\ln(2)^{1.5}$$

$$\Rightarrow \quad W_{\text{isot}}=1.5\left(10^5\right)\left(10^{-3}\right)(0.7)=105\text{ J}$$

Now, $W_{\text{total}}=W_{\text{adia}}+W_{\text{isob}}+W_{\text{isot}}$

$$\Rightarrow \quad W_{\text{total}}=-82-41+105=-18\text{ J}$$

**5.** For Isothermal process, $\Delta U_1=0$

$$\Rightarrow \quad Q_1=W_1=RT\log_e\left(\frac{V_f}{V_i}\right)=RT\log_e(2)$$

$$\Rightarrow \quad Q_1=300R\log_e(2) \qquad \ldots(1)$$

For Isochoric process, $W_2=0$

$$\Rightarrow \quad Q_2=\Delta U_2=C_V\Delta T=\frac{3}{2}R\Delta T \qquad \ldots(2)$$

Since it is given that $Q_1=Q_2$

So, from (1) and (2), we get

$$\Delta T=\left(\frac{2}{3}\right)(300)\left(\log_e 2\right)=138.6\text{ K}$$

That is, final temperature of second vessel is

$$(300+138.6)K=438.6\text{ K}$$

Let $P_0$ and $T_0$ be the final pressure and temperature of the mixture and since, same mass of the same gas is being mixed, so we have

$$T_0=\frac{300+438.6}{2}=369.3\text{ K}$$

$$\Rightarrow \quad P_0=\frac{nRT_0}{V}=\frac{2\times8.3\times369.3}{3\times8.3\times10^{-3}}=2.46\times10^5\text{ Nm}^{-2}$$

**6.** For an adiabatic process, we have

$$P^{1-\gamma}T^{\gamma}=\text{constant}$$

$$\Rightarrow \quad T_2=T_1\left(\frac{P_1}{P_2}\right)^{\frac{1-\gamma}{\gamma}}=300\left(\frac{1}{10}\right)^{-\frac{2}{7}}=300(10)^{2/7}$$

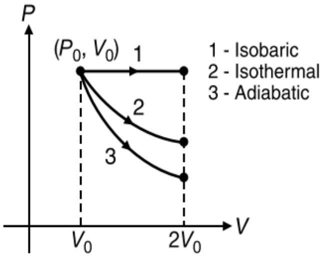
$$\Rightarrow \quad T_2=300(1.4)^2=300(1.96)=588\text{ K}$$

Also, $W_{\text{ad}}=\frac{nR}{1-\gamma}\left(T_2-T_1\right)$

$$\Rightarrow \quad W_{\text{ad}}=\frac{(1)(8.3)}{1-1.4}(588-300)=-5976\text{ J}$$

Negative sign implies that work is being done on the system.

**7.** (a)



Area under graph 3 is least. Therefore, work done is least in adiabatic process

(b) For 1, an Isobaric process, pressure remains constant, so $V\propto T$, so when $V_0$ becomes $2V_0$, $T_0$ also becomes $2T_0$.

For 2, an Isothermal process, $T$ is constant while pressure goes from $P_0$ to $\frac{P_0}{2}$.

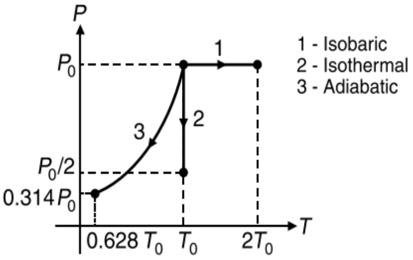
For 3, an Adiabatic equation, the $P$-$T$ equation is given by

$$PT^{\left(\frac{\gamma}{1-\gamma}\right)}=\text{constant}$$

For a monatomic gas, $\gamma=\frac{5}{3}$

$$\Rightarrow \quad P_0V_0^{5/3}=P\left(2V_0\right)^{5/3}$$

$$\Rightarrow \quad P=0.314P_0$$



Also, for an adiabatic process, we have

$$PV^{\gamma}=\text{constant and }TV^{\gamma-1}=\text{constant}$$

$$\Rightarrow \quad \frac{T}{PV}=\text{constant}$$

$$\Rightarrow \quad T \propto PV$$

$$\Rightarrow \quad \frac{T}{T_0} = \left(\frac{P}{P_0}\right)\left(\frac{V}{V_0}\right)$$

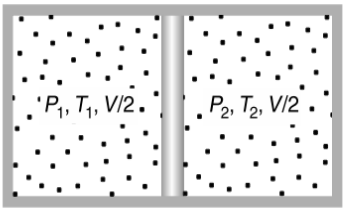
$$\Rightarrow \quad T = (0.314)(2)T_0 = 0.628T_0$$

**8.** For an adiabatic process, $Q = 0$ i.e., $W = -\Delta U$

Given that $\Delta U = -100$ J, so $W = 100$ J

**9.** (a) Let $T$ be the final temperature in both the compartments, then from First Law of Thermodynamics applied to the cylinder, we have

$$Q = \Delta U + W$$



Since the cylinder wall is adiabatic and fixed, so

$$Q = W = 0$$

$$\Rightarrow \quad \Delta U = 0$$

So, there is no change in internal energy of the system

$$\Rightarrow \quad n_1 C_V (T - T_1) = n_2 C_V (T_2 - T)$$

$$\Rightarrow \quad \frac{P_1 V}{2RT_1}(T - T_1) = \frac{P_2 V}{2RT_2}(T_2 - T)$$

Solving, we get $T = \dfrac{(P_1 + P_2)T_1T_2}{P_1T_2 + P_2T_1}$

For the left compartment, $\dfrac{P_1}{T_1} = \dfrac{P_1'}{T}$

where, $P_1'$ is the final pressure in the left compartment

$$\Rightarrow \quad P_1' = \frac{P_1(P_1 + P_2)T_2}{P_1T_2 + P_2T_1}$$

Similarly, we get $P_2' = \dfrac{P_2(P_1 + P_2)T_1}{P_1T_2 + P_2T_1}$

(b) Since, $P_2T_1 > P_1T_2$, it follows that $P_2' > P_1'$. Therefore, the piston moves to the left. Let $\Delta V$ be the change in volume of any compartment, then on applying the Ideal Gas Equation, we get

$$\frac{P_f\left(\frac{V}{2} - \Delta V\right)}{T_f} = \frac{P_1 V}{2T_1} \quad \ldots(1)$$

and

$$\frac{P_f\left(\frac{V}{2} + \Delta V\right)}{T_f} = \frac{P_2 V}{2T_2} \quad \ldots(2)$$

On dividing equation (2) by (1), we get

$$\frac{\left(\frac{V}{2} + \Delta V\right)}{\left(\frac{V}{2} - \Delta V\right)} = \frac{P_2T_1}{P_1T_2}$$

So, volume of left compartment is

$$V_L = \frac{V}{2} - \Delta V = V\left(\frac{P_1T_2}{P_2T_1 + P_1T_2}\right)$$

and volume of right compartment is

$$V_R = \frac{V}{2} + \Delta V = V\left(\frac{P_2T_1}{P_2T_1 + P_1T_2}\right)$$

**10.** Since, $P_1V_1^{\gamma} = P_2V_2^{\gamma}$

$$\Rightarrow \quad \frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^{\gamma}$$

$$\Rightarrow \quad \frac{P_2}{P_1} = \left(\frac{16}{12}\right)^{3/2} = \left(\frac{4}{3}\right)^{3/2} = 1.533$$

Also, $T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1}$

$$\Rightarrow \quad \frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = \left(\frac{16}{12}\right)^{\frac{1}{2}} = \left(\frac{4}{3}\right)^{\frac{1}{2}} = 1.153$$

**11.** For an adiabatic process, we have

$$TV^{\gamma-1} = \text{constant}$$

Differentiating with respect to $T$,

$$V^{\gamma-1}(1) + (T)(\gamma-1)V^{\gamma-2}\frac{dV}{dT} = 0$$

$$\Rightarrow \quad \frac{dV}{dT} = -\frac{V}{T(\gamma-1)}$$

But from the graph, we have slope $= \tan(\pi - \theta)$

$$\Rightarrow \quad \left|\frac{dV}{dT}\right|_{T_0,\, V_0} = \tan(\pi - \theta) = -\tan\theta$$

$$\Rightarrow \quad \frac{V_0}{T_0(\gamma-1)} = \tan\theta$$

$$\Rightarrow \quad \gamma - 1 = \frac{V_0}{T_0\tan\theta}$$

$$\Rightarrow \quad \gamma = \frac{V_0}{T_0\tan\theta} - 1$$

$$\Rightarrow \quad C_P = \frac{\gamma R}{\gamma - 1} = \frac{(V_0 - T_0\tan\theta)R}{(T_0\tan\theta)V_0}T_0\tan\theta$$

$$\Rightarrow \quad C_P = \left(1 - \frac{T_0}{V_0}\tan\theta\right)R$$

and $C_V = \dfrac{R}{\gamma - 1} = \dfrac{RT_0\tan\theta}{V_0}$

## Test Your Concepts-VIII (Based on Polytropic Process)

**1.** Given equation is $VT^2 = \text{constant}$

Since, $PV = nRT$

$$\Rightarrow \quad PV^{3/2} = \text{constant}$$

Comparing with $PV^x = \text{constant}$, we get $x = \dfrac{3}{2}$

Since, $C = C_V + \dfrac{R}{1-x} = \dfrac{R}{\gamma-1} + \dfrac{R}{1-x}$ and $\gamma = \dfrac{7}{5}$

$$\Rightarrow \quad C = \frac{R}{\frac{7}{5}-1} + \frac{R}{1-\frac{3}{2}} = \frac{5}{2}R - 2R = \frac{R}{2}$$

Now, $Q = nC\Delta T$

$$\Rightarrow \quad Q = (3)\left(\frac{R}{2}\right)(2T - T) = \frac{3}{2}RT$$

2. (a) Heat supplied to raise the temperature of one mole of gas from $T_0$ to $\eta T_0$

$$Q = \int C\,dT = \int_{T_0}^{\eta T_0} \frac{\alpha}{T}dT = \alpha \ln(\eta)$$

Increase in internal energy of gas is

$$\Delta U = C_V(\eta T_0 - T_0) = \frac{RT_0}{\gamma - 1}(\eta - 1)$$

From FLTD, work done is

$$W = Q - \Delta U = \alpha \ln(\eta) - \frac{RT_0(\eta-1)}{(\gamma-1)}$$

(b) Since, $C = C_V + \dfrac{PdV}{ndT}$

$$\Rightarrow \quad \frac{\alpha}{T} = \frac{R}{\gamma-1} + \frac{RT}{V}\frac{dV}{dT}$$

$$\Rightarrow \quad \int \frac{dV}{V} = \int \frac{\alpha}{RT^2}dT - \frac{1}{\gamma-1}\int \frac{dT}{T}$$

$$\Rightarrow \quad \ln V = -\frac{\alpha}{R}\frac{1}{T} - \frac{1}{\gamma-1}\ln T + C$$

$$\Rightarrow \quad (\gamma-1)\ln V + \ln T = -\frac{\alpha(\gamma-1)}{RT} + C$$

$$\Rightarrow \quad \ln\left(TV^{\gamma-1}\right) = -\frac{\alpha(\gamma-1)}{RT} + C$$

$$\Rightarrow \quad TV^{\gamma-1}e^{\frac{\alpha(\gamma-1)}{RT}} = \text{constant}$$

$$\Rightarrow \quad PV^{\gamma}e^{\frac{\alpha(\gamma-1)}{PV}} = \text{constant}$$

3. Equation of the process is $P = P_0 - \alpha V^2$

Using ideal gas equation $PV = RT$, we get

$$\left(P_0 - \alpha V^2\right)V = RT$$

$$\Rightarrow \quad T = \frac{P_0 V}{R} - \frac{\alpha V^3}{R}$$

For maximum value of $T$, we have $\dfrac{dT}{dV} = 0$

$$\Rightarrow \quad \frac{dT}{dV} = \frac{P_0}{R} - \frac{3\alpha V^2}{R} = 0$$

$$\Rightarrow \quad V = \sqrt{\frac{P_0}{3\alpha}}$$

$$\Rightarrow \quad T_{\max} = \frac{2P_0}{3R}\sqrt{\frac{P_0}{3\alpha}}$$

4. Equation for first thermodynamic process is

$$T = T_0 e^{\alpha V} \qquad \ldots(1)$$

Since, we know that for any process

$$C = \frac{1}{n}\left(\frac{dQ}{dT}\right) = \frac{1}{n}\left(\frac{dU + dW}{dT}\right)$$

$$\Rightarrow \quad C = \frac{1}{n}\left(\frac{dU}{dT}\right) + \frac{P}{n}\left(\frac{dV}{dT}\right)$$

$$\Rightarrow \quad C = C_V + \frac{P}{n}\left(\frac{dV}{dT}\right) \qquad \ldots(2)$$

From gas law, the pressure and volume relation is

$$P = \frac{nRT}{V} = \frac{nR\left(T_0 e^{\alpha V}\right)}{V} \qquad \ldots(3)$$

Differentiating equation (1) w.r.t. $V$, we get

$$\frac{dT}{dV} = T_0 \alpha e^{\alpha V}$$

$$\Rightarrow \quad \frac{dV}{dT} = \frac{1}{T_0 \alpha e^{\alpha V}} \qquad \ldots(4)$$

Substituting equations (3) and (4) in equation (2), we get

$$C = C_V + \left(\frac{nRT_0 e^{\alpha V}}{nV}\right)\left(\frac{1}{T_0 \alpha e^{\alpha V}}\right)$$

$$\Rightarrow \quad C = C_V + \frac{R}{\alpha V}$$

*Since, the molar specific heat of the gas undergoing this given process is not constant and is a function of volume, so this process is a non-polytropic process.*

Equation for second thermodynamic process is

$$P = P_0 e^{\alpha V} \qquad \ldots(5)$$

$$\Rightarrow \quad \frac{nRT}{V} = P_0 e^{\alpha V}$$

$$\Rightarrow \quad T = \frac{P_0}{nR}\left(Ve^{\alpha V}\right) \qquad \ldots(6)$$

Differentiate equation (6), w.r.t. $V$, we get

$$\frac{dT}{dV} = \frac{P_0}{nR}\left(e^{\alpha V} + V\alpha e^{\alpha V}\right) = \frac{P_0 e^{\alpha V}}{nR}(1 + \alpha V) \qquad \ldots(7)$$

Substituting equations (7) and (5) in equation (2), we get

$$C = C_V + \left(\frac{P_0 e^{\alpha V}}{n}\right)\left(\frac{nR}{P_0 e^{\alpha V}(1+\alpha V)}\right)$$

$$\Rightarrow \quad C = C_V + \frac{R}{1 + \alpha V}$$

*Again, we note that the molar specific heat of the gas undergoing this given process is not constant and is a function of volume, so this process is a non-polytropic process.*

5. Given that $TV = \text{constant}$

Compare with $TV^{x-1} = \text{constant}$, we get $x - 1 = 1$

$$\Rightarrow \quad x = 2$$

$$\Rightarrow \quad C = C_V + \frac{R}{1-x} = C_V + \frac{R}{1-2}$$

$$\Rightarrow \quad C = C_V - R$$

Since, $Q = nC\Delta T = (1)C\Delta T$

$$\Rightarrow \quad Q = (C_V - R)\Delta T = C_V\Delta T - R\Delta T$$

$$\Rightarrow \quad Q = \frac{R}{\gamma-1}\Delta T - R\Delta T = R\Delta T\left(\frac{1}{\gamma-1}-1\right)$$

$$\Rightarrow \quad Q = \frac{R\Delta T(1-\gamma+1)}{\gamma-1} = \frac{\gamma R\Delta T}{1-\gamma}$$

**6.** Since the rate of collisions with wall of vessel

$$N_C = \frac{1}{6}n_0 v_{rms} = \text{constant}$$

where, $n_0$ is the number density of molecules.

$$\Rightarrow \quad \frac{1}{6}\left(\frac{N}{V}\right)\sqrt{\frac{3RT}{m}} = \text{constant}$$

$$\Rightarrow \quad \frac{\sqrt{T}}{V} = \text{constant}$$

$$\Rightarrow \quad T = kV^2$$

$$\Rightarrow \quad \frac{dT}{dV} = 2kV$$

Molar specific of the gas is given by

$$C = C_V + \frac{PdV}{ndT}, \text{ where } C_V = \frac{5R}{2}$$

$$\Rightarrow \quad C = \frac{5R}{2} + \left(\frac{RT}{V}\right)\frac{dV}{dT} = \frac{3R}{2} + \frac{R\left(kV^2\right)}{V}\frac{1}{2kV}$$

$$\Rightarrow \quad C = \frac{5R}{2} + \frac{R}{2} = 3R$$

**7.** Let the initial volume of the gas is $V$ and it is expanded to volume $\eta V$. The work done in the process is given by

$$W = \int_V^{\eta V} PdV = \int_V^{\eta V} \alpha V dV = \frac{\alpha V^2}{2}\left(\eta^2-1\right)$$

The pressure of the gas as a function of volume is $P = \alpha V$. The initial and final values of pressure would be $V_i = \alpha V$ and $V_f = \eta\alpha V$ respectively.

From Ideal Gas Equation, we get

$$T_i = \frac{P_i V_i}{nR} = \frac{\alpha V^2}{nR} \text{ and } T_f = \frac{P_f V_f}{nR} = \frac{\eta^2 \alpha V^2}{nR}$$

$$\text{Since, } \Delta U = nC_V\Delta T = \frac{nR}{\gamma-1}\Delta T = \frac{nR}{\gamma-1}\left(T_f - T_i\right)$$

$$\Rightarrow \quad \Delta U = \left(\frac{nR}{\gamma-1}\right)\left(\frac{\alpha V^2}{nR}\right)\left(\eta^2-1\right) = \frac{\alpha V^2}{\gamma-1}\left(\eta^2-1\right)$$

Since, $P = \alpha V$

$$\Rightarrow \quad PV^{-1} = \text{constant}$$

Compare with $PV^x = \text{constant}$, we get $x = -1$

$$\Rightarrow \quad C = C_V + \frac{R}{1-x} = C_V + \frac{R}{2}$$

**8.** For a given polytropic process $PV^x = \text{constant}$ and molar specific heat is given by

$$C = C_V + \frac{R}{1-x} = \frac{R}{\gamma-1} + \frac{R}{1-x} \qquad \ldots(1)$$

The given equation can be re-written as

$$PV^{-\alpha} = k = \text{constant}$$

So, comparison of the two equations gives

$$x = -\alpha$$

According to the problem, we should have $C = 0$

$$\Rightarrow \quad C = \frac{R}{\gamma-1} + \frac{R}{1-(-\alpha)} = 0$$

$$\Rightarrow \quad \frac{R}{1-\gamma} = \frac{R}{1+\alpha}$$

$$\Rightarrow \quad \alpha = -\gamma$$

*We could have given this answer directly, because for an adiabatic process, $Q = 0$ and hence $C = 0$.*

**9.** (a) Given that $PT^{-1/2} = \text{constant}$ …(1)

For a polytropic process, we have

$$PT^{\frac{x}{1-x}} = \text{constant} \qquad \ldots(2)$$

Comparing equations (1) and (2), we get

$$\frac{x}{1-x} = -\frac{1}{2}$$

$$\Rightarrow \quad -2x = 1-x$$

$$\Rightarrow \quad x = -1$$

Work done by a gas in a polytropic process is

$$W_{\text{poly}} = \frac{nR}{1-x}\left(T_2 - T_1\right), \text{ where } x = -1$$

$$\Rightarrow \quad W_{\text{poly}} = \frac{nR}{1-(-1)}\left(T_2 - T_1\right) = \frac{nR}{2}\Delta T$$

$$\Rightarrow \quad W_{\text{poly}} = \frac{(2)(25/3)}{2}(60) = 500 \text{ J}$$

(b) Since $C = C_V + \frac{R}{1-x}$ where, $\left(C_V\right)_{\text{monatomic}} = \frac{3R}{2}$

$$\Rightarrow \quad C = \frac{3R}{2} + \frac{R}{1-(-1)} = 2R$$

## Test Your Concepts-IX (Based on Cyclic Process, Heat Engine and Refrigerator)

**1.** For process $AB$ we use

$$PT = \text{constant}$$

$$\Rightarrow \quad \left(\frac{RT}{V}\right)T = \text{constant}$$

$$\Rightarrow \quad T^2 \propto V$$

$$\Rightarrow \quad T = k\sqrt{V} \text{ OR } P\sqrt{V} = \text{constant}$$

$$\Rightarrow \quad PV^{\frac{1}{2}} = \text{constant i.e., } x = \frac{1}{2}$$

Thus, molar specific heat of gas is

$$C = C_V + \frac{R}{1-x} = C_V + 2R$$

$$\Rightarrow \quad C = \frac{3R}{2} + 2R = \frac{7R}{2}$$

Work done by gas in process $AB$ is

$$W_{\text{poly}} = \frac{nR}{1-x}\left(T_2 - T_1\right)$$

$$\Rightarrow \quad W_{\text{poly}} = \frac{2R}{1-(1/2)}(T_0 - 2T_0) = -4RT_0$$

$$\Rightarrow \quad W_{\text{poly}} = -4RT_0 = -1200R$$

$$Q_{AB} = 2C(T_0 - 2T_0) = -2\left(\frac{7R}{2}\right)T_0$$

$$\Rightarrow \quad Q_{AB} = -7RT_0 = -2100R$$

$$Q_{BC} = 2C_P(2T_0 - T_0) = 2\left(\frac{5R}{2}\right)T_0 = 1500R$$

$$Q_{CA} = 2R(2T_0)\ln(2)$$

$$\Rightarrow \quad Q_{CA} = 1200R \times 0.693 = 831.6R$$

**2.** Done in Theory

**3.** Let $P$ and $V$ be the initial pressure and volume respectively, then for process $1 \to 2$

$$\frac{P_2}{T_2} = \frac{P}{T_1} \qquad \{\because \text{volume remains constant}\}$$

$$\Rightarrow \quad P_2 = P\frac{T_2}{T_1} \qquad \ldots(1)$$

For process $2 \to 3$

$$\frac{V_3}{T_3} = \frac{V}{T_2}$$

$$\Rightarrow \quad V_3 = V\frac{T_3}{T_2} \qquad \ldots(2)$$

For process $3 \to 4$ (temperature at points 3 and 4 is the same), so

$$V_4 = V\frac{T_2}{T_1} \qquad \ldots(3)$$

Since work done by the gas is area of the trapezium 12341

$$\Rightarrow \quad W = \frac{1}{2}\left[(V_3 - V_2) + (V_4 - V_1)\right](P_2 - P_1)$$

$$\Rightarrow \quad W = \frac{1}{2}\left(V\frac{T_3}{T_2} + V\frac{T_2}{T_1} - 2V\right)\left(P\frac{T_2}{T_1} - P\right)$$

$$\Rightarrow \quad W = \frac{1}{2}PV\left(\frac{T_3}{T_2} + \frac{T_2}{T_1} - 2\right)(T_2 - T_1)$$

But $PV = nRT_1$

$$\Rightarrow \quad W = \frac{1}{2}nR\left(\frac{T_3}{T_2} + \frac{T_2}{T_1} - 2\right)(T_2 - T_1)$$

**4.** For $A \to B$, $V \propto T$

$\Rightarrow \quad P = \text{constant}$

So, $V$ and $T$ both are increasing.

Hence we get a straight line parallel to $V$ axis as $P$ is constant.

For $B \to C$, $V$ is constant

$\Rightarrow \quad P \propto T$

So, $T$ is decreasing and $P$ is also decreasing.

Hence we get a straight line parallel to $P$ axis, as $V$ is constant.

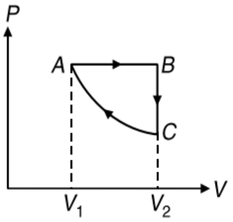
For $C \to A$, $T$ is constant

$\Rightarrow \quad P \propto \frac{1}{V}$ So, if $V$ is decreasing, then $P$ should increase

Hence, we get a rectangular hyperbola because

$PV = \text{constant}$

The corresponding graph is shown in figure given below.



**5.** For process $CA$, volume remains constant, so no work is done in this process.

For process $AB$, since $T \propto V$ so gas pressure remains constant and hence work done by the gas in this process is

$$W_{AB} = nR(T_B - T_A)$$

$$\Rightarrow \quad W_{AB} = 2 \times 8.314 \times (500 - 300)$$

$$\Rightarrow \quad W_{AB} = 2 \times 8.314 \times 200 = 3325.6 \text{ J}$$

For the cyclic process, we have $\Delta U = 0$, so

$$Q = W = W_{AB} + W_{BC} + W_{CA}$$

According to the problem a total 1200 J of heat is rejected by the gas, so we have

$$Q = -1200 \text{ J}$$

$$\Rightarrow \quad -1200 = Q_{AB} + W_{BC} + W_{CA}$$

$$\Rightarrow \quad -1200 = 3325.6 + W_{BC} + 0$$

$$\Rightarrow \quad W_{BC} = -4525.6 \text{ J}$$

**6.** For isothermal process $AB$, we have

$$Q_{AB} = 2R(500)\ln(2)$$

For isothermal process $CD$, we have

$$Q_{CD} = -2R(300)\ln(2)$$

For isochoric process $BC$, we have

$$Q_{BC} = 2C_V(-200) = -400C_V$$

Similarly, for isochoric process $DA$, we have

$$Q_{DA} = 2C_V(200) = 400C_V$$

Total heat supplied to gas is

$$Q = Q_{AB} + Q_{BC} + Q_{CD} + Q_{DA}$$

$$\Rightarrow \quad Q = 400R\ln 2 = (400)(8.314)(0.693)$$

$$\Rightarrow \quad Q = 2304.64 \text{ J}$$

**7.** Since the process is cyclic, i.e., $\Delta U = 0$, so

$$Q = W_{AB} + W_{BC} + W_{CA} \qquad \ldots(1)$$

For process $AB$, volume of gas remains constant, so work done is zero.

$$\Rightarrow \quad W_{AB} = 0$$

For process $BC$, temperature is constant at 500 K and volume of gas changes from $V_1 = 2 \text{ m}^3$ to $V_2 = 5 \text{ m}^3$, so we have

$$W_{BC} = nRT\ln\left(\frac{V_2}{V_1}\right) = (1)R(500)\ln\left(\frac{5}{2}\right)$$

For process $CA$, we observe that $V \propto T$ and the line passes through the origin, so the pressure is constant

$$W_{CA} = P\Delta V = nR\Delta T = nR(T_2 - T_1)$$

$$\Rightarrow \quad W_{CA} = (1)R(300-500) = -200R$$

This is negative as gas is being compressed from volume 5 m$^3$ to 2 m$^3$ or work is done on the gas.

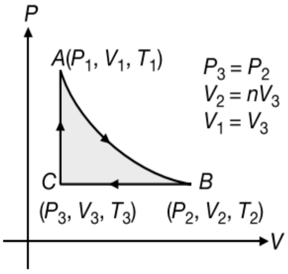
Substituting these values in equation (1), we get

$$Q = 0 + 500R\ln\left(\frac{5}{2}\right) - 200R$$

$$\Rightarrow \quad Q = 8.3[500(0.9) - 200] = 2075 \text{ J}$$

**8.** $Q_1 = 0$ {adiabatic}

$Q_2 = C_P(T_3 - T_2)$ {isobaric}



Further, $\dfrac{V_2}{T_2} = \dfrac{V_3}{T_3}$

$$\Rightarrow \quad \frac{nV}{T_2} = \frac{V}{T_3}$$

$$\Rightarrow \quad T_3 = \frac{T_2}{n}$$

Since, $C_P = \left(\dfrac{\gamma}{\gamma-1}\right)R$

$$\Rightarrow \quad Q_2 = \frac{R\gamma}{\gamma-1}\left(\frac{T_2}{n} - T_2\right) = \frac{R\gamma T_2}{n(\gamma-1)}(1-n)$$

So, heat rejected in isobaric process is

$$Q_2 = -\frac{R\gamma T_2}{n(\gamma-1)}(n-1)$$

At constant volume,

$$Q_3 = C_V(T_1 - T_3) = \frac{R}{\gamma-1}(T_1 - T_3)$$

$$\Rightarrow \quad Q_3 = \frac{R}{\gamma-1}\left(T_1 - \frac{T_2}{n}\right)$$

Further, $T_1V_1^{\gamma-1} = T_2(nV_1)^{\gamma-1}$

$$\Rightarrow \quad T_1 = T_2 n^{\gamma-1}$$

$$\Rightarrow \quad Q_3 = \frac{RT_2}{\gamma-1}\left(n^{\gamma-1} - \frac{1}{n}\right) = \frac{RT_2}{n(\gamma-1)}(n^{\gamma}-1)$$

So, $W_{\text{Total}} = Q_1 + Q_2 + Q_3$

$$W_{\text{Total}} = \frac{RT_2}{n(\gamma-1)}\left[(n^{\gamma}-1) - \gamma(n-1)\right]$$

Now, efficiency $\eta$ is $\eta = \dfrac{W_{\text{Total}}}{Q_{+ive}} = \dfrac{W_{\text{Total}}}{Q_3}$

$$\Rightarrow \quad \eta = \frac{(n^{\gamma}-1) - \gamma(n-1)}{(n^{\gamma}-1)}$$

$$\Rightarrow \quad \eta = 1 - \gamma\left(\frac{n-1}{n^{\gamma}-1}\right)$$

**9.** Given that $U_A = 0$, $U_B = 50$ J and $Q_{BC} = 90$ J.

Also, $P_A = P_B = 10 \text{ Nm}^{-2}$, $P_C = 30 \text{ Nm}^{-2}$

$V_A = 1 \text{ m}^3$ and $V_B = V_C = 3 \text{ m}^3$.

For process $BC$, volume of gas remains constant, so work done by gas in this process is zero i.e., $W_{BC} = 0$

Since heat absorbed by the gas is $Q_{BC} = 90$ J, so from FLTD, we have

$$\Delta U_{BC} = U_C - U_B = Q_{BC} - W_{BC} = 90 \text{ J} - 0$$

$$\Rightarrow \quad \Delta U_{BC} = U_C - U_B = 90 \text{ J}$$

$$\Rightarrow \quad U_C = \Delta U_{BC} + U_B = 90 \text{ J} + 50 \text{ J} = 140 \text{ J}$$

For process $AB$, we have

$$\Delta U_{AB} = U_B - U_A = 50 - 0 = 50 \text{ J}$$

$$W_{AB} = P\Delta V = P_A(V_B - V_A) = 10(3-1) = 20 \text{ J}$$

Thus, heat absorbed by the system is

$$Q_{AB} = (\Delta U)_{AB} + W_{AB} = 50 + 20 = 70 \text{ J}$$

For process $CA$

$$\Delta U_{CA} = U_A - U_C = 0 - 140 = -140 \text{ J}$$

Work done is equal to the negative area under the curve $CA$ (a compression process)

$$W_{CA} = -(\text{Area } ACED)$$

$$\Rightarrow \quad W_{CA} = -\left[\frac{1}{2}(10+30)(3-1)\right] = -40 \text{ J}$$

So, by FLTD, we have

$$Q_{CA} = \Delta U_{CA} + W_{CA} = -140 - 40 = -180 \text{ J}$$

Negative sign shows that heat is being rejected in the process $CA$.

Net work done in the counter clockwise cyclic process $ABCA$ is equal to the negative of the area of triangle $ABC$ i.e.,

$$W_{ABCA} = -(\text{Area } \Delta ABC)$$

$$\Rightarrow \quad W_{ABCA} = -\frac{1}{2} \times 2 \times 20 = -20 \text{ J}$$

Negative sign indicates that the work is being done on the system.

**10.** If $T$ is the temperature of state $A$ we use

$$T_A = T;\ T_B = T_D = nT;\ T_C = n^2T$$

Total work done by gas in cycle for $n_1$ moles of gas

$$W = (P_2 - P_1)(V_2 - V_1)$$

$$n_1R(n^2T - nT - nT + T) = n_1RT(n-1)^2$$

Heat supplied to gas is $Q_{\text{supp}} = \Delta Q_{AB} + \Delta Q_{BC}$

$$\Rightarrow \quad Q_{\text{supp}} = n_1\left(\frac{R}{\gamma-1}\right)T(n-1) + n_1\left(\frac{\gamma R}{\gamma-1}\right)T(n^2 - n)$$

$$\Rightarrow \quad Q_{\text{supp}} = \frac{n_1RT}{\gamma-1}(n - 1 + \gamma n^2 - \gamma n)$$

$$\Rightarrow \quad Q_{\text{supp}} = \frac{n_1RT}{\gamma-1}(n-1)(1+\gamma n)$$

Cycle efficiency is

$$\eta = \frac{W}{Q_{\text{supp}}} = \frac{n_1RT(n-1)^2}{\dfrac{n_1RT}{\gamma-1}(n-1)(1+\gamma n)}$$

$$\Rightarrow \quad \eta = \left(\frac{\gamma-1}{1+\gamma n}\right)(n-1)$$

## Test Your Concepts-X (Based on Conduction)

**1.** (a) Thermal resistance of aluminium cube $R_1 = \dfrac{\ell}{kA}$

$$\Rightarrow \quad R_1 = \frac{(3\times10^{-2})}{(237)(3\times10^{-2})^2} = 0.14\ \text{KW}^{-1}$$

and thermal resistance of copper cube $R_2 = \dfrac{\ell}{kA}$

$$\Rightarrow \quad R_2 = \frac{(3\times10^{-2})}{(401)(3\times10^{-2})^2} = 0.08\ \text{KW}^{-1}$$

As these two resistances are in parallel, their equivalent resistance is given by

$$R = \frac{R_1R_2}{R_1+R_2}$$

$$\Rightarrow \quad R = \frac{(0.14)(0.08)}{(0.14)+(0.08)}$$

$$\Rightarrow \quad R = 0.05\ \text{KW}^{-1}$$

So, thermal current

$$H = \frac{\text{Temperature difference}}{\text{Thermal resistance}}$$

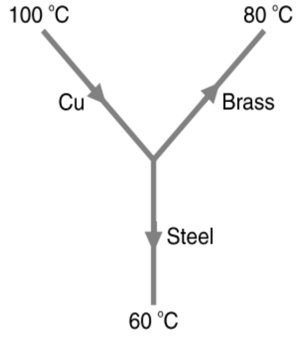
$$\Rightarrow \quad H = \frac{(100-20)}{0.05}$$

$$\Rightarrow \quad H = 1.6\times10^3\ \text{watt}$$

(b) In parallel thermal current distributes in the inverse ratio of resistance, so

$$\frac{H_{Cu}}{H_{Al}} = \frac{R_{Al}}{R_{Cu}} = \frac{R_1}{R_2} = \frac{0.14}{0.08} = 1.75$$

**2.** (a) Since $H_{Cu} = H_{\text{Steel}} + H_{\text{Brass}}$



If $T$ be the temperature of the junction, then

$$\frac{k_{Cu}A(100-T)}{46} = \frac{k_BA(T-80)}{13} + \frac{k_SA(T-60)}{12}$$

$$\Rightarrow \quad \frac{0.92}{46}(100-T) = \frac{0.26}{13}(T-80) + \frac{0.12}{12}(T-60^\circ)$$

$$\Rightarrow \quad 200-2T = 2T-160+T-60$$

$$\Rightarrow \quad 5T = 420$$

$$\Rightarrow \quad T = 84\ ^\circ\text{C}$$

(b) $H_{Cu} = \dfrac{k_{Cu}A(100-T)}{\ell_{Cu}}$

$$\Rightarrow \quad H_{Cu} = \frac{(0.92)(4)(100-84)}{46}$$

$$\Rightarrow \quad H_{Cu} = 1.28\ \text{cals}^{-1}$$

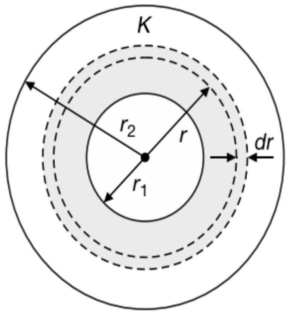
**3.** Consider a differential cylindrical element

$$H = \frac{dQ}{dt} = kA\frac{dT}{dr} = (2\pi kr\ell)\frac{dT}{dr}$$

$$\frac{H}{2\pi k\ell}\int_{r_1}^{r_2}\frac{dr}{r} = \int_0^{50} dT$$

$$\Rightarrow \quad \frac{H}{2\pi k\ell}\log_e\left(\frac{r_2}{r_1}\right) = 50$$

$$\Rightarrow \quad H = \frac{100\pi k\ell}{\log_e\left(\dfrac{r_2}{r_1}\right)}$$



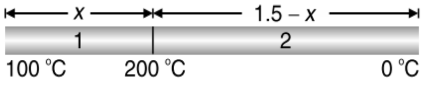
Since, $Q = Ht = mL$

$$\Rightarrow \quad t = \frac{mL}{H} = \frac{mL\log_e\left(\dfrac{r_2}{r_1}\right)}{100\pi k\ell}$$

**4.** Since, $\dfrac{dQ}{dt} = kA\dfrac{\Delta T}{\ell}$

and $\dfrac{dQ}{dt} = L\left(\dfrac{dm}{dt}\right)$ $\qquad \{\because dQ = (dm)L\}$

$$\Rightarrow \quad \left(\frac{dm}{dt}\right) = \left(\frac{kA}{\ell}\right)\left(\frac{\Delta T}{L}\right)$$



Let the desired point be at a distance x from water at $100\ ^\circ\text{C}$. Since

$$\left(\begin{matrix}\text{Rate of Melting}\\ \text{of Ice}\end{matrix}\right) = \left(\begin{matrix}\text{Rate of Production}\\ \text{of Steam}\end{matrix}\right)$$

$$\Rightarrow \quad \left(\frac{dm}{dt}\right)_1 = \left(\frac{dm}{dt}\right)_2$$

$$\Rightarrow \quad \left(\frac{\Delta T}{L\ell}\right)_1 = \left(\frac{\Delta T}{L\ell}\right)_2 \quad \{\text{as } A_1 = A_2 \text{ and } k_1 = k_2\}$$

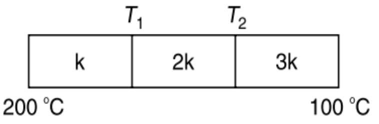
$$\Rightarrow \quad \frac{200-100}{(540)(x)} = \frac{100-0}{(80)(1.5-x)}$$

Solving this, we get

$$x = 0.1034\ \text{m} = 10.34\ \text{cm}$$

So, the temperature of $200\ ^\circ\text{C}$ must be maintained at a distance $10.34\ \text{cm}$ from water at $100\ ^\circ\text{C}$.

**5.** Thermal resistance $\propto \dfrac{1}{k}$



$$\Rightarrow \quad R_1 : R_2 : R_3 = \frac{1}{1} : \frac{1}{2} : \frac{1}{3} = 6:3:2$$

So if, $R_1 = 6R$, $R_2 = 3R$ and $R_3 = 2R$

then, $H = \dfrac{\Delta T}{R_{\text{net}}} = \dfrac{200-100}{6R+3R+2R} = \dfrac{100}{11R}$

Now, $200 - T_1 = HR_1$

$$\Rightarrow \quad T_1 = 200 - \left(\frac{100}{11R}\right)(6R) = 145.5\ ^\circ\text{C}$$

Also, $T_2 - 100 = HR_3$

$$\Rightarrow \quad T_2 = 100 + HR_3$$

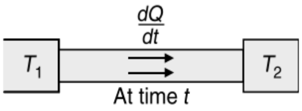
$$\Rightarrow \quad T_2 = 100 + \left(\frac{100}{11R}\right)(2R)$$

$$\Rightarrow \quad T_2 = 118.2\ ^\circ\text{C}$$

**6.** Let $T_1$ and $T_2 (< T_1)$ be the temperatures of the two chunks at time $t$ and $T$ be their temperature difference. Then

$$T = T_1 - T_2$$

$$\Rightarrow \quad \left(-\frac{dT}{dt}\right) = \left(-\frac{dT_1}{dt}\right) + \left(\frac{dT_2}{dt}\right) \qquad \ldots(1)$$



Since, $\dfrac{dQ}{dt} = \dfrac{kAT}{\ell} = C_1\left(-\dfrac{dT_1}{dt}\right) = C_2\left(\dfrac{dT_2}{dt}\right) \quad \{\because T_1 - T_2 = T\}$

$$\Rightarrow \quad \left(-\frac{dT_1}{dt}\right) = \left(\frac{kA}{\ell C_1}\right)T$$

and $\left(\dfrac{dT_2}{dt}\right) = \left(\dfrac{kA}{\ell C_2}\right)T$

Substituting these values in Equation (1), we get

$$\left(-\frac{dT}{dt}\right) = \frac{kA}{\ell}\left(\frac{C_1 + C_2}{C_1 C_2}\right)T = \alpha T \text{ where } \alpha = \frac{kA(C_1 + C_2)}{\ell C_1 C_2}$$

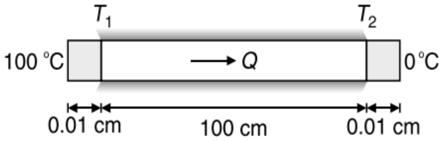
$$\Rightarrow \quad \int_{(\Delta T)_0}^{T} -\frac{dT}{T} = \alpha \int_0^t dt$$

$$\Rightarrow \quad T = (\Delta T)_0 e^{-\alpha t}$$

**7.** Since, $\dfrac{dQ}{dt} = \dfrac{0.0014 \times A \times (100 - T_1)}{0.01} \qquad \ldots(1)$

$$\frac{dQ}{dt} = \frac{1.04 \times A \times (T_1 - T_2)}{100} \qquad \ldots(2)$$

and $\dfrac{dQ}{dt} = \dfrac{0.0014 \times A \times (T_1 - 0)}{0.01} \qquad \ldots(3)$



From Equations (1) and (3), we get

$$100 - T_1 = T_2 \qquad \ldots(4)$$

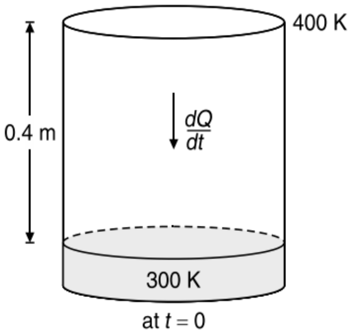
Solving above four equation, we get

$$T_1 = 93.5\ ^\circ\text{C and } T_2 = 6.5\ ^\circ\text{C}$$

So, temperature gradient in the bar

$$\frac{\Delta T}{\ell} = \frac{T_1 - T_2}{100} = 0.87\ (^\circ\text{C})\text{cm}^{-1}$$

**8.** Since, $\dfrac{dQ}{dt} = mc\dfrac{dT}{dt} = \dfrac{KA(T_1 - T_2)}{\ell}$ we have



$$mc\left(\frac{dT}{dt}\right) = \frac{KA(400 - T)}{0.4}$$

$$\Rightarrow \quad (0.4)(600)\frac{dT}{dt} = \frac{(10)(0.04)(400 - T)}{0.4}$$

$$\Rightarrow \quad \left(\frac{dT}{400 - T}\right) = \frac{1}{240}dt$$

$$\Rightarrow \quad \int_0^t dt = 240 \int_{300}^{350} \frac{dT}{400 - T}$$

Solving this, we get $t \approx 166$ s

**9.** (a) Since, $Q = nC_P \Delta T \qquad \{\because P = \text{constant}\}$

$$\Rightarrow \quad \frac{kA(T_S - T)}{a}dt = \left(\frac{P_0 V_0}{RT_0}\right)\left(\frac{5R}{2}\right)dT$$

$$\Rightarrow \quad \frac{kA(T_S - T)}{a}dt = \frac{5P_0 V_0}{2T_0}dT$$

$$\Rightarrow \quad \frac{kA}{a}\int_0^t dt = \frac{5P_0 V_0}{2T_0}\int_{T_0}^{T} \frac{dT}{T_S - T}$$

$$\Rightarrow \quad T = T_S + (T_S - T_0)e^{-\alpha t}$$

where, $\alpha = \dfrac{2T_0 kA}{5P_0 V_0 a}$

(b) Since $P = \text{constant}$, so $\dfrac{V_i}{T_i} = \dfrac{V_f}{T_f}$

$$\Rightarrow \quad \frac{h_0 A}{T_0} = \frac{hA}{T}$$

$$\Rightarrow \quad h = \left(\frac{T}{T_0}\right)h_0$$

**10.** Let $\theta$ be the temperature difference at time $t$, then

$$\frac{dQ}{dt}=\frac{kA\theta}{\ell} \quad \ldots(1)$$

Since, $\dfrac{dQ}{dt}=nC_{V_1}\left(-\dfrac{d\theta_1}{dt}\right)=nC_{V_2}\left(\dfrac{d\theta_2}{dt}\right) \quad \ldots(2)$

where, $C_{V_1}=\dfrac{3R}{2}$ and $C_{V_2}=\dfrac{5R}{2}$

Since, $\left(-\dfrac{d\theta_1}{dt}\right)=\dfrac{2kA\theta}{3nR\ell}$

$$\left(\frac{d\theta_2}{dt}\right)=\frac{2kA\theta}{5nR\ell}$$

Also, $\theta=\theta_1-\theta_2$

$$\Rightarrow \left(-\frac{d\theta}{dt}\right)=\left(-\frac{d\theta_1}{dt}\right)+\left(\frac{d\theta_2}{dt}\right)$$

$$\Rightarrow \left(-\frac{d\theta}{dt}\right)=\frac{16kA\theta}{15nR\ell}$$

$$\Rightarrow dt=-\frac{15nR\ell}{16kA}\int_{T_1-T_2}^{\frac{T_1-T_2}{2}}\frac{d\theta}{\theta}$$

$$\Rightarrow t=\frac{15nR\ell}{16kA}\log_e(2)$$

## Test Your Concepts-XI (Based on Radiation)

**1.** Since, $\begin{pmatrix}\text{Rate of}\\ \text{Cooling}\end{pmatrix}\propto\begin{pmatrix}\text{Average Excess}\\ \text{Temperature}\end{pmatrix}$

$$\Rightarrow \frac{T_i-T_f}{t}=k\left(\frac{T_i+T_f}{2}-T_0\right)$$

$$\Rightarrow \frac{80-50}{5}=k\left(\frac{80+50}{2}-20\right) \quad \ldots(1)$$

Similarly

$$\frac{60-30}{t}=k\left(\frac{60+30}{2}-20\right) \quad \ldots(2)$$

Dividing (1) by (2), we get

$$\Rightarrow \frac{t}{5}=\frac{65-20}{45-20}$$

$$\Rightarrow t=\frac{45}{25}\times 5=9 \text{ minute}$$

**2.** Since temperature of surrounding is very low as compared to that of heating element, so we can ignore the amount of radiant energy absorbed by the filament from its surroundings. So, according to Stefan's Law, we get

$$P=\sigma AT^4$$

$$\Rightarrow 1000=5.67\times10^{-8}\times0.02\times T^4$$

$$\Rightarrow T^4=8.82\times10^{11}$$

$$\Rightarrow T=969.3\text{ K}$$

**3.** Since the curved surface of the rod is insulated, so in steady state, the heat conducted from end $A$ to end $B$ of the rod is lost from the end $B$ of rod by radiation.

The energy received through conduction at end $B$ of rod per unit time is

$$u_1=\left|\frac{dQ}{dt}\right|=\frac{kA(T_A-T_B)}{l} \quad \ldots(1)$$

where, $T_A$, $T_B$ are absolute temperatures of end $A$ and $B$, $l$ is the length and $k$ is thermal conductivity of rod.

Energy radiated per unit time from end $B$ is

$$u_2=\left|\frac{dQ}{dt}\right|=\sigma A\left(T_B^4-T_0^4\right) \quad \ldots(2)$$

where $T_0$ is room temperature, $\sigma$ is Stefan's constant.

In the steady state, we have $u_1=u_2$

$$\Rightarrow \frac{k(T_A-T_B)}{l}=\sigma\left(T_B^4-T_0^4\right)$$

$$\Rightarrow k=\frac{\sigma l\left(T_B^4-T_0^4\right)}{T_A-T_B} \quad \ldots(3)$$

Substituting the values, we get

$$k=36.6\text{ Wm}^{-1}\text{K}^{-1}$$

**4.** Since, $-\dfrac{dQ}{dt}=mc\left(-\dfrac{dT}{dt}\right)=\sigma AT^4$

$$\int_{800\text{ K}}^{300\text{ K}}-\frac{dT}{T^4}=\frac{\sigma A}{mc}\int_0^t dt$$

Substituting $A=4\pi r^2$, $m=\dfrac{4}{3}\pi r^3\rho$, so integrating the above equation, we get

$$t=1.01\times10^5\text{ s}$$

**5.** Since, $-\dfrac{dQ}{dt}=\sigma e\left(\pi d^2\right)T^4$

$$\Rightarrow \rho\left(\frac{4}{3}\pi\frac{d^3}{8}\right)c\frac{dT}{dt}=-\sigma e\pi d^2T^4$$

$$\Rightarrow \frac{\rho dc}{6\sigma e}=\int_{T_0}^{T_0/\eta}\frac{dT}{T^4}=-\int_0^t dt$$

$$\Rightarrow t=\frac{\rho dc}{18\sigma e}\left(\frac{\eta^3}{T_0^3}-\frac{1}{T_0^3}\right)=\frac{\rho dc\left(\eta^3-1\right)}{18\sigma eT_0^3}$$

**6.** The rate of loss of heat by sphere is given by

$$\frac{dQ}{dt}=\sigma A\left(T^4-T_0^4\right)$$

where, $A=4\pi r^2$ is the surface area of the sphere of radius $r=10\text{ cm}=0.1\text{ m}$, $T=327\ ^\circ\text{C}=600\text{ K}$ and $T_0=27\ ^\circ\text{C}=300\text{ K}$, So, we get

$$\frac{dQ}{dt}=\left(5.67\times10^{-8}\right)4\pi(0.1)^2\left[(600)^4-(300)^4\right]$$

$$\Rightarrow \frac{dQ}{dt}=866\text{ Js}^{-1}$$

Since, $dQ = msdT$, where $dT$ is the fall in temperature in time $dt$, hence $\frac{dQ}{dt} = ms\frac{dT}{dt}$

$$\Rightarrow \quad 866 = 10 \times 420 \times \frac{dT}{dt}$$

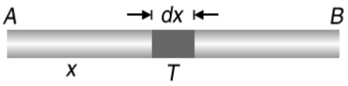
$$\Rightarrow \quad \frac{dT}{dt} = \frac{866}{4200} = 0.206\ °\text{Cs}^{-1}$$

**7.** Since, $\lambda_m T_B = b$

$$\Rightarrow \quad T_B = \frac{b}{\lambda_m}$$

$$\Rightarrow \quad T_B = \frac{2.9 \times 10^{-3}}{14.5 \times 10^{-7}}$$

$$\Rightarrow \quad T_B = 2000\ \text{K}$$



Since, $\frac{dQ}{dt} = P = -\frac{kAdT}{dx}$

$$\Rightarrow \quad P = -\frac{k_0(1+ax)AdT}{dx}$$

$$\Rightarrow \quad -\int_{\ell_0}^{x} \frac{dx}{1+ax} = \frac{k_0 A}{P}\int_{T_B}^{T} dT$$

Solving this equation, we get

$$T = \frac{P}{k_0 a A}\log_e\left(\frac{1+a\ell_0}{1+ax}\right) + T_B$$

Substituting the values, we get

$$T = \frac{4560}{11.4 \times 0.2}\log_e\left(\frac{1+0.2\times 5}{1+0.2x}\right) + 2000$$

$$\Rightarrow \quad T = 2000\left[\log_e\left(\frac{2}{1+0.2x}\right)+1\right]$$

$$\Rightarrow \quad T = 2000\left[\log_e\left(\frac{20}{10+2x}\right)+1\right]$$

$$\Rightarrow \quad T = 2000\left[\log_e\left(\frac{10}{5+x}\right)+1\right]$$

**8.** In this case, rate of heat lost by the block is

$$\frac{dQ}{dt} = \sigma A\left(T^4 - T_5^4\right)$$

where, $A$ is the total surface area of cube given by $6a^2 = 150\ \text{cm}^2 = 150 \times 10^{-4}\ \text{m}^2$

$$\left|\frac{dQ}{dt}\right| = \left(5.67\times 10^{-8}\right)\left(\frac{150}{10^4}\right)\left((500)^4 - (300)^4\right)$$

If $\frac{dT}{dt}$ is rate of cooling of block, then

$$\left|\frac{dQ}{dt}\right| = ms\frac{dT}{dt}$$

$$\Rightarrow \quad \frac{dT}{dt} = \frac{1}{ms}\frac{dQ}{dt} = \left(\frac{1}{1\times 400}\right)38.556$$

$$\Rightarrow \quad \frac{dT}{dt} = 0.115\ °\text{Cs}^{-1}$$

**9.** If emissivity of body is $e$, the power required equals the rate of emission of radiation.

$$P = e\sigma A\left(T^4 - T_5^4\right) \qquad \ldots(1)$$

For a black body

$$P_B = \sigma A\left(T^4 - T_5^4\right) \qquad \ldots(2)$$

Dividing, we get $\frac{P}{P_B} = e$

$$\Rightarrow \quad e = \frac{210}{700} = 0.3$$

**10.** Since temperature difference of water with its surrounding is not large, so according to Newton's Law of Cooling, we have

$$\frac{T_i - T_f}{t} = k\left(\frac{T_i + T_f}{2} - T_0\right), \text{ where } k = \frac{4\sigma A T_0^3}{mc}$$

So, $k = \frac{4\left(5.67\times 10^{-8}\right)6\left(10/100\right)^2(300)^3}{1\times 4200}$

$$\Rightarrow \quad k = 8.75 \times 10^{-5}$$

$$\Rightarrow \quad \frac{30-29}{t} = 8.75\times 10^{-5}(29.5 - 27)$$

$$\Rightarrow \quad t = \frac{1}{\left(8.75\times 10^{-5}\right)(2.5)} = 4571.43\ \text{s} = 76.2\ \text{min}$$

**11.** Using average from of Newton's Law of Cooling, we use For water, we have

$$\frac{40-35}{5} = \frac{k}{0.1\times 4200}\left(\frac{40+35}{2} - T_S\right) \qquad \ldots(1)$$

For liquid, we have

$$\frac{40-35}{2} = \frac{k}{m\times 2100}\left(\frac{40+35}{2} - T_S\right) \qquad \ldots(2)$$

Dividing (1) by (2), we get

$$\frac{2}{5} = \frac{m\times 2100}{0.1\times 4200}$$

$$\Rightarrow \quad m = \frac{2\times 420}{5\times 2100} = 0.08\ \text{kg} = 80\ \text{gm}$$

As the volume of liquid is same that of water 100 cm$^3$, then density of liquid is

$$\rho = \frac{m}{V} = \frac{80\times 10^{-3}}{100\times 10^{-6}} = 800\ \text{kgm}^{-3}$$

**12.** In the bulb filament given, the energy radiated per sec per square metre of its surface area is given as

$$E = \frac{P}{A} = \frac{114.75}{0.25\times 10^{-4}} = 459\times 10^4\ \text{Js}^{-1}\text{m}^2$$

If $T$ is the temperature of the filament then according to Stefan's law, we have

$$E = \sigma T^4$$

$$\Rightarrow \quad 459\times 10^4 = \left(\frac{17}{3}\times 10^{-8}\right)T^4$$

$$\Rightarrow \quad T^4 = \frac{459\times 10^4}{(17/3)\times 10^{-8}} = 81\times 10^{12}$$

$$\Rightarrow \quad T = \left(81\times 10^{12}\right)^{\frac{1}{4}} = 3000\text{ K}$$

## Single Correct Choice Type Questions

1. If temperature of the source is increased by $\alpha$ K and temperature of the sink is decreased by the same amount i.e. $\alpha$ K then efficiency increases more in the second case.

Since $\eta_0 = 1 - \frac{T_2}{T_1}$

According to the problem $\eta_1 = 1 - \left(\frac{T_2-\alpha}{T_1}\right)$

$$\Rightarrow \quad \eta_1 = \left(1-\frac{T_2}{T_1}\right) + \frac{\alpha}{T_1}$$

$$\Rightarrow \quad \eta_1 = \eta_0 + \frac{\alpha}{T_1} = \frac{\eta_0 T_1 + \alpha}{T_1}$$

$$\Rightarrow \quad \eta_1 > \eta_0$$

Further, $\eta_2 = 1 - \frac{T_2}{T_1+\alpha} = \frac{T_1+\alpha-T_2}{T_1+\alpha}$

$$\Rightarrow \quad \eta_2 = \frac{\eta_0 T_1+\alpha}{T_1+\alpha} \qquad \{\because T_1 - T_2 = \eta_0 T_1\}$$

$$\Rightarrow \quad \eta_2 < \eta_1$$

$$\Rightarrow \quad \eta_1 > \eta_2 > \eta_0$$

**Hence, the correct answer is (B).**

2. $T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1}$

$$\Rightarrow \quad 300 = T_2\left(\frac{8}{27}\right)^{\frac{5}{3}-1}$$

$$\Rightarrow \quad T_2 = 300\times\left(\frac{27}{8}\right)^{\frac{2}{3}} = 300\times\frac{9}{4} = 675\text{ K}$$

$$\Rightarrow \quad \Delta T = 375\ ^\circ\text{C}$$

**Hence, the correct answer is (B).**

3. At $V = V_0$, $P = \frac{P_0}{2}$

$$\Rightarrow \quad T_i = \frac{PV}{nR} = \frac{\left(\frac{P_0}{2}\right)(V_0)}{R} = \frac{P_0V_0}{2R} \qquad \{\because n = 1\}$$

and at $V = 2V_0$, $P = \frac{4P_0}{5}$

$$\Rightarrow \quad T_f = \frac{PV}{nR} = \frac{(2V_0)\left(\frac{4P_0}{5}\right)}{R} = \frac{8P_0V_0}{5R}$$

$$\Rightarrow \quad \Delta T = T_f - T_i = \left(\frac{8}{5}-\frac{1}{2}\right)\frac{P_0V_0}{R} = \frac{11P_0V_0}{10R}$$

**Hence, the correct answer is (B).**

4. $-mc\frac{dT}{dt} = \sigma T^4$

$$\Rightarrow \quad -mcT^{-4}dT = \sigma\,dt$$

$$\Rightarrow \quad -\int_{T_1}^{T_2} T^{-4}dT = \frac{\sigma}{mc}\int_0^t dt$$

$$\Rightarrow \quad -\left[\left.\frac{T^{-3}}{-3}\right|_{T_1}^{T_2}\right] = \frac{\sigma}{mc}t$$

$$\Rightarrow \quad t = \frac{mc}{3\sigma}\left(\frac{1}{T_2^3}-\frac{1}{T_1^3}\right)$$

**Hence, the correct answer is (C).**

5. $v_{\text{rms}} = \sqrt{\frac{3RT}{M}}$ and $v_{\text{sound}} = \sqrt{\frac{\gamma RT}{M}}$, $v_{\text{rms}} = \sqrt{2}\ \text{v}_{\text{sound}}$

i.e., $\gamma = \frac{3}{2}$ =ratio of $\frac{C_P}{C_V}$ for the mixture

$$C_V = \frac{n_1C_{V_1}+n_2C_{V_2}}{n_1+n_2}$$

and $C_P = \frac{n_1C_{P_1}+n_2C_{P_2}}{n_1+n_2}$

$$\Rightarrow \quad \gamma = \frac{C_P}{C_V} = \frac{n_1C_{P_1}+n_2C_{P_2}}{n_1C_{V_1}+n_2C_{V_2}}$$

$$\Rightarrow \quad \frac{3}{2} = \frac{(2)\left(\frac{5}{2}R\right)+(n)\left(\frac{7}{2}R\right)}{2\left(\frac{3}{2}R\right)+(n)\left(\frac{5}{2}R\right)}$$

$$\Rightarrow \quad \frac{3}{2} = \frac{10+7n}{6+5n}$$

$$\Rightarrow \quad n = 2$$

**Hence, the correct answer is (C).**

6. For gas $A$, we have

$$PV = n_ART \qquad \ldots(1)$$

When another gas $B$ is also added, then

$$3PV = (n_A+n_B)RT \qquad \ldots(2)$$

$$\Rightarrow \quad n_A + n_B = 3n_A \qquad \{\text{from (1) and (2)}\}$$

$$\Rightarrow \quad n_B = 2n_A$$

Since masses of both the gases are same, so

$$n_BM_B = n_AM_A \qquad \left\{\because n = \frac{m}{M}\right\}$$

Hence, molecular weights are in the ratio

$$\frac{M_A}{M_B} = \frac{n_B}{n_A} = 2$$

**Hence, the correct answer is (B).**

7. $v_{\text{rms}} = \sqrt{\frac{3RT}{M}}$

$$\Rightarrow \quad v_{\text{rms}} \propto \sqrt{T}$$

$v_{\text{rms}}$ is to reduce to time i.e., temperature of the gas will have no reduce four times or

$$\frac{T'}{T} = \frac{1}{4}$$

During adiabatic process

$$TV^{\gamma-1} = T'V'^{\gamma-1}$$

$$\Rightarrow \frac{V'}{V} = \left(\frac{T}{T'}\right)^{\frac{1}{\gamma-1}} = (4)^{\frac{1}{1.5-1}} = (4)^2 = 16$$

$$\Rightarrow V' = 16\text{ V}$$

**Hence, the correct answer is (B).**

**8.** $-\frac{1}{A}\frac{dQ}{dt} = \sigma\left(T^4 - 0^4\right)$

$$\Rightarrow -mc\frac{dT}{dt} = \sigma AT^4$$

$$\Rightarrow T^{-4}dT = -\frac{\sigma A}{mc}dt$$

$$\Rightarrow \int_{200\text{ K}}^{100\text{ K}} T^{-4}dT = -\frac{\sigma A}{mc}\int_0^t dt$$

$$\Rightarrow \left.\frac{T^{-3}}{-3}\right|_{200}^{100} = -\frac{\sigma A}{mc}t$$

$$\Rightarrow \frac{1}{(100)^3} - \frac{1}{(200)^3} = \frac{\sigma\left(4\pi r^2\right)}{\frac{4}{3}\pi r^3\rho c}t$$

$$\Rightarrow t = \frac{7}{72}\frac{r\rho c}{\sigma}\times 10^{-6}\text{ s}$$

$$\Rightarrow t = \frac{7}{72}\frac{r\rho c}{\sigma}\ \mu s$$

**Hence, the correct answer is (B).**

**9.** As two arms of U-tube are maintained at different temperatures, densities in two arms will be different but pressure at the bottom is same. So, we have

$$h_1\left(\frac{\rho_0}{1+\gamma T_1}\right)g = h_2\left(\frac{\rho_0}{1+\gamma T_2}\right)g$$

$$\Rightarrow 49\left(\frac{\rho_0}{1+50\gamma}\right) = 50\left(\frac{\rho_0}{1+60\gamma}\right)$$

$$\Rightarrow 49 + 49(60\gamma) = 50 + 50(50\gamma)$$

$$\Rightarrow \gamma(2940 - 2500) = 1$$

$$\Rightarrow \gamma = \frac{1}{440} \approx 2.3\times 10^{-3}\ {}^\circ\text{C}^{-1}$$

**Hence, the correct answer is (C).**

**10.** Mass of $P = 2(\text{Mass of } Q)$

$$\Rightarrow \frac{4}{3}\pi r_P^3\rho = 2\left(\frac{4}{3}\pi r_Q^3\rho\right)$$

$$\Rightarrow r_P = 2^{\frac{1}{3}}r_Q$$

Since $\frac{1}{A}\frac{dQ}{dt} \propto (T - T_0)$

$$\Rightarrow \frac{1}{A}mc\frac{dT}{dt} \propto (T - T_0)$$

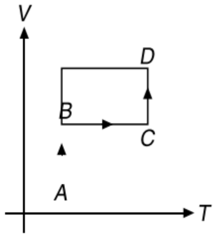
$$\Rightarrow \frac{dT}{dt} \propto \frac{A}{m}$$

$$\Rightarrow \frac{dT}{dt} \propto \frac{4\pi r^2}{\frac{4}{3}\pi r^3\rho}$$

$$\Rightarrow \frac{dT}{dt} \propto \frac{1}{r}$$

$$\Rightarrow \frac{\text{Rate of cooling of P}}{\text{Rate of cooling of Q}} = \frac{r_Q}{r_P} = \frac{1}{2^{1/3}}$$

**Hence, the correct answer is (C).**



**11.** Process $AB$ is isothermal, so its $V$-$T$ curve will remain a vertical straight line. Process $BC$ is isochoric (because it is a straight line passing through origin) hence its $V$-$T$ curve will be a horizontal straight line. Process $CD$ is again isothermal, so it will be represented by a vertical straight line on $V$-$T$ curve and hence the $V$-$T$ curve is shown in Figure.

**Hence, the correct answer is (D).**

**12.** $\frac{mL}{t} = \frac{kA(T_1 - T_2)}{d}$

$$\Rightarrow T_1 - T_2 = \frac{mLd}{KAt}$$

$$\Rightarrow T_1 - T_2 = \left(\frac{1}{60}\right)\frac{(540)(0.2)}{(0.5)(300)}$$

$$\Rightarrow T_1 - T_2 = 0.012\ {}^\circ\text{C}$$

**Hence, the correct answer is (D).**

**13.** From First Law of Thermodynamics,

$$dQ = dU + dW$$

$$\Rightarrow dQ = dU \text{ if } dW = 0$$

Since $dQ < 0$ therefore, $dU < 0$

$$\Rightarrow U_{\text{final}} < U_{\text{initial}}$$

⇒ Temperature will decrease.

### Conceptual Note(s)

Internal energy $U$ of an ideal gas depends only on the temperature of the gas. Internal energy of $n$ moles of an ideal gas is given by

$$U = \left(\frac{nf}{2}\right)RT$$

$$U \propto T$$

Here, $f$ is the degree of freedom of the gas.

**Hence, the correct answer is (A).**

**14.** Heat released when 5 kg of water cools from 20 °C to 0 °C is

$$Q_1 = m_{\text{water}}c_{\text{water}}\Delta T = (5)(1)(20) = 100\text{ kcal}$$

Heat required to raise temperature of 2 kg of ice from −20 °C to 0 °C is

$$Q_2 = m_{\text{ice}}c_{\text{ice}}\Delta T = (2)(0.5)(20) = 20\text{ kcal}$$

Heat required to melt 2 kg of ice at 0 °C is

$$Q_3 = m_{\text{ice}}L_{\text{ice}} = (2)(80) = 160 \text{ kcal}$$

Since $Q_1 > Q_2$, so temperature of ice will reach 0 °C. However we observe that $Q_1 < Q_2 + Q_3$, therefore the complete ice will not melt and final mixture will have both ice and water. The amount of ice melted $m$ is

$$m = \frac{\text{Available Heat}}{\text{Latent Heat}} = \frac{(100-20)\text{ kcal}}{80 \text{ calg}^{-1}} = 1 \text{ kg}$$

So in equilibrium, the vessel will have water given by

$$m'_{\text{water}} = 5 + 1 = 6 \text{ kg}$$

**Hence, the correct answer is (C).**

**15.** Let the initial pressure and volume be $P$ and $V$ respectively.

$$\Rightarrow \quad P_f = P + \frac{P}{100} = \frac{101}{100}P$$

For Boyle's Law

$$P_iV_i = P_fV_f$$

$$\Rightarrow \quad V_f = \frac{100}{101}V$$

$$\Rightarrow \quad \Delta V = \frac{1}{101}V$$

$$\Rightarrow \quad \frac{\Delta V}{V} \times 100 = \frac{100}{101}\%$$

**Hence, the correct answer is (B).**

**16.** Work done $(W) = fx = \mu mg(vt)$

Since half the heat produced is absorbed by body, so

$$\frac{1}{2}\mu mg(vt) = mc\Delta T$$

$$\Rightarrow \quad \frac{1}{2}\mu g(vt) = c\Delta T$$

$$\Rightarrow \quad \frac{1}{2}(0.5)(9.8)(2000) = (0.1 \times 4200)\Delta T$$

$$\Rightarrow \quad \Delta T = 11.6 \text{ °C}$$

**Hence, the correct answer is (D).**

**17.** To double rms speed, temperature must be raised to four times the initial temperature, i.e.

$$T_f = 4 \times 300 = 1200 \text{ K.}$$

Heat required for doing this is

$$Q = \Delta U = n_1(C_V)_1\Delta T + n_2(C_V)_2\Delta T_2$$

$$\Rightarrow \quad Q = [(1)(3R/2) + (1)(5R/2)](1200 - 300)$$

$$\Rightarrow \quad Q = 3600R$$

**Hence, the correct answer is (D).**

**18.** $U = nC_vT = n\left(\frac{3}{2}R\right)T$

$$\Rightarrow \quad \frac{U}{V} = \frac{3nRT}{2V} = \frac{3}{2}P \qquad \left\{\because \frac{nRT}{V} = P\right\}$$

**Hence, the correct answer is (B).**

**19.** Let $M$ be the mass of the sphere and $R$ its radius before increasing the temperature. Then From Conservation of Angular Momentum:

$$I\omega = I_0\omega_0$$

$$\Rightarrow \quad \omega = \left(\frac{I_0}{I}\right)\omega_0$$

$$\Rightarrow \quad \omega = \frac{\frac{2}{5}MR^2\omega_0}{\frac{2}{5}MR^2(1+2\alpha\Delta T)} = \frac{\omega_0}{1+2\alpha\Delta T}$$

$$\Rightarrow \quad \omega = \frac{\omega_0}{1+2(20\times10^{-5})(100)} = 0.996\omega_0$$

**Hence, the correct answer is (C).**

**20.** Since $\beta = \frac{277}{300-277}$

$$\Rightarrow \quad \beta \simeq 12$$

Further $\beta = \frac{Q_2}{W} = 12$

$$\Rightarrow \quad Q_2 = 12(1 \text{ J})$$

$$\Rightarrow \quad Q_2 = 12 \text{ J}$$

Since by Law of Conservation of Energy, we have

$$Q_1 = Q_2 + W$$

$$\Rightarrow \quad Q_1 = 12 + 1$$

$$\Rightarrow \quad Q_1 = 13 \text{ J}$$

**Hence, the correct answer is (D).**

**21.** In a cyclic process, $\Delta U = 0$ i.e. $U$ = constant.

Free expansion is an irreversible process.

In a cyclic process, $\Delta U = 0$, so $W = Q \neq 0$.

Efficiency of Carnot engine is 100% if temperature of sink is 0 K (not 0 °C).

**Hence, the correct answer is (C).**

**22.** Since $Q = \Delta U = U_f - U_i$, where

$$\Delta U = \left(U_{\substack{4\text{ mole}\\ \text{monatomic}}} + U_{\substack{2\text{ mole}\\ \text{diatomic}}}\right) - U_{\substack{4\text{ mole}\\ \text{diatomic}}}$$

$$\Rightarrow \quad \Delta U = \left(4\times\frac{3}{2}RT + 2\times\frac{5}{2}RT\right) - \left(4\times\frac{5}{2}RT\right)$$

$$\Rightarrow \quad \Delta U = (6RT + 5RT) - (10RT) = RT$$

### Conceptual Note(s)

**(a)** Two moles of diatomic gas become 4 moles of a monatomic gas when get dissociated into atoms.

**(b)** Internal energy of $n$ moles of an ideal gas of degrees of freedom $f$ is given by

$$U = \left(\frac{nf}{2}\right)RT$$

$f = 3$ for a monatomic gas and $f = 5$ for diatomic gas

**Hence, the correct answer is (B).**

**23.** $$\begin{pmatrix}\text{Heat}\\ \text{conducted}\\ \text{in at } A\\ \text{per second}\end{pmatrix} + \begin{pmatrix}\text{Heat}\\ \text{generated}\\ \text{by source}\\ \text{per second}\end{pmatrix} = \begin{pmatrix}\text{Heat}\\ \text{conducted}\\ \text{out at } B\\ \text{per second}\end{pmatrix}$$

$$\frac{(0.5)(12)(100-T)}{8}+36=\frac{(0.5)(12)(T-4)}{8}$$

Solving the above equation for $T$, we have

$$T = 76\ ^{\circ}\text{C}$$

**Hence, the correct answer is (C).**

**24.** Since, $V \propto T$, the process is isobaric

$$\Rightarrow \quad \frac{Q}{W}=\frac{nC_P\Delta T}{nR\Delta T}=\frac{C_P}{R}=\frac{5}{2}$$

**Hence, the correct answer is (A).**

**25.** $\frac{Q}{t}=kA\frac{\Delta T}{\ell}$

$$\Rightarrow \quad k \propto \frac{1}{\left(\frac{\Delta T}{\ell}\right)}$$

$$\Rightarrow \quad k \propto \frac{1}{\text{Temperature Gradient}}$$

Since, $K_C > K_M > K_G$

$$\Rightarrow \quad X_C < X_M < X_G$$

**Hence, the correct answer is (C).**

**26.** Let initially $n$ be the total number of moles of $O_2$. Then after dissociation

$$C_v(\text{mixture})=\frac{(0.6)(2)(n)C_{v_1}+(0.4)(n)C_{v_2}}{(0.6)(2)n+(0.4)n}$$

$$\Rightarrow \quad (C_V)_{\text{mix}}=\frac{\left(1.2\times\frac{3}{2}\times R\right)+\left(0.4\times\frac{5}{2}\times R\right)}{1.6}$$

$$\Rightarrow \quad (C_V)_{\text{mix}}=\frac{1.8R+R}{1.6}=\frac{7}{4}R$$

**Hence, the correct answer is (C).**

**27.** Since gas is undergoing a process given by

$$PT = \text{constant}$$

$$\Rightarrow \quad P_0T_0=\frac{P_0}{2}T$$

$$\Rightarrow \quad T = 2T_0$$

Applying Ideal Gas Equation, we get

$$P_0V_0 = 2RT_0$$

So, change in internal energy of the gas is

$$\Delta U = nC_V\Delta T = 2\left(\frac{3R}{2}\right)(T-T_0)=3RT_0=\frac{3P_0V_0}{2}$$

**Hence, the correct answer is (B).**

**28.** $P=\frac{\mu RT}{V}$

where, $\mu$ is the number of molecules of the gas

$$R = k_BN_A$$

where $N_A$ is Avogadro's Number.

$$\Rightarrow \quad P=\frac{\mu k_BN_AT}{V}=\left(\frac{\mu N_A}{V}\right)k_BT$$

$\frac{\mu N_A}{V}$ = number of molecules per unit volume $(n)$

$$\Rightarrow \quad P = nk_BT$$

**Hence, the correct answer is (B).**

**29.** $H_1+H_2=\frac{KA(T_1-T_2)}{3\ell}+\frac{KA(T_1-T_2)}{\ell}=\frac{4}{3\ell}KA(T_1-T_2)$

In later case

$$H_2 = 2H - H_1 = \frac{7KA}{3\ell}(T_1-T_2)=\frac{K'A}{\ell}(T_1-T_2)$$

$$\Rightarrow \quad K'=\frac{7}{3}K$$

**Hence, the correct answer is (A).**

**30.** $Q=\int_0^{20} mS\,dT=\int_0^{20} m(AT^3)\,dT = 4\times 10^4\ \text{mA}$

**Hence, the correct answer is (A).**

**31.** Since the given graph is a straight line, so we have

$$P = P_0 + CT, \text{ where } C \text{ is a constant}$$

Applying Ideal Gas Equation $PV = nRT$, we get

$$V \propto \frac{T}{P_0+CT}$$

$$\Rightarrow \quad \frac{1}{V}\propto\left(\frac{P_0}{T}+C\right)$$

So, as $T$ increases, $\frac{1}{V}$ decreases. Hence, volume increases.

**Hence, the correct answer is (C).**

**32.** Since, $kA\left(\frac{\sqrt{3}T-T_C}{l}\right)=kA\left(\frac{T_C-T}{l}\right)$

$$\Rightarrow \quad \sqrt{3}T-T_C=T_C-T$$

$$\Rightarrow \quad (\sqrt{3}+1)T=2T_C$$

$$\Rightarrow \quad \frac{T_C}{T}=\frac{T_C}{T_B}=\frac{\sqrt{3}+1}{2}$$

**Hence, the correct answer is (A).**

**33.** $PV$ = constant

$$\Rightarrow \quad T = \text{constant}$$

Now, $\rho=\frac{PM}{RT}$

$$\Rightarrow \quad \rho \propto P \text{ for } T = \text{constant}$$

Hence, $P$-$\rho$ graph is a straight line passing through origin.

**Hence, the correct answer is (C).**

**34.** By Laws of Calorimetry

$$\left(\begin{array}{c}\text{Total heat lost}\\ \text{by steam}\end{array}\right)=\left(\begin{array}{c}\text{Total heat gained}\\ \text{by water + ice}\end{array}\right)$$

Let $m$ gram of steam be required for the purpose. Then,

$$Q_{\text{available}} = \underbrace{540m}_{\substack{\text{heat liberated due}\\ \text{to condensation of}\\ m \text{ gram steam at}\\ 100\ ^{\circ}\text{C to water}}} + \underbrace{m(1)(100-5)}_{\substack{\text{heat liberated due}\\ \text{to decrease in}\\ \text{temperature from}\\ 100\ ^{\circ}\text{C to } 5\ ^{\circ}\text{C}}}$$

and $$Q_{\text{required}} = \underbrace{100(1)(5-0)}_{\substack{\text{heat required to}\\ \text{raise temperature}\\ \text{of 100 g of water}\\ \text{from 0 °C to 5 °C}}} + \underbrace{10(80)+10(1)(5-0)}_{\substack{\text{heat required to convert 10 g}\\ \text{of ice to 10 g of water at 0 °C}\\ \text{and then raise temperature of}\\ \text{10 g water from 0 °C to 5 °C}}}$$

By Law of Calorimetry, $Q_{\text{available}} = Q_{\text{required}}$

$\Rightarrow \quad m = 2.1\ g$

**Hence, the correct answer is (A).**

**35.** By FLTD, $Q = \Delta U + W$. Since $\Delta U$ is same for both as it depends upon initial and final state, so $\Delta U_1 = \Delta U_2$. Also, work done for process $A$ is more than that for $B$ because area under the $P$-$V$ graph for the process $A$ is more than that for process $B$ and hence $Q_1 > Q_2$.

**Hence, the correct answer is (D).**

**36.** $\dfrac{\Delta T}{\ell} = \dfrac{80-0}{1} = 80\ °\text{Cm}^{-1}$

$\Delta T_1 = (0.60)(80) = 48\ °\text{C}$

Decrease in temperature after a distance of 60 cm is 48 °C and hence actual temperature is 80 – 48 = 32 °C

**Hence, the correct answer is (B).**

**37. On Mixing $A$ and $C$**

Heat lost by $A$ = Heat gained by $C$

$\Rightarrow \quad (4)s_A(60-55) = (3)s_C(55-50)$

$\Rightarrow \quad 4s_A = 3s_C \qquad \ldots(1)$

**On Mixing $A$ and $B$**

Heat lost by $A$ = Heat gained by $B$

$2s_A(60-57) = 3s_B(57-55)$

$\Rightarrow \quad 6s_A = 6s_B$

$\Rightarrow \quad s_A = s_B \qquad \ldots(2)$

On mixing equal masses of $B$ and $C$, let equilibrium temperature be $T$.

Heat lost by $B$ = Heat gained by $C$

$ms_B(55-T) = ms_C(T-50) \qquad \ldots(3)$

$\Rightarrow \quad \dfrac{s_B}{s_C} = \dfrac{3}{4} \qquad \{\because \text{ of (1) and (2)}\}$

So, equation (3) becomes $\dfrac{3}{4} = \dfrac{T-50}{55-T}$

$\Rightarrow \quad 165 - 3T = 4T - 200$

$\Rightarrow \quad 7T = 365$

$\Rightarrow \quad T = \dfrac{365}{7} = 52.1$

**Hence, the correct answer is (A).**

**38.** For the given process $Q = \Delta U + W$

$\Rightarrow \quad 200 - 100 = \Delta U - 50$

$\Rightarrow \quad \Delta U = 150\ \text{kJ}$

So for the adiabatic process which restores original state, $\Delta U$ must be $-150$ kJ and hence work done in the process will be $+150$ kJ

**Hence, the correct answer is (C).**

**39.** $W_{BA} = -30\ \text{J},\ Q_{BA} = 0$

$\Rightarrow \quad \Delta U_{BA} = -W_{BA} = 30\ \text{J}$

Now, $\Delta U_{AB} = -U_{BA} = -30\ \text{J}$

**Hence, the correct answer is (B).**

**40.** Since air bubble doubles in radius. Hence its volume becomes 8 times. Further since the bubble rises slowly, hence the rising process can be regarded as an isothermal process. So according to Boyle's Law.

$(PV)_{\text{at depth } h} = (PV)_{\text{at surface}}$

If $P_a$ be the atmospheric pressure then

$(P_a + h\rho g)V = P_a(8V) \qquad \{\text{where } P_a = H\rho g\}$

$\Rightarrow \quad P_a + h\rho g = 8P_a$

$\Rightarrow \quad h\rho g = 7P_a = 7(H\rho g)$

$\Rightarrow \quad h = 7H$

**Hence, the correct answer is (C).**

**41.** Since, $PV = nRT$, so $T \propto PV$

$\Rightarrow \quad T_1 : T_2 : T_3 = 1:4:4$

Also, average molecular speed i.e. $v_{av} = v \propto \sqrt{T}$

$\Rightarrow \quad v_1 : v_2 : v_3 = 1:2:2$

**Hence, the correct answer is (A).**

**42.** $\dfrac{PV}{T} = nR = \left(\dfrac{m}{M}\right)R$

$\Rightarrow \quad \dfrac{PV}{T} = \left(\dfrac{R}{M}\right)m$

i.e., $\dfrac{PV}{T}$ versus $m$ graph is a straight line passing through origin with slope $\dfrac{R}{M}$ i.e., the slope depends on molecular mass of the gas $M$ and is different for different gases.

**Hence, the correct answer is (C).**

**43.** Rate of flow of heat $\dfrac{dQ}{dt}$ or $H$ is equal throughout the rod.

Temperature difference is given by

Since, $\Delta T = HR_{\text{Th}}$

where, $R_{\text{Th}} = \dfrac{\ell}{KA}$

$\Rightarrow \quad R_{\text{Th}} \propto \dfrac{1}{A}$

Area across $CD$ is less. Therefore, temperature difference across $CD$ will be more.

**Hence, the correct answer is (C).**

**44.** By FLTD, $Q = \Delta U + W$

Since $U$ is a state function i.e. $\Delta U$ is same for all processes carried between same points.

For process $a \to c \to e$, net work done is negative

For process $a \to d \to e$, net work done is zero.

For process $a \to b \to e$, net work done is positive. Therefore $Q$ is minimum for the process $a \to c \to e$.

**Hence, the correct answer is (D).**

**45.** $\eta = 1 - \left(\dfrac{T_2}{T_1}\right)$ and $\beta = \dfrac{T_2}{T_1 - T_2}$

$$\Rightarrow \quad \eta\beta = \frac{T_2}{T_1}$$

$$\Rightarrow \quad \eta\beta = 1 - \eta$$

$$\Rightarrow \quad \eta(\beta + 1) = 1$$

$$\Rightarrow \quad \eta = \frac{1}{\beta + 1}$$

**Hence, the correct answer is (C).**

**46.** $\eta$ is maximum, when $\beta$ is minimum i.e., 1

$$\Rightarrow \quad \eta_{\max} = \frac{1}{2} = 50\%$$

**Hence, the correct answer is (B).**

**47.** Since, $PV = nRT$ i.e. $T \propto PV$

$$\Rightarrow \quad T_1 : T_2 = 2 \times 2 : 1 \times 1 = 4 : 1$$

Also, $v_{\text{rms}} \propto \sqrt{T}$

$$\Rightarrow \quad \frac{v_1}{v_2} = \sqrt{\frac{T_1}{T_2}} = \sqrt{\frac{4}{1}} = 2$$

**Hence, the correct answer is (C).**

**48.** For the two sheets if $H =$ is rate of heat transfer, then

$$H_1 = H_2$$

$$\Rightarrow \quad \frac{\theta_1 - \theta}{R_1} = \frac{\theta - \theta_2}{R_2}$$

Solving this we get, $\theta = \dfrac{\theta_1 R_2 + \theta_2 R_1}{R_1 + R_2}$

**Hence, the correct answer is (D).**

**49.** Since $P_1 V = n_1 R T_1$ and $P_2 V = n_2 R T_2$

After joining the vessels we have

$$P(2V) = (n_1 + n_2) RT$$

$$\Rightarrow \quad P(2V) = \left(\frac{P_1 V}{R T_1} + \frac{P_2 V}{R T_2}\right) RT$$

$$\Rightarrow \quad P = \frac{1}{2}\left(\frac{P_1}{T_1} + \frac{P_2}{T_2}\right) T$$

**Hence, the correct answer is (B).**

**50.** Gas in cylinder $A$ will undergo an isobaric process and gas in cylinder $B$ will undergo an isochoric process. Since,

$$Q_A = Q_B$$

$$\Rightarrow \quad nC_P \Delta T_A = nC_V \Delta T_B$$

$$\Rightarrow \quad \left(\frac{5}{2}R\right)(15) = \left(\frac{3}{2}R\right)\Delta T_B$$

$$\Rightarrow \quad \Delta T_B = 25 \text{ K}$$

**Hence, the correct answer is (B).**

**51.** $\rho = \dfrac{PM}{RT}$ and $\rho \propto \dfrac{1}{V}$

During $AB$, $\rho$ and hence $V$ is constant.

Therefore, work done is zero.

During $BC$, $P \propto \rho$ i.e., $T$ and hence, $U$ is constant.

**Hence, the correct answer is (D).**

**52.** $P \propto AT^4$

**Hence, the correct answer is (C).**

**53.** $C = \dfrac{dQ}{dT} = 0$, so process is adiabatic, i.e., $n = \gamma = \dfrac{C_P}{C_V}$

**Hence, the correct answer is (A).**

**54.** Since the wall is conducting, temperature of both the gases is same. For rms speed of molecule of $A$ to be equal to mean speed of molecules of $B$, we have

$$\sqrt{\frac{3RT}{M_A}} = \sqrt{\frac{8RT}{\pi M_B}} \quad \Rightarrow \quad \frac{M_A}{M_B} = \frac{3\pi}{8}$$

**Hence, the correct answer is (D).**

**55.** **Method I:** Heat transferred to the gas is

$$Q = \Delta U + W, \text{ where } \Delta U = (1)C_V(T_2 - T_1)$$

$$\Rightarrow \quad \Delta U = (1)C_V[T_0 + \alpha V_2 - T_0 - \alpha V_1]$$

$$\Rightarrow \quad \Delta U = \alpha C_V (V_2 - V_1) \qquad \ldots(1)$$

Since, $dW = PdV = \dfrac{RT}{V}dV = R\left(\dfrac{T_0 + \alpha V}{V}\right)dV$

$$\Rightarrow \quad W = \int dW = R\left[T_0 \int_{V_1}^{V_2} \frac{dV}{V} + \alpha \int_{V_1}^{V_2} dV\right]$$

$$\Rightarrow \quad W = RT_0 \ell n\left(\frac{V_2}{V_1}\right) + \alpha R(V_2 - V_1) \qquad \ldots(2)$$

So, $Q = \alpha C_V (V_2 - V_1) + RT_0 \ell n\left(\dfrac{V_2}{V_1}\right) + \alpha R(V_2 - V_1)$

$$\Rightarrow \quad Q = \alpha(V_2 - V_1)(C_V + R) + RT_0 \ell n\left(\frac{V_2}{V_1}\right)$$

$$\Rightarrow \quad Q = RT_0 \ell n\left(\frac{V_2}{V_1}\right) + \alpha C_P (V_2 - V_1)$$

**Method II:** Since $T = T_0 + \alpha V$

**(a)** Think $\alpha = 0$, then

$T = T_0 =$ constant

(Isothermal process)

$\Rightarrow \quad \Delta U = 0$

$\Rightarrow \quad Q_1 = RT_0 \ell n\left(\dfrac{V_2}{V_1}\right)$

**(b)** Think $T_0 = 0$, then

$T = \alpha V$

where, $\alpha$ is a constant

(Isobarric process)

$\Rightarrow \quad Q_2 = (1)C_P(T_2 - T_1)$

Since, $T_2 = T_0 + \alpha V_2$ and

$T_1 = T_0 + \alpha V_1$

$\Rightarrow \quad Q_2 = \alpha C_P (V_2 - V_1)$

SUPERIMPOSING THE TWO, WE GET

$$Q = RT_0 \ell n\left(\frac{V_2}{V_1}\right) + \alpha C_P (V_2 - V_1)$$

**Hence, the correct answer is (C).**

**56.** Process $A$ is an isobaric expansion process, as $V$ increases, $T$ also increases.

Process $B$ is an isothermal process, so temperature is constant.

Process $C$ is an adiabatic expansion process, so as $V$ increases, $T$ decreases.

Process $D$ is an isochoric process in which $P$ is decreasing, so $T$ is also decreasing.

**Hence, the correct answer is (C).**

**57.** When the temperature of the gas is same as that of the wall there is no exchange of energy. Hence, molecules return with same average speed whether the collision is elastic or inelastic. Hence, the temperature and pressure would not change.

**Hence, the correct answer is (C).**

**58.** Since $T = KV^2$, so $dT = 2KVdV$

$$\Rightarrow \quad dV = \frac{dT}{2KV}$$

Further, $P = \frac{nRT}{V}$

$$\Rightarrow \quad W = \int PdV = \int\left(\frac{nRT}{V}\right)\left(\frac{dT}{2KV}\right)$$

$$\Rightarrow \quad W = \int_{T_0}^{4T_0} \frac{nR}{2}dT = \frac{3nRT_0}{2} \qquad \{\because KV^2 = T\}$$

**Hence, the correct answer is (C).**

**59.** In this problem two concepts are used:

(i) When a solid floats in a liquid, then fraction of volume submerged is

$$k = \frac{\rho_{\text{solid}}}{\rho_{\text{liquid}}}$$

This result comes from the fact that

Weight = Upthrust

$$V\rho_{\text{solid}}g = V_{\text{submerged}}\rho_{\text{liquide}}$$

$$\Rightarrow \quad \frac{V_{\text{submerged}}}{V} = \frac{\rho_{\text{solid}}}{\rho_{\text{liquid}}}$$

(ii) $\dfrac{\rho_{T\,°\text{C}}}{\rho_{0\,°\text{C}}} = \dfrac{1}{1+\gamma T}$

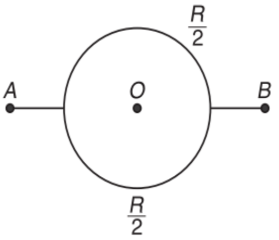
$$k_1 = \left(\frac{\rho_{Fe}}{\rho_{Hg}}\right), k_2 = \left(\frac{\rho_{\text{Fe}}}{\rho_{Hg}}\right)_{60\,°\text{C}} \text{ and } \rho = \text{density}$$

$$\Rightarrow \quad \frac{k_1}{k_2} = \frac{(\rho_{Fe})_{0\,°\text{C}}}{(\rho_{Hg})_{0\,°\text{C}}} \times \left(\frac{\rho_{Hg}}{\rho_{\text{Fe}}}\right) = \frac{(1+60\gamma_{Fe})}{(1+60\gamma_{Hg})}$$

**Hence, the correct answer is (A).**

**60.** When $\theta = 180°$, then thermal resistance of each branch is $\frac{R}{2}$.

So, net thermal resistance is $\frac{R}{4}$. Further



$$\text{Thermal Current } = 1.2 = \frac{\Delta T}{R_{\text{net}}} = \frac{\Delta T}{\left(\frac{R}{4}\right)}$$

$$\Rightarrow \quad \Delta T = 0.3R \qquad \ldots(1)$$

When $\theta = 90°$, then thermal resistance of one branch is $\frac{R}{4}$ and that of other is $\frac{3R}{4}$ and both are in parallel.

$$\Rightarrow \quad R_{\text{net}} = \frac{\left(\frac{R}{4}\right)\left(\frac{3R}{4}\right)}{\frac{R}{4}+\frac{3R}{4}} = \frac{3R}{16}$$

$$\Rightarrow \quad I' = \frac{\Delta T}{\left(\frac{3R}{16}\right)} = \frac{(0.3R)16}{3R} = 1.6 \text{ W}$$

**Hence, the correct answer is (C).**

**61.** Net rate of absorption of heat by water is

$$\Rightarrow \quad 840\Delta t = mc\Delta T = 2 \times 4200 \times (77-27)$$

$$\Rightarrow \quad \Delta t = \frac{2 \times 4200 \times 50}{840} = 500 \text{ s} = 8 \text{ min } 20 \text{ s}$$

**Hence, the correct answer is (A).**

**62.** $C_P = \left(\dfrac{\gamma}{\gamma - 1}\right)R$

$$dQ = nC_P dT \qquad \ldots(1)$$

and $dU = nC_V dT$

Using FLTD, we get

$$dW = dQ - dU = n(C_P - C_V)dT = nRdT \qquad \ldots(2)$$

Given $dQ = 100$ J

$$\Rightarrow \quad ndT = \frac{100}{C_P} \qquad \{\text{from equation (1)}\}$$

Substituting this in equation (2), we get

$$dW = R\left(\frac{100}{C_P}\right) = R\left(\frac{\gamma-1}{\gamma R}\right)100$$

$$\Rightarrow \quad dW = \left(\frac{1.4-1}{1.4}\right) \times 100 = 28.57 \text{ J}$$

**Hence, the correct answer is (D).**

**63.** For the process shown, $32P_0V_0 = RT_A$ and $8P_0V_0 = RT_B$

$$\Rightarrow \quad T_B - T_A = (8-32)\frac{P_0V_0}{R} = -\frac{24P_0V_0}{R}$$

$$\Rightarrow \quad \Delta U = 1.5R(T_B - T_A) = -36P_0V_0$$

Also $W = \frac{1}{2}(32P_0 + P_0)(8V_0 - V_0) = 115.5(P_0V_0)$

Applying FLTD, we get

$$Q = \Delta U + W = -36P_0V_0 + 115.5(P_0V_0) = 79.5P_0V_0$$

The molar specific heat $C$ of the gas is

$$C = \frac{Q}{\Delta T} = \frac{79.5(P_0V_0)}{-(24P_0V_0/R)} = -3.3R$$

**Hence, the correct answer is (B).**

**64.** In Ingen Hausz experiment

$$k \propto (\text{length})^2$$

$$\Rightarrow \quad \frac{k_1}{k_2} = \left(\frac{5}{10}\right)^2 = \frac{1}{4}$$

**Hence, the correct answer is (B).**

**65.** Since, $\left(P + \frac{a}{V^2}\right)(V - b) = RT$

$$\Rightarrow \quad P + \frac{a}{V^2} = \frac{RT}{V - b}$$

$$\Rightarrow \quad P = \frac{RT}{V - b} - \frac{a}{V^2}$$

Further, $W = \int dW = \int_{V_1}^{V_2} P\,dV$

$$\Rightarrow \quad W = RT\int_{V_1}^{V_2} \frac{dV}{V - b} - a\int_{V_1}^{V_2} V^{-2}dV$$

$$\Rightarrow \quad W = RT\ell n\left(\frac{V_2 - b}{V_1 - b}\right) + a\left(\frac{1}{V_2} - \frac{1}{V_1}\right)$$

**Hence, the correct answer is (D).**

**66.** Thermal expansion for both is the same, but in the hollow sphere the air inside it also expands, thus exerting an extra thrust on the walls of the hollow sphere.

**Hence, the correct answer is (C).**

**67.** For Process 1, $W = 0$, so process is isochoric.

For Process 2, the positive work done increases linearly with temperature, so process is isobaric.

For Process 3, the gas heats a linearly with compression i.e. negative work is done and hence process is adiabatic.

**Hence, the correct answer is (D).**

**68.** We observe that $W_{AB}$ is negative (volume is decreasing) and $W_{BC}$ is positive (volume is increasing) and since $|W_{BC}| > |W_{AB}|$, so net work done is positive and area between semicircle which is equal to $\frac{\pi}{2}$ atmlt.

**Hence, the correct answer is (B).**

**69.** $W_{AB} = -P_0V_0$

$W_{BC} = 0$ and $W_{CD} = 4P_0V_0$

$$\Rightarrow \quad W_{ABCD} = -P_0V_0 + 0 + 4P_0V_0 = 3P_0V_0$$

**Hence, the correct answer is (C).**

**70.** Net rate of absorption of heat by water is

$$\frac{\Delta Q}{\Delta t} = 1000 - 160 = 840 \text{ Js}^{-1}$$

$$\Rightarrow \quad 840\Delta t = mc\Delta T = 2 \times 4200 \times (77 - 27)$$

$$\Rightarrow \quad \Delta t = \frac{2 \times 4200 \times 50}{840} = 500 \text{ s} = 8 \text{ min } 20 \text{ s}$$

**Hence, the correct answer is (A).**

**71.** Since, $\eta = \frac{W}{Q_1} = 1 - \frac{300}{600} = 0.5$

$$\Rightarrow \quad \frac{800}{Q_1} = 0.5$$

$$\Rightarrow \quad Q_1 = 1600 \text{ J}$$

**Hence, the correct answer is (C).**

**72.** Since, radius or volume of all the four spheres are equal, the ratio of their masses will be $2:3:5:1$.

Heat capacity = (mass) × (specific heat)

So, ratio of heat capacities will be $6:18:10:4$. The sphere having the maximum heat capacity will show the fastest rate of cooling.

**Hence, the correct answer is (B).**

**73.** Efficiency of heat engine,

$$\eta = 1 - \frac{\text{Total Heat Rejected}}{\text{Total Heat Absorbed}}$$

$$\Rightarrow \quad \eta = 1 - \frac{100 + 50}{500 + 150} = \frac{500}{650} = 0.77$$

**Hence, the correct answer is (A).**

**74.** Internal energy of $n$ moles of an ideal gas having $f$ degrees of freedom at temperature $T$ is given by $U = \frac{f}{2}nRT$

Since, $U_1 = U_2$

$$\Rightarrow \quad f_1n_1T_1 = f_2n_2T_2$$

$$\Rightarrow \quad \frac{n_1}{n_2} = \frac{f_2T_2}{f_1T_1} = \frac{(3)(2)}{(5)(1)} = \frac{6}{5}$$

where $f_2$ = degrees of freedom of $He = 3$

and $f_1$ = degrees of freedom of $He = 5$

**Hence, the correct answer is (C).**

**75.** **For $A \to B$**

$V \propto T$ (i.e., $P = \text{constant} = P_1$ (say)) i.e. $A$ to $B$ is Isobaric expansion, as $T$ is increasing. Since $PV = RT$

$$\Rightarrow \quad \frac{V}{T} = (\text{slope})_{AB} = \frac{R}{P_1} \qquad \ldots(1)$$

**For $B \to C$**

$T = \text{constant}$ (say $T_1$) and $V$ is increasing i.e. $P$ must be decreasing. So $B \to C$ is Isothermal expansion.

**For $C \to D$**

Again $V \propto T$ with greater slope for this process (i.e. $P = \text{constant} = P_2$ (say)) i.e. $C \to D$ is Isobaric compression as $T$ is decreasing. Since $PV = RT$

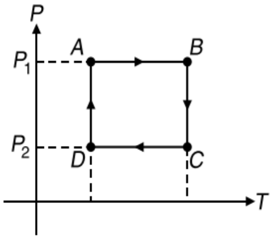
$$\Rightarrow \quad \frac{V}{T} = (\text{slope})_{CD} = \frac{R}{P_2} \qquad \ldots(2)$$

**For** $D \to A$

$T =$ constant (say $T_2$) and $V$ is decreasing, so $P$ must be increasing. So $D \to A$ is Isothermal compression.

Also $(\text{slope})_{CD} > (\text{slope})_{AB}$

$\Rightarrow \quad P_1 > P_2$



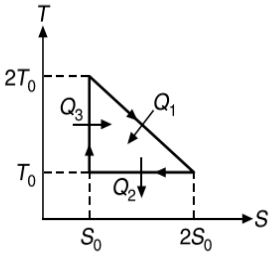
**Hence, the correct answer is (A).**

**76.** Change in entropy is given by $dS = \frac{dQ}{T}$

Therefore, heat exchange $Q$ in a process is

$$Q = \int dQ = \int TdS = \text{Area under } T\text{-}S \text{ graph}$$

$$\Rightarrow \quad Q_1 = T_0S_0 + \frac{1}{2}T_0S_0 = \frac{3}{2}T_0S_0$$



$\Rightarrow \quad Q_2 = -T_0S_0$ and $Q_3 = 0$

So, total work done in this cyclic process is

$$W = \Sigma Q = Q_1 + Q_2 + Q_3 \qquad \{\because \Delta U_{\text{cyclic}} = 0\}$$

$$\Rightarrow \quad W = \frac{3}{2}T_0S_0 - T_0S_0 = \frac{1}{2}T_0S_0$$

$$\Rightarrow \quad \eta = \frac{W}{Q_1} = \frac{T_0S_0/2}{3T_0S_0/2} = \frac{1}{3}$$

**Hence, the correct answer is (A).**

**77.** Since $\gamma = 1 + \frac{2}{f}$, so for $f = 6$, we get

$$\gamma = \frac{4}{3}$$

Also, $dW = 25$ J

By First Law of Thermodynamics $dQ = dU + dW$

where, $dQ = nC_PdT$, $dU = nC_VdT$, $dW = PdV = nRdT$

$$\text{Also, } \frac{dW}{dQ} = \frac{dQ - dU}{dQ} \qquad \{\text{Using First Law}\}$$

$$\Rightarrow \quad \frac{dW}{dQ} = 1 - \frac{dU}{dQ}$$

$$\Rightarrow \quad \frac{dW}{dQ} = 1 - \frac{nC_VdT}{nC_PdT}$$

$$\Rightarrow \quad \frac{dW}{dQ} = 1 - \frac{C_V}{C_P} = \left(1 - \frac{1}{\gamma}\right)$$

$$\Rightarrow \quad dQ = 25 \times 4 = 100 \text{ J}$$

**Hence, the correct answer is (B).**

**78.** Since, $\frac{(Q/t)_1}{4} = \frac{k_1}{k_2}\frac{r_1^2}{r_2^2}\frac{\ell_2}{\ell_1}$

$$\Rightarrow \quad \left(\frac{Q}{t}\right)_1 = \left\{\frac{1}{2}\left(\frac{1}{4}\right)2\right\}4 = 1 \text{ cals}^{-1}$$

**Hence, the correct answer is (A).**

**79.** Since, $\frac{50 - 40}{120 - 40} = \frac{Y - (-30)}{130 - (-30)}$

$$\Rightarrow \quad \frac{10}{80} = \frac{Y + 30}{160}$$

$$\Rightarrow \quad \frac{1}{8} = \frac{Y + 30}{160}$$

$$\Rightarrow \quad Y + 30 = 20$$

$$\Rightarrow \quad Y = -10°$$

**Hence, the correct answer is (C).**

**80.** For $AB$, an isothermal process, pressure is increasing, so volume is decreasing and hence

$$Q = W = \text{NEGATIVE}$$

Also for $AB$, $\Delta U = 0$ and for $BC$, $\Delta U = \text{NEGATIVE}$

**Hence, the correct answer is (B).**

**81.** For adiabatic process $P_1V_1^\gamma = P_2V_2^\gamma$

$$\Rightarrow \quad P_1\left(\frac{m}{\rho_1}\right)^\gamma = P_2\left(\frac{m}{\rho_2}\right)^\gamma$$

$$\Rightarrow \quad \frac{P_1}{\rho_1^\gamma} = \frac{P_2}{\rho_2^\gamma}$$

$$\Rightarrow \quad \frac{P_1}{P_2} = \left(\frac{\rho_1}{\rho_2}\right)^\gamma = \left(\frac{1}{32}\right)^{7/5}$$

$$\Rightarrow \quad \frac{P_1}{P_2} = \frac{1}{2^7} = \frac{1}{128}$$

**Hence, the correct answer is (B).**

**82.** $PV = nRT$ i.e., $n = \frac{PV}{RT}$

$$\Rightarrow \quad n \propto \frac{PV}{T}$$

Number of molecules are directly proportional to the number of moles of the gas. (number of molecules $= nN$)

Here, $P$ and $T$ are doubled while volume is halved. Therefore, number of moles and hence, number of molecules will become half.

**Hence, the correct answer is (B).**

**83.** Condition for a balanced Wheatstone Bridge.

$$\frac{k_1}{k_2} = \frac{k_3}{k_4}$$

$$\Rightarrow \quad k_1k_4 = k_3k_2$$

**Hence, the correct answer is (A).**

**84.** Coefficient of performance is $\beta = \frac{Q_2}{W} = 6$

$$\Rightarrow \quad Q_2 = 6 \times 4 \times 10^6 = 24 \times 10^6 \text{ J}$$

So, mass of water converted to ice is

$$m = \frac{Q_2}{L} = \frac{24 \times 10^6}{80 \times 4.2 \times 1000} \approx 72 \text{ kg}$$

**Hence, the correct answer is (D).**

**85.** Heat rejected by 100 g of water at 80 °C when its temperature becomes 0 °C is

$$Q = ms\Delta\theta = (100)(1)(80) = 8000 \text{ cal}$$

But this heat can melt

$$m = \frac{Q}{L} = \frac{8000}{80} = 100 \text{ g of ice only}$$

Hence, the temperature of the mixture is 0 °C.
**Hence, the correct answer is (A).**

**86.** We have seen in the above question that only 100 gm ice melts. Therefore, mass of water in the mixture is

$$100 + 100 = 200 \text{ g}$$

and mass of ice $= 120 - 100 = 20$ g and temperature of the mixture is 0 °C.
**Hence, the correct answer is (C).**

**87.** Since, $\Delta Q = nC_v\Delta T$

$$\Rightarrow \quad 25R = (1)(C_V)(310 - 300)$$

$$\Rightarrow \quad C_V = \frac{5}{2}R \text{ i.e., gas is diatomic}$$

$$\Rightarrow \quad \gamma = 1.4$$

Now work done in adiabatic process

$$W = \frac{nR(T_i - T_f)}{\gamma - 1} = \frac{(1)(R)(310 - 300)}{1.4 - 1} = 2.5R$$

**Alternate Solution:**

$$Q = nC_V\Delta T = C_V(310 - 300)$$

$$\Rightarrow \quad Q = 10C_V \qquad \text{...(1)}$$

In adiabatic process, $Q = 0$

$$\Rightarrow \quad W = -\Delta U = -nC_V(T_f - T_i) = C_V(T_i - T_f)$$

$$\Rightarrow \quad W = C_V(310 - 300)$$

$$\Rightarrow \quad W = 10C_V \qquad \text{...(2)}$$

From equations (1) and (2), we see that

$$W = Q = 25R$$

**Hence, the correct answer is (C).**

**88.** $\frac{PV}{T} = \frac{P}{\rho T} = \text{constant}$

$$\Rightarrow \quad \frac{\rho_2}{\rho_1} = \left(\frac{T_1}{T_2}\right)\left(\frac{P_2}{P_1}\right) = \left(\frac{T_0}{3T_0}\right)\left(\frac{2.5P_0}{P_0}\right) = \frac{5}{6}$$

**Hence, the correct answer is (A).**

**89.** Since, $\lambda_m T = \text{constant}$, so $T = \frac{4}{3}T_0$

Also, $P \propto T^4$ (from Stefan's Law)

$$\Rightarrow \quad P_{\text{new}} = \frac{256}{81}P$$

**Hence, the correct answer is (A).**

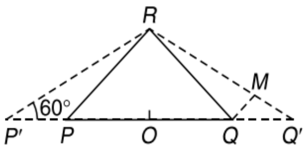
**90.** $W_{BCOB} = -\text{Area of triangle } BCO = -\frac{P_0V_0}{2}$

$$W_{AODA} = +\text{Area of triangle } AOD = +\frac{P_0V_0}{2}$$

$$\Rightarrow \quad W_{\text{net}} = 0$$

**Hence, the correct answer is (D).**

**91.** Since distance $OR$ remains unchanged, the expanded triangle on heating is shown above.



$$MQ' = QQ'\cos 60°$$

$$MQ' \approx L\alpha_2\Delta T \text{ and } QQ' = 0.5L\alpha_1\Delta T$$

Therefore $L\alpha_2\Delta T = 0.5L\alpha_1\Delta T\cos 60°$

$$\Rightarrow \quad 4\alpha_2 = \alpha_1$$

**Hence, the correct answer is (D).**

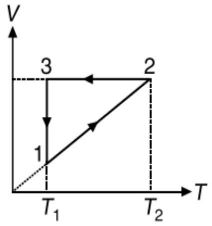
**92.** $C = \frac{dQ}{ndT} = \frac{2dU}{ndT} = \frac{2nC_v dT}{ndT} = 2C_v = 3R$

**Hence, the correct answer is (B).**

**93.** Due to thermal expansion, all $x$, $r$ and $d$ would increase.
**Hence, the correct answer is (C).**

**94.** Energy released in isochoric process 2 → 3 is

$$Q_{23} = nC_V(T_3 - T_2) = nC_V(T_1 - T_2)$$



Work done during isobaric process 1 → 2 is

$$W_{12} = nR(T_2 - T_1)$$

Hence, $\frac{Q_{23}}{W_{12}} = -\frac{C_V}{R} = -\frac{5R/2}{R} = -2.5$

Therefore, ratio of energy released in process 2 → 3 to work done in process 1 → 2 is 2.5
**Hence, the correct answer is (B).**

**95.** Since, $\alpha = \frac{\gamma}{3}$

$$\text{Energy Density} = \frac{(\text{Stress})^2}{2Y} = \frac{1}{2}Y(\text{Strain})^2$$

$$\text{Strain} = \frac{\Delta \ell}{\ell} = \alpha \Delta T = \alpha T = \frac{\gamma T}{3}$$

$$\Rightarrow \quad \text{Stress} = Y(\text{Strain}) = \frac{Y\gamma T}{3} \qquad \left\{\because Y = \frac{\text{stress}}{\text{strain}}\right\}$$

$$\Rightarrow \quad U = \frac{1}{2}\frac{Y^2\gamma^2T^2}{9Y} = \frac{1}{18}\gamma^2T^2Y$$

**Hence, the correct answer is (D).**

**96.** Let, $m$ gram of water whose temperature is $T_0$ $(>30\ ^\circ\text{C})$ and specific heat is $1\ \text{calg}^{-1}\ ^\circ\text{C}$ added to 20 g of water at 30 °C and let $T$ be the final temperature of the mixture.

$$\left(\begin{matrix}\text{Heat given by the}\\ m \text{ g of water}\end{matrix}\right) = \left(\begin{matrix}\text{heat gained by}\\ 20 \text{ g of water}\end{matrix}\right)$$

$$\Rightarrow \quad m(1)(T_0 - T) = (20)(1)(T - 30)$$

Solving this we get, $T = \dfrac{600 + mT_0}{20 + m}$

The right hand side is maximum for OPTION (D). Therefore, the correct answer is (D).

**Hence, the correct answer is (D).**

**97.** When temperature is increased all $a$, $b$, $x$ and $\ell$ should increase.

**Hence, the correct answer is (D).**

**98.** $\left(\dfrac{Q}{t}\right)_C = \left(\dfrac{Q}{t}\right)_A + \left(\dfrac{Q}{t}\right)_B$

$$\Rightarrow \quad k_C A \frac{\Delta T}{\ell} = k_A A \frac{\Delta T}{\ell} + k_B A \frac{\Delta T}{\ell}$$

$$\Rightarrow \quad k_C = k_A + k_B$$

**Hence, the correct answer is (A).**

**99.** Let length of each portion of cylinder be $L$. Since final pressure on both sides of the movable piston must be same, therefore

$$\frac{V_A}{T_A} = \frac{V_B}{T_B}$$

$$\Rightarrow \quad \frac{L+5}{373} = \frac{L-5}{273}$$

$$\Rightarrow \quad L = 32.3 \text{ cm}$$

So, length of the cylinder is

$$L_{\text{cylinder}} = 2L = 64.6 \text{ cm}$$

**Hence, the correct answer is (D).**

**100.** $k_1 A \dfrac{(T_1 - T)}{d_1} = k_2 A \dfrac{(T - T_2)}{d_2}$

$$\Rightarrow \quad T = \frac{k_1T_1d_2 + k_2T_2d_1}{k_1d_2 + k_2d_1}$$

**Hence, the correct answer is (B).**

**101.** Since, $W_1 = P_i(V_f - V_i) = P_iV_i\left(\dfrac{V_f}{V_i} - 1\right)$

$$\Rightarrow \quad W_1 = nRT(2-1) = nRT$$

and $W_2 = nRT\log_e\left(\dfrac{V_f}{V_i}\right) = nRT\log_e(2) = W_1\log_e(2)$

**Hence, the correct answer is (A).**

**102.** At 30 °C, the copper rod will be of length $L_0(1+\alpha_c\Delta\theta)$ while adjacent centimetre marks on the steel tape will be separated by a distance of $(1\text{ cm})(1+\alpha_s\Delta\theta)$. Therefore, the number of centimetres read on the tape will be

$$\frac{L_0(1+\alpha_c\Delta\theta)}{(1\text{ cm})(1+\alpha_s\Delta\theta)} = \frac{(90)[1+1.7\times10^{-5}](20)}{(1)[1+1.2\times10^{-5}](20)} \approx 90.01 \text{ cm}$$

**Hence, the correct answer is (D).**

**103.** Heat exchanged, $\Delta Q = nC_V\Delta T = \dfrac{N}{N_A}C_V\Delta T$

where $N$ is number of molecules of the gas and $N_A$ is Avogadro's number.

In the given situation, let $T$ be the final temperature of the mixture. Then, by Law of Calorimetry, we have

Heat lost = Heat gained

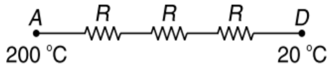
$$\Rightarrow \quad \frac{N_1C_V(T_1 - T)}{N_A} = \frac{N_2C_V(T - T_2)}{N_A}$$

$$\Rightarrow \quad N_1T_1 - N_1T = N_2T - N_2T_2$$

$$\Rightarrow \quad T = \frac{N_1T_1 + N_2T_2}{N_1 + N_2}$$

**Hence, the correct answer is (C).**

**104.** Equivalent electrical circuit will be as shown in figure. Temperature difference between $A$ and $D$ is 180 °C which is equally distributed in all the rods. Therefore, temperature difference between $A$ and $B$ will be 60 °C or temperature of $B$ should be 140 °C.



**Hence, the correct answer is (C).**

**105.** From $A$ to $B$, the process is isobaric i.e., $V \propto T$. From $B$ to $C$ and $D$ to $A$, the process is isothermal but temperature from $B$ to C is higher than that from $D$ to $A$. From $C$ to $D$, the process is isochoric.

**Hence, the correct answer is (B).**

**106.** Given that, $PT = \text{constant}$ ...(1)

According to Ideal Gas Equation, we have $PV = nRT$

$$\Rightarrow \quad T = \frac{PV}{nR}$$

So, equation (1) becomes $P\left(\dfrac{PV}{nR}\right) = \text{constant}$

$$\Rightarrow \quad P^2V = \text{constant}$$

This is best represented by graph in OPTION (C).

**Hence, the correct answer is (C).**

**107.** Temperature decays exponentially with time.

**Hence, the correct answer is (A).**

**108.** 1 g of water equals 1 cc of water

Volume of liquid is $V_\ell = 1\text{ cc} = 10^{-6}\ \text{m}^3$

Volume of vapours is $V_v = 1671\text{ cc} = 1671\times10^{-6}\ \text{m}^3$

$$\Rightarrow \quad \Delta V = V_v - V_\ell = 1670\times10^{-6}\ \text{m}^3$$

$$\Rightarrow \quad W = P\Delta V = 10^5(1670\times10^{-6}) = 167 \text{ J}$$

$$\Rightarrow \quad W = \frac{167}{4.18}\ \text{cal} \simeq 40\ \text{cal}$$

Further $Q = mL$

$$\Rightarrow \quad Q = (1\ g)(540\ \text{calg}^{-1}) = 540\ \text{cal}$$

According to First Law of Thermodynamics

$$Q = \Delta U + W$$

$$\Rightarrow \quad 540 = \Delta U + 40$$

$$\Rightarrow \quad \Delta U = 500\ \text{cal}$$

**Hence, the correct answer is (B).**

**109.** $Y = \frac{\text{Stress}}{\text{Strain}} = \frac{F/A}{\Delta L/L_0}$

$$\Rightarrow \quad Y = \frac{F/A}{\alpha \Delta T} \qquad \{\because \Delta L/L_0 = \alpha \Delta T\}$$

$$\Rightarrow \quad F = YA\alpha\Delta T$$

**Hence, the correct answer is (A).**

**110.** Since, $PV = nRT$

For isobaric process, $V \propto T$, hence slope of the graph is given by

$$\frac{dV}{dT} = \frac{nR}{P} \propto \frac{1}{P} \text{ (if mass remains constant)}$$

**Hence, the correct answer is (C).**

**111.** Rate of melting of ice $\propto$ rate of heat transfer $\left(\frac{dQ}{dt}\right)$

Further $\frac{dQ}{dt} = \frac{\text{temperature difference}}{\left(\frac{\ell}{KA}\right)}$

$$\Rightarrow \quad \frac{dQ}{dt} \propto \frac{(\text{temperature difference})}{\ell} A$$

If temperature difference, $A$ and $\ell$ are all doubled then $\frac{dQ}{dt}$ and hence, rate of melting of ice will be doubled.

**Hence, the correct answer is (D).**

**112.** Let the piston get compressed by $x$. Then for mechanical equilibrium, we have $P'A = P_0A + kx$

$$\Rightarrow \quad P' = P_0 + \frac{kx}{A}$$

$$\Rightarrow \quad 3 \times 10^5 = 1 \times 10^5 + \frac{10^4 x}{0.005}$$

$$\Rightarrow \quad x = 0.1\ \text{m}$$

So, work done is

$$W = P_0 \Delta V + \frac{1}{2} kx^2$$

$$\Rightarrow \quad W = (10^5)(0.005 \times 0.1) + \frac{1}{2}(10^4)(0.1)^2$$

$$\Rightarrow \quad W = 50 + 50 = 100\ \text{J}$$

**Hence, the correct answer is (A).**

**113.** $\begin{pmatrix}\text{Rate of}\\ \text{Cooling}\end{pmatrix} \propto \begin{pmatrix}\text{Average Excess}\\ \text{Temperature}\end{pmatrix}$

$$\Rightarrow \quad \frac{\Delta T}{\Delta t} \propto \left(\frac{T_i + T_f}{2} - T_{\text{surr}}\right)$$

Lets denote $T_{\text{surr}}$ by $T_0$, then

$$\frac{T_f - T_i}{t} \propto \left(\frac{T_i + T_f}{2} - T_{\text{surr}}\right)$$

$$\Rightarrow \quad \frac{60 - 50}{10} \propto \left(\frac{60 + 50}{2} - T_0\right)$$

$$\Rightarrow \quad 1 \propto 55 - T_0 \qquad \ldots(1)$$

Also, $\frac{50 - 42}{10} \propto \left(\frac{50 + 42}{2} - T_0\right)$

$$0.8 \propto 46 - T_0 \qquad \ldots(2)$$

$$\Rightarrow \quad \frac{0.8}{1} = \frac{46 - T_0}{55 - T_0}$$

$$\Rightarrow \quad \frac{4}{5} = \frac{46 - T_0}{55 - T_0}$$

$$\Rightarrow \quad 220 - 4T_0 = 230 - 5T_0$$

$$\Rightarrow \quad T_0 = 10\ ^\circ\text{C}$$

**Hence, the correct answer is (B).**

**114.** $r_0 \propto (600)^4 - (300)^4$

$$r \propto (900)^4 - (300)^4$$

$$\Rightarrow \quad \frac{r}{r_0} = \frac{(900)^4 - (300)^4}{(600)^4 - (300)^4}$$

$$\Rightarrow \quad r = r_0\left(\frac{9^4 - 3^4}{6^4 - 3^4}\right)$$

$$\Rightarrow \quad r = r_0\left(\frac{3^4 - 1}{2^4 - 1}\right)$$

$$\Rightarrow \quad r = r_0\left(\frac{80}{15}\right)$$

$$\Rightarrow \quad r = \frac{16}{3} r_0$$

**Hence, the correct answer is (A).**

**115.** Molar heat capacity $C = \frac{\Delta Q}{\Delta T}$

$$\Rightarrow \quad C = \frac{\Delta U + \Delta W}{dT}$$

$\Delta U$ is same in both the paths but

$$\Delta W_2 > \Delta W_1$$

$$\Rightarrow \quad C_2 > C_1$$

$$\Rightarrow \quad \frac{C_1}{C_2} < 1$$

**Hence, the correct answer is (B).**

**116.** After first stroke, we have $PV = P_1(V + v)$

$$\Rightarrow \quad P_1 = P\left(\frac{V}{V + v}\right)$$

After second stroke, we have $P_1V = P_2(V + v)$

$$\Rightarrow \quad P_2 = P_1\left(\frac{V}{V + v}\right) = P\left(\frac{V}{V + v}\right)^2$$

and so on for $n$ strokes, we have

$$P_n = P_{n-1}\left(\frac{V}{V + v}\right) = P\left(\frac{V}{V + v}\right)^n$$

**Hence, the correct answer is (D).**

**117.** Let $A_1$ be the cross sectional area of silica cylinder, $A_2$ be the cross-sectional area of the mercury in the glass cylinder, then $(A_1 + A_2)$ is cross sectional area of glass cylinder and $h$ is the height of silica cylinder, then

$$h(A_1+A_2)(2\alpha)\Delta T = hA_2\gamma\Delta T$$

$$\Rightarrow \quad \frac{hA_1}{hA_2} = \frac{V_{\text{silica}}}{V_{\text{mercury}}} = \frac{\gamma}{2\alpha} - 1$$

**Hence, the correct answer is (C).**

**118.** $$\frac{50-49.9}{5} \propto \left(\frac{50+49.9}{2} - 30\right) \text{ and} \qquad \ldots(1)$$

$$\frac{40-39.9}{t} \propto \left(\frac{40+39.9}{2} - 30\right) \qquad \ldots(2)$$

$$\Rightarrow \quad \frac{t}{5} = \frac{99.9-60}{79.9-60} = \frac{39.9}{19.9} \approx 2$$

$$\Rightarrow \quad t = 10 \text{ s}$$

**Hence, the correct answer is (C).**

**119.** $$v_{\text{rms}} = \sqrt{\frac{3RT}{M}}$$

Room temperature $T \approx 300$ K

$$\Rightarrow \quad 1930 = \sqrt{\frac{3 \times 8.31 \times 10^3 \times 300}{M}}$$

$$\Rightarrow \quad M = 2 \text{ g mol}^{-1}$$

So, the gas is $H_2$

**Hence, the correct answer is (A).**

**120.** For processes $ab$ and $cd$, $P \propto T$ so $V =$ constant and hence processes $ab$ and $cd$ are isochoric, work done in these processes is zero. So, net work done in cyclic process is

$$W = W_{bc} + W_{da}$$

$$\Rightarrow \quad W = nR(T_c - T_b) + nR(T_a - T_d) \qquad \{\text{isobaric}\}$$

$$\Rightarrow \quad W = (2)(8.31)(1600-800) + (2)(8.31)(400-800)$$

$$\Rightarrow \quad W = 6.6 \text{ kJ}$$

**Hence, the correct answer is (C).**

**121.** Since all $P$, $V$ and $T$ are changing simultaneously and the work is being done at the expense of the internal energy of the gas so this must be an adiabatic process because for an adiabatic process $đQ = 0$ and by First Law of Thermodynamics

$$dU = -dW$$

Hence $C = \dfrac{đQ}{dT} = 0$

**Hence, the correct answer is (A).**

**122.** $$\frac{dQ}{dt} \propto A$$

$$\Rightarrow \quad \frac{\left(\dfrac{dQ}{dt}\right)_1}{\left(\dfrac{dQ}{dt}\right)_2} = \frac{R_1^2}{R_2^2}$$

**Hence, the correct answer is (C).**

**123.** $$mc\left(\frac{dT}{dt}\right) \propto A$$

$$\Rightarrow \quad \frac{dT}{dt} \propto \frac{A}{mc}$$

$$\Rightarrow \quad \frac{\left(\dfrac{dT}{dt}\right)_1}{\left(\dfrac{dT}{dt}\right)_2} = \frac{A_1}{A_2}\frac{m_2}{m_1} = \frac{4\pi R_1^2}{4\pi R_2^2}\left(\frac{\frac{4}{3}\pi R_2^3 \rho}{\frac{4}{3}\pi R_1^3 \rho}\right) = \frac{R_2}{R_1}$$

**Hence, the correct answer is (B).**

**124.** When cooled isochorically (i.e. $V =$ constant)

$$\frac{P}{T} = \frac{P/n}{T'}$$

$$\Rightarrow \quad T' = \frac{T}{n}$$

Heat exchanged is $Q_1 = C_V \Delta T$

$$\Rightarrow \quad Q_1 = C_V\left(\frac{T}{n} - T\right) = -C_V T\left(1 - \frac{1}{n}\right)$$

When heated isobarically (i.e. $P =$ constant) heat exchanged is

$$Q_2 = C_P\left(T - \frac{T}{n}\right) = C_P T\left(1 - \frac{1}{n}\right)$$

Net heat exchanged is

$$Q = Q_2 + Q_1 = C_P T\left(1 - \frac{1}{n}\right) - C_V T\left(1 - \frac{1}{n}\right)$$

$$\Rightarrow \quad Q = (C_P - C_V)T\left(1 - \frac{1}{n}\right) = RT\left(1 - \frac{1}{n}\right)$$

**Hence, the correct answer is (A).**

**125.** Let $M$ be the molecular mass of the gas. Then

So, $M(C_P - C_V) = R$

$$\Rightarrow \quad M(525 - 315) = 8.31$$

$$\Rightarrow \quad M = 0.0392$$

Now let $\rho$ be the density of the gas at NTP. Then it implies that So, mass of 22.4 L or $(22.4 \times 10^{-3})m^3$ of gas should be $(\rho \times 22.4 \times 10^{-3})$ kg which should be equal to its molecular mass i.e.,

$$\rho \times 22.4 \times 10^{-3} = 0.0392$$

$$\Rightarrow \quad \rho = 1.75 \text{ kgm}^{-3}$$

**Hence, the correct answer is (D).**

**126.** For equilibrium $F_1 - F_2 = 0$

$$\Rightarrow \quad Y_1\alpha_1 A\Delta T - Y_2\alpha_2 A\Delta T = 0$$

$$\Rightarrow \quad Y_1\alpha_1 = Y_2\alpha_2$$

**Hence, the correct answer is (C).**

**127.** Two molecules have a speed of 1.6 $\text{kms}^{-1}$, so most probable speed is also 1.6 $\text{kms}^{-1}$.

**Hence, the correct answer is (C).**

**128.** We use $(1 + \alpha_s) \times R = L(1 + \alpha_C)$

$$\Rightarrow \quad R = L\left[\frac{1+\alpha_C}{1+\alpha_S}\right]$$

**Hence, the correct answer is (C).**

**129.** From First Law of Thermodynamics $\Delta U = Q - W$

Here $Q = mL = L$ $\{\because m = 1\}$

and $W = P_0(V_f - V_i) = P_0(V_2 - V_1)$

⇒ $\Delta U = L - P_0(V_2 - V_1)$

**Hence, the correct answer is (C).**

**130.** $C_V(\text{mixture}) = \frac{n_1C_{V_1} + n_2C_{V_2}}{n_1 + n_2}$

Here, $C_{V_1} = \frac{5}{2}R,\ n_1 = \frac{10}{2} = 5$ {for $H_2$}

$C_{V_2} = \frac{3}{2}R,\ n_2 = \frac{40}{4} = 10$ {for $He$}

⇒ $C_V(\text{mixture}) = \frac{11}{6}R$

⇒ $Q = nC_V\Delta T = 2750$ cal

**Hence, the correct answer is (B).**

**131.** $dQ = dU + dW$

⇒ $dQ = dU - \frac{2dU}{3} = \frac{dU}{3} = \frac{1}{3}nC_v dT$

⇒ $dQ = \frac{1}{3}n\left(\frac{3}{2}RdT\right) = \frac{nRdT}{2}$

⇒ $C = \frac{1}{n}\frac{dQ}{dT} = \frac{R}{2}$

which is not equal to 0, infinity or $\frac{5R}{2}$

**Hence, the correct answer is (D).**

**132.** Given that $P\sqrt{T}$ = constant ...(1)

Also, for a polytropic process, we have

$P^{1-x}T^{x}$ = constant

⇒ $PT^{\frac{x}{1-x}}$ = constant ...(2)

Comparing equations (1) and (2), we get $\frac{x}{1-x} = \frac{1}{2}$

⇒ $2x = 1 - x$

⇒ $x = \frac{1}{3}$

⇒ $C = \frac{R}{\gamma - 1} + \frac{R}{1-x} = \frac{R}{(5/3) - 1} + \frac{R}{1 - (1/3)} = 3R$

**Hence, the correct answer is (C).**

**133.** $PV = nRT$

⇒ $PdV = nRdT$ $\{\because P = \text{constant}\}$

⇒ $dV = \left(\frac{nR}{P}\right)dT$

⇒ $dV = \left(\frac{V}{T}\right)dT$ ...(1)

Further $dV = \gamma V dT$ ...(2)

From equations (1) and (2), we get $\gamma = \frac{1}{T}$

**Hence, the correct answer is (C).**

**134.** $PV^{3/2}$ = constant

⇒ $\frac{PV^{2/3}}{PV} = \frac{\text{constant}}{RT}$

⇒ $\frac{1}{V^{1/3}} = \frac{\text{constant}}{RT}$

⇒ $V \propto T^3$

Temperature increases with increase in volume.

**Hence, the correct answer is (A).**

**135.** $K_CA\left(\frac{\Delta T_{Cu}}{\ell}\right) = K_BA\left(\frac{\Delta T_B}{\ell}\right)$

⇒ $\frac{\Delta T_{Cu}}{\Delta T_B} = \frac{K_B}{K_C} < 1$

⇒ $\Delta T_{Cu} < \Delta T_B$

i.e. fall in temperature for copper is less than brass and hence temperature at junction is greater than 50 °C.

**Hence, the correct answer is (A).**

**136.** For the isochoric process $ab$, $W = 0$, so we have

$Q = \Delta U = nC_V\Delta T = 5000$

⇒ $n\left(\frac{5R}{2}\right)(800 - 300) = 5000$

⇒ $nR = 4$

Now, for isobaric process $ca$, we have

$Q_{ca} = nC_P\Delta T = n\left(\frac{7R}{2}\right)(T_a - T_c)$

Since process $bc$ is isothermal, so $T_b = T_c$ and hence $\Delta U = 0$.

For process $ca$, $P$ = constant

⇒ $Q_{ca} = n\left(\frac{7R}{2}\right)(T_a - T_b) = (4)\left(\frac{7}{2}\right)(300 - 800)$

⇒ $Q_{ca} = -7000$ J

**Hence, the correct answer is (C).**

**137.** $\gamma = \frac{\Delta V}{V\Delta T} = \frac{0.12}{100} \times \frac{1}{20} = 6 \times 10^{-5}\,(°\text{C})^{-1}$

⇒ $\alpha = \frac{\gamma}{3} = 2 \times 10^{-5}\,(°\text{C})^{-1}$

**Hence, the correct answer is (A).**

**138.** Since, $\frac{E_2}{E_1} = \left(\frac{727 + 273}{227 + 273}\right)^4 = \left(\frac{1000}{500}\right)^4 = 16$

⇒ $E_2 = 16 \times 5 = 80\ \text{cal}\,\text{s}^{-1}\text{cm}^{-2}$

**Hence, the correct answer is (B).**

**139.** $dQ = +35$ J and $dW = -15$ J

By First Law, we have $dQ = dU + dW$

⇒ $35 = dU - 15$

⇒ $dU = +50$ J

**Hence, the correct answer is (D).**

**140.** Internal energy of $n$ mole of gas having $f$ degrees of freedom is $U = n\left(\frac{1}{2}RT\right)f$.

For 1 mole of helium at 600 K, $f = 3$

⇒ $U_1 = (1)\left[\frac{1}{2} \times R \times 600\right](3) = 900R$

For 56 g of nitrogen at 300 K, $f = 5$

$$\Rightarrow \quad U_2 = \left(\frac{56}{28}\right)\left[\frac{1}{2}\times R\times 300\right](5) = 1500R$$

For 32 g of oxygen at 300 K, $f = 5$ and

$$U_3 = \left(\frac{32}{32}\right)\left[\frac{1}{2}\times R\times 300\right](5) = 750R$$

For $12\times 10^{23}$ molecules of argon at 450 K, $f = 3$

$$\Rightarrow \quad U_4 = \left(\frac{12\times 10^{23}}{6\times 10^{23}}\right)\left[\frac{1}{2}R\times 450\right](3) = 1350R$$

Hence $U$ is maximum for 56 g of nitrogen at 300 K

**Hence, the correct answer is (B).**

**141.** Since, $T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1}$

$$\Rightarrow \quad T_1(AL_1)^{\frac{5}{3}-1} = T_2(AL_2)^{\frac{5}{3}-1}$$

$$\Rightarrow \quad \frac{T_1}{T_2} = \left(\frac{L_2}{L_1}\right)^{\frac{2}{3}}$$

**Hence, the correct answer is (D).**

**142.** $\dfrac{PV}{kT} = \dfrac{nRT}{\left(\dfrac{R}{N}\right)T} = nN = (\text{Number of molecules in the gas})$

**Hence, the correct answer is (C).**

**143.** $V$-$T$ graph is a straight line passing through origin

Hence, $V \propto T$ or $P = \text{constant}$

$$\Rightarrow \quad dQ = nC_PdT \text{ and } dU = nC_VdT$$

Since, $dW = dQ - dU = n(C_P - C_V)dT$

$$\Rightarrow \quad \frac{dQ}{dW} = \frac{nC_PdT}{n(C_P - C_V)dT}$$

$$\Rightarrow \quad \frac{dQ}{dW} = \frac{C_P}{C_P - C_V} = \frac{1}{1 - \dfrac{C_V}{C_P}}$$

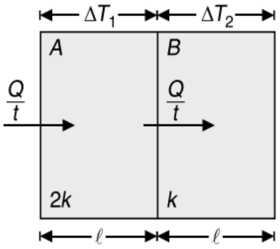
Since, $\dfrac{C_V}{C_P} = \dfrac{3}{5}$ for helium gas

$$\Rightarrow \quad \frac{dQ}{dW} = \frac{1}{1-3/5} = \frac{5}{2}$$

**Hence, the correct answer is (B).**

**144.** $\Delta T_1 + \Delta T_2 = 36$ ...(1)

Also, the slabs are in series. So, same thermal current $\left(\dfrac{Q}{t}\right)$



Flows through both. Hence

$$2kA\left(\frac{\Delta T_1}{\ell}\right) = kA\left(\frac{\Delta T_2}{\ell}\right)$$

$$\Rightarrow \quad \Delta T_2 = 2\Delta T_1 \qquad \text{...(2)}$$

$$\Rightarrow \quad \Delta T_1 = 12\ °\text{C and } \Delta T_2 = 24\ °\text{C}$$

**Hence, the correct answer is (B).**

**145.** Apparent weight $(w_a)$=actual weight $(w)$ − upthrust $(F)$

Here, $F = V\rho_w g$ $\{\rho_w = \text{density of water}\}$

i.e., $F_{0\ °\text{C}} = V_{0\ °\text{C}}(\rho_w)_{50\ °\text{C}}\, g$

and $F_{50\ °\text{C}} = V_{50\ °\text{C}}(\rho_w)_{50\ °\text{C}}\, g$

$$\Rightarrow \quad \frac{F_{50\ °\text{C}}}{F_{0\ °\text{C}}} = \frac{V_{50\ °\text{C}}}{V_{0\ °\text{C}}}\cdot\frac{(\rho_w)_{50\ °\text{C}}}{(\rho_w)_{0\ °\text{C}}} = \frac{(1+\gamma_m\Delta T)}{(1+\gamma_w\Delta T)} \quad \{\Delta T = 50\ °\text{C}\}$$

Given that $\gamma_m < \gamma_w$, so $F_{50\ °\text{C}} < F_{0\ °\text{C}}$

Hence apparent weight at 50 °C will be more.

**Hence, the correct answer is (B).**

**146.** Since $A_t = A_0[1 + \beta\Delta T]$

Let diameter at 0 °C is $d_0$ cm and at dry ice $(-60\ °\text{C})$ is $d$ cm

$$\frac{\pi(10.02)^2}{4} = \frac{\pi d_0^2}{4}\left[1 + (4\times 10^{-5})(40-0)\right] \qquad \text{...(1)}$$

$$\Rightarrow \quad \frac{\pi d^2}{4} = \frac{\pi d_0^2}{4}\left[1 + (4\times 10^{-5})(-60-0)\right] \qquad \text{...(2)}$$

Dividing (1) by (2), we get

$$\frac{(10.02)^2}{d^2} = \frac{1.0016}{0.9976}$$

$$\Rightarrow \quad d = 9.99997 \text{ cm} \approx 10 \text{ cm}$$

**Hence, the correct answer is (D).**

**147.** By First Law of Thermodynamics

$$Q_1 + (-W_1) = Q_2 + (-W_2) = U_B - U_A$$

**Hence, the correct answer is (D).**

**148.** Cooling must lead to a decrease in volume of the system which is possible only if the piston moves to the right.

**Hence, the correct answer is (B).**

**149.** For both graphs, work done is same because area under the curve is same.

However, according to Ideal Gas Equation, $PV = nRT$, we see that the increase in temperature is more in CASE-1. Therefore, increase in internal energy is also more in CASE-1. Hence heat added is more in CASE-1.

**Hence, the correct answer is (A).**

**150.** For a cyclic process $\Delta U = 0$, so $Q = W$

$$\Rightarrow \quad (100 - 20) = 20 + W_2$$

$$\Rightarrow \quad W_2 = 60 \text{ J}$$

**Hence, the correct answer is (A).**

**151.** Let $h$ be the distance of the apex from the middle of the base. Further by Pythagoras theorem

$$L_2^2 - \frac{L_1^2}{4} = h^2 = \text{constant}$$

$$\Rightarrow \quad \Delta(h^2) = \Delta(L_2^2) - \Delta\left(\frac{L_1^2}{4}\right)$$

$$\Rightarrow \quad 0 = 2L_2\Delta L_2 - \frac{1}{4}(2L_1\Delta L_1)$$

Since, $\alpha_1 = \frac{\Delta L_1}{L_1}\frac{1}{\Delta T}$ and $\alpha_2 = \frac{\Delta L_2}{L_2}\frac{1}{\Delta T}$

$$\Rightarrow \quad L_2(L_2\alpha_2\Delta T) = \frac{1}{4}L_1(L_1\alpha_1\Delta T)$$

$$\Rightarrow \quad \frac{L_1}{L_2} = 2\sqrt{\frac{\alpha_2}{\alpha_1}}$$

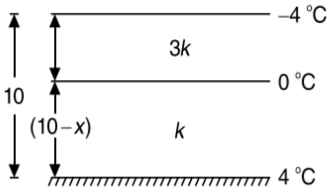
**Hence, the correct answer is (D).**

**152.** 1 g of steam at 100 °C liberates 540 cal to convert to 1 $g$ of water at 100 °C.
Further 1 g of ice at 0 °C melts and converts to water at 0 °C. For this purpose 80 cal of heat is required by it.
This 1 g of water at 0 °C requires 100 cal of heat to convert to 1 g of water at 100 °C.
i.e., a total of $(80+100)$ cal $= 180$ cal of heat is required by ice at 0 °C to convert to water at 100 °C which is much less than the heat liberated by steam at 100 °C to convert to water at 100 °C i.e. 540 cal. Hence equilibrium temperature will just be 100 °C.
**Hence, the correct answer is (D).**

**153.** Even if 3 g of ice at 0 °C is taken then total heat required by 3 g of ice at 0 °C to convert to 3 g of water at 100 °C equals $3(180 \text{ cal}) = 540$ cal, which is the amount of heat liberated by steam at 100 °C to convert to water at 100 °C.
**Hence, the correct answer is (C).**

**154.** A refrigerator is reverse of heat engine and heat pump is same as refrigerator. The coefficient of performance of a refrigerator cannot be infinity and a heat engine cannot convert the heat input fully to work done.
**Hence, the correct answer is (B).**

**155.** $kA\left(\frac{4-0}{10-x}\right) = 3kA\left[\frac{0-(-4)}{x}\right]$

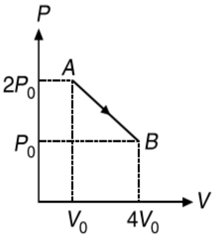


$$\Rightarrow \quad x = 7.5 \text{ m}$$

**Hence, the correct answer is (A).**

**156.** Temperature of liquid oxygen will first increase in the same phase. Then, phase change (liquid to gas) will take place. During which temperature will remain constant. After that temperature of oxygen n gaseous state will further increase.
**Hence, the correct answer is (C).**

**157.** The process carried on an ideal monatomic gas is shown in Figure.



Applying Ideal Gas Equation at points $A$ and $B$, we get

$$2P_0V_0 = nRT_A \text{ and } 4P_0V_0 = nRT_B$$

$$\Rightarrow \quad \Delta U = n(1.5R)(T_B - T_A) = 3P_0V_0$$

Also $W = \frac{1}{2}(2P_0 + P_0)(4V_0 - V_0) = 4.5P_0V_0$

$$\Rightarrow \quad Q = \Delta U + W = 3P_0V_0 + 4.5P_0V_0 = 7.5P_0V_0$$

$$\Rightarrow \quad Q = 7.5\times(0.5\times10^6)\times0.1 = 375\times10^3 \text{ J}$$

**Hence, the correct answer is (B).**

**158.** For an adiabatic process $PV^\gamma = \text{constant}$ ...(1)

Also, density $\rho = \frac{m}{V}$ i.e., $\rho \propto V^{-1}$

So, equation (1) can be written as $P\rho^{-\gamma} = \text{constant}$

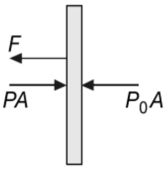
**Hence, the correct answer is (B).**

**159.** Volume of the gas is constant $V = \text{constant}$

$$\Rightarrow \quad P \propto T$$

i.e., pressure will be doubled if temperature is doubled

$$\Rightarrow \quad P = 2P_0$$



Now let $F$ be the tension in the wire. Then equilibrium of any one piston gives

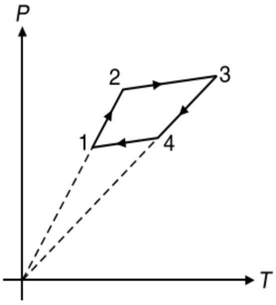
$$F = (P - P_0)A = (2P_0 - P_0)A = P_0A$$

**Hence, the correct answer is (B).**

**160.** Processes $1 \to 2$ and $3 \to 4$ are isochoric, so work done is zero.

$$\Rightarrow \quad W_{\text{total}} = W_{23} + W_{41}$$

$$\Rightarrow \quad W_{\text{total}} = P_2(V_3 - V_2) + P_4(V_1 - V_4)$$



$$\Rightarrow \quad W_{\text{total}} = nR(T_3 - T_2) + nR(T_1 - T_4)$$

$$\Rightarrow \quad W_{\text{total}} = nR(T_3 - T_2 + T_1 - T_4)$$

$$\Rightarrow \quad W_{\text{total}} = 800nR = 2400R$$

**Hence, the correct answer is (C).**

**161.** $PV = nRT$, where $V = \frac{m}{\rho}$

$$\Rightarrow \quad P\left(\frac{m}{\rho}\right) = \left(\frac{m}{M}\right)RT$$

$$\Rightarrow \quad \rho = \left(\frac{M}{RT}\right)P$$

Therefore, slope of $\rho$-$P$ graph is

$$\frac{M}{RT} \propto \frac{1}{T}$$

So, for lesser slope, temperature has to be more.

$$\Rightarrow \quad T_B > T_A$$

**Hence, the correct answer is (B).**

**162.** Let $T$ be the temperature of the mixture. Then

$$U = U_1 + U_2$$

$$\Rightarrow \quad \frac{f}{2}(n_1 + n_2)RT = \frac{f}{2}(n_1)RT_0 + \frac{f}{2}(n_2)(R)(2T_0)$$

$$\Rightarrow \quad (2+4)T = 2T_0 + 8T_0 \qquad (n_1 = 2,\ n_2 = 4)$$

$$\Rightarrow \quad T = \frac{5}{3}T_0$$

**Hence, the correct answer is (A).**

**163.** To 80 cm mark on the aluminium rod is really at a greater distance from the zero position than indicated because of the increase in temperature $\Delta T = 40\ °\text{C}$. The increased length is

$$\Delta L = \alpha_{A\ell}L_{A\ell}\Delta T = (2.5\times10^{-5})(80)(40) = 0.08 \text{ cm}$$

So, the correct length of the line is

$$L = 80 + 0.08 = 80.08 \text{ cm}$$

**Hence, the correct answer is (A).**

**164.** Since, $\frac{(Q/t)_1}{(Q/t)_2} = \left(\frac{r_1}{r_2}\right)^2 \frac{\ell_2}{\ell_1}$

$$\Rightarrow \quad \text{Ratio} = \frac{1}{4}\times\frac{1}{2} = \frac{1}{8}$$

**Hence, the correct answer is (C).**

**165.** Due to Kirchhoff's Laws

**Hence, the correct answer is (A).**

**166.** Since, $dP = g\rho dy$

$$\Rightarrow \quad \int_{P_1}^{P_2}\frac{dP}{P} = \frac{Mg}{RT}$$

Also, $H = \int_{0}^{H} dy$

$$\Rightarrow \quad H = \frac{RT}{Mg}\ln\frac{P_1}{P_2}$$

**Hence, the correct answer is (A).**

**167.** Since $\frac{Q}{t} = kA\frac{\Delta T}{\ell}$, so $t \propto \frac{\ell}{A}$

$$\Rightarrow \quad \frac{t_1}{t_2} = \frac{\ell_1}{\ell_2}\frac{A_2}{A_1} = 4$$

$$\Rightarrow \quad t_2 = \frac{t_1}{4} = \frac{4}{4} = 1 \text{ min}$$

**Hence, the correct answer is (A).**

**168.** $dU = C_v dT = \left(\frac{5}{2}R\right)dT$

$$\Rightarrow \quad dT = \frac{2(dU)}{5R} \qquad \ldots(1)$$

From First Law of Thermodynamics, we have

$$dU = dQ - dW$$

$$\Rightarrow \quad dU = Q - \frac{Q}{4} = \frac{3Q}{4}$$

Now molar heat capacity is $C = \frac{dQ}{dT} = \frac{Q}{2(dU)}$

$$\Rightarrow \quad C = \frac{5RQ}{2\left(\frac{3Q}{4}\right)} = \frac{10}{3}R$$

**Hence, the correct answer is (C).**

**169.** Since volume is constant, so we have

$$\frac{P_2}{T_2} = \frac{P_1}{T_1}$$

When temperature of gas is doubled, then we get

$$P_2 = 2P_1 = 2P_0$$

Now, tension $F$ in the wire is equal to net force on the piston given by

$$F = (2P_0 - P_0)A = (1.013\times10^5)(1) = 10^5 \text{ N}$$

**Hence, the correct answer is (B).**

**170.** Since, $\frac{dL}{L_0} = \alpha(T)dT$

$$\Rightarrow \quad \int_{L_0}^{L} dL = L_0\int_{T_0}^{T}\alpha(T)dT$$

$$\Rightarrow \quad L - L_0 = L_0\int_{T_0}^{T}\alpha(T)dT$$

$$\Rightarrow \quad L = L_0\left[1 - \int_{T}^{T_0}\alpha(T)dT\right]$$

**Hence, the correct answer is (B).**

**171.** Since $t \propto x_2^2 - x_1^2$

$$\Rightarrow \quad t = \beta\left(x_2^2 - x_1^2\right)$$

where $\beta$ is just a constant of proportionality

$$\Rightarrow \quad \frac{t_2}{t_1} = \frac{4-1}{1-0}$$

$$\Rightarrow \quad t_2 = 21 \text{ hour} > 14 \text{ hour}$$

**Hence, the correct answer is (D).**

**172.** Since all have same $k$ (as they are made of same material)

So, the rod which has maximum $\frac{Q}{t}$ will conduct the most. Here

$$\frac{Q}{t} \propto \frac{r^2}{\ell}$$

**Hence, the correct answer is (A).**

**173.** Since both the slabs are in series and hence $\frac{Q}{t}$ is same through both. Hence, required ratio is 1 : 1.

**Hence, the correct answer is (D).**

**174.** Average $KE$ of each molecule is $E_{av} = E = \frac{3}{2}k_B T$

If $N_1$ is the number of molecules of hydrogen and $N_2$ is the number of molecules of oxygen, then

Total $KE$ of hydrogen is $E_1 = N_1\left(\frac{3}{2}k_B T\right)$

Total $KE$ of oxygen is $E_2 = N_2\left(\frac{3}{2}k_B T\right)$

$$\Rightarrow \quad \frac{E_1}{E_2} = \frac{N_1}{N_2} = 2$$

**Hence, the correct answer is (B).**

**175.** Under steady state condition, heat released to the room = heat dissipated out of the room.

Let $\theta$ be the temperature of heater. Then

$$\theta - 20 = \alpha[20 - (-20)] \qquad \ldots(1)$$

and $$\theta - 10 = \alpha[10 - (-40)] \qquad \ldots(2)$$

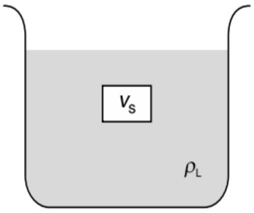
Solving equations (1) and (2), we get

$$\theta = 60\ °\text{C}$$

**Hence, the correct answer is (D).**

**176.** Upthrust, $W_0 = V_s \rho_L g$

where, $V_s$ is volume of solid at 0 °C, $\rho_L$ is density of liquid at 0 °C. As the temperature increases, $V_s$ increases and $\rho_L$ decreases.



Since, $W_0 \propto V_s \rho_L$

$$\Rightarrow \quad \frac{W}{W_0} = \frac{V_s' \rho_L'}{V_s \rho_L} = \frac{(V_s + \Delta V_s)}{V_s} \times \frac{\rho_L (1 + \gamma_L \Delta T)^{-1}}{\rho_L}$$

$$\Rightarrow \quad \frac{W}{W_0} = (1 + \gamma_s \Delta T)(1 - \gamma_L \Delta T) \qquad \text{(Using binomial)}$$

$$\Rightarrow \quad W = W_0(1 + \gamma_s \Delta T - \gamma_L \Delta T) = W_0\left[1 + (\gamma_S - \gamma_L)\Delta T\right]$$

**Hence, the correct answer is (B).**

**177.** Since, $\frac{Q_1}{Q_2} = \frac{T_1}{T_2}$

$$\Rightarrow \quad Q_2 = \left(\frac{T_2}{T_1}\right)Q_1 = \left(\frac{300}{400}\right)600 = 450 \text{ cal}$$

**Hence, the correct answer is (D).**

**178.** Since $PV = nRT$

$$\Rightarrow \quad \text{Slope} = \frac{P}{T} = \frac{nR}{V}$$

The more the volume, the lesser the slope and vice-versa.

**Hence, the correct answer is (B).**

**179.** Given that, $\eta = 40\%$ and $T_2 = 47 + 273 = 320$ K

Since $\eta = 1 - \frac{T_2}{T_1}$, so $\frac{40}{100} = 1 - \frac{320}{T_1}$

$$\Rightarrow \quad \frac{320}{T_1} = 0.6$$

$$\Rightarrow \quad T_1 = \frac{3200}{6} = 533 \text{ K} = 260\ °\text{C}$$

**Hence, the correct answer is (A).**

**180.** Since $P_1 = P_2$

$$\Rightarrow \quad \sigma A_1 T_1^4 = \sigma A_2 T_2^4$$

$$\Rightarrow \quad 4\pi r_1^2 T_1^4 = 4\pi r_2^2 T_2^4$$

$$\Rightarrow \quad \frac{r_1}{r_2} = \left(\frac{T_2}{T_1}\right)^2$$

**Hence, the correct answer is (B).**

**181.** Since, $\Delta U = nC_v \Delta T$

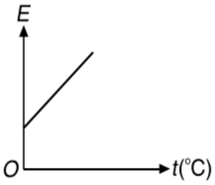
$$\Rightarrow \quad \Delta U = n\left(\frac{R}{\gamma - 1}\right)(T_f - T_i) = \frac{nRT_f - nRT_i}{\gamma - 1}$$

$$\Rightarrow \quad \Delta U = \frac{P(2V) - P(V)}{\gamma - 1} = \frac{PV}{\gamma - 1}$$

**Hence, the correct answer is (C).**

**182.** Mean KE of each molecule, $E_K = \frac{3}{2}k_B T = \frac{3}{2}k_B(t + 273)$

At 0 °C or 273 K, the molecules will possess some kinetic energy. So, the graph does not start from origin.



**Hence, the correct answer is (C).**

**183.** Let $R$ be radius of sphere, $V$ its volume and $\rho$ its density, then $\Delta R = R\alpha\Delta T$. So, percentage change is

$$\frac{\Delta R}{R} \times 100 = 100\alpha\Delta T \qquad \ldots(1)$$

Also, $\Delta V = V\gamma\Delta T = V(3\alpha)\Delta T$, so percentage change is

$$\frac{\Delta V}{V} \times 100 = 300\alpha\Delta T \qquad \ldots(2)$$

Since, $\rho' = \frac{\rho}{1 + \gamma\Delta T} = \frac{\rho}{1 + 3\alpha\Delta T}$

$$\Rightarrow \quad \Delta\rho = \rho - \rho'$$

$$\Rightarrow \quad \Delta\rho = \rho\left(1 - \frac{1}{1+3\alpha\Delta T}\right) = \frac{(3\alpha\Delta T)\rho}{1+3\alpha\Delta T}$$

So, percentage change in density is $\frac{\Delta\rho}{\rho} \times 100$

$$\Rightarrow \quad \frac{\Delta\rho}{\rho} \times 100 = \frac{300\alpha\Delta T}{1+3\alpha\Delta T} \qquad \ldots(3)$$

From equations (1), (2) and (3), we see that percentage change is maximum in volume.

**Hence, the correct answer is (B).**

**184.** Since, $dQ = nC_p dT$

$$\Rightarrow \quad C_p = \frac{dQ}{ndT}$$

$$\Rightarrow \quad C_P = \frac{70}{(2)(5)} = \frac{7}{2}(R)$$

i.e., the gas is diatomic or it may be $H_2$.

**Hence, the correct answer is (A).**

**185.** We use $\Delta l = \alpha l \Delta T$

For rod $A$, $0.075 = 20\alpha_A(100-0)$

$$\Rightarrow \quad \alpha_A = 3.75 \times 10^{-5}\ {}^\circ\text{C}^{-1}$$

For rod $B$, $0.045 = 20\alpha_B(100-0)$

$$\Rightarrow \quad \alpha_B = 2.25 \times 10^{-5}\ {}^\circ\text{C}^{-1}$$

Let portion of metal $A$ is $l$ cm and that of metal $B$ is $(20-l)$ cm

$$\Delta l_A + \Delta l_B = 0.06 \text{ cm}$$

$$\Rightarrow \quad \alpha_A l(100) + \alpha_B(20-l)(100) = 0.06$$

$$\Rightarrow \quad 3.75 \times 10^{-5} l + 4.5 \times 10^{-4} - 2.25 \times 10^{-5} l = 6 \times 10^{-4}$$

$$\Rightarrow \quad 1.5 \times 10^{-5} l = 1.5 \times 10^{-4}$$

$$\Rightarrow \quad l = 10 \text{ cm}$$

**Hence, the correct answer is (B).**

**186.** Since, $\frac{0.1}{t_1} \propto \left(\frac{50+49.9}{2} - 30\right)$

and $\frac{0.1}{t_2} \propto \left(\frac{40+39.9}{2} - 30\right)$

$$\Rightarrow \quad t_2 = 10 \text{ s}$$

**Hence, the correct answer is (B).**

**187.** Let temperature of the junction be $T$, then in steady state, thermal current through steel equals the thermal current through copper, so we have

$$K_{\text{steel}}(2A)\left(\frac{300-T}{15}\right) = K_{\text{copper}}(A)\left(\frac{T-0}{10}\right)$$

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

$$\Rightarrow \quad T \approx 44\ {}^\circ\text{C}$$

**Hence, the correct answer is (A).**

**188.** Let $m$ gram of steam be required for the purpose.

By Law of Calorimetry

$$\begin{pmatrix}\text{Total heat lost}\\ \text{by steam to become}\\ \text{water at } 0\ {}^\circ\text{C}\end{pmatrix} = \begin{pmatrix}\text{Total heat gained}\\ \text{by ice to become}\\ \text{water at } 0\ {}^\circ\text{C}\end{pmatrix}$$

$$\Rightarrow \quad 540m + m(1)(100-0) = 3200(0.5)(10) + 3200(80)$$

$$\Rightarrow \quad 640m = 272000$$

$$\Rightarrow \quad m = 425 \text{ g}$$

**Hence, the correct answer is (C).**

**189.** Energy received per second by the planet is $\frac{P}{4\pi d^2}(\pi R^2)$

where $P$ is power radiated by the sun and $R$ is the radius of the planet.

Further, energy radiated per second by the planet (according to Stefan's Law) is $\sigma(4\pi R^2)T_0^4$. For thermal equilibrium to exist, we get

$$\frac{P}{4\pi d^2}(\pi R^2) = \sigma(4\pi R^2)T_0^4$$

$$\Rightarrow \quad T_0^4 \propto d^{-2}$$

$$\Rightarrow \quad T_0 \propto d^{-1/2} \qquad \{\text{OPTION } \mathbf{(D)}\}$$

**Hence, the correct answer is (D).**

**190.** Since $V = kT^{2/3}$, so $TV^{-3/2} = \text{constant}$

For a polytropic process $TV^{x-1} = \text{constant}$

$$\Rightarrow \quad x - 1 = -\frac{3}{2}$$

$$\Rightarrow \quad x = -\frac{1}{2}$$

Work done in a polytropic process is

$$W = \frac{nR}{1-x}(T_2 - T_1), \text{ where } x = -\frac{1}{2}$$

$$\Rightarrow \quad W = \frac{nR}{1+(1/2)}(30) = 20R$$

**Hence, the correct answer is (B).**

**191.** From Kinetic Theory of Gases, $p = \frac{2}{3}\left(\frac{E}{V}\right)$

$$\Rightarrow \quad E = \frac{3}{2}pV$$

**Hence, the correct answer is (D).**

**192.** Efficiency of generator is,

$$\eta = 0.9 = \frac{P_{\text{out}}}{P_{\text{in}}} = \frac{P_{\text{out}}}{1000}$$

$$\Rightarrow \quad P_{\text{out}} = 900 \text{ W}$$

$$\Rightarrow \quad 900 = mc\Delta T + mL$$

$$\Rightarrow \quad 900 = m(4200)(100-20) + m(2250 \times 10^3)$$

$$\Rightarrow \quad m = \frac{900}{336000 + 2250000} = 0.00035 \text{ kg}$$

$$\Rightarrow \quad m = 0.35 \text{ g}$$

**Hence, the correct answer is (C).**

**193.** Internal energy of an ideal gas depends on temperature only and change in internal energy.

$\Delta U = nC_V\Delta T$ is applicable for all processes.

**Hence, the correct answer is (B).**

**194.** $$W=\int PdV = a\int_{V_1}^{V_2}\frac{dV}{V}+b\int_{V_1}^{V_2}dV$$

$$\Rightarrow \quad W = a\log_e\left(\frac{V_2}{V_1}\right)+b\left(V_2-V_1\right)$$

**Hence, the correct answer is (D).**

**195.** According to *FLTD*, we have

$$\Delta U = Q - W$$

Also, work done $W$ equals area under the curve

$$\Rightarrow \quad W=\begin{pmatrix}\text{Area of Half}\\ \text{Ellipse i.e. } \pi ab/2\end{pmatrix}+\begin{pmatrix}\text{Area of}\\ \text{Rectangle}\end{pmatrix}$$

$$\Rightarrow \quad W=\left[\frac{\pi}{2}\times(7-4.2)\times10^{-3}\times(500-300)\times10^{3}\right]+\left[(7-1.4)\times10^{-3}\times300\times10^{3}\right]\text{ J}$$

$$\Rightarrow \quad W = 2.56\times10^{3}\text{ J}$$

$$\Rightarrow \quad \Delta U = 5.76\times10^{3}-2.56\times10^{3}=3.2\times10^{3}\text{ J}$$

**Hence, the correct answer is (A).**

**196.** Since $v_{\text{rms}}=\sqrt{\dfrac{3RT}{M}}$

$T$ is doubled and $M$ is halved. Therefore, r.m.s. speed will become two times or 600 $\text{ms}^{-1}$.

**Hence, the correct answer is (C).**

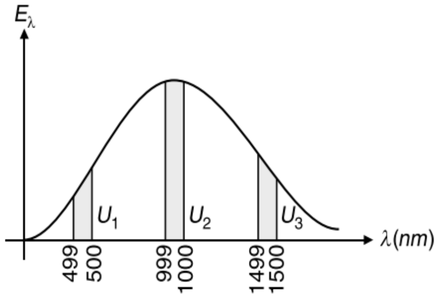
**197.** Wein's Displacement Law is

$$\lambda_m T = b \qquad \{b = \text{Wein's constant}\}$$

$$\Rightarrow \quad \lambda_m=\frac{b}{T}=\frac{2.88\times10^{6}\text{ nm-K}}{2880\text{ K}}$$

$$\Rightarrow \quad \lambda = 1000\text{ nm}$$

Energy distribution with wavelength will be as follows



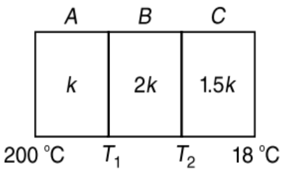
$\lambda_m$ = 1000 nm

From the graph it is clear that

$$U_2 > U_1 \qquad \{\text{In fact } U_2 \text{ is maximum}\}$$

**Hence, the correct answer is (D).**

**198.** $$\frac{kA(200-T_1)}{\ell}=\frac{2kA(T_1-T_2)}{\ell}=\frac{1.5kA(T_2-18)}{\ell}$$



$$\Rightarrow \quad 200-T_1=2T_1-2T_2$$

$$\Rightarrow \quad 3T_1-2T_2=200 \qquad \ldots(1)$$

Further, $200-T_1=\dfrac{3}{2}(T_2-18)$

$$\Rightarrow \quad 2T_1+3T_2=454 \qquad \ldots(2)$$

Solving (1) and (2), we get

$$T_1 = 116\ ^\circ\text{C}$$

**Hence, the correct answer is (D).**

**199.** The change in internal energy for any process is

$$\Delta U = nC_V\Delta T$$

(Do not develop a MISCONCEPTION that $\Delta U = nC_V\Delta T$ only for an isochoric process)

**Hence, the correct answer is (D).**

**200.** Let the initial pressure of the three samples be $P_A$, $P_B$ and $P_C$, then

$$P_A(V)^{3/2}=(2V)^{3/2}P$$

$$\Rightarrow \quad P_B = P$$

$$P_C(V)=P(2V)$$

$$\Rightarrow \quad P_A:P_B:P_C=(2)^{3/2}:1:2=2\sqrt{2}:1:2$$

**Hence, the correct answer is (B).**

**201.** Since, we know that $\dfrac{\Delta Q}{\Delta t}=\dfrac{KA(T_1-T_2)}{L}$

In case of sphere $A$, we get

$$\frac{\frac{4}{3}\pi(20)^3\times\rho_{\text{ice}}\times L_{\text{ice}}}{80\times60}=\frac{K_A\times4\pi\times(20)^2(T_1-T_2)}{0.2} \qquad \ldots(1)$$

In case of sphere $B$, we get

$$\frac{\frac{4}{3}\pi(30)^3\times\rho_{\text{ice}}\times L_{\text{ice}}}{t\times60}=\frac{K_B\times4\pi\times(30)^2(\theta_1-\theta_2)}{0.1} \qquad \ldots(2)$$

Dividing (1) by (2), we get

$$\frac{(20/80)}{(30/t)}=\frac{K_A}{2K_B}=\frac{1}{4}$$

$$\Rightarrow \quad t = 30\text{ minutes}$$

**Hence, the correct answer is (A).**

**202.** $$n=\frac{PV}{RT}=\frac{2\times10^{5}\times10^{-3}}{8.3\times300}=0.080$$

$$\Rightarrow \quad n=\frac{m}{M}=0.080$$

$$\Rightarrow \quad m=(0.080)(4\text{ g})=0.32\text{ g}$$

**Hence, the correct answer is (B).**

**203.** Since, $(3L)\alpha_{\text{eff}}\Delta\theta = L\alpha\Delta\theta+2L(2\alpha)(\Delta\theta)$

$$\Rightarrow \quad \alpha_{\text{eff}}=\frac{5}{3}\alpha$$

**Hence, the correct answer is (C).**

**204.** By Law of Calorimetry, heat lost by steam must be equal to heat gained by water. Since, find temperature of water is 60 °C, so we have

$$(8)L_{\text{steam}}+(8)c_{\text{water}}(100-60)=(80)c_{\text{water}}(60-10)$$

$$\Rightarrow\quad (8)L_{\text{steam}}+(8)(1)(100-60)=(80)(1)(60-10)$$

$$\Rightarrow\quad (8)L_{\text{steam}}=4000-320=3680$$

$$\Rightarrow\quad L_{\text{steam}}=460\text{ calg}^{-1}$$

**Hence, the correct answer is (A).**

**205.** Conceptual

**Hence, the correct answer is (B).**

**206.** $\lambda_m T=\text{constant}$

$$\Rightarrow\quad 510T_1=350T_2$$

$$\Rightarrow\quad \frac{T_1}{T_2}=0.69$$

**Hence, the correct answer is (B).**

**207.** $\%\text{age}=\dfrac{dU}{dQ}\times100=\dfrac{nC_VdT}{nC_PdT}\times100$

$$\Rightarrow\quad \%\text{age}=\frac{C_V}{C_P}\times100=\frac{3}{5}\times100=60\%$$

Remaining $\%\text{age}=(100-60)\%=40\%$

**Hence, the correct answer is (C).**

**208.** The ratio of rms speeds of molecules of gas $A$ to that of molecules of gas $B$ is

$$\frac{v_A}{v_B}=\sqrt{\frac{M_B}{M_A}}=\sqrt{3}$$

Since $v_A^2=v_x^2+v_y^2+v_z^2$ and by postulates of KTG, we have $v_x=v_y=v_z$

$$\Rightarrow\quad v_x^2=v_y^2=v_z^2=\frac{v_A^2}{3}=\frac{1}{3}\left(3v_B^2\right)$$

$$\Rightarrow\quad v_x^2:v_B^2=1:1$$

$$\Rightarrow\quad \frac{v^2}{V^2}=1$$

**Hence, the correct answer is (D).**

**209.** Since, $P\propto V$ $\{\because P=aV\}$

Therefore, pressure and volume both are doubled or temperature becomes four times (as $T\propto PV$) or 1200 K. So, change in temperature is 900 K.

**Hence, the correct answer is (A).**

**210.** Heat released when 20 g of water cools from 20 °C to 0 °C is

$$Q_1=m_{\text{water}}c_{\text{water}}\Delta T=(20)(1)(20)=400\text{ cal}$$

Heat required to raise temperature of 20 g of ice from −10 °C to 0 °C is

$$Q_2=m_{\text{ice}}c_{\text{ice}}\Delta T=(20)(0.5)(10)=100\text{ cal}$$

Heat required to melt 20 g of ice at 0 °C is

$$Q_3=m_{\text{ice}}L_{\text{ice}}=(20)(80)=1600\text{ cal}$$

Since $Q_1>Q_2$, so temperature of ice will reach 0 °C. However, we observe that $Q_1<Q_2+Q_3$, therefore the complete ice will not melt and final mixture will have both ice and water. The amount of ice melted $m$ is

$$m=\frac{\text{Available Heat}}{\text{Latent Heat}}=\frac{400-100}{80}=3.75\text{ g}$$

So in equilibrium, the calorimeter will have the mass of ice and water given by

$$m'_{\text{ice}}=20-3.75=16.25\text{ g}$$

$$m'_{\text{water}}=20+3.75=23.75\text{ g}$$

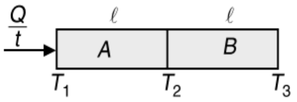
**Hence, the correct answer is (A).**

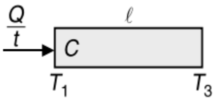
**211.** $\eta=1-\dfrac{300}{600}=0.5$

**Hence, the correct answer is (C).**

**212.** Since $\dfrac{Q}{t}=k_{\text{eq}}A\left(\dfrac{T_1-T_3}{\ell}\right)$

$$\Rightarrow\quad \frac{Q}{t}=\frac{2k_Ak_B}{k_A+k_B}A\left(\frac{T_1-T_3}{2\ell}\right)\qquad\ldots(1)$$





Also, $\dfrac{Q}{t}=k_CA\left(\dfrac{T_1-T_3}{\ell}\right)$ $\ldots(2)$

From (1) and (2), we get $k_C=\dfrac{k_Ak_B}{k_A+k_B}$

**Hence, the correct answer is (B).**

**213.** For Isobaric Process

$$W_{\text{isob}}=P(V_2-V_1)=P(2V-V)=PV$$

For Isothermal Process

$$W_{\text{isot}}=nRT\ln\left(\frac{V_2}{V_1}\right)=nRT\ln(2)=PV\ln(2)$$

For Adiabatic Process

$$W_{\text{ad}}=\frac{P_1V_1-P_2V_2}{\gamma-1}$$

Since $PV^{\gamma}=P_2(2V)^{\gamma}$, so $P_2=P/2^{\gamma}$

$$W_{\text{ad}}=\frac{PV-\left(P/2^{\gamma}\right)(2V)}{\gamma-1}=\frac{PV\left(1-2^{1-\gamma}\right)}{\gamma-1}$$

**Hence, the correct answer is (C).**

**214.** Coefficient of performance

$$\beta=\frac{\text{Heat Extracted }(Q_2)\text{ From Sink}}{\text{External Work Input }(W)}=\frac{T_2}{T_1-T_2}$$

$$\Rightarrow\quad \frac{Q_2}{W}=\frac{(1\text{ g})\left(80\text{ calg}^{-1}\right)}{W}=\frac{273}{27}$$

$$\Rightarrow\quad W=7.9\text{ cal}$$

**Hence, the correct answer is (A).**

**215.** When the vessel is suddenly stopped the ordered motion of gas is converted into its disordered motion i.e., internal energy of the gas is increased. Hence,

$$\Delta U=\frac{1}{2}mv^2 \qquad \{\because\ m=nM\}$$

$$\Rightarrow\quad nC_v\Delta T=\frac{1}{2}(nM)v^2$$

where $n$ is the number of moles of the gas.

$$\Rightarrow\quad \Delta T=\frac{Mv^2}{2C_v}$$

$$\Rightarrow\quad \Delta T=\frac{Mv^2}{2\left(\dfrac{R}{\gamma-1}\right)} \qquad \left\{\because\ C_v=\frac{R}{\gamma-1}\right\}$$

$$\Rightarrow\quad \Delta T=\frac{Mv^2(\gamma-1)}{2R}$$

**Hence, the correct answer is (B).**

**216.** Since $dQ=mcdT$

$$\Rightarrow\quad Q=\int dQ=m\alpha\int_1^3 T^3dT$$

$$\Rightarrow\quad Q=(4\alpha)\frac{T^4}{4}\bigg|_1^3=\alpha\left(3^4-1^4\right)=80\alpha$$

**Hence, the correct answer is (C).**

**217.** Given that, $U=a+bPV=a+b(nRT)$ $\{\because\ PV=nRT\}$

Since, $C_V=\dfrac{1}{n}\dfrac{dU}{dT}=bR$

$$\Rightarrow\quad C_P=C_V+R=bR+R$$

$$\Rightarrow\quad \gamma=\frac{C_P}{C_V}=\frac{b+1}{b}$$

**Hence, the correct answer is (A).**

**218.** Solar power received by earth is $1400\ \text{Wm}^{-2}$

Solar power received by $0.2\ \text{m}^2$ area of earth is

$$P=\left(1400\ \text{Wm}^{-2}\right)\left(0.2\ \text{m}^2\right)=280\ \text{W}$$

Mass of ice $=280\ \text{g}=0.28\ \text{kg}$

Heat required to melt ice is

$$Q=(0.28)\left(3.3\times10^5\right) \qquad \{\because\ Q=mL\}$$

$$\Rightarrow\quad Q=9.24\times10^4\ \text{J}$$

$$\Rightarrow\quad t=\frac{9.28\times10^4}{280}=331\ s\approx330\ s$$

**Hence, the correct answer is (B).**

**219.** Since $C_P-C_V=R$, so $\dfrac{C_P}{C_V}-1=\dfrac{R}{C_V}$

$$\Rightarrow\quad C_V=\frac{R}{\gamma-1}\ \text{and}\ C_P=\frac{\gamma R}{\gamma-1}$$

**Hence, the correct answer is (B).**

**220.** At constant pressure, $\dfrac{V_1}{T_1}=\dfrac{V_2}{T_2}$

$$\Rightarrow\quad \frac{1}{400}=\frac{V_2}{300}$$

$$\Rightarrow\quad V_2=0.75\ \text{L}$$

$$\Rightarrow\quad \Delta V=0.75-1=-0.25\ \text{L}=-250\ \text{mL}$$

**Hence, the correct answer is (D).**

**221.** Since, $PV=nRT$

$$\Rightarrow\quad (2P)V=n'RT$$

$$\Rightarrow\quad n'=2n$$

**Hence, the correct answer is (B).**

**222.** Since $\dfrac{Q_1}{Q_2}=\dfrac{T_1}{T_2}$, so $\dfrac{300}{150}=\dfrac{500}{T_2}$

$$\Rightarrow\quad T_2=250\ \text{K}$$

**Hence, the correct answer is (C).**

**223.** Rate of flow of heat through the cork is

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

$$\Rightarrow\quad \frac{Q}{t}=\frac{0.008\times100\times(30-0)}{4}=6\ \text{cals}^{-1}$$

Therefore, time taken to melt 200 g of ice is

$$t=\frac{mL_{\text{ice}}}{Q/t}=\frac{(200)(80)}{6}=\frac{8000}{3}\ \text{s}$$

$$\Rightarrow\quad t\approx45\ \text{min}$$

**Hence, the correct answer is (A).**

**224.** According to Newton's Law of Cooling Rate of Cooling $R\propto$Temperature Difference

Hence, $R=K(\theta-\theta_0)$

This is an equation of a straight line.

**Hence, the correct answer is (B).**

**225.** Work done in the cycle is

$$W=(\text{Area of rectangle } ABCD)$$

$$\Rightarrow\quad W=(2P_0-P_0)(2V_0-V_0)=P_0V_0$$

Heat added in the process $A$ to $B$ is

$$Q_{AB}=nC_V\Delta T=n\left(\frac{3R}{2}\right)\Delta T=\frac{3}{2}(2P_0V_0-P_0V_0)$$

$$\Rightarrow\quad Q_{AB}=\frac{3}{2}P_0V_0$$

Heat added in the process $B$ to $C$ is

$$Q_{BC}=nC_P\Delta T=n\left(\frac{5R}{2}\right)\Delta T=\frac{5}{2}(4P_0V_0-2P_0V_0)$$

$$\Rightarrow\quad Q_{BC}=5P_0V_0$$

Efficiency $\eta$ is

$$\eta=\frac{W}{Q_{\text{input}}}=\frac{P_0V_0}{\dfrac{3}{2}P_0V_0+5P_0V_0}=\frac{2}{13}$$

$$\Rightarrow\quad \%\ \eta=\frac{200}{13}=15.4\%$$

**Hence, the correct answer is (A).**

**226.** 100 °C ≡ 150° of the thermometer

$$\Rightarrow\quad 1\ ^\circ\text{C}=1.5^\circ\ \text{of the thermometer}$$

$$\Rightarrow\quad 34\ ^\circ\text{C}=51\ ^\circ\text{C of the thermometer}$$

So, thermometer will read $-20^\circ + 51^\circ = 31^\circ$

**Hence, the correct answer is (A).**

**227.** Since $E = \sigma(673)^4$ and $2E = \sigma T^4$

$$\Rightarrow \quad T = 2^{\frac{1}{4}}(673) = 1.18(673) \approx 800 \text{ K}$$

**Hence, the correct answer is (D).**

**228.** Since, the gas is expanding isobarically, so $Q = nC_P\Delta T$

$$\Rightarrow \quad 3.5RT_0 = 10\left(\frac{7R}{2}\right)(T - T_0)$$

$$\Rightarrow \quad T_0 = 10T - 10T_0$$

$$\Rightarrow \quad T = 1.1T_0$$

According to Charle's Law, we have $\dfrac{V}{1.1T_0} = \dfrac{V_0}{T_0}$

$$\Rightarrow \quad V = 1.1V_0$$

**Hence, the correct answer is (A).**

**229.** $P \propto T$ (at constant volume)

**Hence, the correct answer is (D).**

**230.** Since, $v_{O_2} = \dfrac{1}{2}v_{H_2}$

$$\Rightarrow \quad \sqrt{\frac{3RT}{32}} = \frac{1}{2}\sqrt{\frac{3R(273)}{2}}$$

$$\Rightarrow \quad \frac{T}{32} = \frac{273}{8}$$

$$\Rightarrow \quad T = 4(273) = 1092 \text{ K} = 819\ ^\circ\text{C}$$

**Hence, the correct answer is (D).**

**231.** A cooking pot must conduct more. Also, it must absorb less heat itself. Hence a good cooking pot has low specific heat and high conductivity.

**Hence, the correct answer is (D).**

**232.** Since $\dfrac{Q}{t} = kA\left(\dfrac{dT}{dx}\right)$, so $\dfrac{mL}{t} = kA\left(\dfrac{dT}{dx}\right)$

$$\Rightarrow \quad k \propto \frac{1}{t} \text{ i.e., } \frac{k_1}{k_2} = \frac{t_2}{t_1}$$

**Hence, the correct answer is (B).**

**233.** Since $Q_{AB} = nC_P\Delta T = n\dfrac{5}{2}R(2T_0 - T_0)$ and

$$Q_{BC} = W_{BC} = NR \cdot 2T_0 \log_e 2$$

$$\Rightarrow \quad \frac{Q_{AB}}{W_{BC}} = \frac{5}{4\log_e 2}$$

**Hence, the correct answer is (C).**

**234.** Let the length of the part of metal $A$ be $L$ (in cm). Then length of part of metal $B$ will be $(20 - L)$ cm. Since the change in length is proportional to original length, so we have

$$\frac{0.02}{20}L + \frac{0.04}{20}(20 - L) = 0.025$$

$$\Rightarrow \quad 0.02L + 0.8 - 0.04L = 0.5$$

$$\Rightarrow \quad L = 15 \text{ cm}$$

**Hence, the correct answer is (C).**

**235.** The molar specific heat of an ideal gas $C = \dfrac{đQ}{dT}$ can have any value lying between $-\infty$ and $\infty$

**Hence, the correct answer is (D).**

**236.** Adiabatic constant for the mixture is

$$\gamma_{\text{mix}} = \frac{n_1(C_P)_1 + n_2(C_P)_2}{n_1(C_V)_1 + n_2(C_V)_2}$$

$$\Rightarrow \quad \gamma_{\text{mix}} = \frac{(0.125)\left(\frac{7}{2}R\right) + (0.5)\left(\frac{5}{2}R\right)}{(0.125)\left(\frac{5}{2}R\right) + (0.5)\left(\frac{3}{2}R\right)}$$

$$\Rightarrow \quad \gamma_{\text{mix}} = \frac{0.4375 + 1.25}{0.3125 + 0.75} = \frac{27}{17}$$

For an adiabatic process, we have

$$T_2V_2^{\gamma-1} = T_1V_1^{\gamma-1}$$

$$\Rightarrow \quad T_2 = 390\left(\frac{2}{3}\right)^{\frac{10}{17}} \text{ K}$$

**Hence, the correct answer is (A).**

**237.** Since the length of the liquid column does not alter in the tube, hence we have superficial expansion and so $\gamma = 2\alpha$, instead of $\gamma = 3\alpha$.

**Hence, the correct answer is (B).**

**238.** Process $A$-$B$ is an isothermal process i.e., $P \propto \dfrac{1}{V}$ and since, $\rho \propto \dfrac{1}{V}$, $\rho$-$V$ graph will be a rectangular hyperbola. Pressure is increasing. Therefore, volume will decrease and hence, density will increase.

Process $B$-$C$ is an isochoric process. Therefore,

$V$ =constant and since $\rho = \dfrac{m}{V}$, density is also constant i.e., $\rho$-$V$ graph is a dot.

Process $C$-$D$ is inverse of $A$-$B$ and $D$-$A$ is inverse of $B$-$C$.

**Hence, the correct answer is (B).**

**239.** Let $T_{\text{faulty}}$ be the reading of faulty thermometer and $T_C$ be the correct reading on Centigrade scale, then

$$\frac{T_{\text{faulty}} - 10}{90 - 10} = \frac{T_C - 0}{100 - 0}$$

Given that $T_{\text{faulty}} = T_C = T$ (say)

$$\Rightarrow \quad \frac{T - 10}{90 - 10} = \frac{T - 0}{100 - 0}$$

$$\Rightarrow \quad 100(T - 10) = 80T$$

$$\Rightarrow \quad 20T = 1000$$

$$\Rightarrow \quad T = 50\ ^\circ\text{C}$$

**Hence, the correct answer is (C).**

**240.** Using $\dfrac{T_1 - T_2}{t} = \alpha\left(\dfrac{T_1 + T_2}{2} - \theta_0\right)$

In the first case

$$\frac{75 - 65}{2} = \alpha\left(\frac{75 + 65}{2} - 30\right) \qquad \text{...(1)}$$

In the second case

$$\frac{55-45}{t}=\alpha\left(\frac{55+45}{2}-30\right) \qquad \ldots(2)$$

Dividing equations (1) by (2), we get $\frac{t}{2}=2$

$\Rightarrow \quad t=4$ min

**Hence, the correct answer is (C).**

**241.** Since, $H=(1)\left(\frac{3R}{2}\right)(10)=15R \qquad \{\because H=nC_V\Delta T\}$

Also, $H'=(2)\left(\frac{7R}{2}\right)(5)=35R \qquad \{\because H'=nC_P\Delta T'\}$

$\Rightarrow \quad H'=\frac{7}{3}(15R)=\frac{7}{3}H$

**Hence, the correct answer is (D).**

**242.** Let $(P_1,V_1,T_1)$ be the initial pressure, volume and temperature of the gas. When the gas is first expanded isothermally, then $V$ increases and $P$ decreases, such that

$$(P_1,V_1,T_1)\xrightarrow{\text{isothermal}}(P_2,V_2,T_1)$$

When the gas is compressed adiabatically to its original volume, then $V$ decreases and hence $P$ and $T$ both increase, such that

$$(P_2,V_2,T_1)\xrightarrow{\text{adiabatic}}(P_3,V_1,T_2)$$

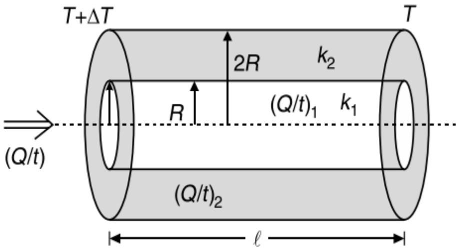
To restore the gas to its original state, the simplest operation is

$$(P_3,V_1,T_2)\xrightarrow{\text{isochoric}}(P_1,V_1,T_1)$$

This simplest operation should decrease both pressure and temperature and hence it can be an isochoric cooling process.

**Hence, the correct answer is (B).**

**243.** Since $\frac{Q}{t}=\left(\frac{Q}{t}\right)_1+\left(\frac{Q}{t}\right)_2$



$\Rightarrow \quad k_{eq}\pi(2R)^2\frac{\Delta T}{\ell}=k_1(\pi R^2)\frac{\Delta T}{\ell}+k_2\left[\pi(2R)^2-\pi R^2\right]\frac{\Delta T}{\ell}$

$\Rightarrow \quad 4k_{eq}=k_1+3k_2$

$\Rightarrow \quad k_{eq}=\frac{k_1+3k_2}{4}$

**Hence, the correct answer is (C).**

**244.** $dQ=mcdT=0.1(100T+500)dT$

$\Rightarrow \quad Q=\int_{20}^{400}(10T+50)dT=\left[10\left(\frac{T^2}{2}\right)+50T\right]_{20}^{40}$

$\Rightarrow \quad Q=5(1600-400)+50(40-20)=7000$ J

**Hence, the correct answer is (C).**

**245.** $P$-$V$ diagram of the gas is a straight line passing through origin. Hence, $P\propto V$

$\Rightarrow \quad PV^{-1}=\text{constant}$

Molar heat capacity in process $PV^x=\text{constant}$ is

$C=\frac{R}{\gamma-1}+\frac{R}{1-x}$, where $\gamma=1.4$ for diatomic gas

$\Rightarrow \quad C=\frac{R}{1.4-1}+\frac{R}{1+1}=3R$

**Hence, the correct answer is (C).**

**246.** Given that, $L_i-L_b=0.1$ m $\qquad \ldots(1)$

$\Rightarrow \quad \Delta L_b-\Delta L_i=0$

$\Rightarrow \quad L_b\alpha_b=L_i\alpha_i$

$\Rightarrow \quad \frac{L_b}{L_i}=\frac{\alpha_i}{\alpha_b}=\frac{12}{18}=\frac{2}{3} \qquad \ldots(2)$

Solving (1) and (2), we get

$L_i=0.3$ m and $L_b=0.2$ m

**Hence, the correct answer is (C).**

**247.** Since, $Q=nC\Delta T \qquad \ldots(1)$

By FLTD, we have

$$\Delta U=Q-W=Q-\frac{Q}{4}=\frac{3Q}{4}$$

$\Rightarrow \quad \frac{3Q}{4}=nC_V\Delta T \qquad \ldots(2)$

Dividing (1) by (2), we get

$$C=\frac{4}{3}C_V=\frac{4}{3}\left(\frac{5R}{2}\right)=\frac{10R}{3}$$

**Hence, the correct answer is (C).**

**248.** Process 2 is an isothermal process

Hence, $\Delta U_2=0$

Process 1 is an isobaric $(P_1=\text{constant})$ expansion

Hence, temperature of the gas will increase

$\Rightarrow \quad \Delta U_1=\text{positive}$

Process 3 is an adiabatic expansion. Hence, temperature will decrease

$\Rightarrow \quad \Delta U_3=\text{negative}$

Therefore, $\Delta U_1>\Delta U_2>\Delta U_3$ is the correct option

**Hence, the correct answer is (A).**

**249.** Conceptual

**Hence, the correct answer is (C).**

**250.** Since, $PV=nRT=\frac{m}{M}RT$, where $m$ is mass of the gas of molar mass $M$. The slope of $T$-$P$ graph is

$$\frac{dT}{dP}=\tan\theta=\frac{MV}{mR}\propto\frac{1}{m}$$

**Hence, the correct answer is (B).**

**251.** $A$ is free to move, therefore, heat will be supplied at constant pressure.

$$dQ_A = nC_P dT_A \qquad \dots(1)$$

$B$ is held fixed, therefore, heat will be supplied at constant volume.

$$dQ_B = nC_V dT_B \qquad \dots(2)$$

But $dQ_A = dQ_B$ {given}

$\Rightarrow \quad nC_P dT_A = nC_V dT_B$

$\Rightarrow \quad dT_B = \left(\dfrac{C_P}{C_V}\right) dT_A$

$\Rightarrow \quad dT_B = \gamma\left(dT_A\right)$

Since, $\gamma_{\text{diatomic}} = 1.4$ and $dT_A = 30\text{ K}$

$\Rightarrow \quad dT_B = (1.4)(30\text{ K}) = 42\text{ K}$

**Hence, the correct answer is (D).**

**252.** Specific heat $C = \dfrac{\Delta Q}{\Delta T} = \dfrac{1}{\Delta T}(\Delta U + W) = C_V + \dfrac{W}{\Delta T}$

For the given process, $W = 4V_0\left(\dfrac{9P_0}{2}\right) = 18P_0V_0$

Also, $\Delta T = T_2 - T_1 = \dfrac{(6P_0)(5V_0)}{R} - \dfrac{(3P_0)V_0}{R} = \dfrac{27P_0V_0}{R}$

and $C_V = \dfrac{3}{2}R$

$\Rightarrow \quad C = \dfrac{3R}{2} + \dfrac{2R}{3} = \dfrac{13R}{6}$

**Hence, the correct answer is (B).**

**253.** Since work is being done at the expense of internal energy so it must be an adiabatic process i.e., $dQ = 0$

$\Rightarrow \quad n = \gamma$

**Hence, the correct answer is (C).**

**254.** Since $V = \text{constant}$, so $W = 0$

$\Rightarrow \quad Q = nC_V\Delta T$

Now, $PV = nRT$

$\Rightarrow \quad V\Delta P = nR\Delta T$ {$V$ =constant}

$\Rightarrow \quad \Delta T = \left(\dfrac{V}{nR}\right)\Delta P$

For both processes $\Delta P$ and number of moles are same. Since $V$ is more for process $CD$, hence $\Delta T$ is more for process $CD$. So, $Q_{CD} > Q_{AB}$

**Hence, the correct answer is (C).**

**255.** Since, no heat flows through $AB$, so

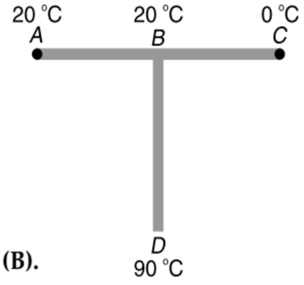
$\theta_B = 20\ °\text{C}$

Since, $H_{DB} = H_{BC}$

$\Rightarrow \quad \dfrac{(90° - 20°)}{\ell_{BD}/KA} = \dfrac{(20° - 0°)}{\ell_{BC}/KA}$

$\Rightarrow \quad \dfrac{\ell_{BD}}{\ell_{BC}} = \dfrac{7}{2}$

**Hence, the correct answer is (B).**



**256.** Since $\rho = \dfrac{PM}{RT}$, so $\rho \propto \dfrac{P}{T}$

Also, $\left(\dfrac{P}{T}\right)_A = \dfrac{P_0}{T_0}$ and $\left(\dfrac{P}{T}\right)_B = \left(\dfrac{3}{2}\right)\dfrac{P_0}{T_0}$

$\Rightarrow \quad \left(\dfrac{P}{T}\right)_B = \dfrac{3}{2}\left(\dfrac{P}{T}\right)_A$

$\Rightarrow \quad \rho_B = \dfrac{3}{2}\rho_A = \dfrac{3}{2}\rho_0$

**Hence, the correct answer is (B).**

**257.** According to Ideal Gas Equation, we have $PV = nRT$

$\Rightarrow \quad n = \dfrac{PV}{RT}$

Given that $P$, $V$, $T$ are same, so, $n_1 = n_2 = n_3$

Also $v_{\text{rms}} = \sqrt{\dfrac{3RT}{M}}$

Since, $M_{\text{neon}} < M_{\text{chlorine}} < M_{\text{uranium hexafluoride}}$

$\Rightarrow \quad v_1 > v_2 > v_3$

**Hence, the correct answer is (D).**

**258.** Since, $\dfrac{\Delta L}{L} = \alpha\Delta T$

$\Rightarrow \quad -\dfrac{1.1\times10^{-3}}{10} = 11\times10^{-6}\Delta T$

$\Rightarrow \quad \Delta T = T_f - T_i = -10$

$\Rightarrow \quad T_f = 27 - 10 = 17\ °\text{C}$

**Hence, the correct answer is (C).**

**259.** In isochoric process $V = \text{constant}$ and $P \propto T$

Therefore, $P$-$T$ graph is a straight line passing through origin. But since

$$P = \left(\frac{nR}{V}\right)T$$

Slope of the straight line $\propto \dfrac{1}{V}$

$$(\text{Slope})_{12} < (\text{Slope})_{34}$$

$\Rightarrow \quad V_2 > V_3$

Also $V_1 = V_2$ and $V_3 = V_4$

**Hence, the correct answer is (A).**

**260.** **METHOD I**

Let resistance at $0\ °\text{C}$ be $R_0$. Then

$$2 = R_0\left(1 + \alpha(20)\right) \qquad \dots(1)$$

$$4 = R_0\left(1 + \alpha(100)\right) \qquad \dots(2)$$

Dividing (2) by (1), we get

$$2 = \frac{1 + 100\alpha}{1 + 20\alpha}$$

$\Rightarrow \quad 2 + 40\alpha = 1 + 100\alpha$

$\Rightarrow \quad \alpha = \dfrac{1}{60}\ °\text{C}^{-1}$

If resistance is $2.2\ \Omega$ at $T\ °\text{C}$, then we have

$$2.2 = R_0(1+\alpha T) \qquad \ldots(3)$$

Dividing equation (3) by (1), we get

$$\frac{2.2}{2} = \frac{1+\alpha T}{1+20T} = \frac{1+\frac{T}{60}}{1+\frac{20}{60}}$$

$$\Rightarrow \quad (1.1)\left(\frac{4}{3}\right) = 1+\frac{T}{60}$$

$$\Rightarrow \quad T = 60(1.463-1) \approx 28\ ^\circ\mathrm{C}$$

### METHOD II

$$\frac{T-20}{100-20} = \frac{R_T - R_{20}}{R_{100}-R_{20}} = \frac{2.2-2}{4-2}$$

$$\Rightarrow \quad T = \left(\frac{0.2}{2}\times 80\right) + 20 = 28\ ^\circ\mathrm{C}$$

**Hence, the correct answer is (D).**

**261.** Conceptual

**Hence, the correct answer is (B).**

**262.** (Rate of Loss of Heat) ∝ (Temperature Difference)

$$\Rightarrow \quad \frac{dQ}{dt} \propto T - T_0$$

$$\Rightarrow \quad 10 = \beta(50-20)$$

$$\Rightarrow \quad \beta = \frac{1}{3} \quad \text{(where } \beta \text{ is just a constant of proportionality)}$$

At average temperature of 35 °C we have

$$\frac{dQ}{dt} = \beta(35-20) = \frac{1}{3}(15) = 5\ \mathrm{Js}^{-1}$$

So, heat lost in a time of one minute (= 60 second) is

$$Q_{\text{total}} = 5\times 60 = 300\ \mathrm{J}$$

By definition, heat capacity is

$$c = \frac{Q_{\text{total}}}{\Delta T} = \frac{300}{0.2} = 1500\ \mathrm{J}\,(^\circ\mathrm{C})^{-1}$$

**Hence, the correct answer is (B).**

**263.** $\mathrm{KE} = n\left(\frac{3}{2}RT\right)$

$$\Rightarrow \quad n_1\left(\frac{3}{2}RT_1\right) = n_2\left(\frac{3}{2}RT_2\right)$$

Since $n_2 = 2n_1$, so $T_1 = 2T_2$

Also $PV = nRT$ and since, $V = \text{constant}$, so $P \propto nT$

$$\Rightarrow \quad \frac{P_1}{P_2} = \left(\frac{n_1}{n_2}\right)\left(\frac{T_1}{T_2}\right) = \left(\frac{1}{2}\right)(2) = 1$$

**Hence, the correct answer is (B).**

**264.** Since $dS = \frac{dQ}{T}$

$$\Rightarrow \quad dS = \frac{dU}{T} + \frac{PdV}{T}$$

$$\Rightarrow \quad dS = nC_V\frac{dT}{T} + \frac{nRT}{V}\frac{dV}{T}$$

$$\Rightarrow \quad dS = nC_V\frac{dT}{T} + nR\frac{dV}{V}$$

$$\Rightarrow \quad \int_{S_1}^{S_2} dS = nC_V\int_{T_1}^{T_2}\frac{dT}{T} + nR\int_{V_1}^{V_2}\frac{dV}{V}$$

$$\Rightarrow \quad S_2 - S_1 = \Delta S = nC_V \ell n\left(\frac{T_2}{T_1}\right) + nR\ell n\left(\frac{V_2}{V_1}\right)$$

**Hence, the correct answer is (A).**

**265.** Since $dU = 0$, so by First Law of Thermodynamics

$$dQ_{\text{Cyclic}} = dW_{\text{Cyclic}}$$

Process $B \to C$ is isochoric, so

$$\Rightarrow \quad \text{đ}W_{B\to C} = 0 \qquad \{\because dV = 0\}$$

$$\Rightarrow \quad 5 = \text{đ}W_{A\to B} + \text{đ}W_{B\to C} + \text{đ}W_{C\to A}$$

$$\Rightarrow \quad 5 = 10(2-1) + 0 + \text{đ}W_{C\to A}$$

$$\Rightarrow \quad \text{đ}W_{C\to A} = -5\ \mathrm{J}$$

**Hence, the correct answer is (A).**

**266.** The volume of the liquid that overflows is $\Delta V = V\gamma_a\Delta T$

$$\Rightarrow \quad \frac{V}{100} = V\gamma_a(80)$$

$$\Rightarrow \quad \gamma_a = \frac{1}{8000} = 1.25\times 10^{-4}\ ^\circ\mathrm{C}^{-1}$$

**Hence, the correct answer is (A).**

**267.** $W_{AB} = 0$ as $V = \text{constant}$

$$\Rightarrow \quad Q_{AB} = \Delta U_{AB} = 50\ \mathrm{J} \qquad \{\text{given}\}$$

$$U_A = 1500\ \mathrm{J}$$

$$\Rightarrow \quad U_B = (1500+50)\ \mathrm{J} = 1550\ \mathrm{J}$$

$$W_{BC} = -\Delta U_{BC} = -40\ \mathrm{J} \qquad \{\text{given}\}$$

$$\Rightarrow \quad \Delta U_{BC} = 40\ \mathrm{J}$$

$$\Rightarrow \quad U_C = (1550+40)\,J = 1590\ \mathrm{J}$$

**Hence, the correct answer is (A).**

**268.** Since, $Q = mc_{\text{body}}\Delta T$, where $c_{\text{body}} = 1\ \mathrm{calg}^{-1}{}^\circ\mathrm{C}^{-1}$ and $\Delta T = (103-98.4)\ ^\circ\mathrm{F} = 4.6\ ^\circ\mathrm{F}$

Also we know that $\Delta C = \frac{5}{9}\Delta F$

So, a temperature increment of 4.6 °F equals a temperature increment of $(4.6)\left(\frac{5}{9}\ ^\circ\mathrm{C}\right) = 2.56\ ^\circ\mathrm{C}$

$$\Rightarrow \quad Q = (60000\ \mathrm{g})\left(1\ \mathrm{calg}^{-1}(^\circ\mathrm{C})^{-1}\right)(2.56\ ^\circ\mathrm{C})$$

$$\Rightarrow \quad Q = 153600\ \mathrm{cal} \approx 154\ \mathrm{kcal}$$

**Hence, the correct answer is (B).**

**269.** Given that, $\left(\frac{C_P}{C_V}\right)_{\text{mix}} = \frac{3}{2}$

Since $C_{P_{\text{mix}}} = \frac{n_1C_{P_1} + n_2C_{P_2}}{n_1+n_2}$ and $C_{V_{\text{mix}}} = \frac{n_1C_{V_1} + n_2C_{V_2}}{n_1+n_2}$

$$\Rightarrow \quad \frac{n_1 C_{P_1} + n_2 C_{P_2}}{n_1 C_{V_1} + n_2 C_{V_2}} = \frac{3}{2}$$

$$\Rightarrow \quad \frac{n_1 (5R/2) + n_2 (7R/2)}{n_1 (3R/2) + n_2 (5R/2)} = \frac{3}{2}$$

$$\Rightarrow \quad 10n_1 + 14n_2 = 9n_1 + 15n_2$$

$$\Rightarrow \quad n_1 = n_2$$

**Hence, the correct answer is (C).**

**270.** Since $Q = nC_p \Delta T = \frac{7}{2} nR\Delta T$ $\quad \left\{\because C_p = \frac{7}{2}R\right\}$

and $\Delta U = nC_v \Delta T = \frac{5}{2} nR\Delta T$ $\quad \left\{\because C_V = \frac{5}{2}R\right\}$

$$\Rightarrow \quad W = Q - \Delta U = nR\Delta T$$

$$\Rightarrow \quad Q : \Delta U : \Delta W = 7 : 5 : 2$$

**Hence, the correct answer is (C).**

**271.** For the first process, we have $Q_1 = \Delta U + W_1$

$$\Rightarrow \quad 8 \times 10^5 = \Delta U + 6.5 \times 10^5$$

$$\Rightarrow \quad \Delta U = 1.5 \times 10^5 \text{ J}$$

For the second process, $\Delta U$ is same, therefore,

$$Q_2 = \Delta U_2 + W_2 = \Delta U + W_2$$

$$\Rightarrow \quad 10^5 = 1.5 \times 10^5 + W_2$$

$$\Rightarrow \quad W_2 = -0.5 \times 10^5 \text{ J}$$

**Hence, the correct answer is (A).**

**272.** Since, $\rho = \frac{PM}{RT}$

Density $\rho$ remains constant, when $\frac{P}{T}$ or volume remains constant

In graph (i) volume is decreasing hence, density is increasing while in graphs (ii) and (iii) volume is increasing hence, density is decreasing. Note that volume would had been constant in case the straight line in graph (iii) had passed through origin.

**Hence, the correct answer is (C).**

**273.** Since $C_P = \frac{3}{2}R$

$$\Rightarrow \quad C_V = \frac{1}{2}R \qquad \{\because C_P - C_V = R\}$$

$$\Rightarrow \quad \gamma = 3$$

Since $\gamma = 1 + \frac{2}{f}$

$$\Rightarrow \quad f = 1$$

Possible for a monatomic gas molecule moving in a straight fixed line (one degrees of freedom).

**Hence, the correct answer is (B).**

**274.** Thermal Resistance $= \text{R} = \dfrac{\text{Temperature Difference}}{\text{Thermal Current}}$

$$\Rightarrow \quad [\text{Thermal Resistance}] = \frac{K}{\left(\dfrac{ML^2T^{-2}}{T}\right)}$$

$$\Rightarrow \quad [R] = M^{-1}L^{-2}T^3K$$

**Hence, the correct answer is (B).**

**275.** Efficiency of an ideal heat engine is $\eta = 1 - \frac{T_2}{T_1}$

$$\Rightarrow \quad \frac{60}{100} = 1 - \frac{300}{T_2}$$

$$\Rightarrow \quad T_2 = 750 \text{ K} = 477\ ^\circ\text{C}$$

**Hence, the correct answer is (C).**

**276.** Since, $P = \frac{\alpha T^2}{V}$ $\qquad (P = \text{constant})$

$$\Rightarrow \quad V = \frac{\alpha T^2}{P}$$

$$\Rightarrow \quad dV = \left(\frac{2\alpha T}{P}\right) dT$$

$$\Rightarrow \quad W = \int_{T_0}^{2T_0} P\,dV = \int_{T_0}^{2T_0} (P)\left(\frac{2\alpha T}{P}\right) dT = 3\alpha T_0^2$$

**Hence, the correct answer is (D).**

**277.** For an adiabatic process

$$dQ = 0 = dU + dW$$

$$\Rightarrow \quad 0 = dU + PdV$$

From the given equation

$$dU = 3(PdV + VdP)$$

$$\Rightarrow \quad 0 = 3(PdV + VdP) + PdV$$

$$\Rightarrow \quad 4P(dV) + 3V(dP) = 0$$

$$\Rightarrow \quad 4\left(\frac{dV}{V}\right) = -3\left(\frac{dP}{P}\right)$$

On integrating, we get

$$\ln(V^4) + \ln(P^3) = \text{constant}$$

$$\Rightarrow \quad PV^{4/3} = \text{constant}$$

$$\Rightarrow \quad \gamma = \frac{4}{3}$$

i.e., gas is polyatomic.

**Hence, the correct answer is (C).**

**278.** For a cyclic process, $\Delta U = 0$ and hence $Q = W$

$$\Rightarrow \quad Q_{ab} + Q_{bc} + Q_{ca} = W_{ab} + W_{bc} + W_{ca}$$

Since the process $ab$ is isochoric, so $W_{ab} = 0$

Also, it is given that $W_{bc} = -50$ J

$$\Rightarrow \quad 100 + 0 + Q_{ca} = 0 + (-50) + W_{ca}$$

$$\Rightarrow \quad Q_{ca} - W_{ca} = -150 \text{ J}$$

$$\Rightarrow \quad \Delta U_{ca} = Q_{ca} - W_{ca} = -150 \text{ J}$$

**Hence, the correct answer is (B).**

**279.** Volume of the gas is constant

$$\Rightarrow \quad \frac{T_2}{T_1} = \frac{P_2}{P_1}$$

$$\Rightarrow \quad \left(\frac{T_1 + 1}{T_1}\right) = \frac{1.01P_1}{P_1}$$

$$\Rightarrow \quad 0.01T_1 = 1$$

$\Rightarrow \quad T_1 = 100 \text{ K}$

**Hence, the correct answer is (A).**

**280.** Since, $P_1V = n_1RT_1$ and $P_2V = n_2RT_2$

$$\Rightarrow \quad \frac{n_1R}{V} = \frac{P_1}{T_1} \text{ and } \frac{n_2R}{V} = \frac{P_2}{T_2}$$

When the vessels are joined, then we have

$$P(V+V) = (n_1+n_2)RT$$

$$\Rightarrow \quad \frac{P}{T} = \frac{(n_1+n_2)R}{2V} = \frac{1}{2}\left(\frac{P_1}{T_1}+\frac{P_2}{T_2}\right)$$

**Hence, the correct answer is (A).**

**281.** $\frac{W}{Q} = \frac{Q-dU}{Q}$ $\{\because$ From First Law $dQ = dU + dW\}$

$$\Rightarrow \quad \frac{W}{Q} = 1 - \frac{dU}{\text{đ}Q} = 1 - \frac{nC_VdT}{nC_PdT} = 1 - \frac{C_V}{C_P}$$

$$\Rightarrow \quad \frac{dW}{dQ} = 1 - \frac{1}{\gamma}$$

**Hence, the correct answer is (B).**

**282.** Since, $P = \frac{1}{3}\frac{mn}{V}v_{\text{rms}}^2$ ...(1)

$$\Rightarrow \quad P \propto m \propto v_{\text{rms}}^2$$

Now, $m$ is halved and $v_{\text{rms}}$ is doubled, so $P$ will become two times.

In equation (1) $m$ is the mass of one gas molecule and $n$ the total number of gas molecules.

**Hence, the correct answer is (B).**

**283.** Pressure is exerted on the wall due to collisions of molecules with the walls of the container. It is independent of the velocity of container and the frame of reference.

**Hence, the correct answer is (A).**

**284.** Since, $U - 0 = nC_V(T-0)$

$$\Rightarrow \quad U = nC_VT$$

$$\Rightarrow \quad U = \frac{nRT}{\gamma-1} = \frac{PV}{\gamma-1} \qquad \{\because PV = nRT\}$$

**Hence, the correct answer is (C).**

**285.** According to Stefan's Law $E = e\sigma T^4$

where $e$ is the emissivity of body and $0 < e < 1$

$$\Rightarrow \quad E = \frac{300}{60\times5\times10^{-4}} = 10000 \text{ Wm}^{-2}$$

$$\Rightarrow \quad 10^4 = e(5.67\times10^{-8})(1000)^4$$

$$\Rightarrow \quad 10^{-8} = e(5.67)$$

$$\Rightarrow \quad e = \frac{1}{5.67} \approx 0.18$$

**Hence, the correct answer is (B).**

**286.** In process $ABC$, work done is

$$W = P_0(2V_0 - V_0) = P_0V_0$$

According to Ideal Gas Equation, we have

$$\frac{P_AV_A}{T_A} = \frac{P_CV_C}{T_C}$$

$$\Rightarrow \quad \frac{P_0V_0}{T_0} = \frac{(0.5P_0)(2V_0)}{T_C}$$

$$\Rightarrow \quad T_C = T_A = T_0$$

$$\Rightarrow \quad \Delta U = nC_V\Delta T = (1)\left(\frac{3R}{2}\right)(T_C - T_A) = 0$$

and $Q = \Delta U + W = 0 + P_0V_0 = RT_0$

**Hence, the correct answer is (C).**

**287.** For an Isotherm $T$ = constant

$\Rightarrow \quad PV$ = constant

$\Rightarrow \quad PV$ vs $V$ is a straight line. {OPTION **(A)**}

Similarly, $S$ vs $T$ is a straight line. {OPTION **(B)**}

$V$ and $P$ plotted together must give a rectangular hyperbola ($PV$ = constant). $P$ vs $T$ will again be a straight line. {OPTION **(D)**}

**Hence, the correct answer is (C).**

**288.** $C_P - C_V = 2 \text{ cal mol}^{-1}(^\circ\text{C})^{-1}$

**Hence, the correct answer is (A).**

**289.** For ideal monatomic gas $C_P = \frac{5}{2}R$

$$\Rightarrow \quad R = \frac{2}{5}C_P = 0.4C_P$$

$$\Rightarrow \quad n = 0.4$$

**Hence, the correct answer is (C).**

**290.** $v_{\text{mps}} = \sqrt{\frac{2RT}{M}}$

$$\Rightarrow \quad 1600 = \sqrt{\frac{2\times8.31\times300}{M}}$$

$$\Rightarrow \quad M \approx 2\times10^{-3} \text{ kg} = 2 \text{ g}$$

Hence the gas is $H_2$

**Hence, the correct answer is (C).**

**291.** When, external work done equals heat supplied, then

$$dU = 0$$

$\Rightarrow \quad T$ = constant i.e., Isothermal process

**Hence, the correct answer is (C).**

**292.** $F = YA\alpha\Delta T = E(1)(\alpha)(1) = E\alpha$

**Hence, the correct answer is (A).**

**293.** Initial and final temperatures are same in the both the graphs. Therefore, $\Delta U$ is same. Also area under $P$-$V$ graphs is same. Therefore, work done is same and hence heat exchanged is also same.

**Hence, the correct answer is (A).**

**294.** Area of the shell is $A = 4\pi R^2$

Rate of flow of heat is $P = k(4\pi R^2)\frac{T}{d}$

$$\Rightarrow \quad d = \frac{4\pi R^2 T k}{P}$$

**Hence, the correct answer is (B).**

**295.** $\frac{E_2}{E_1} = \frac{327+273}{27+273} = 2$

**Hence, the correct answer is (D).**

## Multiple Correct Choice Type Questions

**1.** Potential energy of an ideal gas is zero because intermolecular forces between them is zero. Degree of freedom of an ideal diatomic gas is 5. In this 2 is rotational and 3 is translational. According to Law of Equipartition of Energy internal energy is equally distributed in all degrees of freedom.

Therefore, rotational kinetic energy $= \left(\frac{2}{2+3}\right) \times 100 = 40\text{ J}$

and translational kinetic energy $= \left(\frac{3}{2+3}\right) \times 100 = 60\text{ J}$.

**Hence, (A), (B) and (C) are correct.**

**2.** Internal energy $(U)$ depends only on the initial and final status. Hence, $\Delta U$ will be same in all the three paths. In all the three paths work done by the gas is positive (volume is increasing) and the product $PV$ or temperature. $T$ is increasing. Therefore, internal energy is also increasing so, from First Law of Thermodynamics heat will be absorbed by the gas. Further area under P-V graph is maximum in path 1 while $\Delta U$ is same for all three paths. Therefore, heat absorbed by the gas is maximum in path 1. For temperature of the gas we can see the product $PV$ which first increases in path 1 but whether it is decreasing or increasing later on we cannot say anything about it unless the exact values are known to us.
**Hence, (A), (B) and (C) are correct.**

**3.** $P(\text{in watt}) = \frac{dQ}{dt}(\text{in joule per second})$

$$\Rightarrow \quad P(\text{in watt}) = mc\left(\frac{dT}{dt}\right)$$

$$\Rightarrow \quad P = \left(\frac{180}{1000}\right)(0.10)(4200)(0.5)$$

$$\Rightarrow \quad P = 37.8\text{ watt}$$

Further $P = \tau\omega$

$$\Rightarrow \quad 37.8 = \tau\left(180 \times \frac{2\pi}{60}\right)$$

$$\Rightarrow \quad \tau = 2\text{ Nm}$$

**Hence, (A) and (C) are correct.**

**4.** Since $C_V = \frac{dU}{dT}$ {at constant volume}

$C_P = \left(\frac{dQ}{dT}\right)_P$ {at constant pressure}

$C = \frac{dU + dW}{dT}$ $\left\{\begin{array}{l}\text{for any process other}\\ \text{than an adiabatic process}\end{array}\right\}$

$\Rightarrow \quad C = \frac{dU}{dT} + \frac{PdV}{dT}$ $\{\because \text{work done } dW = PdV\}$

**Hence, (A), (B) and (C) are correct.**

**5.** In 1 mole of all the gases there are $N$ (Avagadro's number) number of molecules which are independent of the nature of gas. Hence, OPTION (A) is correct. The translational kinetic energy of 1 mole of any gas at temperature $T$ is $\frac{3}{2RT}$. Therefore, OPTION (C) is also correct.
**Hence, (A) and (C) are correct.**

**6.** Let $C_A$ and $C_B$ be their heat capacities. Both the spheres have the same surface area. At any given temperature $\theta$ they lose heat at the same rate.

$$\Rightarrow \quad C_A\left(-\frac{d\theta}{dt}\right)_A = C_B\left(-\frac{d\theta}{dt}\right)_B$$

$$\Rightarrow \quad \frac{\left(-\frac{d\theta}{dt}\right)_A}{\left(-\frac{d\theta}{dt}\right)_B} = \frac{C_B}{C_A} = \text{constant}$$

i.e., rate of cooling of $B$ is fast, but their ratio is constant.
**Hence, (C) and (D) are correct.**

**7.** Speed of a gas molecules, $v \propto \sqrt{T}$
Change in momentum of a molecule on hitting a wall and then rebounding is $\Delta p \propto v \propto \sqrt{T}$
Since, pressure of a gas is equal to change in momentum of a molecule colliding with the wall $(\Delta p)$ multiplied by number of collisions per unit area per second $(n)$. So, for
**OPTION (A):** If temperature and volume are doubled, pressure remains same. Therefore, $n$ decreases since $\Delta p$ increases. Thus, OPTION (A) is wrong.
**OPTION (B):** If temperature and volume are halved, $n$ increases since $\Delta p$ decreases. Therefore OPTION (B) is correct.
**OPTION (C):** If pressure and temperature are doubled, $n$ increases because pressure doubles whereas $\Delta p$ increases only $\sqrt{2}$ times.
**Hence, (B) and (C) are correct.**

**8.** $\frac{Q}{t} = KA\left(\frac{T_S - T_R}{\ell}\right)$

$T_S$ = Temperature of steam

$T_R$ = Temperature of room

$T_0$ increase $\frac{Q}{t}$ either $A$ is increased or $\ell$ is decreased or $T_R$ is decreased.
**Hence, (A) and (D) are correct.**

**9.** $H$ =rate of heat flow $= \frac{900}{\frac{\ell_1}{K_i A} + \frac{\ell_0}{K_0 A}}$

Now $1000 - T = H\left(\frac{\ell_1}{K_i A}\right)$

$$\Rightarrow \quad T = 1000 - \left(\frac{900}{\frac{\ell_1}{K_i A} + \frac{\ell_0}{K_0 A}}\right)\frac{\ell_1}{K_i A}$$

$$\Rightarrow \quad T = 1000 - \frac{900}{1 + \frac{\ell_0}{K_0}\frac{K_i}{\ell_1}}$$

We also observe that $T$ can be decreased by increasing thermal conductivity of outer layer $(K_0)$ and thickness of inner layer $(\ell_1)$.

**Hence, (A) and (D) are correct.**

**10.** Since, 1 kg ice at $0\ ^\circ\text{C}$ needs 80000 cal to get converted to water at $0\ ^\circ\text{C}$ and 1.5 kg water at $45\ ^\circ\text{C}$ gives out 67500 cal to get converted to water at $0\ ^\circ\text{C}$.

So, entire ice cannot be converted to water and the equilibrium temperature will be $0\ ^\circ\text{C}$. So mixture contains both ice and water. Amount of ice left unmelted due to insufficiency of available heat is

$$m_{\text{ice}} = \frac{80000 - 67500}{80} = 156.25 \text{ g}$$

**Hence, (A) and (B) are correct.**

**11.** $L_1 - L_2 = \text{constant}$

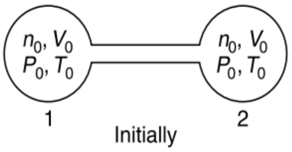
$\Rightarrow \quad \Delta L_1 - \Delta L_2 = 0$

$\Rightarrow \quad \Delta L_2 = \Delta L_1$

$\Rightarrow \quad L_2\alpha_2 = L_1\alpha_1$

**Hence, (B) and (C) are correct.**

**12.** $P_0V_0 = n_0RT_0$ (for container 1) $\quad \ldots(1)$

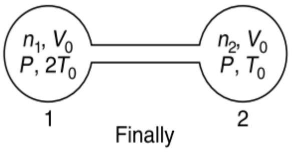


Initially

$P_0V_0 = n_0RT_0$ (for container 2) $\quad \ldots(2)$

Total number of moles $= N = n_0 + n_0 = 2n_0$

Since, even on heating the total number of moles is conserved, hence



Finally

$$n_1 + n_2 = 2n_0 \quad \ldots(3)$$

Further if P be the common pressure, then

$$PV_0 = n_1R(2T_0) \quad \{\text{in container 1}\}$$

$$\Rightarrow \quad n_1 = \frac{PV_0}{2RT_0} \quad \ldots(4)$$

Also, $PV_0 = n_2RT_0$ $\quad$ {in container 2}

$$\Rightarrow \quad n_2 = \frac{PV_0}{RT_0} \quad \ldots(5)$$

Since, $n_1 + n_2 = 2n_0$

$$\Rightarrow \quad \frac{PV_0}{2RT_0} + \frac{PV_0}{RT_0} = 2\frac{P_0V_0}{RT_0} \quad \{\because \text{ of } (1)\}$$

$$\Rightarrow \quad P = \frac{4}{3}P_0$$

Also, $n_1 = \frac{4}{3}\frac{P_0V_0}{2RT_0} = \frac{2}{3}\frac{P_0V_0}{RT_0}$

**Hence, (B) and (C) are correct.**

**13.** During expansion an isotherm lies above an adiabat, so greater work is done in isothermal process than in adiabatic process. {OPTION **(A)**}

Let both expand to a final volume $V$, then

$$P_0V_0 = P_{\text{iso}}V \quad \text{and} \quad P_0V_0^\gamma = P_{\text{adi}}V^\gamma$$

$$\Rightarrow \quad P_{\text{iso}} = P_0\left(\frac{V_0}{V}\right) \quad \text{and} \quad P_{\text{adi}} = P_0\left(\frac{V_0}{V}\right)^\gamma$$

Since $\frac{V_0}{V} < 1$ and $\gamma > 1$

$\Rightarrow \quad P_{\text{iso}} > P_{\text{adi}}$ $\quad$ {OPTION **(B)**}

Finally, since we know that adiabatic expansion always leads to cooling, so we have final temperature of adiabatic process less than the constant temperature of isothermal process. {OPTION **(C)**}

**Hence, (A), (B) and (C) are correct.**

**14.** Refer to SOLUTION of PROBLEM 13.

**Hence, (A), (B) and (C) are correct.**

**15.** Since, $Q_1 = W + Q_2$

$\Rightarrow \quad W = Q_1 - Q_2 > 0$

$\Rightarrow \quad Q_1 > Q_2 > 0$ OR $Q_1 < Q_2 < 0$

**Hence, (A) and (C) are correct.**

**16.** Process $DA$ is isothermal

$\Rightarrow \quad T_D = T_A$

Further $T \propto PV$

From the graph we can see that $(PV)_C > (PV)_D$

$\Rightarrow \quad T_C > T_D$

Further process $BC$ is an adiabatic expansion. So, $T_D > T_C$. Therefore, maximum temperature is at $B$ and minimum temperature at $D$ or $A$. Hence,

$$T_B = 4T_0 \text{ and } T_D = T_A = T_0$$

**In process $CD$:**

$$W = 0$$

$$\Rightarrow \quad Q = \Delta U \quad \{\because \text{ of FLTD}\}$$

Volume of the gas is constant and pressure is decreasing. Therefore, temperature and hence, internal energy will decrease i.e., $Q$ is negative or heat is released by the gas in the process $CD$.

**In process $AB$:**

$$Q = nC_p\Delta T \quad \{\text{process is isobaric}\}$$

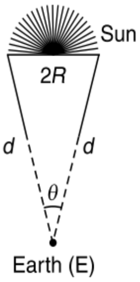
Pressure is constant and volume is increasing. Therefore, temperature will also increase or $Q$ is positive. Thus, heat is supplied to the gas only in process $AB$

and $Q = n\left(\frac{5R}{2}\right)(T_B - T_A)$

$$\Rightarrow \quad Q = n\left(\frac{5R}{2}\right)\left(4T_0 - T_0\right) = \frac{15}{2}nRT_0$$

**Hence, (A), (B) and (C) are correct.**

**17.** Power radiated by the sun is $P = \left(4\pi R^2\right)\sigma T^4$



Further,

$$\text{Solar constant} = \begin{pmatrix}\text{Energy received per}\\ \text{second per unit area}\end{pmatrix} = \frac{P}{4\pi d^2} = S$$

$$\Rightarrow \quad P = 4\pi d^2 S$$

For equilibrium $4\pi R^2\sigma T^4 = 4\pi d^2 S$

$$\Rightarrow \quad S = \frac{1}{4}\sigma T^4\left(\frac{2R}{d}\right)^2 = \frac{1}{4}\sigma T^4\theta^2 \qquad \left\{\because \frac{2R}{d} = \theta\right\}$$

$$\Rightarrow \quad S \propto T^4$$

$$\Rightarrow \quad S \propto \theta^2$$

**Hence, (B) and (D) are correct.**

**18.** Conceptual

**Hence, (B) and (D) are correct.**

**19.** A refrigerator is reverse of heat engine and heat pump is same as refrigerator. The coefficient of performance of a refrigerator cannot be infinity and a heat engine cannot convert the heat input fully to work done.

**Hence, (C) and (D) are correct.**

**20.** Water equivalent (w) of a body of mass m, gram specific heat c is just the product of m and c i.e., $w = mc$. Similarly, heat capacity of a body of mass m, gram specific heat c is also product of m and c. The major difference between both is that w is expressed in the units of mass and heat capacity is expressed in the units of energy (calorie or joule).

**Hence, (A) and (C) are correct.**

**21.** Since, $p^2V = \text{constant}$

$$\Rightarrow \quad \left(\frac{RT}{V}\right)^2 V = \text{constant}$$

$$\Rightarrow \quad T^2 \propto V$$

So, when volume becomes $3V_0$, then temperature also becomes $\sqrt{3}T_0$. Since temperature has increased, so internal energy of the gas will increase.

**Hence, (A) and (B) are correct.**

**22.** $P$-$T$ graph is a straight line passing through origin. Therefore,

$$V = \text{constant}$$

So, work done on the gas is zero.

Further density of the gas $\rho = \dfrac{m}{V} \propto \dfrac{1}{V}$

Volume of the gas is constant. Therefore, density of gas is also constant.

$$PV = nRT$$

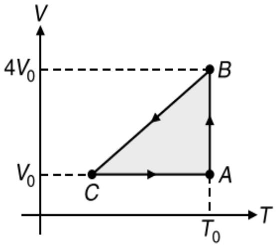
$$\Rightarrow \quad P = \left(\frac{nR}{V}\right)T$$

i.e., slope of $P$-$T$ line $\propto n$

**Hence, (A), (B) and (D) are correct.**

**23.** For $n$ moles of gas with $f$ degrees of freedom at temperature $T$, we have

$$U = \frac{f}{2}nRT$$



Since, temperature $T$ is same at $A$ and $B$, so

$$U_A = U_B$$

Also, $W_{AB} = nRT_0\log_e\left(\dfrac{V_f}{V_i}\right) = nRT_0\log_e\left(\dfrac{4V_0}{V_0}\right)$

$$W_{AB} = nRT_0\log_e(4) = P_0V_0\log_e(4)$$

**Hence, (A) and (B) are correct.**

**24.** Conceptual

**Hence, (A), (B), (C) and (D) are correct.**

**25.** Since work done is area under the graph, OPTION (A) is incorrect.

Since net work done in the cyclic clockwise process is positive and for cyclic process $Q = W$, so OPTION (B) is correct.

Since $PV = nRT$, so temperature is maximum at $C$ and hence OPTION (C) is incorrect.

Process $C$ to $A$ is isochoric and pressure is falling. Therefore, temperature also falls i.e. $\Delta U$ and $Q$ are negative. Therefore OPTION (D) is correct.

**Hence, (B) and (D) are correct.**

**26.** Vibrational kinetic energy of a monatomic gas $= 0$ at all temperatures. So, $C_V = \dfrac{3}{2}R$ for a monatomic gas even at high temperatures also.

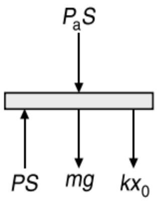
In case of a diatomic gas

$C_V = \dfrac{5}{2}R$ at low temperatures, while

$C_V > \dfrac{5}{2}R$ at high temperature due to vibrational kinetic energy

**Hence, (A) and (D) are correct.**

**27.** Equilibrium of piston gives



$$PS = P_aS + mg + kx_0$$

where, $P$ is the final pressure of the gas

$$\Rightarrow \quad P = P_a + \frac{mg}{S} + \frac{kx_0}{S}$$

Work done by the gas $(W)$ equals the sum of work done against atmospheric pressure $(W_{pr})$, elastic potential energy storied in the spring $(\Delta U_{sp})$ and the increase in gravitational potential energy $(\Delta U_g)$ of the piston.

$$\Rightarrow \quad W = W_{pr} + \Delta U_{sp} + \Delta U_g$$

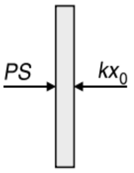
where, $W_{pr} = P_0\Delta V$, $\Delta U_{sp} = \frac{1}{2}kx_0^2$, $\Delta U_g = mvx_0$

$$\Rightarrow \quad W = P_0\Delta V + \frac{1}{2}kx_0^2 + mgx_0$$

$$\Rightarrow \quad W = P_aSx_0 + \frac{1}{2}kx_0^2 + mgx_0$$

This is also the decrease in internal energy of the gas. Because the gas in thermally insulated and this work is done in the expense of internal energy of the gas.
**Hence, (A) and (C) are correct.**

**28.** Equilibrium of piston gives



$$PS = kx_0$$

$$\Rightarrow \quad P = \frac{kx_0}{S}$$

Since, the chamber is thermally insulated

$$\Delta Q = 0$$

$$\Rightarrow \quad \left(\begin{matrix}\text{Elastic Potential Energy}\\ \text{of Spring}\end{matrix}\right) = \left(\begin{matrix}\text{Work Done}\\ \text{by Gas}\end{matrix}\right)$$

$$\Rightarrow \quad \text{Work done by gas} = \frac{1}{2}kx_0^2$$

This work is done in the expense of internal energy of the gas. Therefore, internal energy of the gas is deceased by $\frac{1}{2}kx_0^2$.

Internal energy of an ideal gas depends on its temperature only. Internal energy of the gas is decreasing. Therefore, temperature of the gas will decrease.
**Hence, (A), (B), (C) and (D) are correct.**

**29.** Since $TP^{-2/5} =$ constant, so comparing it with equation of a polytropic process in which

$$TP^{\frac{1-x}{x}} = \text{constant}$$

$$\Rightarrow \quad \frac{1-x}{x} = -\frac{2}{5}$$

$$\Rightarrow \quad 5 - 5x = -2x$$

$$\Rightarrow \quad x = \frac{5}{3} = \gamma_{\text{monatomic}}$$

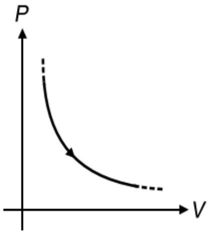
So, this represents an adiabatic process, for which $Q = 0$ i.e., $C = 0$

So, $\Delta U = nC_V\Delta T = (2)\left(\frac{3R}{2}\right)(2T) = 6RT$

For an adiabatic process, $Q = -\Delta U = -6RT$

**Hence, (B), (C) and (D) are correct.**

**30.** (A) It is incorrect because isothermal process is graphically represented like as shown.

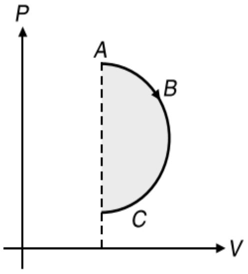


(B) For $B \to C \to D$, $\Delta U = -\text{ve}$ and $W = -\text{ve}$

$$\Rightarrow \quad Q = -\text{ve}$$

(C) $W =$ shaded area $= +\text{ve}$

(D) Since the $P$-$V$ cycle is clockwise, so $W = +\text{ve}$



**Hence, (B) and (D) are correct.**

**31.** Since $U_c - U_a = (1)\left(\frac{3R}{2}\right)(T_c - T_a)$

$$\Rightarrow \quad U_c - U_a = \left(\frac{3R}{2}\right)\left(\frac{8P_0V_0}{R} - \frac{P_0V_0}{R}\right) = \left(\frac{21}{2}\right)P_0V_0$$

$$\Rightarrow \quad U_c - U_a = 10.5RT_0$$

and similarly it can be done for others.
**Hence, (A), (B), (C) and (D) are correct.**

**32.** Internal energy of $n$ moles of an ideal gas is

$$U = \left(\frac{f}{2}\right)(nRT) \; f = \text{degrees of freedom}$$

i.e., $U$ depends on number of moles $n$ and temperature $T$.

Similarly, $PV = nRT$

i.e., $PV$ depends on $n$ and $T$

But $\frac{P}{\rho} = \frac{RT}{M}$

i.e., the ratio $\frac{P}{\rho}$ depends on $T$ only

Similarly, $v_{\text{rms}} = \sqrt{\frac{3RT}{M}}$

i.e., $v_{\text{rms}}$ also depends on $T$ only.

**Hence, (C) and (D) are correct.**

**33.** Heat required to raise the temperature of a solid to its melting point is

$$Q_1 = mc\Delta T = (0.1)\left(0.5\times 10^{-3}\right)(100-0) = 5000 \text{ cal}$$

Therefore, rate of supply of heat is 5000 $\text{cal min}^{-1}$

Since the solid takes one minute to melt, heat required for making the solid is $Q_2 = 5000\times 1 = 5000$ cal

Heat required to raise the temperature of liquid formed to boiling point is $Q_3 = 5000\times 4 = 20000$ cal

If $c$ is the specific heat of the liquid, then

$$20000 = (0.1)c(300-100)$$

$\Rightarrow \quad c = 1000 \text{ cal kg}^{-1}{}^\circ\text{C}^{-1} = 1 \text{ kcal kg}^{-1}{}^\circ\text{C}^{-1}$

**Hence, (A), (B) and (C) are correct.**

**34.** Since $\gamma = \dfrac{C_P}{C_V} = 1 + \dfrac{2}{f}$

$\Rightarrow \quad \dfrac{2}{f} = \dfrac{C_P - C_V}{C_V}$

$\Rightarrow \quad f = \dfrac{2C_V}{R} \qquad \{\because C_P - C_V = R\}$

$\Rightarrow \quad f = 2\left(\dfrac{C_P}{R} - 1\right)$

**Hence, (A) and (B) are correct.**

**35.** When heat is supplied to the gas under Isobarric, Isochoric, Adiabatic conditions then

$\Delta U = nC_v\left(T_2 - T_1\right) \qquad$ {OPTION **(A)**}

For an Adiabatic process $đQ = 0$

$\Rightarrow \quad đW = -dU$

Work is being done at the expense of internal energy and both have equal value. {OPTION **(B)**}

For an Isothermal process $\Delta T = 0$

$\Rightarrow \quad \Delta U = 0 \qquad$ {OPTION **(C)**}

For an Adiabatic process, since $đQ = 0$

$\Rightarrow \quad C = \dfrac{1}{n}\dfrac{đQ}{dT} = 0 \qquad$ {OPTION **(D)**}

**Hence, (A), (B), (C) and (D) are correct.**

**36.** $C = 0$

$\Rightarrow \quad dQ = 0 \qquad \left\{\because C = \dfrac{1}{n}\dfrac{dQ}{dT}\right\}$

$\Rightarrow$ Adiabatic process

**Hence, (A) and (B) are correct.**

**37.** $T$ = constant

$\Rightarrow \quad PV$ =constant $\qquad$ {Boyle's Law}

$\Rightarrow \quad P \propto \dfrac{1}{V}$

Pressure of the gas is increasing. Therefore, volume should decrease. Work done by the gas is negative or work done on the gas will be positive. Further temperature of the gas is constant. Therefore, internal energy will remain constant.

**Hence, (A), (C) and (D) are correct.**

**38.** **Process *AB*:** $P$ = constant

$\Rightarrow \quad V \propto T$

$\Rightarrow \quad T_B = 2T_A = 2T_0$

$\Rightarrow \quad W_{AB} = P_0V_0 = RT_0$

Since, $Q_{AB} = C_P\Delta T = \left(\dfrac{5}{2}R\right)\left(2T_0 - T_0\right)$

$\Rightarrow \quad Q_{AB} = \dfrac{5}{2}RT_0$

So, from $FLTD$, we have

$$Q_{AB} = \Delta U_{AB} + W_{AB}$$

$\Rightarrow \quad \Delta U_{AB} = Q_{AB} - W_{AB} = \dfrac{3}{2}RT_0$

**Process *BC*:** $V$ = constant

$\Rightarrow \quad P \propto T$

$\Rightarrow \quad P_C = 2P_B$

$\Rightarrow \quad T_C = 2T_B = 4T_0$

Since, $W_{BC} = 0$

$\Rightarrow \quad Q_{BC} = \Delta U_{BC} = C_V\Delta T$

$\Rightarrow \quad Q_{BC} = \left(\dfrac{3}{2}R\right)\left(4T_0 - 2T_0\right) = 3RT_0$

$\Rightarrow \quad W_{\text{net}} = RT_0,\ Q_{\text{net}} = \dfrac{11}{2}RT_0$

and $\Delta U_{\text{net}} = \dfrac{9}{2}RT_0$

**Hence, (A) and (C) are correct.**

**39.** Conceptual

**Hence, (A) and (B) are correct.**

**40.** For isobaric process, we have

$$W = nR\Delta T \text{ and } Q = nC_P\Delta T$$

From the graph, we see that

$$\text{Slope} = \frac{W}{Q} = \frac{R}{C_P}$$

**For Graph 1**

$$\frac{W}{Q} = \frac{20}{80} = \frac{1}{4} = \frac{R}{C_P}$$

$\Rightarrow \quad C_P = 4R$

Therefore, gas is polyatomic

**For Graph 2**

$$\frac{W}{Q} = \frac{32}{80} = \frac{2}{5} = \frac{R}{C_P}$$

$\Rightarrow \quad C_P = \dfrac{5R}{2}$

Therefore, gas is monatomic

**For Graph 3**

$$\frac{W}{Q} = \frac{80}{80} = 1 = \frac{R}{C_P}$$

$\Rightarrow \quad C_P = R$

which is not possible because $C_V \neq 0$ for isobaric process

**Hence, the correct answer is (D).**

**41.** $P \propto AT^4$ $\quad\{\because T_0 \ll T\}$

i.e., $P \propto r^2$ $\quad\{\because A = 4\pi r^2\}$

Rate of cooling $\propto \dfrac{1}{r}$

**Hence, (B), (C) and (D) are correct.**

**42.** Rate of cooling $= R = -\dfrac{dT}{dt}$

Since, $\dfrac{1}{A}\dfrac{dQ}{dt} = \sigma\left(T^4 - T_0^4\right)$ (By Stefan's Law)

$$\Rightarrow \quad -\frac{mc}{A}\frac{dT}{dt} = \sigma\left(T^4 - T_0^4\right) \qquad \{\because dQ = mcdT\}$$

$$\Rightarrow \quad -\frac{dT}{dt} = R = \frac{\sigma A}{mc}\left(T^4 - T_0^4\right)$$

For T comparable to $T_0$ we have

$$T^4 - T_0^4 \simeq 4T_0^3\left(T - T_0\right)$$

$$\Rightarrow \quad R = \frac{4\sigma A T_0^3}{mc}\left(T - T_0\right)$$

$$\Rightarrow \quad R \propto \frac{A}{m} \propto \frac{1}{r} \qquad \left\{\because A = 4\pi r^2 \text{ and } m = \frac{4}{3}\pi r^3 \rho\right\}$$

and $R \propto \left(T - T_0\right)$

**Hence, (A) and (C) are correct.**

**43.** $\dfrac{dQ}{dt} = \text{Thermal Current I} = kA\left(\dfrac{dT}{d\ell}\right)$

**Hence, (A) and (B) are correct.**

**44.** Thermal Stress $= \dfrac{\text{Tension}}{\text{Area}} = Y\alpha\Delta T$

$$\Rightarrow \quad \text{Tension} = YA\alpha\Delta T$$

**Hence, (C) and (D) are correct.**

**45.** During process $A$ to $B$, pressure and volume both are decreasing. Therefore, temperature and hence, internal energy of the gas will decrease $(T \propto PV)$ or $\Delta U_{A\to B} =$ negative. Further $\Delta W_{A\to B}$ is also negative as the volume is increasing. Hence, temperature should increase or $\Delta U_{B\to C} =$ positive. During $C$ to $A$ volume is constant while pressure is increasing. Therefore, temperature and hence, internal energy of the gas should increase or $\Delta U_{C\to A}$ =positive. During process $CAB$ volume of the gas is decreasing. hence, work done by the gas is negative.

**Hence, (A), (B) and (D) are correct.**

**46.** $m = nM$

$n$ =number of moles, $M$ =molecular mass of gas

$$\Rightarrow \quad \frac{mkT}{V} = \frac{nMkT}{V} = \frac{nM\left(\frac{R}{N}\right)T}{V} \qquad \left\{\because k = \frac{R}{N}\right\}$$

Since, $PV = nRT$

$$\Rightarrow \quad \frac{mkT}{V} = \frac{PVM}{NV} = \frac{PM}{N}$$

i.e., the given quantity depends on $P$ and $M$ of the gas.

**Hence, (C) and (D) are correct.**

**47.** For adiabat $bc$

$$T_1V_b^{\gamma-1} = T_2V_c^{\gamma-1} \qquad \ldots(1)$$

For adiabat $da$

$$T_2V_d^{\gamma-1} = T_1V_a^{\gamma-1} \qquad \ldots(2)$$

Multiplying both (1) and (2)

$$\Rightarrow \quad T_1T_2\left(V_bV_d\right)^{\gamma-1} = T_1T_2\left(V_aV_c\right)^{\gamma-1}$$

$$\Rightarrow \quad V_bV_d = V_aV_c$$

Since adiabatic expansion leads to cooling,

so $\quad T_1 > T_2$

**Hence, (B) and (C) are correct.**

**48.** Since, net change in internal energy in one cycle of a cyclic process is zero, therefore,

$$\Delta U_1 + \Delta U_2 = 0$$

Also, for the complete cycle, $Q = W$

**Hence, (A) and (C) are correct.**

**49.** $\eta = 1 - \dfrac{T_2}{T_1} = 1 - \dfrac{2}{3} = \dfrac{1}{3} = 0.33$

Further $\eta = \dfrac{W}{Q_1}$

$$\Rightarrow \quad \frac{1}{3} = \frac{W}{1000\text{ cal}}$$

$$\Rightarrow \quad W = \frac{1000 \times 4.2}{3}$$

$$\Rightarrow \quad W = 1400\text{ J}$$

**Hence, (B) and (D) are correct.**

**50.** Conceptual

**Hence, (C) and (D) are correct.**

**51.** Since for any cyclic process $dU = 0$

$\Rightarrow \quad U = \text{constant}$ {OPTION **(A)**}

For an Isothermal process $dT = 0$ i.e., $dU = 0$

$\Rightarrow \quad U = \text{constant}$ {OPTION **(B)**}

Further according to First Law of Thermodynamics

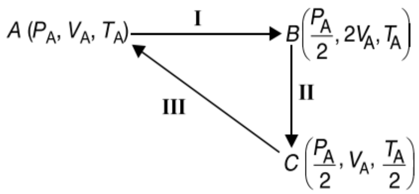
$$dQ = dU + dW$$

For constant $U$, $dU = 0$

$\Rightarrow \quad dQ = dW$ {OPTION **(D)**}

**Hence, (A), (B) and (D) are correct.**

**52.** Let the process start from initial pressure $P_A$, volume $V_A$ and temperature $T_A$.



**I:** Isothermal expansion $(PV = \text{constant})$ at temperature $T_A$ to twice the initial volume $V_A$

**II:** Compression at constant pressure $\frac{P_A}{2}$ to original volume $V_A$ (i.e. $V \propto T$)

**III:** Isochoric process (at volume $V_A$) to initial conditions (i.e. $P \propto T$)

**Hence, (A) and (C) are correct.**

**53.** Since work done is area under the graph, OPTION (A) is incorrect.

Since net work done in the cyclic clockwise process is positive and for cyclic process $Q = W$, so OPTION (B) is correct.

Since $PV = nRT$, so temperature is maximum at $C$ and hence OPTION (C) is incorrect.

Process $C$ to $A$ is isochoric and pressure is falling. Therefore, temperature also falls i.e. $\Delta U$ and $Q$ are negative. Therefore OPTION (D) is correct.

**Hence, (B) and (D) are correct.**

**54.** On heating, a bimetallic strip always bends towards the metal with low $\alpha$ and the reverse process takes place when the bimetallic strip is cooled.

**Hence, (B) and (C) are correct.**

**55.** Container is thermally insulated, so we have

$$Q = 0$$

The gas expands against vacuum, then

$$W = 0$$

From First Law of Thermodynamics, we have

$$Q = \Delta U + W$$

$$\Rightarrow \Delta U = 0$$

i.e., internal energy and hence, temperature of the gas is constant

$$\Rightarrow P \propto \frac{1}{V} \qquad \text{\{Boyle's Law\}}$$

**Hence, (A), (B), (C) and (D) are correct.**

**56.** Since $T = KV^2$, so we have $TV^{-2} = \text{constant}$

Comparing this with equation of a polytropic process i.e., $TV^{x-1} = \text{constant}$, we get

$$x - 1 = -2$$

$$\Rightarrow x = -1$$

So, molar specific heat of the gas is

$$C = C_V + \frac{R}{1-x} = \frac{3R}{2} + \frac{R}{2} = 2R$$

$$\Rightarrow Q = nC\Delta T = n(2R)(3T_0) = 6nRT_0$$

$$\Rightarrow W = \frac{nR\Delta T}{1-x} = \frac{nR(3T_0)}{2} = \frac{3}{2}nRT_0$$

**Hence, (B) and (C) are correct.**

**57.** Since no mechanical contact is there, so angular momentum is conserved.

$$\Rightarrow I\omega = \text{constant}$$

$$\Rightarrow \Delta(I\omega) = 0$$

$$\Rightarrow I\Delta\omega + \omega\Delta I = 0$$

$$\Rightarrow \frac{\Delta\omega}{\omega} = -\frac{\Delta I}{I}$$

$$\Rightarrow \frac{\Delta\omega}{\omega_0} = -\frac{\Delta I}{I} = -2\alpha\Delta T \qquad \left\{\because \frac{\Delta I}{I} = \frac{2\Delta R}{R} = 2\alpha\Delta T\right\}$$

**Hence, (A), (B) and (C) are correct.**

**58.** For isothermal process

$$T = \text{constant}$$

Since, $v_{\text{rms}} = \sqrt{\frac{3RT}{M}}$

$\Rightarrow V_{\text{rms}}$ is also constant

**Hence, (B) and (C) are correct.**

**59.** During free expansion, gas is allowed to expand in vacuum. This happens so quickly that there is no heat transferred. Since the gas does not displace anything, so no work is also done by the gas and hence by FLTD, change in internal energy of the gas is also zero. So, there is no change in temperature of the gas.

**Hence, (A) and (C) are correct.**

**60.** $W_{\text{cyclic}} = nR(T_1 - T_2)\log_e \alpha$

$$\eta = \frac{W}{Q_1} = 1 - \left(\frac{T_2}{T_1}\right)$$

$$\Delta U_{\text{cyclic}} = 0$$

**Hence, (A), (B) and (C) are correct.**

**61.** During expansion an isotherm lies above an adiabat

Since, $(\text{Slope})_{\text{adiabat}} = \gamma(\text{Slope})_{\text{isotherm}}$

$$\Rightarrow m_2 = \frac{C_p}{C_V}(m_1)$$

$$\Rightarrow m_2 C_V = m_1 C_P$$

Since $\gamma > 1$

$$\Rightarrow m_2 > m_1$$

**Hence, (C) and (D) are correct.**

## Reasoning Based Questions

**1.** Since, for an adiabatic process, $TV^{\gamma-1} = \text{constant}$

$$\Rightarrow d\left(TV^{\gamma-1}\right) = 0$$

$$\Rightarrow T(\gamma-1)V^{\gamma}dv + V^{\gamma-1}dT = 0$$

$$\Rightarrow \frac{T}{V}(\gamma-1)dV + dT = 0$$

$$\Rightarrow \frac{dT}{dV} = -\frac{T}{V}(\gamma-1)$$

Slope is negative, so $\frac{dT}{dV} < 0$

**Hence, the correct answer is (C).**

**2.** Since, $C = \frac{\Delta Q}{n\Delta T}$

In adiabatic process, $\Delta Q = 0$

$$\Rightarrow C = 0$$

In isothermal process, $\Delta T = 0$

$\Rightarrow \quad C \to \infty$

**Hence, the correct answer is (A).**

**3.** Statement-1 is true and Statement-2 is false.
We can change the temperature of a body without giving (or taking) heat to (or from) it. For example, in an adiabatic compression temperature rises and in an adiabatic expansion temperature falls, although no heat is given (or taken) from the system in the respective changes.
**Hence, the correct answer is (C).**

**4.** Coefficient of thermal conductivity is the property of the material and changes only when the material changes.
**Hence, the correct answer is (D).**

**5.** Since, $V$-$T$ graph is a rectangular hyperbola, so

$$VT = \text{constant}$$

$$\Rightarrow \quad PV^2 = \text{constant}$$

$$\Rightarrow \quad \frac{P}{T^2} = \text{constant}$$

**Hence, the correct answer is (B).**

**6.** A gas have may values of specific heat capacity depending on the process used.
**Hence, the correct answer is (D).**

**7.** Statement-1 is incorrect, because two isothermal curves can never intersect each other but Statement-2 is correct.
**Hence, the correct answer is (D).**

**8.** In a constant pressure process, the heat supplied has two jobs to do

(i) increase the internal energy of the gas by $\Delta U$ and

(ii) to push the piston to maintain the pressure.

Hence $C_P > C_V$

**Hence, the correct answer is (A).**

**9.** If $V$ increases temperature of gas decreases.
**Hence, the correct answer is (A).**

**10.** Coefficient of volume expansion $\delta = \frac{1}{V}\frac{dV}{dT}$

Since, $PV = nRT$

$$\Rightarrow \quad V = \left(\frac{nR}{P}\right)T$$

$$\Rightarrow \quad \frac{dV}{dT} = \frac{nR}{P}$$

$$\Rightarrow \quad \delta = \frac{1}{V}\frac{dV}{dT} = \frac{nR}{PV} = \frac{nR}{nRT} = \frac{1}{T}$$

**Hence, the correct answer is (D).**

**11.** Conceptual and discussed in Theory.
**Hence, the correct answer is (A).**

**12.** Upon increasing pressure, the ice melts so as to decrease the volume and thereby pressure. To freeze the melted ice one needs to decrease the temperature down and hence the melting point decreases.
**Hence, the correct answer is (A).**

**13.** Internal energy increases in the melting process.
Linked Comprehension
**Hence, the correct answer is (D).**

## Linked Comprehension Type Questions

**1.** Since $W = \frac{Q}{2}$

From $FLTD$, we have $dQ = dU + dW$

$$\Rightarrow \quad dQ = dU + \frac{Q}{2}$$

$$\Rightarrow \quad dU = dW = \frac{Q}{2}$$

$$\Rightarrow \quad C_V dT = PdV$$

$$\Rightarrow \quad \left(\frac{R}{\gamma - 1}\right)dT = PdV$$

Since, for a monatomic gas $\gamma = \frac{5}{3}$, so on integrating, we get

$$P^3V = \text{constant}$$

**Hence, the correct answer is (C).**

**2.** Also, $C = C_V + \frac{PdV}{dT} = 3R$

**Hence, the correct answer is (C).**

**3.** Since, $PV = nRT$

$$\left(\frac{nRT}{V}\right)^3 V = \text{constant}$$

$$\Rightarrow \quad T^3 \propto V^2$$

$$\Rightarrow \quad \frac{T_0^3}{T^3} = \frac{V_0^3}{V^3}$$

$$\Rightarrow \quad V = 8V_0 \qquad \{\because T = 4T_0\}$$

**Hence, the correct answer is (B).**

**4.** $AB$ is an isobaric process. In $B \to C$ magnitude of $\frac{dT}{dv}$ increases and $O \to A$ is an isochoric process.
Hence (C) OPTION is correct.
**Hence, the correct answer is (C).**

**5.** For a cyclic process, we have

$$\Delta U = 0$$

$$\Rightarrow \quad W_{\text{net}} = Q_{\text{net}} = -1000 \text{ J}$$

$$\Rightarrow \quad W_{AB} + W_{BC} + W_{CA} = -1000 \text{ J}$$

$$\Rightarrow \quad (4)(R)(200) + W_{BC} + 0 = -1000 \text{ J}$$

$$\Rightarrow \quad W_{BC} = -7640 \text{ J}$$

**Hence, the correct answer is (C).**

**6.** The volume of gas at state $C$ is given by

$$V_C = V_A = \frac{nRT_A}{P_A}$$

$$\Rightarrow \quad V_C = 0.0332 \text{ m}^3$$

**Hence, the correct answer is (A).**

**7.** The force due to pressure of liquid is Buoyant force. Besides this, gravity and viscous force act on the bubble.
**Hence, the correct answer is (D).**

**8.** Since, no heat exchange takes place, so the gas expands adiabatically.

$$P^{1-\gamma}T^{\gamma} = \text{constant}$$

$$\Rightarrow \quad T_2 = T_1\left(\frac{P_1}{P_2}\right)^{\frac{1-\gamma}{\gamma}}$$

where, $T_1 = T_0$, $P_1 = P_0 + \rho_\ell gH$, $P_2 = P_0 + \rho_\ell g(H-y)$ and $\gamma = \frac{5}{3}$

$$\Rightarrow \quad T_2 = T_0\left(\frac{P_0 + \rho_\ell gH}{P_0 + \rho_\ell g(H-y)}\right)^{\frac{1-\frac{5}{3}}{\frac{5}{3}}}$$

$$\Rightarrow \quad T_2 = T_0\left(\frac{P_0 + \rho_\ell g(H-y)}{P_0 + \rho_\ell gH}\right)^{\frac{2}{5}}$$

**Hence, the correct answer is (B).**

**9.** Buoyant Force $F_B = V\rho_\ell g$

Since, $V = \frac{nRT}{P} = \frac{nRT_2}{\left(P_0 + \rho_\ell g(H-y)\right)}$

Substituting the value of $T_2$, $V$, we get

$$F_B = \frac{\rho_\ell nRgT_0}{\left(P_0 + \rho_\ell gH\right)^{\frac{2}{5}}\left(P_0 + \rho_\ell g(H-y)\right)^{\frac{3}{5}}}$$

**Hence, the correct answer is (B).**

**10.** Since, $\alpha_t > \alpha_b$, therefore, tube tries to expand more than the bolt when assembly is heated. But the tube is tightened by the bolt, therefore, its expansion cannot be more than that of the bolt. Due to this a compressive stress is developed in the tube and a tensile stress in bolt.

Let initial length of the assembly be $\ell$ and let its elongation be $\Delta\ell$. Elongation of tube if it were free to expand would be $\ell\alpha_t\Delta T$. But its actual elongation is $\Delta\ell$, therefore elongation prevented in it is equal to $\left(\ell\alpha_t\Delta T - \Delta\ell\right)$

So, compressive strain in tube is

$$E_t = \frac{\left(\ell\alpha_t\Delta T - \Delta\ell\right)}{\ell} = 5\times10^{-5}$$

**Hence, the correct answer is (B).**

**11.** Compressive stress in tube

$$\sigma_t = E_tY_t = 5\times10^{6}\ \text{Nm}^{-2} \qquad \left\{\because Y = \frac{\text{Stress}}{\text{Strain}}\right\}$$

**Hence, the correct answer is (A).**

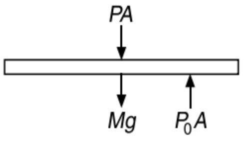
**12.** Tensile stress in bolt $\sigma_b = \frac{Y_b\left(\Delta\ell - \ell\alpha_b\Delta T\right)}{\ell} = 10^{7}\ \text{Nm}^{-2}$

**Hence, the correct answer is (B).**

**13.** Since it is open from top, pressure will be $P_0$.

**Hence, the correct answer is (A).**

**14.** Let $P$ be the pressure in equilibrium.



Then, $PA = P_0A - Mg$

$$\Rightarrow \quad P = P_0 - \frac{Mg}{A} = P_0 - \frac{Mg}{\pi R} \qquad \ldots(1)$$

Applying $P_1V_1 = P_2V_2$

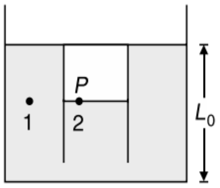
$$\Rightarrow \quad P_0(2AL) = (P)(AL')$$

$$\Rightarrow \quad L' = \frac{2P_0L}{P} = \left(\frac{P_0}{P_0 - \frac{Mg}{\pi R^2}}\right)(2L)$$

$$L' = \left(\frac{P_0\pi R^2}{\pi R^2P_0 - Mg}\right)(2L)$$

**Hence, the correct answer is (D).**

**15.** Since we observe, $P_1 = P_2$



$$\Rightarrow \quad P_0 + \rho g(L_0 - H) = P \qquad \ldots(1)$$

Now, applying $P_1V_1 = P_2V_2$ for the air inside the cylinder, we have

$$P_0(L_0) = P(L_0 - H)$$

$$\Rightarrow \quad P = \frac{P_0L_0}{L_0 - H}$$

Substituting in equation (1), we have

$$P_0 + \rho g(L_0 - H) = \frac{P_0L_0}{L_0 - H}$$

$$\Rightarrow \quad \rho g(L_0 - H)^2 + P_0(L_0 - H) - P_0L_0 = 0$$

**Hence, the correct answer is (C).**

**16.** The given network forms a Wheatstone's bridge. There will be no heat flow through $bd$, if the bridge is balanced.

$$\Rightarrow \quad \frac{R_{ab}}{R_{bc}} = \frac{R_{ad}}{R_{dc}}$$

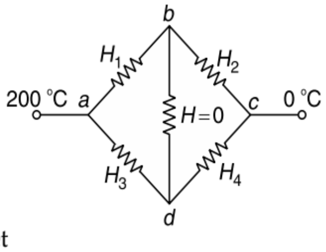
Since, $R \propto \ell$

$$\Rightarrow \quad \frac{\ell}{3\ell} = \frac{2\ell}{x}$$

$$\Rightarrow \quad x = 6\ell$$

**Hence, the correct answer is (C).**

**17.** Since, $H_{bd} = 0$



$$\Rightarrow \quad H_1 = H_2$$

$$\Rightarrow \quad H_3 = H_4$$

$$\Rightarrow \quad \frac{200 - T_b}{\left(\frac{\ell}{KA}\right)} = \frac{T_b - 0}{\left(\frac{3\ell}{KA}\right)}$$

Solving this equation, we get

$$T_b = 150\ ^\circ\text{C}$$

**Hence, the correct answer is (D).**

18. **The correct answer is (D).**

19. **The correct answer is (C).**

**Combined solution to 18 and 19**

Let $m$ be the mass of ice and $q$ be the rate by which the heat is supplied to it. If $T_i$ and $T_f$ be the initial and final temperature of the ice, then

$$Q_1 = q \times 1 = m \times 0.5 \times (-T_i)$$

$$Q_2 = q \times 4 = m \times 80$$

and $Q_3 = q \times 2 = m \times 1 \times T_f$

Solving these three equations, we get

$$T_f = 40\ °\text{C}$$

and $T_i = -40\ °\text{C}$

20. Since, $C_P - C_V = R$

$$\Rightarrow \quad C_V = \frac{R}{\gamma - 1}$$

So, $C_{V_A} = \dfrac{R}{\left(\dfrac{5}{3} - 1\right)} = \dfrac{3R}{2}$

$$\Rightarrow \quad C_{P_A} = \frac{5R}{2}$$

Similarly, $C_{V_B} = \dfrac{R}{\left(\dfrac{7}{5} - 1\right)} = \dfrac{5R}{2}$

$$\Rightarrow \quad C_{P_B} = \frac{7R}{2}$$

Also, $\gamma_{\text{mixture}} = \dfrac{19}{13} = \dfrac{n_A C_{P_A} + n_B C_{P_B}}{n_A C_{V_A} + n_B C_{V_B}}$

where $n_A = 1$

$$\Rightarrow \quad n_B = 2 \text{ mole}$$

**Hence, the correct answer is (D).**

21. Since, Bulk Modulus of the gas under adiabatic conditions is

$$B = \gamma P$$

Compressibility, $K = \dfrac{1}{B} = \dfrac{1}{\gamma P}$

So, change in adiabatic compressibility is

$$\Delta K = K_2 - K_1$$

$$\Rightarrow \quad \Delta K = \frac{1}{\gamma P_2} - \frac{1}{\gamma P_1} = \frac{1}{\gamma}\left(\frac{1}{P_2} - \frac{1}{P_1}\right)$$

Since, the process is adiabatic, so we have

$$P_2 V_2^{\gamma} = P_1 V_2^{\gamma}$$

$$\Rightarrow \quad P_2 = P_1\left(\frac{V_1}{V_2}\right)^{\gamma} = P_1\left(\frac{V_1}{V_1/5}\right)^{\gamma} = P_1 5^{\gamma}$$

$$\Rightarrow \quad \Delta K = \frac{1}{\gamma}\left(\frac{1}{P_1 5^{\gamma}} - \frac{1}{P_1}\right) = \frac{1}{\gamma P_1}\left(\frac{1}{5^{\gamma}} - 1\right)$$

where, $P_1 = \dfrac{(n_A + n_B)RT}{V}$

$$\Rightarrow \quad P_1 = \frac{(1+2) \times 8.31 \times T}{V} = \frac{24.93T}{V}$$

$$\Rightarrow \quad \Delta K = \frac{1}{\left(\dfrac{19}{13}\right)(24.93)\left(\dfrac{T}{V}\right)}\left(\frac{1}{5^{\frac{19}{13}}} - 1\right)$$

$$\Rightarrow \quad \Delta K = -(0.025)\frac{V}{T}$$

**Hence, the correct answer is (A).**

22. **The correct answer is (B).**

23. **The correct answer is (A).**

24. **The correct answer is (B).**

**Combined solution to 22, 23 and 24**

Let $P_1$ and $P_2$ be the initial pressure in lower chamber of gas and upper chamber of gas, then

$$P_2 = P_0 + \frac{mg}{A} = 2P_0 \text{ and } V_2 = A \times 12 \times 10^{-2}\ \text{m}^3$$

If $P_2'$ and $V_2'$ are final pressure and volume in upper chamber, then we have

$$V_2' = A \times (28 - l) \times 10^{-2}\ \text{m}^3$$

Since, $P_2 V_2 = P_2' V_2'$

$$\Rightarrow \quad P_2' = \frac{P_2 V_2}{P_2'} = \frac{24P_0}{28 - l}$$

New consider lower chamber, then

$$P_1 = P_0 + \frac{2mg}{A} = 3P_0 \text{ and } V_1 = A \times 8 \times 10^{-2}\ \text{m}^3$$

Also, $P_1' = P_2' + \dfrac{mg}{A} = P_0\left(\dfrac{52 - l}{28 - l}\right)$

and $V_1' = A \times (8 + l) \times 10^{-2}\ \text{m}^3$

Since, $P_1 V_1 = P_1' V_1'$

$$\Rightarrow \quad (3P_0 A)(8 \times 10^{-2}) = P_0\left(\frac{52 - l}{28 - l}\right)A\left[(8 + l) \times 10^{-2}\right]$$

$$\Rightarrow \quad 24 = \left(\frac{52 - l}{28 - l}\right)(8 + l)$$

$$\Rightarrow \quad l = 4 \text{ cm}$$

So, $P_1' = 2P_0 = 2 \times 10^5\ \text{Am}^{-2}$

and $P_2' = \dfrac{24P_0}{28 - l} = P_0 = 1 \times 10^5\ \text{Nm}^{-2}$

$$\Rightarrow \quad \frac{V_2'}{V_1'} = \frac{28 - l}{8 + l} = \frac{24}{12} = 2$$

25. $W$ = Area under the curve $= \dfrac{3}{2}P_1 V_1$

Since, $P_1 V_1 = nRT_1$

$$\Rightarrow \quad \frac{W}{nRT_1} = \frac{\frac{3}{2}P_1 V_1}{P_1 V_1} = \frac{3}{2}$$

**Hence, the correct answer is (A).**

26. From $FLTD$, we have

$$Q = dU + W$$

Since, $dU = nC_v dT$

For final state, we have

$$P_2V_2 = (2P_1)(2V_1) = 4P_1V_1 = nR(4T_1)$$

Hence final temperature is $4T_1$

$$\Rightarrow \quad dU = n\left(\frac{3R}{2}\right)(3T_1) = \frac{9}{2}nRT_1$$

$$\Rightarrow \quad Q = \frac{3}{2}nRT_1 + \frac{9}{2}nRT_1 = 6nRT_1$$

$$\Rightarrow \quad \frac{Q}{nRT_1} = 6$$

**Hence, the correct answer is (D).**

**27.** Since, $Q = 6nRT_1$ ...(1)

Also, we know that

$$Q = nC\Delta T$$

$$\Rightarrow \quad Q = nC(3T_1) \quad \text{...(2)}$$

Equating (1) and (2), we get

$$6nRT_1 = nC(3T_1)$$

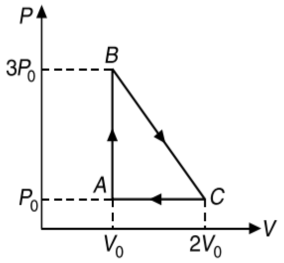
$$\Rightarrow \quad \frac{C}{R} = 2$$

**Hence, the correct answer is (B).**

**28.** $ABCA$ is a clockwise cyclic process, so work done by the gas is

$$W = \text{Area of triangle } ABC = \frac{1}{2}(\text{base})(\text{height})$$

$$\Rightarrow \quad W = \frac{1}{2}(2V_0 - V_0)(3P_0 - P_0) = P_0V_0$$



**Hence, the correct answer is (B).**

**29.** Number of moles $n = 1$ and gas is monatomic, therefore

$$C_V = \frac{3}{2}R \text{ and } C_P = \frac{5}{2}R$$

$$\Rightarrow \quad \frac{C_V}{R} = \frac{3}{2} \text{ and } \frac{C_P}{R} = \frac{5}{2}$$

Heat rejected in path $CA$: (process is isobaric)

$$\Rightarrow \quad C \to D:$$

$$\Rightarrow \quad dQ_{CA} = \frac{C_P}{R}(P_fV_f - P_iV_i)$$

Substituting the values

$$dQ_{CA} = \frac{5}{2}(P_0V_0 - 2P_0V_0) = -\frac{5}{2}P_0V_0$$

**Hence, the correct answer is (C).**

**30.** Heat rejected in the process $AB$ (process is isochoric) is

$$dQ_{AB} = C_V dT = C_V(T_f - T_i)$$

Also, $Q_{CD} = -900R$ (released)

$$\Rightarrow \quad dU = 0$$

$$dQ_{AB} = 3P_0V_0$$

Heat absorbed in the process $AB$ is $3P_0V_0$

**Hence, the correct answer is (B).**

**31.** Let $dQ_{BC}$ be the heat absorbed in the process $BC$:

Total heat absorbed,

$$dQ = dQ_{CA} + dQ_{AB} + dQ_{BC}$$

$$dQ = \left(-\frac{5}{2}P_0V_0\right) + 3(P_0V_0) + dQ_{BC}$$

$$dQ = dQ_{BC} + \frac{P_0V_0}{2}$$

Change in internal energy, $dU = 0$

$$\Rightarrow \quad dQ = dW$$

$$\Rightarrow \quad dQ_{BC} + \frac{P_0V_0}{2} = P_0V_0$$

$$\Rightarrow \quad dQ_{BC} = \frac{P_0V_0}{2}$$

Heat absorbed in the process $BC$ is $\frac{P_0V_0}{2}$

**Hence, the correct answer is (C).**

**32.** Maximum temperature of the gas will be somewhere between $B$ and $C$. Line $BC$ is a straight line. Therefore, $P$-$V$ equation for the process $BC$ can be written as

$$P = -mV + c \quad (y = mx + c)$$

Here, $m = \frac{2P_o}{V_o}$ and $c = 5P_o$

$$\Rightarrow \quad P = -\left(\frac{2P_o}{V_o}\right)V + 5P_o$$

Multiplying the equation by $V$,

$$PV = -\left(\frac{2P_o}{V_o}\right)V^2 + 5P_oV \qquad (PV = RT \text{ for } n = 1)$$

$$+$$

$$RT = -\left(\frac{2P_o}{V_o}\right)V^2 + 5P_oV$$

$$\text{or} \quad T = \frac{1}{R}\left[5P_oV - \frac{2P_o}{V_o}V^2\right] \quad \text{...(1)}$$

For $T$ to be maximum, $\frac{dT}{dV} = 0$

$$\Rightarrow \quad 5P_o - \frac{4P_o}{V_o}V = 0$$

$$\Rightarrow \quad V = \frac{5V_o}{4}$$

i.e. at $V=\frac{5V_o}{4}$, (on line $BC$), temperature of the gas is maximum. From equation (1) this maximum temperature will be

$$T_{\max}=\frac{1}{R}\left[5P_o\left(\frac{5V_o}{4}\right)-\frac{2P_o}{V_o}\left(\frac{5V_o}{4}\right)^2\right]$$

$$\Rightarrow\quad T_{\max}=\frac{25}{8}\frac{P_oV_o}{R}$$

**Hence, the correct answer is (A).**

**33.** $W=\int PdV=\alpha\int_{V_0}^{nV_0}VdV=\frac{\alpha V_0^2}{2}\left(n^2-1\right)$

**Hence, the correct answer is (A).**

**34.** Since, $dU=C_VdT=\frac{R}{\gamma-1}dT$

$$\Rightarrow\quad \Delta U=\frac{R}{\gamma-1}\int dT$$

Since, $PV=RT=\alpha V^2$

$$\Rightarrow\quad RdT=2\alpha VdV$$

$$\Rightarrow\quad \Delta U=\frac{2\alpha}{(\gamma-1)}\int_{V_0}^{nV_0}VdV=\frac{\alpha}{\gamma-1}V_0^2\left(n^2-1\right)$$

**Hence, the correct answer is (B).**

**35.** Since, $Q=\Delta U+W$

and $Q=(1)C\Delta T$

$$\Rightarrow\quad C=\left(\frac{\gamma+1}{\gamma-1}\right)\frac{R}{2}$$

**Hence, the correct answer is (B).**

**36.** At constant pressure, we have

$$W=P\Delta V=P_0\left(2V_0-V_0\right)=P_0V_0$$

$$\Rightarrow\quad \Delta U=3P_0\left(2V_0\right)-3P_0\left(V_0\right)=3P_0V_0$$

So, from FLTD, we get

$$Q=\Delta U+W=4P_0V_0$$

**Hence, the correct answer is (D).**

**37.** Also, for $n$ moles of gas with $f$ degrees of freedom, at temperature $T$, we have

$$U=\frac{f}{2}nRT=\frac{f}{2}(PV)$$

Since $U=3PV$

So, comparing, we get

$$\frac{f}{2}=3$$

$$\Rightarrow\quad f=6$$

Since, $\gamma=1+\frac{2}{f}$

$$\Rightarrow\quad \gamma=1+\frac{2}{6}$$

$$\Rightarrow\quad \gamma=\frac{4}{3}=1.33$$

**Hence, the correct answer is (A).**

**38.** Process $AB:PT=\text{constant}$

Since, $PV=(1)RT$

$$\Rightarrow\quad \left(\frac{RT}{V}\right)T=\text{constant}$$

$$\Rightarrow\quad \frac{RT^2}{V}=\text{constant} \qquad \ldots(1)$$

Since, $W=\int_A^B PdV=\int_A^B\frac{\text{constant}}{T}dV$

Also, $\frac{P_A}{P_B}=\frac{T_B}{T_A}$ $\qquad\{\because PT=\text{constant}\}$

$$\Rightarrow\quad \frac{1}{3}=\frac{T_B}{T_A}$$

$$\Rightarrow\quad T_B=\frac{300}{3}=100$$

From (1), we get

$$\frac{dV}{dT}=\frac{2RT}{\text{constant}}$$

$$\Rightarrow\quad W=\int_{300}^{100}\frac{(\text{constant})}{T}\frac{2RT}{(\text{constant})}dt$$

$$\Rightarrow\quad W=2R(100-300)$$

$$\Rightarrow\quad W_{AB}=-400\text{ R}$$

**Hence, the correct answer is (B).**

**39.** Since, the process $CA$ is isochoric

So, $\frac{P}{T}=\text{constant}$

$$\Rightarrow\quad \frac{T_A}{T_C}=\frac{P_A}{P_C}$$

$$\Rightarrow\quad \frac{T_A}{T_C}=\frac{P_A}{P_B}=\frac{1}{3}$$

$$\Rightarrow\quad T_C=3T_A=900\text{ K}$$

Since, $\Delta U=nC_V\Delta T$

$$\Rightarrow\quad \Delta U=(1)\frac{3}{2}R\times\left(T_A-T_C\right)$$

$$\Rightarrow\quad \Delta U=\frac{3}{2}R\times(300-900)$$

$$\Rightarrow\quad \Delta U=-\frac{3}{2}R\times600=-900R$$

**Hence, the correct answer is (D).**

**40.** Since, process $BC$ is isobaric, so we have

$$Q=nC_P\Delta T$$

$$\Rightarrow\quad Q=(1)\frac{5}{2}R\left(T_C-T_B\right)=\frac{5}{2}R(900-100)$$

$$\Rightarrow \quad Q = \frac{5}{2}R(800) = 2000R$$

**Hence, the correct answer is (C).**

**41.** Let $T_B = T_0$ and $V_C = V_D = V_0$

Then, $T_D = T_A = 4T_0$ and $V_A = (8\sqrt{2})V_0$

Now, $V_B = \left(\frac{V_A}{T_A}\right)T_B = 2\sqrt{2}V_0$

and $T_C = T_B\left(\frac{V_B}{V_C}\right)^{\gamma-1} = 2T_0$

$$\Rightarrow \quad T_C = 2T_B$$

**Hence, the correct answer is (B).**

**42.** Since, we have

$$W = W_{AB} + W_{BC} + W_{CD} + W_{DA}$$

$$\Rightarrow \quad W = R(T_B - T_A) + nC_V(T_B - T_C) + 0 + RT_D\log_e\left(\frac{V_A}{V_D}\right)$$

$$\Rightarrow \quad W = -3RT_0 - \frac{3}{2}RT_0 + 0 + 14RT_0\log_e 2$$

$$\Rightarrow \quad W = 5.2RT_0$$

**Hence, the correct answer is (A).**

**43.** $Q_{\text{absorbed}} = Q_{CD} + Q_{DA}$

$$\Rightarrow \quad Q_{\text{absorbed}} = 3RT_0 + 14RT_0\log_e 2 = 12.7T_0$$

So, efficiency, $\eta = \frac{W}{Q_{\text{absorbed}}} \times 100 = 41\%$

**Hence, the correct answer is (B).**

**44.** $W_{ab} = W_{cd} = 0$ as $V =$ constant

$$W_{da} = nRT_a\log_e\left(\frac{V_a}{V_d}\right)$$

$$W_{bc} = nRT_b\log_e\left(\frac{V_c}{V_b}\right) = -nRT_b\log_e\left(\frac{V_a}{V_d}\right)$$

$$\Rightarrow \quad W_{\text{net}} = nR\log_e\left(\frac{V_a}{V_d}\right)(T_a - T_b)$$

Since $T_b - T_a > 0$ and $\frac{V_a}{V_d} > 1$

$$\Rightarrow \quad W_{\text{net}} = \text{NEGATIVE}$$

**Hence, the correct answer is (C).**

**45.** $d \to a : T =$ constant

$$\Rightarrow \quad \Delta U = 0$$

$$\Rightarrow \quad Q = W$$

Since, volume of the gas is increasing. Hence, $W$ is positive, so $Q$ is positive.

$$a \to b : V = \text{constant}$$

$$\Rightarrow \quad W = 0$$

$$\Rightarrow \quad Q = \Delta U$$

Since, temperature is increasing. Therefore, $\Delta U$ will increase, so $Q$ is positive.

Hence, in processes $d \to a$ and $a \to b$ heat is supplied to the gas while in processes $b \to c$ and $c \to d$ heat is taken from the gas.

**Hence, the correct answer is (B).**

**46.** From ideal gas equation, we have

$$PV = nRT$$

$$\Rightarrow \quad P = \frac{nRT}{V} = \frac{nR(T_0 + aV^3)}{V}$$

$$\Rightarrow \quad P = \frac{nRT_0}{V} + nRaV^2$$

For $P$ to be minimum, we have $\frac{dP}{dV} = 0$

$$\Rightarrow \quad -\frac{nRT_0}{V^2} + 2anRV = 0$$

$$\Rightarrow \quad \frac{T_0}{V^2} = 2aV$$

$$\Rightarrow \quad V^3 = \frac{T_0}{2a}$$

$$\Rightarrow \quad V = \left(\frac{T_0}{2a}\right)^{\frac{1}{3}}$$

**Hence, the correct answer is (A).**

**47.** From ideal gas equation, we get

$$P = \frac{nRT}{V} = \frac{nR(T_0 + aV^3)}{V}$$

$$\Rightarrow \quad P = \frac{nRT_0}{V} + anRV^2$$

$$\Rightarrow \quad P = \frac{nRT_0}{T_0^{\frac{1}{3}}}(2a)^{\frac{1}{3}} + anR\frac{T_0^{\frac{2}{3}}}{(2a)^{\frac{2}{3}}}$$

For $n = 1$, we get

$$\Rightarrow \quad P_{\min} = RT_0^{\frac{2}{3}}(2)^{\frac{1}{3}}(a)^{\frac{1}{3}} + \frac{a^{\frac{1}{3}}RT_0^{\frac{2}{3}}}{2^{\frac{2}{3}}}$$

$$\Rightarrow \quad P_{\min} = \frac{3RT_0^{\frac{2}{3}}a^{\frac{1}{3}}}{2^{\frac{2}{3}}} = \frac{3}{2}\left(a^{\frac{1}{3}}RT_0^{\frac{2}{3}}\right)(2)^{\frac{1}{3}}$$

$$\Rightarrow \quad P_{\min} = \frac{3R}{2}\left(2aT_0^2\right)^{1/3}$$

**Hence, the correct answer is (D).**

**48.** In adiabatic process $TV^{\gamma-1} =$ constant

$$\Rightarrow \quad TV^{\gamma-1} = \left(\frac{T}{2}\right)(5.66V)^{\gamma-1}$$

$$\Rightarrow \quad (5.66V)^{\gamma-1} = 2$$

$$\Rightarrow \quad (\gamma-1)\ln(5.66) = \ln(2)$$

$$\Rightarrow \quad \gamma - 1 = 0.4$$

$$\Rightarrow \quad \gamma = 1.4$$

Since, $\gamma = 1 + \frac{2}{f}$

$\Rightarrow \quad f = 5$ {for $\gamma = 1.4$}

**Hence, the correct answer is (D).**

**49.** Using $PV^{\gamma} = \text{constant}$

$\Rightarrow \quad PV^{1.4} = P_f(5.66V)^{1.4}$

$\Rightarrow \quad P_f = 0.09P$

Since, work done in adiabatic process is given by

$$W = \frac{P_iV_i - P_fV_f}{\gamma - 1} = \frac{(PV) - (0.09P)(5.66V)}{1.4 - 1}$$

$\Rightarrow \quad W = 1.23\,PV$

**Hence, the correct answer is (B).**

**50.** Since, $U = U_0 + 2PV$

$\Rightarrow \quad \Delta U = 2\Delta(PV) = 2R\Delta T$

$\Rightarrow \quad C_V = 2R$

$\Rightarrow \quad C_P = 3R$

**Hence, the correct answer is (B).**

**51.** $W = RT\log_e\left(\frac{2V_0}{V_0}\right) = PV\log_e(2) = \frac{U_1 - U_0}{2}\log_e(2)$

**Hence, the correct answer is (D).**

**52.** $C_V = 2R$, which lies between $C_V$ value of a monatomic and a diatomic gas.

**Hence, the correct answer is (C).**

**53.** Let at any instant $t$ temperature is $T$. The net rate at which heat is absorbed by the gas is

$$\frac{dQ}{dt} = q - \frac{KA(T - T_0)}{\ell} \qquad \ldots(1)$$

Since, $dQ = nC_PdT = n\left(\frac{7R}{2}\right)dT$ …(2)

$\Rightarrow \quad n\left(\frac{7R}{2}\right)\frac{dT}{dt} = q - \frac{KA(T - T_0)}{\ell}$

$\Rightarrow \quad \int_{T_0}^{T}\frac{dT}{q\ell - KA(T - T_0)} = \frac{2}{7nR\ell}\int_0^t dt$

Solving, we get

$$T = T_0 + \frac{q\ell}{KA}\left(1 - e^{-\frac{2KAt}{7nR\ell}}\right)$$

**Hence, the correct answer is (A).**

**54.** At maximum temperature, we have

$$\frac{dQ}{dt} = 0$$

So, from (1), we get

$$q = \frac{KA}{\ell}(T_{\max} - T_0)$$

$\Rightarrow \quad T_{\max} = T_0 + \frac{q\ell}{KA}$

**Hence, the correct answer is (B).**

**55.** Since, the process is isobaric, so we have

$$\frac{V_0}{T_0} = \frac{V_{\max}}{T_{\max}}$$

$\Rightarrow \quad \frac{V_{\max}}{V_0} = \frac{T_{\max}}{T_0}$

**Hence, the correct answer is (D).**

**56.** In process $a \to c$, we observe that

$V \propto T$ i.e., $P = \text{constant}$

$\Rightarrow \quad Q = nC_p\Delta T = 2\left(\frac{5}{2}R\right)(600 - 300) = 1500R$

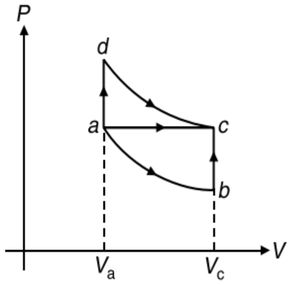
$\Delta U = nC_V\Delta T = 2\left(\frac{3}{2}R\right)(600 - 300) = 900R$

From FLTD, we have $Q = \Delta U + W$

$\Rightarrow \quad W = Q - \Delta U = 600R$

**Hence, the correct answer is (C).**

**57.** The corresponding $P$-$V$ graph is shown in figure.



Since, area under the $P$-$V$ graph gives the work done.

Hence, $W_{adc} > W_{ac} > W_{abc}$

$\Rightarrow \quad W_3 > W_2 > W_1$

**Hence, the correct answer is (D).**

**58.** **The correct answer is (C).**

**59.** **The correct answer is (B).**

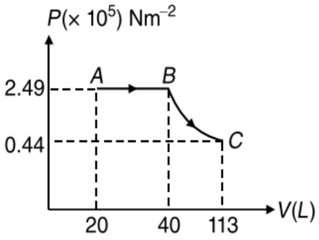
**60.** **The correct answer is (D).**

### Combined solution to 58, 59 and 60

For $AB: P = \text{constant}$

$\Rightarrow \quad V \propto T$

So, if $V$ is doubled, $T$ also becomes two times.



$T_A = 300\,K$

$\Rightarrow \quad T_B = 600\,K$

$V_A = 20\,L$

$\Rightarrow \quad V_B = 40\,L$

$$P_A = \frac{nRT_A}{V_A} = \frac{(2)(8.31)(300)}{20 \times 10^{-3}} = 2.49 \times 10^5\ \text{Nm}^{-2}$$

Process 2: Process is adiabatic. So, applying $T^{\gamma}P^{1-\gamma} = \text{constant}$.

$\Rightarrow \quad \left(\frac{600}{300}\right)^{5/3} = \left(\frac{2.49 \times 10^5}{P_C}\right)^{\frac{5}{3}-1} = \left(\frac{2.49 \times 10^5}{P_C}\right)^{2/3}$

$$\Rightarrow \quad P_C = \left(2.49\times10^5\right)\left(\frac{300}{600}\right)^{5/2}$$

$$\Rightarrow \quad P_C = 0.44\times10^5\ \text{Nm}^{-2} = 4.4\times10^5\ \text{Nm}^{-2}$$

Similarly using $PV^{\gamma} =$ constant we can find that $V_C = 113$ litre

$W_{AB} =$ Area under $P$-$V$ graph

$$\Rightarrow \quad W_{AB} = \left(2.49\times10^5\right)(40-20)\times10^{-3} = 4980\ \text{J}$$

Also, $W_{BC} = -\Delta U = nC_V\left(T_B - T_C\right)$

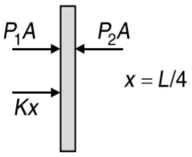
$$\Rightarrow \quad W_{BC} = (2)\left(\frac{3}{2}\times8.31\right)(600-300) = 7479\ \text{J}$$

$$\Rightarrow \quad W_{\text{total}} = 12459\ \text{J}$$

**61.** Since, $P_1A + Kx = P_2A$

$$\Rightarrow \quad \frac{nRT}{(L-x)} + Kx = \frac{nR(T+\Delta T)}{L+x} \qquad \{\because\ PV = nRT\}$$

$$\Rightarrow \quad \frac{nRT}{\left(\frac{3L}{4}\right)} + K\frac{L}{4} = \frac{nR(T+\Delta T)}{\left(\frac{5L}{4}\right)}$$



$$\Rightarrow \quad \Delta T = \frac{2T}{3} + \frac{5}{16}\frac{KL^2}{nR}$$

**Hence, the correct answer is (C).**

**62.** Since, $\Delta U = nC_V\Delta T$

$$\Rightarrow \quad \Delta U = n\left(\frac{3R}{2}\right)\left(\frac{2T}{3} + \frac{5}{16}\frac{KL^2}{nR}\right)$$

$$\Rightarrow \quad \Delta U = nRT + \left(\frac{15}{32}\right)KL^2$$

**Hence, the correct answer is (A).**

**63.** Using $FLTD$, we get

$$Q = \Delta U + W$$

where $W = \dfrac{1}{2}Kx^2 = \dfrac{1}{2}K\left(\dfrac{L}{4}\right)^2$

$$\Rightarrow \quad W = \frac{1}{2}\frac{KL^2}{16} = \frac{KL^2}{32}$$

$$\Rightarrow \quad Q = \Delta U + W = nRT + \frac{KL^2}{2}$$

**Hence, the correct answer is (B).**

**64.** Since, $T = T_0 + \alpha V^3$

For an Ideal Gas, we have

$$PV = nRT$$

$$\Rightarrow \quad T = \frac{PV}{nR}$$

$$\Rightarrow \quad \frac{PV}{nR} = T_0 + \alpha V^3$$

$$\Rightarrow \quad P = \frac{nRT_0}{V} + (nR\alpha)V^2$$

Now $P$ is minimum, when $\dfrac{dP}{dV} = 0$

$$\Rightarrow \quad -\frac{nRT_0}{V^2} + nR\alpha(2V) = 0$$

$$\Rightarrow \quad \frac{T_0}{V^2} = 2\alpha V$$

$$\Rightarrow \quad V^3 = \frac{T_0}{2\alpha}$$

$$\Rightarrow \quad V = \left(\frac{T_0}{2\alpha}\right)^{\frac{1}{3}}$$

**Hence, the correct answer is (C).**

**65.** Since, $C = C_V + \dfrac{P}{n}\left(\dfrac{dV}{dT}\right)$

$$\Rightarrow \quad C = C_V + \frac{P}{n\left(3\alpha V^2\right)} \qquad \left\{\because\ \frac{dV}{dT} = 3\alpha V^2\right\}$$

But $P = \dfrac{nRT_0}{V} + (nR\alpha)V^2$

$$\Rightarrow \quad C = C_V + \left(\frac{nRT_0}{V} + (nR\alpha)V^2\right)\frac{1}{3n\alpha V^2}$$

$$\Rightarrow \quad C = C_V + \frac{nRT_0}{V\left(3n\alpha V^2\right)} + \frac{nR\alpha V^2}{3n\alpha V^2}$$

$$\Rightarrow \quad C = C_V + \frac{R}{3} + \frac{RT_0}{3\alpha V^3}$$

**Hence, the correct answer is (A).**

**66.** Since, $P = \dfrac{nRT_0}{V} + (nR\alpha)V^2$

This $P$ is minimum, when

$$V = \left(\frac{T_0}{2\alpha}\right)^{\frac{1}{3}}$$

$$\Rightarrow \quad P_{\min} = \frac{nRT_0}{\left(\frac{T_0}{2\alpha}\right)^{\frac{1}{3}}} + nR\alpha\left(\frac{T_0}{2\alpha}\right)^{\frac{2}{3}}$$

$$\Rightarrow \quad P_{\min} = 2^{\frac{1}{3}}nRT_0^{\frac{2}{3}}\alpha^{\frac{1}{3}} + 2^{\frac{2}{3}}nRT_0^{\frac{2}{3}}\alpha^{\frac{1}{3}}$$

$$\Rightarrow \quad P_{\min} = 2^{\frac{1}{3}}nRT_0^{\frac{2}{3}}\alpha^{\frac{1}{3}}\left(1+2^{\frac{1}{3}}\right)$$

$$\Rightarrow \quad \frac{P_{\min}}{nRT_0^{\frac{2}{3}}\alpha^{\frac{1}{3}}} = 2^{\frac{1}{3}}\left(1+2^{\frac{1}{3}}\right)$$

$$\Rightarrow \quad \frac{P_{\min}}{nRT_0^{\frac{2}{3}}\alpha^{\frac{1}{3}}} = \left(2^{\frac{1}{3}} + 2^{\frac{2}{3}}\right)$$

**Hence, the correct answer is (B).**

**67.** $E = \displaystyle\int_0^{\infty} E_\lambda d\lambda$

The area under the curve represents the total intensity (energy per unit area per second) radiated at a particular temperature.

**Hence, the correct answer is (C).**

**68.** According to the Stefan's Law, the intensity of each wavelength increases by increasing the temperature and the area under the curve increases in fourth power of temperature.

According to Wein's Law,

$$\lambda_m \propto \frac{1}{T}$$

**Hence, the correct answer is (D).**

69. While answering, we must keep in mind that the curve at higher temperature
   (i) lies above the curve at lower temperature.
   (ii) never intersects with the curve at lower temperature.
   (iii) the maximum occurs at a lower wavelength.

   **Hence, the correct answer is (B).**

70. Initially, we have $U_i = n_1\left(\frac{3}{2}k_B T_1\right) + n_1\left(\frac{3}{2}k_B T_2\right)$

   $$\Rightarrow \quad U_i = \frac{3}{2}k_B\left(n_1T_1 + n_2T_2\right)$$

   **Hence, the correct answer is (B).**

71. Finally, we have $U_i = \frac{3}{2}k_B T\left(n_1 + n_2\right)$

   **Hence, the correct answer is (B).**

72. Heat lost by one equals the heat gained by the other gas, so we have

   $$\frac{n_1}{N_A}\left(\frac{3R}{2}\right)\left(T_1 - T\right) = \frac{n_2}{N_A}\left(\frac{3R}{2}\right)\left(T - T_2\right)$$

   $$\Rightarrow \quad T = \frac{n_1T_1 + n_2T_2}{n_1 + n_2}$$

   **Hence, the correct answer is (D).**

73. $C = \frac{R}{\gamma - 1} + \frac{R}{1 - x} = C_V + \frac{R}{1 - x}$

   Since it is given that $P \propto V$

   $\Rightarrow \quad PV^{-1} = \text{constant}$

   $\Rightarrow \quad x = -1$

   $$\Rightarrow \quad C = C_V + \frac{R}{2} = \frac{5R}{2} + \frac{R}{2} = 3R$$

   **Hence, the correct answer is (A).**

74. $v_{\text{rms}} \propto \sqrt{T}$

   Since, rms speed has doubled. Therefore, temperature must have become four times.

   $\Rightarrow \quad Q = nC\Delta T$

   $\Rightarrow \quad Q = nC\left(4T_0 - T_0\right)$

   $\Rightarrow \quad Q = 3n\left(3RT_0\right)$

   $\Rightarrow \quad Q = 9P_0V_0 \qquad \{\because\ nRT_0 = P_0V_0\}$

   **Hence, the correct answer is (C).**

75. Since, $T_i = T_f$, therefore net change in internal energy, $dU = 0$.

   **Hence, the correct answer is (C).**

76. Given number of moles $n = 2$

   Process $AB$ and $CD$ are isobaric.

   Hence, $Q_{AB} = -Q_{CD}$

   [Because $\left(\Delta T\right)_{AB} = +100\,K$ whereas $\left(\Delta T\right)_{CD} = -100\,K$ and $Q_{isobaric} = nC_P\Delta T$]

   or $\quad Q_{AB} + Q_{CD} = 0$

   Process $BC$ is isothermal $\left(dU = 0\right)$

   $$\Rightarrow \quad Q_{BC} = W_{BC} = nRT_B \ln\left(\frac{P_B}{P_C}\right)$$

   $V_A = 10\text{ m}^3,\ Q_{BC} = 4608\text{ J}$

   Similarly, process $DA$ is also isothermal hence

   $$Q_{DA} = W_{DA} = nRT_o \ln\left(\frac{P_D}{P_A}\right)$$

   $$\Rightarrow \quad Q_{DA} = (2)(8.31)(300)\ln\left(\frac{1}{2}\right)$$

   $$Q_{DA} = 3456\text{ J}$$

   (a) Net heat in the process

   $$Q = Q_{AB} + Q_{BC} + Q_{CD} + Q_{DA} = \left(4608 - 3456\right)\text{ J}$$

   $$Q = 1152\text{ J}$$

   (b) From First Law of Thermodynamics, $dU = 0$ (in complete cycle) $dQ = dW$

   Hence, net work done in the cycle

   $$W = Q = 1152\text{ J}$$

   $$W = 1152\text{ J}$$

   **Hence, the correct answer is (D).**

77. Since entropy is a state function, so $S_f = S_i$ and hence $dS$ for one complete cycle is zero.

   **Hence, the correct answer is (D).**

## Matrix Match/Column Match Type Questions

1. A → (q, t); B → (r); C → (s); D → (p)

   For a cyclic process, $\Delta U = 0$

   By $FLTD$, we get $Q = W$

   For Isobaric process, $W = nR\Delta T$

   For Isochoric process $W = 0$, so $Q = \Delta U$

   Since, adiabatic expansion is accompanied by decrease in temperature, so a decrease in internal energy.

2. A → (p, s); B → (p, r); C → (q, s); D → (q, r)

   **Process $a \rightarrow b$:**

   $T = \text{constant}$

   $\Rightarrow \quad \Delta T = 0$

   $\Rightarrow \quad \Delta U = 0$

   $$\Rightarrow \quad P \propto \frac{1}{V}$$

   $\rho$ is increasing. Therefore, $V$ is decreasing. Since, $V \propto \frac{1}{\rho}$ or $P$ will increase.

   **Process $b \rightarrow c$:**

   $\rho = \text{constant}$

   $\Rightarrow \quad V = \text{constant}$

   Therefore, $P \propto T$

   Since, temperature is increasing. Hence pressure should also increase.

**3.** A → (p, s); B → (q, r); C → (p, r, s); D → (p, s)

**4.** A → (r); B → (s); C → (p); D → (q)

Since, Isothermal Bulk modulus is

$$B_{\text{iso}} = P = \frac{RT}{V} \text{ and}$$

Adiabatic Bulk modulus is

$$B_{\text{ad}} = \gamma P = \frac{5RT}{3V} \qquad \left\{\because \gamma_{\text{monatomic}} = \frac{5}{3}\right\}$$

$$(\text{Slope})_{\text{isot}} = \left(\frac{dP}{dV}\right)_{\text{isot}} = -\frac{P}{V} = -\frac{RT}{V^2}$$

$$(\text{Slope})_{\text{ad}} = \left(\frac{dP}{dV}\right)_{\text{ad}} = -\gamma\left(\frac{P}{V}\right) = -\frac{5P}{3V}$$

**5.** A → (r); B → (p); C → (s); D → (q)

**6.** A → (p, s); B → (r, s); C → (p, t); D → (q, t)

$M \to N$ **is an Isochoric Process**

$\Rightarrow$ $V =$ constant i.e., $P \propto T$

$\Rightarrow$ $W_{\text{isoc}} = 0$

Since, $P$ is increasing, so $T$ is also increasing and hence $\Delta U > 0$

$N \to O$ **is an Isobaric Process**

$\Rightarrow$ $P =$ constant i.e., $V \propto T$

Since, $V$ is increasing, so $T$ is also increasing and hence $\Delta U > 0$

Also, $W > 0$ for isobaric expansion.

$O \to P$ **is an Isochoric Process**

$\Rightarrow$ $V =$ constant i.e., $P \propto T$

$\Rightarrow$ $W_{\text{isoc}} = 0$

Since, $P$ is decreasing, so $T$ is also decreasing and hence $\Delta U < 0$

$P \to M$ **is an Isobaric Process**

$\Rightarrow$ $P =$ constant i.e., $V \propto T$

Since, $V$ is decreasing, so $T$ is also decreasing and hence $\Delta U < 0$

Furthermore, for isobaric compression $W < 0$

**7.** A → (u); B → (p, q, t); C → (s); D → (r)

Since $W_{ad} = \frac{R}{1-\gamma}\left(T_f - T_i\right)$ for 1 mole of gas

$$W_{\text{isochoric}} = 0$$

$$\Delta U_{\text{isothermal}} = 0$$

$$C_{\text{adiabatic}} = 0$$

$$W_{\text{isobaric}} = (1)R\Delta T = R\left(T_f - T_i\right)$$

Since, $U = nC_VT = \frac{nRT}{\gamma - 1}$ $\qquad \left\{\because C_V = \frac{R}{\gamma-1}\right\}$

$\Rightarrow$ $U = \frac{PV}{\gamma - 1}$

**8.** Conceptual

A → (s); B → (r); C → (q); D → (p)

**9.** A → (s); B → (r); C → (q); D → (p)

For an ideal monatomic gas $PV^{\gamma} =$ constant, where $\gamma = \frac{5}{3}$

$\Rightarrow$ $PV^{5/3} =$ constant(for an Adiabatic process)

$\Rightarrow$ $C_{\text{adiabatic}} = 0$

Since, for a polytropic process, $TV^{x-1} =$ constant

$\Rightarrow$ $x - 1 = 2$

$\Rightarrow$ $x = 3$

Also, $C = C_V + \frac{R}{1-x}$

$\Rightarrow$ $C = C_V - \frac{R}{2}$

$\Rightarrow$ $C = \frac{3R}{2} - \frac{R}{2}$ $\qquad \left\{\because C_V = \frac{3R}{2}\right\}$

$\Rightarrow$ $C = R$

When $V =$ constant, then $C = C_V = \frac{3R}{2}$

When $P =$ constant, then $C = C_P = \frac{5R}{2}$

**10.** Conceptual

A → (p, q, r); B → (p, r, s); C → (p, q, r); D → (p, q, r)

**11.** A → (s); B → (r); C → (q); D → (t)

**When** $A$ **and** $B$ **are mixed**

$$(m)(c)(T-20) = (2m)(c)(40-T)$$

$\Rightarrow$ $T = \frac{100}{3} = 33.3\ ^\circ\text{C}$

**When** $A$ **and** $C$ **are mixed**

$$(m)(c)(T-20) = (3m)(c)(60-T)$$

$\Rightarrow$ $T = 50\ ^\circ\text{C}$

**When** $B$ **and** $C$ **are mixed**

$$(2m)(c)(T-40) = (3m)(c)(60-T)$$

$\Rightarrow$ $T = 52\ ^\circ\text{C}$

**When** $A$, $B$ **and** $C$ **are mixed**

$$\left(\begin{array}{c}\text{Heat Gained by}\\ A+B\end{array}\right) = \left(\begin{array}{c}\text{Heat Lost by}\\ \text{C}\end{array}\right)$$

$\Rightarrow$ $mc(T-20) + (2m)c(T-40) = (3m)c(60-T)$

$\Rightarrow$ $(T-20) + 2(T-40) = 3(60-T)$

$\Rightarrow$ $3T - 100 = 180 - 3T$

$\Rightarrow$ $6T = 280$

$\Rightarrow$ $T = 46.67\ ^\circ\text{C}$

## Integer/Numerical Answer Type Questions

**1.** Let $m$ be the mass of the container

Initial temperature of container is

$$T_i = (227 + 273) = 500\ \text{K}$$

And final temperature of container is

$$T_f = (27 + 273) = 300\ \text{K}$$

Now, $\begin{pmatrix}\text{Heat Gained by}\\ \text{the Ice Cube}\end{pmatrix} = \begin{pmatrix}\text{Heat Lost by}\\ \text{the Container}\end{pmatrix}$

$$m_{\text{ice}}L_{\text{ice}} + m_{\text{ice}}c_{\text{water}}\Delta T = -m\int_{T_i}^{T_f} c\,dT$$

$$\Rightarrow \quad (0.1)\left(8\times10^4\right)+(0.1)\left(10^3\right)(27)$$

$$= -m\int_{500}^{300}(A+BT)\,dT$$

$$\Rightarrow \quad 10700 = -m\left(AT+\frac{BT^2}{2}\right)\Bigg|_{500}^{300}$$

After substituting the values of $A$ and $B$ and the proper limits, we get

$$m = 0.495\ \text{kg}$$

$$\Rightarrow \quad m = 495\ \text{g}$$

**2.** Thermal resistance $R = \dfrac{\ell}{kA}$

$$\Rightarrow \quad \frac{R_x}{R_y} = \frac{k_y}{k_x} \qquad \{\because\ \ell_x = \ell_y \text{ and } A_x = A_y\}$$

$$\Rightarrow \quad \frac{R_x}{R_y} = \frac{0.46}{0.92} = \frac{1}{2}$$

If $R_x = R$ then $R_y = 2R$

$CEDB$ forms a balanced Wheatstone bridge, i.e., $T_C = T_D$ and no heat flows through $CD$, so

$$\frac{1}{R_{BE}} = \frac{1}{R+R} + \frac{1}{2R+2R}$$

$$\Rightarrow \quad R_{BE} = \frac{4}{3}R$$

The total resistance between $A$ and $E$ will be,

$$R_{AE} = R_{AB} + R_{BE} = 2R + \frac{4}{3}R = \frac{10}{3}R$$

Now, heat current between $A$ and $E$ is

$$H = \frac{(\Delta T)_{AE}}{R_{AE}} = \frac{(60-10)}{\left(\frac{10}{3}\right)R} = \frac{15}{R}$$

If $T_B$ is the temperature at $B$, then

$$H_{AB} = \frac{(\Delta T)_{AB}}{R_{AB}}$$

$$\Rightarrow \quad \frac{15}{R} = \frac{60-T_B}{2R}$$

$$\Rightarrow \quad T_B = 30\ ^\circ\text{C}$$

Further, $H_{AB} = H_{BC} + H_{BD}$

$$\Rightarrow \quad \frac{15}{R} = \frac{30-T_C}{R} + \frac{30-T_D}{2R} \qquad \{T_C = T_D = T(\text{say})\}$$

$$\Rightarrow \quad 15 = (30-T) + \frac{(30-T)}{2}$$

Solving this, we get

$$T = 20\ ^\circ\text{C}$$

$$\Rightarrow \quad T_C = T_D = 20\ ^\circ\text{C}$$

**3.** For an adiabatic process, we have

$$P_f = \left(\frac{V_i}{V_f}\right)^{\gamma} P_i \qquad \ldots(1)$$

Further, $C_V = \dfrac{3R}{2}$

$$\Rightarrow C_P = C_V + R = \frac{5R}{2}$$

$$\Rightarrow \quad \gamma = \frac{C_P}{C_V} = \frac{5}{3}$$

$$\Rightarrow \quad P_f = \left(\frac{6}{2}\right)^{5/3}(10)^5 = 6.24\times10^5\ \text{Nm}^{-2}$$

Now, work done in adiabatic process is given by

$$W = \frac{P_iV_i - P_fV_f}{\gamma-1}$$

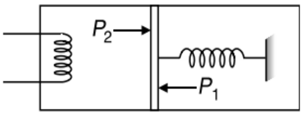
$$\Rightarrow \quad W = \frac{10^5\times6\times10^{-3} - 6.24\times10^5\times2\times10^{-3}}{\left(\frac{5}{3}\right)-1}$$

$$\Rightarrow \quad W = -972\ J$$

⇒ Work done on the gas is 972 J

**4.** (a) Since, $\dfrac{P_1V_1}{T_1} = \dfrac{P_2V_2}{T_2}$

$$\Rightarrow \quad T_2 = \left(\frac{P_2V_2T_1}{P_1V_1}\right) \qquad \ldots(1)$$



Here, $P_1 = 1\times10^5\ \text{Nm}^{-2}$, $V_1 = 2.4\times10^{-3}\ \text{m}^3$, $T_1 = 300\ \text{K}$

Since the piston is light and moves out slowly, so we have

$$P_2A = P_1A + kx$$

$$\Rightarrow \quad P_2 = P_1 + \frac{kx}{A} = \left(1\times10^5\right) + \left(\frac{8000\times0.1}{8\times10^{-3}}\right)$$

$$\Rightarrow \quad P_2 = 2\times10^5\ \text{Nm}^{-2}$$

and $V_2 = V_1 + Ax = 2.4\times10^{-3} + 8\times10^{-3}\times0.1$

$$\Rightarrow \quad V_2 = 3.2\times10^{-3}\ \text{m}^3$$

Substituting in equation (1), we get

$$T_2 = 800\ \text{K}$$

(b) Heat supplied by the heater, using the FLTD is

$$Q = W + \Delta U$$

where, $\Delta U = nC_V\Delta T = \left(\dfrac{P_1V_1}{RT_1}\right)\left(\dfrac{3}{2}R\right)(800-300)$

$$\Rightarrow \quad \Delta U = \frac{\left(1\times10^5\right)\left(2.4\times10^{-3}\right)(1.5)(500)}{(300)}$$

$\Rightarrow \quad \Delta U = 600 \text{ J}$

Further, $W = \frac{1}{2}kx^2 + P_1\Delta V$

$\Rightarrow \quad W = \frac{1}{2}\times(8000)(0.1)^2 + (1\times10^5)(0.1)(8\times10^{-3})$

$\Rightarrow \quad W = (40+80) \text{ J}$

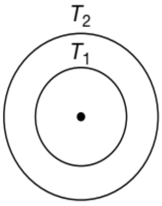
$\Rightarrow \quad W = 120 \text{ J}$

$\Rightarrow \quad Q = 600+120 = 720 \text{ J}$

**5.** Initially when only one sphere is there

$$P_{\text{source}} = \sigma A T_0^4 \qquad \{\because (T_0 = 1000 \text{ K})\}$$

After enveloping, let temperature of the inner sphere is $T_1$ and that of the outer sphere is $T_2$



$$\sigma A T_1^4 = P_{\text{source}} = \sigma A T_0^4$$

$\therefore \quad T_1 = T_0 = 1000 \text{ K}$

Further, $\sigma A T_2^4 - \sigma A T_1^4 = P_{\text{source}} = \sigma A T_0^4$

$\Rightarrow \quad T_2^4 = 2T_0^4$

$\Rightarrow \quad T_2 = (2)^{1/4}(1000)$

$\Rightarrow \quad T_2 = (1.19)(1000)$

$\Rightarrow \quad T_2 = 1190 \text{ K}$

**6.** For the given case $\Delta T = 30\ °\text{C}$

Expansion of girders is $\Delta l = l\alpha\Delta T$

$\Rightarrow \quad \Delta l = 12\times1.1\times10^{-5}\times30 = 0.00396 \text{ m}$

$\Rightarrow \quad \Delta l = 3.96 \text{ mm}$

**7.** For a cyclic process, $\Delta U = 0$

$\Rightarrow \quad Q_{\text{cycle}} = W_{\text{cycle}} \qquad \ldots(1)$

where, $W_{\text{cycle}} = W_{A\to B} + W_{B\to C} + W_{C\to A} \qquad \ldots(2)$

Process $C \to A$ is isochoric, hence $W_{C\to A} = 0$

Process $A \to B$ is isobaric, as its $T$-$V$ graph is a straight line passing through origin.

In an isobaric process, work done is

$$W_{A\to B} = P(V_B - V_A) = nR(T_B - T_A)$$

$\Rightarrow \quad W_{A\to B} = 1\times8.3(400-300) = 830 \text{ J} \qquad \ldots(3)$

$W_{A\to B}$ is positive, so expansion of gas takes place.

From equations (1), (2) and (3), we get

$$-1000 = 830 + W_{B\to C} + 0$$

$\Rightarrow \quad W_{B\to C} = -1830 \text{ J}$

Negative work done implies that compression of the gas takes place or work is done on the system/gas.

**8.** Since $t = 2\pi\sqrt{\frac{\ell}{g}}$

For a pendulum to give correct time, its period must be 2 s.

$\Rightarrow \quad 2 = 2\pi\sqrt{\frac{\ell_0}{9.8}} \qquad \ldots(1)$

$\Rightarrow \quad 2 = 2\pi\sqrt{\frac{\ell_0[1+12\times10^{-6}(T-32)]}{9.788}} \qquad \ldots(2)$

Equating (1) and (2), we get

$$\frac{\ell_0}{9.8} = \frac{\ell_0}{9.788}[1+12\times10^{-6}(T-32)]$$

$\Rightarrow \quad T - 32 = -102$

$\Rightarrow \quad T = -102+32$

$\Rightarrow \quad T = -70\ °\text{C}$

**9.** Since process is a cyclic process, so we have

So, we have

$$\Delta U = 0 \qquad \{\text{Answer to Part (c)}\}$$

Applying FLTD, we get

$$Q_{\text{net}} = W_{\text{net}} = W_{AB} + W_{BC} + W_{CD} + W_{DA}$$

Now $W_{AB} = nR\Delta T = (2)R(100) = 400 \text{ cal}$

$$W_{BC} = (2)R(400)\log_e(2) = 1120 \text{ cal}$$

$$W_{CD} = nR\Delta T = (2)R(-100) = -400 \text{ cal}$$

$$W_{DA} = (2)R(300)\log_e\left(\frac{1}{2}\right) = -840 \text{ cal}$$

So, $W_{\text{net}} = 400+1120-400-840$

$\Rightarrow \quad W_{\text{net}} = 280 \text{ cal} \qquad \{\text{Answer to Part (b)}\}$

$\Rightarrow \quad Q_{\text{net}} = 280 \text{ cal} \qquad \{\text{Answer to Part (a)}\}$

**10.** Thermal expansion in rod is $\Delta l = l\alpha\Delta T$

Due to clamps, the elastic strain developed in the rod is

$$\left|\frac{\Delta l}{l}\right| = \alpha\Delta T = (1.2\times10^{-5})(30) = 36\times10^{-5}$$

**11.** Since, in steady state, rate of heat flow is

$$H = \frac{4\pi K r_1 r_2 \Delta T}{r_2 - r_1} = \frac{(4)(\pi)(0.002)(11)(9)(100-0)}{(11-9)}$$

$\Rightarrow \quad H = \frac{dQ}{dt} = 124.4 \text{ cals}^{-1}$

This rate should be equal to $L\left(\frac{dm}{dt}\right)$

$\Rightarrow \quad \left(\frac{dm}{dt}\right) = \frac{\frac{dQ}{dt}}{L} = \frac{124.4}{80} = 1.555 \text{ gs}^{-1}$

Total mass of ice is $m = \rho_{\text{ice}}(4\pi r_1^2)$

$\Rightarrow \quad m = (0.9)(4)(\pi)(9)^2 = 916 \text{ g}$

So, time taken for the ice to melt completely is

$$t = \frac{m}{\left(\frac{dm}{dt}\right)} = \frac{916}{1.555} = 589 \text{ sec.}$$

**12.** (a) $P = \alpha\sqrt{T}$

$\Rightarrow \quad PT^{-\frac{1}{2}} = \text{constant}$

$\Rightarrow \quad P^{\frac{1}{2}}V^{-\frac{1}{2}} = \text{constant}$

$\Rightarrow \quad PV^{-1} = \text{constant}$

Compare with $PV^x = \text{constant}$, we get

$$x = -1$$

$$\Rightarrow \quad W = \left(\frac{R}{1-x}\right)(\Delta T)$$

$$\Rightarrow \quad W = \frac{R}{2}(50) = 25R$$

$$\Rightarrow \quad * = 25$$

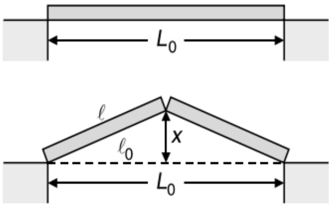
(b) Since, $C = C_V + \frac{R}{1-x} = \frac{3}{2}R + \frac{R}{2} = 2R$

$$\Rightarrow \quad C = 2R$$

$$\Rightarrow \quad * = 2$$

**13.** Consider one-half of the bar, with original length

$$\ell_0 = \frac{L_0}{2}$$



The length after temperature increase is

$$\ell = \ell_0 + \alpha\ell_0\Delta T$$

From Pythagoras theorem, we have

$$x^2 = \ell^2 - \ell_0^2 = \ell_0^2(1+\alpha\Delta T)^2 - \ell_0^2$$

$$\Rightarrow \quad x^2 = \ell_0^2(1+2\alpha\Delta T) - \ell_0^2 = 2\ell_0^2\alpha\Delta T$$

$$\Rightarrow \quad x = \ell_0\sqrt{2\alpha\Delta T}$$

$$\Rightarrow \quad x = \frac{4}{2}\sqrt{2(25\times10^{-6})(32)}$$

$$\Rightarrow \quad x = 2\times40\times10^{-3}$$

$$\Rightarrow \quad x = 80 \text{ mm}$$

**14.** Since it is given that, initially the separator is in equilibrium, so pressures on both sides of gas are equal say $P_i$. If $A$ be the area of cross-section of cylinder, then number of moles of gas in left and right part are $n_1$ and $n_2$ given by

$$n_1 = \frac{P_i(10A)}{R(100)} \text{ and } n_2 = \frac{P_i(20A)}{R(400)}$$

Finally, when separator is displaced to right through a distance $x$, then we have

$$n_1 = \frac{P_f(10+x)A}{RT_f} \text{ and } n_2 = \frac{P_f(20-x)A}{RT_f}$$

where, $P_f$ and $T_f$ be the final pressure and temperature on both sides after a long time.

Equating the ratio of number of moles $\frac{n_1}{n_2}$ in initial and final state, we get

$$\frac{n_1}{n_2} = \frac{(10A/100)}{(20A/400)} = \frac{(10+x)A}{(20-x)A}$$

$$\Rightarrow \quad 2(20-x) = 10+x$$

$$\Rightarrow \quad x = 10 \text{ cm}$$

Hence in final state, when gases in both parts are in thermal equilibrium, the piston is displaced 10 cm to the right from its initial position.

**15.** When the temperature is increased, volume of the cube will increase while density of liquid will decrease. The depth upto which the cube is submerged in the liquid remains the same, hence the upthrust will not change.

$$F = F'$$

$$\Rightarrow \quad V_i\rho_L g = V_i'\rho'_L g \qquad \{\text{where } V_i \text{ is the volume immersed}\}$$

$$\Rightarrow \quad (Ah_i)(\rho_L)(g) = A(1+2\alpha_s\Delta T)(h_i)\left(\frac{\rho_L}{1+\gamma_l\Delta T}\right)g$$

Solving this equation, we get $\gamma_\ell = 2\alpha_s$

$$\Rightarrow \quad \frac{\gamma_\ell}{\alpha_s} = 2$$

**16.** $v_{\text{rms}} = \sqrt{\frac{3RT}{M}} = v_e = 11.2 \text{ kms}^{-1} = 11.2\times10^3 \text{ ms}^{-1}$

$$\Rightarrow \quad \sqrt{\frac{3RT}{M}} = 11.2\times10^3$$

$$\Rightarrow \quad \frac{3(8.314)T}{\left(\frac{2}{1000}\right)} = (11.2\times10^3)^2$$

$$\Rightarrow \quad T \approx 20000 \text{ K}$$

**17.** $n = 1,\ \gamma = \frac{7}{5}$

$$\Rightarrow \quad \gamma - 1 = \frac{2}{5}$$

$$Q_{AB} = Q_{CD} = 0$$

Let $T_A = T_1$ and $T_D = T_2$ with $T_2 > T_1$

For the process $AB$, we have

$$TV^{\gamma-1} = \text{constant}$$

$$\Rightarrow \quad TV^{\frac{2}{5}} = \text{constant}$$

$$\Rightarrow \quad T_A(10V_0)^{\frac{2}{5}} = T_B(V_0)^{\frac{2}{5}}$$

$$\Rightarrow \quad T_B = T_1(10)^{0.4} \approx 2.5T_1$$

Similarly, $T_C = 2.5T_2$

Now, $Q_{BC} = C_V\Delta T$

$$\Rightarrow \quad Q_{BC} = \left(\frac{5}{2}R\right)(T_C - T_B) = (6.25)(T_2 - T_1) \text{ and}$$

$$Q_{DA} = -2.5(T_2 - T_1)$$

So, $W_{\text{net}} = Q_{\text{net}} = 3.75(T_2 - T_1) \qquad \{\because \Delta U = 0\}$

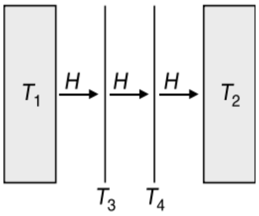
$$\Rightarrow \quad \eta = \frac{W_{\text{net}}}{\text{heat absorbed}}\times100 = \frac{3.75}{6.25}\times100 = 60\%$$

**18.** Under steady state conditions the net rate of heat flow per unit area is the same everywhere.

$$H = \sigma\left(T_1^4 - T_3^4\right)$$

$$H=\sigma\left(T_3^4-T_4^4\right)$$

$$H=\sigma\left(T_4^4-T_2^4\right)$$



Adding these three equations, we get

$$3H=\sigma\left(T_1^4-T_2^4\right)=H_0$$

Here $H_0=\sigma\left(T_1^4-T_2^4\right)$ is the rate of heat flow per unit area in the absence of the shields.

So, the desired fraction is

$$f=\frac{H}{H_0}=\frac{1}{3}$$

$\Rightarrow \quad x=3.$

**19.** Piston $A$ is free to move, so gas will expand isobarically and piston $B$ is fixed, so the process is isochoric.

Given that, $Q_A=Q_B$

$\Rightarrow \quad nC_P\Delta T_A=nC_V\Delta T_B$

$\Rightarrow \quad \left(\frac{7R}{2}\right)(30)=\left(\frac{5R}{2}\right)\Delta T_B$

$\Rightarrow \quad \Delta T_B=42\text{ K}$

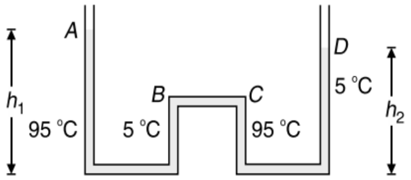
**20.** Density of a liquid varies with temperature as

$$\rho_{t\,^\circ\text{C}}=\left(\frac{\rho_{0\,^\circ\text{C}}}{1+\gamma t}\right)$$

where, $\gamma$ is the coefficient of volume expansion of temperature.

In the figure,

$$h_1=52.8\text{ cm},\ h=49\text{ cm},\ h_2=51\text{ cm}$$



Now, $(\text{Pressure at }B)=(\text{Pressure at }C)$

$\Rightarrow \quad P_o+h_1\rho_{95^\circ}g-h\rho_{5^\circ}g=P_0+h_2\rho_{5^\circ}g-h\rho_{95^\circ}g$

$\Rightarrow \quad \rho_{95^\circ}\left(h_1+h\right)=\rho_{5^\circ}\left(h_2+h\right)$

$\Rightarrow \quad \frac{\rho_{95^\circ}}{\rho_{5^\circ}}=\frac{h_2+h}{h_1+h}$

$\Rightarrow \quad \frac{\left(\frac{\rho_{0^\circ}}{1+95\gamma}\right)}{\left(\frac{\rho_{0^\circ}}{1+5\gamma}\right)}=\frac{h_2+h}{h_1+h}$

$\Rightarrow \quad \frac{1+5\gamma}{1+95\gamma}=\frac{51+49}{52.8+49}=\frac{100}{101.8}$

Solving this equation, we get

$$\gamma=2\times10^{-4}\,(^\circ\text{C})^{-1}$$

$\Rightarrow \quad x=2$

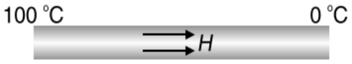
**21.** For an isobaric process, we have

$$W_{\text{isob}}=P\Delta V=nR\Delta T$$

$\Rightarrow \quad W_{\text{isob}}=(0.2)(8.3)(100)=166\text{ J}$

**22.** Thermal resistance of the rod,

$$R=\frac{\ell}{kA}=\frac{1}{(401)\left(4\times10^{-4}\right)}=6.23\text{ KW}^{-1}$$



$\Rightarrow \quad \text{Heat current }H=\frac{\text{Temperature difference}}{\text{Thermal resistance}}$

$\Rightarrow \quad H=\frac{(100-0)}{6.23}=16\text{ watt}$

Heat transferred in 1 hr. is $Q=Ht$ $\quad \left\{\because H=\frac{Q}{t}\right\}$

$\Rightarrow \quad Q=(16)(3600)=57600\text{ J}$

Now, if $m$ mass of ice melts in 1 hr., then $Q=mL$

$$m=\frac{Q}{L}=\frac{57600}{3.35\times10^5}$$

$\Rightarrow \quad m=0.172\text{ kg}=172\text{ g}$

**23.** Force by rod on wall is $F=YA\alpha\Delta T$

$\Rightarrow \quad F=\left(2\times10^{11}\right)\left(2\times10^{-6}\right)\left(1.2\times10^{-5}\right)(80)=384\text{ N}$

**24.** In both the cases, the weight of the body is balanced by the buoyant force acting on it. At $t_0=0\text{ °C}$, we have buoyant force given by

$$F_b=\left(\delta V_0\right)\rho_0 g \quad \ldots(1)$$

where $\delta$ is the fraction of volume submerged in the liquid, $V_0$ is the volume of body and $\rho_0$ is the density of liquid at $t_0=0\text{ °C}$.

At $t=50\text{ °C}$, the volume of the body now becomes $V=V_0\left(1+\gamma_s t\right)$

Further, the density of the liquid at $t=50\text{ °C}$ is $\rho_1=\frac{\rho_0}{1+\gamma_\ell t}$

So, the buoyant force is now given by

$$F_b=\frac{V_0\rho_0 g\left(1+\gamma_s t\right)}{1+\gamma_\ell t} \quad \ldots(2)$$

From (1) and (2), we get $\%\delta=96\%$

**25.** For an adiabatic process $TV^{\gamma-1}=\text{constant}$

$\Rightarrow \quad TV^{\gamma-1}=\left(\frac{T}{2}\right)(5.66V)^{\gamma-1}$

$\Rightarrow \quad (5.66V)^{\gamma-1}=2$

$\Rightarrow \quad (\gamma-1)\log_e(5.66)=\log_e(2)$

$\Rightarrow \quad \gamma-1=0.4$

$\Rightarrow \quad \gamma=1.4$

Since, $\gamma=1+\frac{2}{f}=1.4$

$$\Rightarrow \quad \frac{2}{f}=0.4$$

$$\Rightarrow \quad f=\frac{2}{0.4}=5$$

**26.** $W =$ Area Enclosed $=(10)(4-1)(3-1)\times 10^{5}\ \text{Nm}^{-2}$

$$\Rightarrow \quad W=6\times 10^{6}\ \text{J}=6\ \text{MJ}$$

If the net work is done by the gas, then direction of traversal around the cycle is clockwise.

**27.** Let $m$ be the mass of the steam required to raise the temperature of 100 g of water from 24 °C to 90 °C. Then

$$\begin{pmatrix}\text{Heat Lost}\\ \text{by Steam}\end{pmatrix}=\begin{pmatrix}\text{Heat Gained}\\ \text{by Water}\end{pmatrix}$$

$$\Rightarrow \quad m\left(L+c\Delta T_1\right)=100c\Delta T_2$$

$$\Rightarrow \quad m=\frac{(100)(c)(\Delta T_2)}{L+c(\Delta T_1)}$$

where, $c =$ specific heat of water $= 1\ \text{calg}^{-1}\ {}^{\circ}\text{C}$

$L =$ Latent heat of vaporization $= 540\ \text{calg}^{-1}$

$$\Delta T_1=(100-90)=10\ {}^{\circ}\text{C}$$

and $\Delta T_2=(90-24)=66\ {}^{\circ}\text{C}$

Substituting the values, we get

$$m=\frac{(100)(1)(66)}{(540)+(1)(10)}=12g$$

$$\Rightarrow \quad m=12g$$

**28.** Since the boiling process is an isobaric process, so

$$W_{\text{isob}}=P\Delta V=\left(10^{5}\right)(1671-1)\times 10^{-6}\ \text{Nm}$$

$$\Rightarrow \quad W_{\text{isob}}=167\ \text{J}\cong 40\ \text{cal}$$

Now, according to FLTD we have $Q=\Delta U+W$

where $Q=mL=(1)(540)=540$ cal

$$\Rightarrow \quad 540=\Delta U+40$$

$$\Rightarrow \quad \Delta U=500\ \text{cal}$$

**29.** A constant pressure, $V\propto T$

$$\Rightarrow \quad \frac{V_2}{V_1}=\frac{T_2}{T_1}$$

$$\Rightarrow \quad \frac{Ah_2}{Ah_1}=\frac{T_2}{T_1}$$

$$\Rightarrow \quad h_2=h_1\left(\frac{T_2}{T_1}\right)=(1)\left(\frac{400}{300}\right)m=\frac{4}{3}m$$

As there is no heat loss, process is adiabatic.
For adiabatic process,

$$T_fV_f^{\gamma-1}=T_iV_i^{\gamma-1}$$

$$\Rightarrow \quad T_f=T_i\left(\frac{V_i}{V_f}\right)^{\gamma-1}=(400)\left(\frac{h_i}{h_f}\right)^{1.4-1}=400\left(\frac{4}{3}\right)^{0.4}$$

$$\Rightarrow \quad T_f=(400)(1.12)=448\ \text{K}$$

**30.** If after time $t$, temperature of water inside the pitcher drops to 15 °C, then by law of calorimetry, we have

$$\left(10-\frac{0.2}{1000}t\right)(4200)(5)=\left(\frac{0.2t}{1000}\right)\left(2.27\times 10^{6}\right)$$

Here $\frac{0.2t}{1000}\ll 10$, so we have $210000=454t$

$$\Rightarrow \quad t\approx 462\ \text{s}$$

**31.** (a) $U\propto\sqrt{V}$

Since, $U\propto T$

$$\Rightarrow \quad T\propto V^{\frac{1}{2}}$$

$$\Rightarrow \quad TV^{-\frac{1}{2}}=\text{constant}$$

$$\Rightarrow \quad PV^{\frac{1}{2}}=\text{constant}$$

Comparing with $PV^{x}=\text{constant}$, we get $x=\frac{1}{2}$

Since, molar specific heat is

$$\Rightarrow \quad C=\frac{R}{\gamma-1}+\frac{R}{1-x}=\frac{R}{\frac{7}{5}-1}+\frac{R}{1-\frac{1}{2}}$$

$$\Rightarrow \quad C=\frac{5}{2}R+2R=\frac{9R}{2}$$

$$\Rightarrow \quad *=9$$

(b) Further $Q=nC\Delta T$ and $\Delta U=nC_V\Delta T$

$$\Rightarrow \quad W=Q-\Delta U=n\left(C-C_V\right)\Delta T$$

$$\Rightarrow \quad \frac{W}{\Delta U}=\frac{C-C_V}{C_V}$$

$$\Rightarrow \quad W=\left(\frac{C-C_V}{C_V}\right)\Delta U=\left(\frac{\frac{9}{2}-\frac{5}{2}}{\frac{5}{2}}\right)(100)=80\ \text{J}$$

**32.** According to Newton's Law of Cooling

$$\left(\frac{T_1-T_2}{t}\right)=\alpha\left[\left(\frac{T_1+T_2}{2}\right)-T_0\right]$$

For the given conditions,

$$\frac{60-40}{10}=\alpha\left(\frac{60+40}{2}-10\right) \qquad \ldots(1)$$

Let $T$ be the temperature after next 10 minutes. Then,

$$\frac{40-T}{10}=\alpha\left(\frac{40+T}{2}-10\right) \qquad \ldots(2)$$

Solving equations (1) and (2), we get

$$T=28\ {}^{\circ}\text{C}$$

**33.** Number of moles $(n)$ is $n=\frac{m}{M}$

Since the masses of two gases is same, therefore the ratio of number of moles is

$$\frac{n_1}{n_2}=\frac{M_2}{M_1}=\frac{28}{32}=\frac{7}{8}$$

Also, pressure and temperature of both gases is same, so from Ideal Gas Equation, we get $V \propto n$ therefore their volumes are in the ratio.

$$\Rightarrow \quad \frac{V_1}{V_2} = \frac{n_1}{n_2} = \frac{7}{8} = \frac{360-\theta}{\theta}$$

$$\Rightarrow \quad \theta = 192^\circ$$

**34.** Since, $mgh = mc\Delta T + mL$

$$\Rightarrow \quad L = gh - c\Delta T$$

$$\Rightarrow \quad L = (10)(6\times 10^3) - (125)(200-40)$$

$$\Rightarrow \quad L = 60000 - 20000$$

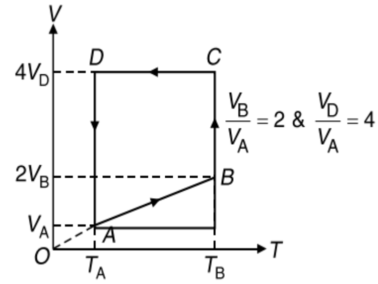
$$\Rightarrow \quad L = 40000 \text{ Jkg}^{-1}$$

$$\Rightarrow \quad L = 40 \text{ kJkg}^{-1}$$

**35.** Number of moles, $n = 2$

$C_V = \frac{3}{2}R$ and $C_P = \frac{5}{2}R$ (Monatomic)

$T_A = 27\ ^\circ\text{C} = 300\ \text{K}$



Let $V_A = V_o$ then $V_B = 2V_o$ and $V_D = V_C = 4V_o$

(a) Process $A \to B$, we have

$V \propto T$

$$\Rightarrow \quad \frac{T_B}{T_A} = \frac{V_B}{V_A}$$

$$\Rightarrow \quad T_B = T_A\left(\frac{V_B}{V_A}\right) = (300)(2) = 600\ \text{K}$$

$$\Rightarrow \quad T_B = 600\ \text{K}$$

(b) Process $A \to B$, we have $V \propto T$

$$\Rightarrow \quad P = \text{constant}$$

$$\Rightarrow \quad Q_{AB} = nC_P dT = nC_P(T_B - T_A)$$

$$\Rightarrow \quad Q_{AB} = (2)\left(\frac{5}{2}R\right)(600-300) = 1500R, \text{ absorbed}$$

$$\Rightarrow \quad Q_{AB} = 3000 \text{ cal, absorbed}$$

Process $B \to C$, we have $T = $ constant

$$\Rightarrow \quad dU = 0$$

$$\Rightarrow \quad Q_{BC} = W_{BC} = nRT_B \log_e\left(\frac{V_C}{V_B}\right)$$

$$\Rightarrow \quad Q_{BC} = (2)(R)(600)\log_e\left(\frac{4V_o}{2V_o}\right)$$

$$\Rightarrow \quad Q_{BC} = (1200R)\log_e(2) = (1200)(2)(0.7)$$

$$\Rightarrow \quad Q_{BC} \approx 1680 \text{ cal, absorbed}$$

Process $C \to D$, we have $V = $ constant

$$\Rightarrow \quad Q_{CD} = nC_V dT = nC_V(T_D - T_C)$$

$$\Rightarrow \quad Q_{CD} = n\left(\frac{3}{2}R\right)(T_A - T_B) \ \{\because T_D = T_A \text{ and } T_C = T_B\}$$

$$\Rightarrow \quad Q_{CD} = (2)\left(\frac{3}{2}R\right)(300-600)$$

$$\Rightarrow \quad Q_{CD} = -900R \text{ (released)}$$

$$\Rightarrow \quad Q_{CD} = -1800 \text{ cal, released}$$

Process $D \to A$, we have $T = $ constant

$$\Rightarrow \quad dU = 0$$

$$\Rightarrow \quad Q_{DA} = W_{DA} = nRT_D \log_e\left(\frac{V_A}{V_D}\right)$$

$$\Rightarrow \quad Q_{DA} = (2)(R)(300)\log_e\left(\frac{V_0}{4V_0}\right)$$

Since, $\log_e\left(\frac{1}{4}\right) = -2\log_e(2)$

$$\Rightarrow \quad Q_{DA} = 600R\log_e\left(\frac{1}{4}\right)$$

$$\Rightarrow \quad Q_{DA} \approx -1680 \text{ cal, released}$$

(c) In the complete cycle, $dU = 0$

Therefore, from *FLTD*, we have

$$W_{\text{net}} = Q_{AB} + Q_{BC} + Q_{CD} + Q_{DA}$$

$$\Rightarrow \quad W_{\text{net}} = 3000 + 1680 - 1800 - 1680$$

$$\Rightarrow \quad W_{\text{net}} = W_{\text{total}} = 1200 \text{ cal}$$

## ARCHIVE: JEE MAIN

**1.** Since, $U = \frac{n_1 f_1 RT}{2} + \frac{n_2 f_2 RT}{2}$

$$\Rightarrow \quad U = \frac{(3)(5)}{2}RT + \frac{(5)(3)}{2}RT = 15RT$$

**Hence, the correct answer is (B).**

**2.** The mean free path of molecules of an ideal gas is

$$\lambda = \frac{V}{\sqrt{2}\pi N d^2} = \frac{RT}{\sqrt{2}\pi N P d^2}$$

where, $V$ is the volume of container, $N$ is number of molecules and $d$ is the diameter of the molecule.

Since volume of container does not change (closed container) i.e., $\frac{T}{P} = \text{constant}$, so mean free path is unchanged. Hence with increasing temp, mean free path does not change if gas is confined to a closed container. Also, average collision time is

Average collision time

$$\tau = \frac{\text{Mean Free Path}}{\text{Average Speed}} = \frac{\lambda}{v_{av}}$$

Since, average speed $v_{av} \propto \sqrt{T}$

So, average collision time $\tau \propto \dfrac{1}{\sqrt{T}}$

Hence with increase in temperature the average collision time decreases.

**Hence, the correct answer is (D).**

**3.** Given that, $\dfrac{\Delta L}{L} = 0.02\%$

Since, $\Delta L = L\alpha\Delta T$

$$\Rightarrow \quad \frac{\Delta L}{L} = \alpha\Delta T = 0.02\%$$

Also, $\beta = 2\alpha$

$$\Rightarrow \quad \beta\Delta T = 2\alpha\Delta T = 0.04\%$$

Since, $\rho = \dfrac{M}{V} = \dfrac{M}{AL}$

$$\Rightarrow \quad \frac{\Delta\rho}{\rho} = \frac{\Delta M}{M} - \frac{\Delta A}{A} - \frac{\Delta L}{L}$$

Due to heating, mass remains constant, so we have

$$\left|\frac{\Delta\rho}{\rho}\right| = \frac{\Delta A}{A} + \frac{\Delta L}{L} = \beta\Delta T + \alpha\Delta T$$

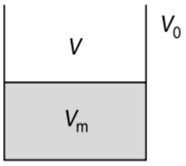
$$\Rightarrow \quad \left|\frac{\Delta\rho}{\rho}\right| = 0.04\% + 0.02\% = 0.06\%$$

**Hence, the correct answer is (B).**

**4.** Unfilled volume $V$ of the beaker is constant, so

$$V = V_0 - V_m = \text{constant}$$

After increasing temperature, $V$ remains same.



$$\Rightarrow \quad \Delta V = 0$$

$$\Rightarrow \quad \Delta V_0 - \Delta V_m = 0$$

$$\Rightarrow \quad V_0\gamma_b\Delta T = V_m\gamma_m\Delta T$$

$$\Rightarrow \quad V_m = \frac{V_0\gamma_b}{\gamma_m} = \frac{(500)(6\times10^{-6})}{(1.5\times10^{-4})} = 20 \text{ cc}$$

**Hence, the correct answer is 20.**

**5.** At constant pressure, $nC_P(50) = 160$

At constant volume, $nC_V(100) = 240$

$$\Rightarrow \quad \frac{C_P}{2C_V} = \frac{160}{240} = \frac{\gamma}{2}$$

$$\Rightarrow \quad \gamma = 1 + \frac{2}{f} = \frac{4}{3}$$

$$\Rightarrow \quad f = \frac{2}{\gamma - 1} = 6$$

**Hence, the correct answer is (C).**

**6.** Initially, we have

$$\underbrace{\text{Calorimeter}}_{20\text{ g},\ 25\ ^\circ\text{C}},\ \underbrace{\text{Water}}_{20\text{ g},\ 25\ ^\circ\text{C}},\ \underbrace{\text{Steam}}_{m,\ 100\ ^\circ\text{C}}$$

Finally, due to condensation of steam, we have

$$\underbrace{\text{Calorimeter}}_{20\text{ g},\ 31\ ^\circ\text{C}},\ \underbrace{\text{Water}}_{20\text{ g},\ 31\ ^\circ\text{C}},\ \underbrace{\text{Water}}_{m,\ 100\ ^\circ\text{C}}$$

By law of calorimetry, we have

$$(180+20)(1)(31-25) = 540m + m(1)(100-31)$$

$$\Rightarrow \quad m = 1.97 \text{ g} \approx 2 \text{ g}$$

**Hence, the correct answer is (B).**

**7.** Since, $\gamma = \dfrac{C_P}{C_V} = 1 + \dfrac{2}{f}$

where, $f$ the is degrees of freedom of a gas.

(A) For monatomic gas molecule, we have

$$f = 3,\ \gamma = 1 + \frac{2}{3} = \frac{5}{3}$$

(B) For diatomic rigid molecules, we have

$$f = 5,\ \gamma = 1 + \frac{2}{3} = \frac{7}{5}$$

(C) For diatomic non-rigid molecules, we have

$$f = 7,\ \gamma = 1 + \frac{2}{7} = \frac{9}{7}$$

(D) For triatomic rigid molecules, we have

$$f = 6,\ \gamma = 1 + \frac{2}{6} = \frac{4}{3}$$

**Hence, the correct answer is (A).**

**8.** Here the water will provide heat for ice to melt therefore

$$m_w c_w \Delta T = m_{\text{ice}} L_{\text{ice}}$$

$$\Rightarrow \quad m_{\text{ice}} = \frac{0.2\times4200\times25}{3.4\times10^5} = 0.0617 \text{ kg}$$

$$\Rightarrow \quad m_{\text{ice}} = 61.7 \text{ g}$$

Remaining ice will remain unmelted

**Hence, the correct answer is (A).**

**9.** As work done on gas and heat supplied to the gas are zero, total internal energy of gases remains same

$$U_1 + U_2 = U_1' + U_2'$$

$$\Rightarrow \quad (0.1)C_V(200) + (0.05)C_V(400) = (0.1+0.05)C_V T$$

$$\Rightarrow \quad T = \frac{800}{3} \text{ K} = 266.67 \text{ K}$$

Or, we could have simply said that internal energy lost by one gas equals the internal energy gained by other i.e.,

$$(0.05)C_V(400-T) = (0.1)C_V(T-200)$$

$$\Rightarrow \quad 400 - T = 2(T-200)$$

$$\Rightarrow \quad 3T = 800$$

$$\Rightarrow \quad T = \frac{800}{3} = 266.67 \text{ K}$$

**Hence, the correct answer is 266.67.**

**10.** For an ideal gas, we have $PV = nRT$

$$\Rightarrow \quad \Delta(PV) = \Delta(nRT)$$

Since volume is constant, so we have

$$V\Delta P = nR\Delta T$$

$$\Rightarrow \quad \frac{\Delta T}{\Delta P} = \frac{V}{nR} = \frac{T}{P} \qquad \{\because PV = nRT\}$$

$$\Rightarrow \quad \left|\frac{\Delta T}{\Delta P}\right| = \left|\frac{300}{2}\right| = 150$$

**Hence, the correct answer is 150.**

**11.** Since, $\frac{1}{2}\left(\frac{1}{2}mv^2\right) = mc\Delta T$

$$\Rightarrow \quad \Delta T = \frac{v^2}{4c} = \frac{(210)^2}{4(0.030\times 4200)} = 87.5\ ^\circ\text{C}$$

**Hence, the correct answer is (B).**

**12.** Mean kinetic energy of a molecule at $T$ is

$$\frac{3}{2}k_BT = 4\times 10^{-14} \qquad \ldots(1)$$

Since $n = \frac{PV}{RT}$ and if $N$ be the number of molecules. then we have $n = \frac{N}{N_A}$

$$\Rightarrow \quad N = \left(\frac{PV}{RT}\right)N_A = \frac{PV}{k_BT} = \frac{2\times 13.6\times 980\times 4}{(8/3)\times 10^{-14}}$$

$$\Rightarrow \quad N = 3.99\times 10^{18}$$

**Hence, the correct answer is (C).**

**13.** Since, $L = L_1 + L_2$

$$\Rightarrow \quad \Delta L = \Delta L_1 + \Delta L_2$$

$$\Rightarrow \quad (L_1 + L_2)\alpha_{\text{eq}}\Delta T = L_1\alpha_1\Delta T + L_2\alpha_2\Delta T$$

$$\Rightarrow \quad \alpha_{\text{eq}} = \frac{L_1\alpha_1 + L_2\alpha_2}{L_1 + L_2}$$

**Hence, the correct answer is (D).**

**14.** Since $v_{\text{rms}} = \sqrt{\frac{3RT}{M}}$ and $v_{N_2} = v_{H_2}$

$$\Rightarrow \quad \sqrt{\frac{3RT_{N_2}}{M_{N_2}}} = \sqrt{\frac{3RT_{H_2}}{M_{H_2}}}$$

$$\Rightarrow \quad \frac{573}{28} = \frac{T_{H_2}}{2}$$

$$\Rightarrow \quad T_{H_2} = 40.93\text{ K} \approx 41\text{ K}$$

**Hence, the correct answer is 41.**

**15.** Total degree of freedom $= 3 + 2 = 5$

$$\Rightarrow \quad U = \frac{nfRT}{2} = \frac{5RT}{2} \qquad \{\because n = 1\}$$

$$\Rightarrow \quad \gamma = \frac{C_P}{C_V} = 1 + \frac{2}{f} = 1 + \frac{2}{5} = \frac{7}{5}$$

**Hence, the correct answer is (D).**

**16.** For an ideal gas, we have $PV = nRT$

So, $P_1V_1 = nR(250) \qquad \ldots(1)$

and $P_2(2V_1) = \left(\frac{5n}{4}\right)R(2000) \qquad \ldots(2)$

Dividing equation (2) by (1), we get

$$\frac{2P_2}{P_1} = \frac{5\times 2000}{4\times 250}$$

$$\Rightarrow \quad \frac{P_2}{P_1} = 5$$

**Hence, the correct answer is (5).**

**17.** Average collision time

$$\tau = \frac{\text{Mean Free Path}}{\text{Average Speed}} = \frac{\lambda}{v_{av}}$$

Since, average speed $v_{av} \propto \sqrt{T}$

So, average collision time $\tau \propto \frac{1}{\sqrt{T}}$

**Hence, the correct answer is (C).**

**18.** Since, $\eta = \frac{\text{Work done}}{\text{Heat Input}} = \frac{W}{\Sigma Q_{\oplus}}$

$$\Rightarrow \quad \frac{1}{2} = \eta = \frac{1915 - 40 + 125 - Q}{1915 + 125}$$

$$\Rightarrow \quad \frac{1}{2} = \frac{2000 - Q}{2040}$$

$$\Rightarrow \quad 2040 = 4000 - 2Q$$

$$\Rightarrow \quad 2Q = 1960$$

$$\Rightarrow \quad Q = 980\text{ J}$$

**Hence, the correct answer is (C).**

**19.** Bursting of helium balloon is an irreversible and adiabatic process.

**Hence, the correct answer is (B).**

**20.** Since $\frac{Q_2}{W} = \frac{T_2}{T_1 - T_2}$, where, $Q_2 = mL_{\text{ice}} = 8000$ cal

Also, $T_2 = 273$ K and $T_1 = 300$ K

$$\Rightarrow \quad \frac{8000}{W} = \frac{273}{300 - 273} = \frac{273}{27}$$

$$\Rightarrow \quad W = 791.2\text{ cal}$$

Also $Q_1 = Q_2 + W$, so we get

$$Q_1 = 791.2 + 8000 = 8791.2\text{ cal} \approx 8791\text{ cal}$$

**Hence, the correct answer is 8791.**

**21.** For an adiabatic process,

$$\Delta Q = 0$$

For an isothermal process, carried on an ideal gas

$$\Delta U = 0$$

For an isochoric process volume remains constant, so

$$W = 0$$

For an isobaric process, $\Delta U \neq 0$, $\Delta W \neq 0$, $\Delta Q \neq 0$

**Hence, the correct answer is (A).**

**22.** Since $\Delta U = nC_V\Delta T$, so internal energy change remains the same in all the cases. Along path $AB$ volume is increasing, so $W > 0$. Along path $AD$ volume is decreasing, so $W < 0$ and along $AC$ volume is constant, so $W = 0$

**Hence, the correct answer is (A).**

**23.** In adiabatic process

$$PV^{\gamma} = \text{constant}$$

$$\Rightarrow \quad P\left(\frac{m}{\rho}\right)^{\gamma} = \text{constant}$$

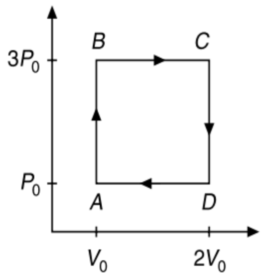
As mass is constant

$$P \propto \rho^{\gamma}$$

$$\Rightarrow \quad \frac{P_f}{P_i} = \left(\frac{\rho_f}{P_i}\right)^{\gamma} = (32)^{\frac{7}{5}} = 2^7 = 128$$

**Hence, the correct answer is (D).**

**24.** Since, $W_{ABCDA} = 2P_0V_0$



Also, $Q_{\text{in}} = Q_{AB} + Q_{BC}$

Along path $AB$, volume is constant, so

$$Q_{AB} = nC_V(T_B - T_A) = n\left(\frac{3R}{2}\right)(T_B - T_A)$$

$$\Rightarrow \quad Q_{AB} = \frac{3}{2}(P_BV_B - P_AV_A)$$

$$\Rightarrow \quad Q_{AB} = \frac{3}{2}(3P_0V_0 - P_0V_0) = 3P_0V_0$$

Along path $BC$, pressure is constant, so

$$Q_{BC} = nC_P(T_C - T_B) = n\left(\frac{5R}{2}\right)(T_C - T_B)$$

$$\Rightarrow \quad Q_{BC} = \frac{5}{2}(P_CV_C - P_BV_B)$$

$$\Rightarrow \quad Q_{BC} = \frac{5}{2}(6P_0V_0 - 3P_0V_0) = \frac{15}{2}P_0V_0$$

The percentage efficiency is given by

$$\eta = \frac{W}{Q_{\text{in}}} \times 100 = \frac{2P_0V_0}{3P_0V_0 + \frac{15}{2}P_0V_0} \times 100$$

$$\Rightarrow \quad \eta = \frac{400}{21} = 19.04 \approx 19$$

**Hence, the correct answer is 19.**

**25.** According to Newton's Law of Cooling, we have the rate of cooling to be proportional to the average excess temperature, so

$$\frac{50-40}{300} = \beta\left(\frac{50+40}{2} - 20\right) \qquad \ldots(1)$$

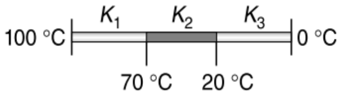
Similarly, $\dfrac{40-T}{300} = \beta\left(\dfrac{40+T}{2} - 20\right) \qquad \ldots(2)$

Solving equations (1) and (2), we get

$$T = \frac{100}{3}\ ^{\circ}\text{C} \approx 33\ ^{\circ}\text{C}$$

**Hence, the correct answer is (A).**

**26.** Rods are identical have same length $(l)$ and area of cross section $(A)$, so for series combination of rods heat current is same, hence



$$\left(\frac{Q}{t}\right)_{AB} = \left(\frac{Q}{t}\right)_{BC} = \left(\frac{Q}{t}\right)_{CD} = \text{Heat current}$$

$$\Rightarrow \quad \frac{(100-70)K_1A}{l} = \frac{(70-20)K_2A}{l} = \frac{(20-0)K_3A}{l}$$

$$\Rightarrow \quad 30K_1 = 50K_2 = 20K_3$$

So, $3K_1 = 2K_3$

$$\Rightarrow \quad \frac{K_1}{K_3} = \frac{2}{3} = 2:3$$

Also, $5K_2 = 2K_3$

$$\Rightarrow \quad \frac{K_2}{K_3} = \frac{2}{5} = 2:5$$

**Hence, the correct answer is (A).**

**27.** Since, $\eta = \dfrac{1}{1+\beta}$

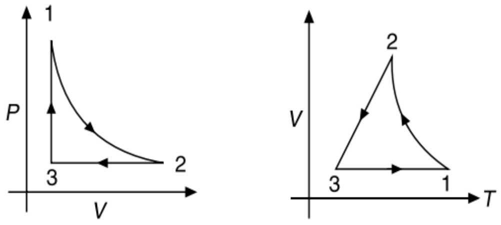
$$\Rightarrow \quad \frac{1}{10} = \frac{1}{1+\beta}$$

$$\Rightarrow \quad \beta = \frac{Q_2}{W} = 9$$

$$\Rightarrow \quad Q_2 = 9W = 90\ \text{J}$$

**Hence, the correct answer is (C).**

**28.** In process 2 to 3 pressure is constant and in process 3 to 1 volume is constant which is correct only in option 4. So, correct graph is



**Hence, the correct answer is (D).**

**29.** Since $PV^{\gamma} = \text{constant}$

$$\Rightarrow \quad T^{\gamma-1} = C$$

$$\Rightarrow \quad 300 \times V^{\frac{7}{5}-1} = T_2\left(\frac{V}{16}\right)^{\frac{7}{5}-1}$$

$$\Rightarrow \quad T_2 = 300 \times 2^{4\times\frac{2}{5}}$$

In an isobaric process, we have

$$V=\frac{nRT}{P}$$

$$\Rightarrow \quad V_2=kT_2 \qquad \ldots(1)$$

$$\Rightarrow \quad 2V_2=KT_f \qquad \ldots(2)$$

$$\Rightarrow \quad T_f=2\times 300\times 2^{\frac{8}{5}}=1818.85$$

**Hence, the correct answer is 1818.15.**

30. **Since,** $T_i=T=273+20=293$ K

If $V_i=V$, then $V_f=\dfrac{V}{10}$

For adiabatic process, we have $TV^{\gamma-1}=\text{constant}$

$$T_1V_1^{\gamma-1}=T_2V_2^{\gamma-1}$$

$$\Rightarrow \quad TV^{\frac{7}{5}-1}=T_2\left(\frac{V}{10}\right)^{\frac{7}{5}-1}$$

$$\Rightarrow \quad T_2=T(10)^{\frac{2}{5}}=293(10)^{\frac{2}{5}}\text{ K}$$

$$\Rightarrow \quad \Delta U=nC_V\Delta T=5\left(\frac{5R}{2}\right)\left(10^{\frac{2}{5}}-1\right)T$$

$$\Rightarrow \quad \Delta U=\frac{25(8.314)(293)(2.5-1)}{2}\approx 46\text{ kJ}$$

**Hence, the correct answer is 46.**

31. Since, $(C_V)_{\text{mix}}=\dfrac{n_1C_{V_1}+n_2C_{V_2}}{n_1+n_2}=\dfrac{2(3R/2)+3(3R)}{2+3}$

$$\Rightarrow \quad (C_V)_{\text{mix}}=\frac{12R}{5}$$

$$\Rightarrow \quad (C_P)_{\text{mix}}=(C_V)_{\text{mix}}+R=\frac{12R}{5}+R=\frac{17R}{5}$$

$$\Rightarrow \quad \gamma_{\text{mix}}=\frac{(C_P)_{\text{mix}}}{(C_V)_{\text{mix}}}=\frac{17}{12}\approx 1.42$$

**Hence, the correct answer is (B).**

32. Since, $\gamma=\alpha_x+\alpha_y+\alpha_z$

$$\Rightarrow \quad \gamma=5\times 10^{-5}+5\times 10^{-6}+5\times 10^{-6}$$

$$\Rightarrow \quad \gamma=(50+5+5)\times 10^{-6}=60\times 10^{-6}\ {}^\circ\text{C}^{-1}$$

$$\Rightarrow \quad C=60$$

**Hence, the correct answer is 60.**

33. Applying Law of Calorimetry, we get

$$540M+M(1)60=(200)(80)+200(1)(40-0)$$

$$\Rightarrow \quad M=40\text{ g}$$

**Hence, the correct answer is 40.**

34. Since, $(C_V)_{\text{mix}}=\dfrac{n_1C_{V_1}+n_2C_{V_2}}{n_1+n_2}=\dfrac{n(3R/2)+2n(5R/2)}{n+2n}$

$$\Rightarrow \quad (C_V)_{\text{mix}}=\frac{13R}{6}$$

$$\Rightarrow \quad (C_P)_{\text{mix}}=(C_V)_{\text{mix}}+R=\frac{13R}{6}+R=\frac{19R}{6}$$

$$\Rightarrow \quad \gamma_{\text{mix}}=\frac{(C_P)_{\text{mix}}}{(C_V)_{\text{mix}}}=\frac{19}{13}$$

**Hence, the correct answer is (B).**

35. According to table and applying law of calorimetry

$$1T_1+2T_2=(1+2)60^\circ=180 \qquad \ldots(1)$$

$$1T_2+2T_3=(1+2)30^\circ=90 \qquad \ldots(2)$$

$$2T_1+1T_3=(1+2)60=180 \qquad \ldots(3)$$

Adding $(1)+(2)+(3)$

$$3(T_1+T_2+T_3)=450$$

$$\Rightarrow \quad T_1+T_2+T_3=150^\circ$$

Also, we have

$$1T_1+1T_2+1T_3=(1+1+1)T$$

$$\Rightarrow \quad 150=3T$$

$$\Rightarrow \quad T=\theta=50\ {}^\circ\text{C}$$

**Hence, the correct answer is 50.**

36. Degree of freedom of a diatomic molecule if vibration is absent is 5

Degree of freedom of a diatomic molecule if vibration is present is 7

$$\Rightarrow \quad \frac{C_V^A}{C_V^B}=\frac{f_AR/2}{f_BR/2}=\frac{f_A}{f_B}=\frac{5}{7}$$

**Hence, the correct answer is (B).**

37. Since, $\lambda=\dfrac{1}{\sqrt{2}\pi n_0d^2}$, where $n_0=\dfrac{N}{V}$

$$\Rightarrow \quad \tau=\frac{\lambda}{v_{\text{rms}}}=\frac{1}{\sqrt{2}\pi n_0d^2v_{\text{rms}}}=\frac{1}{\sqrt{2}\pi n_0d^2}\sqrt{\frac{M}{3RT}}$$

$$\Rightarrow \quad \frac{\tau_1}{\tau_2}=\sqrt{\frac{M_1}{M_2}\frac{d_2^2}{d_1^2}}$$

$$\Rightarrow \quad \frac{\tau_1}{\tau_2}=\sqrt{\frac{40}{140}\frac{(0.1)^2}{(0.07)^2}}$$

$$\Rightarrow \quad \frac{\tau_1}{\tau_2}=1.09$$

Nearest possible answer is 1.83

**Hence, the correct answer is (C).**

38. Let amount of water evaporated be $m$ gram.

$$\Rightarrow \quad mL_v=(150-m)L_s$$

$$\Rightarrow \quad m(2.1\times 10^6)=(150-m)(3.36\times 10^5)$$

$$\Rightarrow \quad m=\frac{150}{7.25}\approx 20\text{ g}$$

**Hence, the correct answer is (C).**

39. Between the isothermal and the adiabatic processes, $P$-$V$ graph for adiabatic is steeper.

**Hence, the correct answer is (C).**

**40.** Since, $v \propto \sqrt{T}$

$$\Rightarrow \quad \frac{v_1}{v_2} = \sqrt{\frac{T_1}{T_2}}$$

$$\Rightarrow \quad \frac{200}{v_2} = \sqrt{\frac{400}{500}}$$

$$\Rightarrow \quad v_2 = 200\sqrt{\frac{5}{4}} = 100\sqrt{5}\ \text{ms}^{-1}$$

**Hence, the correct answer is (A).**

**41.** Since, $\Delta W_A > \Delta W_B$ and $\Delta U_A = \Delta U_B = U_f - U_i$

So from FLTD, we have

$$\Delta Q = \Delta U + \Delta W$$

$$\Rightarrow \quad \Delta Q_A > \Delta Q_B$$

**Hence, the correct answer is (A).**

**42.** Since, $v_{\text{rms}} = \bar{v} = \sqrt{\frac{3RT}{M}}$

$$\Rightarrow \quad \bar{v} = \sqrt{\frac{3RT}{mN_A}} = \sqrt{\frac{3k_BT}{m}}$$

$$\Rightarrow \quad T = \frac{m\bar{v}^2}{3k_B}$$

**Hence, the correct answer is (D).**

**43.** According to Stefan's Law, we have

$$mc\left(-\frac{dT}{dt}\right) = e\sigma A\left(T^4 - T_0^4\right)$$

$$\Rightarrow \quad -\frac{dT}{dt} = \frac{e\sigma A\left(T^4 - T_0^4\right)}{\rho V c} \qquad \{\because m = \rho V\}$$

$$\Rightarrow \quad -\frac{dT}{dt} \propto \frac{1}{\rho c}$$

Since, $\rho_A c_A < \rho_B c_B$

$$\Rightarrow \quad \left(-\frac{dT}{dt}\right)_A > \left(-\frac{dT}{dt}\right)_B$$

So, $A$ cools down at faster rate

**Hence, the correct answer is (B).**

**44.** For gas $A$, $C_P = 29$, $C_V = 22$

For gas $B$, $C_P = 30$, $C_V = 21$

$$\Rightarrow \quad \gamma_A = \frac{C_{P_A}}{C_{V_A}} = \frac{29}{22} = 1.31$$

When $A$ has vibrational degree of freedom, then

$$\gamma_A = \frac{9}{7} \simeq 1.29$$

$$\gamma_B = \frac{C_{P_B}}{C_{V_B}} = \frac{30}{21} = 1.42$$

So, $B$ has no vibrational degree of freedom

**Hence, the correct answer is (B).**

**45.** $H = \frac{3KA}{d}\left(\theta_2 - \theta\right) = \frac{KA}{3d}\left(\theta - \theta_1\right)$

$$\Rightarrow \quad \theta = \frac{9\theta_2}{10} + \frac{\theta_1}{10}$$

**Hence, the correct answer is (B).**

**46.** For isobaric process, work done $W = nR\Delta T$ and heat given $Q = nC_P\Delta T$, so we have

$$\frac{W}{Q} = \frac{R}{C_P} = \frac{R}{C_V + R}$$

**47.** Number of moles of $He$ at STP is $n = \frac{67.2}{22.4} = 3$

Since the volume is constant, so process is isochoric and hence, we have

$$Q = nC_V\Delta T = 3\left(\frac{3R}{2}\right)(20) = 90R = 90(8.31)$$

$$\Rightarrow \quad Q \approx 748\ \text{J}$$

**Hence, the correct answer is (D).**

**48.** When $V_1 = V_0$, then $P_1 = P_0\left(1 - \frac{1}{2}\right) = \frac{P_0}{2}$

When $V_2 = 2V_0$, then $P_2 = P_0\left[1 - \frac{1}{2}\left(\frac{1}{4}\right)\right] = \frac{7P_0}{8}$

Since, $T = \frac{PV}{nR}$

$$\Rightarrow \quad \Delta T = \left|\frac{P_1V_1}{nR} - \frac{P_2V_2}{nR}\right|$$

$$\Rightarrow \quad \Delta T = \left|\left(\frac{\left(P_1V_1 - P_2V_2\right)}{nR}\right)\right| = \frac{1}{nR}\left|\frac{P_0V_0}{2} - \frac{7P_0V_0}{4}\right|$$

$$\Rightarrow \quad \Delta T = \frac{5P_0V_0}{4nR}$$

**Hence, the correct answer is (B).**

**49.** Heat supplied at constant volume $Q = nC_V\Delta T$ and heat supplied at constant pressure is $Q_1 = nC_p\Delta T$

$$\Rightarrow \quad \frac{Q_1}{Q} = \frac{C_p}{C_v}$$

$$\Rightarrow \quad Q_1 = \gamma Q = \frac{7Q}{5}$$

**Hence, the correct answer is (C).**

**50.** For the process $ca$, $\Delta U_{ca} = -180$ J

For process $bc$, isochoric $W_{bc} = 0$

$$\Rightarrow \quad \Delta U = 60\ \text{J}$$

Heat absorbed along $ab$ is $Q_{ab} = 250$ J

Since $\Delta U_{\text{cycle}} = 0$, so $\Delta U_{ab} = 120$ J

So by FLTD, $W_{a \to b} = 130$ J

Total work done from $(a \to b \to c)$

$W = W_{ab} + W_{bc} = 130$ J

**Hence, the correct answer is (A).**

**51.** Applying law of calorimetry, we get

$$5M_1 + M_1L = 50M_2$$

$$\Rightarrow \quad L = \frac{50M_2}{M_1} - 5$$

**Hence, the correct answer is (A).**

**52.** Since, $(2+3)C_V = 2\left(\frac{3R}{2}\right) + 3\left(\frac{5R}{2}\right)$

$$\Rightarrow \quad C_V = \frac{21R}{10}$$

**Hence, the correct answer is (D).**

**53.** Since, $\eta = \frac{1}{6} = 1 - \frac{T_C}{T_H}$

$$\Rightarrow \quad \frac{T_C}{T_H} = \frac{5}{6} \qquad \ldots(1)$$

Now $\eta' = 2\eta = \frac{1}{3} = 1 - \frac{(T_C - 62)}{T_H}$

$$\Rightarrow \quad \frac{T_C - 62}{T_H} = \frac{2}{3} \qquad \ldots(2)$$

Substituting equation (1) in (2), we get

$$\frac{T_C - 62}{T_C} = \frac{2 \times 6}{3 \times 5} = \frac{4}{5}$$

$$\Rightarrow \quad T_C = 310 \text{ K} = 37\ °\text{C} \text{ and } T_H = 372 \text{ K} = 99\ °\text{C}$$

**Hence, the correct answer is (A).**

**54.** Since, $W_{\text{isob}} = nR\Delta T = 10 \text{ J}$

and $Q = nC_P\Delta T = n\left(\frac{7R}{2}\right)\Delta T = \frac{7}{2}(nR\Delta T)$

$$\Rightarrow \quad \Delta Q = \frac{7}{2}(10) = 35 \text{ J}$$

**Hence, the correct answer is (B).**

**55.** Since, $v_{\text{rms}} = \sqrt{\frac{3RT}{M}} = 11.2 \times 10^3 \text{ ms}^{-1}$

$$\Rightarrow \quad T = \frac{M}{3R} \times (11.2 \times 10^3)^2 = \frac{2 \times 10^{-3}}{3 \times 8.3} \times 125.44 \times 10^6$$

$$\Rightarrow \quad T \approx 10^4 \text{ K}$$

**Hence, the correct answer is (A).**

**56.** Given that $V = 25 \times 10^{-3} \text{ m}^3$, $n = 1$ mole of $O_2$

$T = 300$ K, $v_{\text{rms}} = 200 \text{ ms}^{-1}$, $d = 0.3$ nm

Since, $\lambda = \frac{1}{\sqrt{2}\pi n_0 d^2}$, where $n_0 = \frac{N}{V} = \frac{N_A}{V}$

$$\Rightarrow \quad \tau = \frac{\lambda}{v_{\text{rms}}} = \frac{1}{\sqrt{2}\pi n_0 d^2 v_{\text{rms}}}$$

The average collision rate (per second) is

$$\frac{1}{\tau} = \frac{v_{\text{rms}}}{\lambda} = \sqrt{2}\pi\left(\frac{N_A}{V}\right)d^2 v_{\text{rms}}$$

$$\Rightarrow \quad \frac{1}{\tau} = \sqrt{2}(3.14)\left(\frac{6.023 \times 10^{23}}{25 \times 10^{-3}}\right)(0.09 \times 10^{-18})(200)$$

Average number of collisions $\approx 10^{10}$

**Hence, the correct answer is (B).**

**57.** Since, $n = n_0 e^{-\alpha r^4}$

$$\Rightarrow \quad N = \int dN = \int_0^\infty \left(n_0 e^{-\alpha r^4}\right) 4\pi r^2 dr$$

$$\Rightarrow \quad N = 4\pi n_0 \int_0^\infty r^2 e^{-\alpha r^4} dr$$

Substitute $\sqrt{\alpha} r^2 = z$, we get

$$\sqrt{\alpha}(2rdr) = dz$$

$$\Rightarrow \quad N = \frac{4\pi n_0}{2\sqrt{\alpha}} \int_0^\infty \frac{z^{1/2} e^{-z^2}}{\alpha^{1/4}} dz = \frac{4\pi n_0}{2\alpha^{3/4}} \int z^{1/2} e^{-z^2} dz$$

$$\Rightarrow \quad N \propto n_0 \alpha^{-\frac{3}{4}}$$

**Hence, the correct answer is (A).**

**58.** For path $ACB$, applying FLTD, we get

$$Q_{ACB} = W_{ACB} + U_{ACB}$$

$$\Rightarrow \quad 60 = 30 + U_{ACB}$$

$$\Rightarrow \quad U_{ACB} = U_{ADB} = 30 \text{ J}$$

Similarly, for path $ADB$, we get from FLTD

$$Q_{ADB} = W_{ADB} + U_{ADB} = (10 + 30) \text{ J}$$

$$\Rightarrow \quad Q_{ADB} = 40 \text{ J}$$

**Hence, the correct answer is (D).**

**59.** Applying Kirchhoff's Junction Law (KJL) for heat currents at $P$ and $Q$ respectively, we get

At $P$, $\frac{T_A - T_P}{L/2} = \frac{T_P - T_Q}{L} + \frac{T_P - T_Q}{3L/2}$

$$\Rightarrow \quad 2(T_A - T_P) = \frac{5}{3}(T_P - T_Q) \qquad \ldots(1)$$

At $Q$, $\frac{T_P - T_Q}{L} + \frac{T_P - T_Q}{3L/2} = \frac{T_Q - T_B}{L/2}$

$$\Rightarrow \quad 2(T_Q - T_B) = \frac{5}{3}(T_P - T_Q) \qquad \ldots(2)$$

From equations (1) and (2), we get

$$2(T_A - T_B) = 2(T_P - T_Q) + \frac{10}{3}(T_P - T_Q)$$

$$\Rightarrow \quad 2 \times 120 = \frac{16}{3}(T_P - T_Q)$$

$$\Rightarrow \quad T_P - T_Q = \frac{2 \times 120 \times 3}{16} = 45\ °\text{C}$$

**Hence, the correct answer is (B).**

**60.** $\frac{(v_{\text{rms}})_{He}}{(v_{\text{rms}})_{Ar}} = \sqrt{\frac{M_{Ar}}{M_{He}}} = \sqrt{\frac{40}{4}} = \sqrt{10} = 3.16$

**Hence, the correct answer is (C).**

**61.** For no change in length of the rod, we have

$$\Delta L_{\text{Thermal}} - \Delta L_{\text{mechanical}} = 0$$

$$\Rightarrow \quad L_0 \alpha \Delta T = \frac{FL_0}{AY}$$

$\Rightarrow \quad Y = \dfrac{F}{A\alpha\Delta T}$

**Hence, the correct answer is (B).**

**62.** Since, $\dfrac{Q_1}{T_1} = \dfrac{Q_2}{T_2} = \dfrac{Q_3}{T_3}$

Also, $W_1 = Q_1 - Q_2$ and $W_2 = Q_2 - Q_3$

Given $W_1 = W_2$

$\Rightarrow \quad Q_1 - Q_2 = Q_2 - Q_3$

$\Rightarrow \quad 2Q_2 = Q_1 + Q_3$

$\Rightarrow \quad 2T_2 = T_1 + T_3$

$\Rightarrow \quad T_2 = \dfrac{T_1 + T_3}{2} = 500 \text{ K}$

**Hence, the correct answer is (D).**

**63.** Since, $\dfrac{v_2}{v_1} = 2 = \sqrt{\dfrac{T_2}{T_1}}$

$\Rightarrow \quad T_2 = 1200 \text{ K}$

For a closed vessel, volume is constant, so

$Q = nC_V(T_2 - T_1) = \left(\dfrac{15}{28}\right)\left(\dfrac{5R}{2}\right)(900) = 10 \text{ kJ}$

**Hence, the correct answer is (C).**

**64.** Since, $\eta = 1 - \dfrac{T_2}{T_1} = 1 - \dfrac{T_3}{T_2} = 1 - \dfrac{T_4}{T_3}$

$$\Rightarrow \quad \frac{T_2}{T_1} = \frac{T_3}{T_2} = \frac{T_4}{T_3} \qquad \ldots(1)$$

$\Rightarrow \quad T_2 = \sqrt{T_1T_3}$ and $T_3 = \sqrt{T_2T_4}$

Substituting value of $T_2$ in equation (1), we get

$\Rightarrow \quad \dfrac{\sqrt{T_1T_3}}{T_1} = \dfrac{T_4}{T_3}$

$\Rightarrow \quad \dfrac{T_1T_3}{T_1^2} = \dfrac{T_4^2}{T_3^2}$

$\Rightarrow \quad T_3^3 = T_1T_4^2$

$\Rightarrow \quad T_3 = \left(T_1T_4^2\right)^{1/3}$

Similarly, we get $T_2 = \left(T_1^2T_4\right)^{\frac{1}{3}}$

**Hence, the correct answer is (D).**

**65.** Since, $W_{\text{isob}} = P\Delta V = nR\Delta T$

$\Rightarrow \quad W_{\text{isob}} = \dfrac{1}{2}(8.31)(70) \approx 291 \text{ J}$

**Hence, the correct answer is (A).**

**66.** Applying law of calorimetry, we get

$$192c(100 - 21.5) = (128)(0.394)(21.5 - 8.4) + (240)(4.18)(21.5 - 8.4)$$

$\Rightarrow \quad c = \dfrac{660.65 + 13142}{15072} \approx 916 \text{ Jkg}^{-1}\text{K}^{-1}$

**Hence, the correct answer is (A).**

**67.** Since, $V = \dfrac{m}{\rho} = \dfrac{2}{8} = \dfrac{1}{4} \text{ m}^3$

From ideal gas equation, we have $PV = nRT$

$\Rightarrow \quad 4 \times 10^4 \times \dfrac{1}{4} = nRT$

$\Rightarrow \quad nRT = 10^4$

Internal Energy $U = \dfrac{3}{2}nRT = \dfrac{3}{2} \times 10^4 = 1.5 \times 10^4 \text{ J}$

So internal energy is of order of $10^4$ J

**Hence, the correct answer is (C).**

**68.** $\dfrac{Q}{A} = \dfrac{K(T_1 - T_2)}{L} = \dfrac{0.1 \times 900}{1} = 90 \text{ Wm}^{-2}$

**Hence, the correct answer is (D).**

**69.** $U = 3\left(\dfrac{5R}{2}\right)T + 5\left(\dfrac{3R}{2}\right)T$

$\Rightarrow \quad U = 15RT$

**Hence, the correct answer is (C).**

**70.** For adiabatic process, $TV^{\gamma-1} = \text{constant}$

$\Rightarrow \quad x = \gamma - 1$

$\Rightarrow \quad x = \dfrac{2}{5}$

**Hence, the correct answer is (A).**

**71.** Let $m$ gram of ice be added, then heat lost by water is

$$Q_{\text{lost}} = 50(1)(40 - 0) = 2000 \text{ cal}$$

Similarly, heat gained by ice is

$$Q_{\text{gained}} = m(0.5)(20) + (m - 20)(80)$$

By law of calorimetry, we have

$$Q_{\text{lost}} = Q_{\text{gained}}$$

$\Rightarrow \quad m(0.5)(20) + (m - 20)(80) = 2000$

$\Rightarrow \quad 90m = 3600$

$\Rightarrow \quad m = 40 \text{ g}$

**Hence, the correct answer is (B).**

**72.** Let final temperature be $T$. Since, heat lost equals the heat gained, so we have

$$(0.1)(500 - T)(400) = (800 + 0.5 \times 4200)(T - 30)$$

$\Rightarrow \quad (500 - T) = \dfrac{2900}{40}(T - 30)$

$\Rightarrow \quad T = 36.39\ °\text{C}$

$\%\text{ increase} = \dfrac{36.39 - 30}{30} \approx 20\%$

**Hence, the correct answer is (B).**

**73.** Since, $100c_1(100 - 90) = 50c_2(90 - 75)$

$\Rightarrow \quad 20S_1 = 15S_2$

$\Rightarrow \quad 4S_1 = 3S_2$

Let final temperature be $T$, then we have

$$100c_1(100 - T) = 50c_2(T - 50)$$

$\Rightarrow \quad 75c_2(100 - T) = 50c_2(T - 50)$

$\Rightarrow \quad 3(100 - T) = 2T - 100$

$\Rightarrow \quad T = 80\ °\mathrm{C}$

**Hence, the correct answer is (B).**

**74.** Since, $\Delta \ell = \ell \alpha \Delta T$

$\Rightarrow \quad \alpha_A(180-30) = \alpha_B(T-30)$

$\Rightarrow \quad 4(180-30) = 3(T-30)$

$\Rightarrow \quad T = 230\ °\mathrm{C}$

**Hence, the correct answer is (B).**

**75.** Since, for a polytropic process, $TV^{x-1} = \text{constant}$

$\Rightarrow \quad x - 1 = 1$

$\Rightarrow \quad x = 2$

$$\Rightarrow \quad C = C_V + \frac{R}{1-x} = \frac{3R}{2} + \frac{R}{1-2} = \frac{R}{2}$$

So, $Q = nC\Delta T = \dfrac{R}{2}\Delta T$

**Hence, the correct answer is (B).**

**76.** Since, $\dfrac{(x_0/2)-(x_0/3)}{x_0-(x_0/3)} = \dfrac{T-0}{100}$

$$\Rightarrow \quad \frac{x_0/6}{2x_0/3} = \frac{T}{100}$$

$$\Rightarrow \quad \frac{T}{100} = \frac{1}{4}$$

$\Rightarrow \quad T = 25\ °\mathrm{C}$

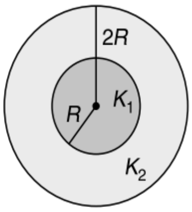
**Hence, the correct answer is (D).**

**77.** Work done, $W$ = Area under $PV$ graph

$$\Rightarrow \quad W = \frac{1}{2} \times 4 \times 5 = 10\ \mathrm{J}$$

**Hence, the correct answer is (B).**

**78.** Since $K_{\text{eq}} = \dfrac{K_1A_1 + K_2A_2}{A_1 + A_2}$



$$\Rightarrow \quad K_{\text{eq}} = \frac{K_1\pi R^2 + K_2 3\pi R^2}{4\pi R^2}$$

$$\Rightarrow \quad K_{\text{eq}} = \frac{K_1 + 3K_2}{4}$$

**Hence, the correct answer is (B).**

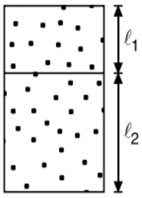
**79.** Since $U = \dfrac{3}{2}nRT$, for a monatomic gas

$$\Rightarrow \quad U = \frac{3}{2}PV = \frac{3}{2} \times 3 \times 10^6 \times 2$$

$\Rightarrow \quad U = 9 \times 10^6\ \mathrm{J}$

**Hence, the correct answer is (B).**

**80.** Since, $(P_2 - P_1)A = mg$



$$\Rightarrow \quad \left(\frac{nRT}{A\ell_2} - \frac{nRT}{A\ell_1}\right)A = mg$$

$$\Rightarrow \quad m = \frac{nRT}{g}\left(\frac{\ell_1 - \ell_2}{\ell_1\ell_2}\right)$$

**Hence, the correct answer is (A).**

**81.** Average collision time

$$\tau = \frac{\text{Mean Free Path}}{\text{Average Speed}} = \frac{\lambda}{v_{av}}$$

The mean free path of molecules of an ideal gas is

$$\lambda = \frac{1}{\sqrt{2}\pi n_0 d^2} = \frac{V}{\sqrt{2}\pi N d^2} = \frac{RT}{\sqrt{2}\pi N P d^2}$$

where, $V$ is the volume of container, $N$ is number of molecules and $d$ is the diameter of the molecule.

$$\tau = \frac{\lambda}{v_{av}} = \frac{RT}{\sqrt{2}\pi N P d^2 v_{av}}$$

Since, average speed $v_{av} \propto \sqrt{T}$

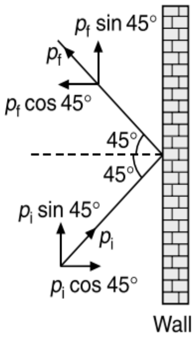
$$\Rightarrow \quad \tau \propto \frac{\sqrt{T}}{P}$$

$$\Rightarrow \quad \frac{\tau_1}{\tau_2} = \sqrt{\frac{5}{3}} \times \frac{1}{2} \times 6 \times 10^{-8} = 3.87 \times 10^{-8}\ \mathrm{s}$$

$$\Rightarrow \quad \frac{\tau_1}{\tau_2} = 4 \times 10^{-8}\ \mathrm{s}$$

**Hence, the correct answer is (D).**

**82.** As $p_i = p_f$



Net force on the wall,

$$F = \frac{dp}{dt} = 2np_f\cos 45° = 2nmv\cos 45°$$

Here, $n$ is the number of hydrogen molecules striking per second.

$$\text{Pressure } P = \frac{F}{A} = \frac{2nmv\cos 45°}{\text{Area}}$$

$$\Rightarrow \quad P = \frac{2 \times 10^{23} \times 3.32 \times 10^{-27} \times 10^3 \times \left(\dfrac{1}{\sqrt{2}}\right)}{2 \times 10^{-4}}$$

$\Rightarrow \quad P = 2.35 \times 10^3\ \mathrm{Nm^{-2}}$

**Hence, the correct answer is (A).**

**83.** Since, $\dfrac{3}{2}k_BT = \dfrac{1}{2}mv^2$

$$\Rightarrow \quad v = \sqrt{\frac{3k_BT}{m}} = \sqrt{\frac{3 \times 1.4 \times 10^{-23} \times 300}{7 \times 10^{-27}}}$$

$\Rightarrow \quad v = \sqrt{1.8} \times 10^3\ \mathrm{ms^{-1}} \approx 1.3 \times 10^3\ \mathrm{ms^{-1}}$

**Hence, the correct answer is (A).**

**84.** Given $\gamma_{\text{mix}} = \frac{3}{2}$, so $(C_V)_{\text{mix}} = \frac{R}{\gamma_{\text{mix}} - 1} = 2R$

$$\Rightarrow \quad (C_V)_{\text{mix}} = \frac{n_1 C_{V_1} + n_2 C_{V_2}}{n_1 + n_2}$$

$$\Rightarrow \quad 2R = \frac{2(3R/2) + n(5R/2)}{2+n}$$

$$\Rightarrow \quad 8 + 4n = 6 + 5n$$

$$\Rightarrow \quad n = 2$$

**Hence, the correct answer is (C).**

**85.** For an adiabatic process $TV^{\gamma-1} = \text{constant}$

$$\Rightarrow \quad T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$$

$$\Rightarrow \quad T_2 = T_1 \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

Here, $T_1 = 27\ °\text{C} = 300\ \text{K}$, $V_1 = V$, $V_2 = 2V$, $\gamma = \frac{5}{3}$

$$\Rightarrow \quad T_2 = 300\left(\frac{V}{2V}\right)^{\left(\frac{5}{3}-1\right)} = 300\left(\frac{1}{2}\right)^{\frac{2}{3}} \approx 189\ \text{K}$$

Change in internal energy, $\Delta U = nC_V \Delta T$

$$\Rightarrow \quad \Delta U = n\left(\frac{fR}{2}\right)(T_2 - T_1) = 2 \times \frac{3}{2} \times \frac{25}{3}(189 - 300)$$

$$\Rightarrow \quad \Delta U = -25 \times 111 = -2775\ \text{J} = -2.7\ \text{kJ}$$

**Hence, the correct answer is (C).**

**86.** Work done on gas $W_{\text{isot}} = nRT \ln\left(\frac{P_f}{P_i}\right)$

$$\Rightarrow \quad W_{\text{isot}} = R(300)\ell\text{n}(2) = 300R\ell n2$$

**Hence, the correct answer is (B).**

**87.** For a refrigerator, $\frac{Q_2}{W} = \frac{T_2}{T_1 - T_2}$

$$\Rightarrow \quad \frac{500}{W} = \frac{250}{50}$$

$$\Rightarrow \quad W = 100\ \text{cal} = (100)(4.2)\ \text{J} = 420\ \text{J}$$

**Hence, the correct answer is (D).**

**88.** Assuming equal works to be done by both the engines (should have been mentioned in the question for solving it), we have

$$T = \frac{T_1 + T_2}{2} = \frac{600 + 100}{2} = 350\ \text{K}$$

$$\Rightarrow \quad \frac{\eta_A}{\eta_B} = \frac{1 - \frac{350}{600}}{1 - \frac{100}{350}} = \frac{250/600}{250/350} = \frac{350}{600} = \frac{7}{12}$$

**Hence, the correct answer is (C).**

**89.** Equation of line $BC$ is given by

$$P = P_0 - \frac{2P_0}{V_0}(V - 2V_0)$$

$$\Rightarrow \quad PV = P_0 V - \frac{2P_0}{V_0}(V - 2V_0)V$$

$$\Rightarrow \quad T = \frac{P_0 V - \frac{2P_0 V^2}{V_0} + 4P_0 V}{1 \times R} \qquad \{\because PV = nRT\}$$

$$\Rightarrow \quad T = \frac{P_0}{R}\left(5V - \frac{2V^2}{V_0}\right)$$

For maximum value of $T$, $\frac{dT}{dV} = 0$

$$\Rightarrow \quad 5 - \frac{4V}{V_0} = 0$$

$$\Rightarrow \quad V = \frac{5}{4}V_0$$

$$\Rightarrow \quad T_{\max} = \frac{P_0}{R}\left[5\left(\frac{5V_0}{4}\right) - \frac{2}{V_0}\left(\frac{25}{16}V_0^2\right)\right] = \frac{25}{8}\frac{P_0 V_0}{R}$$

**Hence, the correct answer is (B).**

**90.** Let molar heat capacity at constant pressure be $X_P$ and molar heat capacity at constant volume be $X_V$

$$X_P - X_V = R$$

$$\Rightarrow \quad MC_P - MC_V = R$$

$$\Rightarrow \quad C_P - C_V = \frac{R}{M}$$

For hydrogen, we have $a = \frac{R}{2}$

For $N_2$, we have $b = \frac{R}{28}$

$$\Rightarrow \quad \frac{a}{b} = 14$$

$$\Rightarrow \quad a = 14b$$

**Hence, the correct answer is (C).**

**91.** An ideal gas has molecules with 5 degrees of freedom, then

$$C_V = \frac{5}{2}R \text{ and } C_P = \frac{7}{2}R$$

$$\Rightarrow \quad \frac{C_P}{C_V} = \frac{7R/2}{5R/2} = \frac{7}{5}$$

**Hence, the correct answer is (D).**

**92.** Initial kinetic energy of the system $K_i = \frac{5}{2}RTN$

Final kinetic energy of the system

$$K_f = \frac{5}{2}RT(N - n) + \frac{3}{2}RT(2n)$$

$$\Rightarrow \quad \Delta K = K_f - K_i - = nRT\left(3 - \frac{5}{2}\right) = \frac{1}{2}nRT$$

**Hence, the correct answer is (C).**

**93.** Let $n_1$ be initial number of moles, so

$$n_1 = \frac{P_1 V_1}{RT_1} = \frac{10^5 \times 30}{8.3 \times 290} \approx 1.24 \times 10^3$$

Let $n_2$ be final number of moles, so

$$n_2 = \frac{P_2 V_2}{RT_2} = \frac{10^5 \times 30}{8.3 \times 300} \approx 1.20 \times 10^3$$

Change of number of molecules is

$$\Delta n = n_f - n_i = (n_2 - n_1) \times 6.023 \times 10^{23}$$

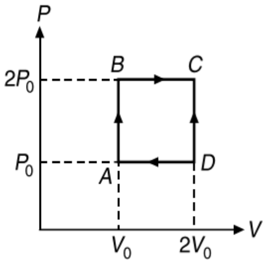
$$\Rightarrow \quad \Delta n \approx -2.5 \times 10^{25}$$

**Hence, the correct answer is (D).**

**94.** Work done by engine equals the area enclosed by the $PV$ diagram, so $W = P_0V_0$

Heat given to the system is

$$Q = Q_{AB} + Q_{BC} = nC_V\Delta T_{AB} + nC_P\Delta T_{BC}$$



$$\Rightarrow \quad Q = \frac{3}{2}(nRT_B - nRT_A) + \frac{5}{2}(nRT_C - nRT_B)$$

$$\Rightarrow \quad Q = \frac{3}{2}(2P_0V_0 - P_0V_0) + \frac{5}{2}(4P_0V_0 - 2P_0V_0)$$

$$\Rightarrow \quad Q = \frac{13}{2}P_0V_0$$

Thermal efficiency, $\eta = \frac{W}{\Sigma Q_{\oplus}} = \frac{W}{Q_{\text{input}}} = \frac{P_0V_0}{13P_0V_0/2}$

$$\Rightarrow \quad \eta = \frac{2}{13} \approx 0.15$$

**Hence, the correct answer is (A).**

**95.** Here, $PV = \text{constant}$, so given process is isothermal i.e., temperature is constant. Pressure at point 1 is higher than that at point 2. So, correct OPTION is (C).

**Hence, the correct answer is (C).**

**96.** Ideal gas equation, $PV = nRT$

As temperature is constant.

$$PV = \text{constant}$$

$$\Rightarrow \quad P\left(\frac{m}{\rho}\right) = \text{constant}$$

$$\Rightarrow \quad P \propto \rho \text{ (for given } m\text{)}$$

**Hence, the correct answer is (D).**

**97.** Specific heat of a polytropic process is

$$C = C_V + \frac{R}{1-n}$$

$$\Rightarrow \quad \frac{R}{1-n} + C_V = C$$

$$\Rightarrow \quad \frac{R}{1-n} = C - C_V$$

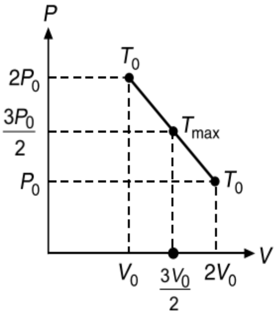
$$\Rightarrow \quad \frac{R}{C - C_V} = 1 - n$$

Since, $R = C_P - C_V$

$$\Rightarrow \quad n = \frac{C - C_P}{C - C_V}$$

**Hence, the correct answer is (C).**

**98.** **Method-I**



Since initial and final temperature are equal hence maximum temperature is at middle of line.

$$PV = nRT$$

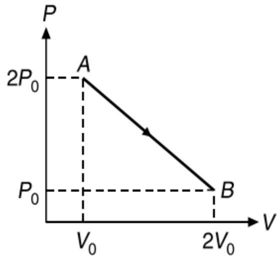
$$\Rightarrow \quad T_{\max} = \frac{(3P_0/2)(3V_0/2)}{nR} = \frac{9P_0V_0}{4nR}$$

**Method-II**

Equation of line

$$P = -\left(\frac{P_0}{V_0}\right)V + 3P_0$$

$$\Rightarrow \quad PV = -\left(\frac{P_0}{V_0}\right)V^2 + 3P_0V = x \text{ (say)}$$



For temperature to be maximum, the product $PV = x$ should also be the maximum, so we have $\frac{dx}{dV} = 0$.

$$\Rightarrow \quad V = \frac{3V_0}{2} \text{ and } P = \frac{3P_0}{2}$$

$$\Rightarrow \quad T = \frac{PV}{nR} = \frac{9}{4}\frac{P_0V_0}{nR}$$

**Hence, the correct answer is (B).**

**99.** For an ideal gas in an isobaric process,

Heat supplied, $Q = nC_p\Delta T$

Work done, $W = P\Delta V = nR\Delta T$

$$\Rightarrow \quad \frac{W}{Q} = \frac{nR\Delta T}{nC_p\Delta T} = \frac{R}{5R/2} = \frac{2}{5}$$

**Hence, the correct answer is (A).**

**100.** For isochoric process, $\Delta U = Q = mc\Delta T$

where, $m = 200 \text{ g} = 0.2 \text{ kg}$, $c = 4184 \text{ Jkg}^{-1}\text{K}^{-1}$

$$\Delta T = 60 - 40 = 20\ °\text{C} = 20\ \text{K}$$

$$\Rightarrow \quad \Delta U = 0.2 \times 4184 \times 20 = 16736\ \text{J} = 16.7\ \text{kJ}$$

**Hence, the correct answer is (D).**

**101.** For a refrigerator, we have

$$\frac{Q_2}{W} = \frac{T_2}{T_1 - T_2}$$

So, energy consumed by the freezer is given by

$$W = Q_2\left(\frac{T_1}{T_2} - 1\right)$$

where, $T_1 = 27\ °\text{C} = 300\ \text{K}$, $T_2 = 0\ °\text{C} = 273\ \text{K}$ and $Q_2 = mL = 5 \times 336 \times 10^3\ \text{J}$

$$\Rightarrow \quad W = 5 \times 336 \times 10^3\left(\frac{300}{273} - 1\right) = 1.67 \times 10^5\ \text{J}$$

**Hence, the correct answer is (D).**

**102.** Since, average time $(\tau)$ is given by

$$\tau = \frac{1}{\sqrt{2}\pi n_0 d^2 v_{\text{rms}}}, \text{ where } n_0 = \frac{N}{V}$$

Now, since $n_0 \propto \dfrac{1}{V}$ and $v_{\text{rms}} \propto \sqrt{T}$

$$\Rightarrow \quad \tau \propto \frac{V}{\sqrt{T}} \qquad \ldots(1)$$

Now, for an adiabatic process,

$$TV^{\gamma-1} = \text{constant} \qquad \ldots(2)$$

So, from (1) and (2), we get

$$\tau \propto V^{\frac{\gamma+1}{2}}$$

**Hence, the correct answer is (C).**

**103.** Average force applied on the walls by a molecule,

$$F = \frac{2mv}{t}$$

$$\Rightarrow \quad t = \frac{2\ell}{v}$$

$$\Rightarrow \quad t \propto \frac{\ell}{v}$$

$$\Rightarrow \quad F \propto v^2 \qquad \ldots(1)$$

Since, $v^2 \propto T$ $\qquad \ldots(2)$

From (1) and (2), we get

$$F \propto T$$

**Hence, the correct answer is (B).**

**104.** For metals, there is no free motion but rather oscillation about mean position. Thus, these have kinetic energy and potential energy, which are almost equal.

$$(\text{P.E.})_{\text{avg}} = (\text{K.E.})_{\text{avg}} = \frac{3}{2}k_B T$$

Energy per molecule is $E = K.E. + P.E. = 3k_B T$

Energy per mole is $E = 3RT$

Also, $E = MCT$

$$\Rightarrow \quad 3RT = MCT$$

$$\Rightarrow \quad C = \frac{3k_B}{m} = \frac{3R}{M}$$

$$\Rightarrow \quad C = \frac{3 \times 8.314}{27 \times 10^{-3}} \approx 925\ \text{Jkg}^{-1}\ \text{K}^{-1}$$

**Hence, the correct answer is (C).**

**105.** Since, entropy is a state function, so it does not depends upon the path and only depends on the initial and final state of the system. So, we have

$$dS = \frac{dQ}{T} = mc\left(\frac{dT}{T}\right)$$

$$\Rightarrow \quad \Delta S = \int ds = mc\int_{T_i}^{T_f} \frac{dT}{T}$$

$$\Rightarrow \quad \Delta S = mc\log_e\left(\frac{T_f}{T_i}\right)$$

Now, $mc = 1\ \text{J°C}^{-1}$

$$\Rightarrow \quad \Delta S = \log_e\left(\frac{527 + 273}{127 + 273}\right) = \log_e(2)$$

**Hence, the correct answer is (B).**

**106.** Since, $p = \dfrac{1}{3}\left(\dfrac{U}{V}\right)$ and $pV = nRT$

$$\Rightarrow \quad \frac{nRT}{V} \propto \frac{T^4}{3} \qquad \left\{\because \frac{U}{V} \propto T^4\right\}$$

$$\Rightarrow \quad VT^3 = \text{constant}$$

$$\Rightarrow \quad \left(\frac{4}{3}\pi R^3\right)T^3 = \text{constant}$$

$$\Rightarrow \quad TR = \text{constant}$$

$$\Rightarrow \quad T \propto \frac{1}{R}$$

**Hence, the correct answer is (C).**

**107.** For a cyclic process, $\Delta U = 0$

So, OPTION (A) is incorrect.

For process $CA$, $\Delta U = (1)\left(\dfrac{5R}{2}\right)(-200)$

$$\Rightarrow \quad \Delta U_{CA} = -500R$$

So, OPTION (B) is incorrect.

For process $AB$, $\Delta U = (1)\left(\dfrac{5R}{2}\right)(400)$

$$\Rightarrow \quad \Delta U_{AB} = 1000R$$

So, OPTION (C) is incorrect.

For process $BC$, $\Delta U = (1)\left(\dfrac{5R}{2}\right)(-200)$

$$\Rightarrow \quad \Delta U_{BC} = -500R$$

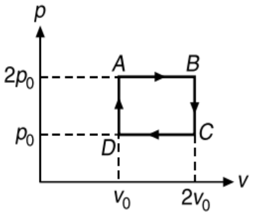
So, OPTION (D) is correct.

**Hence, the correct answer is (D).**

**108.** Heat is extracted from source in $AB$ and $DA$

In $AB$, $Q_{AB} = nC_P\Delta T = n\left(\dfrac{5R}{2}\right)\Delta T$

$$\Rightarrow \quad Q_{AB} = \frac{5}{2}(4p_0v_0 - 2p_0v_0) = 5p_0v_0$$



In $DA$, $Q_{DA} = nC_V\Delta T = n\left(\frac{3R}{2}\right)\Delta T = \frac{3}{2}p_0v_0$

Total heat extracted from source i.e., absorbed is

$$Q = Q_{AB} + Q_{DA} = \frac{13}{2}p_0v_0$$

**Hence, the correct answer is (B).**

**109.** Efficiency of Carnot engine, $\eta = 1 - \frac{T}{T_1}$

where $T_1$ is the temperature of the source and $T_2$ is the temperature of the sink?

For 1st case $\eta = 40\%$, $T_1 = 500$ K

$$\Rightarrow \quad \frac{40}{100} = 1 - \frac{T_2}{500}$$

$$\Rightarrow \quad \frac{T_2}{500} = 1 - \frac{40}{100} = \frac{3}{5}$$

$$T_2 = \frac{3}{5} \times 500 = 300 \text{ K}$$

For 2nd case $\eta = 60\%$, $T_2 = 300$ K

$$\Rightarrow \quad \frac{60}{100} = 1 - \frac{300}{T_1}$$

$$\Rightarrow \quad \frac{300}{T_1} = 1 - \frac{60}{100} = \frac{2}{5}$$

$$T_1 = \frac{5}{2} \times 300 = 750 \text{ K}$$

**Hence, the correct answer is (B).**

**110.** In case of a cyclic process, work done is equal to the area under the cycle and is taken to be positive if the cycle is clockwise, so work done is

$$W = \text{Area of Rectangle } ABCD = P_0V_0$$

Since, helium gas is a monatomic gas, so

$$C_V = \frac{3R}{2} \text{ and } C_P = \frac{5R}{2}$$

Along the path $AB$, heat is supplied to the gas at constant volume, so

$$\Delta Q_{AB} = nC_V\Delta T = n\left(\frac{3R}{2}\right)\Delta T = \frac{3}{2}P_0V_0$$

Along the path $BC$, heat is supplied to the gas at constant pressure, so

$$\Delta Q_{AB} = nC_P\Delta T = n\left(\frac{5R}{2}\right)\Delta T = \frac{5}{2}(2P_0V_0) = 5P_0V_0$$

Along the path $CD$ and $DA$, heat is rejected by the gas, so efficiency of the cycle is

$$\eta = \frac{\text{Work done by the gas}}{\text{Heat supplied to the gas}} \times 100\%$$

$$\Rightarrow \quad \eta = \frac{P_0V_0}{\frac{3P_0V_0}{2} + 5P_0V_0} \times 100 = \frac{200}{13} = 15.4\%$$

**Hence, the correct answer is (D).**

**111.** Kinetic energy of vessel $K = \frac{1}{2}mv^2$

Increase in internal energy is $\Delta U = nC_V\Delta T$

where, $n$ is the number of moles of the gas in vessel. When the vessel is stopped suddenly, its kinetic energy is used to increase temperature of the gas, so

$$\frac{1}{2}mv^2 = \Delta U = nC_V\Delta T = \frac{m}{M}C_V\Delta T \qquad \left\{\because\ n = \frac{m}{M}\right\}$$

$$\Rightarrow \quad \Delta T = \frac{Mv^2}{2C_V}$$

$$\Rightarrow \quad \Delta T = \frac{Mv^2(\gamma - 1)}{2R} \qquad \left\{\because\ C_V = \frac{R}{(\gamma - 1)}\right\}$$

**Hence, the correct answer is (D).**

**112.** The efficiency of Carnot engine, $\eta = 1 - \frac{T_2}{T_1}$

$$\Rightarrow \quad \frac{1}{6} = 1 - \frac{T_2}{T_1} \qquad \left(\text{Given, } \eta = \frac{1}{6}\right)$$

$$\Rightarrow \quad \frac{T_2}{T_1} = \frac{5}{6}$$

$$\Rightarrow \quad T_1 = \frac{6T_2}{5} \qquad \ldots(1)$$

As per question, when $T_2$ is lowered by 62 K, then its efficiency becomes $2\eta = 2\left(\frac{1}{6}\right) = \frac{1}{3}$

$$\Rightarrow \quad \frac{1}{3} = 1 - \frac{T_2 - 62}{T_1}$$

$$\Rightarrow \quad \frac{T_2 - 62}{T_1} = 1 - \frac{1}{3} = \frac{2}{3}$$

$$\Rightarrow \quad \frac{T_2 - 62}{6T_2/5} = \frac{2}{3} \qquad \{\text{using equation (1)}\}$$

$$\Rightarrow \quad \frac{5(T_2 - 62)}{6T_2} = \frac{2}{3}$$

$$\Rightarrow \quad 5T_2 - 310 = 4T_2$$

$$\Rightarrow \quad T_1 = \frac{6 \times 310}{5} = 372 \text{ K}$$

**Hence, the correct answer is (A).**

**113.** Since $Q = mc\Delta T$

where, $m = 100 \text{ g} = 100 \times 10^{-3}$ kg

$$c = 4184 \text{ Jkg}^{-1}\text{K}^{-1} \text{ and } \Delta T = (50 - 30) = 20\ °\text{C}$$

$$\Rightarrow \quad Q = 100 \times 10^{-3} \times 4184 \times 20 = 8.4 \times 10^3 \text{ J}$$

By FLTD, we have $Q = \Delta U + W$

Since we are ignoring the slight expansion of water, so we have $W \approx 0$. Hence change in internal energy is

$$U = Q = 8.4 \times 10^3 \text{ J} = 8.4 \text{ kJ}$$

**Hence, the correct answer is (B).**

**114.** For an adiabatic process $TV^{\gamma-1} = \text{constant}$

$$\Rightarrow \quad T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1}, \text{ where } \gamma = \frac{7}{5}$$

$$\Rightarrow \quad T_1 = T_2\left(\frac{V_2}{V_1}\right)^{\frac{2}{5}} = T_2\left(\frac{32V}{V}\right)^{\frac{2}{5}} = T_2\left(2^5\right)^{\frac{2}{5}} = 4T_2$$

Efficiency of the engine, $\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{1}{4}$

$$\Rightarrow \quad \eta = \frac{3}{4} = 0.75$$

**Hence, the correct answer is (C).**

**115.** For path $AB$, pressure is constant and $\Delta T = 200$ K

$$\Rightarrow \quad W_{\text{isob}} = P\Delta V = nR\Delta T = 2R(200) = 400R$$

**Hence, the correct answer is (C).**

**116.** For path $DA$, temperature is constant

$$\Rightarrow \quad W_{\text{isot}} = nRT_D \ln\left(\frac{V_A}{V_D}\right) = nRT_D \ln\left(\frac{P_D}{P_A}\right)$$

$$\Rightarrow \quad W = 2R(300)\ln(1/2) = -600R(0.69) = -414R$$

So work done on the gas is $W = +414R$

**Hence, the correct answer is (B).**

**117.** Total work done on the gas when taking from $A$ to $B$ is $400R$ and from $C$ to $D$ is equal and opposite, so they cancel each other.

Since $W_{D\to A} = -414R$ and

$$W_{B\to C} = (2)R(500)\ln(2) = 690R$$

$$\Rightarrow \quad W = -414R + 690R = 276R$$

**Hence, the correct answer is (B).**

**118.** The internal energy is the energy due to thermal motion, so we have

$$U = \left(\frac{nf}{2}\right)RT = \left(\frac{5n}{2}\right)RT$$

Since $PV = nRT$, $V = \frac{m}{\rho} = \frac{1\ \text{kg}}{4\ \text{kgm}^{-3}} = \frac{1}{4}\ \text{m}^3$ and $P = 8\times10^4\ \text{Nm}^{-2}$, so we get

$$U = \frac{5}{2}\times 8\times10^4 \times \frac{1}{4} = 5\times10^4\ \text{J}$$

**Hence, the correct answer is (B).**

## ARCHIVE: JEE ADVANCED

### Single Correct Choice Type Questions

**1.** Rate of heat transfer through metal rod is

$$\frac{dQ}{dt} = C\frac{dT}{dt} = P(\text{constant}) \qquad \dots(1)$$

Since temperature variation is given by

$$T = T_0\left(1 + \beta t^{\frac{1}{4}}\right) \qquad \dots(2)$$

$$\Rightarrow \quad \frac{dT}{dt} = \frac{T_0\beta}{4} t^{-\frac{3}{4}}$$

So from equation (1), we get

$$C = \frac{P}{dT/dt} = \frac{4P}{\beta T_0} t^{\frac{3}{4}}$$

Substituting the value of $t$ from equation (2), we get

$$C = \frac{4P(T - T_0)^3}{(\beta T_0)^4}$$

**Hence, the correct answer is (C).**

**2.** Heat generated in device in 3 h is

$$W = Pt = 3\times3600\times3\times10^3 = 324\times10^5\ \text{J}$$

Heat used to heat water

$$Q = mc\Delta T = 120\times1\times4.2\times10^3\times20\ \text{J}$$

$$\Rightarrow \quad Q = 100.8\times10^5\ \text{J}$$

So, heat absorbed by coolant is

$$H = 324\times10^5 - 120\times1\times4.2\times10^3\times20\ \text{J}$$

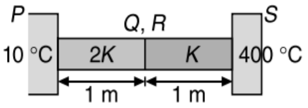
$$\Rightarrow \quad H = P't = (325 - 100.8)\times10^5\ \text{J}$$

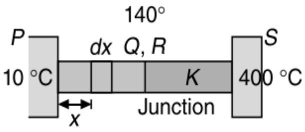
$$\Rightarrow \quad P' = \frac{223.2\times10^8}{3600} = 2067\ \text{W}$$

**Hence, the correct answer is (B).**

**3.** Rate of heat flow from $P$ to $Q$ is

$$\frac{dQ}{dt} = \frac{2KA(T-10)}{1}$$





Rate of heat flow from $Q$ to $S$ is

$$\frac{dQ}{dt} = \frac{KA(4000 - T)}{1}$$

At steady state, rate of heat flow is same

$$\frac{2KA(T-10)}{1} = KA(400 - T)$$

$$\Rightarrow \quad 2T - 20 = 400 - T$$

$$\Rightarrow \quad 3T = 420$$

$$\Rightarrow \quad T = 140^\circ$$

Temperature of junction is 140 °C

Temperature at a distance $x$ from end $P$ is

$$T_x = (130x + 10^\circ)$$

Change in length of $dx$ is supposed to be $dy$, then

$$dy = \alpha dx(T_x - 10) \qquad \{\because \Delta l = l\alpha\Delta T\}$$

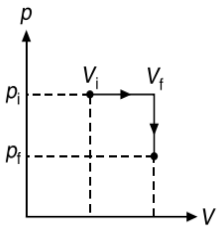
$$\Rightarrow \quad \int_0^{\Delta y} dy = \int_0^1 \alpha dx(130x + 10 - 10)$$

$$\Rightarrow \quad \Delta y = 130\left(\frac{\alpha x^2}{2}\right)\Bigg|_0^1 = (65)(1.2\times10^{-5}) = 78.0\times10^{-5}\ \text{m}$$

$$\Rightarrow \quad \Delta y = 0.78\ \text{mm}$$

**Hence, the correct answer is (A).**

**4.** For the first process, $p_i V_i^{\gamma} = p_f V_f^{\gamma}$



$$\Rightarrow \quad \frac{p_i}{p_f} = \left(\frac{V_f}{V_i}\right)^{\gamma}$$

$$\Rightarrow \quad 32 = 8^{\gamma}$$

$$\Rightarrow \quad 2^5 = 2^{3\gamma}$$

$$\Rightarrow \quad \gamma = \frac{5}{3} \qquad \ldots(1)$$

For the two-step process, we have

$$W = p_i\left(V_f - V_i\right) = 10^5\left(7\times10^{-3}\right)$$

$$\Rightarrow \quad W = 7\times10^2 \text{ J}$$

Also, $\Delta U = \frac{f}{2}\left(p_f V_f - p_i V_i\right)$

$$\Rightarrow \quad \Delta U = \frac{1}{\gamma-1}\left(\frac{1}{4}\times10^2 - 10^2\right) = -\frac{9}{8}\times10^2 \text{ J}$$

By FLTD, we have $\qquad Q = \Delta U + W$

$$\Rightarrow \quad Q = 7\times10^2 - \frac{9}{8}\times10^2 = \frac{47}{8}\times10^2 \text{ J} = 588 \text{ J}$$

**Hence, the correct answer is (C).**

**5.** In CASE-1, $R_I = R_1 + R_2 = \left(\frac{l}{KA}\right) + \left(\frac{l}{2KA}\right) = \frac{3}{2}\left(\frac{l}{KA}\right)$

In CASE-2, $\frac{1}{R_{\text{II}}} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{KA}{l} + \frac{2KA}{l}$

$$\Rightarrow \quad R_{II} = \frac{l}{3KA} = \frac{R_1}{4.5}$$

Since thermal resistance $R_{\text{II}}$ in 4.5 times less than thermal resistance $R_1$.

$$\Rightarrow \quad t_{II} = \frac{t_1}{4.5} = \frac{9}{4.5} \text{ s} = 2 \text{ s}$$

**Hence, the correct answer is (A).**

**6.** From ideal gas equation, we have $\rho = \frac{pM}{RT}$

$$\Rightarrow \quad \rho \propto pM$$

$$\Rightarrow \quad \frac{\rho_1}{\rho_2} = \left(\frac{p_1}{p_2}\right)\left(\frac{M_1}{M_2}\right) = \left(\frac{2}{3}\right)\left(\frac{4}{3}\right) = \frac{8}{9}$$

**Hence, the correct answer is (D).**

**7.** $Q = nCp\Delta T = 208$ J

**Hence, the correct answer is (D).**

**8.** At equilibrium, $(\text{Heat Absorbed}) = (\text{Heat Radiated})$

$$\Rightarrow \quad A(3T)^4 + A(2T)^4 = 2AT_0^4$$

$$\Rightarrow \quad T_0 = \left(\frac{97}{2}\right)^{1/4} T$$

**Hence, the correct answer is (C).**

**9.** $\frac{v_{He}}{v_{Ar}} = \sqrt{\frac{M_{Ar}}{M_{He}}} = \sqrt{10} = 3.16$

**Hence, the correct answer is (D).**

**10.** Since, $T_1 V_1^{(\gamma-1)} = T_2 V_2^{(\gamma-1)}$

$$\Rightarrow \quad T_2 = T_1\left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

$$\Rightarrow \quad T_2 = 4T_1 \qquad \left\{\because \gamma = \frac{5}{3}\right\}$$

$n$ =Number of moles of gas $= \frac{5.6 \text{ lt}}{22.4 \text{ lt}} = \frac{1}{4}$

$$\Rightarrow \quad W_{\text{ext}} = \frac{nR}{1-\gamma}\left(T_2 - T_1\right)$$

$$\Rightarrow \quad W_{\text{ext}} = +\frac{9}{8}RT_1$$

**Hence, the correct answer is (A).**

**11.** Since $ML = Pt$

$$\Rightarrow \quad L = \frac{Pt}{M}$$

**Hence, the correct answer is (C).**

**12.** A real gas behaves like an ideal gas at low pressure and high temperature.

**Hence, the correct answer is (D).**

**13.** It cracks due to low thermal conductivity.

**Hence, the correct answer is (A).**

**14.** $PT^2 = \text{constant}$

Since, $PV = nRT$

$$\Rightarrow \quad \left(\frac{T}{V}\right)T^2 = \text{constant}$$

$$\Rightarrow \quad V \propto T^3$$

$$\Rightarrow \quad \frac{\Delta V}{V} = \frac{3\Delta T}{T}$$

$$\Rightarrow \quad \frac{\Delta V}{V\Delta T} = \frac{3}{T}$$

**Hence, the correct answer is (C).**

**15.** 1 calorie is the heat required to raise the temperature of 1 g of water from 14.5 °C to 15.5 °C at 760 mm of $Hg$.

**Hence, the correct answer is (A).**

**16.** $\lambda_m T = \text{constant}$

From the graph $T_3 > T_2 > T_1$

Temperature of sun will be maximum. Therefore, (C) is the correct OPTION.

**Hence, the correct answer is (C).**

**17.** Glass of bulb heats due to filament by radiation.

**Hence, the correct answer is (C).**

**18.** Energy gained by water (in 1 s) is

$$\frac{dQ}{dt} = 1000 - 160 = 840 \text{ W}$$

Total heat required to raise the temperature of water from 27 °C to 77 °C is $mc\Delta T$.

Hence, the required time

$$t = \frac{mc\Delta T}{\text{Rate at which energy is gained by water}}$$

$$\Rightarrow \quad t=\frac{(2)(4.2\times10^3)(50)}{840}=500\text{ s}=8\text{ min }20\text{ s}$$

**Hence, the correct answer is (A).**

**19.** $Q\propto AT^4$ and $\lambda_m T=\text{constant}$. Hence,

$$Q\propto\frac{A}{(\lambda_m)^4}$$

$$\Rightarrow \quad Q\propto\frac{r^2}{(\lambda_m)^4}$$

$$\Rightarrow \quad Q_A:Q_B:Q_C=\frac{(2)^2}{(3)^4}:\frac{(4)^2}{(4)^4}:\frac{(6)^2}{(5)^4}$$

$$\Rightarrow \quad Q_A:Q_B:Q_C=\frac{4}{81}:\frac{1}{16}:\frac{36}{625}$$

$$\Rightarrow \quad Q_A:Q_B:Q_C=0.05:0.0625:0.0576$$

$\Rightarrow \quad Q_B$ is maximum.

**Hence, the correct answer is (B).**

**20.** $$\frac{dQ}{dt}=L\left(\frac{dm}{dt}\right)$$

$$\Rightarrow \quad \frac{\text{Temperature difference}}{\text{Thermal resistance}}=L\left(\frac{dm}{dt}\right)$$

$$\Rightarrow \quad \frac{dm}{dt}\propto\frac{1}{\text{Thermal resistance}}$$

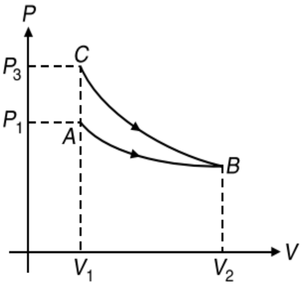
$$q\propto\frac{1}{R}$$

In the first case rode are in parallel and thermal resistance is $\frac{R}{2}$ while in second case rods are in series and thermal resistance is $2R$.

$$\frac{q_1}{q_2}=\frac{2R}{R/2}=\frac{4}{1}$$

**Hence, the correct answer is (C).**

**21.** Slope of adiabatic process a given state $(P,\ V,\ T)$ is more than the slope of isothermal process. The corresponding P-V graph for the two processes is as shown in figure.



In the graph, $AB$ is isothermal and $BC$ is adiabatic.

$W_{AB}$ =positive (as volume is increasing)

and $W_{BC}$ =negative (as volume is decreasing) plus, $|W_{BC}|>|W_{AB}|$, as area under P-V graph gives the work done.

Hence, $W_{AB}+W_{BC}=W<0$

From the graph itself, it is clear that $P_3>P_1$.

**Conceptual Note(s)**

At point $B$, slope of adiabatic (process $BC$) is greater than the slope of isothermal (process $AB$).

**Hence, the correct answer is (C).**

**22.** Temperature of liquid oxygen will first increase in the same phase. Then, phase change (liquid to gas) will take place. During which temperature will remain constant. After that temperature of oxygen n gaseous state will further increase.
**Hence, the correct answer is (C).**

**23.** Out of the alternative provided, none appears completely correct.
$AB$ is an isothermal process.
$\left(T=\text{constant},\ p\propto\frac{1}{V}\right)$. So, $p$-$V$ graph should be rectangular hyperbola with $p$ decreasing and $V$ increasing.
$BC$ is an isobaric process.
$(p=\text{constant},\ V\propto T)$. Temperature is increasing. Hence, volume should also increase.
$CA$ is an adiabatic process $\left(pV^\gamma=\text{constant}\right)$. Pressure is increasing. So, volume should decrease. At point $A$, an isotherm $AB$ and an adiabatic curve $AC$ are meeting. We know that (slope of an adiabatic graph in $p$-$V$ diagram) $=\gamma$ (slope of an isothermal graph in the same diagram) with $\gamma>1$ or $(\text{Slope})_{\text{adiabatic}}>(\text{Slope})_{\text{isothermal}}$

None of the given examples fulfill all the above requirements.
**Hence, the correct answer is (None).**

**24.** Heat released by 5 kg of water when its temperature falls from 20 °C to 0 °C is,

$$Q_1=mc\Delta\theta=(5)(10^3)(20-0)=10^5\text{ cal}$$

when 2 kg ice at –20 °C comes to a temperature of 0 °C, it takes an energy.

$$Q_2=mc\Delta\theta=(2)(500)(20)=0.2\times10^5\text{ cal}$$

The remaining heat

$$Q=Q_1-Q_2=0.8\times10^5\text{ cal}$$

will melt a mass $m$ of the ice, where

$$m=\frac{Q}{L}=\frac{0.8\times10^5}{80\times10^3}=1\text{ kg}$$

So, the temperature of the mixture will be 0 °C, mass of water in it is $5+1=6$ kg and mass of ice is $2-1=1$ kg.
**Hence, the correct answer is (B).**

**25.** Given $\Delta\ell_1=\Delta\ell_2$

$$\Rightarrow \quad \ell_1\alpha_a t=\ell_2\alpha_s t$$

$$\Rightarrow \quad \frac{\ell_1}{\ell_2}=\frac{\alpha_s}{\alpha_a}$$

$$\Rightarrow \quad \frac{\ell_1}{\ell_1+\ell_2}=\frac{\alpha_s}{\alpha_a+\alpha_s}$$

**Hence, the correct answer is (C).**

**26.** Rate of cooling $\left(-\dfrac{dT}{dt}\right) \propto$ emissivity $(E)$

From the graph, $\left(-\dfrac{dT}{dt}\right)_x > \left(-\dfrac{dT}{dt}\right)_y$

$\Rightarrow \quad E_x > E_y$

Further emissivity $(E) \propto$ absorptive power $(a)$ (good absorbers are good emitters also)

$\Rightarrow \quad a_x > a_y$

### Conceptual Note(s)

Emissivity is a pure ratio (dimensionless) while the emissive power has a unit $\text{Js}^{-1}$ or watt.

**Hence, the correct answer is (C).**

**27.** Black body radiates maximum number of wavelength and maximum energy if all other conditions (e.g., temperature surface area etc.) are same. So, when the temperature of black body becomes equal to the temperature of the furnace, the black body will radiate maximum energy and it will be brightest of all. Initially it will absorb all the radient energy incident on it, so, it is the darkest one.
**Hence, the correct answer is (A).**

**28.** $\beta = -\dfrac{dV/dP}{V}$ = compressibility of gas

$$\Rightarrow \quad \beta = \frac{1}{\text{Bulk modulus of elasticity}}$$

$\Rightarrow \quad \beta = \dfrac{1}{P}$ under isothermal conditions

Thus, $\beta$ versus $P$ graph will be a rectangular hyperbola.
**Hence, the correct answer is (A).**

**29.** $\Delta W_{AB} = P\Delta V = (10)(20-1) = 10\ \text{J}$

$\Delta W_{BC} = 0$

From First Law of Thermodynamics

$\Delta Q = \Delta W + \Delta U$

$\Delta U = 0 \qquad \{\because$ process $ABCA$ is cyclic$\}$

$\Rightarrow \quad \Delta Q = \Delta W_{AB} + \Delta W_{BC} + \Delta W_{CA}$

$\Rightarrow \quad \Delta W_{CA} = \Delta Q - \Delta W_{AB} - \Delta W_{BC} = 5 - 10 - 0 = -5\ \text{J}$

**Hence, the correct answer is (A).**

**30.** In adiabatic process

Slope of $P$-$V$ graph, $\dfrac{dP}{dV} = -\gamma\dfrac{P}{V}$

Slope $\propto \gamma$ {with negative sign}

From the given graph, $(\text{slope})_2 > (\text{slope})_1$

$\Rightarrow \quad \gamma_2 > \gamma_1$

Therefore, 1 should correspond to $O_2(\gamma = 1.4)$ and 2 should correspond to $He(\gamma = 1.67)$.

**Hence, the correct answer is (B).**

**31.** $dW = 0$

$\Rightarrow$ Isochoric process

$\Rightarrow \quad \text{đ}Q = dU$ (by First Law of Thermodynamics)

Since $\text{đ}Q < 0$

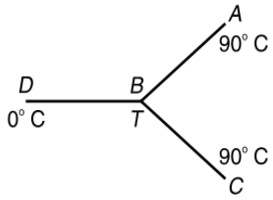
$\Rightarrow \quad dU < 0$

There must be a fall in temperature.
**Hence, the correct answer is (A).**

**32.** Let $\theta$ be the temperature of the junction (say $B$). Thermal resistance of all the three rods is equal.

$$\begin{pmatrix}\text{Rate of}\\ \text{heat flow}\\ \text{through}\\ AB\end{pmatrix} + \begin{pmatrix}\text{Rate of}\\ \text{heat flow}\\ \text{through}\\ CB\end{pmatrix} = \begin{pmatrix}\text{Rate of}\\ \text{heat flow}\\ \text{through}\\ BD\end{pmatrix}$$

$$\Rightarrow \quad \frac{90-T}{R} + \frac{90-T}{R} = \frac{T-0}{R}$$



Here, $R$ = Thermal resistance

$\Rightarrow \quad 3T = 180^\circ$

$\Rightarrow \quad T = 60\ ^\circ\text{C}$

### Conceptual Note(s)

Rate of heat flow

$$(H) = \frac{\text{Temperature difference (TD)}}{\text{Thermal resistnace }(R)}$$

where $R = \dfrac{\ell}{KA}$

$K$ = Thermal conductivity of the rod.

This is similar to the current flow through a resistance $(R)$ where current $(i)$ = Rate of flow of charge

$$= \frac{\text{Potential difference }(PD)}{\text{Electrical resistance }(R)}$$

Here, $R = \dfrac{\ell}{\sigma A}$ where $\sigma$ = Electrical conductivity

**Hence, the correct answer is (B).**

**33.** $v \propto \dfrac{1}{\sqrt{m}}$

**Hence, the correct answer is (B).**

**34.** At constant pressure

$V = kT$

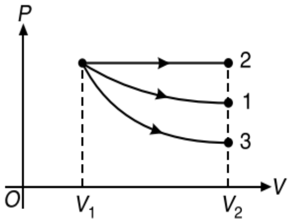
$\Rightarrow \quad \Delta V = k\Delta T$

$\Rightarrow \quad \dfrac{\Delta V}{V} = \dfrac{\Delta T}{T}$

$\Rightarrow \quad \delta = \dfrac{\Delta V}{V\Delta T} = \dfrac{1}{T}$

$\Rightarrow$ Plot of $\delta$ vs $T$ must represent a rectangular hyperbola.
**Hence, the correct answer is (C).**

**35.** The work done equals area under the curve



$\Rightarrow \quad W_2 > W_1 > W_3$

**Hence, the correct answer is (A).**

**36.** Following steps are involved in this process

(a) Ice at –10 °C will convert to ice at 0 °C and will absorb heat in accordance with formula $dQ = mc_{\text{ice}}dT$ i.e. $Q$ vs $T$ must be a straight line with slope $\frac{1}{mc_{\text{ice}}} = s_1$ (say) (for $T$ on y-axis and $Q$ on $x$-axis)

(b) Ice at 0 °C will melt to water at 0 °C (at constant temperature) by absorbing a heat $Q_2 = mL_{\text{ice}}$

(c) Water at 0 °C will convert to water at 100 °C and will again absorb heat in accordance with formula $dQ = mc_{\text{water}}dT$ i.e. $Q$ vs $T$ is again a straight line with slope $\frac{1}{mc_{\text{water}}} = s_2$ (say) $(s_2 < s_1)$

(d) Water at 100 °C will vapourise to steam at 100 °C (at constant temperature) by absorbing heat $Q_4 = mL_{\text{steam}}$

**Hence, the correct answer is (A).**

**37.** According to Wien's Displacement Law

$$\lambda_m T = \text{constant}$$

Since, $\lambda_1 < \lambda_3 < \lambda_2$

$\Rightarrow \quad T_1 > T_3 > T_2$

**Hence, the correct answer is (B).**

**38.** $T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1}$

$$\Rightarrow \quad T_1(AL_1)^{\frac{5}{3}-1} = T_2(AL_2)^{\frac{5}{3}-1}$$

$$\Rightarrow \quad \frac{T_1}{T_2} = \left(\frac{L_2}{L_1}\right)^{\frac{2}{3}}$$

**Hence, the correct answer is (D).**

**39.** $U = U_{\text{Oxygen}} + U_{\text{Argon}}$

$$\Rightarrow \quad U = (2)\left(\frac{5R}{2}\right)T + 4\left(\frac{3R}{2}\right)T$$

$$\Rightarrow \quad U = 11RT$$

**Hence, the correct answer is (D).**

**40.** Speed of sound in an ideal gas is given by

$$v = \sqrt{\frac{\gamma RT}{M}}$$

$$\Rightarrow \quad v \propto \sqrt{\frac{\gamma}{M}} \qquad \{T \text{ is same for both the gases}\}$$

$$\Rightarrow \quad \frac{v_{N_2}}{v_{He}} = \sqrt{\frac{\gamma_{N_2}}{\gamma_{He}} \cdot \frac{M_{He}}{M_{N_2}}} = \sqrt{\frac{7/5}{5/3}\left(\frac{4}{28}\right)}$$

Since, $\gamma_{N_2} = \frac{7}{5}$ {Diatomic}

and $\gamma_{He} = \frac{5}{3}$ {Monatomic}

$$\Rightarrow \quad v = \frac{\sqrt{3}}{5} \text{ ms}^{-1}$$

**Hence, the correct answer is (C).**

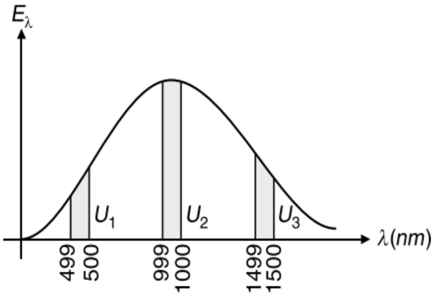
**41.** Wein's Displacement Law is

$$\lambda_m T = b \qquad \{b = \text{Wein's constant}\}$$

$$\Rightarrow \quad \lambda_m = \frac{b}{T} = \frac{2.88 \times 10^6 \text{ nm-K}}{2880 \text{ K}}$$

$$\Rightarrow \quad \lambda = 1000 \text{ nm}$$

Energy distribution with wavelength will be as follows



$\lambda_m = 1000$ nm

From the graph it is clear that

$U_2 > U_1$ {In fact $U_2$ is maximum}

**Hence, the correct answer is (D).**

**42.** $P = \frac{nRT}{V} = \frac{mRT}{MV} \qquad \left\{\because n = \frac{m}{M}\right\}$

So, at constant volume pressure versus temperature graph is a straight line passing through origin with slope $\frac{mR}{MV}$.

As the mass is doubled and volume is halved slope becomes four times. Therefore, pressure versus temperature graph will be shown by the line $B$.

**Hence, the correct answer is (B).**

**43. For gas in container** $A$

$$\Delta P = (P_A)_{\text{final}} - (P_A)_{\text{initial}} = \frac{n_ART}{2V} - \frac{n_ART}{V}$$

$$\Delta P = -\frac{n_ART}{2V} \qquad \ldots(1)$$

**For gas in container** $B$

$$1.5\Delta P = (P_B)_{\text{final}} - (P_B)_{\text{initial}} = \frac{n_BRT}{2V} - \frac{n_BRT}{V}$$

$$1.5\Delta P = -\frac{n_BRT}{2V} \qquad \ldots(2)$$

From (1) and (2), we get

$$n_B = 1.5\, n_A$$

$\Rightarrow \quad 2n_B = 3n_A$

$\Rightarrow \quad 2m_B = 3m_A$ {OPTION **(C)**}

**Hence, the correct answer is (C).**

**44.** A diatomic molecule has 5 degrees of freedom out of which 3 are translational degrees of freedom and remaining 2 are rotational degrees of freedom. According to Theorem of Equipartition of Energy, the energy associated with each degree of freedom per molecule of a gas in thermal equilibrium is $\frac{1}{2}k_BT$, where $k_B$ is the Boltzmann constant. So, the average rotational kinetic energy associated with each $O_2$molecule is $2\left(\frac{1}{2}k_BT\right) = k_BT$. Similarly, average rotational kinetic energy associated with each $N_2$ molecule is $2\left(\frac{1}{2}k_BT\right) = k_BT$. So, the ratio amounts to $1:1$.

{OPTION **(A)**}

However, if we are asked to compare the total rotational kinetic energy associated with 1 mole $O_2$ gas to that with 2 mole of $N_2$ gas, then our answer would have been $1:2$.

**Hence, the correct answer is (A).**

**45.** Power radiated ∝ (surface area) $(T)^4$. The radius is halved, hence, surface area will become $\frac{1}{4}$ times. Temperature is doubled, therefore, $T^4$ becomes 16 times. New power $= (450)\left(\frac{1}{4}\right)(16) = 1800$ W.

**Hence, the correct answer is (D).**

**46.** $PV = nRT$

$$\Rightarrow \quad P = \frac{nRT}{V}$$

$$\frac{P_2}{P_1} = \frac{n_2}{n_1}\frac{T_2}{T_1}$$

$$\frac{P_2}{P_1} = \frac{1}{1} \times \frac{2}{1}$$

$$\Rightarrow \quad P_2 = 2P$$

**Hence, the correct answer is (C).**

**47.** Average translational kinetic energy of an ideal gas molecule is $\frac{3}{2}$ kT which depends on temperature only. Therefore, if temperature is same, translational kinetic energy of $O_2$ and $N_2$ both will be equal.

**Hence, the correct answer is (C).**

**48.** From Wein's Displacement Law

$$\lambda_m T = \text{constant}$$

$$\Rightarrow \quad T = \frac{1}{\lambda_m}$$

$$\Rightarrow \quad \frac{T_{\text{sun}}}{T_{\text{north star}}} = \frac{(\lambda_m)_{\text{north star}}}{(\lambda_m)}$$

$$\Rightarrow \quad \frac{T_{\text{sun}}}{T_{\text{north star}}} = \frac{350}{510} \approx 0.69$$

**Hence, the correct answer is (B).**

**49.** The average translational KE $= \frac{3}{2}kT$ which is directly proportional to $T$, while rms speed molecules is given by

$$v_{\text{rms}} = \sqrt{\frac{3RT}{M}} \text{ i.e., } v_{\text{rms}} \propto \sqrt{T}$$

When temperature of gas is increased from 300 K to 600 K (i.e., 2 times), the average translational KE will increase to 2 times and rms speed to $\sqrt{2}$ or 1.414 times.

So, average translational KE $= 2 \times 6.21 \times 10^{-21}$ J

$$(\text{KE})_{av} = 12.42 \times 10^{-21} \text{ J and}$$

$$v_{\text{rms}} = (1.414)(484) \text{ ms}^{-1}$$

$$\Rightarrow \quad v_{\text{rms}} \approx 684 \text{ ms}^{-1}$$

**Hence, the correct answer is (D).**

**50.** $v_{\text{rms}} = \sqrt{\frac{3RT}{M}}$

i.e., $v_{\text{rms}} \propto \sqrt{T}$

When temperature is increased from 120 K to 480 K (i.e., four times), the root mean square speed will become $\sqrt{4}$ or 2 times i.e., $2v$.

**Hence, the correct answer is (B).**

**51.** The rate at which energy leaves the object is $\frac{\Delta Q}{\Delta t} = e\sigma AT^4$

Since, $\Delta Q = mC\Delta T$, we get

$$\frac{\Delta T}{\Delta t} = \frac{e\sigma AT^4}{mC}$$

Also, since $m = \frac{4}{3}\pi r^3 \rho$ for a sphere, we get

$$A = \pi r^2 = \pi\left(\frac{3m}{4\pi\rho}\right)^{2/3}$$

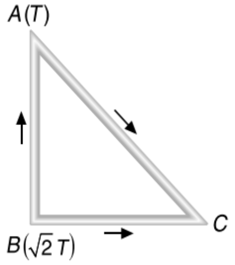
Hence, $\frac{\Delta T}{\Delta t} = \frac{e\sigma T^4}{mC}\left[\pi\left(\frac{3m}{4\pi\rho}\right)^{2/3}\right] = K\left(\frac{1}{m}\right)^{1/3}$

For the given two bodies

$$\frac{(\Delta T/\Delta t)_1}{(\Delta T/\Delta t)_2} = \left(\frac{m_2}{m_1}\right)^{1/3} = \left(\frac{1}{3}\right)^{1/3}$$

**Hence, the correct answer is (D).**

**52.** As $T_B > T_A$, heat flows from $B$ to $A$ through both paths



Rate of heat flow in $BC$ = Rate of heat flow in $CA$

$$\Rightarrow \quad \frac{KA(\sqrt{2}T - T_C)}{\ell} = \frac{KA(T_C - T)}{\sqrt{2}\ell}$$

Solving this we get,

$$T_C = \frac{3T}{\sqrt{2}+1}$$

**Hence, the correct answer is (A).**

**53.** The average speed of a gas molecule is $\langle v \rangle = \sqrt{\frac{8k_BT}{\pi m}}$, where $m$ is the mass of the molecule. Since, all the three vessels have same temperature, so average speed of $O_2$ molecule in the vessel $C$ is also $v_1$.

**Hence, the correct answer is (B).**

**54.** The desired fraction is

$$f = \frac{\Delta U}{\Delta Q} = \frac{nC_V\Delta T}{nC_P\Delta T} = \frac{C_V}{C_P} = \frac{1}{\gamma}$$

$$\Rightarrow \quad f = \frac{5}{7} \qquad \left\{\text{as } \gamma = \frac{7}{5}\right\}$$

**Hence, the correct answer is (D).**

**55.** In the process $PV^x = \text{constant}$

Molar heat capacity is given by

$$C = \frac{R}{\gamma - 1} + \frac{R}{1-x}$$

Here the process is $PV^{-1} = \text{constant}$

i.e., $x = -1$

and gas is monatomic. Therefore, $\gamma = \frac{5}{3}$

$$\Rightarrow \quad C = \frac{R}{\frac{5}{3}-1} + \frac{R}{1-(-1)} = 2R$$

$$\Rightarrow \quad \Delta Q = nC\Delta T \qquad \{\because n = 1\}$$

$$\Rightarrow \quad \Delta Q = (1)(2R)(2T_0 - T_0)$$

$$\Rightarrow \quad \Delta Q = 2RT_0$$

**Hence, the correct answer is (A).**

**56.** $$C_{V_{\text{mixture}}} = \frac{n_1C_{V_1} + n_2C_{V_2}}{n_1+n_2}$$

$$C_{P_{\text{mixture}}} = \frac{n_1C_{P_1} + n_2C_{P_2}}{n_1+n_2}$$

**Hence, the correct answer is (B).**

**57.** Heat required $Q = (1.1 + 0.02) \times 10^2 \times 1 \times (80 - 15)$

$$\Rightarrow \quad Q = 72800 \text{ cal}$$

Therefore, mass of steam condensed (in kg)

$$m = \frac{Q}{L} = \frac{72800}{540} \times 10^{-2} = 0.135 \text{ kg}$$

**Hence, the correct answer is (D).**

**58.** Since $70 = (2)C_P(45 - 40)$

$$\Rightarrow \quad C_P = 7 \text{ calmol}^{-1}\text{k}^{-1}$$

$$\Rightarrow \quad C_V = 5 \text{ calmol}^{-1}\text{k}^{-1} \qquad \left\{\text{Since } C_P - C_V = 2 \text{ calmol}^{-1}\text{k}^{-1}\right\}$$

$$\Rightarrow \quad Q = (2)(5)(5) = 50 \text{ cal}$$

**Hence, the correct answer is (C).**

**59.** $$v_{\text{rms}}^2 = \frac{3RT}{M}$$

$$\Rightarrow \quad M = \frac{3RT}{v_{\text{rms}}^2} = \frac{3(8.3)(300)}{(1930)^2} \approx 2\,g \qquad (\text{for } H_2 \text{ gas})$$

**Hence, the correct answer is (A).**

**60.** Since, $\begin{pmatrix}\text{Work done in a}\\ \text{cyclic process}\end{pmatrix} = \begin{pmatrix}\text{Positive area enclosed}\\ \text{by the cycle}\end{pmatrix}$

$$\Rightarrow \quad W = AB \times BC = (2P - P) \times (2V - V) = PV$$

**Hence, the correct answer is (A).**

## Multiple Correct Choice Type Questions

**1.** Since, $P = \sigma AT^4$

$$\Rightarrow \quad P = 5.67 \times 10^{-8} \times 64 \times 10^{-6} \times (2500)^4$$

$$\Rightarrow \quad P = 141.75 \text{ W}$$

Also, $I = \frac{P}{4\pi r^2} = \frac{141.75}{4\pi \times (100)^2} = 1.13 \times 10^{-3} \text{ Wm}^{-2}$

$$\Rightarrow \quad \Delta E_{\text{eye}} = I \times \left(\pi r_e^2\right)$$

$$\Rightarrow \quad \Delta E_{\text{eye}} = I \times \left(\pi \times 9 \times 10^{-6}\right)$$

$$\Rightarrow \quad \Delta E_{\text{eye}} = 3.2 \times 10^{-8} \text{ W}$$

According to Wein's Law, we have

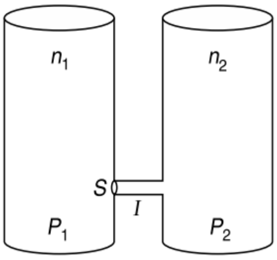
$$\lambda_m = \frac{b}{T} = \frac{2.90 \times 10^{-3}}{2500} = 1160 \text{ nm}$$

$$\Rightarrow \quad N_{\text{photons}} = \frac{\Delta E}{\left(\frac{hc}{\lambda}\right)} = \frac{3.2 \times 10^{-8} \times 1740 \times 10^{-9}}{6.63 \times 10^{-34} \times 3 \times 10^8}$$

$$\Rightarrow \quad N_{\text{photons}} = 2.8 \times 10^{11}$$

**Hence, (B), (C) and (D) are correct.**

**2.** Since, $P_1 = n_1k_BT$ and $P_2 = n_2k_BT$



$$\Rightarrow \quad \Delta F = (P_1 - P_2)S$$

$$\Rightarrow \quad \Delta F = (n_1 - n_2)k_BTS = \Delta nk_BTS \qquad \ldots(1)$$

For balancing of force, we have

$$\beta v \times (S\ell)n_1 = \Delta nk_BTS$$

$$\Rightarrow \quad n_1\beta vl = \Delta nk_BT \qquad \ldots(2)$$

$$\Rightarrow \quad v = \frac{\Delta nk_BT}{\beta n_1 I}$$

Number of molecules per second is

$$\frac{\Delta N}{\Delta t} = \frac{(vdt) \times S \times n_1}{dt} = vSn_1$$

$$\Rightarrow \quad \frac{\Delta N}{\Delta t}=\frac{\Delta n k_B T}{\beta n_1 I}\times S n_1=\left(\frac{\Delta n}{I}\right)\left(\frac{k_B T}{\beta}\right)S \qquad \ldots(3)$$

So, $\Delta n$ decreases with time, so rate of transfer decreases with time.

**Hence, (A), (B) and (C) are correct.**

**3.** Since, $\gamma_{\text{mixture}}=\dfrac{5(5R/2)+1(7R/2)}{5(3R/2)+1(5R/2)}=\dfrac{8}{5}=1.6$

For adiabatic process, $PV^{\gamma}=\text{constant}$

$$\Rightarrow \quad P=P_0\left(\frac{V_0}{V}\right)^{\gamma}=(4)^{\frac{8}{5}}P_0=9.2P_0$$

$$\Rightarrow \quad W=\frac{P_0V_0-9.2P_0(V_0/4)}{\gamma-1}=-\frac{13P_0V_0}{6}$$

From ideal gas equation, we have $P_0V_0=6RT_0$

$$\Rightarrow \quad W=-\frac{13P_0V_0}{6}=-13RT_0$$

Final temperature after compression is

$$T=T_0\left(\frac{PV}{P_0V_0}\right)=2.3T_0$$

Also, $(C_V)_{\text{mixture}}=\dfrac{n_1C_{V_1}+n_2C_{V_2}}{n_1+n_2}=\dfrac{5R}{3}$

So, average kinetic energy of gas is

$$U_f=nC_VT=6\left(\frac{5R}{3}\right)(2.3T_0)=23RT_0$$

**Hence, (A), (B) and (C) are correct.**

**4.** $|Q_{1\to 2}|=nC_PdT=n\left(\dfrac{5R}{2}\right)T_0=\dfrac{5RT_0}{2}$

$$|Q_{3\to 4}|=nC_PdT=n\left(\frac{5R}{2}\right)\left(\frac{T_0}{2}\right)=\frac{5RT_0}{4}$$

$$\Rightarrow \quad \frac{|Q_{1\to 2}|}{|Q_{3\to 4}|}=2$$

Also $|Q_{2\to 3}|=\dfrac{3}{2}RT_0$

$$\frac{Q_{1\to 2}}{Q_{2\to 3}}=\frac{5RT_0/2}{3RT_0/2}=\frac{5}{3}$$

Since, $W=W_{1\to 2}+W_{2\to 3}+W_{3\to 4}+W_{4\to 1}$

$$\Rightarrow \quad W=(1)R(2T_0-T_0)+0+(1)R\left(\frac{T_0}{2}-T_0\right)+0$$

$$\Rightarrow \quad W=\frac{RT_0}{2}$$

**Hence, (C) and (D) are correct.**

**5.** In Process II, $T$ is constant, so $V$ is increasing. Hence$Q$ is positive i.e., gas absorbs heat. Similarly, in process IV, gas releases heat. For an isobaric process, $V\propto T$.

**Hence, (B), (C) and (D) are correct.**

**6.** Assumption $e=1$ i.e., body is a black body, so

$$P=\sigma A\left(T^4-T_0^4\right)$$

$$\Rightarrow \quad P_{\text{rad}}=\sigma AT^4=\sigma 1(T_0+10)^4$$

$$\Rightarrow \quad P_{\text{rad}}=\sigma T_0^4\left(1+\frac{10}{T_0}\right)^4 \qquad [T_0=300\text{ K given}]$$

$$\Rightarrow \quad P_{\text{rad}}=\sigma(300)^4\left(1+\frac{40}{300}\right)\approx 460\times\frac{17}{15}\approx 520\text{ J}$$

$$\Rightarrow \quad P_{\text{net}}=520-460\approx 60\text{ W}$$

So, energy radiated in $1\text{ s}=60\text{ J}$

Since, $P=\sigma A\left(T^4-T_0^4\right)$

$$\Rightarrow \quad dP=\sigma A\left(0-4T_0^3dT\right)\text{ and } dT=-\Delta T$$

$$\Rightarrow \quad dP=4\sigma AT_0^3\Delta T$$

If surface area decreases, then energy radiation also decreases.

## Conceptual Note(s)

While giving answer (B) and (C) it is assumed that energy radiated refers the net radiation. If energy radiated is taken as only emission, then (B) and (C) will not include in answer.

**Hence, (B), (C) and (D) are correct.**

**7.** (A) Total internal energy $U=\dfrac{f_1}{2}nRT+\dfrac{f_2}{2}nRT$

$$(U_{\text{ave}})_{\text{per mole}}=\frac{U}{2n}=\frac{1}{4}[5RT+3RT]=2RT$$

(B) $\gamma_{\text{mix}}=\dfrac{n_1C_{p1}+n_2C_{p2}}{n_2C_{V_1}+n_2C_{V_2}}=\dfrac{(1)\frac{7R}{2}+(1)\frac{5R}{2}}{(1)\frac{5R}{2}+(1)\frac{3R}{2}}=\dfrac{3}{2}$

$$\Rightarrow \quad M_{\text{mix}}=\frac{n_1M_1+n_2M_2}{n_1+n_2}=\frac{M_1+M_2}{2}=\frac{2+4}{2}=3$$

Speed of sound $v=\sqrt{\dfrac{\gamma RT}{M}}$

$$\Rightarrow \quad v\propto\sqrt{\frac{\gamma}{M}}$$

$$\Rightarrow \quad \frac{v_{\text{mix}}}{v_{\text{He}}}=\sqrt{\frac{\gamma_{\text{mix}}}{\gamma_{\text{He}}}\times\frac{M_{\text{He}}}{M_{\text{mix}}}}=\sqrt{\frac{3/2}{5/3}\times\frac{4}{3}}=\sqrt{\frac{6}{5}}$$

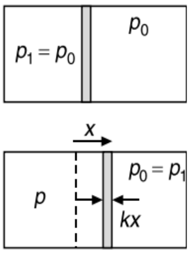
(D) $v_{\text{rms}}=\sqrt{\dfrac{3RT}{M}}$

$$\Rightarrow \quad v_{\text{rms}}\propto\frac{1}{\sqrt{M}}$$

$$\Rightarrow \quad \frac{v_{\text{He}}}{v_H}=\sqrt{\frac{M_H}{M_{\text{He}}}}=\sqrt{\frac{2}{4}}=\frac{1}{\sqrt{2}}$$

**Hence, (A), (B) and (D) are correct.**

**8.** Please note that this question can be solved if right hand side hand side chamber is assumed open, so that its pressure remains constant even if the piston shifts towards right.



(A) Since $pV = nRT$, so $p \propto \frac{T}{V}$

When temperature is made three times and volume is doubled, then

$$p_2 = \frac{3}{2}p_1$$

Further $x = \frac{\Delta V}{A} = \frac{V_2 - V_1}{A} = \frac{2V_1 - V_1}{A} = \frac{V_1}{A}$

$$\Rightarrow \quad p_2 = \frac{3p_1}{2} = p_1 + \frac{kx}{A}$$

$$\Rightarrow \quad kx = \frac{p_1 A}{2}$$

So, energy stored in the spring is

$$\frac{1}{2}kx^2 = \frac{1}{2}(kx)x = \frac{p_1 A}{4}x = \frac{p_1 V_1}{4}$$

(B) Since, $\Delta U = nC_V\Delta T = n\left(\frac{3R}{2}\right)\Delta T$

$$\Rightarrow \quad \Delta U = \frac{3}{2}(p_2V_2 - p_1V_1) = \frac{3}{2}\left[\left(\frac{3}{2}p_1\right)(2V_1) - p_1V_1\right]$$

$$\Rightarrow \quad \Delta U = 3p_1V_1$$

(C) When $V_2 = 3V_1$, $T_2 = 4T_1$, then $p_2 = \frac{4p_1}{3}$

$$\Rightarrow \quad p_2 = \frac{4}{3}p_1 = p_1 + \frac{kx}{A}$$

$$\Rightarrow \quad kx = \frac{p_1 A}{3}$$

$$\Rightarrow \quad x = \frac{\Delta V}{A} = \frac{2V_1}{A}$$

Since, $W_{\text{gas}} = \left(p_0\Delta V + W_{\text{spring}}\right) = \left(p_1 A x + \frac{1}{2}(kx)x\right)$

$$\Rightarrow \quad W = +\left(p_1 A \frac{2V_1}{A} + \frac{1}{2}\frac{p_1 A}{3}\frac{2V_1}{A}\right)$$

$$\Rightarrow \quad W = 2p_1V_1 + \frac{p_1V_1}{3} = \frac{7p_1V_1}{3}$$

(D) By FLTD, we have $Q = \Delta U + W$

$$\Rightarrow \quad Q = \frac{7p_1V_1}{3} + \frac{3}{2}(p_2V_2 - p_1V_1)$$

$$\Rightarrow \quad Q = \frac{7p_1V_1}{3} + \frac{3}{2}\left(\frac{4}{3}p_1 3V_1 - p_1V_1\right)$$

$$\Rightarrow \quad Q = \frac{7p_1V_1}{3} + \frac{9}{2}p_1V_1 = \frac{41p_1V_1}{6}$$

**Hence, (A), (B) and (C) are correct.**

**9.** $dQ = mCdT$

$$\Rightarrow \quad \frac{dQ}{dT} = mC$$

For $0 < T < 100$ graph is approximately linear

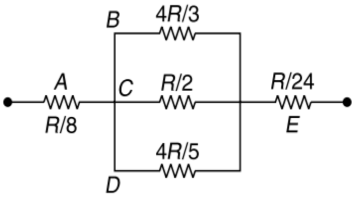
$$\Delta Q = m\int CdT = m(\text{area under } C\text{-}T \text{ graph})$$

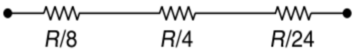
For 400-500 K area is more than for 0-100 K, so

$\frac{dQ}{dT}$ increases for $200 < T < 300$ K as $C$ increases in this region.

**Hence, (A), (B), (C) and (D) are correct.**

**10.** In steady state: (Heat In) = (Heat Out). So, $A$ is true





OPTION (B) is also true because total heat is flowing through $E$.

$$(\text{Heat current}) = Q = \frac{\Delta T}{R}$$

Since, heat current $(Q)$ is the same and

$R_E$ is minimum. So, $\Delta T$ is minimum

Hence, OPTION (C) is true

So, $Q_B = \frac{\Delta T}{\frac{4R}{3}}$, $Q_C = \frac{\Delta T}{\frac{4R}{2}}$ and $Q_D = \frac{\Delta T}{\frac{4R}{5}}$

$$\Rightarrow \quad Q_B + Q_D = Q_C$$

So, (D) is also true.

**Hence, (A), (B), (C) and (D) are correct.**

**11.** For monatomic gas, $C_P = \frac{5}{2}R$, $C_V = \frac{3}{2}R$, $C_P - C_V = R$

For diatomic gas $C_P = \frac{7}{2}R$, $C_V = \frac{5}{2}R$, $C_P - C_V = R$

So, $(C_P - C_V)$ is same for both

$C_P + C_V = 6R$ {for diatomic}

$C_P + C_V = 4R$ {for monatomic}

So, $(C_P + C_V)_{\text{dia}} > (C_P + C_V)_{\text{mono}}$

$\frac{C_P}{C_V} = \frac{7}{5} = 1.4$ {for diatomic}

$\frac{C_P}{C_V} = \frac{5}{3} = 1.66$ {for monatomic}

$(C_P)(C_V) = \frac{35}{4}R^2 = 8.75R^2$ {for diatomic}

$$(C_P)(C_V)=\frac{15}{4}R^2 \qquad \text{\{for monatomic\}}$$

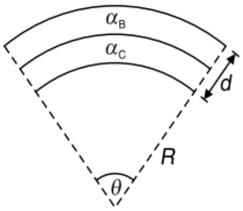
So, $(C_P\cdot C_V)_{\text{diatomic}}>(C_P\cdot C_V)_{\text{monatomic}}$

**Hence, (B) and (D) are correct.**

**12.** Since, the temperature of black body is constant, total heat absorbed = total heat radiated.
**Hence, the correct answer is (D).**

**13.** Let $\ell_0$ be the initial length of each strip before heating.

Length after heating will be



$$\ell_B=\ell_0(1+\alpha_B\Delta T)=(R+d)\theta$$

and $\ell_C=\ell_0(1+\alpha_C\Delta T)=R\theta$

$$\Rightarrow \quad \frac{R+d}{R}=\left(\frac{1+\alpha_B\Delta T}{1+\alpha_C\Delta T}\right)$$

$$\Rightarrow \quad 1+\frac{d}{R}=1+(\alpha_B-\alpha_C)\Delta T \qquad \text{\{From binomial expansion\}}$$

$$\Rightarrow \quad R=\frac{d}{(\alpha_B-\alpha_C)\Delta T}$$

$$\Rightarrow \quad R\propto\frac{1}{\Delta T}\text{ and }\propto\frac{1}{|\alpha_B-\alpha_C|}$$

**Hence, (B) and (D) are correct.**

**14.** There is a decrease in volume during melting on an ice slab at 273 K. Therefore, negative work is done by ice-water system on the atmosphere or positive work is done on the ice-water system by the atmosphere. Hence, OPTION (B) is correct. Secondly heat is absorbed during melting (i.e., $dQ$ is positive) and as we have seen, work done by ice-water system is negative ($dW$ is negative). Therefore, From First Law of Thermodynamics

$$dU=dQ-dW$$

Change in internal energy of ice-water system, $dU$ will be positive or internal energy will increase.
**Hence, (B) and (C) are correct.**

**15.** Average speed $=\langle v\rangle=\sqrt{\dfrac{8RT}{\pi M}}$,

RMS speed $=v_{\text{rms}}=\sqrt{\dfrac{3RT}{M}}$ and

Most probable speed $=v_P=\sqrt{\dfrac{2RT}{M}}$

From these we have

$$v_P<\langle v\rangle<v_{\text{rms}}$$

Also, the average kinetic energy of the gaseous molecules is

$$\langle E\rangle=\frac{1}{2}mv_{\text{rms}}^2=\frac{1}{2}m\left(\frac{3}{2}v_P^2\right)=\frac{3}{4}mv_P^2$$

**Hence, (C) and (D) are correct.**

**16.** For one mole of an ideal gas $PV=RT$
The coefficient of volume expansion at constant pressure is given by

$$\left(\frac{\Delta V}{\Delta T}\right)_P=\frac{R}{P}=\text{constant} \qquad \text{\{OPTION (A)\}}$$

The average translational kinetic energy per molecule is $\frac{3}{2}$kT and not 3kT. With decrease of pressure, collisions between molecules will be less frequent, hence mean free path will increase.

The average translational kinetic energy of the molecules is independent of their nature, so each component of the gaseous mixture will have the same value of average translational kinetic energy.
**Hence, (A) and (C) are correct.**

**17.** Since both bodies emit total radiant power at the same rate.

$$\Rightarrow \quad e_A\sigma(T_A^4)=e_B\sigma(T_B^4)$$

$$\Rightarrow \quad 0.01(T_A^4)=0.81(T_B^4)$$

$$\Rightarrow \quad T_A=3T_B$$

$$\Rightarrow \quad T_B=\frac{1}{3}T_A=\frac{1}{3}(5802\text{ K})$$

$$\Rightarrow \quad T_B=1934\text{ K}$$

$$\lambda_A=\frac{1}{3}\lambda_B \text{ (due to Wien's Law)}$$

Since, $\lambda_B-\lambda_A=1\ \mu\text{m}$

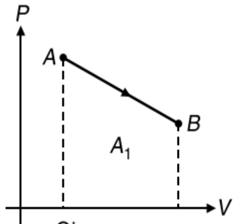
$$\Rightarrow \quad \lambda_B-\frac{\lambda_B}{3}=1\ \mu\text{m}$$

$$\Rightarrow \quad \frac{2}{3}\lambda_B=1\ \mu\text{m}$$

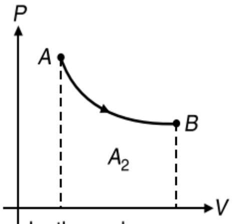
$$\Rightarrow \quad \lambda_B=1.5\ \mu\text{m}$$

**Hence, (A) and (B) are correct.**

**18.** (a) Work done = Area under $P$-$V$ graph



Given process



Isothermal process

(b) In the given process $P$-$V$ equation will be a straight line with negative slope and positive intercept i.e., $P=-\alpha V+\beta$ (Here, $\alpha$ and $\beta$ are positive constant)

$$\Rightarrow \quad PV=-\alpha V^2+\beta V$$

$$\Rightarrow \quad nRT=-\alpha V^2+\beta V$$

$$\Rightarrow \quad T=\frac{1}{nR}(-\alpha V^2+\beta V) \qquad \ldots(1)$$

This is an equation of parabola in $T$ and $V$.

(c) $\dfrac{dT}{dV}=0=\beta-2\alpha V$

$$\Rightarrow \quad V=\frac{B}{2\alpha}$$

Now, $\dfrac{d^2T}{dV^2}=-2\alpha=-\text{ve}$

i.e., $T$ has some maximum value.

Now, $T \propto PV$

and $(PA)_A = (PV)_B$

$\Rightarrow \quad T_A = T_B$

We conclude that temperatures are same at $A$ and $B$ and temperature has a maximum value. Therefore, in going from $A$ to $B$, $T$ will first increase to a maximum value and then decrease.

**Hence, (A), (B) and (D) are correct.**

**19.** (a) $\Delta U = nC_V \Delta T = nC_V(T_2 - T_1)$ in all processes

(b) For an adiabatic process $Q = 0$

$\Rightarrow \quad \Delta U = -W$

$\Rightarrow \quad |\Delta U| = |W|$

(c) In isothermal process $\Delta T = 0$

$\Rightarrow \quad \Delta U = 0 \qquad \{\because \Delta U = nC_V \Delta T\}$

(d) In adiabatic process $Q = 0$

Hence, all options are correct.

**Hence, (A), (B), (C) and (D) are correct.**

## Reasoning Based Questions

**1.** Total translational kinetic energy

$$K_T = \frac{3}{2}nRT = \frac{3}{2}pV = 1.5pV$$

**Hence, the correct answer is (B).**

## Matrix Match/Column Match Type Questions

**1.** **A → (q, r, s, u); B → (q, s, r, u); C → (s, r, q, t); D → (q, r, p, u)**

(A) $W_{1\to2\to3} = P_0V_0 = \frac{1}{3}RT_0$

(B) $\Delta U_{1\to2\to3} = \frac{3}{2}\left[\left(\frac{3P_0}{2}\right)(2V_0) - P_0V_0\right] = RT_0$

(C) $Q_{1\to2\to3} = \Delta U + W = \frac{4}{3}RT_0$

(D) $Q_{1\to2} = \frac{1}{3}RT_0 + \frac{3}{2}(2P_0V_0 - P_0V_0) = \frac{5}{6}RT_0$

**2.** **A → (p, r, t, s); B → (p, t, q, t); C → (p, r, t, p); D → (s, t, q, u)**

Since, $W_{1\to2\to3} = W_{1\to2} + W_{2\to3} = R\left(\frac{T_0}{3}\right)\ln\left(\frac{2V_0}{V_0}\right) + 0$

$\Rightarrow \quad W_{1\to2\to3} = \frac{RT_0}{3}\ln 2$

$$\Delta U_{1\to2\to3} = \Delta U_{1\to2} + \Delta U_{2\to3} = 0 + nC_V\left(T_0 - \frac{T_0}{3}\right)$$

$\Rightarrow \quad \Delta U_{1\to2\to3} = (1)\left(\frac{3R}{2}\right)\left(\frac{2T_0}{3}\right) = RT_0$

Along the path $1 \to 2$, we have $dT = 0$, so

$$Q_{1\to2} = \int T dX = \int T\left(\frac{3R}{2T}dT + \frac{R}{2}dV\right)$$

$$Q_{1\to2} = \int_{V_0}^{2V_0} \frac{RT}{V}dV = 0 + RT\ln 2$$

Similarly, along the path $2 \to 3$, we have $dV = 0$, so

$$Q_{2\to3} = \int T dX = \frac{3R}{2}\int_{\frac{T_0}{3}}^{T_0} dT = \left(\frac{3R}{2}\right)\left(\frac{2T_0}{3}\right) + 0$$

$\Rightarrow \quad Q_{2\to3} = RT_0$

$\Rightarrow \quad Q_{1\to2\to3} = RT\ln 2 + RT_0 = \frac{1}{3}RT_0(3 + \ln 2)$

**3.** **A → (r); B → (s); C → (p); D → (q)**

Since $\left(\frac{dP}{dV}\right)_{\text{adia}} = \gamma\left(\frac{dP}{dV}\right)_{\text{isot}}$, so process I is adiabatic and hence $Q = 0$

Process II is isobaric, so work done is

$$W_{\text{isob}} = P\Delta V = 3P_0(3V_0 - V_0) = 6P_0V_0$$

Process III is isochoric, so $W_{\text{isoc}} = 0$

Process IV is isothermal, so temperature is constant.

**4.** Since, $v_{\text{sound}} = \sqrt{\frac{\gamma RT}{M}}$. As the sound wave propagates, the air in a chamber undergoes compression and rarefaction very fastly, hence undergo a adiabatic process. So, curves are steeper than isothermal.

$$\left(\frac{dp}{dV}\right)_{\text{Adi}} = -\gamma\left(\frac{p}{V}\right) \qquad \ldots(1)$$

$$\left(\frac{dp}{dV}\right)_{\text{Iso}} = -\left(\frac{p}{V}\right) \qquad \ldots(2)$$

Graph $Q$ satisfied Equation (1)

**Hence, the correct answer is (C).**

**5.** By FLTD, we have $Q = \Delta U + p\Delta V$

Since, $\Delta U \neq 0$, $W \neq 0$, $\Delta Q \neq 0$. The process represents, isobaric process, so

$$W_{\text{gas}} = -p\Delta V = -p(V_2 - V_1) = -pV_2 + pV_1$$

Graph $P$ satisfies isochoric process.

**Hence, the correct answer is (B).**

**6.** Work done in isochoric process is zero.

$W_{12} = 0$ as $\Delta V = 0$

Graph $S$ represents isochoric process.

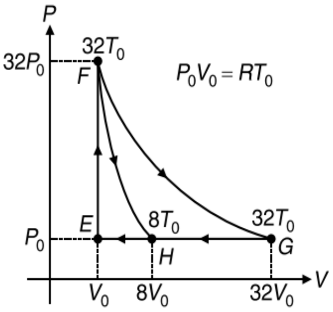
**Hence, the correct answer is (B).**

**7.** **A → (s); B → (r); C → (q); D → (p)**

$FG$ is isothermal and $FH$ is adiabatic, so we have

$$P_0V_G^{\frac{5}{3}} = 32P_0V_0^{\frac{5}{3}} \qquad \{\because \gamma_{\text{monatomic}} = 5/3\}$$

$\Rightarrow \quad V_G = (32)^{\frac{3}{5}}V_0 = 8V_0$



So, $W_{GE} = P_0\left(V_0 - 32V_0\right) = -31P_0V_0$

$$W_{GH} = P_0\left(8V_0 - 32V_0\right) = -24P_0V_0$$

$$W_{FH} = \frac{P_0\left(8V_0\right) - 32P_0V_0}{1-\left(5/3\right)} = \frac{-24P_0V_0}{-2/3} = 36P_0V_0$$

$$W_{FG} = 32RT_0 \log_e 32 = 32RT_0 \log_e 2^5$$

Hence, $W_{FG} = 160RT_0 \log_e 2$

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

In $AB$ temperature and volume are decreasing

In $BC$ temperature decreases, volume does not change

In $CD$ temperature and volume increase

In $DA$ final temperature equals initial temperature. Also, volume decreases

For all processes, we have

$$\Delta U = nC_V\Delta T,\ W = \int P dV,\ Q = \Delta U + W$$

**9.** **A → (q); B → (p, r); C → (p, s); D → (q, s)**

(A) in free expansion, we have

$$W = \Delta U = Q = 0$$

For a polytropic process, we have

$PV^x = \text{constant if } x < \gamma, Q > 0$

$x > \gamma, Q < 0$

$x = \gamma, Q = 0$

$x = 1, T = \text{constant}$

$x > 1, T = \text{decreases}$

$x < 1, T = \text{increases}$

**10.** Conceptual

**A → (s); B → (q); C → (p, q); D → (q, r)**

**11.** **A → (s); B → (p, r); C → (p); D → (q, s)**

In process $J \to K$ $V$ is constant whereas $p$ is decreasing. Therefore, $T$ should also decrease.

$\Rightarrow$ $W = 0$, $\Delta U = -\text{ve}$ and $Q < 0$

In process $K \to L$ $p$ is constant while $V$ is increasing. Therefore, temperature should also increase.

$\Rightarrow$ $W > 0$, $\Delta U > 0$ and $Q > 0$

In process $L \to M$ This is inverse of process $J \to K$.

$\Rightarrow$ $W = 0$, $\Delta U > 0$ and $Q > 0$

In process $M \to J$

$V$ is decreasing. Therefore, $W < 0$

$$(pV)_J < (pV)_M$$

$\Rightarrow$ $T_J < T_M$

$\Rightarrow$ $\Delta U < 0$

Therefore, $Q < 0$

## Linked Comprehension Type Questions

**1.** Let final equilibrium temperature of gases is $T$

Heat rejected by gas in lower compartment is

$$Q_{\text{lower}} = nC_V\Delta T = 2 \times \frac{3}{2}R(700 - T)$$

Heat received by the gas in above compartment

$$Q_{\text{upper}} = nC_p\Delta T = 2 \times \frac{7}{2}R(T - 400)$$

Equating the two, we get

$$2100 - 3T = 7T - 2800$$

$\Rightarrow$ $T = 490$ K

**Hence, the correct answer is (D).**

**2.** By FLTD, we get

$$Q_1 = \Delta U_1 + W_1 \qquad \ldots(1)$$

Also, $Q_2 = \Delta U_2 + W_2$ ...(2)

Since, $Q_1 + Q_2 = 0$

$\Rightarrow$ $\left(nC_p\Delta T\right)_1 + \left(nC_p\Delta T\right)_2 = 0$

Since, $n_1 = n_2 = 2$

$\Rightarrow$ $\frac{5}{2}R(T - 700) + \frac{7}{2}R(T - 400) = 0$

Solving, we get $T = 525$ K

From equations (1) and (2), we get

$$\Delta W_1 + W_2 = -\Delta U_1 - \Delta U_2 \qquad \{\because \Delta Q_1 + \Delta Q_2 = 0\}$$

$\Rightarrow$ $W_1 + W_2 = -\left[\left(nC_V\Delta T\right)_1 + \left(nC_V\Delta T\right)_2\right]$

$\Rightarrow$ $W = -\left[2\left(\frac{3R}{2}\right)(525 - 700) + 2\left(\frac{5R}{2}\right)(525 - 400)\right]$

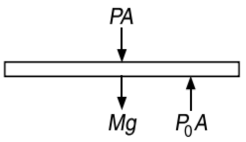
$\Rightarrow$ $W = -100R$

**Hence, the correct answer is (D).**

**3.** Since it is open from top, pressure will be $P_0$.

**Hence, the correct answer is (A).**

**4.** Let $P$ be the pressure in equilibrium



Then $PA = P_0A - Mg$

$$P = P_0 - \frac{Mg}{A} = P_0 - \frac{Mg}{\pi R} \qquad \ldots(1)$$

Applying $P_1V_1 = P_2V_2$

$$\Rightarrow \quad P_0(2AL) = (P)(AL')$$

$$\Rightarrow \quad L' = \frac{2P_0L}{P} = \left(\frac{P_0}{P_0 - \frac{Mg}{\pi R^2}}\right)(2L)$$

$$L' = \left(\frac{P_0\pi R^2}{\pi R^2 P_0 - Mg}\right)(2L)$$

**Hence, the correct answer is (D).**

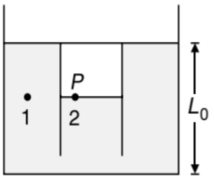
5. Since we observe, $P_1 = P_2$

$$\Rightarrow \quad P_0 + \rho g(L_0 - H) = P \qquad \ldots(1)$$

Now, applying $P_1V_1 = P_2V_2$ for the air inside the cylinder, we have

$$P_0(L_0) = P(L_0 - H)$$

$$\Rightarrow \quad P = \frac{P_0L_0}{L_0 - H}$$



Substituting in equation (1), we have

$$P_0 + \rho g(L_0 - H) = \frac{P_0L_0}{L_0 - H}$$

$$\Rightarrow \quad \rho g(L_0 - H)^2 + P_0(L_0 - H) - P_0L_0 = 0$$

**Hence, the correct answer is (C).**

## Integer/Numerical Answer Type Questions

1. In an isothermal process, work done is

$$W_{\text{isot}} = RT\ln 4$$

In an adiabatic process, we have

$$T(4V_1)^{\frac{2}{3}} = T'(32V_1)^{\frac{2}{3}}$$

$$\Rightarrow \quad T' = \frac{T}{4}$$

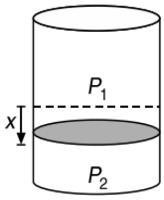
So, $W_{\text{adia}} = \dfrac{2R\left(T - \frac{T}{4}\right)}{3} = \left(\dfrac{9RT}{8}\right)$

$$\Rightarrow \quad \frac{W_{\text{isot}}}{W_{\text{ad}}} = \frac{8}{9}\ln 4 = \frac{16}{9}\ln 2$$

$$\Rightarrow \quad f = \frac{16}{9} = 1.78$$

2. Assuming the gas to be an ideal monoatomic gas

$$\Rightarrow \quad C_V = \frac{3}{2}R$$



Let area of cross section of the cylinder be $A$.

Initially, we have $PV = nRT$

$$\Rightarrow \quad P_0(4A) = 0.1R \times 300 \qquad \text{(For both)}$$

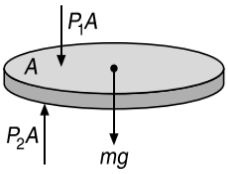
Let partition shifts by $x$ meter and final temperature be $T$, then we have (for lower portion)

$$P_2A(4 - x) = 0.1RT$$

$$\Rightarrow \quad P_2A = \frac{0.1RT}{4 - x} = \frac{RT}{10(4 - x)}$$

Similarly, for upper portion, we have

$$P_1A = \frac{RT}{10(4 + x)}$$



But finally, in equilibrium, we have

$$P_1A + mg = P_2A$$

$$\Rightarrow \quad P_2A - P_1A = mg = 83$$

$$\frac{RT}{10}\left(\frac{1}{4 - x} - \frac{1}{4 + x}\right) = 83$$

$$\Rightarrow \quad \frac{RT}{10}\left(\frac{2x}{16 - x^2}\right) = 83 \qquad \ldots(1)$$

Also, we have

$$0.2C_V \times 300 + mgx = 0.2C_VT$$

$$\Rightarrow \quad \left(\frac{2}{10}\right)\left(\frac{3}{2}R\right)(300) + 83x = \left(\frac{2}{10}\right)\left(\frac{3}{2}R\right)T$$

$$\Rightarrow \quad \frac{900R}{10} + 83x = 3\left(\frac{RT}{10}\right)$$

$$\frac{300R}{10} + \frac{83}{3}x = \frac{RT}{10}$$

Using equation (1), we get

$$\left(30R + \frac{83x}{3}\right)\left(\frac{2x}{16 - x^2}\right) = 83$$

$$\Rightarrow \quad 83\left(3 + \frac{x}{3}\right)\left(\frac{2x}{16 - x^2}\right) = 83$$

$$\Rightarrow \quad \frac{(9 + x)}{3}\frac{(2x)}{(16 - x^2)} = 1$$

$$\Rightarrow \quad 18x + 2x^2 = 48 - 3x^2$$

$$\Rightarrow \quad 5x^2 + 18x - 48 = 0$$

$$\Rightarrow \quad x = 1.78 \approx 2$$

So, the distance from top is 6 m.

3. For an adiabatic process, we have

$$\Delta P = -\left(\frac{rP}{V}\right)\Delta V$$

where, $P = p_0$ and $\Delta V = -(4\pi R^2)a$

$$\Rightarrow \quad \Delta P = \left(\frac{rp_0}{\frac{4}{3}\pi R^3}\right)(4\pi R^2)a = \frac{3rp_0a}{R}$$

Work done in the process is

$$W = -(\Delta P)_{av}\,\Delta V$$

Since the change is small, so $(\Delta P)_{av}$ equals the arithmetic mean and hence $(\Delta P)_{av} = \dfrac{\Delta P}{2}$

$$\Rightarrow \quad W = -\left(\frac{\Delta P}{2}\right)\left(-4\pi R^2 a\right) = \left(\frac{3rp_0a}{2R}\right)\left(4\pi R^2 a\right)$$

$$\Rightarrow \quad W = \left(4\pi p_0 R a^2\right)\left(\frac{3r}{2}\right)$$

$$\Rightarrow \quad W = \left(4\pi p_0 R a^2\right)\left(\frac{3}{2}\times\frac{41}{30}\right)$$

$$\Rightarrow \quad W = \left(4\pi p_0 R a^2\right)(2.05)$$

$$\Rightarrow \quad X = 2.05$$

**4.** In steady state, heat lost per second equals the heat gained per second.

$$\left(\frac{dQ}{dt}\right)_{\text{lost}} = \left(\frac{dQ}{dt}\right)_{\text{gained}} \qquad \ldots(1)$$

Since, $\left(\frac{dQ}{dt}\right)_{\text{gained}} = (700)(0.05)\ \text{W}$

Also, according to Newton's Law of cooling, we have

$$\frac{1}{A}\frac{dQ}{dt} = \left(4\sigma e T_0^3\right)\Delta T$$

$$\Rightarrow \quad \left(\frac{dQ}{dt}\right)_{\text{lost}} = \left(4\sigma e T_0^3\right)A\Delta T \qquad \ldots(2)$$

Given that the constant of proportionality for Newton's Law of cooling is $0.001\ \text{s}^{-1}$

Also, $-\frac{dT}{dt} = \left(\frac{4\sigma e A}{mc}\right)T_0^3 \Delta T$

So, constant of proportionality for Newton's Law of cooling is $k = \left(\frac{4\sigma e A}{mc}\right)T_0^3$

$$\Rightarrow \quad 4\sigma e T_0^3 A = k(mc)$$

Substituting in (2), we get

$$\left(\frac{dQ}{dt}\right)_{\text{lost}} = k(mc)\Delta T$$

$$\Rightarrow \quad 700 \times 0.05 = (0.001)(4200)\Delta T$$

$$\Rightarrow \quad \Delta T = \frac{25}{3}\ \text{K}$$

$$\Rightarrow \quad \Delta T = 8.33\ \text{K}$$

**5.** CASE-1: $5c(50) + 5L = c_2(30)$ …(1)

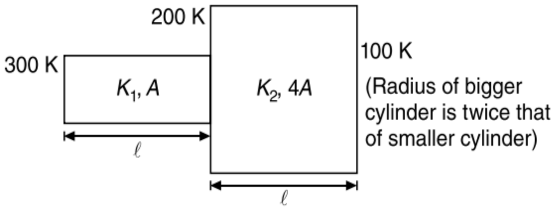
CASE-2: $80c(50-30) = c_2(80-50)$ …(2)

From equations (1) and (2), we get

$$1600c = 250c + 5L$$

$$\Rightarrow \quad \frac{L}{c} = \frac{1350}{5} = 270\ ^\circ\text{C}$$

**6.** In steady state, the rate of flow of heat through both the conducting cylinders will be equal. So, we have



$$\frac{K_1 A(300-200)}{\ell} = \frac{K_2 4A(200-100)}{\ell}$$

$$\Rightarrow \quad \frac{K_1}{K_2} = 4 = 4.00$$

**7.** For an adiabatic process, $T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1}$

where $\gamma = \gamma_{\text{monatomic}} = \frac{5}{3}$

$$\Rightarrow \quad T_2 = T_1\left(\frac{V_1}{V_2}\right)^{\gamma-1} = 100\left(\frac{1}{8}\right)^{\frac{2}{3}}$$

$$\Rightarrow \quad T_2 = 25\ \text{K}$$

Since, $\Delta U = nC_V\Delta T = 1\left(\frac{3R}{2}\right)(T_2 - T_1)$

$$\Delta U = 1\left(\frac{3}{2}\times 8\right)(25-100) = -900\ \text{J}$$

Hence, decrease in internal energy is 900 J

**8.** For reading of sensor to be 1, we have

$$\Rightarrow \quad \log_2\frac{P_1}{P_0} = 1$$

$$\Rightarrow \quad \frac{P_1}{P_0} = 2$$

According to Stefan's law, we have

$$P \propto T^2$$

$$\Rightarrow \quad \frac{P_2}{P_1} = \left(\frac{T_2}{T_1}\right)^4 = \left(\frac{2767+273}{487+273}\right)^4 = 4^4$$

$$\Rightarrow \quad \frac{P_2}{P_1} = \frac{P_2}{2P_0} = 4^4$$

$$\Rightarrow \quad \frac{P_2}{P_0} = 2\times 4^4$$

So, new reading is

$$\log_2\left(\frac{P_2}{P_0}\right) = \log_2 2 + \log_2 4^4$$

$$\log_2\left(\frac{P_2}{P_0}\right) = 1 + \log_2\left(2^8\right) = 9$$

**9.** Power, $P_{\text{radiated}} = P = \sigma T^4 A = \sigma T^4\left(4\pi R^2\right)$

$$\Rightarrow \quad P \propto T^4R^2 \qquad \ldots(1)$$

If $\lambda$ is the wavelength at which peak occurs, then according to Wien's law, we have

$$\lambda \propto \frac{1}{T}$$

So, equation (1) becomes

$$P \propto \frac{R^2}{\lambda^4}$$

$$\Rightarrow \quad \lambda \propto \left(\frac{R^2}{P}\right)^{\frac{1}{4}}$$

$$\Rightarrow \quad \frac{\lambda_A}{\lambda_B} = \left(\frac{R_A}{R_B}\right)^{1/2}\left(\frac{P_B}{P_A}\right)^{1/4} = (400)^{1/2}\left(\frac{1}{10^4}\right)^{1/4} = 2$$

**10.** Since, $W_{ibf} = W_{ib} + W_{bf} = 50\text{ J} + 100\text{ J} = 150\text{ J}$

Similarly, $W_{iaf} = W_{ia} + W_{af} = 0 + 200\text{ J} = 200\text{ J}$

Also, $Q_{iaf} = 500\text{ J}$

So, by FLTD, we have $\Delta U_{iaf} = Q_{iaf} - W_{iaf}$

$\Rightarrow \quad \Delta U_{iaf} = 500\text{ J} - 200\text{ J} = 300\text{ J}$

$\Rightarrow \quad U_f - U_i = 300\text{ J}$

$\Rightarrow U_f = U_{iaf} + U_i = 300\text{ J} + 100\text{ J} = 400\text{ J}$

Similarly, $\Delta U_{ib} = U_b - U_i = 200\text{ J} - 100\text{ J} = 100\text{ J}$

By FLTD, we have $Q_{ib} = \Delta U_{ib} + W_{ib}$

$\Rightarrow \quad Q_{ib} = 100\text{ J} + 50\text{ J} = 150\text{ J}$

Similarly by FLTD, we have

$$Q_{ibf} = \Delta U_{ibf} + W_{ibf} = \Delta U_{iaf} + W_{ibf}$$

$$Q_{ibf} = 300\text{ J} + 150\text{ J} = 450\text{ J}$$

So, the required ratio is

$$\frac{Q_{bf}}{Q_{ib}} = \frac{Q_{ibf} - Q_{ib}}{Q_{ib}} = \frac{450 - 150}{150} = 2$$

**11.** Increase in length is $\Delta l_1 = \frac{FL}{AY} = \frac{mgL}{\pi r^2 Y}$

On cooling, the decrease in length is $\Delta l_2 = L\alpha\Delta T$

To regain its original length, we must have $\Delta l_1 = \Delta l_2$

$$\Rightarrow \quad \frac{mgL}{\pi r^2 Y} = L\alpha\Delta T$$

$$\Rightarrow \quad m = \frac{r^2 Y\alpha\Delta T}{g}$$

Substituting the values, we get

$$m \approx 3\text{ kg}$$

**12.** $S = 2100\text{ Jkg}^{-1}\ {}^\circ\text{C}^{-1}$

$$L = 3.36 \times 10^5\text{ Jkg}^{-1}$$

$$420 = mc\Delta T + \left(1 \times 10^{-3}\right)L$$

$\Rightarrow \quad 420 = mc(5) + 3.36 \times 10^2$

$\Rightarrow \quad 420 - 336 = m(2100)(5)$

$\Rightarrow \quad m = \frac{1000}{125} = 8\text{ g}$

**13.** Given that, $\left(\lambda_m\right)_B = 3\left(\lambda_m\right)_A$

$\Rightarrow \quad T_A = 3T_B$

So, $E_1 = 4\pi(6)^2 \sigma T_A^4 = 4\pi(6)^2\left(3T_B\right)^4$

and $E_2 = 4\pi(18)^2 \sigma T_B^4$

$\Rightarrow \quad \frac{E_1}{E_2} = 9$

**14.** For adiabatic process,

$$TV^{\gamma-1} = \text{constant}$$

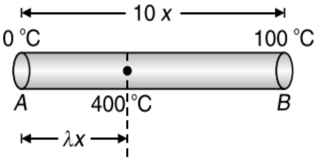
$\Rightarrow \quad T_2 = T_1\left(\frac{V_1}{V_2}\right)^{\gamma-1}$

$\Rightarrow \quad T_2 = T_1(32)^{\frac{7}{5}-1}$

$\Rightarrow \quad T_2 = 4T_1$

$\Rightarrow \quad a = 4$

**15.**



$$\frac{400 - 0}{\frac{\lambda x}{KA}} = \frac{dm_\ell}{dt} \times L_{\text{ice}}$$

Also, $\frac{400 - 100}{\frac{10x - \lambda x}{KA}} = \frac{dm_w}{dt} \times L_{steam}$

$\Rightarrow \quad \frac{400(10 - \lambda)}{\lambda \times 300} = \frac{L_{\text{ice}}}{L_{\text{Steam}}} = \frac{80}{540} = \frac{4}{27}$

$\Rightarrow \quad 9(10 - \lambda) = \lambda$

$\Rightarrow \quad 90 = 10\lambda$

$\Rightarrow \quad \lambda = 9$