CHAPTER

# 8 Thermodynamics

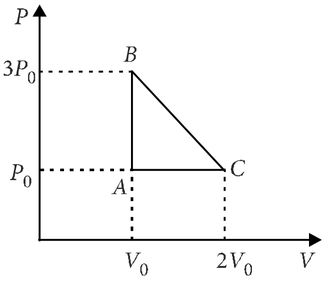
**1.** Two moles of an ideal monatomic gas occupies a volume $V$ at 27°C. The gas expands adiabatically to a volume $2V$. Calculate (i) the final temperature of the gas and (ii) change in its internal energy.
(a) (i) 198 K (ii) 2.7 kJ
(b) (i) 195 K (ii) −2.7 kJ
(c) (i) 189 K (ii) −2.7 kJ
(d) (i) 195 K (ii) 2.7 kJ *(2018)*

**2.** One mole of an ideal monoatomic gas is compressed isothermally in a rigid vessel to double its pressure at room temperature, 27°C. The work done on the gas will be
(a) $300\,R$ (b) $300\,R \ln 2$
(c) $300\,R \ln 6$ (d) $300\,R \ln 7$
*(Online 2018)*

**3.** A Carnot's engine works as a refrigerator between 250 K and 300 K. It receives 500 cal heat from the reservoir at the lower temperature. The amount of work done in each cycle to operate the refrigerator is
(a) 2520 J (b) 772 J (c) 2100 J (d) 420 J
*(Online 2018)*

**4.** Two Carnot engines $A$ and $B$ are operated in series. Engine $A$ receives heat from a reservoir at 600 K and rejects heat to a reservoir at temperature $T$. Engine $B$ receives heat rejected by engine $A$ and in turn rejects it to a reservoir at 100 K. If the efficiencies of the two engines $A$ and $B$ are represented by $\eta_A$ and $\eta_B$, respectively, then what is the value of $\eta_B/\eta_A$?
(a) $\frac{7}{12}$ (b) $\frac{5}{12}$ (c) $\frac{12}{7}$ (d) $\frac{12}{5}$
*(Online 2018)*

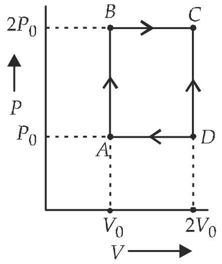
**5.** One mole of an ideal monoatomic gas is taken along the path $ABCA$ as shown in the $PV$ diagram. The maximum temperature attained by the gas along the path $BC$ is given by




(a) $\frac{5}{8}\frac{P_0V_0}{R}$
(b) $\frac{25}{8}\frac{P_0V_0}{R}$
(c) $\frac{25}{4}\frac{P_0V_0}{R}$ (d) $\frac{25}{16}\frac{P_0V_0}{R}$ *(Online 2018)*

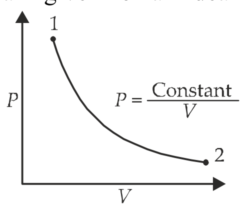
**6.** The temperature of an open room of volume 30 $m^3$ increases from 17°C to 27°C due to the sunshine. The atmospheric pressure in the room remains $1 \times 10^5$ Pa. If $N_i$ and $N_f$ are the number of molecules in the room before and after heating, then $N_f - N_i$ will be
(a) $-1.61 \times 10^{23}$ (b) $1.38 \times 10^{23}$
(c) $2.5 \times 10^{25}$ (d) $-2.5 \times 10^{25}$ *(2017)*

**7.** An engine operates by taking $n$ moles of an ideal gas through the cycle $ABCDA$ shown in figure. The thermal efficiency of the engine is (Take $C_V = 1.5R$, where $R$ is gas constant)

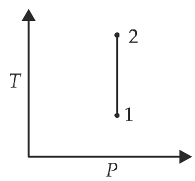


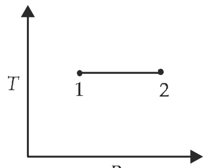

(a) 0.15
(b) 0.32
(c) 0.24
(d) 0.08
*(2017)*

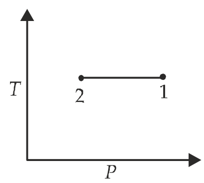
**8.** For the $P$-$V$ diagram given for an ideal gas,

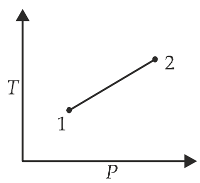



out of the following which one correctly represents the $T$-$P$ diagram?

(a)



(b)



(c)



(d)


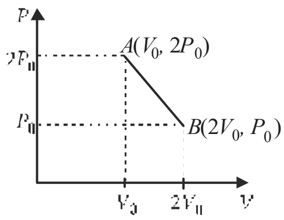

*(Online 2017)*

**9.** An ideal gas undergoes a quasi static, reversible process in which its molar heat capacity $C$ remains constant. If during this process the relation of pressure $P$ and volume $V$ is given by $PV^n$ = constant, then $n$ is given by (Here $C_P$ and $C_V$ are molar specific heat at constant pressure and constant volume, respectively) :

(a) $= \frac{Y_m}{Y_s}$ (b) $= \frac{Y - Y_m}{Y - Y_s}$

(c) $= \frac{Y_m - Y}{Y - Y_s}$ (d) $= \frac{Y - Y_s}{Y - Y_m}$ 5GEFL6

**10.** '$n$' moles of an ideal gas undergoes a process $A \to B$ as shown in the figure. The maximum temperature of the gas during the process will be :




(a) $\frac{>mgs\ 5}{9\ o}$

(b) $\frac{8mgs\ 5}{7\ o}$

(c) $\frac{>mgs\ 5}{7\ o}$ (d) $\frac{>mgs\ 5}{o}$ *(2016)*

**11.** The ratio of work done by an ideal monoatomic gas to the heat supplied to it in an isobaric process is

(a) $\frac{2}{5}$ (b) $\frac{3}{2}$ (c) $\frac{3}{5}$ (d) $\frac{2}{3}$ *(Online 2016)*

**12.** 200 g water is heated from 40° C to 60°C. Ignoring the slight expansion of water, the change in its internal energy is close to (Given specific heat of water = 4184 J/kg/K)

(a) 167.4 kJ (b) 8.4 kJ

(c) 4.2 kJ (d) 16.7 kJ *(Online 2016)*

**13.** A Carnot freezer takes heat from water at 0°C inside it and rejects it to the room at a temperature of 27°C. The latent heat of ice is 336 × $10^3$ J $kg^{-1}$. If 5 kg of water at 0°C is converted into ice at 0°C by the freezer, then the energy consumed by the freezer is close to

(a) 1.51 × $10^5$ J (b) 1.68 × $10^6$ J

(c) 1.71 × $10^7$ J (d) 1.67 × $10^5$ J *(Online 2016)*

**14.** A solid body of constant heat capacity 1 J/°C is being heated by keeping it in contact with reservoirs in two ways

(i) Sequentially keeping in contact with 2 reservoirs such that each reservoir supplies same amount of heat.

(ii) Sequentially keeping in contact with 8 reservoirs such that each reservoir supplies same amount of heat.

In both the cases body is brought from initial temperature 100°C to final temperature 200°C. Entropy change of the body in the two cases respectively is

(a) ln2, 2ln2 (b) 2ln2, 8ln2

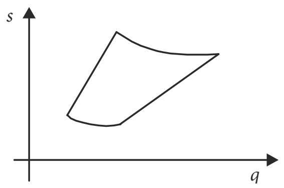
(c) ln2, 4ln2 (d) ln2, ln2 *(2015)*

**15.** Consider a spherical shell of radius $R$ at temperature $T$. The black body radiation inside it can be considered as an ideal gas of photons with internal energy per unit volume $= \frac{r}{s} \propto q^9$ and pressure $= \frac{6}{8}\left(\frac{r}{s}\right)$. If the shell now undergoes an adiabatic expansion the relation between $T$ and $R$ is

(a) $q \propto \frac{6}{o}$ (b) $q \propto \frac{6}{o^8}$

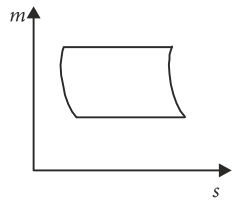
(c) $T \propto e^{-R}$ (d) $T \propto e^{-3R}$ *(2015)*

**16.** An ideal gas goes through a reversible cycle $a \to b \to c \to d$ has the $V$-$T$ diagram shown below. Process $d \to a$ and $b \to c$ are adiabatic.

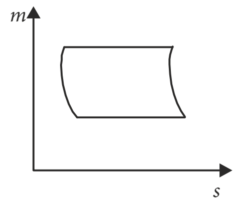



The corresponding $P$-$V$ diagram for the process is (all figures are schematic and not drawn to scale)

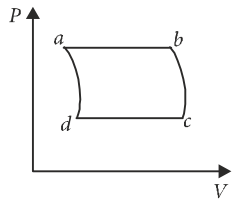
(a)



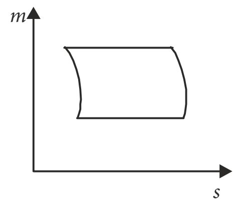

(b)




(c)

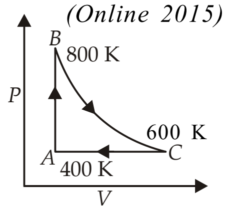



(d)




*(Online 2015)*

**17.** One mole of diatomic ideal gas undergoes a cyclic process $ABC$ as shown in figure. The process $BC$ is adiabatic. The temperatures at $A$, $B$ and $C$ are 400 K, 800 K and 600 K respectively.




Choose the correct statement.

(a) The change in internal energy in the process $BC$ is – 500 $R$.

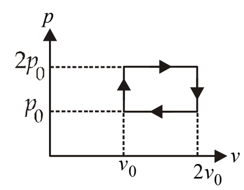
(b) The change in internal energy in whole cyclic process is 250 $R$.

(c) The change in internal energy in the process $CA$ is 700 $R$.

(d) The change in internal energy in the process $AB$ is – 350 $R$.

*(2014)*

**18.** The above $p$-$v$ diagram represents the thermodynamic cycle of an engine, operating with an ideal monoatomic gas. The amount of heat, extracted from the source in a single cycle is




(a) $4p_0v_0$ (b) $p_0v_0$

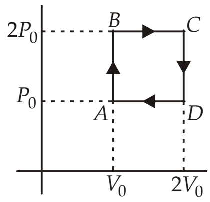
(c) $\left(\frac{13}{2}\right)p_0v_0$ (d) $\left(\frac{11}{2}\right)p_0v_0$ *(2013)*

**19.** A Carnot engine, whose efficiency is 40%, takes in heat from a source maintained at a temperature of 500 K. It is desired to have an engine of efficiency 60%. Then, the intake temperature for the same exhaust (sink) temperature must be

(a) 1200 K (b) 750 K
(c) 600 K
(d) efficiency of Carnot engine cannot be made larger than 50%

*(2012)*

**20.** Helium gas goes through a cycle $ABCDA$ (consisting of two isochoric and two isobaric lines) as shown in figure. Efficiency of this cycle is nearly (Assume the gas to be close to ideal gas)




(a) 9.1% (b) 10.5% (c) 12.5% (d) 15.4%

*(2012)*

**21.** Three perfect gases at absolute temperatures $T_1, T_2$ and $T_3$ are mixed. The masses of molecules are $m_1, m_2$ and $m_3$ and the number of molecules are $n_1$, $n_2$ and $n_3$ respectively. Assuming no loss of energy, the final temperature of the mixture is

(a) $\frac{(T_1 + T_2 + T_3)}{3}$ (b) $\frac{n_1T_1 + n_2T_2 + n_3T_3}{n_1 + n_2 + n_3}$

(c) $\frac{n_1T_1^2 + n_2T_2^2 + n_3T_3^2}{n_1T_1 + n_2T_2 + n_3T_3}$ (d) $\frac{n_1^2T_1^2 + n_2^2T_2^2 + n_3^2T_3^2}{n_1T_1 + n_2T_2 + n_3T_3}$

*(2011)*

**22.** A Carnot engine operating between temperatures $T_1$ and $T_2$ has efficiency $\frac{1}{6}$. When $T_2$ is lowered by 62 K, its efficiency increases to $\frac{1}{3}$. Then $T_1$ and $T_2$ are, respectively

(a) 372 K and 310 K (b) 372 K and 330 K
(c) 330 K and 268 K (d) 310 K and 248 K

*(2011)*

**23.** 100 g of water is heated from 30°C to 50°C. Ignoring the slight expansion of the water, the change in its internal energy is (specific heat of water is 4184 J $kg^{-1}$ $K^{-1}$)

(a) 4.2 kJ (b) 8.4 kJ
(c) 84 kJ (d) 2.1 kJ *(2011)*

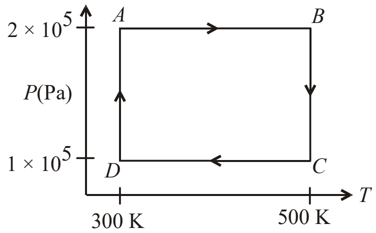
**24.** A diatomic ideal gas is used in a Carnot engine as the working substance. If during the adiabatic expansion part of the cycle the volume of the gas increases from $V$ to $32V$, the efficiency of the engine is

(a) 0.25 (b) 0.5 (c) 0.75 (d) 0.99

*(2010)*

**Directions:** Question numbers 25, 26 and 27 are based on the following paragraph.

Two moles of helium gas are taken over the cycle $ABCDA$, as shown in the $P$ - $T$ diagram.




**25.** Assuming the gas to be ideal the work done on the gas in taking it from $A$ to $B$ is

(a) $200R$ (b) $300R$
(c) $400R$ (d) $500R$

**26.** The work done on the gas in taking it from $D$ to $A$ is

(a) $-414R$ (b) $+414R$
(c) $-690R$ (d) $+690R$

**27.** The net work done on the gas in the cycle $ABCDA$ is

(a) zero (b) $276R$
(c) $1076R$ (d) $1904R$ *(2009)*

**28.** An insulated container of gas has two chambers separated by an insulating partition. One of the chambers has volume $V_1$ and contains ideal gas at pressure $P_1$ and temperature $T_1$. The other chamber has volume $V_2$ and contains ideal gas at pressure $P_2$ and temperature $T_2$. If the partition is removed without doing any work on the gas, the final equilibrium temperature of the gas in the container will be

(a) $\frac{T_1T_2(P_1V_1 + P_2V_2)}{P_1V_1T_1 + P_2V_2T_2}$ (b) $\frac{T_1T_2(P_1V_1 + P_2V_2)}{P_1V_1T_2 + P_2V_2T_1}$

(c) $\frac{P_1V_1T_1 + P_2V_2T_2}{P_1V_1 + P_2V_2}$ (d) $\frac{P_1V_1T_2 + P_2V_2T_1}{P_1V_1 + P_2V_2}$

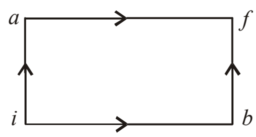
*(2008, 2004)*

**29.** A Carnot engine, having an efficiency of $\eta = 1/10$ as heat engine, is used as a refrigerator. If the work done on the system is 10 J, the amount of energy absorbed from the reservoir at lower temperature is

(a) 100 J (b) 99 J (c) 90 J (d) 1 J

*(2007)*

**30.** When a system is taken from state $i$ to state $f$ along the path $iaf$, it is found that $Q$ = 50 cal and $W$ = 20 cal. Along the path $ibf$, $Q$ = 36 cal. $W$ along the path $ibf$ is

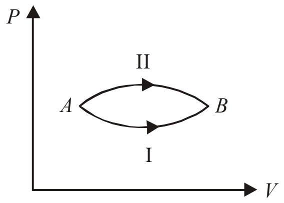



(a) 14 cal (b) 6 cal
(c) 16 cal (d) 66 cal *(2007)*

**31.** The work of 146 kJ is performed in order to compress one kilo mole of gas adiabatically and in this process the temperature of the gas increases by 7ºC. The gas is ($R$ = 8.3 J $mol^{-1}$ $K^{-1}$)

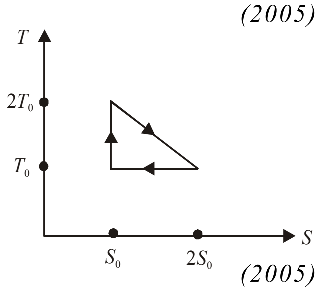
(a) monoatomic (b) diatomic
(c) triatomic
(d) a mixture of monoatomic and diatomic. *(2006)*

**32.** A system goes from $A$ to $B$ *via* two processes I and II as shown in figure. If $\Delta U_1$ and $\Delta U_2$ are the changes in internal energies in the processes I and II respectively, then




(a) $\Delta U_2 > \Delta U_1$
(b) $\Delta U_2 < \Delta U_2$
(c) $\Delta U_1 = \Delta U_2$
(d) relation between $\Delta U_1$ and $\Delta U_2$ cannot be determined *(2005)*

**33.** The temperature-entropy diagram of a reversible engine cycle is given in the figure. Its efficiency is




(a) 1/3
(b) 2/3
(c) 1/2
(d) 1/4 *(2005)*

**34.** Which of the following is incorrect regarding the first law of thermodynamics?
(a) It introduces the concept of the internal energy.
(b) It introduces the concept of entropy.
(c) It is not applicable to any cyclic process.
(d) It is a restatement of the principle of conservation of energy. *(2005)*

**35.** Which of the following statements is correct for any thermodynamic system?
(a) The internal energy changes in all processes.
(b) Internal energy and entropy are state functions.
(c) The change in entropy can never be zero.
(d) The work done in an adiabatic process is always zero. *(2004)*

**36.** A Carnot engine takes $3 \times 10^6$ cal of heat from a reservoir at 627°C, and gives it to a sink at 27°C. The work done by the engine is
(a) $4.2 \times 10^6$ J (b) $8.4 \times 10^6$ J
(c) $16.8 \times 10^6$ J (d) zero. *(2003)*

**37.** Which of the following parameters does not characterize the thermodynamic state of matter?
(a) temperature (b) pressure
(c) work (d) volume. *(2003)*

**38.** During an adiabatic process, the pressure of a gas is found to be proportional to the cube of its absolute temperature. The ratio $C_P/C_V$ for the gas is
(a) 4/3 (b) 2 (c) 5/3 (d) 3/2. *(2003)*

**39.** "Heat cannot by itself flow from a body at lower temperature to a body at higher temperature" is a statement or consequence of
(a) second law of thermodynamics
(b) conservation of momentum
(c) conservation of mass
(d) first law of thermodynamics. *(2003)*

**40.** Even Carnot engine cannot give 100% efficiency because we cannot
(a) prevent radiation
(b) find ideal sources
(c) reach absolute zero temperature
(d) eliminate friction. *(2002)*

**41.** Which statement is incorrect?
(a) All reversible cycles have same efficiency.
(b) Reversible cycle has more efficiency than an irreversible one.
(c) Carnot cycle is a reversible one.
(d) Carnot cycle has the maximum efficiency in all cycles. *(2002)*

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

## ANSWER KEY

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1.** (c) | **2.** (b) | **3.** (d) | **4.** (c) | **5.** (b) | **6.** (d) | **7.** (a) | **8.** (c) | **9.** (b) | **10.** (a) | **11.** (a) | **12.** (d) |
| **13.** (d) | **14.** (*) | **15.** (a) | **16.** (a) | **17.** (a) | **18.** (c) | **19.** (b) | **20.** (d) | **21.** (b) | **22.** (a) | **23.** (b) | **24.** (c) |
| **25.** (c) | **26.** (b) | **27.** (b) | **28.** (b) | **29.** (c) | **30.** (b) | **31.** (b) | **32.** (c) | **33.** (a) | **34.** (b, c) | **35.** (b) | **36.** (b) |
| **37.** (c) | **38.** (d) | **39.** (a) | **40.** (c) | **41.** (a) | **42.** (b) | | | | | | |

# Explanations

**1.** **(c) :** For an adiabatic process, $PV^{\gamma}$ = constant

$\frac{nRT}{V}V^{\gamma}$ = constant or $TV^{\gamma-1}$ = constant

$\therefore \; T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1}; \; T_2 = T_1\left(\frac{V_1}{V_2}\right)^{\gamma-1}$

Here, $T_1$ = 27°C = 300 K, $V_1 = V$, $V_2 = 2V$

$\gamma = \frac{5}{3}$

$$\therefore \; T_2 = 300\left(\frac{V}{2V}\right)^{\left(\frac{5}{3}-1\right)} = 300\left(\frac{1}{2}\right)^{\frac{2}{3}} \approx 189 \text{ K}$$

Change in internal energy, $\Delta U = nC_V\,\Delta T$

$$= n\left(\frac{f}{2}R\right)(T_2 - T_1) = 2 \times \frac{3}{2} \times \frac{25}{3}(189 - 300)$$

$= -25 \times 111 = -2775$ J = $-$ 2.7 kJ

**2.** **(b) :** Work done on gas = $nRT\ln\left(\frac{P_f}{P_i}\right)$

= $R(300)\ln(2) = 300\,R\ln2$

**3.** **(d) :** For a refrigerator, $1 - \frac{T_2}{T_1} = \frac{W}{Q_2 + W}$

$$\Rightarrow \; 1 - \frac{250}{300} = \frac{W}{Q_2 + W} \;\Rightarrow\; \frac{Q_2 + W}{W} = \frac{300}{50} = 6$$

$$W = \frac{Q_2}{5} = \frac{500 \times 4.2}{5} \text{ J} = 420 \text{ J}$$

**4.** **(c)**

**5.** **(b) :** Equation of line $BC$ is given by

$$P = P_0 - \frac{2P_0}{V_0}(V - 2V_0) \text{ or } PV = P_0V - \frac{2P_0}{V_0}(V - 2V_0)V$$

$$T = \frac{P_0V - \frac{2P_0V^2}{V_0} + 4P_0V}{1 \times R} \quad (\because \; PV = nRT)$$

$$T = \frac{P_0}{R}\left[5V - \frac{2V^2}{V_0}\right]$$

For maximum value of $T$, $\frac{dT}{dV} = 0$ or $5 - \frac{4V}{V_0} = 0 \Rightarrow V = \frac{5}{4}V_0$

$$\therefore \; T_{\max} = \frac{P_0}{R}\left[5 \times \frac{5V_0}{4} - \frac{2}{V_0} \times \frac{25}{16}V_0^2\right] = \frac{25}{8}\frac{P_0V_0}{R}$$

**6.** **(d) :** Initially, the gas equation can be written as

$P_0V_0 = n_iRT_0$

$P_0V_0 = n_iR\,(290)$ … (i)

After heating the gas equation will be

$P_0V_0 = n_fR(300)$ … (ii)

$$n_f - n_i = \frac{P_0V_0}{R(300)} - \frac{P_0V_0}{R(290)}$$

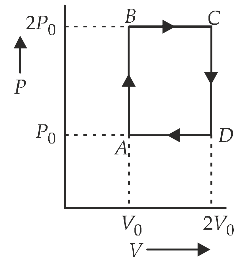
$$\Rightarrow \; n_f - n_i = -\frac{P_0V_0}{R}\left(\frac{10}{290 \times 300}\right)$$

$$\Rightarrow \; N_f - N_i = -\frac{P_0V_0}{R}\left(\frac{10}{290 \times 300}\right)N_A$$

where $N_f$ and $N_i$ are the number of molecules and $N_A$ is Avagadro number.

$$N_f - N_i = \frac{10^5 \times 30 \times 10 \times 6.023 \times 10^{23}}{8.3 \times 290 \times 300} \Rightarrow N_f - N_i = -2.5 \times 10^{25}$$

**7.** **(a) :**




Work done by engine = area under closed curve = $P_0V_0$

Heat given to the system, $Q = Q_{AB} + Q_{BC} = nC_V\Delta T_{AB} + nC_P\Delta T_{BC}$

$= \frac{3}{2}(nRT_B - nRT_A) + \frac{5}{2}(nRT_C - nRT_B)$

$= \frac{3}{2}(2P_0V_0 - P_0V_0) + \frac{5}{2}(4P_0V_0 - 2P_0V_0) = \frac{13}{2}P_0V_0$

Thermal efficiency, $\eta = \frac{W}{Q} = \frac{P_0V_0}{\frac{13}{2}P_0V_0} = \frac{2}{13} \approx 0.15$

**8.** **(c) :** Here, $PV$ = constant, so given process is isothermal *i.e.*, temperature is constant. Pressure at point 1 is higher than that at point 2. So, correct option is (c).

**9.** **(b) :** Here, $PV^n$ = constant

or, $PnV^{n-1}\,dV + V^n\,dP = 0$ or, $nPdV = -\,V\,dP$

Also, from ideal gas equation $PV = nRT$

$PdV + VdP = nR\,dT$ or, $PdV - nPdV = nRdT$

or, $m\;s \;= \frac{o\;\;q}{\text{-}6-\;\;.}$ ...(i)

Also, $dQ = dU + dW \Rightarrow nC\,dT = nC_VdT + PdV$

$Y\;\;q = \;Y_s\;\;q + \frac{o\;\;q}{\text{-}6-\;\;.}$

or, $C = \;Y_s\;\; + \frac{o}{\text{-}6-\;\;.}$ or, $\text{-}6-\;\;. = \frac{o}{Y - Y_s}$

or, $\;\;= 6 - \frac{o}{Y - Y_s} = \frac{Y - \text{-}Y_s\;\;+ o\,.}{Y - Y_s} = \frac{Y - Y_m}{Y - Y_s}$

**10.** **(a) :** Equation of line $AB$ is given by $\;-\;\;6 = \frac{7\;-\;\;6}{7\;-\;\;6}\text{-}\;\;-\;\;6.$

$m - m_5 = \frac{7m_5 - m_5}{s_5 - 7s_5}\text{-}s\;\;-7s_5.$

or, $m = -\frac{m_3}{s_5}s + 8m_3$ or, $ms = -\frac{m_3}{s_5}s^7 + 8m_3 s$

or, $oq = -\frac{m_3}{s_5}s^7 + 8m_3 s$

or, $q = \frac{6}{o}\left(-\frac{m_3}{s_5}s^7 + 8m_3 s\right)$ ...(i)

For maximum value of $T$, $\frac{q}{s} = 5$

or, $-\frac{m_3}{s_5}$-7s . $+8m_3 = 5$ $\therefore$ $s = \frac{8}{7}s_5$

So, from equation (i)

$$q_{y\,m} = \frac{6}{o}\left(-\frac{m_3}{s_5} \times \frac{>}{9}s_5^7 + \frac{>}{7}m_3 s_5\right) = \frac{>}{9}\frac{m_3 s_5}{o}$$

**11. (a):** For an ideal gas in an isobaric process,
Heat supplied, $Q = nC_p\Delta T$
Work done, $W = P\Delta V = nR\Delta T$

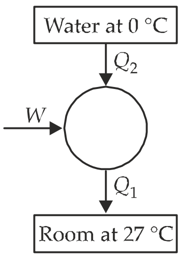
$\therefore$ Required Ratio $= \frac{W}{Q} = \frac{nR\Delta T}{nC_p\Delta T} = \frac{R}{\frac{5}{2}R} = \frac{2}{5}$

( For monoatomic gas, $C_p = \frac{5}{2}R$ )

**12. (d):** For isochoric process, $\Delta U = Q = ms\,\Delta T$
Here, $m = 200$ g $= 0.2$ kg, $s = 4184$ J/kg/K
$\Delta T = 60°C - 40°C = 20$ °C $= 20$ K
$\therefore$ $\Delta U = 0.2 \times 4184 \times 20 = 16736$ J $= 16.7$ kJ

**13. (d) :** Energy consumed by the freezer,

$$W = Q_2\left(\frac{T_1}{T_2} - 1\right)$$




Here, $T_1 = 27$ °C $= 300$ K,
$T_2 = 0$ °C $= 273$ K
$Q_2 = mL = 5 \times 336 \times 10^3$ J

$\therefore$ $W = 5 \times 336 \times 10^3\left(\frac{300}{273} - 1\right)$
$= 1.67 \times 10^5$ J

**14. (*) :** Since entropy is a state function and the entropy change is independent of the path followed, therefore for both cases

$$\Delta S = \int \frac{n}{q} = Y\int_{q_6}^{q_7} \frac{q}{q} = Y\,\text{xz}\left(\frac{q_7}{q_6}\right)$$

Here, $T_1 = 100°C = 373$ K

$T_2 = 200°C = 473$ K $\therefore \Delta S = Y\,\text{xz}\left(\frac{9<8}{8<8}\right)$

*None of the given options is correct. If unit of temperatures in question paper were Kelvin, then $\Delta S = Y\,\text{xz}\left(\frac{755}{655}\right)$
$= C\ln 2 = \ln 2$ *i.e.*, option (d) would have been correct.

**15. (a) :** According to first law of thermodynamics,
$dQ = dU + dW$

Since the shell undergoes an adiabatic expansion
$\therefore$ $dQ = 0$, *i.e.*, $dU = -dW = -pdV$

$\{\sim \frac{r}{s} = - = -\frac{6r}{8s}$ $\left(\text{Nu qz A} = \frac{6r}{8s}\right)$

$\Rightarrow \frac{r}{r} = -\frac{6}{8}\frac{s}{s}$

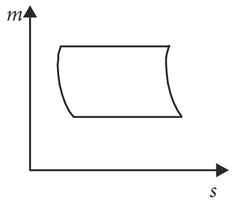
Integrating both sides $\ln U = -\frac{6}{8}\ln V + \ln C$
or $UV^{1/3} = C$ ...(i)

Given, $u = \frac{r}{s} \propto T^4$ or $U = KVT^4$
Putting this in eqn. (i)
$KVT^4V^{1/3} = C$
$T^4V^{4/3} = C/K$

or $q^9\left(\frac{9\pi}{8}o^8\right)^{948} = C/K$ $\left(\because V = \frac{9\pi}{8}R^3\right)$

$\Rightarrow T^4R^4 = C' \Rightarrow T \propto \frac{6}{o}$

**16. (a) :** In $V - T$ graph,
Process $ab$ : Isobaric, increasing temperature.
Process $bc$ : Adiabatic, increasing volume.
Process $cd$ : Isobaric, decreasing temperature.
Process $da$ : Adiabatic, decreasing volume.
Hence, corresponding $P$–$V$ graph is shown in the figure.




**17. (a) :** Change in internal energy $\Delta U = nC_v\Delta T = 1 \times \frac{5R}{2}\Delta T$

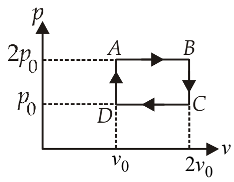
In the process $AB$, $\Delta U_{AB} = \frac{5R}{2}(400) = 1000\,R$

In the process $BC$, $\Delta U_{BC} = \frac{5R}{2}(-200) = -500\,R$

In the process $CA$, $\Delta U_{CA} = \frac{5R}{2}(-200) = -500\,R$

The change in internal energy in cyclic process is zero.

**18. (c) :** Heat is extracted from the source in path $DA$ and $AB$.
Along path $DA$, volume is constant. Hence,
$\Delta Q_{DA} = nC_v\Delta T = nC_v(T_A - T_D)$
According to ideal gas equation




$pv = nRT$ or $T = \frac{pv}{nR}$

For a monoatomic gas, $C_v = \frac{3}{2}R$

$\therefore$ $\Delta Q_{DA} = n\left(\frac{3}{2}R\right)\left[\frac{2p_0v_0}{nR} - \frac{p_0v_0}{nR}\right] = \frac{3}{2}p_0v_0$

Along the path $AB$, pressure is constant. Hence

$$\Delta Q_{AB} = nC_p\Delta T = nC_p(T_B - T_A)$$

For monoatomic gas, $C_p = \frac{5}{2}R$

$$\therefore \quad \Delta Q_{AB} = n\left(\frac{5}{2}R\right)\left[\frac{2p_0 2v_0}{nR} - \frac{2p_0v_0}{nR}\right] = \frac{10}{2}p_0v_0$$

$\therefore$ The amount of heat extracted from the source in a single cycle is

$$\Delta Q = \Delta Q_{DA} + \Delta Q_{AB} = \frac{3}{2}p_0v_0 + \frac{10}{2}p_0v_0 = \frac{13}{2}p_0v_0$$

**19. (b) :** Efficiency of Carnot engine, $\eta = 1 - \frac{T_2}{T_1}$

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

For 1st case $\eta = 40\%$, $T_1 = 500$ K

$$\therefore \quad \frac{40}{100} = 1 - \frac{T_2}{500} \Rightarrow \frac{T_2}{500} = 1 - \frac{40}{100} = \frac{3}{5}$$

$$T_2 = \frac{3}{5} \times 500 = 300 \text{ K}$$

For 2nd case $\eta = 60\%$, $T_2 = 300$ K

$$\therefore \quad \frac{60}{100} = 1 - \frac{300}{T_1} \Rightarrow \frac{300}{T_1} = 1 - \frac{60}{100} = \frac{2}{5}$$

$$T_1 = \frac{5}{2} \times 300 = 750 \text{ K}$$

**20. (d) :** In case of a cyclic process, work done is equal to the area under the cycle and is taken to be positive if the cycle is clockwise.

$\therefore$ Work done by the gas

$W$ = Area of the rectangle $ABCD = P_0V_0$

Helium gas is a monoatomic gas.

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

Along the path $AB$, heat supplied to the gas at constant volume,

$$\therefore \Delta Q_{AB} = nC_V\Delta T = n\frac{3}{2}R\Delta T = \frac{3}{2}V_0\Delta P = \frac{3}{2}P_0V_0$$

Along the path $BC$, heat supplied to the gas at constant pressure,

$$\therefore \Delta Q_{BC} = nC_P\Delta T = n\frac{5}{2}R\Delta T = \frac{5}{2}(2P_0)\Delta V = 5P_0V_0$$

Along the path $CD$ and $DA$, heat is rejected by the gas

$$\text{Efficiency, } \eta = \frac{\text{Work done by the gas}}{\text{Heat supplied to the gas}} \times 100$$

$$= \frac{P_0V_0}{\frac{3}{2}P_0V_0 + 5P_0V_0} \times 100 = \frac{200}{13} = 15.4\%$$

**21. (b) :** The final temperature of the mixture is

$$T_{\text{mixture}} = \frac{T_1n_1 + n_2T_2 + n_3T_3}{n_1 + n_2 + n_3}$$

**22. (a) :** The efficiency of Carnot engine, $\eta = \left(1 - \frac{T_2}{T_1}\right)$

$$\therefore \quad \frac{1}{6} = \left(1 - \frac{T_2}{T_1}\right) \qquad \left(\text{Given, } \eta = \frac{1}{6}\right)$$

$$\frac{T_2}{T_1} = \frac{5}{6} \Rightarrow T_1 = \frac{6T_2}{5} \qquad \text{...(i)}$$

As per question, when $T_2$ is lowered by 62 K, then its efficiency becomes $\frac{1}{3}$

$$\therefore \quad \frac{1}{3} = \left(1 - \frac{T_2 - 62}{T_1}\right)$$

$$\frac{T_2 - 62}{T_1} = 1 - \frac{1}{3}; \quad \frac{T_2 - 62}{\frac{6}{5}T_2} = \frac{2}{3} \qquad \text{(Using (i))}$$

$$\frac{5(T_2 - 62)}{6T_2} = \frac{2}{3}$$

$5T_2 - 310 = 4T_2 \Rightarrow T_2 = 310$ K

From equation (i), $T_1 = \frac{6 \times 310}{5} = 372$ K

**23. (b) :** $\Delta Q = ms\Delta T$

Here, $m = 100$ g $= 100 \times 10^{-3}$ kg

$s = 4184$ J kg$^{-1}$ K$^{-1}$ and $\Delta T = (50 - 30) = 20°$C

$\therefore \quad \Delta Q = 100 \times 10^{-3} \times 4184 \times 20 = 8.4 \times 10^3$ J

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

$\therefore$ Change in internal energy

$\Delta U = \Delta Q = 8.4 \times 10^3$ J $= 8.4$ kJ $\qquad (\because \Delta W = 0)$

**24. (c) :** For an adiabatic process $TV^{\gamma-1}$ = constant

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

$$T_1 = T_2\left(\frac{V_2}{V_1}\right)^{\gamma-1} = T_2\left(\frac{32V}{V}\right)^{\gamma-1} = T_2(32)^{\gamma-1}$$

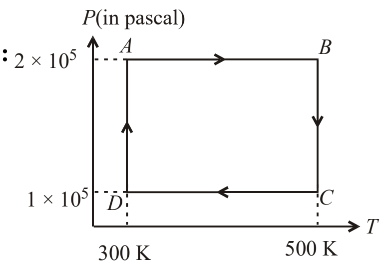
For diatomic gas, $\gamma = \frac{7}{5}$

$$\therefore \quad T_1 = T_2(32)^{\frac{7}{5}-1} = T_2(32)^{2/5} = T_2(2^5)^{2/5} = 4T_2$$

Efficiency of the engine, $\eta = 1 - \frac{T_2}{T_1} = \left(1 - \frac{1}{4}\right)$

$$\eta = \frac{3}{4} = 0.75$$

**25. (c) :**




Path $AB$, $P$ is the same, $\Delta T$ is 200 K.

$PV = nRT$ for all process

$\therefore \quad P\Delta V = nR\Delta T = 2R\ 200 = 400R$.

Work done on the gas from $A$ to $B = 400R$.

**26. (b) :** $D$ to $A$, temperature remains the same.

$$\therefore \quad \text{Work done by the gas } = W = nRT\ln\frac{V_2}{V_1} = nRT\ln\frac{P_1}{P_2}$$

$\Rightarrow \quad W = -600R\,(0.693) = -415.8R$.

This is the work done by the gas

$\therefore$ Work done on the gas $= +415.8R$.

Nearest to (b).

**27. (b) :** Total work done on the gas when taking from $A$ to $B = 400R$, from $C$ to $D$ is equal and opposite.
They cancel each other.
For taking from $D$ to $A$, work done on the gas = $+414R$.
Work done on the gas in taking it from $B$ to $C$, pressure is decreased, temperature remain the same, volume increases.
$\Rightarrow \quad W_{BC} + W_{DA} = 2 \ln 2(500R - 300R)$.
$\Rightarrow \quad W_{BC+DA} = (2 \ln 2) \times (200R) = 400R \times 0.693 = 277R$.
$\therefore$ Work done along $AB$ and $CD$ cancel each other because pressure changes but temperature is the same.
Net work done on the gas of 2 moles of helium through the whole network = $277R$ per cycle or nearest to the answer (b).

**28. (b) :** As this is a simple mixing of gas, even if adiabatic conditions are satisfied, $PV = nRT$ for adiabatic as well as isothermal changes. The total number of molecules is conserved.

$$\therefore \; n_1 = \frac{P_1V_1}{RT_1}, n_2 = \frac{P_2V_2}{RT_2}$$

Final state = $(n_1 + n_2)RT$

$$(n_1 + n_2) = \frac{P_1V_1}{RT_1} + \frac{P_2V_2}{RT_2} = \frac{T_2P_1V_1 + T_1P_2V_2}{RT_1T_2}$$

$$T = \frac{T_1n_1 + T_2n_2}{n_1 + n_2}, \; T = \frac{T_1T_2(P_1V_1 + P_2V_2)}{T_2P_1V_1 + T_1P_2V_2}$$

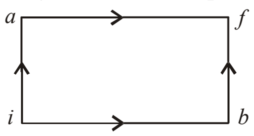
**29. (c) :** For Carnot engine efficiency $\eta = \frac{Q_H - Q_L}{Q_L}$

Coefficient of performance of a refrigerator $\beta = \frac{1-\eta}{\eta}$

$$\beta = \frac{1 - \frac{1}{10}}{1/10} = 9$$

Also $\beta = \frac{Q_L}{W}$ (where $W$ is the work done)
or $\quad Q_L = \beta \times W = 9 \times 10 = 90$ J.

**30. (b) :** According to first law of thermodynamics for the path $iaf$,




$Q_{iaf} = \Delta U_{iaf} + W_{iaf}$
or $\quad \Delta U_{iaf} = Q_{iaf} - W_{iaf} = 50 - 20 = 30$ cal
For the path $ibf$, $Q_{ibf} = \Delta U_{ibf} + W_{ibf}$
Since $\Delta U_{iaf} = \Delta U_{ibf}$, change in internal energy are path independent.
$Q_{ibf} = \Delta U_{iaf} + W_{ibf} \therefore W_{ibf} = Q_{ibf} - \Delta U_{iaf} = 36 - 30 = 6$ cal.

**31. (b) :** According to first law of thermodynamics
$\Delta Q = \Delta U + \Delta W$
For an adiabatic process, $\Delta Q = 0$
$\therefore \quad 0 = \Delta U + \Delta W$ or $\Delta U = -\Delta W$
or $\quad nC_V \, \Delta T = -\Delta W$

$$\text{or} \quad C_V = \frac{-\Delta W}{n\Delta T} = \frac{-(-146)\times 10^3}{(1\times 10^3)\times 7} = 20.8 \text{ J mol}^{-1} \text{ K}^{-1}$$

For diatomic gas, $C_V = \frac{5}{2}R = \frac{5}{2}\times 8.3 = 20.8 \text{ J mol}^{-1} \text{ K}^{-1}$
Hence the gas is diatomic.

**32. (c) :** $\Delta U_1 = \Delta U_2$, because the change in internal energy depends only upon the initial and final states $A$ and $B$.

**33. (a) :** Efficiency $\eta = 1 - \frac{Q_2}{Q_1}$

$$Q_2 = T_0\,(2S_0 - S_0) = T_0\,S_0$$

$$Q_1 = T_0S_0 + \frac{T_0S_0}{2} = \frac{3}{2}T_0S_0 \;\; \therefore \; \eta = 1 - \frac{T_0S_0\times 2}{3T_0S_0} = 1 - \frac{2}{3} = \frac{1}{3}.$$

**34. (b, c) :** Statements (b) and (c) are incorrect regarding the first law of thermodynamics.

**35. (b) :** Internal energy and entropy are state functions.

**36. (b) :** Efficiency $= 1 - \frac{T_2}{T_1} = 1 - \frac{300}{900} = 1 - \frac{1}{3} = \frac{2}{3}$

Heat energy = $3 \times 10^6$ cal = $3 \times 10^6 \times 4.2$ J
$\therefore$ Workdone by engine = (Heat energy) $\times$ (efficiency)
$= (3\times 10^6 \times 4.2)\times \frac{2}{3}$ J = $8.4 \times 10^6$ J.

**37. (c) :** The work does not characterize the thermodynamic state of matter.

**38. (d) :** In an adiabatic process, $T^{\gamma} = (\text{constant})P^{\gamma-1}$
or $\quad T^{\gamma/\gamma-1}$ = (constant) $P$

Given $T^3$ = (constant) $P \quad \therefore \; \frac{\gamma}{\gamma - 1} = 3 \Rightarrow 3\gamma - 3 = \gamma$

or $\quad 2\gamma = 3 \Rightarrow \gamma = 3/2$

**Note :** For monoatomic gas, $\gamma = \frac{5}{3} = 1.67$

For diatomic gas, $\gamma = \frac{7}{5} = 1.4$

when $\gamma = 1.5$, the gas must be a suitable mixture of monoatomic and diatomic gases $\therefore \; \gamma = 3/2$.

**39. (a) :** Second law of thermodynamics.

**40. (c) :** We cannot reach absolute zero temperature.

**41. (a) :** All reversible cycles do not have same efficiency.

**42. (b) :** Thermal capacity.