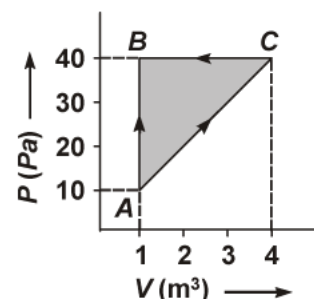


- Q1. What is the total internal energy possessed by molecules of an ideal gas?
- Q2. In summer, when the valve of a bicycle tube is removed, the escaping air appears cold. Why?
- Q3. Why does the brake drum of an automobile get heated up while moving down at constant speed?
- Q4. A cloudy night is hotter than a clear sky night. Why?
- Q5. What thermodynamic variable is defined by (a) Zeroth law (b) First law?
- Q6. What is the change in the internal energy of a system over one complete cycle of a cyclic process?
- Q7. A piece of metal is hammered. Does its internal energy increase?
- Q8. What is zeroth law of thermodynamic?
- Q9. Out of the parameters-temperature, pressure, work and volume, which parameter does not characterize the thermodynamic state of matter?
- Q10. What are the conditions for thermodynamic equilibrium?
- Q11. Is the internal energy of a gas a function of the pressure? Explain.
- Q12. Which of the two will increase the pressure more an adiabatic or an isothermal process in reducing the volume to 50%.
- Q13. What is an indicator diagram? What is its significance?
- Q14. An electric heater supplies heat to a system at a rate of 100 W. If system performs work at a rate of 75 Joules per second. At what rate is the internal energy increasing?
- Q15. The thermodynamics state of a gas is changed from the state A to C along the paths ABC and AC as shown in figure (a) Along which path, greater amount of work will have to be done? (b) If the internal energy of the gas in the state A is 5 J and 100 J of heat is supplied to change the state through the path AC, then calculate the internal energy of the gas in the state C.
- Q16. A system goes from A to B via two processes I and II as shown in figure. How are  $\Delta U_1$  and  $\Delta U_2$  (the changes in internal energies in the processes I and II respectively) related to each other?
- Q17. What is an isothermal process? Also give essential conditions for an isothermal process to take place.

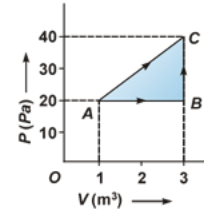


**Q18.** A heavy box having a mass of 300 kg is pulled along a level road for a distance of 10 metre. How many kilocalorie of heat are produced? Given Coefficient of sliding friction = 0.2.

**Q19. (a)** Differentiate between 'Evaporation' and 'Boiling'.

**(b)** From what height must a block of ice be dropped into a well of water so that 5% of it may melt. Given: both ice and water are at  $0^\circ\text{C}$ ,  $L = 80 \text{ cal g}^{-1}$ ,  $J = 4.2 \text{ J cal}^{-1}$  and  $g = 980 \text{ cm c}^{-2}$ .

**Q20.** A thermodynamic system goes from state *A* to the states *B* and *C* and finally returns to the state *A* as shown in figure.

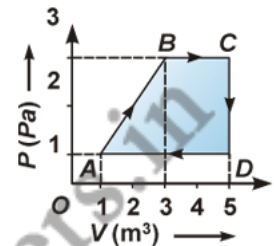


If  $U_A = 0 \text{ J}$ ,  $U_B = 30 \text{ J}$  and the heat spent in the change from state *B* to *C* is 50 J, then determine: (a) work done by the system in the change from *B* to *C*, (b) value of  $U_C$ , (c) heat released from the system in the change from *C* to *A* and (d) the net work done in the complete cycle.

**Q21.** One mole of ideal monoatomic gas ( $\gamma = 5/3$ ) is mixed with one mole of diatomic gas ( $\gamma = 7/5$ ). What is  $\gamma$  for the mixture?  $\gamma$  denotes the ratio of specific heat at constant pressure to that at constant volume.

**Q22.** A thermodynamic system takes place as shown in figure.

The internal energy of the system in the state *D* is 10 J. Determine (a) the internal energy of the system in the state *A*, if the heat given to the system in going from the state *D* to *A* is 10 J, (b) total work done by the system in going from the state *A* to the state *B*, *C* and *D* and finally returning to the state *A* and (c) nature of the process from *C* to *D*.



- S1.** Since in an ideal gas, there is no molecular attraction, the potential energy of the molecules is zero. Therefore, internal energy of an ideal gas is only kinetic in nature.
- S2.** This happens due to adiabatic expansion of the air of the tube of the bicycle.
- S3.** To make the vehicle to move at constant speed, constantly the brake has to be applied to work against the available energy. So, it gets heated up.
- S4.** This is because in the cloudy night, heat radiated out from Earth is reflected by the clouds back to Earth. Hence, temperature of the Earth does not fall.
- S5.** Zeroth law defines temperature and first law defines internal energy.
- S6.** Zero. It is because, when a system is moved over a complete cycle, it returns to its original state.
- S7.** The work done during hammering gets converted into heat energy. Due to this, its internal energy increases.
- S8.** It states that if two system *A* and *B* are in thermal equilibrium with a third system *C*, *A* and *B* must be thermal equilibrium with each other.
- S9.** Work.
- S10.** (a) Temperature of every part of the system must be the same.  
(b) There should be no net unbalanced force on a part or whole of the system.  
(c) There should be no changes due to chemical reactions.
- S11.** The internal energy of an ideal gas depends on the temperature of the gas only, while that of a real gas depends on the temperature and pressure. thus, the internal energy of an ideal gas is not a function of its pressure but that of a real gas is a function of pressure also.

**S12.** For Isothermal process,  $P'V' = PV$

$$V' = \frac{V}{2}$$

$$\therefore P' = 2P$$

For adiabatic process,  $P''V''^\gamma = PV^\gamma$

$$\therefore V'' = \frac{V}{2}$$

$$P'' = 2^\gamma P.$$

Since  $\gamma > 1$ , the adiabatic process will increase the pressure more.

**S13.** An indicator diagram is a  $P$ - $V$  graph showing the variation of pressure and volume during a thermodynamically process. It gives us:

- (a) The nature of process
- (b) The work done during the process.

**S14.** Heat is supplied to the system at a rate of 100 W.

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

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

$$\therefore \text{Work done, } W = 75 \text{ J/s}$$

From the first law of thermodynamics, we have:

$$Q = U + W$$

Where,  $U$  = Internal energy

$$\begin{aligned} \therefore U &= Q - W \\ &= 100 - 75 = 25 \text{ J/s} = \mathbf{25 \text{ W}}. \end{aligned}$$

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

**S15.** (a) As the area under the path  $ABC$  is greater than that under  $AC$ , greater amount of work will be done along the **path  $ABC$** .

(b) According to the first law of thermodynamics,

$$Q_{AC} = (U_C - U_A) + W_{AC}$$

$$\text{or } U_C = U_A + Q_{AC} - W_{AC}$$

$$\begin{aligned} \text{or } U_C &= 5 + 100 - (\text{area under the path } AC) \\ &= 105 - \frac{1}{2} (4 - 1) \times (40 - 10) = 105 - 45 = \mathbf{60 \text{ J}}. \end{aligned}$$

**S16.** When the system is taken from the state  $A$  to  $B$ , the change in internal energy is independent of the path followed.

$$\text{Therefore, } \Delta U_1 = \Delta U_2.$$

**S17.** A change in pressure and volume of a gas without any change in its temperature is called an isothermal process.

Two essential conditions for perfect isothermal process are:

- (a) The walls of the container must be perfectly conducting to allow free exchange of heat between the gas and its surrounding.

- (b) The process of compression or expansion should be slow so as to provide time for exchange of heat.

**S18.** Mass of box  $m = 300$  kg; distance  $S = 10$  m; Coefficient of sliding friction,  $\mu = 0.2$

If  $f$  be the frictional force, then

Work done,  $W = f \times S = \mu RS = \mu mg S,$

where  $R$  is the normal reaction.

or  $W = 0.2 \times 300 \times 9.8 \times 10$  J

Heat produced,  $Q = \frac{W}{J} = \frac{0.2 \times 300 \times 9.8 \times 10}{4.2 \times 10^3}$  k cal

**= 1.4 kilocalorie.**

**S19.** (a) **Evaporation:** Evaporation is a slow process from the liquid to the gaseous state which takes place at the surface of a liquid and at all temperatures.

**Boiling:** Boiling is a rapid change of a substance from the liquid to the gaseous state which takes place throughout the mass of the liquid at a definite temperature.

- (b) Let  $m$  be the mass of ice. Let  $h$  be the height from which block of ice is dropped.

Work done,  $W = mgh = m \times 980$  h erg

Mass of ice to be melted  $= \frac{5}{100} \times mg$

Heat required,  $Q = \frac{5}{100} \times m \times 80$  cal [ $\because L = 80$  cal  $g^{-1}$ ]

or  $Q = 4$  m cal [ $\because W = JQ$ ]

Now,  $m \times 980 \times h = J \cdot 4$  m

or  $h = \frac{4.2 \times 10^7 \times 4m}{m \times 980}$  [ $\because J = 4.2 \times 10^7$  erg  $cal^{-1}$ ]  
**= 1714.3 m.**

**S20.** Given,  $U_A = 0$ ;  $U_B = 30$  J and  $Q_{BC} = 50$  J

- (a) The change between the points  $B$  and  $C$  is isochoric in nature, Since  $\Delta V = 0$

$$W_{BC} = P\Delta V = P \times 0 = 0.$$

- (b) According to the first law of thermodynamics,

$$Q_{BC} = (U_C - U_B) + W_{BC}$$

or  $U_C = U_B + Q_{BC} - W_{BC}$

or  $U_C = 30 + 50 - 0 = 80$  J.

(c) Now,

$$\begin{aligned}Q_{CA} &= (U_A - U_C) + W_{CA} \\&= 0 - 80 + (- \text{area under path CA}) \\&\quad (\because \text{compression takes place along CA}) \\&= -80 - (3 - 1) \times \frac{20 + 40}{2} \\&= -80 - 60 = -140 \text{ J.}\end{aligned}$$

(d) The work done during complete cycle

$$\begin{aligned}W &= - \text{area ABCA} \\&\quad (\because \text{cycle is traced in anticlockwise direction}) \\&= -\frac{1}{2} (3 - 1) \times (40 - 20) = -20 \text{ J.}\end{aligned}$$

**S21.** Here,  $\gamma_{\text{mono}} = 5/3$  and  $\gamma_{\text{di}} = 7/5$

Now,

$$\begin{aligned}\gamma &= \frac{C_p}{C_v} \\&= \frac{C_v + R}{C_v} = 1 + \frac{R}{C_v}\end{aligned}$$

or

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

**For monoatomic gas:**

If the molar specific heat at constant volume for the monoatomic gas is  $C_v(\text{mono})$ , then

$$C_v(\text{mono}) = \frac{R}{\gamma - 1} = \frac{R}{\frac{5}{3} - 1} = \frac{3}{2} R$$

**For diatomic gas:**

If the molar specific heat at constant volume for the diatomic gas is  $C_v(\text{di})$ , then

$$C_v(\text{di}) = \frac{R}{\gamma(\text{di}) - 1} = \frac{R}{\frac{7}{5} - 1} = \frac{5}{2} R$$

**For the gas mixture:**

If the mixture contains  $n_1$  moles of monoatomic gas and  $n_2$  moles of diatomic gas, then the molar specific heat at constant volume of the mixture is given by

$$C_v(\text{mix}) = \frac{n_1 C_v(\text{mono}) + n_2 C_v(\text{di})}{n_1 + n_2}$$

Here,  $n_1 = n_2 = 1$

$$\therefore C_v(\text{mix}) = \frac{1 \times \frac{3}{2}R + 1 \times \frac{5}{2}R}{1+1} = 2R$$

Now,

$$\gamma_{\text{mix}} = 1 + \frac{R}{C_v(\text{mix})} = 1 + \frac{R}{2R} = 1.5.$$

**S22.** (a) Given,  $U_D = 10 \text{ J}; Q_{DA} = 10 \text{ J}$

According to the first law of thermodynamics,

$$Q_{DA} = (U_A - U_D) + W_{DA}$$

or  $U_A = U_D + Q_{DA} - W_{DA}$

$$= 10 + 10 - (- \text{area under the path } DA)$$

( $\because$  comparison takes place along  $DA$ )

$$= 10 + 10 + (5 - 1) \times 1 = 10 + 10 + 4 = \mathbf{24 \text{ J.}}$$

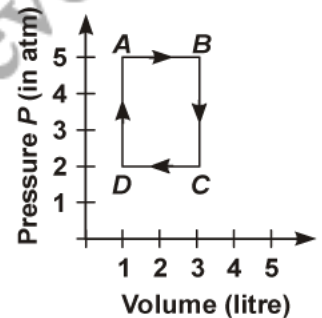
(b) The work done during complete cycle,

$$W = (3 - 1) \times \left( \frac{(5 - 1) + (5 - 3)}{2} \right) = 2 \times 3 = \mathbf{6 \text{ J.}}$$

(c) As the volume remains constant from  $C$  to  $D$ , the change is **isochoric** in nature.

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- Q1. Work depends on path in a thermodynamically process. How?
- Q2. Change in internal energy is independent of path followed. Is it true? Why?
- Q3. What is the temperature at the bottom of a lake when water gets frozen with  $-ve$  temperature in the atmosphere?
- Q4. Draw the expansion and compression graph.
- Q5. A match stick is lighted by rubbing it against a rough surface. How?
- Q6. When an iron nail is hammered, it becomes hot. Why?
- Q7. In a thermodynamic process, 400 J of heat is given to a gas and 100 J work is also done on it. What is the change in the internal energy of the gas?
- Q8. Give two properties of Carnot's engine as compared to other engines. (Carnot's theorem).
- Q9. Does the internal energy of an ideal gas change in an adiabatic process?
- Q10. What is the change in internal energy of a system if on giving 40 J of heat to a system, the work done on the system is 8 J.
- Q11. A system containing one mole of an ideal gas is expanded adiabatically. If the temperature falls from  $T_1$  to  $T_2$ , find the work done by the gas.
- Q12. What is first law of thermodynamics? Write its definition
- Q13. One mole of an ideal gas undergoes a cyclic change  $ABCD$ . Calculate the following from  $P$ - $V$  diagram.
- Work done along  $AB$ ,  $BC$ ,  $CD$  and  $DA$
  - Net work done the brass
  - Efficiency the internal energy of the gas
- (Given  $1 \text{ atm} = 1.01 \times 10^5 \text{ Nm}^{-2}$ ).
- Q14. What is the energy required for 1 gm of ice to become steam?
- Q15. How much does the internal energy of ice at  $0^\circ\text{C}$  increase as it is changed to water at  $0^\circ\text{C}$ ? Neglect the small change in volume.
- Q16. Why a gas has two principal specific heat capacities?
- Q17. If hot air rises, why is it cooler at the top of a mountain than near sea level?
- Q18. State the law of equipartition of energy. What is the internal energy with mono, di and tri-atomic gases?
- Q19. State and explain first law of thermodynamics. Apply this to derive an expression for the change in internal energy during boiling process.

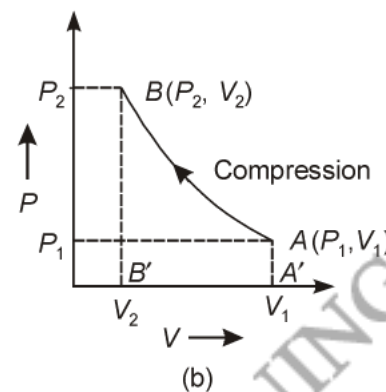
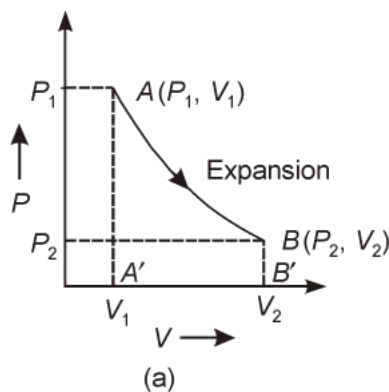




- Q20. A motor supplies 0.4 h.p to stir 5 kg of water. Assuming that all of the work goes into heating the water by friction losses, how long will it take to increase the temperature of the water by 6°C?
- Q21. 1 kg of water at 373 K is converted into the same temperature. The volume of 1 cm<sup>3</sup> of steams 1,671 cm<sup>3</sup> on boiling. Calculate change in that energy of the system, if heat of veporisation is latent. Given that standard atmospheric pressure is 10<sup>5</sup> Nm<sup>-2</sup>.
- Q22. State and explain first law of thermodynamics and apply it to the cyclic process of a liquid.
- Q23. State the first law of thermodynamics and apply it to find the relation between  $C_p$  and  $C_v$ , where the symbols have their usual meanings.
- Q24. Explain, how first law of thermodynamics may be applied to (a) cyclic process and (b) boiling process.
- Q25. 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  $4.0 \times 10^4$  J/g?
- Q26. Define 1<sup>st</sup> law of thermodynamics. By using this law, derive relationship between  $C_p$  and  $C_v$ .

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- S1.** Depending on the process carried out, the work done varies. So, it is dependent on path.
- S2.** Yes, change in internal energy depends on the change in temperature alone. So, it is independent of path.
- S3.** It can go down only upto 4 °C.
- S4.** The expansion graph shown in figure (a) and compression graph shown in figure (b).



- S5.** The work done against friction is converted into heat. This lights up the match stick.
- S6.** The kinetic energy of the hammer gets converted into heat energy which increases the temperature of the nail.
- S7.** Given

$$\Delta Q = 400 \text{ J} \quad \text{and} \quad \Delta W = -100 \text{ J}$$

$$\Delta Q = \Delta U + \Delta W \quad \Rightarrow \quad \Delta U = \Delta Q - \Delta W$$

$$\Delta U = 400 - (-100) \text{ J} = \mathbf{500 \text{ J}}$$

- S8.** (a) Efficiency is independent of fuel used.  
(b) No engine can have an efficiency greater than that of the Carnot's engine.

**S9.** Yes.

**S10.** Given

$$\Delta Q = 40 \text{ J} \quad \text{and} \quad \Delta W = -8 \text{ J}$$

$$\Delta U = \Delta Q - \Delta W = 40 - (-8) \text{ J}$$

$$\Delta U = \mathbf{48 \text{ J}}$$

Internal energy shall increase by 48 J.

**S11.** W.D. in adiabatic process,

$$W = \frac{1}{1-\gamma} [P_2 V_2 - P_1 V_1]$$

If  $T_2$  is final temperature of gas in adiabatic expansion, then from standard Eq.

$$P_1 V_1 = RT_1 \quad \text{and} \quad P_2 V_2 = RT_2.$$

Putting these values, we have

$$W = \frac{1}{1-\gamma} [RT_2 - RT_1] = \frac{R(T_1 - T_2)}{\gamma - 1}.$$

**S12.** According to this law, the energy can neither be created nor it destroy but can change itself one form to another form

**Or**

According to first law of thermodynamics when some quantity of heat ( $dQ$ ) is supplied to a system capable of doing external work, then quantity of heat absorbed by the system ( $dQ$ ) is equal to sum of increase in internal energy of system ( $dU$ ) due to rise in temperature and external work done by system ( $dW$ ) in expansion *i.e.*,

$$dQ = dU + dW.$$

First law of thermodynamics did not tell us about

- (a) the quick or slow nature of a process.
- (b) whether a process is possible or not.

**S13.** (i) Work done along AB,  $W_{AB} = PdV$

$$= 5 \times 1.01 \times 10^5 \times 2 \times 10^{-3} \text{ m}$$

$$= 1010 \text{ J.}$$

Work done along BC,  $E_{BC} = 0$  ( $\because dV = 0$ )

Work done along CD,  $W_{CD} = -2 \times 1.01 \times 10^5 \times 2 \times 10^{-3}$

$$= -404 \text{ J}$$

Work done along DA,  $W_{DA} = 0$  ( $\because dV = 0$ )

(ii) Net work done  $W = (1010 - 404)$

$$= 606 \text{ J}$$

(iii) Efficiency  $\eta = \frac{606}{1010} \times 100 = 60\%$

**S14.** Latent heat of fusion = 80 cal/gm

Latent heat of vapourisation = 540 cal/gm

Specific heat of water = 1 cal/gm °C

Energy required to make 1 gm of ice to vapour

$$= 1 \times 80 + 1 \times 1 (100 - 0) + 540$$

$$= 80 + 100 + 540 = 720 \text{ calories.}$$

**S15.** Heat removed from the ice

$$dQ = -ML$$

$$= -5 \times 80 \text{ cal}$$

$$= -5 \times 80 \times 4.2$$

$$= -1,680 \text{ J}$$

According to the first law of thermodynamics,

$$dQ = dU + P dV$$

or 
$$dU = dQ - P dV$$

Since the small change in volume of the ice is neglected,

$$dV = 0$$

$$\therefore dU = -1,680 - P \times 0$$

$$= -1,680 \text{ J.}$$

**S16.** A solid or a liquid, when heated, does not undergo any change in the volume or pressure. But in case of a gas, both the pressure and volume change on heating. Therefore, specific heat of a gas is defined either at constant volume or a constant pressure and hence a gas has two specific heats.

**S17.** Since atmospheric pressure decreases with height, pressure at the top of the mountain is lesser. When the hot air rises up, it suffers adiabatic expansion at the top of the mountain. For an adiabatic change, first law of thermodynamics may be expressed as

$$dQ = dU + dW$$

$$dU + dW = 0 \quad (\because dQ = 0)$$

or 
$$dW = -dU$$

Therefore, work done by the air in rising up ( $dW = +ve$ ) results in decrease in internal energy of the air ( $dU = -ve$ ) and hence a fall in its temperature.

**S18.** Law of equi-partition of energy states that every degree of freedom will provide the same amount of energy to the internal energy of the system, *i.e.*,  $\frac{1}{2} RT$ . Internal energy with mono, di and tri-atomic gas is,  $\frac{3}{2} R$ ,  $\frac{5}{2} R$  and  $\frac{7}{2} R$  respectively.

**S19.** According to first law of thermodynamics when some quantity of heat ( $dQ$ ) is supplied to a system capable of doing external work, then quantity of heat absorbed by the system ( $dQ$ ) is equal to sum of increase in internal energy of system ( $dU$ ) due to rise in temperature and external work done by system ( $dQ$ ) in expansion *i.e.*,

$$dQ = dU + dW.$$

**Boiling process:** When a liquid is supplied heat, it starts boiling at a particular temperature, called its boiling point. At boiling point (pressure kept constant), the unit mass of the liquid requires a definite amount of heat energy to change from liquid to vapour state. The amount of heat supplied is called **latent heat of vaporisation** of the liquid.

Consider a liquid of mass  $m$  at a temperature equal to its boiling point. Let  $P$  be the constant external pressure, at which it is boiling and  $L$  be its latent heat of vaporisation. Then,

amount of heat required to convert whole of the liquid into vapour,

$$\Delta Q = m L$$

From the first law of thermodynamics,

heat absorbed = increase in internal energy + external work performed

*i.e.*, 
$$\Delta Q = \Delta U + \Delta W \quad \dots (i)$$

If  $U_i$  and  $U_f$  are the initial and final values of the internal energy and  $V_i$  and  $V_f$  are initial and final values of the volume, then

increase in internal energy, 
$$\Delta U = U_f - U_i$$

and external work done, 
$$\Delta W = P dV = P(V_f - V_i)$$

In the Eq. (i), substituting for  $\Delta Q$ ,  $\Delta U$  and  $\Delta W$ , we have

$$m L = (U_f - U_i) + P(V_f - V_i)$$

$$(U_f - U_i) = m L - P(V_f - V_i).$$

**S20.** Here, power of motor, 
$$P = 0.4 \text{ h.p} = 0.4 \times 746 \text{ W} = 298.4 \text{ W}.$$

Suppose that the energy supplied by the motor produces the required amount of heat in time  $t$ . then,

energy supplied by the motor, 
$$W = P \times t = 0.4 \times 746 \times t$$

Therefore, heat produced, 
$$dQ = \frac{W}{J} = \frac{0.4 \times 746 \times t}{4.2} \text{ cal}$$

As the heat produced is used up in raising the temperature of water, the change in internal energy of the water

$$dQ = dU \quad \text{or} \quad dQ = Mc\Delta T$$

$$\therefore \frac{0.4 \times 746 \times t}{4.2} = 5 \times 10^3 \times 6 \quad (\because c = 10^3 \text{ cal kg}^{-1} \text{ }^\circ\text{C}^{-1})$$

or 
$$t = \frac{5 \times 10^3 \times 6 \times 4.2}{0.4 \times 746} = 422.3 \text{ s}.$$

**S21.** Here, standard atmospheric pressure,

$$P = 1.013 \times 10^5 \text{ Nm}^{-2}$$

$$\text{Volume of water} = 1 \text{ cm}^3$$

and

$$\text{Volume of steam} = 1.671 \text{ cm}^3$$

Therefore, increase in volume,

$$dV = 1,671 - 1 = 1,670 \text{ cm}^3 = 1.67 \times 10^{-3} \text{ m}^3$$

If we assume that the expansion occurs at the constant atmospheric pressure, then external work done,

$$dW = P dV = 1.013 \times 10^5 \times 1.67 \times 10^{-3} \text{ J} = 169.17 \text{ J}$$

Now, Mass of water,  $m = 1 \text{ g}$ ;

Latent heat of veporisation for water,

$$L = 540 \text{ cal g}^{-1}$$

Therefore, heat absorbed by water,

$$dQ = mL = 1 \times 540 \text{ cal} = 540 \times 4.2 \text{ J} = 2,268 \text{ J}$$

According to the first law of thermodynamics,

$$dQ = dU + dW$$

$\therefore$

$$dU = dQ - dW = 2,268 - 169.17 = 2,098.83 \text{ J}$$

**S22.** According to first law of thermodynamics when some quantity of heat ( $dQ$ ) is supplied to a system capable of doing external work, then quantity of heat absorbed by the system ( $dQ$ ) is equal to sum of increase in internal energy of system ( $dU$ ) due to rise in temperature and external work done by system ( $dQ$ ) in expansion *i.e.*,

$$dQ = dU + dW.$$

**Cyclic process:** In a cyclic process, the system returns to its initial state at the end of the cycle. The figure shows a cyclic process, in which the system proceeds from the state A to B along the path X and then returns back to the initial state A along the path Y.

Obviously, the change in internal energy of the system along the complete cyclic process is zero *i.e.*,  $dU = 0$ .

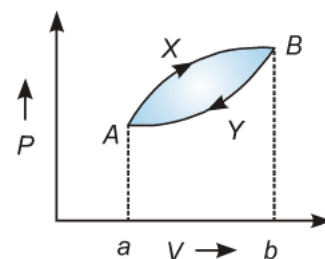
Therefore, for a cyclic process, th first law of thermodynamic becomes

$$dQ = 0 = P dV$$

or

$$dW = P dV$$

*i.e.*, in a cyclic process, the heat supplied to the gas is wholly converted into work and the area of the cyclic process is numerically equal to the work done during the process.



**S23.** According to first law of thermodynamics when some quantity of heat ( $dQ$ ) is supplied to a system capable of doing external work, then quantity of heat absorbed by the system ( $dQ$ ) is equal to sum of increase in internal energy of system ( $dU$ ) due to rise in temperature and external work done by system ( $dQ$ ) in expansion *i.e.*,

$$dQ = dU + dW.$$

The relation between two specific heats of a gas can also be derived by applying first law of thermodynamics.

Consider one mole of an ideal gas. Suppose that the gas is heated at constant volume, so that its temperature increases by  $dT$ . If  $dQ$  is the amount of heat supplied, then

$$dQ = 1 \times C_v \times dT$$

or 
$$dQ = C_v dT \quad \dots (i)$$

As the gas is heated at constant volume, it will not perform any external work and in accordance with the first law of thermodynamics.

$$dQ = dU + 0 = dU$$

Setting  $dQ = dU$  in the Eq. (i), we have

$$dU = C_v dT \quad \dots (ii)$$

Now, heat the gas at constant pressure so as to again increase its temperature by  $dT$ . If  $dQ'$  is the amount of heat supplied, then

$$dQ' = 1 \times C_p \times dT$$

or 
$$dQ' = C_p \times dT \quad \dots (iii)$$

The heat supplied at constant pressure increases the temperature of the gas by  $dT$ . *i.e.*, increases its internal energy by  $dU$  and as well as enables the gas to perform work  $dW$ . If  $dV$  is the increase in volume of the gas, then work performed by the gas,

$$dW = P dV \quad \dots (iv)$$

According to the first law of thermodynamics, the total heat supplied to the gas to heat it at constant pressure,

$$dQ' = dU + dW$$

Using the Eq. (ii), (iii) and (iv), we get

$$C_p dT = C_v dT + P dV \quad \dots (v)$$

For one mole of a perfect gas,

$$PV = RT$$

The heat  $dQ'$  is supplied to the gas at constant pressure  $P$ . Therefore, differentiating both sides of the above equation w.r.t.  $T$  by treating  $P$  as constant, we obtain

$$\frac{d}{dT}(PV) = \frac{d}{dT}(RT) \quad \text{or} \quad P \frac{dV}{dT} = R$$

or 
$$P dV = R dT \quad \dots (vi)$$

From the Eqs. (v) and (vi), we have

$$C_p dT = C_v dT + R dV$$

or 
$$C_p = C_v + R. \quad (vii)$$

- S24. (a) Cyclic process:** In a cyclic process, the system returns to its initial state at the end of the cycle. The figure shows a cyclic process, in which the system proceeds from the state  $A$  to  $B$  along the path  $X$  and then returns back to the initial state  $A$  along the path  $Y$ .

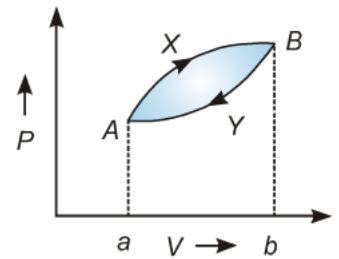
Obviously, the change in internal energy of the system along the complete cyclic process is zero *i.e.*,  $dU = 0$ .

Therefore, for a cyclic process, the first law of thermodynamic becomes

$$dQ = 0 = P dV$$

or

$$dW = P dV$$



*i.e.*, in a cyclic process, the heat supplied to the gas is wholly converted into work and the area of the cyclic process is numerically equal to the work done during the process.

- (b) **Boiling process:** When a liquid is supplied heat, it starts boiling at a particular temperature, called its boiling point. At boiling point (pressure kept constant), the unit mass of the liquid requires a definite amount of heat energy to change from liquid to vapour state. The amount of heat supplied is called **latent heat of vaporisation** of the liquid.

Consider a liquid of mass  $m$  at a temperature equal to its boiling point. Let  $P$  be the constant external pressure, at which it is boiling and  $L$  be its latent heat of vaporisation. Then, amount of heat required to convert whole of the liquid into vapour,

$$\Delta Q = m L$$

From the first law of thermodynamics,

heat absorbed = increase in internal energy + external work performed

$$\text{i.e.,} \quad \Delta Q = \Delta U + \Delta W \quad \dots (i)$$

If  $U_i$  and  $U_f$  are the initial and final values of the internal energy and  $V_i$  and  $V_f$  are initial and final values of the volume, then

$$\text{increase in internal energy, } \Delta U = U_f - U_i$$

$$\text{and external work done, } \Delta E = P dV = P(V_f - V_i)$$

In the Eq. (i), substituting for  $\Delta Q$ ,  $\Delta U$  and  $\Delta W$ , we have

$$m L = (U_f - U_i) + P(V_f - V_i)$$

$$(U_f - U_i) = m L - P(V_f - V_i).$$

- S25.** Water is flowing at a rate of 3.0 litre/min.

The geyser heats the water, raising the temperature from  $27^\circ\text{C}$  to  $77^\circ\text{C}$ .

$$\text{Initial temperature,} \quad T_1 = 27^\circ\text{C}$$

$$\text{Final temperature,} \quad T_2 = 77^\circ\text{C}$$



$$\begin{aligned}
 \therefore \text{ Rise in temperature, } & \Delta T = T_2 - T_1 \\
 & = 77 - 27 = 50^\circ\text{C} \\
 \text{Heat of combustion} & = 4 \times 10^4 \text{ J/g} \\
 \text{Specific heat of water,} & c = 4.2 \text{ J g}^{-1} \text{ }^\circ\text{C}^{-1} \\
 \text{Mass of flowing water,} & m = 3.0 \text{ litre/min} = 3000 \text{ g/min} \\
 \text{Total heat used,} & \Delta Q = mc \Delta T \\
 & = 3000 \times 4.2 \times 50 \\
 & = 6.3 \times 10^5 \text{ J/min} \\
 \therefore \text{ Rate of consumption} & = \frac{6.3 \times 10^5}{4 \times 10^4} = 15.75 \text{ g/min.}
 \end{aligned}$$

**S26. First law of Thermodynamics:** It is based on the conservation of energy. The total heat energy change in any system is the sum of the internal energy change and the work done, i.e.,

$$dQ = dU + dW.$$

where  $dU \rightarrow$  internal energy change and  $dW = PdV$  is the work done by/on the system,  $dU$  is a state function and depends on  $dT$ . ( $dU = nC_v dT$ ).  $dW$  depends on the path followed and so, is different in various processes.

**Relationship between  $C_p$  and  $C_v$ :** Suppose one mole of a gas is heated at constant volume so that its temperature rises by  $dT$ .

$$\text{Heat supplied} = 1 \times C_v \times dT = C_v dT \quad \dots \text{ (i)}$$

Since the volume is constant, the gas will not perform external work in accordance with the first law of thermodynamics and the heat supplied will be just equal to the increase in the internal energy of the gas.

$$\therefore dU = C_v dT \quad \dots \text{ (ii)}$$

Let the gas be heated at constant pressure to again increase its temperature by  $dT$ , and  $dQ$  be the amount of heat supplied, therefore,

$$dQ = 1 \times C_p \times dT = C_p dT \quad \dots \text{ (iii)}$$

The heat supplied at a constant pressure increases the temperature by  $dT$  hence increases its internal energy by  $dU = C_v dT$  as well as enables the gas to perform work  $dW$ .

$$dW = PdV \quad \dots \text{ (iv)}$$

From the first law of thermodynamics, we have

$$dQ = dU + dW$$

Substituting the values, we get

$$C_p dT = C_v dT + PdV$$

But  $PV = RT$  (For one mole of an ideal gas)

or  $PdV = RdT,$  ( $\therefore C_p dT = C_v dT + RdT$ )

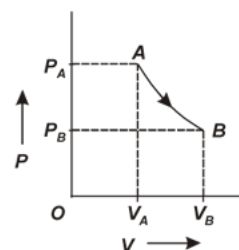
or  $C_p - C_v = R$  ... (v)

This is the relationship between two principal specific heats of the gas when  $C_p$ ,  $C_v$  and  $R$  are measured in the units of either heat or of work.

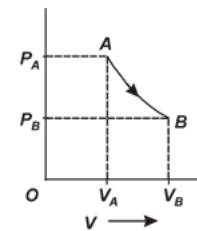
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- Q1. Why is molar specific heat at constant volume ( $C_v$ ) less than molar specific heat at constant pressure ( $C_p$ )?
- Q2. 100 joule of work is done on a gas to reduce its volume by compressing it. What is change in the internal energy of the gas if the compression is carried out adiabatically?
- Q3. What is the value of  $\gamma$  for a gas having ' $n$ ' degrees of freedom?
- Q4.  $C_p$  is greater than  $C_v$ , why?
- Q5. What is the specific heat of a gas in an isothermal process and in an adiabatic process?
- Q6. What is the value of specific heat of water in SI units? Does it vary with temperature?
- Q7. Plot a graph showing the variation of specific heat of water with temperature.
- Q8. Is it possible to heat a body without providing heat energy? How?
- Q9. Can the value of specific heat of a gas be infinity?
- Q10. How many specific heats does a gas possess?
- Q11. Does specific heat of a gas possess a unique value?
- Q12. Explain, why a gas can only expand at constant temperature, if a certain quantity of heat is supplied to it.
- Q13. Define molar specific heat at constant volume and specific heat of a gas at constant volume.
- Q14. Can two isothermal curves intersect? Why?
- Q15. A refrigerator is to maintain eatables kept inside at  $9^\circ\text{C}$ . If room temperature is  $36^\circ\text{C}$ , calculate the coefficient of performance.
- Q16. Define two principle specific heats of a gas. Which is greater and why?
- Q17. By applying the first law of thermodynamics to isobaric process, obtain relation between two specific heats of a gas.
- Q18. Of what significance is the difference between the two specific heat capacities and their ratio?
- Q19. One gram molecule of oxygen is heated at a constant pressure from  $0^\circ\text{C}$ . What amount of heat should be imparted to the gas to double its volume? The heat capacity of oxygen under these conditions is  $C_p = 0.218 \text{ Cal g}^{-1} \text{ }^\circ\text{C}^{-1}$ .
- Q20. A cylinder of fixed capacity 44.8 liters contains helium gas at standard temperature and pressure. What is the amount of heat needed to raise the temperature of the gas in cylinder by  $15^\circ\text{C}$ . given that  $R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$ .

- Q21. 15 moles of oxygen is heated at constant volume from 30 °C to 75 °C. Calculate the amount of heat required. Given that specific heat of oxygen at constant pressure,  $C_p = 8 \text{ cal mole}^{-1} \text{ }^\circ\text{C}^{-1}$ ,  $1 \text{ cal} = 4.2 \text{ J}$  and  $R = 8.31 \text{ J mole}^{-1} \text{ K}^{-1}$ .
- Q22. Calculate the specific heat at constant volume for the hydrogen gas. Given,  $C_p = 6.85 \text{ Cal mol}^{-1} \text{ K}^{-1}$ ; density of hydrogen at N.T.P. =  $0.089 \text{ g liter}^{-1}$  and  $1 \text{ cal} = 4.2 \text{ J}$ .
- Q23. When two conductors having thermal resistances  $R_1$  and  $R_2$  are joined end to end and placed between two reservoirs, find the equivalent thermal resistance.
- Q24. During an adiabatic process, the pressure of a gas is found to be proportional to the cube of its absolute temperature. Find the ratio  $C_p / C_v$  for the gas
- Q25. Two specific heats at constant pressure and volume for 1 g of a gas are 0.26 and 0.21 respectively. Calculate the density of the gas at N.T.P. Given,  $g = 980 \text{ cm s}^{-2}$  and  $J = 4.2 \times 10^7 \text{ erg cal}^{-1}$ .
- Q26. What amount of heat must be supplied to 0.016 kg of oxygen to raise its temperature by 22 °C at constant pressure? Given that molecular weight of oxygen = 32,  $R = 8.3 \text{ J mol}^{-1} \text{ K}^{-1}$  and  $C_p$  (diatomic gases) =  $3.5 R$ .
- Q27. Calculate the two specific heats of nitrogen from the following data: Ratio of the specific heats of nitrogen,  $\gamma = 1.41$  and density of nitrogen at N.T.P. =  $1.234 \text{ g litre}^{-1}$ .
- Q28. The specific heats at constant volume and constant pressure of oxygen (per gram) are given by 0.115 and 0.179 respectively and density of gas at N.T.P. is  $1.433 \text{ g liter}^{-1}$ . Calculate the value of J.
- Q29. Calculate the difference between two specific heats of 1 g of nitrogen. Given, molecular weight of nitrogen = 28 and  $J = 4.2 \times 10^7 \text{ erg cal}^{-1}$ .
- Q30. What is work done in isothermal process, derived it?
- Q31. Establish relation between two specific heats of a gas. Which is greater and why?
- Q32. 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?
- Q33. 5 moles of an gas is carried by a quasi-static isothermal process at 500 K to twice its volume as shown in figure.
- How much work was done by the gas along the path AB?
  - How much heat was supplied to the gas along the path AB?
  - Calculate the pressure ratio  $P_B / P_A$ .
- Given,  $R = 831 \text{ J mole}^{-1} \text{ K}^{-1}$ .



Q34. 5 moles of an ideal gas is carried by a quasi-static isothermal process at 500 K to twice its volume as shown in figure.



- How much work was done by the gas along the path  $AB$ ?
  - How much heat was supplied to the gas along the path  $AB$ ?
  - Calculate the pressure ratio  $P_B/P_A$ .
- (Given,  $R = 831 \text{ J mole}^{-1} \text{ K}^{-1}$ ;  $\log 2 = 0.3010$ ).

Q35. Prove that for an adiabatic process  $PV^\gamma = \text{constant}$ , where the symbols have their usual meanings.

Q36. Define molar specific heat capacities at constant volume and pressure. Considering thermodynamical process in a cylinder with parameters  $P$ ,  $V$  and  $T$ , derive the Mayer's relation.

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**S1.**  $C_p > C_v$ : Since for constant pressure process, both volume and temperature are altered and for constant volume process, only temperature varies.

**S2.** Increase of 100 joule.

**S3.** For  $n$  degrees of freedom,

$$C_v = \frac{n}{2} R, \quad C_p = \left(\frac{n}{2} + 1\right) R$$

$$\therefore \gamma = \frac{C_p}{C_v} = \frac{\frac{n}{2} + 1}{n/2} = \frac{2+n}{n} = \frac{2}{n} + 1.$$

**S4.**  $C_p$  is greater since under constant pressure process, the energy also does work.

**S5.** Since

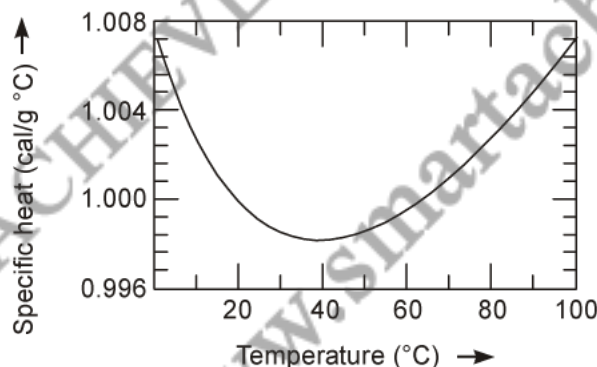
$$s = \frac{Q}{m\Delta t}.$$

For isothermal process,  $s = \infty$  ( $\because \Delta t = 0$ )

For adiabatic process,  $s = 0$  ( $\because Q = 0$ )

**S6.** Specific heat of water is  $4180 \text{ J kg}^{-1} \text{ K}^{-1}$ . Yes, it does vary little with temperature.

**S7.** Variation of specific heat of water with temperature:



**S8.** Yes, by doing work to change its volume (decrease).

**S9.** Yes.

**S10.** A gas can possess infinite number of specific heat, depending upon the pressure and volume conditions during the process of heating. However in practice, it is either measured at constant pressure.

**S11.** No.

**S12.** When a gas expands, its temperature tends to fall. The heat supplied to the gas must be just enough to keep its temperature constant.

**S13.** **Molar specific heat at constant volume:** It is defined as the amount of heat to raise the temperature of 1 mole a gas through 1 °C at constant volume.

**Specific heat of a gas at constant volume:** It is defined as the amount of heat required to raise the temperature of 1 g of gas through 1 °C at constant volume.

**S14.** No, since then for two different sets of physical parameters the system may be identified, leading to different states.

**S15.** Temperature inside the refrigerator,  $T_1 = 9^\circ\text{C} = 282 \text{ K}$

Room temperature,  $T_2 = 36^\circ\text{C} = 309 \text{ K}$

$$\begin{aligned}\text{Coefficient of performance} &= \frac{T_1}{T_2 - T_1} \\ &= \frac{282}{309 - 282} = 10.44\end{aligned}$$

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

**S16.**  $C_p$ : The amount of energy required for 1 mole of a gas to raise its temperature by 1 K at constant pressure condition.

$C_v$ : The amount of energy required for 1 mole of a gas to raise its temperature by 1 K at constant volume conditions.

$C_p > C_v$ : Since for constant pressure process, both volume and temperature are altered and for constant volume process, only temperature varies.

**S17.** In an isobaric process, pressure remains constant. If an amount of heat  $dQ$  is supplied to one mole is a gas at constant pressure and its temperature increase by  $dT$ , then

$$dQ = C_p dT$$

Here,  $C_p$  is molar specific heat of the gas at constant pressure. Therefore, for an isobaric process, the first law of thermodynamic becomes

$$C_p dT = dU + PdV \quad \dots \text{(i)}$$

From perfect gas equation, it follows that

$$PdV = RdT \quad \dots \text{(ii)}$$

In the equation (i), substituting for  $PdV$  and  $dU = C_v dT$ , we have

$$C_p dT = C_v dT + RdT$$

or 
$$C_p = C_v + R \quad \Rightarrow \quad C_p - C_v = R.$$

**S18.** The difference between two specific heat of a gas is proportional to the amount of heat converted into mechanical work, when a gas is heated at constant volume and at constant pressure through the same range of temperature.

More the difference between the two specific heats of a gas, more amount of heat can be converted into mechanical work with the aid of the gas. The bigger ratio of two specific heats of a gas also implies the bigger different between the two specific heats of a gas.

**S19.** Given,  $C_p = 0.218 \text{ cal g}^{-1} \text{ } ^\circ\text{C}^{-1}$ ;  $T_1 = 0 + 273 = 273 \text{ K}$

If  $V_1 = V$ , then  $V_2 = 2V$ .

At constant pressure,

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

or 
$$T_2 = T_1 \times \frac{V_2}{V_1} = 273 \times \frac{2V}{V} = 546 \text{ K}$$

If  $M$  is molecular weigh of oxygen, then amount of heat required,

$$\begin{aligned} Q &= MC_p (T_2 - T_1) = 32 \times 0.218 \times (546 - 273) \\ &= \mathbf{1,904.4 \text{ cal.}} \end{aligned}$$

**S20.** At N.T.P.; a gas occupies a volume of 22.4 liters. Since the volume of helium gas at N.T.P. is 44.8 liters,

amount of gas in the cylinder  $n = \frac{44.8}{22.4} = 2 \text{ moles}$

The molar specific heat of helium (monoatomic gas) at constant volume,

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

Also,  $\Delta T = 15 \text{ } ^\circ\text{C}$

Therefore, amount of heat required,

$$\begin{aligned} Q &= n C_v \Delta T = 2 \times \frac{3}{2} R \times \Delta T = 3R\Delta T \\ &= 3 \times 8.31 \times 15 = \mathbf{373.95 \text{ J.}} \end{aligned}$$

**S21.** Given,  $n = 156 \text{ moles}$ ;  $\Delta T = 75 - 30 = 45 \text{ } ^\circ\text{C}$ ;  $C_p = 8 \text{ cal mol}^{-1} \text{ } ^\circ\text{C}^{-1}$

and  $R = 8.31 \text{ J mole}^{-1} \text{ K}^{-1} = \frac{8.31}{4.2} = 1.98 \text{ cal mole}^{-1} \text{ K}^{-1}$

Now,  $C_v = C_p - R = 8 - 1.98 = 6.02 \text{ cal mole}^{-1} \text{ K}^{-1}$

Now,  $Q = n C_v \Delta T = 156 \times 6.02 \times 45 = \mathbf{4,063.5 \text{ cal.}}$



**S22.** Molar volume of the hydrogen gas,

$$V = \frac{M}{\rho} = \frac{32}{1.433} = 22.472 \text{ liters} = 22.472 \times 10^{-3} \text{ m}^3$$

$$\begin{aligned} \therefore R &= \frac{PV}{T} = \frac{1.013 \times 10^5 \times 22.33 \times 10^{-3}}{273} \\ &= 8.339 \text{ J mol}^{-1} \text{ } ^\circ\text{C}^{-1} \\ &= \frac{8.339}{4.2} = 1.985 \text{ cal mole}^{-1} \text{ } ^\circ\text{C}^{-1} \end{aligned}$$

$$\begin{aligned} \text{Now, } C_v &= C_p - R = 6.85 - 1.985 \\ &= \mathbf{4.865 \text{ cal mole}^{-1} \text{ } ^\circ\text{C}^{-1}}. \end{aligned}$$

**S23.** Since  $\frac{Q}{t}$  is same in both and  $(\theta_1 - \theta) + (\theta - \theta_2)$  is  $(\theta_1 - \theta_2)$  we have,  $R_{\text{eq}} = R_1 + R_2$ .

**S24.** Given,  $P \propto T^3$  ... (i)

Now, for an adiabatic process,

$$\frac{P^{\gamma-1}}{T^\gamma} = \text{constant} \quad \text{or} \quad P^{\gamma-1} \propto T^\gamma$$

or  $P \propto T^{\gamma/(\gamma-1)}$  ... (ii)

From the Eq. (i) and (ii), we have

$$\frac{P}{P} = \frac{T^3}{T^{\frac{\gamma}{\gamma-1}}}$$

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

$$\frac{\gamma}{\gamma-1} = 3 \quad \text{or} \quad 3\gamma - 3 = \gamma$$

$$2\gamma = 3$$

or  $\gamma = \mathbf{1.5}$ .

**S25.** Here,  $C_p = 0.26$ ;  $C_v = 0.21$ ;  $J = 4.2 \times 10^7 \text{ erg cal}^{-1}$

$$\text{Now, } c_p - c_v = \frac{r}{J}$$

$$\text{or } r = J(C_p - C_v)$$

$$\text{or } r = 4.2 \times 10^7 (0.26 - 0.21) = 2.1 \times 10^6 \text{ erg g}^{-1} \text{ K}^{-1}$$

If  $V$  is volume of 1 g of the gas at N.T.P, then

$$V = \frac{rT}{P} = \frac{2.1 \times 10^6 \times 273}{76 \times 13.6 \times 980} = 5.66 \times 10^2 \text{ cm}^3$$

Therefore, density of the gas,

$$\rho = \frac{\text{Mass}}{\text{Volume}} = \frac{1}{5.66 \times 10^2} = 1.767 \times 10^{-3} \text{ g cm}^{-3}.$$

**S26.** Here,  $R = 8.3 \text{ J mol}^{-1} \text{ K}^{-1}$ ;  $dT = 22 \text{ }^\circ\text{C}$ ;

mass of the gas,  $m = 0.016 \text{ kg}$ ;

molecular weight of oxygen gas,

$$M = 32 \text{ g mole}^{-1} = 32 \times 10^{-3} \text{ kg mole}^{-1}$$

Therefore, number of moles of the gas,

$$\mu = \frac{m}{M} = \frac{0.016}{32 \times 10^{-3}} = 0.5 \text{ mole}$$

Now, molar specific heat of nitrogen at constant pressure,

$$C_p = 3.5 R = 3.5 \times 8.3 \text{ J mol}^{-1} \text{ K}^{-1}$$

Therefore, heat supplied to the gas,

$$Q = \mu C_p \Delta T = 0.5 \times 3.5 \times 8.3 \times 22 = 319.55 \text{ J}.$$

**S27.** Here

$$\gamma = 1.41 \quad \text{or} \quad \frac{C_p}{C_v} = 1.41$$

or

$$C_p = 1.41 C_v$$

... (i)

Molar volume of the nitrogen gas,

$$V = \frac{M}{\rho} = \frac{28}{1.234} = 22.69 \text{ litres} = 22.69 \times 10^{-3} \text{ m}^3$$

$\therefore$

$$R = \frac{PV}{T} = \frac{1.013 \times 10^5 \times 22.69 \times 10^{-3}}{273} \\ = 8.42 \text{ J mole}^{-1} \text{ K}^{-1} = 8.42 \times 10^7 \text{ erg mole}^{-1} \text{ }^\circ\text{C}^{-1}$$

or

$$r = \frac{R}{M} = \frac{8.42 \times 10^7}{28} = 3.007 \times 10^6 \text{ erg g}^{-1} \text{ }^\circ\text{C}^{-1}$$

Now,

$$C_p - C_v = \frac{r}{J}$$

or

$$C_p - C_v = \frac{3.007 \times 10^6}{4.2 \times 10^7}$$

or

$$C_p - C_v = 0.0716$$

... (ii)

On solving the equations (i) and (ii), we get

$$c_V = 0.1746 \text{ cal g}^{-1} \text{ }^\circ\text{C}^{-1}$$

and

$$c_P = 0.246 \text{ cal g}^{-1} \text{ }^\circ\text{C}^{-1}.$$

**S28.** Molar volume of oxygen,

$$V = \frac{M}{\rho} = \frac{32}{1.433} = 22.33 \text{ litres}$$
$$= 22.33 \times 10^{-3} \text{ m}^3$$

$$\therefore R = \frac{PV}{T} = \frac{1.013 \times 10^5 \times 22.33 \times 10^{-3}}{273}$$
$$= 8.286 \text{ J mole}^{-1} \text{ K}^{-1} = 8.286 \times 10^7 \text{ erg mole}^{-1} \text{ K}^{-1}$$

and

$$r = \frac{R}{M} = \frac{8.286 \times 10^7}{32} = 2.59 \times 10^6 \text{ erg g}^{-1} \text{ K}^{-1}$$

Now,

$$c_P - c_V = \frac{r}{J}$$

or

$$J = \frac{r}{c_P - c_V}$$

or

$$J = \frac{2.59 \times 10^6}{0.179 - 0.115} = 4.05 \times 10^7 \text{ erg cal}^{-1}.$$

**S29.** We know,

$$R = \frac{PV}{T} = \frac{1.013 \times 10^5 \times 22.4 \times 10^{-3}}{273}$$
$$= 8.31 \text{ J mole}^{-1} \text{ K}^{-1}$$
$$= 8.31 \times 10^7 \text{ erg mole}^{-1} \text{ K}^{-1}$$

Now,

$$c_P = c_V = \frac{r}{J} \quad \text{or} \quad c_P - c_V = \frac{R}{MJ}$$

$$\therefore c_P - c_V = \frac{8.31 \times 10^7}{28 \times 4.2 \times 10^7} = 0.0707 \text{ cal g}^{-1} \text{ K}^{-1}.$$

**S30.** Suppose that at any instant during the expansion, the pressure and volume of the gas are  $P$  and  $V$  respectively (as shown in the figure).

Further, suppose that the piston moves through infinitesimally small distance  $dx$  against the constant pressure  $P$ , so that volume becomes  $V + dV$ . Then, small work done,

$$dW = \text{Force on piston} \times \text{small distance moved}$$

If  $a$  is area of cross-section of the piston, then the force on piston will be  $Pa$ . Therefore,

$$dW = Pa \times dx$$

Now,  $a \times dx = dV$

(the small increase in volume of the gas)

$$\therefore dW = PdV$$

... (i)

The total work  $W$  done during the expansion of the gas from the initial state  $A(P_1, V_1)$  to the final state  $B(P_2, V_2)$  can be obtained by integrating the equation (i) between the limits  $V_1$  to  $V_2$ .

Therefore, total work done is given by

$$W = \int_{V_1}^{V_2} P dV \quad \dots \text{(ii)}$$

For one mole of an ideal gas,

$$PV = RT$$

or

$$P = \frac{RT}{V}$$

In the equation (ii), substituting for  $P$ , we have

$$W = \int_{V_1}^{V_2} \frac{RT}{V} dV$$

During an isothermal process, the temperature of the gas remains constant.

Therefore,

$$\begin{aligned} W_{\text{iso}} &= RT \int_{V_1}^{V_2} \frac{1}{V} dV = RT [\log_e V]_{V_1}^{V_2} \\ &= RT [\log_e V_2 - \log_e V_1] \end{aligned}$$

or

$$W_{\text{iso}} = RT \log_e \frac{V_2}{V_1} = 2.303 RT \log_{10} \frac{V_2}{V_1} \quad \dots \text{(iii)}$$

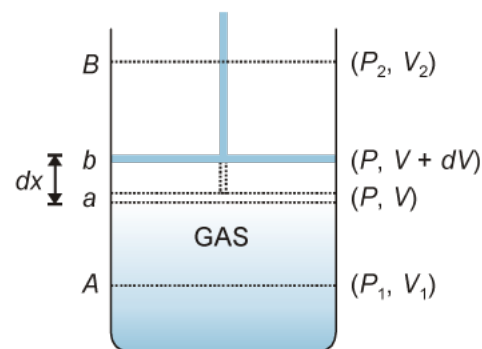
This is expression for the work done during an isothermal process for one mole of an ideal gas, when its volume changes from  $V_1$  to  $V_2$  at constant temperature  $T$ .

Also, for an isothermal change,

$$P_1 V_1 = P_2 V_2$$

or

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



Therefore, the equation (iii) can be written as

$$W_{\text{iso}} = 2.303 RT \log_{10} \frac{P_1}{P_2} \quad \dots \text{(iv)}$$

**S31. Relation between  $C_p$  and  $C_v$ .** Suppose one mole of a gas is heated so that its temperature rises by  $dT$ . Heat supplied

$$1 \times C_v \times dT = C_v dT \quad \dots \text{(i)}$$

Since the volume is constant, the gas will not perform external work in accordance with the first law of thermodynamics and the heat supplied will be just equal to the increase in the internal energy of the gas.

$$\therefore dU = C_v dT \quad \dots \text{(ii)}$$

Let the gas be heated at constant pressure to again increase its temperature by  $dT$  and  $dQ$  be the amount of heat supplied, therefore,

$$dQ = 1 \times C_p \times dT = C_p dT \quad \dots \text{(iii)}$$

The heat supplied at a constant pressure increases the temperature by  $dT$  hence, increases its internal energy by  $dU$  as well as enables the gas to perform work  $dW$ .

$$dW = PdV \quad \dots \text{(iv)}$$

From the first law of thermodynamics, we have

$$dQ = dU + dW$$

Substituting the values, we get

$$C_p dT = C_v dT + PdV$$

But  $PV = RT$  (For one mole of the gas)

or  $PdV = RdT$

$$\therefore C_p dT = C_v dT + RdT$$

$$\text{or } C_p - C_v = R \quad \dots \text{(v)}$$

This is the relation between two principal specific heats of the gas when  $C_p$ ,  $C_v$  and  $R$  are measured in the units of either heat or of work.

$C_p > C_v$  because a part of the energy supplied in the adiabatic process goes to increase the volume of the gas and the remaining increases the temperature.

**S32.** 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.

$$\text{Initial pressure inside the cylinder} = P_1$$

$$\text{Final pressure inside the cylinder} = P_2$$

$$\text{Initial volume inside the cylinder} = V_1$$

$$\text{Final volume inside the cylinder} = V_2$$

Ratio of specific heats,  $\gamma = 1.4$

For an adiabatic process, we have:

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

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.

**S33.** Here,  $\mu = 5$ ;  $T = 500$ ;  $V_B = 2V_A$ ;  $R = 8.31 \text{ J mole}^{-1} \text{ K}^{-1}$

(a) Now,

$$\begin{aligned} W_{\text{iso}} &= \mu \times 2.303 \times RT \log \frac{V_B}{V_A} \\ &= 5 \times 2.303 \times 8.31 \times 500 \log \frac{2V_A}{V_A} \\ &= 5 \times 2.303 \times 8.31 \times 500 \log 2 \\ &= 5 \times 2.303 \times 8.31 \times 500 \times 0.3010 = \mathbf{14,401.3 \text{ J}} \end{aligned}$$

(b) For isothermal change,  $dQ = dW$  ( $\because dU = 0$ )

$$\therefore dQ = 14,401.3 \text{ J} = \frac{14,401.3}{4.2} = \mathbf{3,428.9 \text{ cal}}$$

(c) For an isothermal change,

$$\begin{aligned} P_A V_A &= P_B V_B \\ \therefore \frac{P_B}{P_A} &= \frac{V_A}{V_B} = \frac{V_A}{2V_A} = \frac{1}{2} \end{aligned}$$

**S34.** Given,  $\mu = 5$ ;  $T = 500 \text{ K}$ ;  $V_B = 2 V_A$ ;  $R = 8.31 \text{ J mole}^{-1} \text{ K}^{-1}$

(a) Now,

$$\begin{aligned} W_{\text{iso}} &= \mu \times 2.303 \times RT \log \frac{V_B}{V_A} \\ &= 5 \times 2.303 \times 8.31 \times 500 \log \frac{2V_A}{V_A} \\ &= 5 \times 2.303 \times 8.31 \times 500 \log 2 \\ &= 5 \times 2.303 \times 8.31 \times 500 \times 0.3010 = \mathbf{14,401.3 \text{ J}} \end{aligned}$$

(b) For isothermal change,  $dQ = dW$  ( $\because dU = 0$ )

$$\therefore dQ = 14,401.3 \text{ J} = \frac{14,401.3}{4.2} = 3,428.9 \text{ cal}$$

(c) For an isothermal change,

$$P_A V_A = P_B V_B$$

$$\therefore \frac{P_B}{P_A} = \frac{V_A}{V_B} = \frac{V_A}{2V_A} = \frac{1}{2}$$

**S35.** For an adiabatic process,  $dQ = 0$

$dU = nC_v dT$  for a process, where there is a temperature change by  $dT$ .

From gas equation,

$$PV = nRT$$

Differentiating both sides, we have

$$PdV + VdP = nRdT$$

$$\therefore dT = \frac{PdV + VdP}{nR} \quad \dots (i)$$

From first law of thermodynamics,

$$0 = nC_v dT + PdV \quad \dots (ii)$$

Putting  $dT$  from (i) in (ii), we have

$$nC_v \left( \frac{PdV + VdP}{nR} \right) + PdV = 0$$

$$\text{or } C_v (PdV + VdP) + R PdV = 0$$

$$\text{or } C_v (PdV + VdP) + (C_p - C_v) PdV = 0 \quad [\because R = C_p - C_v]$$

$$C_v PdV + C_v VdP + C_p PdV - C_v PdV = 0$$

$$C_v VdP + C_p PdV = 0 \quad \text{or} \quad \frac{dP}{P} + \frac{dV}{V} \gamma = 0 \quad [\because C_p/C_v = \gamma]$$

Integrating, we get

$$\int \frac{dP}{P} + \gamma \int \frac{dV}{V} = \text{constant}$$

$$\text{or } \log P + \gamma \log V = \text{constant}$$

$$\text{or } \log PV^\gamma = \text{constant}$$

$$\text{or } PV^\gamma = \text{constant}$$

This is the equation for an adiabatic change in an ideal gas.

**S36.** Molar specific heat capacity is the heat energy required to raise the temperature of 1 mole of a substance by 1 K and expressed in  $\text{J mol}^{-1} \text{K}^{-1}$ .

$$C = \frac{Q}{1 \text{ mole } 1 \text{ K}}$$

Depending on the condition that whether volume or pressure is constant, molar specific heat is written as  $C_v$  and  $C_p$ .

**Relation between  $C_p$  and  $C_v$ :** Suppose one mole of a gas is heated so that its temperature rises by  $dT$ .

$$\text{Heat supplied} = 1 \times C_v \times dT = C_v dT \quad \dots \text{ (i)}$$

Since the volume is constant, the gas will not perform external work in accordance with the first law of thermodynamics and the heat supplied will be just equal to the increase in the internal energy of the gas.

$$\therefore dU = C_v dT \quad \dots \text{ (ii)}$$

Let the gas be heated at constant pressure to again increase its temperature by  $dT$ , and  $dQ$  be the amount of heat supplied, therefore,

$$dQ = 1 \times C_p \times dT = C_p dT \quad \dots \text{ (iii)}$$

The heat supplied at a constant pressure increases the temperature by  $dT$  hence increases its internal energy by  $dU = C_v dT$  as well as enables the gas to perform work  $dW$ .

$$dW = PdV \quad \dots \text{ (iv)}$$

From the first law of thermodynamics, we have

$$dQ = dU + dW$$

Substituting the values, we get,

$$C_p dT = C_v dT + PdV$$

But  $PV = RT$  (For one mole of the gas)

or  $PdV = RdT$

$$\therefore C_p dT = C_v dT + RdT$$

or  $C_p - C_v = R \quad \dots \text{ (v)}$

This is the relation between two principal specific heats of the gas when  $C_p$ ,  $C_v$  and  $R$  are measured in the units of either heat or of work.



- Q1. At what temperature do the Celsius and Fahrenheit scales coincide?
- Q2. Is it possible to liquefy a gas at any condition?
- Q3. What is the amount of work done in a cyclic process?
- Q4. A cylinder filled with gas is placed in a heat-proof jacket. How will the temperature of the gas change, if the volume of the cylinder is gradually increased?
- Q5. Is it possible to increase the temperature of a gas without giving it heat?
- Q6. Heat is supplied to a system, but the system does not perform any external work. What is the process involved?
- Q7. What is the change in the internal energy of a gas, which is compressed isothermally?
- Q8. Heat is supplied to a system, but its internal energy does not increase. What is the process involved?
- Q9. What is the significance of critical temperature?
- Q10. What type of process is Carnot's cycle?
- Q11. What is adiabatic process?
- Q12. What is Isobaric process?
- Q13. What is isothermal process?
- Q14. What is thermodynamics process?
- Q15. A body at higher temperature contains more heat. Comment.
- Q16. Name the principle used in the mercury thermometer.
- Q17. Three stars A, B, C appear as green, red and blue respectively. Which star has minimum temperature?
- Q18. Do all solids expand on heating? Name the solid that contracts on heating.
- Q19. If on giving 40 J of heat to a system, work done on the system is 10 J. What will be the change in internal energy of the system?
- Q20. How much will be the internal energy change in (a) Isothermal process (b) Adiabatic process?
- Q21. Define an *isothermal process* and state two essential conditions for such a process to take place.
- Q22. Define an *adiabatic process* and state two essential condition for such a process to take place.

- Q23. Give two examples each of (a) an isothermal change and (b) an adiabatic change.
- Q24. How does an adiabatic process differ from an isothermal process? State essential conditions for these processes.
- Q25. Is the heat supplied to a system always equal to the increase in its internal energy?
- Q26. Why does the temperature of a gas decrease, when it is allowed to expand adiabatically?
- Q27. A certain amount of gas initially occupying a volume  $V_0$  at a pressure  $P_0$  and a temperature  $T_0$  expands first at constant pressure and then at constant temperature to a volume  $V$ . In which of these two cases will the gas do more work?
- Q28. Two identical samples of a gas are expanded, so that the volume is increased to twice the initial value. However, sample number 1 is expanded isothermally, while sample number 2 is expanded adiabatically. (a) Which sample is the pressure greater and why? (b) Which sample does more work and why?
- Q29. Two sample of a gas initially at the same temperature and pressure are composed from volume  $V$  to a volume  $V/2$ . One sample is compressed isothermally and the other adiabatically. In which sample is the pressure greater? Justify.
- Q30. What happens to the internal energy of a gas during (a) isothermal expansion, (b) adiabatic expansion?
- Q31. Cooling is produced, when a gas at high pressure is allowed to expand suddenly . Why?
- Q32. On removing the valve, the air escaping from a cycle tube becomes cool. Why?
- Q33. 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 why?
- Q34. 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. Explain why?
- Q35. Air pressure in a car tyre increases during driving. Explain why?
- Q36. The climate of a Harbour town is more temperature than that of a town in a desert at the same latitude. Explain why?
- Q37. What do you mean by the 'phases' of a substance?
- Q38. Compare an isothermal and an adiabatic process.
- Q39. Calculate the fall in temperature of helium initially at  $15^\circ\text{C}$ , when it is suddenly expanded to 8 times of its volume. Given  $\gamma = 5/3$ .
- Q40. A gas at a pressure of  $2 \times 10^5$  Pa posses a volume of  $1.2 \text{ m}^3$ . find the amount of work done to expand the gas isothermally, till its volume becomes  $6 \text{ m}^3$ .
- Q41. Calculate the work done in joule in expanding isothermally 5 mole of an ideal gas from 1 to 20 litres at  $0^\circ\text{C}$ . given,  $R = 8.31 \text{ J mol}^{-1}\text{K}^{-1}$ .
- Q42. If 1 g oxygen at 760 mm of pressure at  $0^\circ\text{C}$  has its volume doubled by adiabatic change, calculate the change in internal energy. Given that  $R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$ , and  $\gamma = 1.4$ .

- Q43. A Carnot's engine whose sink is at a temperature of 300 K has an efficiency of 40%. By how much should the temperature of the source be increased so as to increase the efficiency to 60%?
- Q44. A Carnot engine operates between 500 K and 400 K. If it absorbs  $6 \times 10^5$  cal heat at higher temperature, how much work per cycle can the engine perform?
- Q45. One litre of hydrogen at  $127^\circ\text{C}$  and  $10^6$  dyne  $\text{cm}^{-2}$  pressure expands isothermally, until its volume is doubled and then adiabatically until its volume is re-doubled. Find the pressure of the gas. Given  $\gamma = 1.4$ .
- Q46. Find the work required to compress adiabatically 1 g of air initially at N.T.P. to half its volume. Density of air at N.T.P. =  $1.29 \times 10^{-3}$  g  $\text{cm}^{-3}$  and  $\gamma = 1.4$ .
- Q47. One mole of oxygen at N.T.P. is taken and compressed adiabatically, till its pressure is 5 atmosphere. (a) What is its new volume? (b) What is its new temperature? (c) What is the work done in the compression? Given that  $\gamma = 1.4$  and  $R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$ .
- Q48. A certain volume of dry air at N.T.P. is allowed to expand four times of its original volume under (a) isothermal conditions (b) adiabatic conditions. Calculate the final pressure and temperature in each case. Given that  $\gamma = 1.4$ .
- Q49. (a) Distinguish between a cyclic process and a non-cyclic process.  
(b) Prove that the slope of  $P$ - $V$  graph for an adiabatic process is  $\gamma$  times that of the isothermal process.
- Q50. Obtain an expression for work done by a gas in an isothermal expansion.
- Q51. What amount of heat must be supplied to  $2.0 \times 10^{-2}$  kg of nitrogen (at room temperature) to raise its temperature by  $45^\circ\text{C}$  at constant pressure? (Molecular mass of  $\text{N}_2 = 28$ ;  $R = 8.3 \text{ J mol}^{-1} \text{ K}^{-1}$ .)
- Q52. An ideal gas at 75 cm mercury pressure is compressed isothermally, until its volume is reduced to  $3/4^{\text{th}}$  of its original volume. It is then allowed to expand adiabatically to a volume 20% greater than its original volume. If the initial temperature of the gas is  $17^\circ\text{C}$ , calculate the final pressure and temperature. Given,  $\gamma = 1.4$ .
- Q53. A sample of hydrogen gas of mass 6 g is allowed to expand isothermally at  $27^\circ\text{C}$ , till its volume is doubled. (a) How many moles of  $\text{H}_2$  do we have? (b) What is the final temperature of the  $\text{H}_2$ ? (c) Calculate work done during expansion? given,  $R = 8.31 \text{ J mole}^{-1} \text{ K}^{-1}$ .
- Q54. (a) A steam engine delivers  $5.4 \times 10^8$  J of work per minute and services  $3.6 \times 10^9$  J of heat per minute from its boiler. What is the efficiency of the engine? How much heat is wasted per minute?  
(b) 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?

- Q55. (a)** In a Carnot engine, temperature of sink is increased. What will happen to its efficiency?
- (b)** A Carnot engine absorbs 1000 J of heat from a reservoir at 127 °C and rejects 600 J of heat during each cycle. Calculate the
- (i)** efficiency of engine.
  - (ii)** temperature of the sink.
  - (iii)** amount of the useful work done during each cycle.
- Q56.** A gas undergoes reduction in volume (a) adiabatically, (b) isothermally. Find the work done in the process.

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- S1.**  $-40^{\circ}\text{C}$ , they are coincide.
- S2.** No. Beyond critical temperature, it is not possible to liquefy however large the pressure may be.
- S3.** It is numerically equal to the area of the cyclic process.
- S4.** When the volume of the gas is increased in a heat-proof jacket, the work is done by the gas at the expense of its internal energy. Due to decrease in internal energy, the temperature of the gas will decrease.
- S5.** It happens during an adiabatic change.
- S6.** It happens during an isochoric change.
- S7.** Zero.
- S8.** It happens during the isothermal expansion.
- S9.** The critical temperature is the temperature beyond which a gas cannot be liquefied, whatever large the pressure applied may be.
- S10.** It is a **cyclic process**.
- S11. Adiabatic process:** A thermodynamic process in which no heat enters or leaves the system is called **adiabatic process**.
- S12. Isobaric process:** A thermodynamic process that takes place at constant pressure is called **isobaric process**.
- S13. Isothermal process:** A thermodynamic process that takes place at constant temperature is called **isothermal process**.
- S14. Thermodynamics process:** A thermodynamics process is said to be taking place, if the thermodynamics variables of the system change with time.
- S15.** The statement may not be true always because heat content of a body depends on mass of body, its specific heat and temperature.
- S16.** It is based on the fact that the change in volume of mercury is nearly proportional to the change in temperature.
- S17.** As  $T \propto \frac{1}{\lambda_m}$  and  $\lambda_m$  for red colour is maximum, therefore temperature  $T$  is minimum for star  $B$  emitting red colour.

**S18.** No. Comphor.

**S19.** Internal energy of the system will increase by  $40 + 10 = 50$  Joule.

**S20.** (a) Zero (b)  $nC_v dT$ .

**S21. Isothermal process:** An isothermal process is one, in which the pressure and volume of the system change but temperature remains constant.

**Conditions:** For an isothermal process to take place:

- (a) the cylinder should have conducting walls and
- (b) the gas should be compressed or allowed to expand very slowly.

**S22. Adiabatic process:** An adiabatic process is one, in which pressure, volume and temperature of the system change but there is no exchange of heat between the system and the surroundings.

**Conditions:** For an adiabatic process to take place:

- (a) the cylinder should have insulating walls and
- (b) the gas should be compressed or allowed to expand very quickly.

**S23. (a) Isothermal change:**

1. A gas contained in a metallic cylinder and compressed or allowed to expand slowly.
2. Boyle's law.

**(b) Adiabatic change:**

1. A gas contained in a non-conducting cylinder and compressed or allowed to expand quickly.
2. Air escaping from the cycle tube on removing the valve undergoes adiabatic expansion.

**S24. Adiabatic process:** An adiabatic process is one, in which pressure, volume and temperature of the system change but there is no exchange of heat between the system and the surroundings.

Adiabatic process to take place:

- (a) the cylinder should have insulating walls
- (b) the gas should be compressed or allowed to expand very quickly.

**Isothermal process:** An isothermal process is one, in which the pressure and volume of the system change but temperature remains constant.

Isothermal process to take place:

- (a) the cylinder should have conducting walls.
- (b) the gas should be compressed or allowed to expand very slowly.

**S25.** According to first law of thermodynamics,

$$dQ = dU + PdV$$

If heat is supplied in such a manner that volume does not change ( $dV = 0$  i.e., an isochoric change), then whole of the heat energy supplied to the system will increase its internal energy only. Normally, a part of the heat supplied is used up by the system in performing the external work.

**S26.** For an adiabatic change, the first law of thermodynamics may be expressed as

$$dU + PdV = 0$$

or  $PdV = -dU$  ... (i)

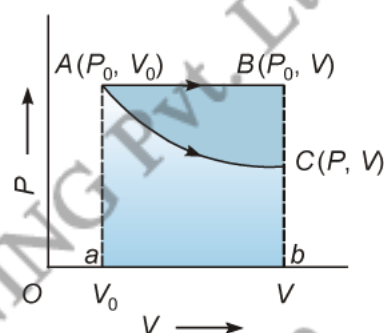
During expansion,  $dV$  is positive. Therefore, the equation (i) will hold, if  $dU$  is negative i.e., temperature decreases.

**S27.** The point  $A(P_0, V_0)$  represents the initial state of the gas on  $P$ - $V$  [as shown in the figure].

**When gas expands at constant pressure:** The expansion of the gas from its volume  $V_0$  to  $V$  at constant pressure  $P_0$  is represented by the straight line  $AB$ . Therefore,

$$\text{work done by the gas, } W_1 = \text{area } ABba$$

**When gas expands at constant temperature:** When the expansion of the gas takes place from volume  $V_0$  to  $V$  at constant temperature, the pressure will decrease from  $P_0$  to  $P$ , such that  $P_0 V_0 = PV$ .



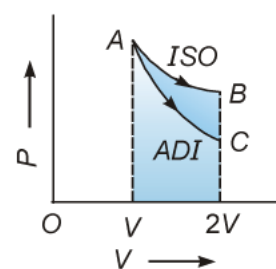
The expansion of the gas at constant temperature is represented by the curve  $AC$ . Therefore,

$$\text{work done by the gas, } W_2 = \text{area } ACba$$

Since area  $ABba$  is greater than area  $ACba$ ,  $W_1 > W_2$  i.e., gas will do more work, when it expands at constant pressure.

**S28.** The figure shows the  $P$ - $V$  graphs for two samples of a gas, one expanded isothermally (sample 1) and the other adiabatically (sample 2). As adiabatic curve is steeper than the isothermal curve, the adiabatic expansion curve  $AC$  will lie below the isothermal curve  $AB$ .

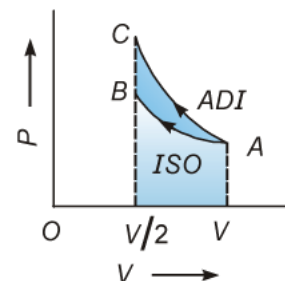
- Since pressure corresponding to the point  $B$  is greater than that corresponding to the point  $C$ , pressure in sample 1 is greater.
- Since area under the isothermal expansion curve is more than that under the adiabatic expansion curve, work done by the sample 1 is more.



**S29.** The figure shows the  $P$ - $V$  graphs for two samples of gas compresses from volume  $V$  to  $V/2$  isothermally and adiabatically.

As the adiabatic curve is steeper than the isothermal curve, adiabatic compression curve.  $AC$  lies above the isothermal compression curve  $AB$ .

From the figure, it follows that final pressure corresponding to the point  $C$  is greater than that corresponding to the point  $B$ . Hence, in the sample compressed **adiabatically**, the pressure is greater.



**S30.** (a) **Isothermal expansion:** In an isothermal change, temperature remains constant. Therefore, the internal energy which is a function of temperature only, will remain constant during the isothermal change.

(b) **Adiabatic expansion:** For adiabatic change,  $dQ = 0$  and hence for adiabatic change, first law of thermodynamics becomes

$$0 = dU + dW$$

or  $dW = -dU$

During expansion, work is done by the gas *i.e.*,  $dW$  is positive. Hence,  $dU$  must be negative. thus, in an adiabatic expansion, internal energy of the system decreases.

**S31.** When a system cooling is produced, air is present at a pressure greater than the atmospheric pressure. As soon as the valve is removed, the gas expands suddenly *i.e.*, adiabatic expansion takes place. During adiabatic expansion, the air performs work at the expense of its internal energy.

Hence, the temperature decreases and the air escaping from the system becomes cool.

**S32.** In the cycle tube air is present at a pressure greater than the atmospheric pressure. As soon as the valve is removed, the gas expands suddenly *i.e.* adiabatic expansion take place. During adiabatic expansion, the air performs work at the expense of its internal energy.

Hence, the temperature decreases and the air escaping from the cycle tube becomes cool.

**S33.** 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.

**S34.** 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.

**S35.** 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.



- S36.** 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.
- S37.** The three states of a substance, namely solid, liquid and gas are called its phases. Whenever a substance can occur in several forms which are homogeneous, physically distinct, and mechanically separable from each other, the forms are called the phases of the same substance. The phases of a substance generally involve either absorption or evolution of heat.

<b>S38.</b>	<i>Isothermal process</i>	<i>Adiabatic process</i>
	1. $dT = 0$ .	1. $dQ = 0$ .
	2. Generally a slow process.	2. Generally a fast process.
	3. Carried out in a conducting cylinder.	3. Carried out in a non-conducting cylinder.

- S39.** Given,  $T_1 = 273 + 15 = 288 \text{ K}$ ,  $T_2 = ?$   $V_2 = 8 V_1$ ,  $\gamma = 5/3$

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

$$T_2 = T_1 \left( \frac{V_1}{V_2} \right)^{\gamma-1}; \quad T_2 = 288 \left( \frac{V_1}{8V_1} \right)^{\frac{5}{3}-1}$$

$$\log T_2 = \log 288 + \frac{2}{3} \log \left( \frac{1}{8} \right)$$

$$= \log 288 + \frac{2}{3} (\log(1) - \log(8))$$

$$= 2.459 + \frac{2}{3} (0 - 0.9021)$$

$$= 2.459 + \frac{2}{3} (-0.9021)$$

$$= 1.8573$$

$$T_2 = \text{antilog } 1.8573 = 71.99 \text{ K}$$

Fall in temperature of helium,

$$T_1 - T_2 = 288 - 71.99 = 216.01 \text{ K.}$$

- S40.** Here,  $P_1 = 2 \times 10^5 \text{ Pa}$ ;  $V_1 = 1.2 \text{ m}^3$ ;  $V_2 = 6 \text{ m}^3$

Now, work done during an isothermal change,

$$W_{\text{iso}} = 2.303 \times P_1 V_1 \log \frac{V_2}{V_1}$$

$$= 2.303 \times 2 \times 10^5 \times 1.2 \times \log \frac{6}{1.2}$$

$$= 2.303 \times 2 \times 10^5 \times 1.2 \times \log 5$$

$$= 2.303 \times 2 \times 10^5 \times 1.2 \times 0.6990 = \mathbf{3.864 \times 10^5 \text{ J.}}$$

**S41.** Given,  $n = 5$ ;  $V_1 = 1$  litre;  $V_2 = 20$  litres;  $T = 0 + 273 = 273 \text{ K}$ ;  $R = 8.31 \text{ J mole}^{-1} \text{ K}^{-1}$

Now,

$$W_{\text{iso}} = n \times 2.303 \times RT \log \frac{V_2}{V_1}$$

$$= 5 \times 2.303 \times 8.31 \times 273 \times \log \frac{20}{1}$$

$$= 5 \times 2.303 \times 8.31 \times 273 \times \log 20$$

$$= 5 \times 2.303 \times 8.31 \times 273 \times 1.3010$$

$$= \mathbf{33,577.4 \text{ J.}}$$

**S42.** Given  $T_1 = 273 \text{ K}$ ,  $V_2 = 2V_1$ ,  $\gamma = 1.4$

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

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

$$= 273 \left( \frac{V_1}{2V_1} \right)^{1.4-1}$$

$$= 206.90$$

For one gram of oxygen, work done during adiabatic change

$$W_{\text{adia}} = \frac{R(T_1 - T_2)}{\gamma - 1} = \frac{8.31 \times (273 - 206.90)}{1.4 - 1}$$

$$= \mathbf{1373.23 \text{ J.}}$$

**S43.** Let  $T$  be the temperature of the source.

$$\frac{40}{100} = \frac{T - 300}{T}$$

or

$$T = 500 \text{ K}$$

Let the temperature be increased by  $\theta$ , therefore,

$$\frac{60}{100} = \frac{(T + \theta) - 300}{(T + \theta)}$$

or

$$\frac{3}{5} = \frac{500 + \theta - 300}{500 + \theta}$$

or

$$\theta = \frac{500}{2} = \mathbf{250 \text{ K.}}$$

**S44.** Given:  $Q_1 = 6 \times 10^5$  cal,  $T_1 = 500$  K,  $T_2 = 400$  K

As, 
$$\frac{Q_2}{Q_1} = \frac{T_2}{T_1}$$

or 
$$Q_2 = Q_1 \left( \frac{T_2}{T_1} \right) = 6 \times 10^5 \left( \frac{400}{500} \right)$$
$$= 4.8 \times 10^5 \text{ cal}$$

$\therefore$  Work done per cycle

$$\begin{aligned} W &= Q_1 - Q_2 \\ &= 6 \times 10^5 - 4.8 \times 10^5 \\ &= 1.2 \times 10^5 \text{ cal} \\ &= 1.2 \times 4.2 \times 10^5 \text{ J} \\ &= \mathbf{5.04 \times 10^5 \text{ J}}. \end{aligned}$$

**S45. Isothermal expansion:**

Given,  $T_1 = 127 + 273 = 400$  K;  $P_1 = 10^6$  dyne  $\text{cm}^{-2}$ ;  $V_1 = 1$  litre = 1,000  $\text{cm}^3$ ;  $V_2 = 2V_1 = 2,000$   $\text{cm}^3$

Now, for an isothermal change,

$$P_1 V_1 = P_2 V_2$$

or 
$$P_2 = \frac{P_1 V_1}{V_2} = \frac{10^6 \times 1,000}{2,000}$$
$$= \mathbf{5 \times 10^5 \text{ dyne cm}^{-2}}$$

**Adiabatic expansion:**

Here,  $V_1 = 2,000$   $\text{cm}^3$ ;  $V_2 = 2(2,000) = 4,000$   $\text{cm}^3$ ;  $P_1 = 5 \times 10^5$  dyne  $\text{cm}^{-2}$ ;  $\gamma = 1.4$

Now, for an adiabatic change,

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

or 
$$P_2 = P_1 \times \left( \frac{V_1}{V_2} \right)^\gamma = 5 \times 10^5 \left( \frac{2,000}{4,000} \right)^{1.4}$$
$$= 5 \times 10^5 \times (0.5)^{1.4}$$

Taking log of both sides, we get

$$\begin{aligned} \log P_2 &= \log 5 + 5 \log 10 + 1.4 \log 0.5 \\ &= 0.6990 + 5.0000 + 1.4(0.6990 - 1) \end{aligned}$$

$$= 5.6990 + 1.4(-0.3010)$$

$$= 5.6990 - 0.4214 = 5.2776$$

Taking antilog, we get

$$P_2 = 1.895 \times 10^5 \text{ dyne cm}^{-2}.$$

**S46.** Here,  $T_1 = 0 + 273 = 273 \text{ K}$ ;  $P_1 = 1.013 \times 10^6 \text{ dyne cm}^{-2}$ ;  $\gamma = 1.4$  and density of air at N.T.P.,  $\rho = 1.29 \times 10^{-3} \text{ g cm}^{-3}$

$$\therefore V_1 = \frac{\text{Mass}}{\text{Density}} = \frac{1}{1.29 \times 10^{-3}} = 775.2 \text{ cm}^3$$

and 
$$V_2 = \frac{V_1}{2} = \frac{775.2}{2} = 387.6 \text{ cm}^3$$

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

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

or 
$$P_2 = 1.013 \times 10^6 \times \left(\frac{V_1}{V_1/2}\right)^{1.4}$$

$$= 1.013 \times 10^6 \times (2)^{1.4}$$

$$= 1.013 \times 10^6 \times 2.639$$

$$= 2.673 \times 10^6 \times \text{dyne cm}^{-2}$$

Work done during adiabatic change,

$$W = \frac{1.013 \times 10^6 \times 775.2 - 2.673 \times 10^6 \times 387.6}{1.4 - 1}$$

$$= \frac{7.853 \times 10^8 - 10.36 \times 10^8}{0.4} = -6.27 \times 10^8 \text{ erg}$$

$$= -62.7 \text{ J.}$$

**S47.** Here,  $\mu = 1$ ;  $V_1 = 22400 \text{ cm}^3 = 2.24 \times 10^{-2} \text{ m}^3$ ;  $T_1 = 273 \text{ K}$ ;  $P_1 = 1 \text{ atm}$ ;  $P_2 = 5 \text{ atm}$ ;  $R = 8.31 \text{ J mole}^{-1} \text{ K}^{-1}$ ;  $\gamma = 1.4$

(a) Now, 
$$P_1 V_1^\gamma = P_2 V_2^\gamma$$

or 
$$V_2 = V_1 \times \left(\frac{P_1}{P_2}\right)^{1/\gamma}$$

or 
$$V_2 = 2.24 \times 10^{-2} \times \left(\frac{1}{5}\right)^{1/1.4}$$

$$= 2.24 \times 10^{-2} \times \left(\frac{1}{5}\right)^{0.7143}$$

$$= 2.24 \times 10^{-2} \times 0.3168$$

$$= 7.1 \times 10^{-3} \text{ m}^3.$$

(b) Also, 
$$\frac{P_1^{\gamma-1}}{T_1^{\gamma}} = \frac{P_2^{\gamma-1}}{T_2^{\gamma}}$$

or 
$$T_2 = T_1 \times \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

or 
$$T_2 = 273 \times \left(\frac{5}{1}\right)^{\frac{1.4-1}{1.4}}$$

$$= 273 \times (5)^{0.287} = 273 \times 1.5838$$

$$= 432.4 \text{ K} = 432.4 - 273 = 159.4^\circ\text{C}.$$

(c) Work done during adiabatic change,

$$W_{\text{adia}} = \frac{R(T_1 - T_2)}{\gamma - 1} = \frac{8.31 \times (273 - 432.4)}{1.4 - 1}$$

$$= -3,211.54 \text{ J}.$$

**S48.** Given,  $P_1 = 76 \text{ cm of Hg}; T_1 = 273 \text{ K};$

Suppose that  $V_1 = V$ . Then,  $V_2 = 4V$

(a) **Isothermal expansion:** For an isothermal change,

$$P_1 V_1 = P_2 V_2$$

or 
$$P_2 = \frac{P_1 V_1}{V_2} = \frac{76 \times V}{4V} = 19 \text{ cm of Hg}$$

The final temperature will remain as 273 K (in isothermal change, temperature remains constant).

(b) **Adiabatic expansion:** Here,  $\gamma = 1.4$

For an adiabatic change,

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

$$\therefore P_2 = P_1 \left( \frac{V_1}{V_2} \right)^\gamma = 273 \left( \frac{V}{4V} \right)^{1.4} = 273 \times (0.25)^{1.4}$$

Taking log of both sides, we get

$$\begin{aligned} \log P_2 &= \log 273 + 1.4 \log (0.25) \\ &= 2.4361 + 1.4 (-0.6020) = 1.5932 \end{aligned}$$

Taking antilog, we get

$$P_2 = \mathbf{10.912 \text{ cm of Hg}}$$

Also,

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

or

$$T_2 = T_1 \left( \frac{V_1}{V_2} \right)^{\gamma-1} = 273 \left( \frac{V}{4V} \right)^{1.4-1} = 273 \times (0.25)^{0.4}$$

Taking log of both sides, we get

$$\begin{aligned} \log T_2 &= \log 273 + 0.4 \log (0.25) \\ &= 2.4362 + 0.4 (1.3979) = 2.1954 \end{aligned}$$

Taking antilog, we get

$$T_2 = \mathbf{156.82 \text{ K}} = 156.82 - 273 = \mathbf{-116.18^\circ \text{C.}}$$

**S49.** (a) A cyclic process is that in which the system returns to its initial state after under going a series of a changes. A non-cyclic process is that in which the system does not return to its initial state.

(b) For isothermal process,  $PV = \text{constant}$

Differentiating,  $VdP + PdV = 0$

$$\therefore \frac{dP}{dV} = -\frac{P}{V}$$

For adiabatic process,  $PV^\gamma = \text{constant}$ .

Differentiating,

$$V^\gamma dP + \gamma PV^{\gamma-1} dV = 0$$

$$\therefore \frac{dP}{dV} = -\frac{\gamma P}{V}$$

Comparing the two ratios, we can say, slope of adiabatic process is  $\gamma$  times the slope of isothermal process.

**S50.** For a small change in volume, work done is given by  $dW = PdV$ .

We know,  $PV = nRT$   $\left( \because P = \frac{nRT}{V} \right)$

For  $T = \text{Constant}$ ,

$$dW = nRT \frac{dV}{V}$$

Net work done under isothermal condition to change the volume from  $V_i$  to  $V_f$  is,

$$\begin{aligned} W &= \int_{V_i}^{V_f} dW = nRT \int_{V_i}^{V_f} \frac{dV}{V} \\ &= nRT \left| \log_e V \right|_{V_i}^{V_f} \\ &= nRT \log_e \left( \frac{V_f}{V_i} \right) \end{aligned}$$

$$\therefore W = 2.3026 nRT \log_{10} \left( \frac{V_f}{V_i} \right)$$

where  $n$  is the number of moles. If  $P_f$  and  $P_i$  are the pressures, we can also write,

$$W = 2.3026 nRT \log_{10} \left( \frac{P_i}{P_f} \right)$$

**S51.** Given, Mass of nitrogen,  $m = 2.0 \times 10^{-2} \text{ kg} = 20 \text{ g}$   
Rise in temperature,  $\Delta T = 45^\circ\text{C}$   
Molecular mass of  $\text{N}_2$ ,  $M = 28$   
Universal gas constant,  $R = 8.3 \text{ J mol}^{-1} \text{ K}^{-1}$   
Number of moles,  $n = \frac{m}{M}$   
$$= \frac{2.0 \times 10^{-1} \times 10^3}{28} = 0.714$$

Molar specific heat at constant pressure for nitrogen,

$$C_p = \frac{7}{2} R = \frac{7}{2} \times 8.3 = 29.05 \text{ J mol}^{-1} \text{ K}^{-1}$$

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

$$\begin{aligned} \Delta Q &= nC_p \Delta T \\ &= 0.714 \times 29.05 \times 45 \\ &= \mathbf{933.38 \text{ J}}. \end{aligned}$$

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

**S52.** Given,  $P = 75$  cm of mercury;  $T = 17 + 273 = 290$  K;  $\gamma = 1.4$

Let  $V$  be the original volume of the gas.

**On isothermal expansion:**

Here,  $V_1 = \frac{3V}{4}$

$\therefore P_1 = \frac{PV}{V_1} = \frac{75 \times V}{3V/4} = 100$  cm of mercury

**On adiabatic expansion:**

Here,  $P_1 = 100$  cm of mercury;  $V_1 = \frac{3V}{4}$ ;  $V_2 = \frac{V \times 120}{100} = 1.2V$ ;  $T_1 = 290$  K (unchanged)

Let  $P_2$  and  $T_2$  be the pressure and temperature of the gas on adiabatic expansion.

Now, 
$$P_2 = P_1 \times \left( \frac{V_1}{V_2} \right)^\gamma = 100 \times \left( \frac{3V/4}{1.2V} \right)^{1.4} = 100 \times (0.625)^{1.4}$$
$$= 100 \times 0.518 = \mathbf{51.8}$$
 cm of mercury.

Also, 
$$T_2 = T_1 \times \left( \frac{V_1}{V_2} \right)^{\gamma-1} = 290 \times \left( \frac{3V/4}{1.2V} \right)^{1.4-1}$$
$$= 290 \times (0.625)^{0.4} = 290 \times 0.829 = 240.4$$
 K  
$$= 240.4 - 273 = \mathbf{-32.6^\circ C}.$$

**S53.** Given, mass of the gas = 6 g;  $T = 27 + 273 = 300$  K;  $V_2 = 2V_1$ ;  $R = 8.31$  J mole<sup>-1</sup> K<sup>-1</sup>

(a) Number of moles of the gas,

$$n = \frac{\text{Mass}}{\text{Molecular weight}} = \frac{6}{2} = 3$$

(b) Since the change is isothermal, temperature will remain unchanged *i.e.*,  $27^\circ$  C.

(c) 
$$W_{\text{iso}} = 2.303 \times nRT \log \frac{V_2}{V_1}$$
$$= 2.303 \times 3 \times 8.31 \times 300 \times \log \frac{2V_1}{V_1}$$
$$= 2.303 \times 3 \times 8.31 \times 300 \times \log 2$$
$$= 2.303 \times 3 \times 8.31 \times 300 \times 0.3010 = \mathbf{5,184.47}$$
 J.

**S54.** (a) Work done by the steam engine per minute,

$$W = 5.4 \times 10^8 \text{ J}$$

Heat supplied from the boiler,

$$H = 3.6 \times 10^9 \text{ J}$$



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

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

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

$$\text{Amount of heat wasted} = 3.6 \times 10^9 - 5.4 \times 10^8 = 30.6 \times 10^8 = 3.06 \times 10^9 \text{ J}$$

Therefore, the amount of heat wasted per minute is  $3.06 \times 10^9 \text{ J}$ .

(b) As no heat is allowed to be exchanged, the process is adiabatic.

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

$$\text{As} \quad V_2 = \frac{1}{2} V_1$$

$$\therefore \frac{P_2}{P_1} = \left( \frac{V_1}{\frac{1}{2} V_1} \right)^{1.4} = (2)^{1.4} = \mathbf{2.64}$$

**S55.**  $T_1$  = Temperature of the source,  $T_2$  = Temperature of sink.

(a) Since  $\eta = 1 - \frac{T_2}{T_1}$ . On increasing  $T_2$ , efficiency drops.

(b) Given,  $Q_1 = 1000 \text{ J}$ ,  $T_1 = 127 + 273 = 400 \text{ K}$ ,  $Q_2 = 600 \text{ J}$ .

$$\begin{aligned} \text{(i) Efficiency} \quad \eta &= \frac{Q_1 - Q_2}{Q_1} \\ &= \frac{400}{1000} = 0.4 \quad \text{or} \quad 40\% \end{aligned}$$

$$\text{(ii) Using} \quad \eta = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{T_2}{T_1}$$

$$\text{we get} \quad \frac{400}{1000} = 1 - \frac{T_2}{T_1}$$

$$\Rightarrow T_2 = 400 \times \frac{600}{1000} = 240 \text{ K}$$

(iii) Work done =  $Q_1 - Q_2 = 400 \text{ J}$ .

**S56.** (a) For an adiabatic process of thermodynamics,

$$dQ = 0.$$

Since  $dU = n C_V dT$  irrespective of the process, from 1<sup>st</sup> law, we get

$$dW = -dU = -nC_v dT$$

So work done,

$$W = -nC_v(T_f - T_i)$$

$$= -\frac{C_v}{R}(P_f V_f - P_i V_i)$$

(b) For an isothermal process,  $dT = 0$ .

So

$$dW = \int P dV = \int \frac{nRT}{V} dV \quad (PV = nRT)$$

Work done

$$W = nRT \left| \log_e \right|_{V_i}^{V_f}$$

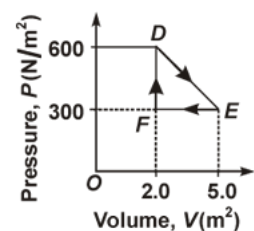
$$W = nRT \log_e \left( \frac{V_f}{V_i} \right).$$

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- Q1. State Carnot's principle.**
- Q2. What are the four steps in a Carnot's engine?**
- Q3. What is the thermodynamically work in a reversible process?**
- Q4. Is coefficient of performance of a refrigerator a constant quantity?**
- Q5. In a Carnot engine, temperature of sink is increased. What will happen to its efficiency?**
- Q6. On what factors, the efficiency of a Carnot engine depends?**
- Q7. What is the nature of  $P$ - $V$  diagram for isobaric and isochoric processes?**
- Q8. How can an isochoric and isobaric change be represented using an equation of state?**
- Q9. Give an example of irreversible process?**
- Q10. "Heat cannot itself flow from a body at lower temperature to a body at higher temperature" is a statement or consequence of which law of thermodynamics?**
- Q11. Can mechanical energy be converted continuously and completely into heat? Is the reverse also possible?**
- Q12. Mention two essential characteristics of an ideal heat engine.**
- Q13. Can the Carnot engine be realised in actual practice?**
- Q14. Can we increase the coefficient of performance of a refrigerator by increasing the amount of working substance?**
- Q15. Why can a Carnot's engine not get 100% efficiency?**
- Q16. What is the principle of calorimetry?**
- Q17. Can water be made to boil without heating?**
- Q18. Write the second law of thermodynamics.**
- Q19. We cannot move a ship in an ocean by utilising the energy of the ocean. Why?**
- Q20. In a Carnot engine, the temperature of the sink is  $27^\circ\text{C}$  and that of the source is  $327^\circ\text{C}$ . What is the efficiency of the Carnot engine?**
- Q21. How is the efficiency of a Carnot engine affected by the nature of the working substance?**
- Q22. Give one example of a heat pump.**
- Q23. What is a heat pump?**
- Q24. Refrigerator transfers heat from a cold body to a hot body. Does this not violate the second law of thermodynamics?**

- Q25. The door of an operating refrigerator is kept open in a closed room. Will it make the room warm or cool?
- Q26. In a Carnot's engine plan, the temperature of the sink is raised. How will the efficiency of the engine be affected?
- Q27. Is coefficient of performance of a refrigerator constant?
- Q28. Can mechanical work be 'completely' converted into heat? Is reverse also possible?
- Q29. Give three examples of heat engines.
- Q30. What is a heat engine?
- Q31. Milk is poured into a cup of tea and is mixed with a spoon. Is this an example of reversible process? Give reason for answer.
- Q32. Define irreversible process.
- Q33. Define reversible process.
- Q34. Is it possible to construct a heat engine which would not reject any heat to the surroundings?
- Q35. What is meant by reversible engine ? Explain, why the efficiency of a reversible engine is maximum.
- Q36. Why is the conversion of heat into work not possible without a sink at lower temperature?
- Q37. If you were asked to increase the efficiency of a Carnot engine by increasing the temperature of the source or by decreasing the temperature of the sink by 10 K, which would you prefer and why?
- Q38. State second law of thermodynamics. How is heat engine different from a refrigerator?
- Q39. Which working substances are used in a steam engine, petrol engine and diesel engine?
- Q40. What does the flat portion in an isotherm indicate?
- Q41. Define reversible and irreversible processes with example.
- Q42. Give two example of reversible processes. Discuss their reversibility.
- Q43. Why is it impossible for a ship to use the internal energy of sea water to operator its engine?
- Q44. The temperature of the surface of the sun is approximately 6,000 K. If we take a big lens and focus the sun rays, can we produce a temperature of 8,000 K.
- Q45. What is calorimetry? What is the principle of calorimetry
- Q46. How the atmosphere is important thermodynamically?
- Q47. Discuss whether the following phenomena are reversible ? (a) Waterfall; (b) rusting iron and (c) Electrolysis.
- Q48. It is impossible to construct a heat engine of 100% efficiency. Why?
- Q49. Write the statements of second law of thermodynamics applicable to  
(a) Heat engine (b) Refrigerator.

- Q50.** A refrigerator, whose coefficient of performance is 5, extract heat from the cooling compartment at the rate of 250 J per cycle. How much heat per cycle is discharged to the room? How much electric energy is spent per cycle?
- Q51.** Ice in a refrigerator melts at the rate of 3kg per hour. the temperature outside is 27 °C. Find the minimum power output of a motor used to drive the refrigerator, which just prevents ice from melting. Latent heat of ice = 80 cal g<sup>-1</sup>, 1cal = 4.2 J . given, 1 h.p. = 746W.
- Q52.** One mole of an ideal gas is taken in a Carnot engine working between 27 °C and 227 °C. the useful work done in one cycle is 600 J. Calculate the ratio of volume of the gas at the end and beginning of the isothermal expansion. Given  $R = 8.31 \text{ J mole}^{-1}\text{K}^{-1}$ .
- Q53.** Assuming a domestic refrigerator as a reversible engine working between melting point of ice and the room temperature of 27 °C, calculate the energy in joule that must be supplied to freeze 1kg of water already at 0 °C.
- Q54.** Efficiency of an engine is 0.4, when temperature of its sink (cold body) is 300 K. What is the temperature of the hot body? Find its efficiency, if the temperature of the hot body is kept unchanged, while temperature of the sink (cold body) is lowered by 50 K. (Treat it as reversible engine).
- Q55.** A Carnot engine absorbs 300 cal of heat from a reservoir and rejects 250 cal of heat at 300 K during each cycle. Calculate (a) the efficiency of the engine and (b) the temperature of the reservoir.
- Q56.** A reversible engine operates with an efficiency of 50%. If during each cycle, it rejects 150 cal to a reservoir of heat at 30 °C, then (a) what is the temperature of the other reservoir? (b) How much work does it carry out per cycle?
- Q57.** A Carnot engine absorbs 100 cal per cycle from its source at 1,600 K. Its efficiency is 60%. Find the temperature the sink and work done per cycle.
- Q58.** A Carnot engine takes in 1,000 kcal of heat from a reservoir at 627 °C and exhausts heat to a sink at 27 °C. What is its efficiency and output? When its efficiency will be 100%?
- Q59.** A thermodynamic system is taken from an original state to an intermediate state by the linear process shown in figure.  
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.



- Q60.** A Carnot engine has the same efficiency, when operated between 500 K and 100 K or between 900 K and  $T$  K. Find the value of temperature  $T$ .
- Q61.** In a refrigerator, heat from inside at 277 K is transferred to a room at 300 K. How many joule of heat will be delivered to the room for each joule of electric energy consumed ideally?
- Q62.** (a) What is the heat engine and defined the thermal efficiency of heat engine.  
(b) A Carnot engine, whose low temperature reservoir is at 7 °C, has an efficiency of 40%. It is desired to increase the efficiency to 50%. By how many degree must the temperature of the high temperature reservoir be increased?

- Q63.** A Carnot engine takes in 100 cal of heat from a reservoir at 427 °C and performs 60 J of work. Calculate (a) the amount of heat absorbed in joule, (b) heat rejected in joule, (c) efficiency of the engine and (d) the temperature of the cold reservoir.
- Q64.** A Carnot heat engine works between temperatures 300 K and 600 K. If it consumes 100 cal in each cycle, (a) what is its efficiency? (b) What is the amount of heat rejected to the sink in each (c) What is amount of work done in each cycle?
- Q65.** 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)
- Q66.** 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:
- (a) What is the final pressure of the gas in *A* and *B*?
  - (b) What is the change in internal energy of the gas?
  - (c) What is the change in the temperature of the gas?
  - (d) Do the intermediate states of the system (before settling to the final equilibrium state) lie on its *P-V-T* surface?
- Q67.** Explain how Carnot's cycle works with the heat flow diagram. Using the same, explain the working of a refrigerator. Also, give its coefficient of performance.

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- S1.** No engine working between two temperatures can be more efficient than a Carnot's reversible engine working between the same temperatures.
- S2.** Isothermal expansion, adiabatic expansion, isothermal compression and adiabatic compression are four steps.
- S3.** Zero.
- S4.** No. The coefficient of performance of a refrigerator decreases, as its inside temperature decreases.
- S5.** We know that

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

On increasing temperature of sink ( $T_2$ ), the efficiency of the Carnot engine will decrease.

- S6.** On the temperature of source of heat and the sink.
- S7.** The  $P$ - $V$  diagram for an isobaric change is a straight line parallel to volume-axis; while that for an isochoric process, it is a straight line parallel to pressure-axis.
- S8.** Equation of an isochoric change ( $V = \text{constant}$ ):

$$\frac{P}{T} = \text{constant}$$

Equation of an isobaric change ( $P = \text{constant}$ )

$$\frac{V}{T} = \text{constant.}$$

- S9.** Rusting of iron is an irreversible process.
- S10.** It is a consequence of second law of thermodynamics.
- S11.** The mechanical energy can be completely and continuously converted into heat. But heat energy cannot be completely and continuously converted into work.
- S12.** Two essential characteristics of an ideal heat engine are:
1. It should have a source of infinite thermal capacity.
  2. It should have a sink of infinite thermal capacity.
- S13.** No. It is an ideal heat engine.

S14. No.

S15. Due to transmission loss, the energy required to carry the process itself and the inability to build a sink at zero kelvin, one cannot get 100% efficient Carnot's engine.

S16. Heat lost by a body is equal to heat gained by the other when they are mixed.

S17. Yes, by reducing pressure on water, boiling point of water can be brought down to room temperature.

S18. According to second law, it is not possible to cool a system cooler than its surrounding without doing work on it.

S19. This is because no sink is available.

S20. 
$$\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{273 + 27}{273 + 327} = 1 - \frac{300}{600} = \frac{1}{2}$$

S21. The efficiency is independent of the nature of the working substance.

S22. Refrigerator is an example of a heat pump.

S23. A heat pump is a device which uses mechanical work to remove heat.

S24. No. This is because external work is being performed.

S25. The room will be slightly warmed.

S26. The efficiency will decrease.

S27. No, the coefficient of performance of refrigerator decreases with decrease in its inside temperature.

S28. The mechanical work can be completely converted into heat, but heat extracted from some body *cannot* be completely converted into useful work.

S29. Steam engine, Petrol engine and Diesel engine are three examples of heat engines.

S30. Heat engine is a device which converts heat energy into mechanical energy at a steady rate.

S31. When milk is poured into a cup of tea and mixed, some work is performed and the same gets converted into heat. It is not possible to convert the heat produced back into work, which will separate the milk from tea. Hence, the process of mixing milk into the tea is an **irreversible process**.

S32. **Irreversible process:** It is a process which is not exactly reversed, *i.e.*, the system does not pass through the same intermediate state as in the direct process.

S33. **Reversible process:** It is that process which can be retraced in the opposite direction so that the system and the surroundings pass through exactly the same state at each stage as in the direct process.



- S34.** No, any engine cannot convert the *whole* heat extracted from the source into mechanical work; it has to reject a part of heat to the colder surroundings.
- S35.** The engine, in which the process can be retraced at any stage of its operation by reversing the boundary conditions, is called a **reversible heat engine**. Its efficiency is maximum, as no dissipation of energy takes place against friction, etc in such a heat engine.
- S36.** For converting heat energy into work continuously, a part of the heat energy absorbed from the source has to be rejected. The heat energy can be rejected only if there is a body, whose temperature is less than that of the source. This body at low temperature is called sink.
- S37.** To increase the efficiency of the Carnot engine; the decreasing of temperature of the sink will be preferred. It is because, decreasing the temperature of sink by 10 K brings about greater increase in the efficiency of the heat engine than that is achieved by increasing the temperature of the source by 10 K.
- S38.** According to second law, it is not possible to cool a system cooler than its surrounding without doing work on it.  
A refrigerator is a heat engine working in the reverse direction.
- S39.** Steam is the working substance in a steam engine, while air is the working substance in petrol and diesel engines. Petrol and diesel are mixed with air to produce combustion.
- S40.** Flat portion refers to the transition from gas to liquid as the gas is compressed. As temperature increases, the flat portion's size reduces.
- S41. Reversible processes:** Any process which can be made to proceed in reverse direction with equal ease by variations in its conditions, so that all changes occurring in the direct process are exactly reversed in the reverse process, is called a **reversible processes**.

- Example:** (a) An ideal gas allowed to expand slowly and then compressed slowly so as to return to its initial state.  
(b) The working substance taken along the complete Carnot's cycle.

**Irreversible processes:** Any process which cannot be made to proceed in reverse direction is called an **irreversible processes**.

- Example:** (a) A diffusion of gases is an irreversible process. Two gases always have a tendency to mix together, when allowed to do so but they cannot separate out from the mixture by themselves.  
(b) Exchange of heat between the two bodies is also an irreversible process. Heat energy flows in a natural manner from a body at higher temperature to a body at lower temperature. However, the heat energy cannot flow in the reverse direction by itself.

- S42.** (a) Melting of a solid and vaporisation of a liquid are reversible processes. On reversing the conditions under which these process occur, the liquid can be converted back into solid and vapour into liquid.

- (b) All isothermal and adiabatic process, in which no loss of heat occurs due to conduction, convection or radiation can be retraced by reversing the boundary conditions and hence these are reversible processes.

**S43.** For using the internal energy of sea water to operator the engine of a ship, the internal energy of the sea water has to be converted into mechanical energy. Since whole of the internal energy cannot be converted into mechanical energy, part has to be rejected to a colder body (sink).

Since no such body is available, the internal energy of sea water cannot be used to operate the engine of the ship.

**S44.** It will amount to transfer of heat from a body at lower temperature to a body at higher temperature without the aid of an external agent. Since it is against second law of thermodynamics, it is not possible to produce temperature of 8,000 K by collecting the sun rays with a lens.

**S45.** Calorimetry deals with the measurement of heat. The vessel which is largely used in such a measurement is called a calorimeter.

The principle of calorimetry is

$$\text{Heat Gained} = \text{Heat Lost.}$$

**S46.** The atmosphere is important thermodynamically because

- (a) the temperature difference brings wind.
- (b) the reflected energy from surface is prevented from escaping so that appropriate life supporting temperature exists.

**S47.** (a) **Waterfall:** The falling of water is not a reversible process. During the fall of the water, the major part of its potential energy is converted into kinetic energy of the water. However, on striking the ground, a part of potential energy is converted into heat and sound.

It is not possible to convert the heat and sound produced along with the K.E. of water into potential energy so that the water may rise back to its initial height. Therefore, waterfall is not a **reversible process**.

- (b) **Rusting of iron:** In the rusting of iron, the iron gets oxidised by the oxygen from the air. Since it is a chemical change, it is **not a reversible process**.
- (c) **Electrolysis:** It is **reversible process**, provided the electrolyte does not offer any resistance to the flow of current. If we reverse the direction of current, the direction of motion of ions is also reversed.

**S48.** The efficiency of an 'ideal' heat engine is given by

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

The efficiency will be 1 (that is 100%) when the temperature  $T_2$  of the sink is 0 K. Since absolute zero temperature cannot be achieved, a heat engine of 100% efficiency is a theoretical impossibility.

**S49.** (a) **Heat engine:** One cannot devise a process whose only purpose is to convert heat into work.

(b) **Refrigerator:** One cannot make heat to flow from a cold to a hot body by itself, without using any external agency.

**S50.** Here,  $\beta = 5$ ;  $Q_2 = 250 \text{ J}$

Now,  $\beta = \frac{Q_2}{Q_1 - Q_2}$  or  $5 = \frac{250}{Q_1 - 250}$

or  $Q_1 = 300 \text{ J}$

Therefore, heat discharged per cycle to the room = **300 J**.

Now, electric energy spent per cycle,

$$W = Q_1 - Q_2 = 300 - 250 = 50 \text{ J.}$$

**S51.** Given,  $T_1 = 27 + 273 = 300 \text{ K}$ ;  $T_2 = 0 + 273 = 273 \text{ K}$

Rate at which ice melts in the cold storage.

$$m = 3 \text{ kg h}^{-1} = \frac{3 \times 1,000}{3,600} = 0.833 \text{ g s}^{-1}$$

Heat required to be removed per second, so that the ice does not melt,

$$Q_2 = mL = 0.833 \times 80 \text{ cal s}^{-1}$$

$$= 0.833 \times 80 \times 4.2 = 279.9 \text{ J s}^{-1}$$

Now,

$$Q_1 = \frac{T_1}{T_2} \times Q_2 = \frac{300 \times 279.9}{273} = 307.58 \text{ J s}^{-1}$$

Therefore, work done per second or the power of the motor of refrigerator,

$$P = Q_1 - Q_2 = 307.58 - 279.9 = 27.68 \text{ W}$$

$$= \frac{27.68}{746} = 0.0371 \text{ h.p.}$$

**S52.** Here,  $T_1 = 227 + 273 = 500 \text{ K}$ ;  $T_2 = 27 + 273 = 300 \text{ K}$ ;  $W = 600 \text{ J}$ ;  $R = 8.31 \text{ J mole}^{-1} \text{ K}^{-1}$

$$W = 2.303 \times R(T_1 - T_2) \log \frac{V_2}{V_1}$$

or 
$$\log \frac{V_2}{V_1} = \frac{W}{2.303R(T_1 - T_2)}$$

or 
$$\log \frac{V_2}{V_1} = \frac{600}{2.303 \times 8.31 \times (500 - 300)} = 0.1568$$

or 
$$\frac{V_2}{V_1} = \mathbf{1.435}.$$

**S53.** Here,  $T_1 = 27 + 273 = 300 \text{ K}$ ;  $T_2 = 0 + 273 = 273 \text{ K}$

Mass of water to be freezed,  $M = 1 \text{ kg} = 1,000 \text{ g}$

Amount of heat that should be removed to freeze the water,

$$\begin{aligned} Q_2 &= ML = 1,000 \times 80 \text{ cal} \\ &= 1,000 \times 80 \times 4.2 = 3.36 \times 10^5 \text{ J} \end{aligned}$$

Now, 
$$Q_1 = \frac{T_1}{T_2} \times Q_2 = \frac{300}{273} \times 3.36 \times 10^5 = 3.692 \times 10^5 \text{ J}$$

Therefore, energy supplied to freeze the water,

$$\begin{aligned} W &= Q_1 - Q_2 \\ &= 3.692 \times 10^5 - 3.36 \times 10^5 = \mathbf{3.32 \times 10^4 \text{ J}}. \end{aligned}$$

**S54. Case (i):**  $\eta = 0.4$ ;  $T_2 = 300 \text{ K}$

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

$\therefore 0.4 = 1 - \frac{300}{T_1}$  or  $\frac{300}{T_1} = 1 - 0.4 = 0.6$

or 
$$T_1 = \frac{300}{0.6} = \mathbf{500 \text{ K}}$$

**Case (ii):**  $T_1 = 500 \text{ K}$ ;  $T_2 = 300 - 50 = 250 \text{ K}$

Now, 
$$\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{250}{500} = 1 - 0.5 = \mathbf{0.5}.$$

**S55.** Given,  $Q_1 = 300 \text{ cal}$ ;  $Q_2 = 250 \text{ cal}$ ;  $T_2 = 300 \text{ K}$

(a) Now, 
$$\eta = \frac{Q_1 - Q_2}{Q_1} \times 100 = \frac{300 - 250}{300} \times 100 = \mathbf{16.67\%}$$

(b) Also, 
$$\frac{Q_1}{Q_2} = \frac{T_1}{T_2}$$

or 
$$T_1 = \frac{Q_1}{Q_2} \times T_2 = \frac{300}{250} \times 300 = \mathbf{360 \text{ K.}}$$

**S56.** Given,  $Q_2 = 150 \text{ cal}$ ;  $T_2 = 30 + 273 = 303 \text{ K}$ ;  $\eta = 50\% = 0.5$

(a) Now, 
$$\eta = 1 - \frac{T_2}{T_1}$$

$\therefore$  
$$0.5 = 1 - \frac{303}{T_1} \quad \text{or} \quad \frac{303}{T_1} = 1 - 0.5 = 0.5$$

or 
$$T_1 = \frac{303}{0.5} = 606 \text{ K} = 606 - 273 = 333^\circ\text{C}$$

(b) Also, 
$$\eta = 1 - \frac{Q_2}{Q_1}$$

$\therefore$  
$$0.5 = 1 - \frac{150}{Q_1} \quad \text{or} \quad Q_1 = \frac{150}{0.5} = 300 \text{ cal}$$

Therefore, work done per cycle,

$$W = Q_1 - Q_2 = 300 - 150 = 150 \text{ cal} = 150 \times 4.2 = \mathbf{630 \text{ J.}}$$

**S57.** Here,  $Q_1 = 100 \text{ cal}$ ;  $T_1 = 1600 \text{ K}$ ;  $\eta = 60\% = 0.6$

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

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

or 
$$T_2 = 640 \text{ K}$$

Also, 
$$\eta = \frac{W}{Q_1}$$

or 
$$W = \eta \times Q_1$$

or 
$$W = 0.6 \times 100 = 60 \text{ cal} = 60 \times 4.2 = \mathbf{252 \text{ J.}}$$

**S58.** Given,  $Q_1 = 1000 \text{ kcal}$ ;  $T_1 = 627 + 273 = 900 \text{ K}$ ;  $T_2 = 27 + 273 = 300 \text{ K}$

Now, 
$$\eta = \frac{T_1 - T_2}{T_1} \times 100 = \frac{900 - 300}{900} \times 100 = \mathbf{66.67\%}$$

Also, 
$$\text{output} = \eta \times Q_1 = \frac{66.67}{100} \times 1,000 = 666.7 \text{ kcal}$$

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

For  $\eta$  to be 100% i.e., 1,

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

or 
$$T_2 = 0 \text{ K.}$$

**S59.** Total work done by the gas from  $D$  to  $E$  to  $F$  = Area of  $\triangle DEF$

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

Where, 
$$\begin{aligned} DF &= \text{Change in pressure} \\ &= 600 \text{ N/m}^2 - 300 \text{ N/m}^2 \\ &= 300 \text{ N/m}^2 \end{aligned}$$

$$\begin{aligned} FE &= \text{Change in volume} \\ &= 5.0 \text{ m}^3 - 2.0 \text{ m}^3 \\ &= 3.0 \text{ m}^3 \end{aligned}$$

$$\text{Area of } \triangle DEF = \frac{1}{2} \times 300 \times 3 = 450 \text{ J}$$

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

**S60.** *When Carnot engine is operated between 500 K and 100 K:*

Given, 
$$T_1 = 500 \text{ K} \quad \text{or} \quad T_2 = 100 \text{ K}$$

Now, 
$$\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{100}{500} = 0.8$$

*When Carnot engine is operated between 900 K and  $T$ :*

Here, 
$$T'_1 = 900 \text{ K}; \quad T'_2 = T$$

Now, 
$$\eta' = 1 - \frac{T'_2}{T'_1} = 1 - \frac{T}{900}$$

Since  $\eta = \eta'$ , we have

$$0.8 = 1 - \frac{T}{900} \quad \text{or} \quad \frac{T}{900} = 0.2$$

or 
$$T = 180 \text{ K.}$$

**S61.** Given,  $T_1 = 300 \text{ K}$ ;  $T_2 = 277 \text{ K}$

and  $W = 1 \text{ J}$  ... (i)

The coefficient of performance of a refrigerator,

$$\beta = \frac{T_2}{T_1 - T_2} = \frac{277}{300 - 277} = \frac{277}{23}$$

or  $\beta = 12.04$  ... (ii)

Suppose that for each joule of electrical energy consumed, an amount of heat  $Q_2$  is removed from the inside of refrigerator. Therefore, amount of heat delivered to the room for each joule of electrical energy consumed is given by

$$Q_1 = Q_2 + W = Q_2 + 1$$

or  $Q_2 = Q_1 - 1$  ... (iii)

Also for a refrigerator,

$$\beta = \frac{Q_2}{Q_1 - Q_2}$$

Since  $Q_1 - Q_2 = W$ , we have

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

Using the equation (i), (ii) and (iii), the above equation becomes

$$12.04 = \frac{Q_1 - 1}{1} \quad \text{or} \quad Q_1 - 1 = 12.04$$

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

**S62.** (a) **Heat engine:** It is a device used for converting heat energy into mechanical energy.

**Thermal efficiency of heat engine:** It is defined as the ratio of net external work done by the engine one cycle to the heat absorbed from the source during that cycle.

(b) **When  $\eta$  is 40%:**

Here,  $\eta = 40\% = 0.4$ ;  $T_2 = 7 + 273 = 280 \text{ K}$

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

or  $0.4 = 1 - \frac{280}{T_1}$

or  $T_1 = 466.67 \text{ K}$

**When  $\eta$  is 50%:**

Here,  $\eta' = 50\% = 0.5$ ;  $T_2 = 280\text{ K}$

Suppose that the temperature of the source has to be raised to  $T_1'$ .

Now, 
$$\eta' = 1 - \frac{T_2}{T_1'}$$

or 
$$0.5 = 1 - \frac{280}{T_1'}$$

or 
$$T_1' = 560\text{ K}$$

Therefore, change in temperature of the source,

$$\begin{aligned} T_1' - T_1 &= 560 - 466.67 \\ &= 93.93\text{ K or } \mathbf{93.93^\circ\text{C (increases)}}. \end{aligned}$$

**S63.** Given,  $Q_1 = 100\text{ cal}$ ,  $T_1 = 427 + 273 = 700\text{ K}$ ;  $W = 60\text{ J}$

(a) Now, 
$$Q_1 = 100\text{ cal} = 100 \times 4.2 = \mathbf{420\text{ J}}$$

(b) Also, 
$$Q_2 = Q_1 - W = 420 - 60 = \mathbf{360\text{ J}}$$

(c) Now, 
$$\eta = \frac{W}{Q_1} \times 100 = \frac{60}{420} \times 100 = \mathbf{14.29\%}$$

(d) Let  $T_2$  be temperature of the sink. Then,

$$\begin{aligned} T_2 &= \frac{Q_2}{Q_1} \times T_1 = \frac{360}{420} \times 700 = 600\text{ K} \\ &= 600 - 273 = \mathbf{327^\circ\text{C}}. \end{aligned}$$

**S64.** Here,  $T_1 = 600\text{ K}$ ;  $T_2 = 300\text{ K}$ ;  $Q_1 = 100\text{ cal}$

(a) Now, 
$$\eta = \frac{T_1 - T_2}{T_1} \times 100 = \frac{600 - 300}{600} \times 100 = \mathbf{50\%}$$

(b) Also, 
$$\frac{Q_1}{Q_2} = \frac{T_1}{T_2}$$

or 
$$Q_2 = \frac{T_2}{T_1} \times Q_1 = \frac{300}{600} \times 100 = \mathbf{50\text{ cal}}$$

(c) Therefore, work done during each cycle,

$$\begin{aligned} W &= Q_1 - Q_2 = 100 - 50 = 50\text{ cal} \\ &= 50 \times 4.2 = \mathbf{210\text{ J}}. \end{aligned}$$



**S65.** 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.

$$\therefore \Delta Q = 0$$

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

From the first law of thermodynamics, we have:

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

Where,

$$\Delta U = \text{Change in the internal energy of the gas}$$

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

$$\Delta U = +22.3 \text{ J}$$

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

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

From 1<sup>st</sup> law of thermodynamics

$$\text{Heat absorbed, } \Delta Q = \Delta U + \Delta W$$

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

$$= 39.1765 - 22.3$$

$$= 16.8765 \text{ J}$$

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

**S66.** (a) 0.5 atm      (b) Zero      (c) Zero      (d) No

**Explanation:**

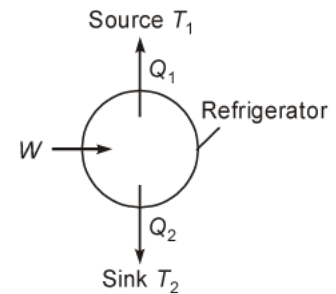
- (a) The volume available to the gas is doubled as soon as the stopcock between cylinders  $A$  and  $B$  is opened. Since volume is inversely proportional to pressure, the pressure will decrease to one-half of the original value. Since the initial pressure of the gas is 1 atm, the pressure in each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

**S67.** Refrigerator absorbs heat from the body at a high temperature by doing work. It can be shown by the given diagram.

$Q_2 \rightarrow$  Energy absorbed from sink.

$Q_1 \rightarrow$  Energy liberated to source.

$W \rightarrow$  Work done on the system.



$$\text{Coefficient of performance } (\beta) = \frac{Q_2}{Q_1 - Q_2}.$$

$Q_1 - Q_2$  refers to the work done on the system/refrigerator.

$$\text{Coefficient of performance } (\beta) = \frac{Q_2}{Q_1 - Q_2} = \frac{T_2}{T_1 - T_2}$$

**Refrigerator:** It works in the reverse Carnot's cycle. Heat is absorbed from sink at low temperature  $T_2$  and given to the source at higher temperature  $T_1$  with the help of an external agency doing work on the system. ( $W = Q_1 - Q_2$ ).

The compressor in the refrigerator uses electrical energy and does work on the system. The coefficient of performance is defined as the heat energy absorbed from low temperature sink  $Q_2$  to the amount of work done

$$W = Q_1 - Q_2$$

i.e.,

$$\beta = \frac{Q_2}{Q_1 - Q_2} = \frac{T_2}{T_1 - T_2}$$

