Vol 2 Chapter 4 – Laws of Thermodynamics

5. (a) In the process the volume of the system increases continuously. Thus, the work done increases continuously.

6. (c) for A → In a so thermal system temp remains same although heat is added. for B → For the work done by the system volume increase as is consumes heat.

7. (c) In this case P and T vary proportionally i.e. P/T = constant. This is possible only when volume does not change. \( \therefore pvd = 0 \omega \)

8. (c) Given : \( \Delta V_A = \Delta V_B \). But \( P_A < P_B \)

Now, \( W_A = P_A \Delta V_A, W_B = P_B \Delta V_B \); So, \( W_A < W_B \)

9. (b) As the volume of the gas decreases, the temperature increases as well as the pressure. But, on passage of time, the heat develops radiates through the metallic cylinder thus T decreases as well as the pressure.

**OBJECTIVE – II**

1. (b), (c) Pressure P and Volume V both increases. Thus work done is positive (V increases). Heat must be added to the system to follow this process. So temperature must increases.

2. (a) (b) Initial temp = Final temp. Initial internal energy = Final internal energy.
   \[ \text{i.e. } \Delta U = 0, \text{ So, this is found in case of a cyclic process.} \]

3. (d) \( \Delta U = \text{Heat supplied}, \Delta W = \text{Work done.} \)
   \( \Delta Q - \Delta W = du, du \text{ is same for both the methods since it is a state function.} \)

4. (a) (c) Since it is a cyclic process.
   \[ \Delta U_1 = -\Delta U_2, \text{ hence } \Delta U_1 + \Delta U_2 = 0 \]
   \[ \Delta Q - \Delta W = 0 \]

5. (d) Internal energy decreases by the same amount as work done.
   \[ du = dw, \text{ d}Q = 0. \text{ Thus the process is adiabatic. In adiabatic process, } dU = -dw. \text{ Since } 'U' \text{ decreases } \]
   \[ U_2 - U_1 = -ve. \text{ d}w \text{ should be } +ve \Rightarrow \frac{nR}{U-1}(t_1 - t_2) \text{ is } +ve, T_1 > T_2 \text{ : Temperature decreases.} \]

**EXERCISES**

1. \( t_1 = 15^\circ C \quad t_2 = 17^\circ C \quad \Delta t = t_2 - t_1 = 17 - 15 = 2^\circ C = 2 + 273 = 275 K \)
   \( m_v = 100 \text{ g} = 0.1 \text{ kg} \quad m_w = 200 \text{ g} = 0.2 \text{ kg} \)
   \( c_v = 420 \text{ J/kg.k} \quad c_w = 4200 \text{ J/kg.k} \)
   (a) The heat transferred to the liquid vessel system is 0. The internal heat is shared in between the vessel and water.
   (b) Work done on the system = Heat produced unit
   \[ \Rightarrow dw = 100 \times 10^{-3} \times 420 \times 2 + 200 \times 10^{-3} \times 4200 \times 2 = 84 + 20 = 84 \times 21 = 1764 \text{ J} \]
   (c) \( dQ = 0, dU = dW = 1764. \text{ [since } dw = -ve \text{ work done on the system]} \)

2. (a) Heat is not given to the liquid. Instead the mechanical work done is converted to heat. So, heat given to liquid is Z.
   (b) Work done on the liquid is the PE lost by the mass \( m = 12 \times 10 \times 0.70 = 84 \text{ J} \)
   (c) Rise in temp at \( \Delta t \)
      \[ \Rightarrow 84 = 1 \times 4200 \times \Delta t \text{ (for } 'm' = 1 \text{ kg}) \Rightarrow \Delta t = \frac{84}{4200} = 0.02 \text{ k} \]
3. mass of block = 100 kg
   \( m = 2 \text{ m/s}, \quad v = 0 \)
   \( dQ = du + dw \)
   In this case \( dQ = 0 \)
   \[
   \Rightarrow -du = dw \Rightarrow du = -\frac{1}{2}mv^2 - \frac{1}{2}mu^2 = \frac{1}{2} \times 100 \times 2 \times 2 = 200 \text{ J} 
   \]

4. \( Q = 100 \text{ J} \)
   We know, \( \Delta U = \Delta Q - \Delta W \)
   Here since the container is rigid, \( \Delta V = 0 \),
   Hence the \( \Delta W = P\Delta V = 0 \),
   So, \( \Delta U = \Delta Q = 100 \text{ J} \).

5. \( P_1 = 10 \text{ kPa} = 10 \times 10^3 \text{ pa}, \quad P_2 = 50 \times 10^4 \text{ pa} \)
   \( V_1 = 200 \text{ cc}, \quad V_2 = 50 \text{ cc} \)
   (i) Work done on the gas = \( \frac{1}{2} (10+50) \times 10^3 \times (50-200) \times 10^{-6} = -4.5 \text{ J} \)
   (ii) \( dQ = 0 \Rightarrow 0 = du + dw \Rightarrow du = -dw = 4.5 \text{ J} \)

6. Initial State 'i' Final State 'f'
   Given \( \frac{P_1}{T_1} = \frac{P_2}{T_2} \)
   where \( P_1 \rightarrow \) Initial Pressure; \( P_2 \rightarrow \) Final Pressure.
   \( T_2, T_1 \rightarrow \) Absolute temp. So, \( \Delta V = 0 \)
   Work done by gas = \( P\Delta V = 0 \)

7. In path ACB,
   \( W_{AC} + W_{BC} = 0 + pdV = 30 \times 10^3 \times (25 - 10) \times 10^{-6} = 0.45 \text{ J} \)
   In path AB, \( W_{AB} = \frac{1}{2} \times (10 + 30) \times 10^4 \times 15 \times 10^{-6} = 0.30 \text{ J} \)
   In path ADB, \( W = W_{AD} + W_{DB} = 10 \times 10^3 \times (25 - 10) \times 10^{-6} = 0 = 0.15 \text{ J} \)

8. \( \Delta Q = \Delta U + \Delta W \)
   In abc, \( \Delta Q = 80 \text{ J} \quad \Delta W = 30 \text{ J} \)
   So, \( \Delta U = (80 - 30) \text{ J} = 50 \text{ J} \)
   Now in acc, \( \Delta W = 10 \text{ J} \)
   So, \( \Delta Q = 10 + 50 = 60 \text{ J} \) [\( \therefore \Delta U = 50 \text{ J} \)]

9. In path ACB,
   \( dQ = 50 \times 50 \times 4.2 = 210 \text{ J} \)
   \( dW = W_{AC} + W_{CB} = 50 \times 10^3 \times 200 \times 10^{-6} = 10 \text{ J} \)
   \( dQ = du + dw \)
   \( \Rightarrow du = dQ - dw = 210 - 10 = 200 \text{ J} \)
   In path ADB, \( dQ = ? \)
   \( du = 200 \text{ J} \) (Internal energy change between 2 points is always same)
   \( dW = W_{AD} + W_{DB} = 0 + 155 \times 10^3 \times 200 \times 10^{-6} = 31 \text{ J} \)
   \( dQ = du + dw = 200 + 31 = 231 \text{ J} = 55 \text{ cal} \)

10. Heat absorbed = work done = Area under the graph
   In the given case heat absorbed = area of the circle
   \( = \pi \times 10^4 \times 10^4 \times 10^3 = 3.14 \times 10 = 31.4 \text{ J} \)
11. \( dQ = 2.4 \text{ cal} = 2.4 \text{ J Joules} \)
   \( dw = W_{ab} + W_{bc} + W_{ac} \)
   \[ = 0 + \frac{1}{2} \times (100 + 200) \times 10^3 \times 200 \times 10^{-4} - 100 \times 10^3 \times 200 \times 10^{-4} = (1/2) \times 300 \times 10^3 \times 200 \times 10^{-5} - 20 = 30 - 20 = 10 \text{joules.} \]
   \( du = 0 \) (in a cyclic process)
   \( dQ = du + dw \Rightarrow 2.4 J = 10 \)
   \[ \Rightarrow J = \frac{10}{2.4} \approx 4.17 \text{ J/Cal.} \]

12. Now, \( \Delta Q = (2625 \times J) J \)
   \[ \Delta U = 5000 \text{ J} \]
   From Graph \( \Delta W = 200 \times 10^3 \times 0.03 = 6000 \text{ J.} \)
   Now, \( \Delta Q = \Delta W + \Delta U \)
   \[ \Rightarrow 2625 J = 6000 + 5000 \text{ J} \]
   \[ J = \frac{11000}{2625} = 4.19 \text{ J/Cal} \]

13. \( dQ = 70 \text{ cal} = (70 \times 4.2) \text{ J} \)
    \( dW = (1/2) \times (200 + 500) \times 10^3 \times 150 \times 10^{-4} \)
    \[ = (1/2) \times 500 \times 150 \times 10^{-2} = 525 \times 10^{-1} = 52.5 \text{ J} \]
    \[ dU = ? \quad dQ = du + dw \]
    \[ \Rightarrow -294 = du + 52.5 \]
    \[ \Rightarrow du = -294 - 52.5 = -346.5 \text{ J} \]

14. \( U = 1.5 \text{ pV} \quad P = 1 \times 10^5 \text{ Pa} \)
    \( dv = (200 - 100) \times 10^{-6} \text{ m}^3 = 100 \text{ cm}^3 = 10^{-4} \text{ m}^3 \)
    \( du = 1.5 \times 10^5 \times 10^{-4} = 15 \)
    \( dw = 10 \times 10^{-4} = 10 \)
    \( dQ = du + dw = 10 + 15 = 25 \text{ J} \)

15. \( dQ = 10 \text{ J} \)
    \( dv = A \times 10 \text{ cm}^3 = 4 \times 10 \text{ cm}^3 = 40 \times 10^{-3} \text{ cm}^3 \)
    \( dw = Pdv = 100 \times 10^{-2} \times 40 \times 10^{-3} = 4 \text{ cm}^3 \)
    \( du = ? \quad 10 = du + dw \Rightarrow 10 = du + 4 \Rightarrow du = 6 \text{ J.} \)

16. (a) \( P_1 = 100 \text{ KPa} \)
    \( V_1 = 2 \text{ m}^3 \)
    \( \Delta V_1 = 0.5 \text{ m}^3 \)
    \( \Delta P_1 = 100 \text{ KPa} \)

    From the graph, We find that area under AC is greater than area under AB. So, we see that heat is extracted from the system.

    (b) Amount of heat = Area under ABC.
    \[ = \frac{1}{2} \times 5 \times 10^5 = 25000 \text{ J.} \]

17. \( n = 2 \text{ mole} \)
    \( dQ = -1200 \text{ J} \)
    \( dU = 0 \) (During cyclic Process)
    \( dQ = du + dw \)
    \[ \Rightarrow -1200 = W_{ab} + W_{bc} + W_{ca} \]
    \[ \Rightarrow -1200 = nR\Delta T + W_{bc} + 0 \]
    \[ \Rightarrow -1200 = 2 \times 8.3 \times 200 + W_{bc} \]
    \[ \Rightarrow W_{bc} = -400 \times 8.3 - 1200 = -4520 \text{ J.} \]
18. Given \( n = 2 \) moles
\[ dV = 0 \]
in \( ad \) and \( bc \).
Hence \( dW = dQ \)
\[ dQ = dW_{ad} + dW_{bc} \]
\[ = nRT \ln \frac{V_f}{V_i} + nRT \ln \frac{V_2}{V_0} \]
\[ = nR \times 2.303 \times \log (2(500 - 300)) \]
\[ = 2 \times 8.314 \times 2.303 \times 0.301 \times 200 = 2365.31 \text{ J} \]

19. Given \( M = 2 \) kg  \( 2t = 4 \text{ c} \)  \( Sw = 4200 \text{ J/kg-} \text{k} \)
\( f_s = 996.9 \text{ kg/m}^2 \quad f_i = 1000 \text{ kg/m}^2 \quad P = 10^5 \text{ Pa} \).
Net internal energy = \( dv \)
\[ dQ = dU + dW \Rightarrow \text{mas}\Delta Qv = dU + P(v_i - v_f) \]
\[ = 2 \times 4200 \times 4 = dU + 10^5 (m - m) \]
\[ \Rightarrow 33600 = dU + 10^5 \left( \frac{m}{V_0} - \frac{m}{v_i} \right) - dU + 10^5 (0.00020002 - 0.0002) - dU + 10^5 0.00000002 \]
\[ \Rightarrow 33600 = du + 0.02 \Rightarrow du = (33600 - 0.02) \text{ J} \]

20. Mass = 10g = 0.01kg.
\( P = 10^5 \text{Pa} \)
\( dQ = Q_{w,0}0^1 - 100^1 + Q_{w,0} - \text{steam} \)
\[ = 0.01 \times 4200 \times 100 + 0.01 \times 2.5 \times 10^5 = 4200 + 25000 = 29200 \]
\( dW = P \Delta V \)
\[ \Rightarrow \Delta = \frac{0.01}{0.01} = 0.01699 \]
\[ = \frac{0.61}{1000} \]
\( dW = P \Delta V = 0.01699 \times 10^4 = 1699 \text{ J} \)
\( dQ = dW + dU \text{ or } dW = dQ - dU = 29200 - 1699 = 27501 = 2.75 \times 10^4 \text{ J} \]

21. (a) Since the wall can not be moved thus \( dU = 0 \) and \( dQ = 0 \).
Hence \( dW = 0 \).

(b) Let final pressure in LHS = \( P_1 \)
In RHS = \( P_2 \)
(\( \therefore \) no. of mole remains constant)
\[ \frac{P_1 V}{2RT_1} = \frac{P_2 V}{2RT_2} \]
\[ \Rightarrow P_1 = \frac{P_2 T_2}{T_1} = \frac{P_1 (P_1 + P_2) T_1 T_2}{\lambda} \]
As, \( T = \frac{(P_1 + P_2) T_1 T_2}{\lambda} \)

Similarly \( P_2 = \frac{P_2 T_2 (P_1 + P_2)}{\lambda} \)

(c) Let \( T_2 > T_1 \) and \( T^* \) be the common temp.
Initially \( \frac{P_1 V}{2} = n_1 r_1 \Rightarrow n_1 = \frac{P_1 V}{2RT_1} \)
\[ n_2 = \frac{P_2 V}{2RT_2} \]
Hence \( dQ = 0 \), \( dW = 0 \), Hence \( dU = 0 \).
In case (LHS) \( \text{RHS} \)
\[ \Delta u_1 = 1.5n_1 R(T_1 - T_1) \text{ But } \Delta u_1 - \Delta u_2 = 0 \]
\[ \Delta u_2 = 1.5n_2 R(T_2 - T) \]
\[ \Rightarrow 1.5 n_1 R(T_2 - T) = 1.5 n_2 R(T_2 - T) \]
\[ \Rightarrow n_2 T - n_1 T = n_2 T_2 - n_1 T_1 \therefore T(n_1 + n_2) = n_1 T_1 + n_2 T_2 \]
\[ T = \frac{n_1 T_1 + n_2 T_2}{n_1 + n_2} \]
\[ = \frac{P_1 V}{2 RT_1} T_1 + \frac{P_2 V}{2 RT_2} T_2 = \frac{P_1 + P_2}{P_1 T_1 + P_2 T_2} \]
\[ = \frac{(P_1 + P_2) T_1 T_2}{P_1 T_1 + P_2 T_2} \]
\[ = \frac{(P_1 + P_2) T_1 T_2}{\lambda} \]
\[ (\text{as } P_1 T_1 + P_2 T_2 = \lambda) \]

(d) For RHS \( dQ = dU \) (As \( dw = 0 \))
\[ = 1.5 \ n_2 \ R (T_2 - t) \]
\[ = \frac{1.5 P_2 V}{2 RT_2} \left( T_2 - \frac{(P_1 - P_2) T_2}{P_1 T_1 + P_2 T_2} \right) \]
\[ = \frac{1.5 P_2 V}{2 T_2} \left( T_2 - \frac{(P_1 T_2 - P_2 T_1)}{\lambda} \right) \]
\[ = \frac{3 P_2 (T_2 - T_1) V}{4 \lambda} \]

22. (a) As the conducting wall is fixed the work done by the gas on the left part during the process is Zero.

(b) For left side
Pressure = \( P \)
Volume = \( V \)
No. of moles = \( n_1 \) (mole)
Let initial Temperature = \( T_1 \)
\[ \frac{P V}{2} = n_1 R T_1 \]
\[ \Rightarrow \frac{P V}{2} = (1)RT_1 \]
\[ \Rightarrow T_1 = \frac{PV}{2(\text{moles} R)} \]

(c) Let the final Temperature = \( T \)
Final Pressure = \( R \)
No. of mole = 1 mole + 2 moles = 3 moles
\[ \therefore P V = n R T \Rightarrow \frac{P V}{n R} = \frac{P V}{3(\text{mole} R)} \]

(d) For RHS \( dQ = dU \) [as, \( dW = 0 \)]
\[ = 1.5 n_2 R (T - T_2) = 1.5 \times 2 \times R \times \left( \frac{PV}{3(\text{mole} R)} - \frac{PV}{4(\text{mole} R)} \right) \]
\[ = 1.5 \times 2 \times R \times \frac{4PV - 3PV}{4 	imes 43(\text{mole})} = \frac{3xR \times PV}{3x4 \times R} = \frac{PV}{4} \]

(e) As, \( dQ = -dU \)
\[ \Rightarrow dU = -dQ = \frac{-PV}{4} \]