Heat and Thermodynamics

Question1

If some heat is given to a metal of mass 100 g , its temperature rises by $20^\circ\mathrm{C}$. If the same heat is given to 20 g of water, the change in its temperature (in $^\circ\mathrm{C}$) is (The ratio of specific heat capacities of metal and water is $1:10$)

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Options:

A.

5

B.

10

C.

12

D.

15

Answer: B

Solution:

Given Values:

Let C_1 be the specific heat of the metal and C_2 be the specific heat of water.

The ratio of their specific heats is $\frac{C_1}{C_2} = \frac{1}{10}$, so $C_2 = 10C_1$.

A piece of metal with mass 100 g gets some heat and its temperature increases by 20°C.

The same amount of heat is then given to 20 g of water. We must find how much the temperature of water changes (ΔT).

Step 1: Find Heat Given to Metal

The heat required to change temperature is given by $\Delta Q = mC\Delta T$.

Here: $m = 100$ g, $C = C_1$, and $\Delta T = 20$.

So, $\Delta Q = 100C_1 \times 20$.

Step 2: Set Heat Given to Water Equal to Heat Given to Metal

For water: $m = 20$ g, $C = C_2$, and temperature change is ΔT.

So, $\Delta Q = 20 \times C_2 \times \Delta T$.

Since both heats (ΔQ) are the same:

$100C_1 \times 20 = 20 \times C_2 \times \Delta T$

Step 3: Substitute the Value of C_2

We know $C_2 = 10C_1$. Substitute this value:

$100C_1 \times 20 = 20 \times 10C_1 \times \Delta T$

Step 4: Simplify to Find ΔT

$2000C_1 = 200C_1 \times \Delta T$

Divide both sides by $200C_1$:

$$\Delta T = \frac{2000C_1}{200C_1} = 10^\circ\text{C}$$

So, the temperature of the water increases by 10°C.

Question2

The ratio of the efficiencies of two Carnot engines A and B is 1.25 and the temperature difference between the source and the sink is same in both the engines. The ratio of the absolute temperature of the sources of the engines A and B is

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Options:

A.

2 : 3

B.

2 : 5

C.

3 : 4

D.

4 : 5

Answer: D

Solution:

$$\begin{aligned} \eta_A &= 1 - \frac{T_2}{T_1} = \frac{T_1 - T_2}{T_1} = \frac{\Delta T}{T_1} \\ \eta_B &= 1 - \frac{T_2'}{T_1'} = \frac{T_1' - T_2'}{T_1'} = \frac{\Delta T}{T_1'} \end{aligned}$$

$$\therefore \quad \frac{\eta_A}{\eta_B} = \frac{\frac{\Delta T}{T_1}}{\frac{\Delta T}{T_1'}} \Rightarrow 1.25 = \frac{T_1'}{T_1}$$

$$\Rightarrow \quad \frac{T_1'}{T_1} = 1.25 = \frac{125}{100}$$

$$\frac{T_1'}{T_1} = \frac{5}{4} \Rightarrow \frac{T_1}{T_1'} = \frac{4}{5}$$

Question3

The heat supplied to a gas at a constant pressure of 5×10^5 Pa is 1000 kJ . If the volume of gas changes from 1 m^3 to 2.5 m^3, then the change in internal energy of the gas is

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Options:

A.

250 kJ

B.

225 kJ

C.

200 kJ

D.

175 kJ

Answer: A

Solution:

Work done,

$$W = P\Delta V = P(V_2 - V_1)$$
$$= 5 \times 10^5(2.5 - 1) = 7.5 \times 10^5 \text{ J}$$

According to first law of thermodynamics

$$\Delta U = Q - W = 1000 \times 10^3 - 7.5 \times 10^5$$
$$= 2.5 \times 10^5 = 250 \times 10^3 \text{ J} = 250 \text{ kJ}$$

Question4

When an ideal diatomic gas undergoes adiabatic expansion, if the increase in its volume is 0.5%, then the change in the pressure of the gas is

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Options:

A.

$+0.5\%$

B.

-0.5%

C.

-0.7%

D.

$+0.7\%$

Answer: C

Solution:

For adiabatic process

$$pV^{\gamma} = \text{ constant}$$

$$\Rightarrow \ln p + \gamma \ln(V) = \text{ constant}$$

$$\Rightarrow \quad \frac{dp}{p} + \gamma \frac{dV}{V} = 0 \Rightarrow \frac{dp}{p} = -\gamma \frac{dV}{V}$$

$$\Rightarrow \quad \frac{\Delta p}{p} = -\gamma \frac{\Delta V}{V}$$

$$= -1.4 \times 0.005 = -0.007$$

$$\therefore \frac{\Delta p}{P} \times 100\% = -0.007 \times 100\% = -0.7\%$$

Question5

To increase the rms speed of gas molecules by 25%, the percentage increase in absolute temperature of the gas is to be

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Options:

A.

42.75

B.

56.25

C.

36.75

D.

18.25

Answer: B

Solution:

$$V_{\text{rms}} = \sqrt{\frac{3RT}{M}}$$
$$\Rightarrow \quad V_{\text{rms}} \propto \sqrt{T}$$
$$\Rightarrow \quad \frac{(V_{\text{rms}})_2}{(V_{\text{rms}})_1} = \sqrt{\frac{T_2}{T_1}} \qquad \ldots(i)$$

$$Since, (V_{\text{rms}})_2 = (V_{\text{rms}})_1 + 25\% \text{ of } (V_{\text{rms}})_1$$
$$= (V_{\text{rms}})_1 + \frac{1}{4}(V_{\text{rms}})_1$$
$$= \frac{5}{4}(V_{\text{rms}})_1$$

$\therefore$ From equation (i), we get

$$\frac{\frac{5}{4}(V_{\text{rms}})_1}{(V_{\text{rms}})_1} = \sqrt{\frac{T_2}{T_1}} \Rightarrow \frac{T_2}{T_1} = \frac{25}{16}$$
$$\therefore \quad \frac{T_2 - T_1}{T_1} \times 100\% = \left(\frac{T_2}{T_1} - 1\right) \times 100\%$$
$$= \left(\frac{25}{16} - 1\right) \times 100\%$$
$$= \frac{9}{16} \times 100\% = 56.25\%$$

Question6

If a body cools from a temperature of 62°C to 50°C in 10 minutes and to 42°C in the next 10 minutes, then the temperature of the surroundings is

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Options:

A.

12°C

B.

$26^\circ C$

C.

$36^\circ C$

D.

$21^\circ C$

Answer: B

Solution:

Newton's Law of Cooling:

Newton's law of cooling says that the rate at which something cools down depends on the difference between its temperature and the temperature of its surroundings.

The formula for Newton's law of cooling is:

$\frac{T_1 - T_2}{t} = K\left(\frac{T_1 + T_2}{2} - T_0\right)$

Step 1: Use the formula for the first 10 minutes

The body cools from $62^\circ C$ to $50^\circ C$ in 10 minutes.

- Here, $T_1 = 62$, $T_2 = 50$, and $t = 10$.
- Plug these into the formula:

$\frac{62-50}{10} = K\left(\frac{62+50}{2} - T_0\right)$

This simplifies to:

$1.2 = K(56 - T_0) \quad \ldots(i)$

where 56 comes from $(62 + 50)/2$.

Step 2: Use the formula for the next 10 minutes

The body cools from $50^\circ C$ to $42^\circ C$ in the next 10 minutes.

- Now, $T_1 = 50$, $T_2 = 42$, and $t = 10$.
- Plug these values in:

$\frac{50-42}{10} = K\left(\frac{50+42}{2} - T_0\right)$

This simplifies to:

$0.8 = K(46 - T_0) \quad \ldots(ii)$

where 46 comes from $(50 + 42)/2$.

Step 3: Set up a ratio to find T_0

Divide equation (i) by equation (ii) (the K cancels out):

$\frac{1.2}{0.8} = \frac{K(56-T_0)}{K(46-T_0)}$

So,

$\frac{1.2}{0.8} = \frac{56-T_0}{46-T_0}$

Step 4: Solve for T_0

$\frac{1.2}{0.8} = 1.5$

Set up the equation:

$1.5 = \frac{56-T_0}{46-T_0}$

Multiply both sides by $(46 - T_0)$:

$1.5(46 - T_0) = 56 - T_0$

$69 - 1.5T_0 = 56 - T_0$

$69 - 56 = 1.5T_0 - T_0$

$13 = 0.5T_0$

$T_0 = 26^\circ\text{C}$

Final Answer:

The temperature of the surroundings is 26°C.

Question7

If the ratio of universal gas constant and specific heat capacity at constant volume of a gas is given by 0.67 , then the gas is

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Options:

A.

monoatomic

B.

diatomic

C.

polyatomic

D.

a mixture of diatomic and polyatomic gases

Answer: A

Solution:

The formula for specific heat at constant volume is $C_V = \frac{f}{2}R$, where f is the number of degrees of freedom and R is the universal gas constant.

For a monoatomic gas, $f = 3$.

So, $C_V = \frac{3}{2}R$.

This means $\frac{R}{C_V} = \frac{R}{\frac{3}{2}R} = \frac{2}{3} = 0.67$.

Therefore, the gas is monoatomic because it matches the given ratio of 0.67.

Question8

The internal energy of 4 moles of a monoatomic gas at a temperature of $77^{\circ}\mathrm{C}$ is

($R =$ Universal gas constant)

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Options:

A.

$1500R$

B.

$1800R$

C.

$2100R$

D.

$3500R$

Answer: C

Solution:

Internal energy,

$U=\frac{f}{2} nRT$

For monoatomic gas, $f=3$

$$\begin{aligned} U & =\frac{3}{2} nRT=\frac{3}{2} \times 4 \times R \times(273+77) \\ & =6R \times 350=2100R \end{aligned}$$

Question9

If 5.6 litres of a monoatomic gas at STP is adiabatically compressed to 0.7 litres, then the work done on the gas is nearly ($R=$ Universal gas constant)

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Options:

A.

$307R$

B.

$357R$

C.

$367R$

D.

$407R$

Answer: A

Solution:

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

For adiabatic process,

$$\begin{aligned} & T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1} \\ \Rightarrow \quad & T_2 = T_1 \left(\frac{V_1}{V_2}\right)^{\gamma-1} = T_1 \left(\frac{5.6}{0.7}\right)^{\frac{5}{3}-1} \\ & = 4T_1 \end{aligned}$$

$$\begin{aligned} \therefore \quad W &= \frac{nR(T_2 - T_1)}{\gamma - 1} \\ &= \frac{0.25R(4T_1 - T_1)}{\frac{5}{2} - 1} \end{aligned}$$

$$\left[\because n = \frac{5.6}{22.4} = 0.25 \text{ mol}\right]$$

$$\begin{aligned} &= 0.25R \times \frac{3}{2} \times 3T_1 \\ &= 4.5 \times 0.25R \times 273 \\ &\simeq 307.29R \\ &\simeq 307R \end{aligned}$$

Question10

If the rms speed of the molecules of a diatomic gas at a temperature of 322 K is 2000 ms^{-1}, then the gas is (Universal gas constant $= 8.31 \text{Jmol}^{-1} \text{ K}^{-1}$)

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Options:

A.

hydrogen

B.

nitrogen

C.

oxygen

D.

chlorine

Answer: A

Solution:

$$\begin{aligned} v_{\text{rms}} &= \sqrt{\frac{3RT}{M}} \\ \Rightarrow \quad 2000 &= \sqrt{\frac{3 \times 8.31 \times 322}{M}} \end{aligned}$$

$$\begin{aligned} \Rightarrow \quad 4000000 &= \frac{8027.5}{M} \\ \Rightarrow \quad M &= \frac{8027.5}{4000000} \end{aligned}$$

$$\begin{aligned} &= 0.002007 \text{ kg/mole} \\ &= 2.007 \text{ g/mole} \approx 2 \text{ g/mole} \end{aligned}$$

Therefore, gas is hydrogen.

Question11

The temperature of water of mass 100 g is rasied from $24^{\circ}\mathrm{C}$ to $90^{\circ}\mathrm{C}$ by adding steam to it. The mass of the steam added is(Latent heat of steam $= 540 \mathrm{cal g}^{-1}$ and specific heat capacity of water $= 1 \mathrm{cal g}^{-1}{}^{\circ}\mathrm{C}^{-1}$)

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Options:

A.

10 g

B.

12 g

C.

8 g

D.

16 g

Answer: B

Solution:

Let $m=$ mass of steam condensed. Then, m grams of steam forms m grams of water at $100^{\circ}\mathrm{C}$ which further losses heat and comes at $90^{\circ}\mathrm{C}$.

Final mixture is water at $90^{\circ}\mathrm{C}$

Now using Heat lost = Heat gained, we gel

Heat lost by steam in condensation + Heat lost by water formed at $100^{\circ}\mathrm{C}$

$=$ Heat gained by water at $24^{\circ}\mathrm{C}$

$$\begin{aligned}
&\Rightarrow mL+mc(100-90)=100(c)(90-24)\\
&\Rightarrow m(540+1\times 10)=100\times 1\times 66\\
&\Rightarrow m=\frac{100\times 66}{550}=\frac{10\times 6}{5}=12\ \mathrm{g}
\end{aligned}$$

Question12

When 80 J of heat is supplied to a gas at constant pressure, if the work done by the gas is 20 J , then the ratio of the specific heat capacities of the gas is

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Options:

A.

$\frac{4}{3}$

B.

$\frac{5}{3}$

C.

$\frac{7}{5}$

D.

$\frac{9}{7}$

Answer: A

Solution:

Heat supplied at constant pressure is used to do work and to raise temperature of the gas.

$$\begin{aligned} \therefore \quad & \Delta Q = \Delta W + \Delta U \\ \Rightarrow \quad & 80 = 20 + \Delta U \\ \Rightarrow \quad & \Delta U = 60 \text{ J} \end{aligned}$$

Now, $\Delta Q = nC_p \Delta T$

and $\Delta U = nC_V \Delta T$

$\therefore$ Ratio $\frac{C_p}{C_V} = \frac{\Delta Q}{\Delta U} = \frac{80}{60} = \frac{4}{3}$

Question13

A refrigerator of coefficient of performance 5 that extracts heat from the cooling compartment at the rate of 250 J per cycle is placed in a room. The heat released per cycle to the room by the refrigerator is

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Options:

A.

250 J

B.

50 J

C.

200 J

D.

300 J

Answer: D

Solution:

Step 1: Understand the COP formula

The coefficient of performance (COP) for a refrigerator shows how well it works. The formula is:

$\text{COP} = \frac{Q_H}{Q_H - Q_C}$

Step 2: Identify what the symbols mean

Q_H stands for the heat given to the room (hot side). This is the heat released.

Q_C is the heat taken from inside the fridge (cold side). This is the heat extracted, which is 250 J per cycle here.

Step 3: Set up the equation with the given numbers

We are told the COP is 5 and Q_C is 250 J. So, we use:

$5 = \frac{Q_H}{Q_H - 250}$

Step 4: Solve for Q_H

Multiply both sides by $(Q_H - 250)$:

$5(Q_H - 250) = Q_H$

Expand:

$5Q_H - 1250 = Q_H$

Bring Q_H to one side:

$5Q_H - Q_H = 1250$

$4Q_H = 1250$

Divide both sides by 4:

$Q_H = \frac{1250}{4}$

$Q_H = 312.5$ J

Step 5: Answer

The refrigerator releases about 312.5 J of heat to the room per cycle.

Question14

In a container of volume $16.62\ \text{m}^3$ at 0°C temperature, 2 moles of oxygen 5 moles of nitrogen and 3 moles of hydrogen are present,

then the pressure in the container is

(Universal gas constant $= 8.31 \mathrm{~J} \mathrm{~mol}^{-1} \mathrm{~K}^{-1}$ **)**

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Options:

A.

1570 Pa

B.

1270 Pa

C.

1365 Pa

D.

2270 Pa

Answer: C

Solution:

Using $pV = nRT$

we get, $p = \frac{nRT}{V} \quad \ldots (i)$

Here, $n = n_1 + n_2 + n_3$

$= 2 + 5 + 3 = 10$

$V = 16.62 \mathrm{~m}^3, T = 0^{\circ}\mathrm{C} = 273 \mathrm{~K}$

Substituting in (i) we get,

$$p = \frac{10 \times 8.31 \times 273}{16.62}$$
$$= 1365 \mathrm{~Pa}$$

Question15

A small quantity of water of mass ' m ' at temperature $\theta°C$ is mixed with a large mass ' M ' of ice which is at its melting point. If ' s ' is specific heat capacity of water and ' L ' is the latent heat of fusion of ice, then the mass of ice melted is

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Options:

A.

$\frac{ML}{ms\theta}$

B.

$\frac{ms\theta}{ML}$

C.

$\frac{Ms\theta}{L}$

D.

$\frac{ms\theta}{L}$

Answer: D

Solution:

Given:

- Mass of water = m
- Temperature of water = $\theta°C$
- Mass of ice = M
- Ice is at its melting point ($0°C$)
- s = specific heat capacity of water
- L = latent heat of fusion of ice.

Concept:

When water (at temperature θ) is mixed with ice (at $0°$), heat will flow from the warmer water to the ice.

- The **water cools down** from θ to $0°C$.
- The **ice melts**, using that heat.

No heat is lost to surroundings.

Step 1: Heat lost by water cooling to $0°C$

$$Q_{\text{lost}} = ms\theta$$

Step 2: Heat gained by ice (for melting)

If x is the **mass of ice melted**, then:

$$Q_{\text{gained}} = xL$$

Step 3: Equating heat lost and gained

$$ms\theta = xL$$

Step 4: Solve for x

$$x = \frac{ms\theta}{L}$$

Step 5: Check if M (the large mass of ice) matters

Since M is very large, its temperature doesn't rise; it only partly melts.

Hence M appears only to indicate that the ice remains at 0°C.

✅ **Final Answer:**

$$\boxed{x = \frac{ms\theta}{L}}$$

Correct Option: D

Question16

In a Carnot engine, if the absolute temperature of the source is 25% more than the absolute temperature of the sink, then the efficiency of the engine is

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Options:

A.

25%

B.

50%

C.

20%

D.

40%

Answer: C

Solution:

The efficiency formula for a Carnot engine is:

$\eta = 1 - \frac{T_2}{T_1}$

Here, T_1 is the absolute temperature of the source, and T_2 is the absolute temperature of the sink.

The problem says the source is 25% hotter than the sink. That means:

$T_1 = T_2 + 0.25 \times T_2 = 1.25T_2$

Now, plug $T_1 = 1.25T_2$ into the efficiency formula:

$\eta = 1 - \frac{T_2}{1.25T_2}$

$\eta = 1 - \frac{1}{1.25}$

$\frac{1}{1.25} = \frac{4}{5}$

So,

$\eta = 1 - \frac{4}{5}$

$\eta = \frac{1}{5}$

To change this to a percentage, multiply by 100%:

$\eta = \frac{1}{5} \times 100\% = 20\%$

So, the engine's efficiency is 20%.

Question17

The work done by 6 moles of helium gas when its temperature increases by $20^{\circ}\mathrm{C}$ at constant pressure is (Universal gas constant $= 8.31 \mathrm{Jmol}^{-1} \mathrm{~K}^{-1}$)

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Options:

A.

807.2 J

B.

887.2 J

C.

997.2 J

D.

1007.2 J

Answer: C

Solution:

Step 1: Use the ideal gas law

We know that $pV = nRT$ describes how pressure, volume, and temperature are related for an ideal gas.

Step 2: Set up the formula for work at constant pressure

When pressure is constant, the work (W) done by the gas is:

$W = p\Delta V$

From the ideal gas law, we can find that:

$p\Delta V = nR\Delta T$

This means the work done is:

$W = nR\Delta T$

Step 3: Insert the given values

Number of moles, $n = 6$

Change in temperature, $\Delta T = 20^{\circ}\mathrm{C}$. (This is the same as 20 K for a temperature difference.)

Gas constant, $R = 8.31 \mathrm{~J} \mathrm{~mol}^{-1} \mathrm{~K}^{-1}$

Step 4: Calculate the work

$W = 6 \times 8.31 \times 20$

$W = 997.2 \mathrm{~J}$

Question18

If a heat engine and a refrigerator are working between the same two temperatures T_1 and T_2 $(T_1 > T_2)$, then the ratio of efficiency of heat engine to coefficient of performance of refrigerator is

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Options:

A.

$\frac{(T_1-T_2)}{T_1 T_2}$

B.

$\frac{(T_1+T_2)}{T_1 T_2}$

C.

$\frac{(T_1-T_2)^2}{T_1 T_2}$

D.

$\frac{(T_1+T_2)^2}{T_1 T_2}$

Answer: C

Solution:

Efficiency of heat engine,

$\eta = 1 - \frac{T_2}{T_1} \Rightarrow \eta = \frac{T_1 - T_2}{T_1}$

Coefficient of performance of refrigerator,

$$\beta=\frac{T_2}{T_1-T_2}$$

$$\therefore \quad \frac{\eta}{\beta}=\frac{\frac{T_1-T_2}{T_1}}{\frac{T_2}{T_1-T_2}}=\frac{(T_1-T_2)^2}{T_1 T_2}$$

Question19

If the internal energy of 3 moles of a gas at a temperature of $27^{\circ} \mathrm{C}$ is 2250 R , then the number of degrees of freedom of the gas is

($R=$ Universal gas constant)

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Options:

A.

3

B.

5

C.

4

D.

6

Answer: B

Solution:

We are told:

$U=2250 R$

for

$n = 3\,\text{moles}$ and $T = 27^\circ\text{C} = 300\,\text{K}$.

We are asked to find the **number of degrees of freedom** f of the gas.

Formula

For an ideal gas, the internal energy is given by:

$U = \frac{f}{2} nRT$

Substitute known values

$2250R = \frac{f}{2}(3)R(300)$

Cancel R from both sides:

$2250 = \frac{f}{2} \times 3 \times 300$

Simplify

$2250 = \frac{f}{2} \times 900$

$2250 = 450f$

$f = \frac{2250}{450} = 5$

✅ **Answer:** $f = 5$

That corresponds to **Option B**.

Interpretation: The gas has 5 degrees of freedom — likely a **diatomic gas** (3 translational + 2 rotational).

Question20

Steam at 100°C is passed into 114 g of water at 30^o The mass of water present in the mixture when the temperature of the water becomes 70°C is(Latent heat of steam $= 540\text{calg}^{-1}$, Specific heat capacity of water $= 1\text{calg}^{-1\circ}\text{C}^{-1}$)

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Options:

A.

122 g

B.

132 g

C.

142 g

D.

152 g

Answer: A

Solution:

According to the principle of calorimetry,

$$\begin{aligned}
& Q_{\text{gained}} = Q_{\text{lost}} \\
& \Rightarrow m_{\text{water}} \times C_{\text{water}} \times \Delta T = m_{\text{steam}} \times L_{\text{steam}} + m_{\text{steam}} \times C_{\text{water}} \times \Delta T \\
& \Rightarrow 114 \times 1 \times (70-30) = m_{\text{steam}} \times 540 + m_{\text{steam}} \times 1 \times 30 \\
& \Rightarrow m_{\text{steam}} = 8 \text{ g} \\
& \therefore \text{ Total mass of water } = m_{\text{water}} + m_{\text{steam}} \\
& = 114 + 8 = 122 \text{ g}
\end{aligned}$$

Question21

In a Carnot engine if the work done during isothermal expansion is 25% more than the work done during isothermal compression, then the efficiency of the engine is

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Options:

A.

10%

B.

15%

C.

20%

D.

25%

Answer: C

Solution:

If W_1 and W_2 represents work done during isothermal compression and isothermal expansion.

Then, $\quad W_2 = W_1 + 25\%$ of W_1

$$= W_1 + \frac{25}{100} W_1 = \frac{5W_1}{4}$$

$$\therefore \quad Q_2 = \frac{5Q_1}{4}$$

$$Thus, \eta = 1 - \frac{W_1}{W_2} = 1 - \frac{Q_1}{Q_2} = 1 - \frac{Q_1}{\frac{5Q_1}{4}}$$

$$= 1 - \frac{4}{5} = \frac{1}{5} = 0.20 \text{ or } 20\%$$

Question22

The work done to increase the volume of 2 moles of an ideal gas from V to 2 V at a constant temperature T is W . The work to be done to increase the volume of 2 moles of the same gas from 2 V to 4 V at the same constant temperature T is

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Options:

A.

0.5 W

B.

W

C.

2 W

D.

4 W

Answer: B

Solution:

Formula for Work in Isothermal Process

The work done when a gas changes its volume at constant temperature (isothermal process) is given by:

$W = nRT\ln\left(\frac{V_2}{V_1}\right)$

First Case: From V to $2V$

We have $n = 2$, $V_1 = V$, and $V_2 = 2V$.

So, the work done is:

$W = 2RT\ln\left(\frac{2V}{V}\right) = 2RT\ln(2) \quad \ldots(i)$

Second Case: From $2V$ to $4V$

Now, $n = 2$, $V_1 = 2V$, and $V_2 = 4V$.

So, the work done here is:

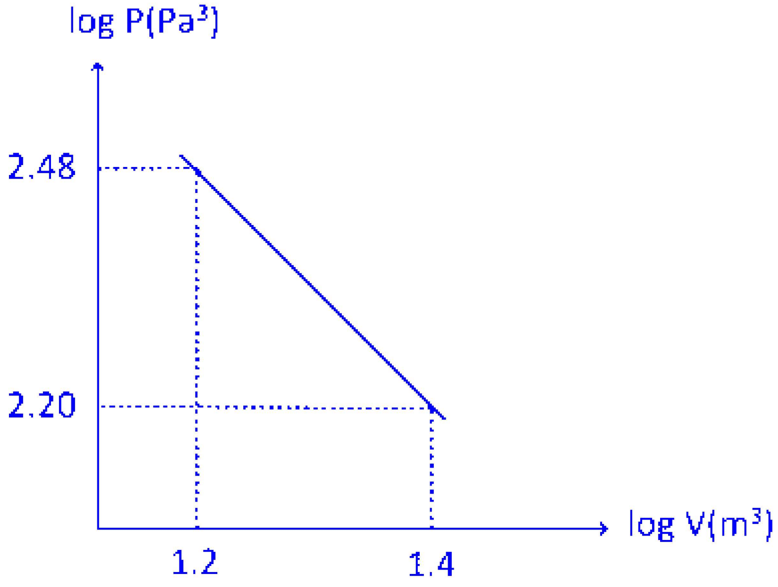
$W' = 2RT\ln\left(\frac{4V}{2V}\right)$

$= 2RT\ln(2) = W$

The work done in increasing the volume from $2V$ to $4V$ is the same as the work done from V to $2V$, both are W.

Question23

If the given graph shows the logarithmic values of pressure (p) and volume (V) of an ideal gas, then the ratio of the specific heat capacities of the gas is



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Options:

A.

1.5

B.

1.4

C.

1.2

D.

1.3

Answer: B

Solution:

Step 1: Write the adiabatic equation

An adiabatic process for an ideal gas can be written as:

$pV^{\gamma} = \text{constant}$

Step 2: Take logarithms on both sides

If we take the logarithm of both sides, we get:

$\log(p) + \gamma \log(V) = \text{constant}$

This can be rearranged as:

$\log(p) = -\gamma \log(V) + \text{constant}$

Step 3: Compare to the standard line equation

This equation looks like the equation of a straight line:

$y = mx + c$

Here, $y = \log(p)$, $x = \log(V)$, and the slope $m = -\gamma$.

Step 4: Find the slope from the graph

The slope of the line is:

$m = \frac{\Delta \log p}{\Delta \log V}$

From the graph, pick two points and subtract their values:

$= \frac{2.20-2.48}{1.4-1.2} = \frac{-0.28}{0.2} = -1.4$

Step 5: Interpret the value of γ

The slope $m = -\gamma = -1.4$, so:

$\gamma = 1.4$

Step 6: Final answer

The ratio of the specific heat capacities of the gas is 1.4.

Question24

The internal energy of one mole of a rigid diatomic gas at absolute temperature T is

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Options:

A.

$3RT$

B.

$\frac{3}{2}RT$

C.

$\frac{5}{2}RT$

D.

$\frac{1}{2}RT$

Answer: C

Solution:

$U=\frac{f}{2}nRT$

For one mole gas, $n=1$

For rigid diatomic gas, $f=5$

$\therefore \quad U=\frac{5}{2}RT$

Question25

If the wavelengths of maximum intensity of radiation emitted by two black bodies A and B are $0.5\mu\ \mathrm{m}$ and 0.1 mm respectively, then ratio of the temperatures of the bodies A and B is

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Options:

A.

5

B.

25

C.

100

D.

200

Answer: D

Solution:

According to Wien's displacement law.

$$\lambda_m \cdot T = b$$

$$\Rightarrow \lambda_m \propto \frac{1}{T} \Rightarrow \frac{(\lambda_m)_A}{(\lambda_m)_B} = \frac{T_B}{T_A}$$

$$\Rightarrow \frac{0.5 \times 10^{-6}}{0.1 \times 10^{-3}} = \frac{T_B}{T_A}$$

$$\Rightarrow \frac{5 \times 10^{-3}}{1} = \frac{T_B}{T_A}$$

$$\Rightarrow \frac{T_A}{T_B} = \frac{1}{5 \times 10^{-3}} = \frac{10^3}{5} = \frac{1000}{5} = 200$$

Question26

Water of mass 5 kg in a closed vessel is at a temperature of $20^\circ\mathrm{C}$. If the temperature of the water when heated for a time of 10 minutes becomes $30^\circ\mathrm{C}$, then the increase in the internal energy of the water is (Specific heat capacity of water $= 4200\ \mathrm{J\ kg^{-1}\ K^{-1}}$)

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Options:

A.

100 kJ

B.

420 kJ

C.

510 kJ

D.

210 kJ

Answer: D

Solution:

Increase in internal energy,

$$\begin{aligned} \Delta U &= ms\Delta T \\ &= 5 \times 4200(30-20) \\ &= 210000 \text{ J} \\ &= 210 \times 10^3 \text{ J} = 210 \text{ kJ} \end{aligned}$$

Question27

A Carnot engine A working between temperatures 600 K and $T(< 600 \text{ K})$ and another Carnot engine B working between temperatures $T(> 400 \text{ K})$ and 400 K are connected in series. If the work done by both the engines is same, then $T =$

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Options:

A.

550 K

B.

500 K

C.

575 K

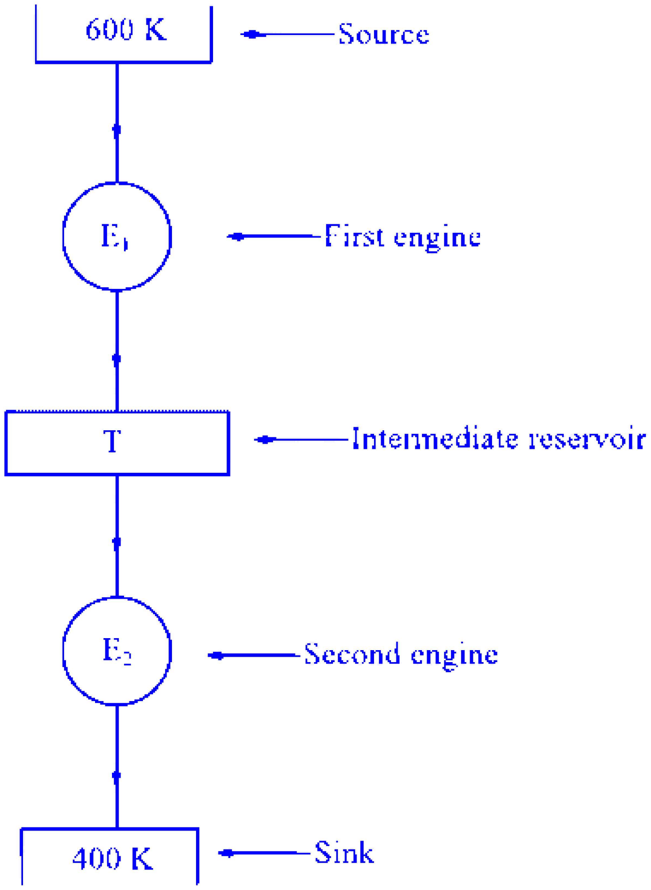
D.

525 K

Answer: B

Solution:

Work done by Carnot engine
$W = (Q_1 - Q_2) \propto (T_1 - T_2)$



Now for engine A

$W_1 = (Q_1 - Q_2) \propto (600 - T)$

and for engine B

$W_2 = (Q_1 - Q_2) \propto (T - 400)$

When work done by both engine is same than

$600 - T = T - 400$
$2T = 1000 \Rightarrow T = 500$ K

Question28

When an ideal diatomic gas is heated at constant pressure, the fraction of the heat utilised to increase the internal energy of the gas

is

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Options:

A.

$\frac{2}{5}$

B.

$\frac{3}{5}$

C.

$\frac{3}{7}$

D.

$\frac{5}{7}$

Answer: D

Solution:

At constant pressure, the heat supplied goes into both increasing the internal energy and doing work.

For diatomic gas, $C_p = \frac{7}{2}R$ and $C_V = \frac{5}{2}R$

$\frac{(\Delta U)_V}{(\Delta U)_p} = \frac{{}^nC_V \Delta T}{{}^nC_p \Delta T} = \frac{C_V}{C_p} = \frac{\frac{5}{2}}{\frac{7}{2}} = \frac{5}{7}$

Question29

If the degrees of freedom of a gas molecule is 6 , then the total internal energy of the gas molecule at a temperature of $47^{\circ}\mathrm{C}$ (in eV) is

(Boltzmann constant $= 1.38 \times 10^{-23} \mathrm{JK}^{-1}$)

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Options:

A.

414×10^{-4}

B.

828×10^{-4}

C.

927×10^{-4}

D.

572×10^{-4}

Answer: B

Solution:

Energy per molecule,

$$E = \frac{f}{2} kT = \frac{6}{2} \times 1.38 \times 10^{-23} \times (273 + 47)$$
$$= 3 \times 1.38 \times 10^{-23} \times 320$$
$$= 13.28 \times 10^{-21} \text{ J}$$
$$= \frac{13.28 \times 10^{-21}}{1.6 \times 10^{-19}} \text{eV}$$
$$= 830.6 \times 10^{-4} \text{eV} \approx 828 \times 10^{-4} \text{eV}$$

Question30

If the values of the temperature of a body in Fahrenheit and Celsius scales are in the ratio of $13 : 5$, then the temperature of the body is

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Options:

A.

$80^{\circ}\mathrm{F}$

B.

$104^{\circ}\mathrm{C}$

C.

$40^{\circ}\mathrm{C}$

D.

$40^{\circ}\mathrm{F}$

Answer: C

Solution:

$F : C = 13 : 5$

$\Rightarrow \quad \frac{F}{C} = \frac{13}{5} \Rightarrow F = \frac{13}{5}C$

We know that,

$$\frac{C}{5} = \frac{F-32}{9}$$
$$\Rightarrow \frac{C}{5} = \frac{\frac{13}{5}C - 32}{9}$$
$$\Rightarrow \frac{9C}{5} = \frac{13C}{5} - 32$$
$$\Rightarrow \frac{13C}{5} - \frac{9C}{5} = 32$$
$$\Rightarrow \frac{4C}{5} = 32 \Rightarrow C = 40^{\circ}\mathrm{C}$$

Question31

A Carnot heat engine absorbs 600 J of heat from a source at a temperature of $127^{\circ}\mathrm{C}$ and rejects 400 J of heat to a sink in each cycle. The temperature of the sink is

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Options:

A.

266.7 K

B.

166.7 K

C.

133.3 K

D.

333.3 K

Answer: A

Solution:

Efficiency of Carnot engine,

$$\eta = 1 - \frac{Q_2}{Q_1} = 1 - \frac{400}{600} = \frac{1}{3}$$

$$\text{but } \eta = 1 - \frac{T_2}{T_1}$$

$$\Rightarrow \quad \frac{1}{3} = 1 - \frac{T_2}{(273 + 127)}$$

$$\Rightarrow \quad \frac{1}{3} = 1 - \frac{T_2}{400}$$

$$\Rightarrow \frac{T_2}{400} = 1 - \frac{1}{3} = \frac{2}{3}$$

$$\therefore \quad T_2 = \frac{2}{3} \times 400 = 266.7 \text{ K}$$

Question32

During adiabatic expansion, if the temperature of 3 moles of a diatomic gas decreases by $50^{\circ}\mathrm{C}$, then the work done by the gas is

($R =$ Universal gas constant)

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Options:

A.

$375R$

B.

$1500R$

C.

$750R$

D.

$825R$

Answer: A

Solution:

We know that in adiabatic expansion, there is no heat exchange. So, $\Delta Q = 0$.

From the first law of thermodynamics:

$\Delta Q = \Delta U + W$Since $\Delta Q = 0$, this means:$0 = \Delta U + W$So,$W = -\Delta U$

The change in internal energy for n moles of a diatomic gas is:$\Delta U = nC_V\Delta T$where C_V for a diatomic gas is $\frac{5}{2}R$.

Here, $n = 3$ moles and the temperature change $\Delta T = -50^{\circ}\mathrm{C}$ (or -50 in Kelvin, since the size of the degree is the same).

So,$W = -\Delta U = -nC_V\Delta T = -3 \times \frac{5}{2}R \times (-50)$

Multiplying out:$-3 \times \frac{5}{2}R \times (-50) = 7.5R \times 50 = 375R$

The work done by the gas is $375R$.

Question33

The fundamental limitation to the coefficient of performance of a refrigerator is given by

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Options:

A.

First law of thermodynamics

B.

Newton's law of cooling

C.

Zeroth law of thermodynamics

D.

Second law of thermodynamics

Answer: D

Solution:

The fundamental limitation to the coefficient of performance of a refrigerator is given by second law of thermodynamics.

Question34

If the ratio of specific heats of a gas at constant pressure and at constant volume is γ, then the number of degrees of freedom of the rigid molecules of the gas is

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Options:

A.

$\frac{3\gamma-1}{2\gamma-1}$

B.

$\frac{2}{\gamma-1}$

C.

$\frac{9}{2}(\gamma-1)$

D.

$\frac{25}{2}(\gamma-1)$

Answer: B

Solution:

As we know that,

$$\gamma=1+\frac{2}{f}$$

$$\Rightarrow \quad \frac{2}{f}=\gamma-1 \Rightarrow f=\frac{2}{\gamma-1}$$

Question35

If a gas of volume 400 cc at an initial pressure p is suddenly compressed to 100 cc , then its final pressure is

(The ratio of the specific heat capacities of the gas at constant pressure and constant volume is 1.5)

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Options:

A.

$\frac{p}{32}$

B.

$8p$

C.

$32p$

D.

$16p$

Answer: B

Solution:

Given:

- Initial volume $V_1 = 400$ cc
- Final volume $V_2 = 100$ cc
- Initial pressure $P_1 = p$
- The process is **sudden (adiabatic)**

Thus, for an adiabatic process:

$P_1 V_1^{\gamma} = P_2 V_2^{\gamma}$

Given:

$\gamma = 1.5$

Step 1: Write the equation for P_2

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

Step 2: Substitute the values

$P_2 = p\left(\frac{400}{100}\right)^{1.5} = p(4)^{1.5}$

Step 3: Simplify

$(4)^{1.5} = 4^1 \times 4^{0.5} = 4 \times 2 = 8$

$P_2 = 8p$

✅ **Final Answer:**

$\boxed{P_2 = 8p}$

Correct Option: (B) $8p$

Question36

> **A Carnot engine having efficiency 60% receives heat from a source at a temperature 600 K . For the same sink temperature, to increase its efficiency to 80%, then the temperature of the source is**

Options:

A.

300 K

B.

900 K

C.

1200 K

D.

720 K

Answer: C

Solution:

Efficiency of Carnot's engine is

$$\eta_1 = 1 - \frac{T_2}{T_1}$$

$$0.6 = 1 - \frac{T_2}{600}$$

$$\Rightarrow \quad T_2 = 240 \text{ K}$$

Again, $\eta_2 = 80\% = 0.8$

$$\therefore \quad \eta_2 = 1 - \frac{T_2'}{T_1'}$$

$$0.8 = 1 - \frac{240}{T_1'} \quad [\because T_2' = T_2 = 240 \text{ K}]$$

$$\Rightarrow T_1' = 1200 \text{ K}$$

Question37

A gaseous mixture consists of 2 moles of oxygen and 4 moles of argon at an absolute temperature T. Neglecting all vibrational modes, the total internal energy of the mixture of the gases is

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Options:

A.

$4RT$

B.

$15RT$

C.

$9RT$

D.

$11RT$

Answer: D

Solution:

Total internal energy of mixture of the gases $=$ Total internal energy of $O_2 +$ Total internal energy of Ar

$$= 2 \times \frac{5}{2} RT + 4 \times \frac{3}{2} RT$$
$$= 11RT$$

Question38

The average translational kinetic energy of the oxygen molecules at a temperature of $127^\circ C$ is

(Boltzmann constant $= 1.38 \times 10^{-23} JK^{-1}$)

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Options:

A.

4.07×10^{-21} J

B.

2.07×10^{-21} J

C.

8.28×10^{-21} J

D.

8.00×10^{-21} J

Answer: C

Solution:

Given:

- Temperature $T = 127°\text{C}$
- Boltzmann constant $k = 1.38 \times 10^{-23}$ J/K

We know that:

Average translational kinetic energy per molecule $= \frac{3}{2}kT$

Step 1: Convert temperature to kelvins

$T = 127 + 273 = 400\,\text{K}$

Step 2: Substitute the values

$E = \frac{3}{2}kT = \frac{3}{2}(1.38 \times 10^{-23})(400)$

Step 3: Simplify

$E = 1.5 \times 1.38 \times 400 \times 10^{-23}$

$E = 2.07 \times 400 \times 10^{-23}$

$E = 8.28 \times 10^{-21}$ J

✅ **Final Answer:**

$\boxed{8.28 \times 10^{-21}\text{ J}}$

Correct Option: C

Question39

An electric kettle takes 4 A current at 220 V . If the entire electric energy is converted into heat energy, then the time (in minutes) taken to increase the temperature of 1 kg of water from $34^{\circ}\mathrm{C}$ to $100^{\circ}\mathrm{C}$ is

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Options:

A.

7.50

B.

4.50

C.

5.25

D.

6.25

Answer: C

Solution:

Power consumed, $P=VI=220\times 4$

$=880$ W

Heat energy required

$$\begin{aligned} H &= ms\Delta T \\ &= 1000\times 1\times(100-34)\times 4.2 \\ &= 2.772\times 10^{5}\ \mathrm{J} \end{aligned}$$

$\therefore$ Time taken $= \frac{H}{P} = \frac{2.772 \times 10^5}{880}$

$= 315$ s

$= \frac{315}{60}$ minutes

$= 5.25$ minutes

Question40

According to Zeroth law of thermodynamics, the physical quantity which is same for two bodies in thermal equilibrium is

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Options:

A.

heat

B.

temperature

C.

volume

D.

pressure

Answer: B

Solution:

According to Zeroth law of thermodynamics, temperature is same for two bodies in thermal equilibrium.

Question41

If a refrigerator of coefficient of performance of 5 has a freezer at a temperature of $-13^{\circ}\mathrm{C}$, then the room temperature is

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Options:

A.

$325^{\circ}\mathrm{C}$

B.

$225^{\circ}\mathrm{C}$

C.

$39^{\circ}\mathrm{C}$

D.

$29^{\circ}\mathrm{C}$

Answer: C

Solution:

Coefficient of performance of refrigerator

$$\begin{aligned} \mathrm{COP} &= \frac{T_c}{T_h - T_c} \\ 5 &= \frac{(-13+273)}{T_h-(-13+273)} \\ \Rightarrow \quad 5 &= \frac{260}{T_h-260} \end{aligned}$$

$$\Rightarrow 5T_h - 1300 = 260$$

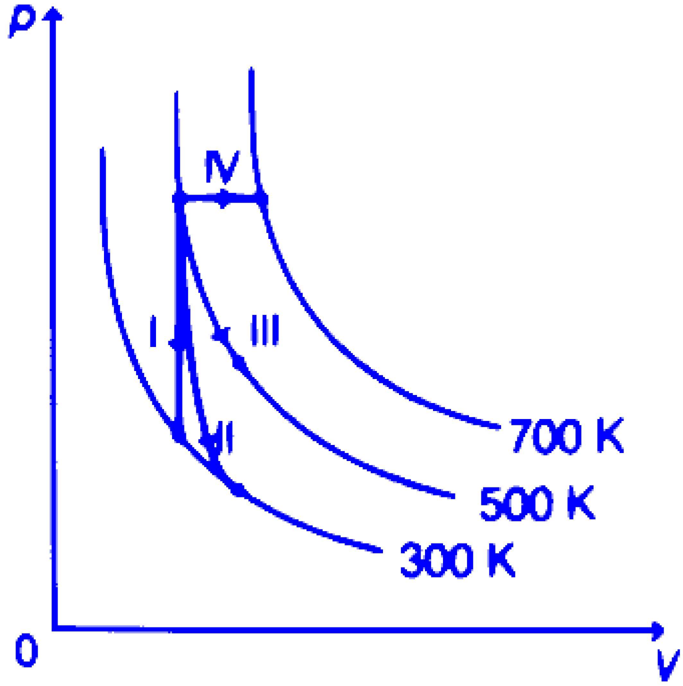
$$\begin{aligned} \Rightarrow T_h &= \frac{1560}{5} \\ &= 312^{\circ}\mathrm{K} = (312-273)^{\circ}\mathrm{C} \\ &= 39^{\circ}\mathrm{C} \end{aligned}$$

Question42

From the figure shown for a thermodynamic system, match the curves with their respective thermodynamic processes.

(p = Pressure and V = volume)

	Curve		Process
(i)	I	A	Adiabatic
(ii)	II	B	Isobaric
(iii)	III	C	Isochoric
(iv)	IV	D	Isothermal



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Options:

A.

(i) -C , (ii) -A , (iii)- D , (iv)- B

B.

(i) -C , (ii) -D , (iii) -B , (iv) -A

C.

(i) -D , (ii) -B , (iii) -A , (iv) -C

D.

(i) -A , (ii) -C , (iii) -D , (iv) -B

Answer: A

Solution:

Process I is isochoric because volume is constant.

In process II, no heat exchange takes place.

$\therefore$ Process is adiabatic.

In process III, temperature is constant. So it is isothermal process.

In process IV, pressure is constant. Thus, it is isobaric process.

Question43

If 2 moles of an ideal monoatomic gas at a temperature of $27^{\circ}\mathrm{C}$ is mixed with 4 moles of another ideal monoatomic gas at a temperature of $327^{\circ}\mathrm{C}$, then the temperature of mixture of the two gases is

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Options:

A.

$300^{\circ}\mathrm{C}$

B.

$227^{\circ}\mathrm{C}$

C.

$233^{\circ}\mathrm{C}$

D.

$327^{\circ}\mathrm{C}$

Answer: B

Solution:

Total initial internal energy

$$\begin{aligned} U^{\prime}=U_1+U_2 & =\frac{3}{2} n_1 R T_1+\frac{3}{2} n_2 R T_2 \\ & =\frac{3}{2} R\left(n_1 T_1+n_2 T_2\right) \\ & =\frac{3}{2} R(2 \times 300+4 \times 600) \\ & =4500 R \end{aligned}$$

Total number of moles after mixing

$$\begin{aligned} n_{\text{total}} & =n_1+n_2=2+4=6 \\ \therefore \quad U_{\text{final}} & =\frac{3}{2} n_{\text{total}} \quad R T_{\text{final}} \\ U_{\text{final}} & =\frac{3}{2} \times 6 \times R T_{\text{final}} \end{aligned}$$

Since, $U^{\prime}=U_{\text{final}}$

$$\begin{aligned} & \Rightarrow 4500 R=\frac{3}{2} \times 6 \times R \times T_{\text{final}} \\ & T_{\text{final}} \quad=500 \mathrm{~K}=(500-273)^{\circ} \mathrm{C}=227^{\circ} \mathrm{C} \end{aligned}$$

Question44

When 2 moles of a monoatomic gas expands adiabatically from a temperature of $80^{\circ}\mathrm{C}$ to $50^{\circ}\mathrm{C}$, the work done is W. The work done when 3 moles of a diatomic gas expands adiabatically from $50^{\circ}\mathrm{C}$ to $20^{\circ}\mathrm{C}$, is

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Options:

A. 7 W

B. 5 W

C. 2.5 W

D. 3.5 W

Answer: C

Solution:

Using first law of thermodynamies

$\Delta U = \Delta Q - W$

For adiabatic process, $\Delta Q = 0$

$$\begin{aligned} \therefore \quad W &= -\Delta U = -nC_V \Delta T \\ &= -nC_V [T_1 - T_2] \\ \Rightarrow \quad W &= W_1 = 2 \times \frac{3}{2} R \times (80 - 50) \\ \Rightarrow \quad W &= 90R \qquad \ldots (i) \\ W_2 &= 3 \times \frac{5}{2} R \times (50 - 20) = 225R \\ &= 225 \times \frac{W}{90} \qquad [form\ eq.\, ii] \\ &= 2.5 \text{ W} \end{aligned}$$

Question45

A gas absorbs 18 J of heat and work done on the gas is 12 J . Then, the change in internal energy of the gas

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Options:

A. 24 J

B. 36 J

C. 6 J

D. 30 J

Answer: D

Solution:

By using the first law of thermodynamics,

$\Delta U = Q - W$

Here, internal energy =?

Work done on the gas, $W=-12$ J

Heat absorbed, $Q=18$ J

From Eq. (i), $\Delta U=18-(-12)=30$ J

$\Delta U=18+12=30$ J

So, the change in internal energy of the gas is 30 J .

Question46

If the ratio of the absolute temperature of the sink and source of a Carnot engine is changed from $2:3$ to $3:4$, the efficiency of the engine change by

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Options:

A. 25%

B. 40%

C. 50%

D. 15%

Answer: A

Solution:

The efficiency of a Carnot engine is calculated using the formula:

$\eta=1-\frac{T_{\text{sink}}}{T_{\text{source}}}$

Initially, the efficiency η_1 is:

$\eta_1=1-\frac{2}{3}=\frac{1}{3}$

After the change in the temperature ratio, the efficiency η_2 becomes:

$\eta_2=1-\frac{3}{4}=\frac{1}{4}$

To determine the change in efficiency, we calculate $\Delta\eta$:

$\Delta\eta=\eta_2-\eta_1=\frac{1}{4}-\frac{1}{3}=-\frac{1}{12}$

The percentage change in efficiency is calculated as follows:

$$\frac{\Delta\eta}{\eta_1} \times 100\% = \frac{-\frac{1}{12}}{\frac{1}{3}} \times 100 = -\frac{1}{4} \times 100\% = -25\%$$

The negative sign indicates that there is a 25% decrease in efficiency.

Question47

The ratio of the molar specific heat capacities of monoatomic and diatomic gases at constant pressure is

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Options:

A. 1 : 7

B. 5 : 7

C. 3 : 7

D. 2 : 7

Answer: B

Solution:

The molar specific heat capacities of gases at constant pressure vary depending on whether the gas is monoatomic or diatomic due to differences in their degrees of freedom.

For a monoatomic gas, the molar specific heat capacity at constant pressure, denoted as C_{p_m}, is given by:

$$C_{p_m} = \frac{5}{2}R$$

For a diatomic gas, the molar specific heat capacity at constant pressure, denoted as C_{p_d}, is:

$$C_{p_d} = \frac{7}{2}R$$

The ratio of the molar specific heat capacities for monoatomic and diatomic gases is therefore:

$$\frac{C_{pm}}{C_{p_d}} = \frac{\left(\frac{5}{2}R\right)}{\left(\frac{7}{2}R\right)} = \frac{5\times2\times R}{2\times7\times R} = \frac{5}{7}$$

Thus, the ratio is 5 : 7.

Question48

Water of mass m at $30^{\circ}\mathrm{C}$ is mixed with with 5 g of ice at $-20^{\circ}\mathrm{C}$. If the resultant temperature of the mixture is $6^{\circ}\mathrm{C}$, then the value of m is (specific heat capacity of ice $= 0.5 \mathrm{calg}^{-10} \mathrm{C}^{-1}$, specific heat capacity of water $= 1$ calg $^{-1\circ} \mathrm{C}^{-1}$ and latent heat of fusion of ice $= 80 \mathrm{calg}^{-1}$)

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Options:

A. 48 g

B. 20 g

C. 24 g

D. 40 g

Answer: B

Solution:

To find the mass of water m that results in a final mixture temperature of $6^{\circ}\mathrm{C}$, let's break down the heat exchanges that occur during the process.

Step 1: Heating Ice from $-20^{\circ}\mathrm{C}$ to $0^{\circ}\mathrm{C}$

The heat required is given by:

$$Q_1 = m_{\text{ice}} \cdot c_{\text{ice}} \cdot \Delta T = 5 \mathrm{~g} \times 0.5 \mathrm{~cal/g}^{\circ}\mathrm{C} \times 20^{\circ}\mathrm{C} = 50 \mathrm{~cal}$$

Step 2: Melting Ice at $0^{\circ}\mathrm{C}$ to Water

The heat required for melting the ice is:

$$Q_2 = m_{\text{ice}} \times L_f = 5 \mathrm{~g} \times 80 \mathrm{~cal/g} = 400 \mathrm{~cal}$$

Step 3: Heating Water from Ice from $0^{\circ}\mathrm{C}$ to $6^{\circ}\mathrm{C}$

The heat required to raise the temperature of the resulting water is:

$$Q_3 = m_{\text{water from ice}} \cdot c_{\text{water}} \cdot \Delta T = 5 \mathrm{~g} \times 1 \mathrm{~cal/g}^{\circ}\mathrm{C} \times 6^{\circ}\mathrm{C} = 30 \mathrm{~cal}$$

Total Heat Required

Summing these components, the total heat absorbed by the ice and converted water is:

$$Q_{\text{total gained}} = Q_1 + Q_2 + Q_3 = 50 + 400 + 30 = 480 \mathrm{~cal}$$

Step 4: Heat Lost by Water Initially at $30^{\circ}\mathrm{C}$ Cooling to $6^{\circ}\mathrm{C}$

The heat lost is calculated by:

$Q_{\text{lost}} = m_{\text{water}} \cdot c_{\text{water}} \cdot \Delta T = m \times 1\,\text{cal/g}^{\circ}\text{C} \times 24^{\circ}\text{C} = 24m\,\text{cal}$

Equilibrium Condition

The heat gained must equal the heat lost:

$Q_{\text{total gained}} = Q_{\text{lost}}$

$480 = 24m$

Solving for m:

$m = \frac{480}{24} = 20\,\text{g}$

Therefore, the mass of water required is $20\,\text{g}$.

Question49

Two ideal gases A and B of same number of moles expand at constant temperatures T_1 and T_2 respectively such that the pressure of gas A decreases by 50% and the pressure of gas B decreases by 75%. If the work done by both the gases is same, then $T_1 : T_2$

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Options:

A. 1 : 3

B. 2 : 3

C. 3 : 4

D. 2 : 1

Answer: D

Solution:

Work Done During Isothermal Expansion:

For an ideal gas expanding isothermally, the work done W is given by:

$W = nRT \ln\left(\frac{V_f}{V_i}\right)$

where n is the number of moles, R is the ideal gas constant, T is the temperature, V_f is the final volume, and V_i is the initial volume.

Gas A Expansion:

The pressure of gas A decreases by 50%, thus:

$p_f = 0.5p_i$

Using the ideal gas law $pV = nRT$, we have:

$p_f V_f = p_i V_i$

$0.5p_i V_f = p_i V_i \Rightarrow V_f = 2V_i$, thus $\frac{V_f}{V_i} = 2$

Therefore, the work done by gas A is:

$W_A = nRT_1 \ln(2)$

Gas B Expansion:

The pressure of gas B decreases by 75%, thus:

$p_f = 0.25p_i$

Using the ideal gas law again:

$p_f V_f = p_i V_i$

$0.25p_i V_f = p_i V_i \Rightarrow V_f = 4V_i$, thus $\frac{V_f}{V_i} = 4$

The work done by gas B is:

$W_B = nRT_2 \ln(4)$

Determining the Temperature Ratio

Given that the work done by both gases is the same, $W_A = W_B$, we equate the expressions for work:

$nRT_1 \ln(2) = nRT_2 \ln(4)$

Solving for the temperature ratio:

$T_1 \ln(2) = T_2 \ln(4)$

$T_1 \ln(2) = T_2 \cdot 2\ln(2)$

$\frac{T_1}{T_2} = \frac{2\ln(2)}{\ln(2)} = 2$

Thus, the ratio of temperatures $T_1 : T_2$ is:

$2 : 1$

Question50

When 80 J of heat is absorbed by a monoatomic gas, its volume increases by $16 \times 10^{-5}\ \mathrm{m}^3$. The pressure of the gas is

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Options:

A. $2 \times 10^5 \mathrm{Nm}^{-2}$

B. $4 \times 10^5 \mathrm{Nm}^{-2}$

C. $6 \times 10^5 \mathrm{Nm}^{-2}$

D. $5 \times 10^5 \mathrm{Nm}^{-2}$

Answer: A

Solution:

Given:

Heat absorbed, $Q = 80\ \mathrm{J}$

Change in volume, $\Delta V = 16 \times 10^{-5}\ \mathrm{m}^3$

First Law of Thermodynamics

$Q = \Delta U + W$

For a monoatomic ideal gas, the change in internal energy (ΔU) can be expressed as:

$\Delta U = \frac{3}{2} nR\Delta T$

The work done (W) by the gas during expansion is:

$W = p\Delta V$

Using the ideal gas law:

$pV = nRT$
$p\Delta V = nR\Delta T$

Substitute into the internal energy equation:

$\Delta U = \frac{3}{2} p\Delta V$

Now substitute equations for W and ΔU into the first law:

$$Q = \frac{3}{2} p\Delta V + p\Delta V$$

$$80 = \frac{5}{2} \times p \times 16 \times 10^{-5}$$

Solve for pressure p:

$$\frac{2 \times 80}{16 \times 10^{-5} \times 5} = p$$
$$\frac{160}{80 \times 10^{-5}} = p$$
$$2 \times 10^5 \text{ N/m}^2 = p$$

Thus, the pressure of the gas is $2 \times 10^5 \text{ N/m}^2$.

Question51

The efficiency of a Carnot heat engine is 25% and the temperature of its source is 127°C. Without changing the temperature of the source, if absolute temperature of the sink is decreased by 10%, the efficiency of the engine is

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Options:

A. 27.5%

B. 17.5%

C. 32.5%

D. 22.5%

Answer: C

Solution:

The efficiency (η) of a Carnot engine is determined by the formula:

$$\eta = 1 - \frac{T_{\text{sink}}}{T_{\text{source}}}$$

Given that the initial efficiency is 25% and the source temperature is 127°C, which converts to $400\,\text{K}$ in absolute temperature, we have:

$$0.25 = 1 - \frac{T_{\text{sink}}}{T_{\text{source}}}$$

This implies:

$$\frac{T_{\text{sink}}}{T_{\text{source}}} = 0.75$$

From which:

$T_{\text{sink}} = 0.75 \times 400 = 300\,\text{K}$

If we decrease the sink temperature by 10%, the new sink temperature T'_{sink} becomes:

$T'_{\text{sink}} = T_{\text{sink}} - \frac{T_{\text{sink}} \times 10}{100} = 300 - 30 = 270\,\text{K}$

The new efficiency η' of the engine is calculated as follows:

$\eta' = 1 - \frac{T'_{\text{sink}}}{T_{\text{source}}} \times 100\%$

Substituting the values, we get:

$\eta' = 1 - \frac{270}{400} \times 100\%$

$= 1 - 0.675 \times 100\%$

$\eta' = 0.325 \times 100\%$

Therefore, the new efficiency is:

$\eta' = 32.5\%$

Question52

The total internal energy of 2 moles of a monoatomic gas at a temperature 27°C is U. The total internal energy of 3 moles of a diatomic gas at a temperature 127°C is

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Options:

A. U

B. $\frac{10U}{3}$

C. 2 U

D. $\frac{2U}{3}$

Answer: B

Solution:

For a monoatomic gas:

Number of moles, $n_m = 2$.

Temperature, $\Delta T_m = 27^\circ\text{C} = 300\,\text{K}$.

Internal energy, $U_m = U$.

The total internal energy for a monoatomic gas is calculated as:

$U_m = \frac{3}{2} nR\Delta T$

Substituting the values:

$U = \frac{3}{2} \times 2 \times R \times 300$

So,

$U = 900R \quad$ ...(i)

For a diatomic gas:

Number of moles, $n_d = 3$.

Temperature, $\Delta T_d = 127^\circ\text{C} = 400\,\text{K}$.

The total internal energy for a diatomic gas is given by:

$U_d = \frac{5}{2} nR\Delta T$

Substitute the known values:

$U' = \frac{5}{2} \times 3 \times R \times 400$

Thus,

$U' = 3000R \quad$ ...(ii)

To find the relationship between U' and U, divide Eq. (ii) by Eq. (i):

$\frac{U'}{U} = \frac{3000R}{900R}$

Therefore,

$U' = \frac{10}{3} U$

Question53

A metal ball of mass 100 g at 20°C is dropped in 200 g of water at 80°C. If the resultant temperature is 70°C, then the ratio of specific heat of the metal to that of water is

Options:

A. $\frac{5}{2}$

B. $\frac{1}{2}$

C. $\frac{2}{5}$

D. $\frac{2}{1}$

Answer: C

Solution:

The specific details are as follows:

Mass of water, $m_w = 200\,\text{g}$

Specific heat capacity of water, $C_w = 1\,\text{cal/g}^{\circ}\text{C}$

Change in temperature of the water, $\Delta T_w = 10^{\circ}\text{C}$ (from 80°C to 70°C)

Mass of the metal, $m_m = 100\,\text{g}$

Change in temperature of the metal, $\Delta T_m = 50^{\circ}\text{C}$ (from 20°C to 70°C)

Calculating Heat Exchanged

Using the heat equation, we calculate:

Heat lost by the water:

$Q_w = m_w \times C_w \times \Delta T_w$

Heat gained by the metal:

$Q_m = m_m \times C_m \times \Delta T_m$

Setting Heat Lost Equal to Heat Gained

The principle of conservation of energy tells us that the heat lost by the water equals the heat gained by the metal:

$m_w \times C_w \times \Delta T_w = m_m \times C_m \times \Delta T_m$

Substituting the values, we have:

$200 \times 1 \times 10 = 100 \times C_m \times 50$

By solving for C_m:

$C_m = \frac{200\times1\times10}{100\times50} = \frac{2}{5}\ \text{cal/g}^{\circ}\text{C}$

Calculating the Ratio

Finally, the ratio of the specific heat capacity of the metal to that of water is:

$\frac{C_m}{C_w} = \frac{\frac{2}{5}}{1} = \frac{2}{5}$

Question54

The efficiency of a heat engine that works between the temperatures where Celsius-Fahrenheit scales coincides and Kelvin-Fahrenheit scales coincides is (approximately)

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Options:

A. 45%

B. 35%

C. 60%

D. 50%

Answer: C

Solution:

To determine the efficiency of a heat engine operating between two specific temperatures, we use the formula:

$\eta = 1 - \frac{T_C}{T_H}$

where:

T_C is the temperature of the cold reservoir.

T_H is the temperature of the hot reservoir.

From the temperature scale relationships:

The Celsius and Fahrenheit scales coincide at -40°, which is equivalent to 233.15 Kelvin.

The Kelvin and Fahrenheit scales coincide at 574.59 Kelvin.

Using these temperatures, we calculate the efficiency:

$$\begin{aligned}\eta &= 1-\frac{233.15}{574.59} \\ &\approx 1-0.4056 \\ &\approx 0.5944\end{aligned}$$

Therefore, the efficiency of the heat engine operating between these temperatures is approximately 59.44%.

Question55

Initially the pressure of 1 mole of an ideal gas is $10^5 \mathrm{Nm}^{-2}$ and its volume is 16 L . When it is adiabatically compressed, its final volume is 2 L . Work-done on the gas is

[molar specific heat at constant volume $=\frac{3}{2} R$]

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Options:

A. 72 kJ

B. 7.2 kJ

C. 720 kJ

D. 360 kJ

Answer: B

Solution:

Given the initial conditions of the problem:

Pressure, $p_1=10^5 \mathrm{~Nm}^{-2}$

Initial volume, $V_1=16 \mathrm{~L}$

Final volume, $V_2=2 \mathrm{~L}$

The molar specific heat at constant volume is given as $\frac{3}{2} R$.

For an adiabatic process, the work done on the gas is calculated using the formula:

$W=\frac{nR\Delta T}{\gamma-1}=\frac{p_2V_2-p_1V_1}{\gamma-1}$

First, we determine the final pressure p_2 using the adiabatic relation:

$p_2=p_1\left(\frac{V_1}{V_2}\right)^\gamma$

Substituting the given values:

$p_2=10^5\left(\frac{16}{2}\right)^{1.66}=3.15\times10^6\,\mathrm{N/m^2}$

Next, we calculate the work done:

$W=\frac{(3.15\times10^6\times2)-(10^5\times16)}{1.66-1}$

Simplifying further:

$W=\frac{6.3\times10^6-16\times10^5}{0.66}$

$W=\frac{63\times10^5-16\times10^5}{0.66}$

$W=\frac{47\times10^5}{0.66}=71.21\times10^5$

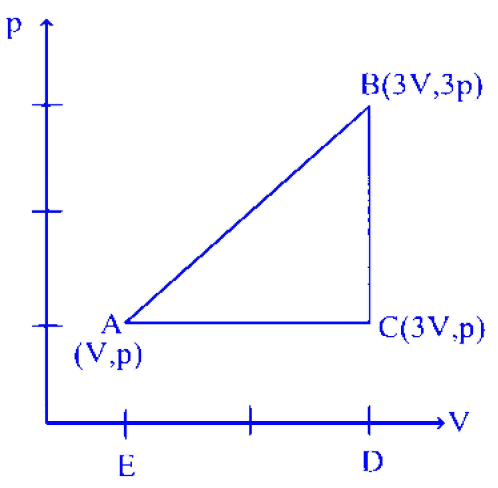
Finally, converting the work done to kilojoules:

Work done $=71.21\times10^5\times10^{-3}\,\mathrm{J}=7.1\,\mathrm{kJ}$

Thus, the work done on the gas is 7.1 kJ.

Question56

An ideal gas is taken around $ABCA$ as shown in the P'' diagram. The work done during the cycle is



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Options:

A. $2\rho V$

B. pV

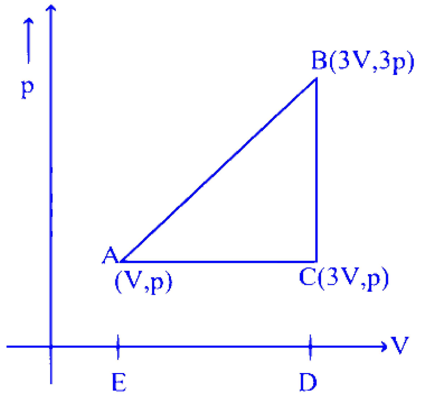
C. $\frac{1}{2}pV$

D. Zero

Answer: A

Solution:

The work done during a cycle is equal to the area under p - V diagram.



From the given p - V diagram,

$$W=\frac{1}{2}\times AC\times BC$$
$$W=\frac{1}{2}\times(3V-V)\times(3p-p)$$
$$=\frac{1}{2}\times 2V\times 2p$$
$$W=2pV$$

Question57

The ratio of kinetic energy of a diatomic gas molecule at a high temperature to that of NTP is

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Options:

A. $\frac{3}{2}$

B. $\frac{5}{3}$

C. $\frac{5}{7}$

D. $\frac{7}{5}$

Answer: D

Solution:

The kinetic energy of a gas molecule is related to the temperature by the equation:

$$E_k = \frac{3}{2} k_B T$$

where k_B is the Boltzmann constant, and T is the temperature.

At NTP (Normal Temperature and Pressure):

- Temperature $T_{\text{NTP}} = 273 \text{ K}$
- Kinetic energy at NTP for a diatomic gas molecule (considering only translational energy):

$$E_k = \frac{5}{2} k_B T$$

(For a diatomic molecule, there are 3 translational and 2 rotational degrees of freedom.)

At high temperature (assuming the temperature is much higher):

- At high temperatures, the rotational energy is fully excited, and the molecule can also vibrate. So, for a diatomic molecule, the total kinetic energy is given by:

$$E_k = \frac{7}{2} k_B T$$

(3 translational + 2 rotational + 2 vibrational degrees of freedom, each contributing $\frac{1}{2} k_B T$.)

Ratio of kinetic energy:

$$\text{Ratio} = \frac{\text{Kinetic energy at high temperature}}{\text{Kinetic energy at NTP}} = \frac{\frac{7}{2} k_B T}{\frac{5}{2} k_B T} = \frac{7}{5}$$

Thus, the correct answer is:

✅ $\frac{7}{5}$ (Option D).

Question58

A metal block is made from mixture of 2.4 kg of aluminium, 1.6 kg of brass and 0.8 kg of copper. The metal block is initially at 20°C. If the heat supplied to the metal block is 44.4 cal . Find the final temperature of the block if specific heats of aluminium, brass and

copper are $0.216, 0.0917$ and $0.0931 \mathrm{calkg}^{-10} \mathrm{C}^{-1}$ respectively

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Options:

A. $100^{\circ} \mathrm{C}$

B. $60^{\circ} \mathrm{C}$

C. $40^{\circ} \mathrm{C}$

D. $80^{\circ} \mathrm{C}$

Answer: D

Solution:

Given a metal block composed of various metals:

Aluminium mass: $m_{\text{Al}} = 2.4 \text{ kg}$

Brass mass: $m_{\text{Brass}} = 1.6 \text{ kg}$

Copper mass: $m_{\text{Cu}} = 0.8 \text{ kg}$

The specific heats of the components are:

Aluminium: $C_{\text{Al}} = 0.216 \text{ cal kg}^{-1} {}^{\circ}\text{C}^{-1}$

Brass: $C_{\text{Brass}} = 0.0917 \text{ cal kg}^{-1} {}^{\circ}\text{C}^{-1}$

Copper: $C_{\text{Cu}} = 0.0931 \text{ cal kg}^{-1} {}^{\circ}\text{C}^{-1}$

The heat supplied to the block is 44.4 cal. To find the final temperature of the block, we use the formula for heat energy:

$Q = mC\Delta T$

The total heat equation is:

$Q = (m_{\text{Al}} C_{\text{Al}} + m_{\text{Brass}} C_{\text{Brass}} + m_{\text{Cu}} C_{\text{Cu}})\Delta T$

Substitute the given values:

$44.4 = (2.4 \times 0.216 + 1.6 \times 0.0917 + 0.8 \times 0.0931)\Delta T$

Calculate the product inside the brackets:

$44.4 = [0.5184 + 0.14672 + 0.07448]\Delta T$

Simplifying further:

$44.4 = 0.7396\Delta T$

Solving for ΔT:

$\Delta T = \frac{44.4}{0.7396}$

$\Delta T = 60$

The initial temperature $T_i = 20^{\circ}\mathrm{C}$. Therefore, the final temperature T_f is:

$T_f = \Delta T + T_i$

$T_f = 60 + 20$

$T_f = 80^{\circ}\mathrm{C}$

Question59

An ideal gas is found to obey $pV^{\frac{3}{2}} =$ constant during an adiabatic process. If such a gas initially at temperature T is adiabatically compressed to $\frac{1}{4}$ th of its volume, then its final temperature is

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Options:

A. $\sqrt{3T}$

B. $\sqrt{2}T$

C. $2T$

D. $3T$

Answer: C

Solution:

During an adiabatic process, the given relationship is $pV^{\frac{3}{2}} =$ constant. In general, for an adiabatic process, the equation is $pV^{\gamma} =$ constant. By comparing these equations, we deduce that $\gamma = \frac{3}{2}$.

Consider the initial volume $V_1 = V_0$ and the final volume $V_2 = \frac{V_0}{4}$.

The relation between temperature and volume in an adiabatic process is given by:

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

Thus:

$T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$

Substituting the known values, we have:

$T(V_0)^{\gamma-1} = T_2\left[\frac{V_0}{4}\right]^{\gamma-1}$

This simplifies to:

$T_2 = T(4)^{\frac{3}{2}-1}$

Therefore, the final temperature is:

$T_2 = T\sqrt{2}$

Question60

The condition $dW = dQ$ holds good in the following process.

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Options:

A. Adiabatic process

B. Isothermal process

C. Isochoric process

D. Isobaric process

Answer: B

Solution:

The condition $dW = dQ$ is valid in an isothermal process.

According to the first law of thermodynamics:

$dQ = dW + dU$

In an isothermal process, the temperature remains constant, which implies $dU = 0$. Therefore:

$\therefore \quad dQ = dW$

Question61

The efficiency of a Carnot engine found to increase from 25% to 40% on increasing the temperature (T_1) of source alone through 100 K . The temperature (T_2) of the sink is given by

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Options:

A. 300 K

B. 250 K

C. 325 K

D. 125 K

Answer: A

Solution:

To find the temperature of the sink (T_2), we begin by analyzing the efficiency increase of a Carnot engine.

Initial Conditions

Initial efficiency: $\eta = 25\%$ or 0.25.

Efficiency formula:

$$\eta = 1 - \frac{T_{\text{sink}}}{T_{\text{source}}}$$

Substitute the given efficiency:

$$0.25 = 1 - \frac{T_{\text{sink}}}{T_{\text{source}}} \quad \Rightarrow \quad \frac{T_{\text{sink}}}{T_{\text{source}}} = 0.75$$

Thus, the temperature of the sink is:

$$T_{\text{sink}} = 0.75 \times T_{\text{source}}$$

After Increasing the Source Temperature

The source temperature is increased by 100 K:

$$T'_{\text{source}} = T_{\text{source}} + 100$$

New efficiency: $\eta' = 40\%$ or 0.40. Using the efficiency formula again:

$$\eta' = 1 - \frac{T_{\text{sink}}}{T'_{\text{source}}}$$

Substitute the known values:

$0.40 = 1 - \frac{0.75 \times T_{\text{source}}}{T_{\text{source}} + 100}$

Solving for T_{source}, we find:

$T_{\text{source}} = 400 \text{ K}$

Calculating the Sink Temperature

Substitute T_{source} in the sink temperature equation:

$T_{\text{sink}} = 0.75 \times 400 = 300 \text{ K}$

Thus, the temperature of the sink (T_2) is 300 K.

Question62

Match the following (f is number of degrees of freedom)

	Gases		$\frac{C_p}{C_v}$ value
A	Monoatomic	I	$\frac{4+f}{3+f}$
B	Diatomic (rigid)	II	$\frac{5}{3}$
C	Diatomic (non-rigid)	III	$\frac{7}{5}$
D	Polyatomic	IV	$\frac{9}{7}$

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Options:

A. A - III B-IV C-I D-II

B. A-II B-I C-III D-IV

C. A - IV B-III C-I D-II

D. A - II B-III C -IV D-I

Answer: D

Solution:

For a deeper understanding of how the heat capacity ratio $\gamma = \frac{C_p}{C_v}$ varies with different types of gases based on their degrees of freedom, consider the following explanations:

Monoatomic Gases: The ratio γ is typically $\frac{5}{3}$. These gases have three translational degrees of freedom, which leads to this specific ratio.

Diatomic Gases (Rigid): For diatomic gases that behave rigidly (i.e., where vibrational modes are not considered), γ is $\frac{7}{5}$. The degrees of freedom include three translational and two rotational.

Diatomic Gases (Non-Rigid): For non-rigid diatomic gases, where vibrational modes are considered, γ is $\frac{9}{7}$. Additional vibrational degrees of freedom affect this ratio.

Polyatomic Gases: These gases can have more complex molecular structures, resulting in more degrees of freedom. Here, for any polyatomic gas, the heat capacities are given by $C_p = 4 + f$ and $C_V = 3 + f$, where f represents the additional degrees of freedom available to the gas. Therefore, the ratio γ is expressed as:

$\gamma = \frac{C_p}{C_V} = \frac{4+f}{3+f}$

Using this understanding, the correct pairing is as follows:

A (Monoatomic): Corresponds to II ($\frac{5}{3}$)

B (Diatomic Rigid): Corresponds to III ($\frac{7}{5}$)

C (Diatomic Non-Rigid): Corresponds to IV ($\frac{9}{7}$)

D (Polyatomic): Corresponds to I ($\frac{4+f}{3+f}$)

Consequently, the correct match is A-II, B-III, C-IV, D-I.

Question63

A slab consists of two identical plates of copper and brass. The free face of the brass is at $0°C$ and that of copper at $100°C$. If the thermal conductivities of brass and copper are in the ratio $1 : 4$, then the temperature of interface is

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Options:

A. $20°C$

B. $40°C$

C. $60°C$

D. $80°C$

Answer: D

Solution:

Given,

Area of thickness is same for both plates.

Free face of brass $= 0^{\circ}\mathrm{C}$

Free face of copper $= 100^{\circ}\mathrm{C}$

$\frac{K_B}{K_C} = \frac{1}{4} \Rightarrow K_C = 4K_B$

Let, the temperature of interface $= T^{\circ}\mathrm{C}$

$100^{\circ}\mathrm{C} \quad T^{\circ}\mathrm{C} \quad 0^{\circ}\mathrm{C}$

Copper	Brass

Heat transfer by copper = Heat gained by brass

$$\left(\frac{Q}{t}\right)_{\mathrm{Cu}} = \left(\frac{Q}{t}\right)_{\mathrm{brass}}$$

$$\Rightarrow \quad \frac{K_C A\left(100^{\circ} - T\right)}{l} = \frac{K_B A\left(T - 0^{\circ}\right)}{l}$$

$$\Rightarrow \quad 4K_B\left(100^{\circ} - T\right) = K_B(T - 0)$$

$$\Rightarrow \quad 400 - 4T = T \Rightarrow 400 = 5T$$

$$\Rightarrow \quad T = \frac{400}{5} = 80^{\circ}\mathrm{C}$$

Question64

A monoatomic gas of n moles is heated from temperature T_1 to T_2 under two different conditions, (i) at constant volume and (ii) at constant pressure. The change in internal energy of the gas is

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Options:

A. more when heated at constant volume

B. more when heated at constant pressure

C. same in both the cases

D. zero in both the cases

Answer: C

Solution:

For an ideal monatomic gas, the internal energy depends only on the temperature, not on the process by which the temperature change occurs. Here's a quick breakdown:

The internal energy of a monatomic ideal gas is given by:

$U = \frac{3}{2} nRT$

where:

n is the number of moles,

R is the gas constant,

T is the temperature.

The change in internal energy when the gas is heated from T_1 to T_2 is therefore:

$\Delta U = \frac{3}{2} nR(T_2 - T_1)$

This expression is valid regardless of whether the heating occurs at constant volume or constant pressure, because the internal energy is a state function—it depends only on the initial and final temperatures.

Thus, the change in internal energy is the same in both cases.

Correct Answer: Option C.

Question65

In a Carnot engine, when the temperatures are $T_2 = 0^\circ\mathrm{C}$ and $T_1 = 200^\circ\mathrm{C}$, its efficiency is η_1 and when the temperature are $T_1 = 0^\circ\mathrm{C}$ and $T_2 = -200^\circ\mathrm{C}$, its efficiency is η_2. Then, the value of $\frac{\eta_1}{\eta_2}$ is

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Options:

A. 0.58

B. 0.73

C. 0.64

D. 0.42

Answer: A

Solution:

When the temperatures are $T_1 = 200^\circ\mathrm{C} = 473$ K and $T_2 = 0^\circ\mathrm{C} = 273$ K, the efficiency η_1 of the Carnot engine is calculated as:

$\eta_1 = 1 - \frac{T_2}{T_1} = 1 - \frac{273}{473} = 1 - 0.577 = 0.423$

When the temperatures are $T_1 = 0^\circ\mathrm{C} = 273$ K and $T_2 = -200^\circ\mathrm{C} = 73$ K, the efficiency η_2 is calculated as:

$\eta_2 = 1 - \frac{T_2}{T_1} = 1 - \frac{73}{273} = 1 - 0.267 = 0.733$

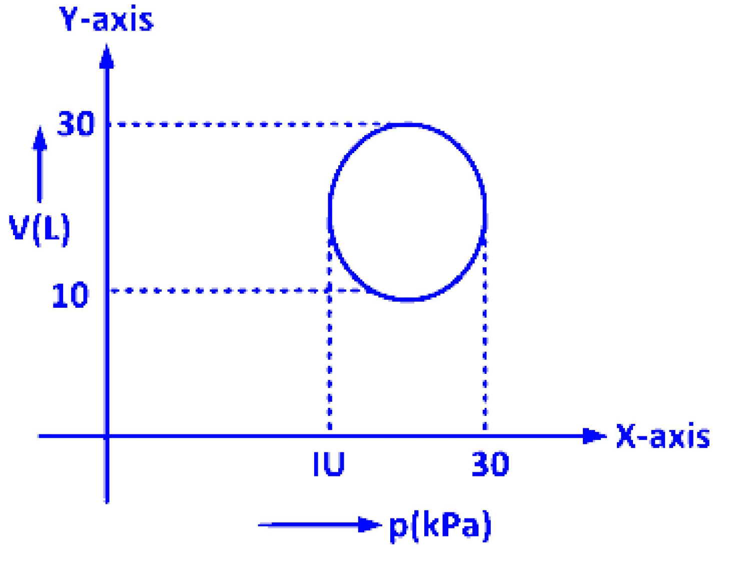
Therefore, the ratio of the efficiencies $\frac{\eta_1}{\eta_2}$ is given by:

$\frac{\eta_1}{\eta_2} = \frac{0.423}{0.733} \approx 0.577$

Thus, $\frac{\eta_1}{\eta_2} \approx 0.58$.

Question66

Heat energy absorbed by a system going through the cyclic process shown in the figure is



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Options:

A. $10^7 \pi J$

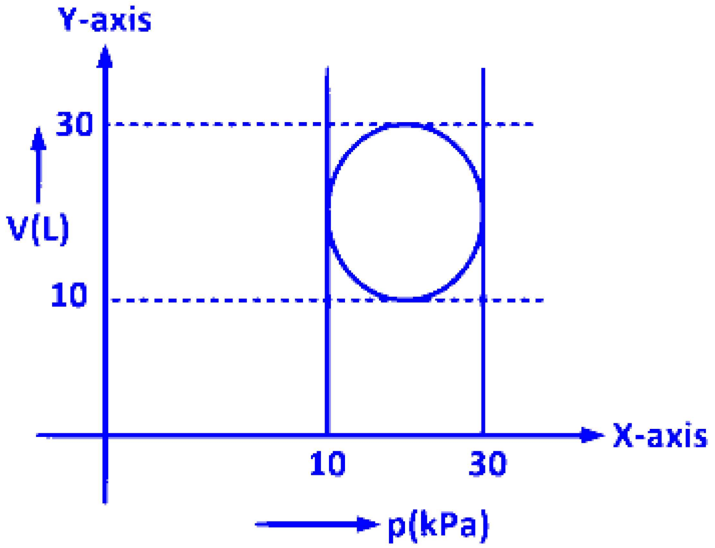
B. $10^4\pi$ J

C. $10^2\pi$ J

D. $10^{-3}\pi$ J

Answer: C

Solution:



We know that,

In a cyclic process, $\Delta U = 0$

According to first law of thermodynamics,

$$\Delta Q = \Delta U + W$$
$$\Delta Q = 0 + \text{ Area under } p - V \text{ curve}$$

$$\Delta Q = \pi \times \left(10 \times 10^3\right) \times \left(10 \times 10^{-3}\right)$$
$$\Delta Q = \pi \times 10 \times 10$$
$$\Delta Q = 10^2\pi \text{ J}$$

Question67

A polyatomic gas with n degrees of freedom has a mean kinetic energy per molecule given by (if N is Avogadro's number)

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Options:

A. $\frac{nk_BT}{N}$

B. $\frac{nk_BT}{2N}$

C. $\frac{nk_BT}{2}$

D. $\frac{3k_BT}{N}$

Answer: C

Solution:

According to the law of equipartition of energy, the energy associated with each degree of freedom of a molecule is $\frac{1}{2}k_BT$, where k_B is the Boltzmann constant and T is the temperature in Kelvin.

For a polyatomic gas with n degrees of freedom, the total mean kinetic energy per molecule can be calculated as:

Mean kinetic energy per molecule $= \frac{1}{2}nk_BT$

This formula reflects that each degree of freedom contributes $\frac{1}{2}k_BT$ to the total energy, and the number of degrees of freedom, n, multiplies this contribution to give the total mean kinetic energy of each molecule in the gas.

Question68

The absorption coefficient value of a perfect black body is

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Options:

A. zero

B. < 1

C. > 1

D. 1

Answer: D

Solution:

A perfect black body is defined as an object that absorbs all incident electromagnetic radiation. This means the fraction of radiation it absorbs, known as the absorption coefficient or absorptivity, is exactly 1.

Here's a brief explanation:

The absorption coefficient represents the proportion of radiation absorbed.

For a perfect black body, by definition, no radiation is reflected or transmitted.

Therefore, the absorption coefficient is 1, meaning it absorbs 100% of the incident radiation.

So, the correct answer is:

Option D: 1.

Question69

A certain volume of a gas at 300 K expands adiabatically until its volume is doubled. The resultant fall in temperature of the gas is nearly (The ratio of the specific heats of the gas $= 1.5$)

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Options:

A. 88 K

B. 77 K

C. 67 K

D. 54 K

Answer: A

Solution:

Given that the initial temperature $T_1 = 300\,\mathrm{K}$, the ratio of specific heats $\gamma = 1.50$, and the final volume $V_2 = 2V_1$, we can calculate the resultant fall in temperature during adiabatic expansion using the following process:

For an adiabatic expansion, the relation is given by:

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

This implies:

$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$

Substitute the given values:

$T_2 = T_1\left(\frac{1}{2}\right)^{1.50-1} = 300\left(\frac{1}{2}\right)^{0.5}$

Calculating T_2, we find:

$T_2 = 213.13\,\text{K}$

Thus, the resultant fall in temperature is:

$= T_1 - T_2 \approx 88\,\text{K}$

Question70

The efficiency of a Carnot's engine is 25%. When the temperature of sink is 300 K . The increase in the temperature of source required for the efficiency to become 50% is

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Options:

A. 225 K

B. 400 K

C. 200 K

D. 100 K

Answer: C

Solution:

To solve this problem, we need to find how much we must increase the temperature of the source to double the efficiency of the Carnot engine from 25% to 50%.

Given:

Sink temperature, $T_L = 300\,\text{K}$

Initial efficiency, $\eta = 25\% = 0.25$

Step 1: Calculate the Original Source Temperature

Using the efficiency formula for a Carnot engine:

$\eta = 1 - \frac{T_L}{T_H}$

Substitute the known values:

$0.25 = 1 - \frac{300}{T_H}$

Solving for T_H:

$T_H = \frac{300}{1-0.25} = \frac{300}{0.75} = 400\,\mathrm{K} \quad \ldots \text{(i)}$

Step 2: Calculate the New Source Temperature for 50% Efficiency

New efficiency, $\eta' = 50\% = 0.50$

Using the efficiency formula again:

$\eta' = 1 - \frac{T_L}{T'_H}$

Substitute the values:

$0.50 = 1 - \frac{300}{T'_H}$

Solving for T'_H:

$T'_H = \frac{300}{1-0.50} = \frac{300}{0.50} = 600\,\mathrm{K} \quad \ldots \text{(ii)}$

Step 3: Calculate the Increase in Temperature

The increase in temperature required is:

$= T'_H - T_H = 600\,\mathrm{K} - 400\,\mathrm{K} = 200\,\mathrm{K}$

Thus, the required increase in the source temperature is 200 K.

Question71

When 100 J of heat is supplied to a gas, the increase in the internal energy of the gas is 60 J . Then the gas is /can

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Options:

A. be triatomic or diatomic gas

B. triatomic gas

C. monoatomic gas

D. diatomic gas

Answer: C

Solution:

Given the following:

Heat supplied, $Q = 100\,\text{J}$

Increase in internal energy, $\Delta U = 60\,\text{J}$

Using the first law of thermodynamics, we have:

$Q = W + \Delta U$

Substitute the given values:

$100 = W + 60$

$W = 40\,\text{J} \quad \ldots \text{(i)}$

For a monoatomic gas, the heat capacity ratio $\gamma = \frac{5}{3}$.

The ratio of work done (ΔW) to the heat supplied (ΔQ) for a monoatomic gas is:

$\frac{\Delta W}{\Delta Q} = \frac{\gamma-1}{\gamma} = \frac{\frac{5}{3}-1}{\frac{5}{3}} = 0.4 \text{ or } 40\% \quad \ldots \text{(ii)}$

This calculation indicates that 40% of the supplied heat is converted into work done in a monoatomic gas.

Equation (i) confirms this analysis.

Therefore, the gas is monoatomic in nature.

Question72

An ideal gas is kept in a cylinder of volume $3\ \text{m}^3$ at a pressure of $3 \times 10^5\ \text{Pa}$. The energy of the gas is

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Options:

A. 13.5×10^6 J

B. 1.35×10^5 J

C. 13.5×10^5 J

D. 135×10^6 J

Answer: C

Solution:

Given:

Volume, $V = 3\,\mathrm{m}^3$

Pressure, $p = 3 \times 10^5$ Pa

The internal energy of an ideal gas can be calculated using the formula:

$E = \frac{3}{2} pV$

Substituting the given values:

$E = \frac{3}{2} \times 3 \times 10^5 \times 3$

Calculating the above expression gives:

$E = 13.5 \times 10^5$ J

Question73

The temperature difference across two cylindrical rods A and B of same material and same mass are $40^\circ\mathrm{C}$ and $60^\circ\mathrm{C}$ respectively. In steady state, if the rates of flow of heat through the rods A and B are in the ratio 3:8, the ratio of the length of the rods A and B is

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Options:

A. 1 : 3

B. 5 : 3

C. 4 : 3

D. 2 : 3

Answer: C

Solution:

To determine the ratio of the lengths of two cylindrical rods, let's review the thermal conductivity formula:

$K = \frac{Q \cdot L}{A \cdot \Delta T}$

Where:

Q is the rate of heat flow.

L is the length of the rod.

A is the cross-sectional area.

ΔT is the temperature difference across the rod.

Since the rods A and B are made of the same material, their thermal conductivity, K, is equal. This gives us:

$K_A = \frac{Q_A \cdot L_A}{A_A \cdot \Delta T_A}$ and $K_B = \frac{Q_B \cdot L_B}{A_B \cdot \Delta T_B}$

Given that the rods have the same mass and material, their volumes are equal:

$V_A = V_B$

Thus, the equation for equal volumes becomes:

$A_A \cdot L_A = A_B \cdot L_B$

From this, we derive:

$\frac{L_A}{L_B} = \frac{A_B}{A_A}$

Since $K_A = K_B$, we equate the expressions:

$\frac{Q_A \cdot L_A}{A_A \cdot \Delta T_A} = \frac{Q_B \cdot L_B}{A_B \cdot \Delta T_B}$

Substituting the ratio of volumes, we get:

$\frac{L_A}{L_B} = \frac{Q_B}{Q_A} \times \frac{A_A}{A_B} \times \frac{\Delta T_A}{\Delta T_B}$

Using the given values:

$\frac{L_A}{L_B} = \frac{8}{3} \times \frac{L_B}{L_A} \times \frac{40}{60}$

Solving the equation:

$\frac{L_A^2}{L_B^2} = \frac{8}{3} \times \frac{4}{6} = \frac{32}{18} = \frac{16}{9}$

Taking the square root gives:

$\frac{L_A}{L_B} = \sqrt{\frac{16}{9}} = \frac{4}{3}$

Thus, the ratio of the lengths of rods A and B is $\frac{4}{3}$.

Question74

The efficiency of Carnot cycle is $\frac{1}{6}$. By lowering the temperature of sink by 65 K , it increases to $\frac{1}{3}$. The initial and final temperature of

the sink are

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Options:

A. 400 K, 310 K

B. 525 K, 65 K

C. 309 K, 235 K

D. 325 K, 260 K

Answer: D

Solution:

Given the efficiency of the Carnot cycle, $\eta = \frac{1}{6}$, and a scenario where the sink's temperature is lowered by 65 K, resulting in an increased efficiency of $\eta_2 = \frac{1}{3}$.

Efficiency of the Carnot Cycle

The efficiency η of a Carnot cycle is expressed by:

$\eta_1 = 1 - \frac{T_2}{T_1}$

where T_2 is the temperature of the sink, and T_1 is the temperature of the source.

Given:

$\frac{1}{6} = 1 - \frac{T_2}{T_1}$

Now, when the sink's temperature is reduced by 65 K, the efficiency becomes:

$\eta_2 = 1 - \frac{(T_2 - 65)}{T_1}$

Calculation

Substitute the expression for $\frac{T_2}{T_1}$ from the first situation into the new efficiency equation:

$\frac{T_2}{T_1} = 1 - \frac{1}{6} = \frac{5}{6}$

So, for the new condition:

$\frac{1}{3} = 1 - \left(\frac{T_2}{T_1} - \frac{65}{T_1}\right)$

Substitute the value from the previous step:

$\frac{65}{T_1} = \frac{1}{3} - \frac{1}{6} = \frac{3}{18} = \frac{1}{6}$

Solve for T_1:

$T_1 = 65 \times 6 = 390\,\text{K}$

Initial Temperature of Sink

Calculate T_2 using the ratio determined earlier:

$\frac{T_2}{T_1} = \frac{5}{6}$

Thus:

$T_2 = \frac{5}{6} \times 390 = 325\,\text{K}$

Final Temperature of Sink

When the sink's temperature is lowered by 65 K:

$T_2 - 65 = 325 - 65 = 260\,\text{K}$

The initial temperature of the sink is 325 K, and the final temperature of the sink is 260 K.

Question75

In a cold storage ice melts at the rate of 2 kg per hour when the external temperature is 20°C. The minimum power output of the motor used to drive the refrigerator which just prevents the ice from melting is (latent heat of fusion of ice $= 80\text{calg}^{-1}$)

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Options:

A. 28.5 W

B. 13.6 W

C. 9.75 W

D. 16.4 W

Answer: B

Solution:

To determine the minimum power output of the motor needed to prevent ice melting in a refrigerator, we must use the concept of the Coefficient of Performance (COP) for a refrigeration system.

The COP is defined as:

$\omega = \frac{T_2}{T_1 - T_2}$

Where:

$T_2 = 273$ K (temperature inside the refrigerator, equivalent to 0°C)

$T_1 = 293$ K (external temperature, equivalent to 20°C)

Plugging in the values:

$\omega = \frac{273}{293-273} = \frac{273}{20}$

Next, calculate the rate of ice melting. Given that ice melts at the rate of 2 kg per hour, convert this to grams per second:

Rate of mass of ice melting per second $= \frac{2\times1000}{3600} = \frac{5}{9}$ g/s

To prevent the ice from melting, the heat that needs to be expelled per second, Q_2, is determined using the latent heat of fusion for ice, 80 cal/g:

$Q_2 = \left(\frac{5}{9}\right) \times 80 = \frac{400}{9} = 44.44 \text{ cal/s}$

Convert Q_2 from calories to Joules (since $1 \text{ cal} = 4.186 \text{ J}$):

$Q_2 = 44.44 \times 4.186 = 186 \text{ J/s}$

Given this heat must be extracted to prevent melting, and using the COP:

$\omega = \frac{Q_2}{W} \implies W = \frac{Q_2}{\omega} = \frac{186}{\left(\frac{273}{20}\right)} = 13.6 \text{ J}$

Thus, in an ideal refrigerator, the minimum power output of the motor required is:

$P_{\text{min}} = \frac{W}{1 \text{ s}} = 13.6 \text{ J/s} = 13.6 \text{ W}$

Therefore, the minimum necessary power output is 13.6 W.

Question76

A Carnot engine has the same efficiency between 800 K and 500 K and $x > 600$ K and 600 K . The value of x is

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Options:

A. 1000 K

B. 960 K

C. 846 K

D. 754 K

Answer: B

Solution:

The efficiency of a Carnot engine is expressed as:

$\eta = 1 - \frac{T_2}{T_1}$

where:

T_1 is the temperature of the source,

T_2 is the temperature of the sink, and

$T_1 > T_2$.

Case 1:

For a Carnot engine operating between 800 K and 500 K, the efficiency is:

$\eta_1 = 1 - \frac{500}{800}$

Case 2:

For another Carnot engine with unknown source temperature x and a sink at 600 K, the efficiency is:

$\eta_2 = 1 - \frac{600}{x}$

Given that the efficiencies are the same in both cases:

$$\eta_1 = \eta_2$$
$$1 - \frac{600}{x} = 1 - \frac{500}{800}$$
$$\frac{600}{x} = \frac{5}{8}$$

Solving for x:

$$x = \frac{600 \times 8}{5}$$
$$x = \frac{4800}{5}$$
$$x = 960\,\mathrm{K}$$

Question77

When the temperature of a gas is raised from $27^\circ\mathrm{C}$ to $90^\circ\mathrm{C}$. The increase in the rms velocity of the gas molecule is

Options:

A. 10%

B. 15%

C. 20%

D. 17.5%

Answer: A

Solution:

The rms velocity (root mean square velocity) of gas molecules is given by the formula:

$v_{\text{rms}} = \sqrt{\frac{3RT}{M}}$

Where:

R is the Universal gas constant

T is the temperature of the gas in Kelvin

M is the molar mass of the gas

For a constant R and M, the rms velocity is proportional to the square root of the temperature:

$v_{\text{rms}} \propto \sqrt{T}$

Given a change in temperature from $T' = 27^\circ\text{C}$ to $T'' = 90^\circ\text{C}$, we first convert these temperatures to Kelvin:

$T' = 273 + 27 = 300\,\text{K}$

$T'' = 273 + 90 = 363\,\text{K}$

The ratio of the rms velocities at these temperatures is:

$\frac{v_{\text{rms,new}}}{v_{\text{rms,old}}} = \sqrt{\frac{T''}{T'}} = \sqrt{\frac{363}{300}}$

This calculation gives:

$\frac{v_{\text{rms,new}}}{v_{\text{rms,old}}} = \sqrt{1.21} \approx 1.1$

The percentage increase in the rms velocity of the gas molecules is calculated by:

$\left(\frac{v_{\text{rms,new}} - v_{\text{rms,old}}}{v_{\text{rms,old}}}\right) \times 100 = (1.1 - 1) \times 100 = 0.1 \times 100 = 10\%$

Thus, the increase in the rms velocity of the gas molecules is 10%.

Question78

If ambient temperature is 300 K , the rate of cooling at 600 K is H. In the same surroundings, the rate of cooling at 900 K is

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Options:

A. $\frac{16}{3}\mathrm{H}$

B. 2 H

C. 3 H

D. $\frac{2}{3}\mathrm{H}$

Answer: A

Solution:

According to Stefan's law, the rate of cooling is proportional to the difference between the fourth powers of the object's temperature and the ambient temperature:

$H \propto \left(T^4 - T_0^4\right)$

Given:

Ambient temperature, $T_0 = 300\,\mathrm{K}$

Rate of cooling at $600\,\mathrm{K}$ is H

We are asked to find the rate of cooling at $900\,\mathrm{K}$.

Using Stefan's law, compare the rates of cooling:

$\frac{H'}{H} = \frac{(900)^4-(300)^4}{(600)^4-(300)^4}$

Calculate:

$900^4 - 300^4$

$600^4 - 300^4$

$\Rightarrow \frac{H'}{H} = \frac{9^4-3^4}{6^4-3^4}$

Simplify the expression:

$9^4 = 6561$

$3^4 = 81$

$6^4 = 1296$

Substitute these values back:

$\frac{H'}{H} = \frac{6561-81}{1296-81} = \frac{6480}{1215} = \frac{16}{3}$

Thus, the rate of cooling at 900 K is:

$H' = \frac{16}{3} H$

Question79

An ideal heat engine operates in Carnot cycle between $127^\circ \mathrm{C}$ and $27^\circ \mathrm{C}$. It absorbs $5 \times 10^4 \mathrm{Cal}$ of heat at height temperature. Amount of heat converted to work is

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Options:

A. $4.8 \times 10^4 \mathrm{cal}$

B. $2.4 \times 10^4 \mathrm{cal}$

C. $125 \times 10^4 \mathrm{cal}$

D. $6 \times 10^4 \mathrm{cal}$

Answer: C

Solution:

Explanation:

For a Carnot cycle, the efficiency (η) of the heat engine is defined as:

$\eta = 1 - \frac{T_2}{T_1}$

where T_1 is the absolute temperature of the heat source (in Kelvin), and T_2 is the absolute temperature of the heat sink (in Kelvin).

Convert the given temperatures from Celsius to Kelvin:

$T_1 = 127^\circ \mathrm{C} + 273 = 400 \mathrm{~K}$

$T_2 = 27^{\circ}\mathrm{C} + 273 = 300\ \mathrm{K}$

Plug these values into the efficiency formula:

$\eta = 1 - \frac{300}{400} = 1 - 0.75 = 0.25$

This means the efficiency is $\frac{1}{4}$.

The efficiency also relates to the work output (W_{out}) and the heat absorbed (W_{absorb}) as follows:

$\eta = \frac{W_{\text{out}}}{W_{\text{absorb}}}$

Given that the heat absorbed (W_{absorb}) is 5×10^4 cal, we can calculate the work output:

$W_{\text{out}} = \frac{1}{4} \times 5 \times 10^4 = 1.25 \times 10^4\ \mathrm{cal}$

Thus, the amount of heat converted to work is 1.25×10^4 cal.

Question80

One mole of a gas having $\gamma = \frac{7}{5}$ is mixed with one mole of a gas having $\gamma = \frac{4}{3}$. The value of γ for the mixture is (γ is the ratio of the specific heats of the gas)

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Options:

A. $\frac{5}{11}$

B. $\frac{11}{15}$

C. $\frac{15}{11}$

D. $\frac{5}{13}$

Answer: C

Solution:

To find the value of γ for the mixture of two gases, we use the formula:

$\frac{n_1+n_2}{\gamma_{\text{mix}} - 1} = \frac{n_1}{\gamma_1 - 1} + \frac{n_2}{\gamma_2 - 1}$

For our specific case:

$n_1 = 1, \gamma_1 = \frac{7}{5}$

$n_2 = 1, \gamma_2 = \frac{4}{3}$

Substituting these into the formula gives:

$$\frac{1+1}{\gamma_{\text{mix}} - 1} = \frac{1}{\frac{7}{5}-1} + \frac{1}{\frac{4}{3}-1}$$

This simplifies to:

$$\frac{2}{\gamma_{\text{mix}} - 1} = \frac{1}{\frac{2}{5}} + \frac{1}{\frac{1}{3}}$$

Calculating further:

$$\frac{2}{\gamma_{\text{mix}} - 1} = \frac{5}{2} + 3 = \frac{5}{2} + \frac{9}{3} = \frac{5}{2} + \frac{6}{2} = \frac{11}{2}$$

Now, solving for γ_{mix} :

$$\gamma_{\text{mix}} - 1 = \frac{2}{\frac{11}{2}} = \frac{4}{11}$$

So, γ_{mix} is:

$$\gamma_{\text{mix}} = 1 + \frac{4}{11} = \frac{15}{11}$$

Question81

A Carnot heat engine has an efficiency of 10%. If the same engine is worked backward to obtain a refrigerator, then the coefficient of performance of the refrigerator is

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Options:

A. 8

B. 9

C. 5

D. 6

Answer: B

Solution:

A Carnot heat engine with an efficiency of 10% can be transformed into a refrigerator. To find the coefficient of performance (COP) of this refrigerator, we use the relationships between efficiency and temperature in a Carnot cycle.

The efficiency η of a Carnot engine is given by:

$\eta = 1 - \frac{T_2}{T_1}$

Rearranging this formula, we find:

$\frac{T_1}{T_2} = \frac{1}{1-\eta}$

For a refrigerator, the coefficient of performance ω is defined as:

$\omega = \frac{T_2}{T_1 - T_2}$

Substituting equation (i) into this, we have:

$\omega = \frac{1}{\left(\frac{T_1}{T_2}\right)-1} = \frac{1}{\left[\frac{1}{1-\eta}\right]-1} = \frac{1-\eta}{\eta}$

Plugging in the given efficiency ($\eta = 0.1$):

$\omega = \frac{1-0.1}{0.1} = \frac{0.9}{0.1} = 9$

Therefore, the coefficient of performance of the refrigerator is 9.

Question82

The rms velocity of a gas molecules oí mass m at a given temperature is proportional to

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Options:

A. m$^\circ$

B. m

C. $\sqrt{m}$

D. $\frac{1}{\sqrt{m}}$

Answer: D

Solution:

To determine the relationship between the root-mean-square (rms) velocity of gas molecules and their mass, we use the formula:

$v_{\text{rms}} = \sqrt{\frac{3RT}{m}}$

In this equation:

v_{rms} is the rms velocity,

R is the gas constant,

T is the temperature,

m is the mass of the gas molecules.

From the equation, it's clear that:

$v_{\text{rms}} \propto \frac{1}{\sqrt{m}}$

This means the rms velocity of gas molecules is inversely proportional to the square root of their mass. As the mass m of the molecules increases, the rms velocity decreases, and vice versa.

Question83

Match the following.

(a) Thermal conductivity	(i) $\left[\mathrm{MLT}^{-3}\mathrm{~K}^{-1}\right]$
(b) Boltzmann constant	(ii) $\left[M^0L^2T^{-2}K^{-1}\right]$
(c) Latent heat	(iii) $\left[ML^2T^{-2}K^{-1}\right]$
(d) Specific heat	(iv) $\left[M^0L^2T^{-2}\right]$

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Options:

A. $a - i, b - iii, c - iv, d - ii$

B. $a - i, b - ii, c - iv, d - iii$

C. $a - iii, b - ii, c - i, d - iv$

D. $a - ii, b - i, c - iii, d - iv$

Answer: A

Solution:

The dimensions of various thermal properties are given and described as follows:

Thermal Conductivity (K):

Formula: $K = \frac{Q \cdot d}{A \cdot \Delta T}$

Dimensional Analysis:

$$\left[\frac{(ML^2T^{-3})(L)}{(L^2)(K)}\right] = [MLT^{-3}K^{-1}]$$

Boltzmann Constant (k):

Defined as the ratio of energy to temperature:

Dimensional Analysis:

$$\frac{[ML^2T^{-2}]}{[K]} = [ML^2T^{-2}K^{-1}]$$

Latent Heat (L):

Defined as the ratio of energy to mass:

Dimensional Analysis:

$$\frac{[ML^2T^{-2}]}{[M]} = [L^2T^{-2}]$$

Specific Heat (C):

Defined as the ratio of energy to the product of mass and temperature:

Dimensional Analysis:

$$\frac{[ML^2T^{-2}]}{[M][K]} = [M^0L^2T^{-2}K^{-1}]$$

These analyses help in determining the correct dimension pairings for each property.

Question84

The length of a metal bar is 20 cm and the ares of cross-section is $4 \times 10^{-4}\ \mathrm{m}^2$. If one end of the rod is kept in ice at $0^{\circ}\mathrm{C}$ and the other end is kept in steamat $100^{\circ}\mathrm{C}$, the mass of ice melted in one minute is 5 g , the thermal conductivity of the matal in $\mathrm{Wm}^{-1}\ \mathrm{K}^{-1}$ is (Latent heat of fusion $= 80 \mathrm{cal}/\mathrm{g}$)

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Options:

A. 140

B. 120

C. 100

D. 160

Answer: A

Solution:

Given:

Length of the rod, $x = 20\,\text{cm} = 0.2\,\text{m}$

Temperatures at the ends:

$T_1 = 0^\circ\text{C} = 273\,\text{K}$

$T_2 = 100^\circ\text{C} = 373\,\text{K}$

Cross-sectional area, $A = 4 \times 10^{-4}\,\text{m}^2$

Mass of ice melted, $m = 5\,\text{g}$

Time, $t = 1\,\text{min} = 60\,\text{s}$

Latent heat of fusion, $L_{\text{ice}} = 80\,\text{cal/g} = 336\,\text{J/g}$

Calculation:

Total Heat Required to Melt the Ice:

$Q = m \times L_{\text{ice}} = 5 \times 336 = 1680\,\text{J}$

Rate of Heat Transfer:

$\frac{Q}{t} = \frac{1680}{60} = 28\,\text{J/s}$

Thermal Conductivity (K):

$K = \frac{\Delta Q \cdot x}{A \cdot \Delta T} = \frac{28 \times 0.2}{4 \times 10^{-4}(373 - 273)}$

$K = \frac{1.4 \times 10^4}{100}$

$K = 1.4 \times 10^2$

$K = 140\,\text{W/mK}$

Question85

The work done by an ideal gas of 2 moles in increasins its volume from V to 2 V at constant temperature T is V . The work done by an ideal gas of 4 moles in increasits its wolume from V to $8V$ at constant temperature $\frac{T}{2}$ is

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Options:

A. W

B. 2 W

C. 3 W

D. 4 V

Answer: C

Solution:

Given:

Initial work done by the gas, $W_1 = W$

Final volume for the first process, $V_{f_1} = 2V$

Initial volume for the first process, $V_{i_1} = V$

Temperature for the first process, $T_1 = T$

Number of moles for the first process, $n = 2$

The work done by an ideal gas during an isothermal expansion is given by the equation:

$W = n \cdot R \cdot T \ln\left(\frac{V_f}{V_i}\right)$

Substituting the given values for the first process:

$W_1 = 2 \cdot R \cdot T \ln\left(\frac{2V}{V}\right) = 2 \cdot R \cdot T \ln 2$

For the second process:

Final volume, $V_{f_2} = 8V$

Initial volume, $V_{i_2} = V$

Temperature, $T_2 = \frac{T}{2}$

Number of moles, $n_2 = 4$

The work done for the second process is:

$W_2 = n_2 \cdot R \cdot T_2 \ln\left(\frac{V_{f_2}}{V_{i_2}}\right)$

Substituting the values:

$W_2 = 4 \cdot R \cdot \frac{T}{2} \ln\left(\frac{8V}{V}\right)$

$W_2 = 2 \cdot R \cdot T \ln\left(2^3\right)$

$W_2 = 3 \cdot 2 \cdot R \cdot T \ln 2$

This simplifies to:

$W_2 = 3 \cdot W$

Hence, the work done by the ideal gas in the second process is $3W$.

Question86

When 403 of heat is absorbed by a monoatomic gas the increase in the internal energy of the gas is

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Options:

A. 12 J

B. 16 J

C. 24 J

D. 32. J

Answer: C

Solution:

To analyze the increase in internal energy when heat is absorbed by a monoatomic gas:

First, we know that the heat absorbed, Q, is given as 40 J.

For a monoatomic ideal gas, the specific heat capacities are:

$C_p = \frac{5R}{2}$

$C_V = \frac{3R}{2}$

The relationship for heat transfer in terms of C_p is:

$Q = nC_p\Delta T$

Substituting in known values:

$40 = n \cdot \frac{5R}{2} \cdot \Delta T$

From this, we obtain:

$nR\Delta T = 16 \quad (i)$

Next, we determine the increase in internal energy, ΔU, which is given by:

$\Delta U = nC_V\Delta T$

$\Delta U = n \cdot \frac{3}{2}R\Delta T$

$\Delta U = \frac{3}{2} \cdot nR\Delta T$

Using Equation (i), we substitute for $nR\Delta T$:

$\Delta U = \frac{3}{2} \times 16$

This simplifies to:

$\Delta U = 24\,\text{J}$

Thus, the increase in the internal energy of the gas is 24 J.

Question87

In a Carnot engine, the absolute temperature of the source is 25% more than the absolute temperature of the sink. The efficiency of the engine is

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Options:

A. 10%

B. 50%

C. 25%

D. 20%

Answer: D

Solution:

The efficiency of a Carnot engine is calculated using the formula:

$\eta=1-\frac{T_{\text{sink}}}{T_{\text{source}}}$

Given that the absolute temperature of the source (T_{source}) is 25% more than that of the sink (T_{sink}), we can express this relationship as:

$T_{\text{source}}=T_{\text{sink}}+\frac{25\times T_{\text{sink}}}{100}$

Simplifying, this becomes:

$T_{\text{source}}=1.25\times T_{\text{sink}}$

Substituting into the efficiency equation, we have:

$\eta=\left(1-\frac{T_{\text{sink}}}{1.25\times T_{\text{sink}}}\right)\times 100\%$

This simplifies to:

$\eta=\left(1-\frac{1}{1.25}\right)\times 100\%$

$\eta=(1-0.8)\times 100\%$

$\eta=0.2\times 100\%$

Thus, the efficiency of the Carnot engine is:

$\eta=20\%$

Question88

The molar specific heat capacity of a diatomic gas at constant pressure is C. The molar specific heat capadtr of a monoatomic gas at constant volume is

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Options:

A. $\frac{2C}{7}$

B. $\frac{3C}{7}$

C. $\frac{C}{7}$

D. $\frac{4C}{7}$

Answer: B

Solution:

Given:

Molar heat capacity at constant pressure for a diatomic gas, $C_p = C$

We need to find the molar heat capacity at constant volume for a monoatomic gas, C_V.

Calculations:

For a Diatomic Gas:

For a diatomic gas, the molar heat capacity at constant volume is:

$C_V = \frac{5}{2}R$

Therefore, the relation between C_p and C_V is:

$C_p = C_V + R = \frac{5}{2}R + R = \frac{7}{2}R$

Since $C_p = C$, we have:

$\frac{7}{2}R = C$

Solving for R, we get:

$R = \frac{2C}{7}$

For a Monoatomic Gas:

The molar heat capacity at constant volume for a monoatomic gas is:

$C_V = \frac{3}{2}R$

Substituting the value of R from Equation (i):

$C_V = \frac{3}{2} \cdot \frac{2C}{7} = \frac{3C}{7}$

Therefore, the molar specific heat capacity of a monoatomic gas at constant volume is $\frac{3C}{7}$.

Question89

5 g of ice at -30°C and 20 g of water at 35°C are mixed together in a calorimeter.The final temperature of the mixture is (Neglect heat capacity of the calorimeter, specific heat capacity of ice

$= 0.5 \mathrm{cal} \mathrm{g}^{-1} {}^{\circ}\mathrm{C}^{-1}$ **and latent heat of fusion of ice** $= 80 \mathrm{cal} \mathrm{g}^{-1}$ **and specific heat. capacity of water** $= 1 \mathrm{cal} \mathrm{g}^{-1} {}^{\circ}\mathrm{C}^{-1}$**)**

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Options:

A. $0^{\circ}\mathrm{C}$

B. $4^{\circ}\mathrm{C}$

C. $5^{\circ}\mathrm{C}$

D. $9^{\circ}\mathrm{C}$

Answer: D

Solution:

Given, $s_w = 1 \mathrm{cal} \mathrm{g}^{-1} {}^{\circ}\mathrm{C}^{-1}$

$s_{\text{lece}} = 0.5 \mathrm{cal} \mathrm{g}^{-1} {}^{\circ}\mathrm{C}^{-1}$
$L_f = 80 \mathrm{cal} \mathrm{g}^{-1}$

Mass of ice, $m_{\text{cee}} = 5 \mathrm{~g}$

Mass of water, $m_w = 20 \mathrm{~g}$

Let final temperature of the mixture be $T^{\circ}\mathrm{C}$.

According to principle of calorimetry,

Heat lost by water $=$ Heat gained by ice

$m_w s_w (35 - T) = m_{\text{cce}} \ s_{\text{ce}} \ [0 - (-30)]$
$+ \mathrm{m}_{icc} \times L_f + m_{\text{kec}} \ \times S_w \times T$
$\Rightarrow 20 \times 1 \times (35 - T) = 5 \times 0.5 \times 30 + 5 \times 80 + 5 \times 0.5 \times T$

On solving, we get

$T = 9^{\circ}\mathrm{C}$

Question90

An iron sphere having diameter D and mass M is immersed in hot water so that the temperature of the sphere increases by δT. If α is the coefficient of linear expansion of the iron then the change in the surface area of the sphere is

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Options:

A. $\pi D^2 \cdot \alpha\delta T(\alpha \cdot \delta T - 4)$

B. $\pi D^2 \cdot \alpha : \delta T(\alpha \cdot \delta T + 4)$

C. $\pi D^2 \cdot \alpha \cdot \delta T(\alpha \cdot \delta T - 2)$

D. $\pi D^2 \cdot \alpha \cdot \delta T(\alpha \cdot \delta T + 2)$

Answer: D

Solution:

Given :

- Diameter of the sphere, D

Initial surface area, A is:

$A = 4\pi R^2$

where $R = \frac{D}{2}$.

So,

$A = 4\pi\left(\frac{D}{2}\right)^2 = \pi D^2 \quad \text{(i)}$

After heating by temperature δT, the new surface area, A', is:

$A' = 4\pi\left(\frac{D'}{2}\right)^2 = \pi(D')^2 \quad \text{(ii)}$

Here, D' is the new diameter.

Using the equation for linear expansion:

$D' = D(1 + \alpha\delta T) \quad \text{(iii)}$

Substituting the value of D' from equation (iii) into equation (ii), we get:

$$A' = \pi D^2(1+\alpha\delta T)^2$$
$$= \pi D^2\left(1+\alpha^2\delta T^2 + 2\alpha\delta T\right) \quad \text{(iv)}$$

Simplifying further:

$$A' = \pi D^2\left(1+\alpha^2\delta T^2 + 2\alpha\delta T\right) - \pi D^2$$
$$= \pi D^2\left[1+\alpha^2\delta T^2 + 2\alpha\delta T - 1\right]$$
$$= \pi D^2\left[\alpha^2\delta T^2 + 2\alpha\delta T\right]$$

The change in surface area is:

$$\Delta A = A' - A$$
$$= \pi D'^2 - \pi D^2$$
$$= \pi D^2\left(\alpha\delta T(\alpha\delta T + 2)\right)$$

Question91

The work done by a Carnot engine operating between 300 K and 400 K is 400 J. The energy exhausted by the engine is

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Options:

A. 800 J

B. 1200 J

C. 400 J

D. 1600 J

Answer: B

Solution:

To find the energy exhausted by the Carnot engine, we need to understand the relationship between the work done, the heat absorbed, and the heat exhausted in a Carnot cycle.

The efficiency (η) of a Carnot engine operating between two temperatures T_h (hot reservoir) and T_c (cold reservoir) is given by the formula:

$$\eta = 1 - \frac{T_c}{T_h}$$

In this case, the temperatures are:

$T_h = 400\,\text{K}$

$T_c = 300\,\text{K}$

Substituting these values into the efficiency formula, we get:

$\eta = 1 - \frac{300}{400}$

$\eta = 1 - 0.75$

$\eta = 0.25$

The efficiency of the Carnot engine is 0.25 (or 25%). This means that 25% of the heat absorbed (Q_h) is converted into work (W), and the rest is exhausted as waste heat (Q_c).

We know that the work done by the engine (W) is 400 J. Using the efficiency, we can find the heat absorbed (Q_h):

$W = \eta \cdot Q_h$

$400 = 0.25 \cdot Q_h$

$Q_h = \frac{400}{0.25}$

$Q_h = 1600\,\text{J}$

The heat absorbed by the engine is 1600 J. To find the energy exhausted (Q_c), we use the relationship:

$Q_h = W + Q_c$

Substituting the known values, we get:

$1600 = 400 + Q_c$

$Q_c = 1600 - 400$

$Q_c = 1200\,\text{J}$

Therefore, the energy exhausted by the engine is 1200 J.

The correct answer is:

Option B: 1200 J

Question92

The slopes of the isothermal and adiabatic $p - V$ graphs of a gas are by S_I and S_A respectively. If the heat capacity ratio of the gas is $\frac{3}{2}$, then $\frac{S_I}{S_A} =$

Options:

A. $\frac{3}{2}$

B. $\frac{2}{3}$

C. $\frac{1}{2}$

D. $\frac{1}{3}$

Answer: B

Solution:

To solve this problem, we need to understand the relationship between the slopes of isothermal and adiabatic processes in a pressure-volume ($p - V$) diagram for a gas, as well as the heat capacity ratio (also known as the adiabatic index γ).

For an isothermal process (constant temperature), the pressure and volume relationship is given by Boyle's law:

$pV = \text{constant}$

Differentiating the above with respect to volume, we get:

$\frac{dp}{dV} = -\frac{p}{V}$

Thus, the slope of the isothermal $p - V$ graph, S_I, is:

$S_I = -\frac{p}{V}$

For an adiabatic process (no heat exchange), the relationship between pressure and volume is given by:

$pV^{\gamma} = \text{constant}$

where γ is the heat capacity ratio. Differentiating the above with respect to volume, we get:

$\frac{dp}{dV} = -\gamma\frac{p}{V}$

Thus, the slope of the adiabatic $p - V$ graph, S_A, is:

$S_A = -\gamma\frac{p}{V}$

From the above, we can see that the ratio of S_I to S_A is:

$\frac{S_I}{S_A} = \frac{-\frac{p}{V}}{-\gamma\frac{p}{V}} = \frac{1}{\gamma}$

Given that the heat capacity ratio $\gamma = \frac{3}{2}$, we substitute this value into the ratio:

$\frac{S_I}{S_A} = \frac{1}{\frac{3}{2}} = \frac{2}{3}$

Thus, the correct answer is:

Option B: $\frac{2}{3}$

Question93

The number of rotational degrees of freedom of a diatomic molecule

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Options:

A. 0

B. 1

C. 2

D. 3

Answer: C

Solution:

The number of rotational degrees of freedom of a diatomic molecule is an important concept in molecular physics, which helps in understanding how the molecule can rotate in space.

A diatomic molecule consists of two atoms connected by a bond. Due to this structure, the molecule can rotate around two axes perpendicular to the bond axis. However, rotation around the bond axis itself does not count as a rotational degree of freedom for rigid diatomic molecules because the moment of inertia around this axis is negligible.

Therefore, the diatomic molecule has:

- Two rotational degrees of freedom: rotation around two axes perpendicular to the bond axis.

Based on this explanation, the correct answer is:

Option C: 2

Question94

A metal tape is calibrated at $25^{\circ}\mathrm{C}$. On a cold day when the temperature is $-15^{\circ}\mathrm{C}$, the percentage error in the measurement of length is

(Coefficient of linear expansion of metal $= 1 \times 10^{-5}{}^{\circ}\mathrm{C}^{-1}$)

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Options:

A. 0.04%

B. 0.05%

C. 0.1%

D. 0.08%

Answer: A

Solution:

Given:

- Coefficient of linear expansion, $\alpha = 1 \times 10^{-5}\ {}^{\circ}\mathrm{C}^{-1}$
- Initial temperature, $T_1 = 25^{\circ}\mathrm{C}$
- Final temperature, $T_2 = -15^{\circ}\mathrm{C}$

Firstly, calculate the change in temperature:

$\Delta T = T_1 - T_2 = 25 - (-15) = 40^{\circ}\mathrm{C}$

Next, determine the change in length (ΔL) with respect to the original length (L):

$\Delta L = L\alpha\Delta T$

Thus, the fractional change in length is:

$\frac{\Delta L}{L} = \alpha\Delta T$

$\frac{\Delta L}{L} = 1 \times 10^{-5} \times 40$

$\frac{\Delta L}{L} = 4 \times 10^{-4}$

To express this as a percentage change in the measurement of length:

$\frac{\Delta L}{L} \times 100 = 4 \times 10^{-4} \times 100$

$\frac{\Delta L}{L} \times 100=0.04 \%$

Therefore, the percentage error in the measurement of length is 0.04%.

Question95

A gas is expanded from an initial state to a final state along a path on a p-V diagram. The path consists of (i) an isothermal expansion of work 50 J , (ii) an adiabatic expansion and (iii) an isothermal expansion of work 20 J . If the internal energy of gas is changed by -30 J , then the work done by gas during adiabatic expansion is

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Options:

A. 40 J

B. 100 J

C. 30 J

D. 20 J

Answer: C

Solution:

Hint : Work done by adiabatic expansion $=-$ (Change in internal energy) $=-(-30 \mathrm{~J})=30 \mathrm{~J}$

Question96

The temperature of the sink of a Carnot engine is 250 K . In order to increase the efficiency of the Carnot engine from 25% to 50%, the temperature of the sink should be increased by

Options:

A. $\frac{1}{3} \times 10^3$ K

B. $\frac{1}{2} \times 10^3$ K

C. 200 K

D. $\frac{1}{6} \times 10^3$ K

Answer: A

Solution:

Initial temperature of the sink, $T_2 = 250$ K

Initial efficiency of carnot engine,

$\eta_1 = 25\% = 0.25$

If T_1 be the temperature of the sink, then

$$\begin{aligned} \eta_1 &= 1 - \frac{T_2}{T_1} \\ 0.25 &= 1 - \frac{250}{T_1} \Rightarrow \frac{250}{T_1} = 0.75 \\ \Rightarrow \quad T_1 &= \frac{1000}{3} \text{ K} \end{aligned}$$

When efficiency is increased by 50%

i.e $\eta_2 = 50\% = 0.5$

Then if T_2' be temperature of sink, then

$$\begin{aligned} \eta_2 &= 1 - \tfrac{T_2'}{T_1} \\ \Rightarrow \quad 0.5 &= 1 - \tfrac{T_2'}{1000/3} \\ \Rightarrow \quad \tfrac{T_2'}{1000/3} &= 1 - 0.5 = 0.5 = \tfrac{1}{2} \\ \Rightarrow \quad T_2' &= \tfrac{1}{2} \times \tfrac{1000}{3} = \tfrac{500}{3} \text{ K} \end{aligned}$$

Here we see that to increase the efficiency of carnot engine temperature of the sink should be decreased, but in question, asked about increasing temperature of sink to increase efficiency, which is not possible. Hence, no option is correct.

Question97

In non-rigid diatomic molecule with an additional vibrational mode

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Options:

A. $81 C_V^2=49 C_p^2$

B. $49 C_V^2=25 C_p^2$

C. $49 C_V^2=81 C_p^2$

D. $25 C_V^2=49 C_p^2$

Answer: A

Solution:

In non-rigid diatomic molecule with an additional vibrational mode, each molecule has additional energy equal to $2 \times \frac{1}{2} k_B T=k_B T$, because a vibrational frequency has both kinetic and potential energy modes.

$$\begin{aligned} \therefore \quad U & =\left(\frac{5}{2} k_B T+k_B T\right) N_A=\frac{7}{2} k_B N_A T \\ & =\frac{7}{2} R T \quad\left[R=k_B N_A\right] \end{aligned}$$

$$\begin{aligned} \therefore \quad C_v & =\frac{d U}{d T}=\frac{d}{d T}\left(\frac{7}{2} R T\right)=\frac{7}{2} R \\ C_p & =C_V+R=\frac{7}{2} R+R=\frac{9}{2} R \\ \frac{C_p}{C_V} & =\frac{9 / 2 R}{7 / 2 R} \Rightarrow \frac{C_p}{C_V}=\frac{9}{7} \end{aligned}$$

$$\Rightarrow \quad 49 C_p^2=81 C_V^2$$

Question98

A sphere of surface area $4 \mathrm{~m}^2$ at temperature 400 K and having emissivity 0.5 is located in an environment of temperature 200 K. The net rate of energy exchange of the sphere is (Stefan Boltzmann constant, $\sigma=5.67 \times 10^{-8} \mathrm{Wm}^{-2} \mathrm{~K}^4$)

Options:

A. 3260.8 W

B. 1632.4 W

C. 2721.6 W

D. 4216.4 W

Answer: C

Solution:

Given surface area of sphere, $A = 4 \text{ m}^2$

Temperature, $T = 400 \text{ K}$

Emissivity, $\varepsilon = 0.5$

Environment temperature,

$T_0 = 200 \text{ K}$

Stefan Boltzmann constant, $\sigma = 5.67 \times 10^{-8} \text{Wm}^{-2} \text{ K}^4$

According to Stefan Boltzmann law, rate of energy exchange of the sphere

$$\begin{aligned} E &= \varepsilon \sigma A \left(T^4 - T_0^4\right) \\ &= 0.5 \times 5.67 \times 10^{-8} \times 4 \left(400^4 - 200^4\right) \\ &= 27216 \times 10^3 \text{ W} = 2721.6 \text{ W} \end{aligned}$$

Question99

A Carnot engine operates between a source and a sink. The efficiency of the engine is 40% and the temperature of the sink is 27°C. If the efficiency is to be increased to 50%, then the temperature of the source must be increased by

Options:

A. 80 K

B. 120 K

C. 100 K

D. 160 K

Answer: C

Solution:

Efficiency of carnot engine,

$\eta=1-\frac{T_2}{T_1}$ ... (i)

Where, $T_2=$ Temperature of sink and $T_1=$ temperature of source According to first condition,

$T_2=27+273=300 \mathrm{~K}$
$\eta=40\%=0.4$

From Eq. (i), $0.4=1-\frac{300}{T_1}$

$\Rightarrow \quad \frac{300}{T_1}=0.6 \Rightarrow T_1=\frac{300}{0.6}=500 \mathrm{~K}$

$\Rightarrow \quad T_1=500 \mathrm{~K}$

Again, when, $\eta=50\%=0.5$, then

$$0.5=1-\frac{300}{T_1^{\prime}}$$

$$\Rightarrow \quad \frac{300}{T_1^{\prime}}=0.5 \Rightarrow T_1^{\prime}=600 \mathrm{~K}$$

$\therefore$ Increase of source temperature $=T^{\prime}-T_1$
$=600-500=100 \mathrm{~K}$

Question100

A car engine has a power of 20 kW. The car makes a roundtrip of 1 h. If the thermal efficiency of the engine is 40% and the ambient temperature is 300 K . The energy generated by fuel combustion is

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Options:

A. 180000 kJ

B. 240000 kJ

C. 360000 kJ

D. 270000 kJ

Answer: A

Solution:

given, power of engine, $P = 20$ kW

$= 2 \times 10^4$ W

Efficiency, $\eta = 40\% = 0.4$

Time, $t = 1$ hour $= 60 \times 60$ s

Energy of car, $E =$ Power $\times$ Time

$= 2 \times 10^4 \times 60 \times 60 = 7.2 \times 10^7$ J

Energy generated by fuel Combustion $= \frac{E}{\eta}$

$= \frac{7.2 \times 10^7}{0.4} = 18 \times 10^7$ J

$= 18 \times 10^4 \times 10^3$ J $= 18 \times 10^4$ kJ $= 180000$ kJ

Question101

The number of vibrational degree of freedom of a diatomic molecule is

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Options:

A. 0

B. 1

C. 2

D. 3

Answer: B

Solution:

A diatomic molecule has one normal mode of vibration, since it can only stretch or compress the single bond. Hence, it has only one vibrational degree of freedom.

Question102

A glass vessel of volume V_o is completely filled with a liquid and its temperature is raised by ΔT. What volume of the liquid will flow over, if the coefficient of linear expansion of glass is α_g and coefficient of volume expansion of the liquid is γ_l ?

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Options:

A. $V_0 \Delta T\left(\gamma_1-3 \alpha_g\right)$

B. $V_0 \Delta T\left(3 \alpha_g-\gamma_1\right)$

C. $\left(\lambda_l-3 \alpha_g\right) \Delta T$

D. $\left(3 \alpha_g-\gamma_1\right) \Delta T$

Answer: A

Solution:

Given,

Volume of glass vessel and liquid $=V_o$

Change in temperature $= \Delta T$

Linear expansion of glass $= \alpha_g$

Volume expansion of liquid $= \gamma_l$

Let final volume of glass and liquid be V_g and V_l, then

$$V_g = V_o\left(1 + 3\alpha_g \Delta T\right)$$
$$V_l = V_o\left(1 + \gamma_l \Delta T\right)$$

Volume of liquid flowing out,

$$V_l - V_g = V_0\left(1 + \gamma_l \Delta T\right) - V_0\left(1 + 3\alpha_g \Delta T\right) = V_o \Delta T\left(\gamma_l - 3\alpha_g\right)$$

Question103

A Carnot engine whose heat sink is at 27°Chas an efficiency of 40%. By how muchshould its source temperature be changed, soas to increase its efficiency to 60%?

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Options:

A. 250 K

B. 100 K

C. 500 K

D. 350 K

Answer: A

Solution:

Given, sink temperature, $T_2 = 27^\circ\text{C} = 300$ K

Case I Efficiency, $\eta_1 = 40\%$

Case II Efficiency, $\eta_2 = 60\%$

Let temperature of source in two cases be T_1 and T_1'.

As we know that,

$$\eta_1 = 1 - \frac{T_2}{T_1}$$

$$\Rightarrow \quad \frac{40}{100} = 1 - \frac{300}{T_1}$$

$$\Rightarrow \quad T_1 = 500 \text{ K}$$

and $\quad \eta_2 = 1 - \frac{T_2}{T_1'}$

$$\Rightarrow \quad \frac{60}{100} = 1 - \frac{300}{T_1'} \Rightarrow \frac{300}{T_1'} = \frac{40}{100}$$

$$\Rightarrow \quad T_1' = 750 \text{ K}$$

$\therefore$ Change is temperature, $\Delta T = T_1' - T_1$

$= 750 - 500 = 250$ K

Question104

A diatomic gas is heated at constantpressure, what fraction of the heat energy isused to increase the internal energy?

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Options:

A. $\frac{3}{5}$

B. $\frac{3}{7}$

C. $\frac{5}{7}$

D. $\frac{5}{9}$

Answer: C

Solution:

Given, nature of gas = Diatomic (at constant pressure)

As we know that,

Internal energy, $U = nC_V\Delta T$ ...... (i)

Heat energy, $Q = nC_p\Delta T$ ...... (ii) where, n = number of mole

C_V = specific heat at constant volume

C_p = specific heat at constant pressure

and $C_p = C_V + R$

If f = degree of freedom, then

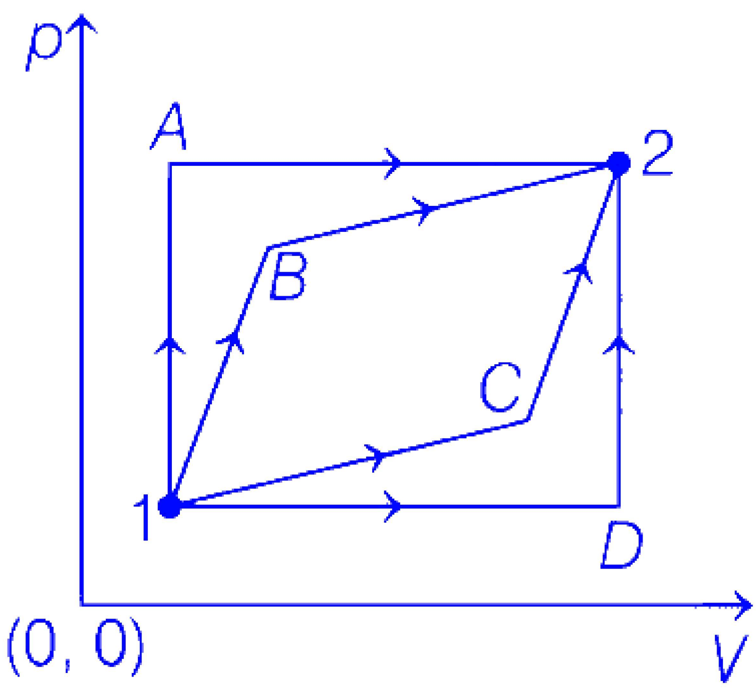
$C_p = \frac{f}{2} + R = \frac{5R}{2} + R = \frac{7R}{2}$

Now, dividing Eq. (i) by Eq. (ii), we get

$\Rightarrow \quad \frac{U}{Q} = \frac{nC_V\Delta T}{nC_p\Delta T} = \frac{C_V}{C_p} = \frac{5R/2}{7R/2} = \frac{5}{7}$

Question105

An ideal gas is taken from state-1 to state- 2 through optional path A, B, C and D as shown in the p - V diagram. Let Q, W and U represent the heat supplied, work done and change in internal energy respectively, then



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Options:

A. $Q_A - Q_D = W_A - W_D$

B. $Q_B - W_B > Q_C - W_C$

C. $W_A < W_B < W_C < W_D$

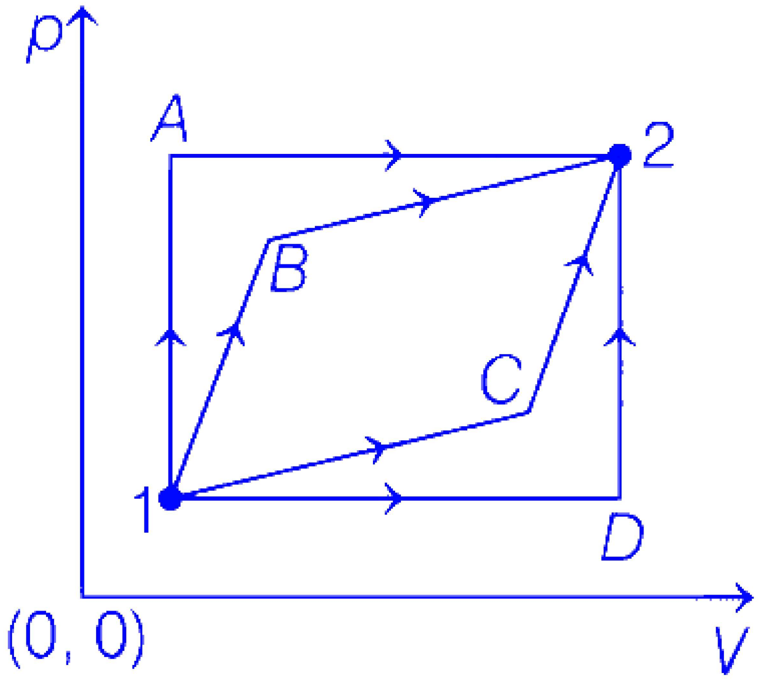
D. $Q_A < Q_B < Q_C < Q_D$

Answer: A

Solution:

According to given p - V diagram,

As we know that work is equal to area under p-V graph.



$\therefore \quad W_A > W_B > W_C > W_D$

and by using 1st law of thermodynamics,

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

Here, internal energy, $\Delta U = 0$

$\because$ Initial and final positions are same.

$\therefore$ Heat (ΔQ) sequence will be

$\Delta Q_A > \Delta Q_B > \Delta Q_C > \Delta Q_D$

Hence, $Q_A - Q_D = W_A - W_D$

Question106

When the temperature of an ideal gas is increased from 27°C to 127° C. Calculate the percentage increase in its v_{rms}.

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Options:

A. 37%

B. 11%

C. 33%

D. 15.5%

Answer: D

Solution:

The gas has its temperature increased from 27°C to 127°C.

First, change the temperatures from degrees Celsius to Kelvin:

$T_1 = 27 + 273 = 300\ K$

$T_2 = 127 + 273 = 400\ K$

The root mean square (rms) speed of a gas, v_{rms}, is related to temperature by the formula:

$v_{rms} = \sqrt{\frac{3RT}{M}}$

Here, R is the gas constant and M is the molar mass. Because R and M stay the same, v_{rms} depends only on temperature. We can say:

$v_{rms} \propto \sqrt{T}$

So, the ratio of the rms speeds at T_1 and T_2 is:

$\frac{v_2}{v_1} = \sqrt{\frac{T_2}{T_1}} = \sqrt{\frac{400}{300}} = \frac{2}{\sqrt{3}}$

To find the percentage increase in v_{rms}, use:

Percentage increase $= \left(\frac{v_2 - v_1}{v_1}\right) \times 100$

Substitute the values:

$\left(\frac{v_2}{v_1}-1\right)\times 100=\left(\frac{2}{\sqrt{3}}-1\right)\times 100$

This gives about 15.5% increase in v_{rms}.

Question107

Boiling water is changing into steam. The specific heat of boiling water is

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Options:

A. zero

B. one

C. infinity

D. less than one

Answer: C

Solution:

Specific heat is the amount of heat required to raise the temperature of water by $1^{\circ}\mathrm{C}$.

For boiling of water to turn into steam, $\Delta T=0$

Since, $\Delta Q=nC_p\Delta T$

If $\Delta T=0, C_p=\frac{\Delta Q}{\Delta T}=\frac{\Delta Q}{0}=\infty$

Question108

If the volume of a block of metal changes by 0.12% when heated through $20^{\circ}\mathrm{C}$, then find its coefficient of linear expansion.

Options:

A. $4 \times 10^{-5\circ} \mathrm{C}^{-1}$

B. $4 \times 10^{-4\circ} \mathrm{C}^{-1}$

C. $2 \times 0^{-5\circ} \mathrm{C}^{-1}$

D. $2 \times 10^{-4\circ} \mathrm{C}^{-1}$

Answer: C

Solution:

Given,

Volume change, $\frac{\Delta V}{V} = \frac{0.12}{100} = 12 \times 10^{-4}$

Change in temperature, $\Delta T = 20\Upsilon C$

Since, $\Delta V / V = 3\alpha\Delta T$

where, α is coefficient of linear expansion.

$\therefore \quad \alpha = \frac{\Delta V}{V} \times \frac{1}{3\Delta T} \Rightarrow \alpha = \frac{12 \times 10^{-4}}{3 \times 20} = 2 \times 10^{-5\circ} \mathrm{C}^{-1}$

Question109

Isothermal process is the graph between

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Options:

A. pressure and temperature

B. pressure and volume

C. volume and temperature

D. pV and temperature

Answer: B

Solution:

As we know that,

In case of isothermal condition, T = constant

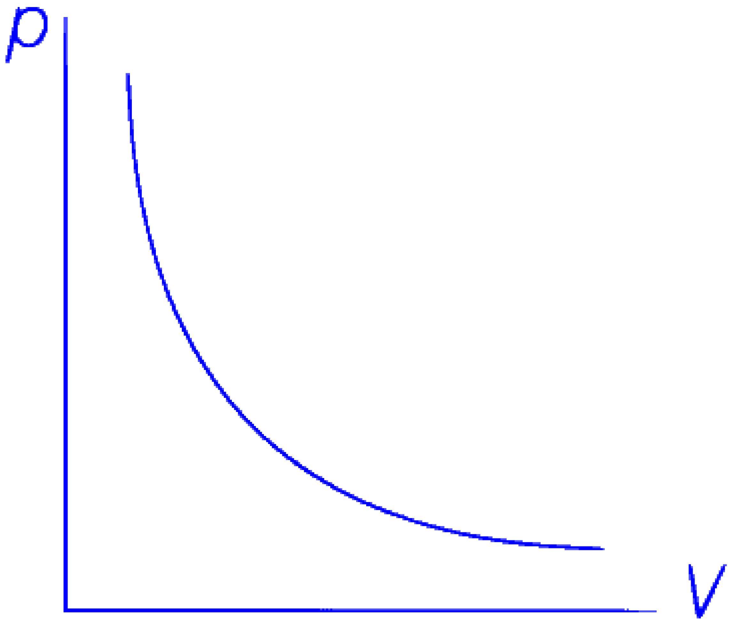
By ideal gas law,

$pV = nRT$

$\Rightarrow \quad pV = \text{constant}$

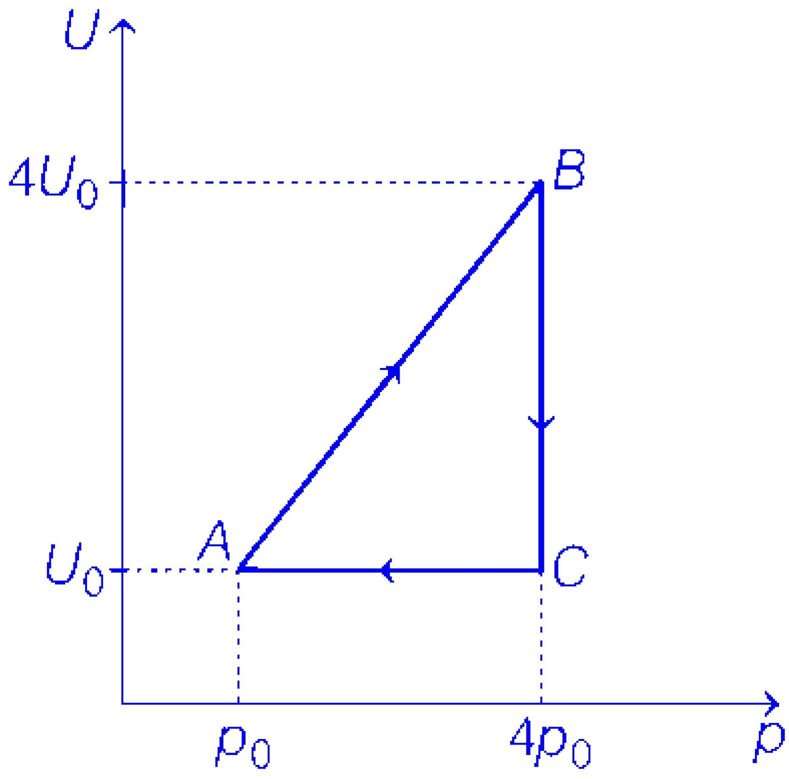
$\Rightarrow \quad p \propto \frac{1}{V}$

$\therefore$ p-V graph is given as:



Question110

For a monoatomic ideal gas is following thecyclic process ABCA shown in the U versus pplot, identify the incorrect option.



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Options:

A. Molar heat capacity of the process AB is $\frac{R}{2}$

B. Heat is rejected by the system in path BC

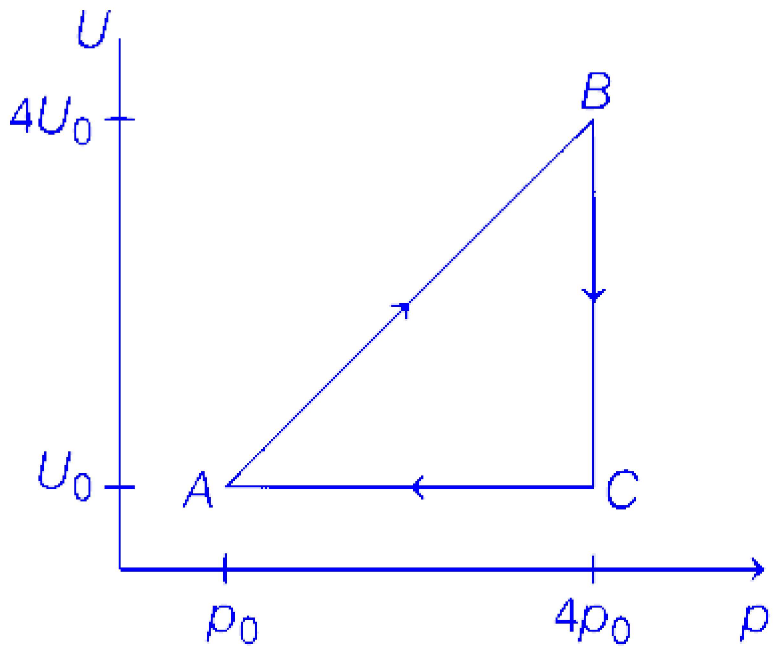
C. Molar heat capacity for the process BC is $\frac{2R}{3}$

D. Work done by the system in the process CA is $\frac{2U_0}{3} \ln 4$

Answer: C

Solution:

According to given graph,



As we know that,

$C=\frac{R}{\gamma-1}-\frac{R}{m-1}$ ..... (i)

where, C_V is heat coefficient at constant volume, R is universal gas constant = 8.314 J K^{-1}, γ is adiabatic constant and m is polytropic constant.

For path $AB, pV^2=$ constant

$\therefore \quad m=2$

and $\gamma_{\text{monoatomic}} \quad =5/2$

Put these values in Eq (i), we get

$C=\frac{R}{\frac{5}{3}-1}-\frac{R}{2-1}=\frac{3R}{2}-R=\frac{R}{2}$

For path BC, density is fixed

$\therefore$ Volume will remain unchanged.

Since, $U=nC_V\Delta T$

where, U is internal energyand C_V (monoatomic gas) $=\frac{3}{2}R$.

Isochoric process, $\Delta V=0$

But temperature is decreasingand $C_V=\frac{3}{2}R$

$\therefore$ Option (c) is incorrect.

For path CA (isothermal)

$W=nRT\ln\frac{p_2}{p_1}=nRT\ln\frac{4p_0}{p_0}=nRT\ln 4$

and $\quad U_0=\frac{3}{2}nRT$

$\therefore \quad W=\frac{2}{3}U_0(\ln 4)$

Question111

The pressure of a gas is proportional to

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Options:

A. the sum of kinetic and potential energies

B. potential energy

C. kinetic energy

D. None of the above

Answer: C

Solution:

As we know that,

Kinetic energy, per unit volume, $E=\frac{1}{2}\rho V^2$ ..... (i)

and pressure per unit volume, $p=\frac{1}{3}\rho V^2$ ..... (ii)

From Eqs. (i) and (ii), we get

$\therefore \quad p=\frac{1}{3}2E \Rightarrow p=\frac{2}{3}E$

Hence, $p \propto E$.

Question112

Expansion during heating

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Options:

A. increases the weight of a material

B. decreases density of material

C. occurs only in solid

D. occurs at same rate of all liquids and solids

Answer: B

Solution:

As we know that, during expansion due to heating, change in volume $\Delta V = V_0 \gamma \Delta T$

Here, V_0, γ and ΔT are initial volume, volumetric expansion coefficient and change in temperature.

Since, density $(\rho) = \frac{\text{mass}(m)}{\text{volume} \quad (V)}$

As volume increases by ΔV.

$\therefore$ Density decreases.

Question113

Match the following.

	Column I		Column II
(A)	Ratio of change in time-period of a sample pendulum with temperature to its original time period	1.	$\alpha \Delta T$
(B)	Ratio of the value of a length to its scale reading	2.	T
(C)	Reciprocal of coefficient of volume expansion for an ideal gas of constant pressure	3.	$(1 + \alpha \Delta T)$
(D)	$\frac{F}{YA}$	4.	$\frac{1}{2} \alpha \Delta T$

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Options:

A. A - 4, B - 2, C - 1, D - 3

B. A - 3, B - 4, C - 2, D - 1

C. A - 4, B - 1, C - 2, D - 3

D. A - 4, B - 3, C - 2, D - 1

Answer: D

Solution:

As we know that,

(A) Since, time period $(T) = 2\pi\sqrt{l/g}$ where, l is length and g is gravity.

$\therefore \quad \frac{\Delta T}{T} = \frac{1}{2}\frac{\Delta l}{l}$ ..... (i)

and by using concept of linear expansion,

$\frac{\Delta l}{l} = \alpha \Delta T$ ..... (ii)

Substituting in Eq. (i), we get

$\frac{\Delta T}{T} = \frac{1}{2}\alpha \Delta T$

(A $\rightarrow$ 4)

(B) Now, from Eq. (ii)

$$\Delta l = l\alpha\Delta T$$
$$\Rightarrow \quad l_0 - l = l\alpha\Delta T \Rightarrow l_0 = l + l\alpha\Delta T$$
$$\Rightarrow \quad l_0/l = l + \alpha\Delta T$$

(B) $\rightarrow$ (3)

(C) $\because p\Delta V = nRT \quad .....$(i)
and $\Delta V = V_0\gamma\Delta T$
$\Rightarrow \Delta V \propto \gamma$
$\Rightarrow \gamma \propto T \quad$ [Using Eq. (i)]

(C) $\rightarrow$ (2)

(D) Since, $Y = \frac{Fl}{A\Delta l} \Rightarrow \frac{\Delta l}{l} = \frac{F}{AY} = \alpha\Delta T$

(D) $\rightarrow$ (1)

$\therefore \quad$ A $\rightarrow$ 4, B $\rightarrow$ 3, C $\rightarrow$ 2, D $\rightarrow$ 1 is correct.

Question114

Which of the following is not a reversibleprocess?

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Options:

A. Melting of ice

B. Conduction of heat

C. Isothermal expansion of gas

D. Adiabatic expansion of gas

Answer: B

Solution:

As we know that,

Irreversible process is the phenomenon whichcan't be reversed back to initial condition.

Since, conduction is the phenomenon in whichheat flows from higher temperature to lowertemperature.

$\therefore$ Conduction is irreversible process.

Question115

Which one of the graphs below bestillustrates the relationship between internalenergy U of an ideal gas and temperature T ofthe gas in K?

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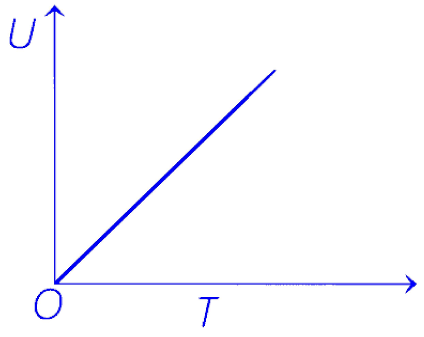
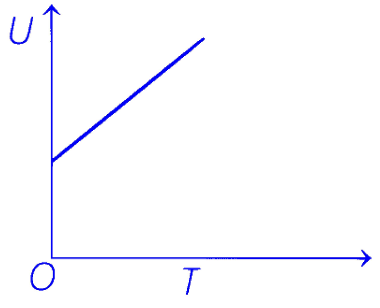
Options:

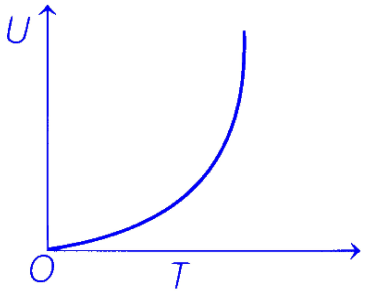
A.



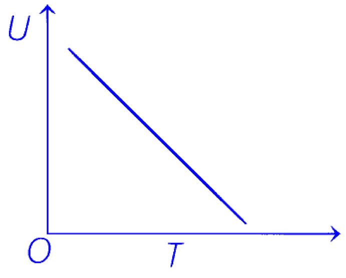
B.



C.



D.



Answer: A

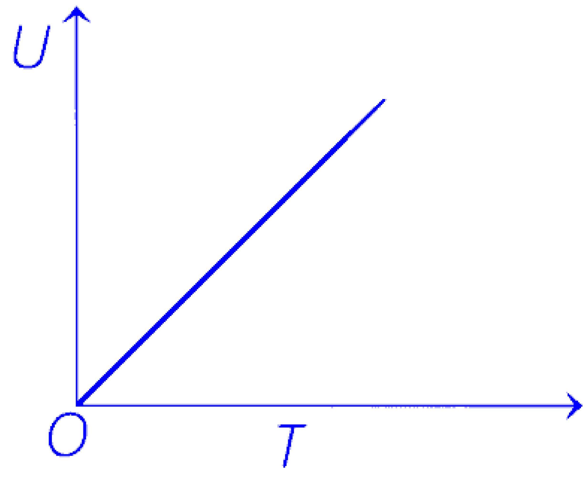
Solution:

Given, internal energy = U

Temperature = T

Since, $U = \frac{3}{2}KT$

$\therefore \quad U \propto T$



Question116

A refrigerator with coefficient ofperformance 0.25 releases 250 J of heat to ahot reservoir. The work done on the workingsubstance is

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Options:

A. $\frac{100}{3}$ J

B. 150 J

C. 200 J

D. 50 J

Answer: C

Solution:

Given, coefficient of performance $(\mathrm{COP}) = 0.25$

Heat coming out, $Q_c = 250$ J

Since,

$$\mathrm{COP} = \frac{Q_L}{\mathrm{Work}(W)}$$

$$\Rightarrow \quad \mathrm{COP} = \frac{Q_L}{Q_H - Q_L} \Rightarrow \frac{Q_H - Q_L}{Q_L} = \frac{100}{25} = 4$$

$$\Rightarrow \quad \frac{Q_H}{Q_L} - 1 = 4 \Rightarrow \frac{Q_H}{Q_L} = 5$$

$$\Rightarrow \quad Q_L = \frac{250}{5} = 50$$

$$\therefore \quad W = Q_H - Q_L$$

$$= 250 - 50 = 200 \mathrm{~J}$$

Question117

A vessel has 6 g of oxygen at pressure p andtemperature 400 K. A small hole is made init, so that oxygen leaks out. How muchoxygen leaks out if the final pressure is p/2and temperature is 300 K?

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Options:

A. 5 g

B. 4 g

C. 2 g

D. 3 g

Answer: C

Solution:

Given, mass of oxygen, $m_i = 6$ g

Initial pressure $p_i = p$

Initial temperature $T_i = 400$ K

Mass of oxygen leak $= m'$

Final pressure, $p_f = \frac{p}{2}$

Final temperature, $T_f = 300$ K

Since, $pV = \frac{m}{M} RT$

where, m is given mass

M is molar mass and R is gas constant

Now, $\frac{p_i}{T_i m_i} = \frac{p_f}{T_f m_f}$

$\Rightarrow m_f = \left(\frac{p_f}{T_f}\right) \cdot \left(\frac{T_i m_i}{p_i}\right) = \left(\frac{p}{2 \times 300} \times \frac{400 \times 6}{p}\right) = 4 \text{ g}$

$\therefore$ Mass of oxygen leakes out $= 6 - 4 = 2$ g

Question118

In a steady state, the temperature at the end A and end B of a 20 cm long rod AB are 100Υ and $0^{\circ}\mathrm{C}$. The temperature of a point 9 cm from A is

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Options:

A. 55°C

B. 45°C

C. 65°C

D. 50°C

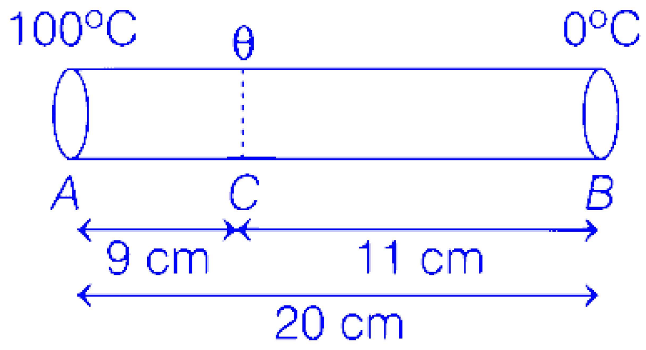
Answer: A

Solution:

Given, initial and final length of rod is l_1 and l_2 i.e., 20 cm and 9 cm from A, and temperature at A and B is T_A and T_B i.e., 100°C and 0°C.

Now, since, heat flow rate $= \frac{dQ}{dt} = \frac{KA\Delta\theta}{\lambda}$

As the flow is steady,



$$\therefore \quad \frac{KA(100-\theta)}{9} = \frac{KA(\theta-0)}{11}$$

$$\Rightarrow \quad 1100 - 11\theta = 9\theta$$

$$\Rightarrow \quad 1100 = 20\theta$$

$$\therefore \quad \theta = 55^{\circ}\mathrm{C}$$

Question119

If two rods of length L and $2L$, having coefficients of linear expansion α and 2α respectively are connected end-to-end, then find the average coefficient of linear expansion of the composite rod.

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Options:

A. $\frac{3\alpha}{2}$

B. $\frac{5\alpha}{2}$

C. $\frac{5\alpha}{4}$

D. $\frac{5\alpha}{3}$

Answer: D

Solution:

Given, length of rods are L and $2L$.

Coefficient of linear expansion α and 2α.

As, we know that,

$\Delta l = l_0 \alpha \Delta T$

where, Δl is change in length,

T is temperature

and l_0 is initial length

let final heat coefficient be α'

$$\begin{aligned} \therefore \quad (L+2L)\alpha'\Delta T &= L\alpha\Delta T + 2L \cdot 2\alpha \cdot \Delta T \\ \Rightarrow \quad 3\alpha' &= \alpha + 4\alpha = 5\alpha \\ \Rightarrow \quad \alpha' &= 5\alpha/3 \end{aligned}$$

Question120

A system is taken from state-A to state-Balong two different paths. The heat absorbedand work done by the system along thesetwo paths are Q_1, Q_2 and W_1, W_2 respectively, then

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Options:

A. $Q_1 = Q_2$

B. $W_1 = W_2$

C. $Q_1 - W_1 = Q_2 - W_2$

D. $Q_1 + W_1 = Q_2 + W_2$

Answer: C

Solution:

Given, heat absorbed and work done by two systems be Q_1, Q_2 and W_1, W_2 and as we know that, By using Ist law of thermodynamics,

$\Delta Q = \Delta U + \Delta W \Rightarrow \Delta U = \Delta Q - \Delta W$

where, ΔQ is heat change, ΔU is internal energy change i.e. state function and ΔW is work done.

$$\therefore \quad \Delta Q_1 - \Delta W_1 = \Delta Q_2 - \Delta W_2$$
$$\text{or} \quad Q_1 - W_1 = Q_2 - W_2$$

Question121

A gas ($\gamma = 1.5$) is suddenly compressed to(1/4)th its initial volume. Then, find the ratioof its final to initial pressure.

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Options:

A. 1 : 16

B. 1 : 8

C. 1 : 4

D. 8 : 1

Answer: D

Solution:

Given, adiabatic constant $\gamma = 1.5 = 3/2$

Let initial volume, $V_1 = V$

$\therefore$ Final volume, $V_2 = V/4$

Initial and final pressure be p_1 and p_2.

$$\text{Since,} \quad pV^\gamma = \text{ constant}$$
$$\therefore \quad p_1 V_1^\gamma = p_2 V_2^\gamma$$
$$\Rightarrow \quad p_1/p_2 = (V_2/V_1)^\gamma = \left(\frac{V}{4 \times V}\right)^{3/2}$$

$\Rightarrow p_1/p_2 = \frac{1}{8}$

Hence, $p_2 : p_1 = 8 : 1$

Question122

A cylinder has a piston at temperature of 30ΥC. There is all round clearance of 0.08 mm between the piston and cylinder wall if internal diameter of the cylinder is 15 cm. What is the temperature at which piston will fit into the cylinder exactly?

$\left(\alpha_p = 1.6 \times 10^{-5} / \Upsilon\mathrm{C} \text{ and } \alpha_c = 1.2 \times 10^{-5} / \Upsilon\mathrm{C}\right)$

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Options:

A. 298ΥC

B. 273ΥC

C. 305ΥC

D. 268ΥC

Answer: C

Solution:

Given, initial temperature $T_1 = 30^{\circ}\mathrm{C} = 303$ K

Change in radius, $\Delta r = 0.08$ mm

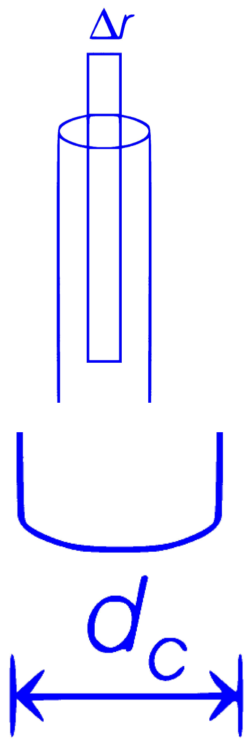
Internal diameter of cylinder $d_c = 15$ cm

$\therefore$ Internal radius of cylinder, $r_c = 7.5 \times 10^{-2}$ m

Radius of piston, $r_p = (7.5 - 0.008) \times 10^{-2}$ m

$= 7.492 \times 10^{-2}$ m

Linear expansion of cylinder α_C and piston α_p are $1.2 \times 10^{-5} / {}^{\circ}\mathrm{C}$ and $1.6 \times 10^{-5} / {}^{\circ}\mathrm{C}$.



Let, Δr_C and Δr_p is increase in radius of cylinder and piston respectively, for fully filled piston in cylinder.

By using equation of linear expansion,

$$r = r_0(1 + \alpha \Delta T)$$
$$\therefore \quad \Delta r_C = r_C \alpha_C \Delta T, \text{ for cylinder}$$

New radius will be $r'_C = r_C + \Delta r_C$

$$= r_C + r_C \alpha_C \Delta T = r_C (1 + \alpha_C \Delta T)$$
$$= 7.5 \times 10^{-2} \left[1 + 1.2 \times 10^{-5}(T - 303)\right]$$

Similarly, new radius of piston,

$$r_p{}' = 7.492 \times 10^{-2} \left[1 + 1.6 \times 10^{-5}(T - 303)\right]$$

Now, for fully fitted piston, $r_C = r_p$

$$7.5 \times 10^{-2}[1{+}1.2 \times 10^{-5}(T - 303)]$$
$$= 7.492 \times 10^{-2} \left[1 + 1.6 \times 10^{-5}(T - 303)\right]$$
$$\Rightarrow \quad 1.0011 + 1.2013 \times 10^{-5}(T - 303)$$
$$= 1 + 1.6 \times 10^{-5}(T - 303)$$
$$\Rightarrow 1.1 \times 10^{-3} = (T - 303) \times 10^{-5}(1.6 - 1.2013)$$
$$= (T - 303) \times 10^{-5} \times 0.3987$$
$$\Rightarrow T - 303 = 275$$
$$\Rightarrow \quad T = 578 \text{ K} = 305^\circ\text{C}$$

Question123

A balloon contains 1500 m^3 of He at 27ϒC and 4 atmospheric pressure, the volume of He at -3ϒC temperature and 2 atmospheric pressure will be

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Options:

A. 1500 m^3

B. 1700 m^3

C. 1900 m^3

D. 2700 m^3

Answer: D

Solution:

Given, initial volume, temperature and pressure be V_1, T_1 and p_1 are 1500 m^3, 27°C and 4 atm.

Final volume, temperature and pressure are V_2, T_2 and p_2 are V_2, -3°C and 2 atm

By using ideal gas equation,

$$pV = nRT$$

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

$$\Rightarrow \quad \frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

$$\Rightarrow \quad V_2 = \frac{p_1 V_1 T_2}{T_1 p_2}$$

$$\therefore \quad V_2 = \frac{4 \times 1500 \times 270}{300 \times 2} = 2700 \text{ m}^3$$
