

CHAPTER - 12

THERMODYNAMICS

ONE MARK QUESTIONS

1. What is Thermodynamics?
2. Mention the Macroscopic variables to specify the thermodynamics.
3. How does thermodynamics differ from Mechanics?
4. What is thermodynamic equilibrium?
5. Give the meaning of the term 'adiabatic wall'.
6. Give the meaning of 'diathermic wall'.
7. Name the scientist who formulated. Zeroth law of thermodynamics.
8. Write the significance of Zero'th law of thermodynamics?
9. Mention the factor on which internal energy depends on.
10. Mention the modes of changing internal energy.
11. What are thermodynamic state variables?
12. Mention the modes of energy transfer to a system.
13. Define Internal energy.
14. Mention the principle of first law of thermodynamics
15. Define specific heat capacity of water.
16. Write the value of specific heat capacity of water.
17. Define one calorie.
18. What is equation of state?
19. Give the equation of state of ideal gas.
20. What is isothermal curve?
21. Mention the kinds of thermodynamic state variables.
22. Give an example of extensive state variable.
23. Give an example of intensive state variable.
24. What is quasi-static process?
25. What is isothermal process?
26. What is isobaric process?
27. What is isochoric process?

28. What is adiabatic process?
29. When does gas absorb heat and does work during isothermal process?
30. When does gas release heat and work is done by the surrounding?
31. Mention the condition for work done by the gas in an adiabatic process.
32. Mention the condition for work done on the gas in an adiabatic process.
33. What is the work done in isochoric process?
34. Mention the expression for work done in isobaric process.
35. What is the work done in cyclic process?
36. What is heat engine?
37. Define the efficiency of a heat engine.
38. Mention the expression for coefficient of performance of refrigerator
39. Mention the expression for amount of heat released to the heat reservoir.
40. What is Heat pump?
41. Mention the thermodynamic process in which highest efficiency is possible.
42. Mention the thermodynamic process in which lowest efficiency is possible.
43. What is Carnot engine?
44. Who designed the Carnot engine?
45. What is Carnot cycle?
46. Name the working substance used in Carnot cycle.

TWO MARK QUESTIONS :

1. State and explain Zero'th law of thermodynamics.
2. Justify the statement "A gas in a given state has a certain amount of work".
3. Justify the statement "A gas in a given state has a certain amount of heat"
4. State and explain First law of thermodynamics.
5. Explain isothermal process by applying first law of thermodynamics.
6. Explain isobaric process by applying first law of thermodynamics.
7. Write the equation of state for ideal gas. Explain the terms.
8. Show that molar specific heat of solids, $C = 3R$.
9. Mention the two ways of Mechanism of conversion of heat into work.
10. State both forms of second law of thermodynamics.

11. According to II law of thermodynamic, what are the limitations of efficiency and co-efficient of performance.
12. What is reversible process? Give an example.
13. What is irreversible process? Give an example.
14. Mention the causes of irreversibility.

QUESTIONS CARRIES 4 OR 5 MARKS.

1. Using first law of thermodynamics, arrive at the relation, $C_p - C_v = R$.
2. What is isothermal process? Obtain the equation of isothermal process

OR

What is isothermal process? Obtain the expression for work done by isothermal process.

3. What is adiabatic process? Obtain the expression for work done in adiabatic process.
4. Explain the features of a heat engine with schematic diagram.
5. Distinguish between isothermal and adiabatic process.
6. Describe the Carnot cycle of operation using PV diagram.
7. Discuss the Carnot cycle of operation and deduce the expression for efficiency.
8. What is refrigerator? Explain the working of refrigerator with schematic diagram.

PROBLEMS :

1. A cylinder with a movable piston contains 3 moles of hydrogen at constant temperature and pressure. The walls of a cylinder are made up of a heat insulator, and the piston is insulated by having a pile of sand on it. By what factor does the pressure of a gas increases if the gas is compressed to half its original volume?
2. In changing the state of a gas adiabatically from an equilibrium state A to another equilibrium state B, an amount of work equal to 22.3 J is done on the system. If the gas is taken from state A to B via a process in which the net heat absorbed by the system is 9.35 cal., how much is the network done by the system in the later case? (Take 1 cal = 4.19J)

3. An electric heater supplies heat to a system at the rate of 10W. If the system performs work at a rate of 75 joules per second. At what rate is the internal energy increasing ?
4. A steam engine delivers $5.4 \times 10^8 \text{ J}$ of work per minute and services $3.6 \times 10^9 \text{ J}$ of heat per minute from the boiler. What is the efficiency of the engine? How much heat is wasted per minute?
5. A perfect Carnot engine utilizes an ideal gas. The source temperature is 500 K and sink temperature is 375K. If the engine takes 600K cal per cycle from the source, compute:
 - (a) the efficiency of the engine.
 - (b) Work done per cycle.
 - (c) Heat rejected to the sink per cycle.
6. A refrigerator has to transfer an average of 263 J of heat per second from temperature - 10°C to 25°C . Calculate the average power consumed assuming ideal reversible cycle and no other losses.
7. What is the coefficient of performance (β) or a Carnot refrigerator working between 30°C and 0°C ?
8. A certain volume of dry air at NTP is allowed to expand 4 times of its original volume under (a) isothermal conditions (b) adiabatic conditions. Calculate the final pressure and temperature in each case $\gamma = 1.4$.
9. In a refrigerator, heat from inside at 277 K is transferred to a room at 300K. How many joules of heat will be delivered to the room for each joule of electric energy consumed ideally?

ANSWER TO ONE MARK QUESTIONS

1. The branch of physics that deals with the concept of heat and temperature and inter-conversion of heat and other forms of energy.
2. Pressure, Volume, Temperature, mass and composition.
3. Mechanics deals with motion of particles under the action of forces, while Thermodynamics concerned with internal Microscopic state of the body.
4. The system is said to be in the Thermodynamic equilibrium when the macroscopic variables do not change with time.
5. It is an insulating wall (can be movable) that does not allow flow of energy (heat) from one system to another.
6. It is a conducting wall that allows energy flow (heat) from one system to another.
7. R.H. Fowler in 1931.
8. It signifies the concept of temperature.
9. It depends on 'state of system'
10. Heat and work.
11. Variables like Pressure, Temperature, internal Energy which determines the Thermodynamic state are called Thermodynamics state variables.
12. Heat and work.
13. Internal energy is the sum of molecular kinetic and potential energies in the frame of reference relative to which the centre of mass of the system is at rest.
14. Law of conservation of energy.
15. Specific heat capacity of water is equal to the amount of heat required to raise the temperature of 1kg of water by 1K.
16. $4186 \text{ J kg}^{-1} \text{ K}^{-1}$
17. One calorie is defined to be the amount of heat required to raise the temperature of 1g of water from 14.5°C to 15.5°C .
18. The relation connecting between state variables is called equation of state.

19. $PV = RT$ for moles of ideal gas.
20. The pressure- volume curve for fixed temperature is called isothermal curve.
21. Extensive variables and intensive variable.
22. Volume, Mass, Internal Energy etc.
23. Pressure, Temperature, Density etc.
24. The process in the system the variables (PTV) changes vary slowly so that the system remain in thermal and mechanical equilibrium with its surrounding throughout is called quasi-static process.
25. A process in which the temperature of the system is kept constant throughout is called isothermal process. (i.e. $\Delta T = 0$)
26. A process in which the pressure is kept constant is called isobaric process. (i.e. $\Delta P = 0$)
27. A process in which the volume is kept fixed is called isochoric process (i.e. $\Delta V = 0$)
28. A process in which no heat flows between system and its surrounding is called adiabatic process. (i.e. $\Delta Q = 0$)
29. during isothermal expansion.
30. during isothermal compression.
31. during adiabatic expansion.
32. during adiabatic compression.
33. Zero Joule (because heat absorbed by the gas is entirely utilized to change its internal energy only).
34. $W = P(V_2 - V_1)$
35. Total work done is equal to total heat absorbed.
36. Heat engine is a device by which a system is made to undergo a cyclic process that results in conversion of heat into work.
37. It is defined as the ratio of useful work done (W) to the heat input (Q_1)

38. $\alpha = \frac{Q_2}{W}$
39. $Q_1 = W + Q_2$
40. A device used to increase the temperature of a system is known as heat pump.
41. Reversible process.
42. Irreversible process.
43. A reversible heat engine operating between two temperatures is called a Carnot engine.
44. N.L. Sodi Carnot - a French Engineer.
45. The sequence of steps constituting one cycle of operation of Carnot Engine is called Carnot cycle.
46. Ideal Gas.

TWO MARK QUESTIONS :

1. Statement: “two systems in thermal equilibrium with a third system separately are in thermal equilibrium with each other”.

Explanation : If A and B are two systems are equilibrium with system C then $T_A = T_C$ and $T_B = T_C$.

This implies that $T_A = T_B$ i.e. the system A and B are also in thermal equilibrium.

Thus we arrived the concept of temperature formally via the Zero'th Law.

2. No, “A gas in a given state has a certain amount of internal energy” is a meaningful statement.
3. No, “A certain amount of heat is supplied to the system or a certain amount of work was done by the system” is a meaningful statement.
4. “When an amount of heat energy is supplied to the system, part of it increases internal energy of the system and remaining is utilized by the system to do work”.

Explanation: If ΔQ is heat supplied to the system by the surrounding, Δu is change in internal energy of the system and Δw is work done by the system on the surrounding.

Then according to first law of thermodynamics $\Delta Q = \Delta u + \Delta w$

* It is the principle of the conservation of energy.

5. For isothermal process temperature remains constant i.e. $\Delta u = 0$.
Therefore according to first law of thermodynamics $\Delta Q = \Delta w$ Heat supplied to the system is used up entirely by the system in doing work on environment.
6. For isobaric process pressure remains constant. $\Delta W = P \Delta V$ i.e. work done by the system. Then we write first law of thermodynamics as $\Delta Q = \Delta u + P \Delta V$.
7. For an ideal gas, the equation of state is $PV = \mu RT$, where P is pressure, V is volume, R is universal gas constant and T is absolute temperature and μ is number of moles.

8. Consider a solid of N atoms, each vibrating about its mean position. An oscillator in one dimension has average energy of $2 \times \frac{1}{2} k_B T = k_B T$. For a mole of a solid.

The total energy, $U = 3k_B T \times N_A = 3 RT$

At constant pressure, $\Delta Q = \Delta u + P \Delta V \cong \Delta U$

Since for a solid ΔV is negligible. Therefore, molar specific heat.

$$C = \frac{\Delta Q}{\Delta T} = \frac{\Delta U}{\Delta T} = 3R \qquad C = 3R$$

9. *The system is heated by an external furnace as in steam engine.
*The system is heated internally by an exothermic chemical reaction as in internal combustion engine.
10. Kelvin-Planck statement: "No process is possible whose sole result is the absorption of heat from a reservoir and the complete conversion of the heat into work"
Clausius statement: "No process is possible whose sole result is the transfer of heat from a colder object to a hotter object".
* It can be proved that the two statements above are completely equivalent.
11. According the II Law,
*efficiency never be unity or never exceed unity.
*Coefficient of performance never be infinite.
12. A process is reversible only if it is quasi-static and non dissipative.
Eg. A quasi-static isothermal expansion of an ideal gas in a cylinder fitted with a frictionless movable piston is reversible process.

13. A process which takes the system to the non equilibrium state is called irreversible process.

*It can't be retraced in the reverse direction.

Eg. The Free expansion of gas. The combustion reaction of mixture of petrol and air, ignited by a spark.

14. Friction, viscosity and other dissipative effect.

QUESTIONS CARRIES 4 OR 5 MARKS.

1. According to 1st law of thermodynamics $\Delta Q = \Delta u + P \Delta V$, consider one mole of ideal gas, if ΔQ is the amount of heat absorbed at constant volume then $\Delta V = 0$.

and molar specific heat of gas at constant volume becomes

$$C_v = \left(\frac{\Delta Q}{\Delta T} \right)_v = \left(\frac{\Delta U}{\Delta T} \right)_v = \left(\frac{\Delta U}{\Delta T} \right) \text{-----} 1$$

Where the subscript v is dropped in the last step, since U of an ideal gas depends only on temperature.

If ΔQ is the amount of heat absorbed at constant pressure then

$$C_p = \left(\frac{\Delta Q}{\Delta T} \right)_p = \left(\frac{\Delta U}{\Delta T} \right)_p + P \left(\frac{\Delta V}{\Delta T} \right)_p \quad \text{or}$$

$$C_p = \left(\frac{\Delta Q}{\Delta T} \right) = \left(\frac{\Delta U}{\Delta T} \right) + P \left(\frac{\Delta V}{\Delta T} \right) \text{-----} 2$$

Since U of an ideal gas depend only on T.

For one mole of ideal gas $PV = RT$

$$\text{which gives } P \left(\frac{\Delta V}{\Delta T} \right)_p = R \text{-----} 3$$

substituting equations 1 and 3 in equation 2, we get

$$C_p = C_v + R \\ \Rightarrow C_p - C_v = R$$

[This relation is called Mayer's relation. Where R is universal gas constant and C_p and C_v are molar specific heat capacities of an ideal gas at constant pressure and constant volume respectively.]

2. A thermodynamic process which takes place at a constant temperature is called an isothermal process.

For an ideal gas in isothermal process, the equation of state for mole of gas is

$$PV = \text{constant} \Rightarrow PV = \mu RT$$

The gas under goes isothermal expansion from $(P_1 V_1)$ to $(P_2 V_2)$, at any intermediate stage with pressure P , and volume changes from V to $V + \Delta V$

Then work done $\Delta W = P \Delta V$.

Taking $(\Delta V \rightarrow 0)$ and summing the quantity ΔW over the entire process.

$$\begin{aligned} W &= \int_{V_1}^{V_2} P dV \\ &= \mu RT \int_{V_1}^{V_2} \frac{dV}{V} = \mu RT \ln \frac{V_2}{V_1} \\ W &= \mu RT \ln \frac{V_2}{V_1} \end{aligned}$$

This is the expression for work done during isothermal expansion.

3. A thermodynamic process during which no heat enters or leaves the system is known as an adiabatic process.

Consider ' μ ' moles of ideal gas undergoing a adiabatic expansion from V_1 to V_2 .

For adiabatic process $PV^\gamma = \text{constant}$, where ' γ ' is the ratio of specific heats at constant pressure and at constant volume. i.e. $\gamma = \frac{C_p}{C_v}$

If gas under goes change in its state adiabatically from (P_1, V_1) to (P_2, V_2)

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

The work done in adiabatic change of an ideal gas from the state (P_1, V_1, T_1) to the state (P_2, V_2, T_2) is

$$\begin{aligned} W &= \int_{V_1}^{V_2} P dV \\ &= \text{constant} \times \int_{V_1}^{V_2} \frac{dV}{V^\gamma} = \text{constant} \times \frac{V^{-\gamma+1}}{1-\gamma} \Bigg|_{V_1}^{V_2} \end{aligned}$$

$$= \frac{\text{const } t}{(1-\gamma)} \times \left[\frac{1}{V_2^{\gamma-1}} - \frac{1}{V_1^{\gamma-1}} \right]$$

From equation (1) the constant is $P_1 V_1^\gamma$ or $P_2 V_2^\gamma$ then

$$W = \frac{\text{const } t}{(1-\gamma)} \times \left[\frac{1}{V_2^{\gamma-1}} - \frac{1}{V_1^{\gamma-1}} \right]$$

$$W = \frac{1}{(1-\gamma)} \times \left[\frac{P_2 V_2^\gamma}{V_2^{\gamma-1}} - \frac{P_1 V_1^\gamma}{V_1^{\gamma-1}} \right]$$

$$\text{or } W = \frac{1}{(1-\gamma)} (P_2 V_2 - P_1 V_1) = \frac{\mu R (T_1 - T_2)}{\gamma - 1}$$

$$W = \frac{\mu R (T_1 - T_2)}{\gamma - 1}$$

is the expression for work done by the gas in adiabatic process.

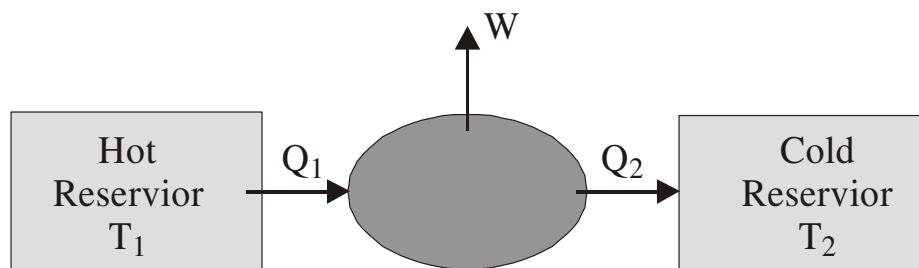
4. Heat engine is a device by which a system is made to undergo a cyclic process that results in conversion of heat to work.

* It consists of a working substance-the system. Eg. a mixture of fuel vapour and air in a gasoline.

* The working substance goes through a cycle consisting of several processes. In some of these processes, it absorbs a total amount of heat Q_1 from an external reservoir at some high temperature T_1 .

* In some other processes of the cycle, the working substance releases a total amount of heat Q_2 to an external reservoir at some lower temperature T_2 .

* The work done (W) by the system in a cycle is transferred to the environment via some arrangement like cylinder with piston system and is as shown in fig.



The cycle is repeated again and again to get useful work for some purpose.

- | | | |
|----|---|---|
| 5. | 1. Temperature remains constant | 1. Heat energy exchange is 0. |
| | 2. It is a slow process | 2. It is sudden process. |
| | 3. It is represented by equation $PV = \text{Const.}$ | 3. It is represented by equation $PV^\gamma = \text{constant.}$ |
| | 4. Slope of PV graph is comparatively small. | 4. Slope of PV graph is comparatively large(γ time) |
| | 5. Work done $W = \mu RT \ln \frac{V_2}{V_1}$ | 5. $W = \frac{\mu R(T_1 - T_2)}{\gamma - 1}$ |

6. Carnot cycle consists of two adiabatic and two isothermal processes, all are reversible. To describe the carnot cycle, assume the working substance or ideal gas contained in a cylinder fitted with a movable piston.

* The cylinder walls and piston are non-conducting.

Step $1 \rightarrow 2$: Isothermal expansion of the gas taking its state from (P_1, V_1, T_1) to (P_2, V_2, T_1) .

Thus the work done ($W_{1 \rightarrow 2}$) by the gas on the environment is

$$W_{1 \rightarrow 2} = Q_1 = \mu RT_1 \ln \frac{V_2}{V_1} \quad \text{----- (1)}$$

Step $2 \rightarrow 3$: Adiabatic expansion of the gas from (P_2, V_2, T_1) to (P_3, V_3, T_2) .

Thus the work done ($w_{2 \rightarrow 3}$) by the gas is

$$w_{2 \rightarrow 3} = \frac{\mu R(T_1 - T_2)}{\gamma - 1} \quad \text{----- (2)}$$

Step $3 \rightarrow 4$: Isothermal compression of the gas taking its state from (P_3, V_3, T_2) to (P_4, V_4, T_2) .

Heat released (Q_2) by the gas to the reservoir at temperature T_2 .

Thus the work done ($w_{3 \rightarrow 4}$) on the gas by the environment is

$$w_{3 \rightarrow 4} = Q_2 = \mu RT_2 \ln \frac{V_3}{V_4} \quad \text{----- (3)}$$

Step $4 \rightarrow 1$: Adiabatic compression of the gas from (P_4, V_4, T_2) to (P_1, V_1, T_1) .

Thus the work done ($w_{4 \rightarrow 1}$) on the gas is

$$w_{4 \rightarrow 1} = \frac{\mu R(T_1 - T_2)}{\gamma - 1} \quad \text{----- (4)}$$

From equation (1) to (4) total work done by the gas in one complete cycle

$$W = w_{1 \rightarrow 2} + w_{2 \rightarrow 3} - w_{3 \rightarrow 4} - w_{4 \rightarrow 1}$$

$$W = \mu R T_1 \ln \frac{V_2}{V_1} - \mu R T_2 \ln \frac{V_3}{V_4}$$

The efficiency of the carnot engine is

$$\eta = \frac{W}{Q_1} = 1 - \frac{Q_2}{Q_1}$$

$$\eta = 1 - \frac{T_2}{T_1} \left(\frac{\ln \frac{V_3}{V_4}}{\ln \frac{V_2}{V_1}} \right) \quad \text{----- (5)}$$

Step $2 \rightarrow 3$: is an adiabatic process

$$\text{Then } T_1 V_2^{\gamma-1} = T_2 V_3^{\gamma-1}$$

$$\text{i.e. } \frac{V_2}{V_3} = \left(\frac{T_2}{T_1} \right)^{1/(\gamma-1)} \quad \text{----- (6)}$$

Similarly in Step $4 \rightarrow 1$ is an adiabatic process

$$\text{Then } T_2 V_4^{\gamma-1} = T_1 V_1^{\gamma-1}$$

$$\text{i.e. } \frac{V_1}{V_4} = \left(\frac{T_2}{T_1} \right)^{1/(\gamma-1)} \quad \text{----- (7)}$$

From equations (6) and (7) we get

$$\frac{V_3}{V_4} = \frac{V_2}{V_1} \quad \text{----- (8)}$$

From equations (8) and (5) we get

$$\eta = 1 - \frac{T_2}{T_1} \text{-----(9)}$$

is the expression for efficiency of carnot engine.

Note : (i) The interesting aspect of η of Carnot engine is that it is independent of the nature of the working substance. But Carnot used an ideal gas operation which is not strictly followed by real gases or fuels.

(ii) Theoretically η can be 100%.

(iii) The efficiency of Carnot's ideal engine depends only on the temperatures of the source and the sink.

(iv) Efficiency of any reversible engine working between same two temperatures is same.

7. Discuss the Carnot cycle of operation and deduce the expression for efficiency. Carnot engine is works on the principle of Carnot cycle made up of four stages are represented as shown in (PV) diagram.

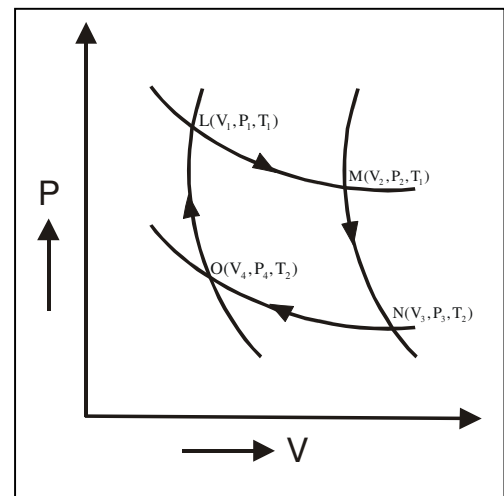
1) Isothermal expansion (LM): The gas is allowed to expand isothermally. During the expansion gas absorb an amount of heat Q_1 from the source at T_1 ,

(2)Adiabatic expansion (MN): The gas is allowed to expand adiabatically till the temperature of gas falls to T_2 , the temperature of the sink,

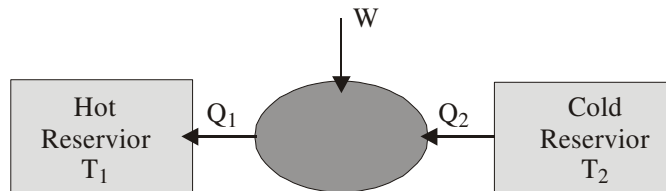
(3) Isothermal compression (NO): The gas is compressed slowly at constant temperature T_2 . During this process a certain amount of heat Q_2 is rejected into the sink,

(4) Adiabatic compression (OL): The gas is further compressed adiabatically till it returns to its initial state L.

The cycle of operations, LM, MN, NO and OL is called the Carnot cycle. It is represented by the closed loop LMNOL.



8. A refrigerator is the reverse of a heat engine. Here the working substance extracts heat Q_2 from the cold reservoir at temperature T_2 , some external work W is done on it and heat Q_1 is released to the hot reservoir at temperature T_1 .



In a refrigerator the working substance (usually, in gaseous form) goes through the following steps:

- Sudden expansion of the gas from high to low pressure which cools it and converts it into a vapour-liquid mixture,
- Absorption by the cold fluid of heat from the region to be cooled converting it into vapour.
- Heating up of the vapour due to external work done on the system, and
- Release of heat by the vapour to the surroundings, bringing it to the initial state and completing the cycle.

The coefficient of performance (a) of a refrigerator is given by $\alpha = \frac{Q_2}{W}$

SOLUTIONS TO THE PROBLEMS :

1. since the process is adiabatic

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

$$\frac{V_1}{V_2} = \frac{2}{1}, \quad \gamma = 7/5 \text{ for hydrogen}$$

\therefore Factor by which the pressure of the gas increases

$$\Rightarrow \frac{P_2}{P_1} = \left(\frac{V_1}{V_2} \right)^\gamma \qquad \Rightarrow \frac{P_2}{P_1} = (2)^{7/5}$$

2. Since, the system is going from A to B and then back to A, it is undergoing a cyclic change. Now in cyclic change there is no change in internal energy $\Delta U = 0$.

From first law of thermodynamics

$$\Delta Q = \Delta U + \Delta W = \Delta W \quad [\because \Delta U = 0]$$

The amount of heat absorbed by the system

$$\begin{aligned} \Delta Q &= 9.35 \text{ cal} - 22.3 \text{ J} \\ &= (9.35 \times 4.19 - 22.3) \text{ J} \\ &= 16.87 \text{ J} \end{aligned}$$

\therefore The net work done by the system $\Delta W = 16.87 \text{ J}$

3. Given : heat supplied per second, $\Delta Q = 100 \text{ J}$

Work done by the system per second $\Delta W = 75 \text{ J}$

Increase in internal energy per second = ΔU ?

From the first law of thermodynamics

$$\begin{aligned} \Delta Q &= \Delta U + \Delta W & \Delta U &= \Delta Q - \Delta W \\ \Delta U &= 100 \text{ J} - 75 \text{ J} & \Delta U &= 25 \text{ J per second.} \\ & \text{or } \Delta U &= 25 \text{ W} \end{aligned}$$

4. Given : Q_1 = heat absorbed from the boiler per minute = $3.6 \times 10^9 \text{ J}$
 W = work done per minute by the steam engine = $5.4 \times 10^8 \text{ J}$
 Q_2 = heat wasted / rejected per minute = ?
 = percentage efficiency of the heat engine = ?

$$\text{We have } \eta\% = \frac{W}{Q_1} \times 100$$

$$= \frac{5.4 \times 10^8 \text{ J}}{3.6 \times 10^9 \text{ J}} \times 100$$

$$= \frac{3}{20} \times 100 = 15\%$$

Also heat absorbed $Q_1 = W + Q_2$

$$\begin{aligned} \text{heat wasted } Q_2 &= Q_1 - W = 3.6 \times 10^9 - 5.4 \times 10^8 \\ &= 3.06 \times 10^9 \text{ J/min.} = 3.06 \times 10^9 \text{ J/m} \\ &= 3.1 \times 10^9 \text{ J/min.} \end{aligned}$$

5. Given : $T_1 = 500\text{K}$
 $T_2 = 375\text{K}$
 $Q_1 = \text{Heat absorbed per cycle} = 600\text{K cal.}$

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

$$\eta = \frac{T_1 - T_2}{T_1} = \frac{500 - 375}{500} = \frac{125}{500} = 0.25$$

$$\eta\% = 0.25 \times 100 = 25\%$$

Suppose $W = \text{work done per cycle}$

from the relation , $\eta = \frac{W}{Q_1}$ we get

$$W = \eta Q_1 = 0.25 \times 600 \text{ K cal.}$$

$$= 150\text{K cal}$$

$$= 150 \times 10^3 \times 4.2 \text{ J}$$

$$= 6.3 \times 10^5 \text{ J.}$$

Suppose $Q_2 = \text{heat rejected to the sink.}$

Then $W = Q_1 - Q_2$, we get

$$Q_2 = Q_1 - W = 600 - 150 = 450 \text{ K cal.}$$

6. $T_1 = 25 + 273 = 298 \text{ K}$ $T_2 = -10 + 273 = 263 \text{ K}$ $Q_2 = 263 \text{ Js}^{-1}$

We have $\frac{Q_1}{Q_2} = \frac{T_1}{T_2}$ $Q_1 = \frac{T_1}{T_2} \times Q_2 = \frac{298}{263} \times 263$

$$Q_1 = 298\text{Js}^{-1}$$

Average power consumed = $Q_1 - Q_2$
 $= (298 - 263) \text{ Js}^{-1}$
 $= 35 \text{ W}$

7. Given : $T_2 = 00^\circ\text{C} = 273 \text{ K}$
 $T_1 = 300^\circ\text{C} = 273 + 30 = 303 \text{ K}$
 $\beta = ?$

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

$$\beta = \frac{273}{303 - 273} = \frac{273}{30} = 9.1$$

8. Given : $V_1 = V$
 $V_2 = 4V$
 $P_1 = 76 \text{ cm of Hg.}$
 $P_2 = ?$
 $\gamma = 1.4$
 $T_1 = 273 \text{ K}$
 $T_2 = ?$

For isothermal expansion

$$P_1 V_1 = P_2 V_2$$

$$P_2 = P_1 \frac{V_1}{V_2}$$

$$= \frac{76}{4} = 19 \text{ cm of Hg.}$$

As the process is isothermal, therefore the final temperature will be the same as the initial temperature.

i.e. $T_2 = 273 \text{ K}$

For Adiabatic expansion: $P_1 V_1^\gamma = P_2 V_2^\gamma$

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

$$P_2 = 76 \left(\frac{1}{4} \right)^{1.4}$$

$$= 76 \times (0.25)^{1.4}$$

$$= 10.91 \text{ cm of Hg.}$$

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

$$T_2 = T_1 \left(\frac{V_1}{V_2} \right)^{\gamma-1} \quad T_2 = 273 \left(\frac{1}{4} \right)^{1.4-1}$$

$$= \frac{273}{(4)^{0.4}} = 156.8 \text{ K}$$

9. $T_2 = 277\text{K}$, $T_1 = 300 \text{ K}$, $Q_1 = ?$, $W = 1 \text{ J}$

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

$$\beta = \frac{277}{300 - 277} = \frac{277}{23} = 12.04$$

Also $\beta = \frac{Q_2}{W} = \frac{Q_2}{1}$

We get $\beta = Q_2$

$$Q_2 = 12.04 \text{ J}$$

Now $W = Q_1 - Q_2$

or $Q_1 = W + Q_2$

i.e. Total heat delivered to the room,

$$Q_1 = 1 + 12.04 = 13.04 \text{ J}$$

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