UNIT-8 (CHAPTER-12)

Question 12.1:

A geyser heats water flowing at the rate of 3.0 litres per minute from 27 °C to 77 °C. If the geyser operates on a gas burner, what is the rate of consumption of the fuel if its heat of combustion is 4.0×10^4 J/g?

Answer

Water is flowing at a rate of 3.0 litre/min.

The geyser heats the water, raising the temperature from 27°C to 77°C.

Initial temperature, $T_1 = 27°C$

Final temperature, $T_2 = 77°C$

∴Rise in temperature, $\Delta T = T_2 - T_1$

$= 77 - 27 = 50°C$

Heat of combustion = 4×10^4 J/g

Specific heat of water, $c = 4.2 \text{ J g}^{-1} \text{ °C}^{-1}$

Mass of flowing water, m = 3.0 litre/min = 3000 g/min

Total heat used, $\Delta Q = mc\,\Delta T$

$= 3000 \times 4.2 \times 50$

$= 6.3 \times 10^5$ J/min

∴Rate of consumption = $\dfrac{6.3 \times 10^5}{4 \times 10^4}$ = 15.75 g/min

Question 12.2:

What amount of heat must be supplied to 2.0×10^{-2} kg of nitrogen (at room temperature) to raise its temperature by 45 °C at constant pressure? (Molecular mass of $N_2 = 28$; $R = 8.3 \text{ J mol}^{-1} \text{ K}^{-1}$.)

Answer

Mass of nitrogen, $m = 2.0 \times 10^{-2}$ kg = 20 g

Rise in temperature, $\Delta T = 45°C$

Molecular mass of N_2, $M = 28$

Universal gas constant, $R = 8.3$ J mol^{-1} K^{-1}

Number of moles, $n = \dfrac{m}{M}$

$$= \frac{2.0 \times 10^{-2} \times 10^{3}}{28} = 0.714$$

Molar specific heat at constant pressure for nitrogen, $C_P = \dfrac{7}{2}R$

$$= \frac{7}{2} \times 8.3$$

$$= 29.05 \text{ J mol}^{-1} \text{ K}^{-1}$$

The total amount of heat to be supplied is given by the relation:

$\Delta Q = nC_P \Delta T$

= 0.714 × 29.05 × 45

= 933.38 J

Therefore, the amount of heat to be supplied is 933.38 J.

Question 12.3:

Explain why

Two bodies at different temperatures T_1 and T_2 if brought in thermal contact do not necessarily settle to the mean temperature $(T_1 + T_2)/2$.

The coolant in a chemical or a nuclear plant (i.e., the liquid used to prevent the different parts of a plant from getting too hot) should have high specific heat.

Air pressure in a car tyre increases during driving.

The climate of a harbour town is more temperate than that of a town in a desert at the same latitude.

Answer

When two bodies at different temperatures T_1 and T_2 are brought in thermal contact, heat flows from the body at the higher temperature to the body at the lower temperature till equilibrium is achieved, i.e., the temperatures of both the bodies become equal. The equilibrium temperature is equal to the mean temperature $(T_1 + T_2)/2$ only when the thermal capacities of both the bodies are equal.

The coolant in a chemical or nuclear plant should have a high specific heat. This is because higher the specific heat of the coolant, higher is its heat-absorbing capacity and vice versa. Hence, a liquid having a high specific heat is the best coolant to be used in a nuclear or chemical plant. This would prevent different parts of the plant from getting too hot.

When a car is in motion, the air temperature inside the car increases because of the motion of the air molecules. According to Charles' law, temperature is directly proportional to pressure. Hence, if the temperature inside a tyre increases, then the air pressure in it will also increase.

A harbour town has a more temperate climate (i.e., without the extremes of heat or cold) than a town located in a desert at the same latitude. This is because the relative humidity in a harbour town is more than it is in a desert town.

Question 12.4:

A cylinder with a movable piston contains 3 moles of hydrogen at standard temperature and pressure. The walls of the cylinder are made of a heat insulator, and the piston is insulated by having a pile of sand on it. By what factor does the pressure of the gas increase if the gas is compressed to half its original volume?

Answer

The cylinder is completely insulated from its surroundings. As a result, no heat is exchanged between the system (cylinder) and its surroundings. Thus, the process is adiabatic.

Initial pressure inside the cylinder = P_1

Final pressure inside the cylinder = P_2

Initial volume inside the cylinder = V_1

Final volume inside the cylinder = V_2

Ratio of specific heats, $\gamma = 1.4$

For an adiabatic process, we have:

$$P_1V_1^{\gamma} = P_2V_2^{\gamma}$$

The final volume is compressed to half of its initial volume.

$$\therefore V_2 = \frac{V_1}{2}$$

$$P_1(V_1)^{\gamma} = P_2\left(\frac{V_1}{2}\right)^{\gamma}$$

$$\frac{P_2}{P_1} = \frac{(V_1)^{\gamma}}{\left(\frac{V_1}{2}\right)^{\gamma}} = (2)^{\gamma} = (2)^{1.4} = 2.639$$

Hence, the pressure increases by a factor of 2.639.

Question 12.5:

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 net work done by the system in the latter case? (Take 1 cal = 4.19 J)

Answer

The work done (W) on the system while the gas changes from state A to state B is 22.3 J.

This is an adiabatic process. Hence, change in heat is zero.

$\therefore \Delta Q = 0$

$\Delta W = -22.3$ J (Since the work is done on the system)

From the first law of thermodynamics, we have:

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

Where,

ΔU = Change in the internal energy of the gas

$\therefore \Delta U = \Delta Q - \Delta W = -(-22.3 \text{ J})$

$\Delta U = +22.3$ J

When the gas goes from state A to state B via a process, the net heat absorbed by the system is:

$\Delta Q = 9.35 \text{ cal} = 9.35 \times 4.19 = 39.1765$ J

Heat absorbed, $\Delta Q = \Delta U + \Delta Q$

$\therefore \Delta W = \Delta Q - \Delta U$

$= 39.1765 - 22.3$

$= 16.8765$ J

Therefore, 16.88 J of work is done by the system.

Question 12.6:

Two cylinders A and B of equal capacity are connected to each other via a stopcock. A contains a gas at standard temperature and pressure. B is completely evacuated. The entire system is thermally insulated. The stopcock is suddenly opened. Answer the following:

What is the final pressure of the gas in *A* and *B?*

What is the change in internal energy of the gas?

What is the change in the temperature of the gas?

Do the intermediate states of the system (before settling to the final equilibrium state) lie on its *P*-*V*-*T* surface?

Answer

Answer:

0.5 atm

Zero

Zero

No

Explanation:

The volume available to the gas is doubled as soon as the stopcock between cylinders *A* and *B* is opened. Since volume is inversely proportional to pressure, the pressure will decrease to one-half of the original value. Since the initial pressure of the gas is 1 atm, the pressure in each cylinder will be 0.5 atm.

The internal energy of the gas can change only when work is done by or on the gas. Since in this case no work is done by or on the gas, the internal energy of the gas will not change.

Since no work is being done by the gas during the expansion of the gas, the temperature of the gas will not change at all.

The given process is a case of free expansion. It is rapid and cannot be controlled. The intermediate states do not satisfy the gas equation and since they are in non-equilibrium states, they do not lie on the *P*-*V*-*T* surface of the system.

Question 12.7:

A steam engine delivers 5.4×10^{8} J of work per minute and services 3.6×10^{9} J of heat per minute from its boiler. What is the efficiency of the engine? How much heat is wasted per minute?

Answer

Work done by the steam engine per minute, $W = 5.4 \times 10^8$ J

Heat supplied from the boiler, $H = 3.6 \times 10^9$ J

Efficiency of the engine = $\dfrac{\text{Output energy}}{\text{Input energy}}$

$$\therefore \eta = \frac{W}{H} = \frac{5.4 \times 10^8}{3.6 \times 10^9} = 0.15$$

Hence, the percentage efficiency of the engine is 15 %.

Amount of heat wasted = $3.6 \times 10^9 - 5.4 \times 10^8$

$= 30.6 \times 10^8 = 3.06 \times 10^9$ J

Therefore, the amount of heat wasted per minute is 3.06×10^9 J.

Question 12.8:

An electric heater supplies heat to a system at a rate of 100W. If system performs work at a rate of 75 Joules per second. At what rate is the internal energy increasing?

Answer

Heat is supplied to the system at a rate of 100 W.

$\therefore$Heat supplied, $Q = 100$ J/s

The system performs at a rate of 75 J/s.

∴Work done, $W = 75$ J/s

From the first law of thermodynamics, we have:

$Q = U + W$

Where,

U = Internal energy

$\therefore U = Q - W$

$= 100 - 75$

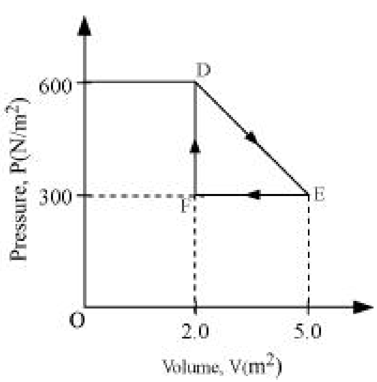
$= 25$ J/s

$= 25$ W

Therefore, the internal energy of the given electric heater increases at a rate of 25 W.

Question 12.9:

A thermodynamic system is taken from an original state to an intermediate state by the linear process shown in Fig. (12.13)



Its volume is then reduced to the original value from E to F by an isobaric process. Calculate the total work done by the gas from D to E to F

Answer

Total work done by the gas from D to E to F = Area of ΔDEF

Area of ΔDEF = $\frac{1}{2}\text{DE} \times \text{EF}$

Where,

DF = Change in pressure

= 600 N/m^2 – 300 N/m^2

= 300 N/m^2

FE = Change in volume

= 5.0 m^3 – 2.0 m^3

= 3.0 m^3

Area of ΔDEF = $\frac{1}{2} \times 300 \times 3$ = 450 J

Therefore, the total work done by the gas from D to E to F is 450 J.

Question 12.10:

A refrigerator is to maintain eatables kept inside at 9°C. If room temperature is 36° C, calculate the coefficient of performance.

Answer

Temperature inside the refrigerator, T_1 = 9°C = 282 K

Room temperature, T_2 = 36°C = 309 K

Coefficient of performance = $\frac{T_1}{T_2 - T_1}$

$$= \frac{282}{309 - 282}$$

$$= 10.44$$

Therefore, the coefficient of performance of the given refrigerator is 10.44.

UNIT VIII

THERMODYNAMICS

KEY CONCEPTS

- The ratio of work done (W) to the amount of heat produced (Q) is always a constant, represented by J.

  i.e., $\frac{W}{Q} = J$

  where J is called **Joule's mechanical equivalent of heat.** The value of J = 4.186 joule/calorie.

- If temperature of a body of mass m rises by ΔT, then $Q = mc\,\Delta T$ where c is specific heat of the material of the body,

  When the state of body of mass m changes at its melting point/boiling point, then $Q = m\,L$, where L is latent heat of the body.

- All solids expand on heating. The coefficient of linear expansion (α), coefficient of superficial expansion (β) and coefficient of cubical expansion (γ) are related as

  $$\alpha = \frac{\beta}{2} = \frac{\gamma}{3}.$$

- In case of liquids, $\gamma_r = \gamma_a + \gamma_c$ where γ_r is coefficient of real expansion of a liquid, γ_a is coefficient of apparent expansion of the liquid and γ_r is coefficient of cubical expansion of the vessel.

- **Principle of calorimetry :** When two substances at different temperatures are mixed together, they exchange heat. If we assume that no heat is lost to the surroundings, then according to principle of calorimetry.

  Heat lost by one substance = Heat gained by another substance

- **Specific heat of gases :** Specific heat of a gas is the amount of heat required to raise the temperature of one gram of gas through 1°C.

Principal specific heat of a gas :

(i) Specific heat at constant volume (c_v)

(ii) Specific heat at constant pressure (c_p)

$C_v \rightarrow$ molar heat capacity at constant volume

$C_p \rightarrow$ molar heat capacity at constant pressure

$$C_p - C_V = R/J \qquad R = 8.314 \frac{J}{\text{Mole-K}}$$

- Coefficient of thermal conductivity (K) of a solid conductor is calculated from the relation

$$\frac{\Delta Q}{\Delta t} = KA\left(\frac{\Delta T}{\Delta t}\right)$$

where A is area of hot face, Δx is distance between the hot and cold faces, ΔQ is the small amount of heat conducted in a small time (Δt), ΔT is difference in temperatures of hot and cold faces.

Here ($\Delta T/\Delta x$) temperature gradient, i.e., rate of fall of temperature with distance in the direction of flow of heat.

All liquids and gases are heated by convection. Heat comes to us from the sun by radiation.

- When the temperature difference between body and surroundings is large, then Stefan's law for cooling of body is obeyed. According to it,

$$E = \sigma (T^4 - T_0^4)$$

where E is the amount of thermal energy emitted per second per unit area of a black body. T is the temperature of black body and T_0 is the temperature of surroundings, σ is the Stefan's constant.

Wien's Displacement Law : The wavelength λ_{max} at which the maximum amount of energy is radiated decreases with the increase of temperature and is such that

$$\lambda_{max} T = \text{a constant}$$

where T is the temperature of black body in Kelvin.

- **Thermodynamical system :** An assembly of extremely large number of gas molecules is called a thermodynamical system. The pressure P, volume V, temperature T and heat content Q are called Thermodynamical parameters.

- **Zeroth Law of Thermodynamics :** (Concept of temperature) According to this law, when thermodynamic systems A and B are separately in thermal equilibrium with a third thermodynamic system C, then the systems A and B are in thermal equilibrium with each other also.

- **Internal Energy of a Gas** is the sum of kinetic energy and the potential energy of the molecules of the gas.

  K.E./molecule $= \frac{1}{2}mc^2 = \frac{3}{2}k\,T$ where k is Boltzmann's constant.

  internal energy of an ideal gas is wholly kinetic.

- **First Law of Thermodynamics** (principle of conservation of energy)

  According to this law dQ = dU + dW

  where dQ is the small amount of heat energy exchange with a system, dU is small change in internal energy of the system and dW is the small external work done by or on the system.

- Sign conventions used in thermodynamics.

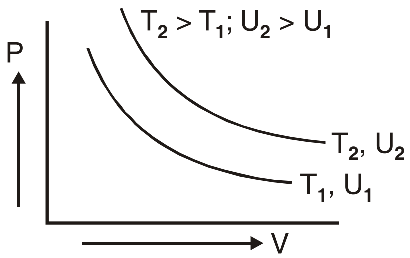
  (a) Heat absorbed by the system = positive and heat rejected by the system = negative.

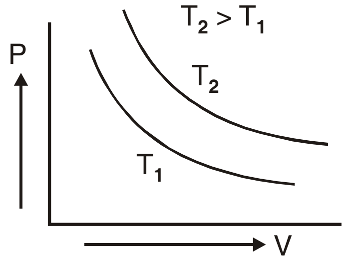
  (b) When temperature of the system rises, its internal energy increases ΔU = positive.

  When temperature of the system falls, its internal energy decreases, ΔU = negative.

  (c) When a gas expands, work is done by the system. It is taken as positive. When a gas is compressed, work is done on the system. It is taken as negative.

Isothermal changes	Adiabatic changes
● Temperature (T) remains constant, i.e., $\Delta T = 0$	1. Heat content and entropy are constant, i.e., Q = const ; S = constant, $\Delta Q = 0$; $\Delta S = 0$
● Changes are slow.	2. Changes are fast.
● System is thermally conducting.	3. System is thermally insulated.
● Internal energy, U = constant $\therefore \Delta U = 0$	4. Internal energy changes, i.e., $\Delta U \neq 0$
● Specific heat, $c = \infty$	5. Specific heat, c = 0
● Equation of isothermal changes, PV = constant.	6. Eqn. of adiabatic changes (i) PV^{γ} = constant (ii) $TV^{\gamma-1}$ = constant (iii) $P^{1-\gamma}T^{\gamma}$ = constant





● Slope of isothermal curve, $\frac{dP}{dV} = -\left(\frac{P}{V}\right)$	7. Slope of adiabatic curve, $\frac{dP}{dV} = -\gamma\left(\frac{P}{V}\right)$
● Coeff, of isothermal elasticity, $K_i = P$	8. Coeff. of adiabatic elasticity, $K_a = \gamma P$
● Work done in isothermal expansion	9. Work done in adiabatic expansion
$W = 2.303\ nRT \log_{10} (V_2/V_1)$ $n \rightarrow$ number of mole $W = 2.303\ P_1 V_1 \log_{10} (V_2/V_1)$ $W = 2.303\ nRT \log_{10} (P_1/P_2)$	$W = \frac{nR(T_2 - T_1)}{1-\gamma}$ $\frac{P_2V_2 - P_1V_1}{1-\gamma}$ $W = C_v (T_1 - T_2)$

- **Second Law of Thermodynamics :** It is impossible for self acting machine, unaided by an external agency to convey heat from the body at lower temperature to another at higher temperature. This statement of the law was made by **Clausius.**

  According to **Kelvin,** it is impossible to derive a continuous supply of work by cooling a body to a temperature lower than that of the coldest of its surroundings.

  Heat Engines : A heat engine is a device which converts heat energy into mechanical energy. Efficiency of a heat engine is the ratio of work done (W) by the engine per cycle to the energy absorbed from the source (Q_1) per cycle.

$$\eta = \frac{W}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1}$$ where Q_2 = heat rejected to the sink

- **Carnot Engine :** is an ideal heat engine which is based on Carnot's reversible cycle. Its working consists of four steps. (Isothermal expansion, Adiabatic expansion isothermal compression and adiabatic compression).

  The efficiency of Carnot engine is given by $\eta = 1 - \frac{Q_2}{Q_1} = 1 - \frac{T_2}{T_1}$

  where Q_1 is heat energy absorbed from the source maintained at high temperature T_1K and Q_2 is amount of heat energy rejected to the sink at low temperature T_2K.

  A Refrigerator absorbs heat Q2 from a sink (substance to be cooled) at lower temperature TK. Electric energy W has to be supplied for this purpose

  $$Q_1 = Q_2 + W$$

  Coefficient of performance (β) of a refrigerator is the ratio of the heat absorbed per cycle from the sink (Q2) to the electric energy supplied (W) for this purpose per cycle, i.e.,

  $$\beta = \frac{Q_2}{W}, \text{ i.e., } \beta = \frac{Q_2}{Q_1 - Q_2} = \frac{T_2}{T_1 - T_2} = \frac{1-\eta}{\eta}$$

QUESTIONS

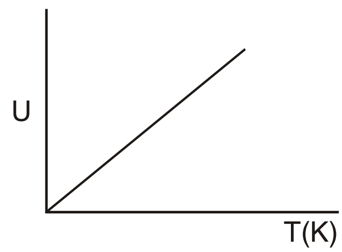
1. Why spark is produced when two substances are struck hard against each other?
2. What is the specific heat of a gas in an isothermal process.
3. On what factors, does the efficiency of Carnot engine depend?
4. What are two essential features of Carnot's ideal heat engine.
5. Plot a graph between internal energy U and Temperature (T) of an ideal gas.

6. Refrigerator transfers heat from cold body to a hot body. Does this violate the second law of thermodynamics.
7. Is it possible to increase the temperature of gas without giving it heat?
8. Can the specific heat of a gas be infinity?
9. Out of the parameters : temperature, pressure, work and volume, which parameter does not characterise the thermodynamics state of matter?
10. Why a gas is cooled when expanded?
11. On what factors, the efficiency of a Carnot engine depends?
12. Heat is supplied to a system, but its internal energy does not increase. What is the process involved?
13. Under what ideal condition the efficiency of a Carnot engine be 100%.
14. Which thermodynamic variable is defined by the first law of thermo-dynamics?
15. If coefficient of performance of a refrigerator a constant quantity?
16. What is the efficiency of carnot engine working between ice point and steam point?
17. Heat cannot flow itself from a body at lower temperature to a body at higher temperature is a statement or consequence of which low of thermodynamics?
18. What is the specific heat of a gas in an adiabatic process.

SHORT ANSWERS (1 MARK)

1. Work is converted into heat.
2. Infinite
3. $\eta = 1 - T_2/T_1$
4. (i) Source and sink have infinite heat capacities.

   (ii) Each process of the engine's cycle is fully reversible

5. 

6. No, External work is done
7. Yes, it happens during an adiabatic process.
8. Yes
9. Work.
10. Decrease in internal energy.
11. Temperatures of source of heat and sink.
12. Isothermal expansion.
13. If the temperature of sink is OK.
14. Internal energy.
15. No. As the inside temperature of the refrigerator decreases, its coefficient of performance decreases.
16. $\eta = 1 - T_2/T_1 = 1 - 273/373 = 26.8\%$
17. Second law of thermodynamics.
18. Zero.

SHORT ANSWER TYPE QUESTIONS (2 MARKS)

1. A thermos bottle containing tea is vigorously shaken. What will be the effect on the temperature of tea.
2. Write two limitation of the first law of thermodynamics.
3. Write the expressions for C_v and C_p of a gas in terms of gas constant R and γ where

$$\gamma = C_p/C_v$$

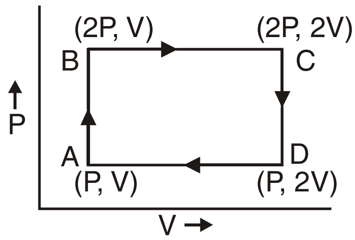
4. No real engine can have an efficiency greater that of a carnot engine working between the same tow temperatures. Why?

5. Why water at the base of a waterfall is slightly warmer than at the top?

6. When ice melts, the change in internal energy is greater than the heat supplied. Why?

7. Give two statements for the second law of thermodynamics.

8. An ideal monatomic gas is taken round the cycle ABCDA as shown. Calculate the work done during the cycle.



9. Can a room be cooled by opening the door of refrigerator in a closed room?

10. Explain what is meant by isothermal and adiabatic operations.

11. Two bodies at different temperatures T_1 and T_2, if brought in thermal contact do not necessarily settle to the mean temperature $(T_1 + T_2)/2$ Explain?

SHORT ANSWERS (2 MARKS)

1. Temperature of tea will rise.

2. (i) It does not give the direction of flow of heat.

   (ii) It does not explain why heat cannot be spontaneously converted into work.

3. $\gamma = C_p/C_v$

   $C_p - C_v = R$

   $C_p = \gamma C_v$

$$(\gamma - 1)C_v = R; C_v = \frac{R}{\gamma - 1}$$

$$C_p = \frac{\gamma R}{\gamma - 1}$$

4. In carnot engine.

   (i) There is absolutely no friction between the wall of cylinder and piston.

   (ii) Working substance is an ideal gas

   In real engine these condition cannot be fulfilled.

5. Potential energy converted in to kinetic energy, some part of kinetic energy is converted in to heat.

6. dq = du + dw

   du = dq – pdv

8. PV

9. No, It a violates seconds law.

10. Adiabatic a Process – Pressure, volume and temperature of the system changes but there is no exchange of heat.

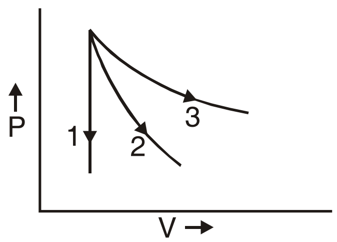
    Isothermal Process – Pressure, volume changes temperature remain constant.

11. Heat flows from higher temperature to lower temperature until the temperature become equal only where the thermal capacities of two bodies are equal.

SHORT ANSWER TYPE QUESTIONS (3 MARKS)

1. Obtain an expression for work done in an isothermal process.

2. Identify and name the Thermodynamic processes 1,2,3 as shown in figure.



3. Two samples of gas initially at the same temperature and pressure are compressed from volume V to V/2 one sample is compressed isothermally and the other adiabatically in which case the pressure will be higher? Explain?

4. Explain briefly the principle of a heat pump. What is meant by coefficient of performance?

5. (a) Why a gas has two principal specific heat capacities?

   (b) Which one is greater and why?

   (c) Of what significance is the difference between these two specific heat capacities and their ratio?

6. Is it a violation of the second law of thermodynamics to convert

   (a) Work completely in to heat

   (b) Heat completely in to work

   Why or why not?

7. State first law of thermodynamics on its basis establish the relation between two molar specific heat for a gas.

8. Explain briefly the working principle of a refrigerator and obtain an expression for its coefficient of performance.

9. State zeroth law of thermodynamics. How does it lead to the concept of temperature?

10. What is a cyclic process? Show that the net work done during a cyclic process is numerically equal to the area of the loop representing the cycle.

11. State second law of thermodynamics.

12. What is an isothermal process? Derive an expression for work done during an isothermal process.

LONG ANSWER TYPE QUESTIONS (5 MARKS)

1. Describe briefly carnot engine and obtain an expression for its efficiency.
2. Define adiabatic process. Derive an expression for work done during adiabatic process.
3. Why a gas has two principle specific heat capacities? What is the significance of $C_p - C_v$ and C_p/C_v where symbols have usual meaning.

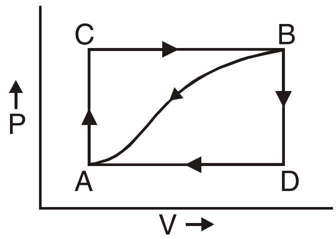
NUMERICALS

1. When a system is taken from state A to state B along the path ACB, 80 k cal of heat flows into the system and 30 kcal of work is done.

   (a) How much heat flows into the system along path ADB if the work done is 10 k cal?

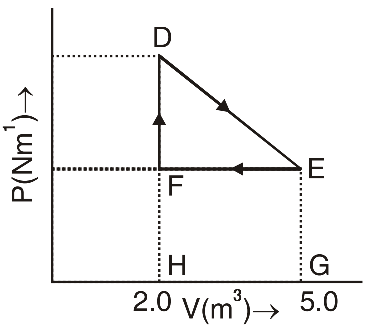
   (b) When the system is returned from B to A along the curved path the work done is 20 k cal. Does the system absorb or liberate heat.

   (c) If $U_A = 0$ and $U_D = 40$ k cal, find the heat absorbed in the process AD



2. $\frac{1}{2}$ mole of helium is contained in a container at S.T.P. How much heat energy is needed to double the pressure of the gas, keeping the volume constant? Heat capacity of gas is 3 J g^{-1} K^{-1}.
3. A thermodynamic system is taken from an original state to an intermediate state by the linear process shown in Fig.

   Its volume is then reduced to the original value from E to F by an isobaric process. Calculate the total work done by the gas from D to E to F.



4. What is the coefficient of performance (β) of a carnot refrigerator working between 30°C and 0°C?

5. Calculate the fall in temperature when a gas initially at 72°C is expanded suddenly to eight times its original volume. (γ = 5/3)

6. Refrigerator is to maintain eatables kept inside at 9°C. If room temperature is 36°C calculate the coefficient of performance.

7. A perfect carnot engine utilizes an ideal gas the source temperature is 500K and sink temperature is 375K. If the engine takes 600k cal per cycle from the source, calculate

   (i) The efficiency of engine

   (ii) Work done per cycle

   (iii) Heat rejected to sink per cycle.

8. Two carnot engines A and B are operated in series. The first one A receives heat at 900 K and reject to a reservoir at temperature T K. The second engine B receives the heat rejected by the first engine and in turn rejects to a heat reservoir at 400 K calculate the temperature T when

   (i) The efficiencies of the two engines are equal

   (ii) The work output of the two engines are equal

9. Ten mole of hydrogen at NTP is compressed adiabatically so that its temperature become 400°C How much work is done on the gas? What is the increase in the internal energy of the gas

   R = 8.4 J $mol^{-1}K^{-1}$ γ = 1.4

10. The temperature T_1 and T_2 of the two heat reservoirs in an ideal carnot engine be 1500°C and 500°C respectively. which of these increasing T_1 by 100°C or decreasing T_2 by 100°C would result in a greater improvement in the efficiency of the engine.

ANSWERS

1. (a) $dw_{ADB} = +10$ k cal

Internal energy is path independent

$du_{ADB} = du_{ACB} = 50$ k cal

$dQ_{ADB} = 50 + 10 = 60$ k cal.

(b) $dw_{BA} = -20$ k cal

$du_{BA} = -du_{ADB}$

$dQ_{BA} = du_{BA} + dW_{BA}$

$= -50 - 20 = -70$ k cal

(c) $U_A = 0$ $U_D = 40$ k cal

$du_{AD} = 40$ k cal

$dw_{ADB} = 10$ k cal

$dw_{DB} = 0$ since $dV = 0$

$dQ_{AD} = 40 + 10 = 50$ k cal

2. $n = \frac{1}{2}$, $C_v = 3$J/gK. M = 4

$C_v = MC_v = 12$ J/mole k   M $\rightarrow$ Molecular mass

$$\frac{P_2}{P_1} = \frac{T_2}{T_1} = 2$$

$\Delta T = 2T_1 - T_1 = 273$ k

$\Delta Q = n\, c_v\, \Delta T = 1638$ J

3. Total work done by the gas from D to E to F.

$$W = W_{DE} + W_{EF}$$

= Area of trapezium DEGHD – Area of rectangle EFHG

= Area of triangle DEF

$$= \frac{1}{2} DE \times FE$$

$$= \frac{1}{2}(600 - 300)\,Nm^{-2} \times (5.0 - 2.0)\,m^3$$

= 450 J.

4. $\beta = \frac{T_2}{T_1 - T_2} = \frac{273}{303 - 273} = 9.1$

5. $T_1 V_1^{v-1} = T_2 V_2^{v-1}$

$$T_2 = T_1 \left(\frac{V_1}{V_2}\right)^{v-1} = 345 \left(\frac{x}{8x}\right)^{2/3}$$

$$= 345 \times \frac{1}{4} = 86.25 \text{ k}$$

6. Here $T_1 = 273 + 36 = 309$ K,

$T_2 = 273 + 9 = 282$ K.

Coefficient of performance,

$$\beta = \frac{T_2}{T_1 - T_2} = \frac{282}{309 - 282} = \frac{282}{27} = 10.4$$

7. $T_1 = 500$ K $T_2 = 375$ K

Q_1 = Heat absorbed = 600 k cal

$$\eta = 1 - T_2/T_1 = \frac{125}{500} = 0.25$$

= 25%

(b) $\eta = \frac{w}{Q_1}$

$W = \eta Q_1 = 0.25 \times 60$ k cal = 150 k cal

= 450 k cal

(c) $w = Q_1 - Q_2$ $Q_2 = Q_1 - W = 600 - 150$

= 450 k cal

8. $W_A = W_B$

$$\frac{W}{Q_1} = \left(1 - \frac{T_2}{T_1}\right)$$

$$W = Q_1(1 - T_2/T_1)$$

$$Q_2\left(1 - T_3/T_2\right) = Q_1\left(1 - T_2/T_1\right)$$

$$\left(1 - T/900\right) \quad Q_1 = \left(1 - \frac{400}{T}\right) Q_2$$

$$\left(1 - T/900\right) \quad Q_1 = \left(1 - \frac{400}{T}\right) T/900$$

$$1 - T/900 = \frac{T}{900} - \frac{400}{900}$$

$$\frac{2T}{900} = 13/9$$

$$T = 650 \text{ K}$$

$$\eta_A = \eta_B$$

$$1 - T/900 = \frac{1 - 400}{T}$$

$$T^2 = 900 \times 400$$

$$= 600 \text{ k}$$

$$T_1 = 273 \text{ k } T_2 = 673 \text{ k}$$

mass of gas = 10 mole

$$w_{adia} = \frac{10\ R}{(\gamma - 1)}(T_1 - T_2)$$

$$= \frac{10 \times 8.4}{(1.4 - 1)}(273 - 673)$$

$= -8.4 \times 10^4$ J work being done on the gas

$du = -dw = 8.4 \times 10^4$ J

10. $\eta = 1 - T_2/T_1$

(i) T_1 is increased from 1500°C to 1600°C

$T_1 = 1873$ k

T_2 remain constant $T_2 = 773$ k

$$\eta_1 = \frac{1873 - 773}{1873} = 58.73\%$$

(ii) T_1 remain constant 1500°C

$T_1 = 1500 + 273 = 1773$ k

T_2 is decreased by 100 i.e. 400°C

$T_2 = 400 + 273 = 673$ k

$$\eta_2 = \frac{1773 - 673}{1773} = \frac{1100}{1773} = 62.04\%$$

$\eta_2 > \eta_1$