THERMODYNAMICS

Points to Remember

1. Thermodynamics is the branch of physics dealing with the interrelation between heat and mechanical energy.

2. Thermodynamics is applicable only when the system is in equilibrium.

3. Temperature is a thermal condition of a substance and measures its relative hotness

4. The mathematical representation of Zeroth law of thermodynamics $f(P,V,T)=0$.

5. The mechanical equivalent J is the amount of mechanical work to be done to produce unit quantity of heat.

6. **First law of thermodynamics**: The heat supplied to the system is equal to the sum of the increase in internal energy of the system and the external work done by the system. First law of thermodynamics is only another statement of the Law of Conservation of Energy.

7. **Two specific heats of a gas** 1) Specific heat at constant pressure Cp

   2) Specific heat at constant volume Cv

   Specific heat at constant pressure (Cp): It is the amount of heat required to rise the temperature of 1 mole of gas at constant pressure through 1K.

   Specific heat at constant volume (Cv): it is the amount of heat required to rise the temperature of 1 mole of gas at constant volume through 1K.

8. **Isothermal change**: The changes of pressure and volume of a gas at constant temperature with exchange of heat is called isothermal changes.

9. **Adiabatic change**: The change in pressure and volume of a gas resulting a change in temperature without exchange of heat in an isolated system is called adiabatic changes.

10. **Clausius statement of second law**: Heat cannot itself flow from cold body to hot body.

11. **Kelvin's Statement:** It is impossible to derive continuous supply of energy in cooling a body below the coldest of its surrounding.

12. **Latent heat (L):** The quantity of heat absorbed or liberated during the change of state by unit mass of substance, without any change in temperature is called latent heat.

13. **Quasi-static process**: An infinitesimally slow process in which at each and every intermediate stage the system remains in thermal and mechanical equilibrium with the surrounding throughout the entire process.

14. **Cycle process**: A process in which the system after passing through various stages (of pressure volume and temperature changes) returns to its initial state is called a cycle process.

15. **Reversible process**: A process that can be retraced back in the opposite direction in such a way that the system passes through the same states as in the direct process and finally the system and the surrounding return to their original states, with no other changes any where else in the universe is called a reversible process

16. **Irreversible process**: A process that cannot be retraced back in the opposite direction is called as irreversible process.

Long Answer Questions:

1. Obtain the relation (a) P, V (b) V, T (C) P, T during adiabatic change

A. 1. Let us assume an ideal gas in adiabatic process.

2. According to first law of thermodynamics, dQ = dU + dW

3. In an adiabatic process, dQ = 0 and for one mole of an ideal gas, change in internal energy is given by $dU = C_V dT$, where dT is the change in temperature.

4. Now, the first law of thermodynamics becomes

$$C_V dT + PdV = 0 \qquad \text{…….(1)}$$

According to ideal gas equation, PV = RT on differentiating.

$pdV + Vdp = RdT$

$$dT = \frac{PdV + VdP}{R}$$

$$dT = \frac{PdV + VdP}{C_P - C_V} \qquad \text{……..(2)}$$

Substitute (2) in (1)

$$\Rightarrow C_v PdV + C_v VdP + C_p PdV - C_V PdV = 0$$

$$\Rightarrow C_v VdP + C_p PdV = 0$$

Dividing the equation on both sides by $C_v PV$

$$\Rightarrow \frac{dP}{P} + \frac{C_P}{C_V}\frac{dV}{V} = 0 \qquad \Rightarrow \frac{dP}{P} + \gamma\frac{dV}{V} = 0$$

Integrating on both sides

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

$\Rightarrow \log PV^{\gamma} = \text{cons tan t}$

$\Rightarrow PV^{\gamma} = \text{cons tan t}$

b) Relation between V,T :

From ideal gas equation, PV = RT

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

Substitute the above expression in PV constant

$$\Rightarrow \left(\frac{RT}{V}\right)\left(V^{r}\right) = \text{cons tan t}$$

$\Rightarrow TV^{r-1} = \text{cons tan t}$

c) Relation between P,T :

From ideal gas equation, PV = RT

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

Substitute the above expression in PV^r = constant

$$\Rightarrow P\left[\frac{RT}{P}\right]^{r} = \text{co ns tan t}$$

$\Rightarrow P^{1-r}.T^{r} = \text{cons tan t}$

2. Define the molar specific heats of a gas and deduce the relation between them.

A. Molar specific heat at constant volume:

At constant volume, the heat energy required to raise the temperature of one mole of a gas through 1°C is called molar specific heat at constant volume.

Molar specific heat at constant pressure:

At constant pressure, the heat energy required to raise the temperature of one mole of a gas through 1°C is called molar specific heat at constant pressure.

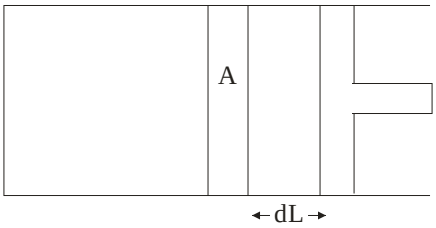
Relation between C_P and C_V:

1) Consider on mole of an ideal gas in a cylindrical vessel with tight piston.

2) Let ‘A’ be the area of cross section of the piston

3) At constant pressure, Let the temperature of the gas is increased through 1ºC, then let 'dL' is the displacement in the piston.

$\therefore$ Force exerted by the gas on the piston, F = PA



Work done by the gas on the piston, dW = F.dL

$$\Rightarrow dW = PAdl$$

$$\Rightarrow dW = PdV \qquad \ldots\ldots\ldots\ldots(1)$$

Also $C_P = \frac{1}{n}\frac{d\theta}{dT}$

$$\Rightarrow C_P = d\theta \qquad \ldots\ldots\ldots..(2)\ [\because \text{ in = 1 mole, } dT = 1^oC]$$

Substitute (1), (2) in Ist law of thermodynamics $dQ = dU + dW$

$$\Rightarrow C_P = dU + PdV \qquad \ldots\ldots\ldots\ldots(3)$$

Also from PV = RT

$$\Rightarrow PdV = RdT$$

$$\Rightarrow PdV = R \qquad \ldots\ldots\ldots\ldots(4) \quad [\because dT = 1^oC]$$

Substitute (4) in (3)

$$\therefore C_P = dU + R \qquad \ldots\ldots\ldots.....(5)$$

At constant volume

$$C_V = \frac{1}{m}\frac{dQ}{dT}$$

$$\Rightarrow C_V = dQ \qquad \ldots\ldots\ldots (6) \quad [\because dT = 1°C, n = 1mole]$$

Also from Ist law of thermodynamics, $dQ = dU$ $\ldots\ldots\ldots..(7)$ $[\because dW = 0]$

From (6) and (7) $dU = C_V$ $\ldots\ldots\ldots(8)$

Substitute (8) in (5

$$\therefore C_P = C_V + R$$

$\Rightarrow C_P - C_V = R$

3. Describe the method of determination of specific heat of a solid by method of mixture.

Principle of method of mixtures:

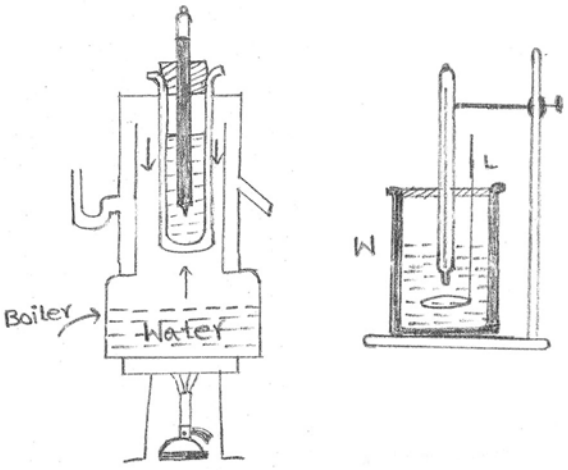
When two bodies at different temperature are mixed, then heat flows from body at higher temperature to the body at lower temperature until they are in thermal equilibrium.

$\therefore$ Heat lost by the hot body = Heat gained by the cold body

This is called principle of method of mixtures (or) law of calorimetry.

Experimental determination of specific heat:

Aim: To determine the specific heat of the given solid by method of mixture.



Apparatus: Calorimeter, common balance, steam heater, thermometer, solid pieces.

Description:

1) A cylindrical copper vessel, kept in wooden box(W), containing non – conducting material on the inner side, provided with a metallic stirrer and with a suitable Lip 'L' is called a 'calorimeter'.

2) The solid whose specific heat is to be determined is taken in the form of small pieces and heater in a steam heater.

Procedure:

1) The weight of the empty calorimeter with sirror is measured by common balance as (W_1).

2) Sufficient amount of water is taken in calorimeters and weight of water along with calorimeter is found (W_2)

3) The initial temperature of the water $(t_1°C)$, the steady temperature of hot solid pieces is noted quickly hot solid pieces are dropped into calorimeter.

4) The water is stirred and when the temperature of calorimeter and contents is steady, the resultant temperature $t_3°C$ is noted.

5) Here heat is lost by solid substance and gained by calorimeter and water.

6) Weight of calorimeter + water + solid pieces only is $(W_3 – W_2)$ and weight of water only $(W_2 – W_1)$

Calculation:

Heat lost by hot solid = $(W_3 – W_2)\ S_1\ (t_2 – t_3)$

Heat gain by calorimeter $= W_1S(t_3 - t_1)$ S_1 = sp.heat of solid

Heat gain by water $= (W_2 - W_1)S_W(t_3 - t_1)$ S_2 = Sp. Heat of water

According to law of calorimetery, S = Sp. Heat of calorimeter

Heat lost = heat gain

$$(W_3 - W_2)S_1(t_2 - t_3) = \left[W_1S + (W_2 - W_1)S_W\right](t_2 - t_1)$$

Knowing the remaining all values, specific heat of solid is determined.

4. Describe how the value of latent heat of vaporization of water is determined by method of mixtures.

Determination of latent heat of steam:

AIM: Our aim is to determine the latest heat of steam:

1) Description: A calorimeter in a thin copper vessel provided with a stirrer of same material.

2) The calorimeter is placed inside a wooden box to reduce the loss of heat to the surroundings, due to conduction and convection.

3) the space between 2 vessels is packed with bed conductor like cotton.

4) It is provided with a non – conducting lid with 2 holes to insert thermometer and stirrer.

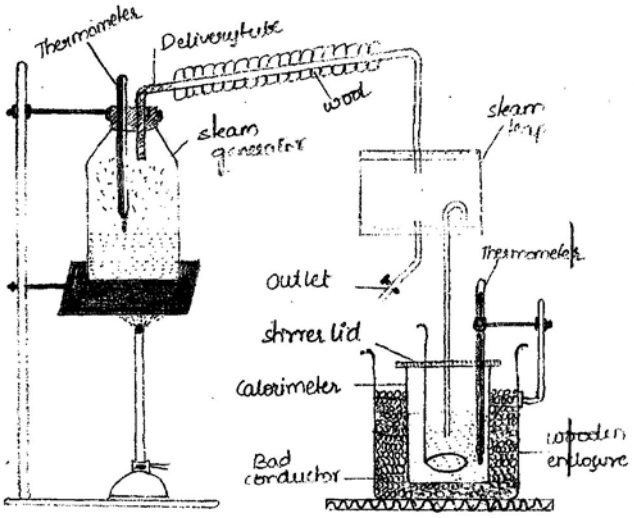
PROCEDURE:

1) The wt of the empty calorimeter with stirrer is found to be W_1.

2) Sufficient amount of water at $t_1°C$ is taken in calorimeter and its weight is found to be W_2.

3) The temperature of steam $t_2°C$ in noted with the help of thermometer.

4) The steam is passed into the calorimeter until the temperature of the water in it raises by 5ºC.



5) Later the resultant temperature of the mixture $t_3°C$ is noted with the help of thermometer. Then wt of the calorimeter with stirrer, water is noted as W_3.

$\therefore$ wt of empty calorimeter + stirrer + water = W_2

wt of water only = $(W_2 - W_1)$.

Temperature of the steam = t_2ºC

$\therefore$ Resultant temperature = t_3ºC

wt of calorimeter + stirrer + water + steam = W_3g

$\therefore$ wt of steam only ($W_3 - W_2$)

Heat lost by the steam for change of state $(W_3 - W_2)L$

Heat lost by the condensed water $(W_3 - W_2)S_W(t_2 - t_3)$

Total heat lost $= (W_3 - W_2)L + (W_3 - W_2)S_W(t_2 - t_3)$

$= (W_3 - W_2)(L + S_W(t_2 - t_3))$

Heat gained by the calorimeter $= W_1S(t_3 - t_1)$

Heat gained by the water = $(W_2 - W_1)S_W(t_3 - t_1)$

$\therefore$ Total heat gain = $\left[W_1S + (W_2 - W_1)S_W\right](t_3 - t_1)$

According to principle of calorimeter equate. Heat lost and heat gain

i.e., heat lost by hot body = heat gain by colt body.

By substituting all the remaining values, latent heat (L) of the steam is determined.

5. Explain the following processes.

a) Quasi – static process

b) Cyclic process

c) Reversible process

d) Irreversible process

Quasi – static process : An infinitesimally slow process in which at each and every intermediate stage, the system remains in thermal and thermodynamic equilibrium with the surroundings throughout the entire process is called quasi – static process.

Explanation:

1) Consider a gas enclosed in a cylinder by piston. If suddenly the piston pushed down words, the gas inside will undergo sudden compression. During the compression, the gas inside the cylinder passes through several states that are not in equilibrium states. This is because of the pressure and temperature of the system will rapidly change. But after certain time, the gas will attain the thermodynamic equilibrium with surroundings.

2) In stead of pushing the piston in a sudden manner. Let us lower it down in infinitely slow manner such that at every stage of the system, the pressure difference, and temperature difference between system and surroundings should be infinitesimally small. It is called quasi-static.

Reversible process: A process that can be retracted back in opposite direction in a such away that the system passes through the same states as in the direct process and finally the system and surroundings return to their original states is called reversible process.

Conditions for a process to be reversible:

1) The process should be quasi-static.

2) No amount of heat is to be converted into electric (or) magnetic forms of energy.

3) There should be no loss of energy due to conduction, convection (or) dissipation of energy against any resistance like friction, viscosity etc.

Example: 1) Pettier effect and see beck effect.

2) Fusion of ice and vaporization of water.

Irreversible process: A process that cannot be retraced back in opposite direction is called irreversible process.

Eg : 1) Diffusion of gases 2) Magnetization of material

3) Work done against friction

4) Joule heating – heat produced in a conductor by passing a current through it.

Cyclic Process: The process in which the system after passing through various stages (or pressure, volume and temperature changes) returns to its initial depends on the state of the system not on the path followed.

i) In cyclic process, dU = 0, Hence $dQ = dW$

ii) P – V graph for a cyclic process is a closed curve.

6. Explain qualitatively the working of heat engines and refrigerators.

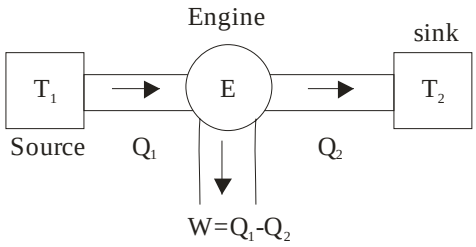
Heat Engines is a device used to convert heat energy into work.

1) Heat engine consists of (1) a body at higher temperature (J_1), heat Q_1 is extracted from this body called source [Hot reservoir]

2) A body of the engine containing working substance. In a steam engine working substance is stem.

3) A body at a lower temperature T_2. Heat Q_2 is rejected by the working substance to this body called 'sink' (or cold reservoir)

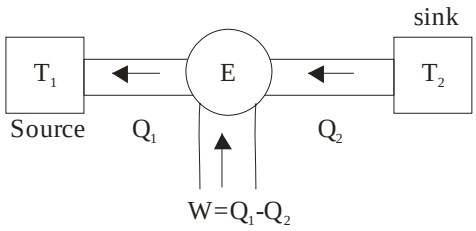
4) Working by the system, $W = Q_1 - Q_2$.



5) The efficiency of a heat engine is defined as ratio of workdone by the engine to the amount of heat absorbed by the engine.

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

Refrigeration: If is just the reverse of heat engine. In this working substance extracts heat from sink and amount of work done on the working substance and finally heat is rejected to hot reservoir.



Efficient of the refrigerator is called coefficient of performance (β)

It is defined as the ratio of heat absorbed from sink to the work done by the external agency.

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

In this case work is done on the working substance

Short Answer Questions:

1. State and explain first law of thermodynamics.

A. **First law of thermodynamics:** The amount of heat energy supplied to the system is utilized is two ways. They are (i) to increase the internal energy (2) to do the external work.

It dQ is the amount of heat supplied to the system, dU is the increase in internal energy and 'dW' is the external work, then dQ = dU + dW.

Sign convention:

- If work is done by the system, dW is + ve
- If work is done on the system, dW is – ve
- When heat is supplied to the system, dQ is + ve
- When is heat is taken out from the system, dQ is – ve
- When gas expands, then dW is taken as +ve
- When gas contracts, then dW is taken as – ve
- When internal energy of the system increases dU is + ve
- When internal energy of the system decreases dU is - ve

Limitations:

1) It does not tell about the direction of heat flow.

2) It does not tell us about the efficiency with which heat can be converted into work.

Note: First law of thermodynamics is the consequence of law of conservation of energy.

2. State and explain the second law of thermodynamics.

A. Classics statement: Heat cannot flow from cold body to hot body for a self acting machine without the help of any external agency. This statement explains direction of heat flow in which conversion of heat into work is not included.

Kelvin statement: It is impossible to construct a heat engine operating in a cycle to convert the heat energy completely into work without any change in the state of working substance. The above statement represents, we cannot construct any heat engine with 100% efficiency.

3. Write down the expression for the work done by an ideal gas during isothermal change and explain.

A. The expression for the work done by an ideal gas in isothermal change is

$$W = 2.303RT\log_{10}\left(\frac{V_2}{V_1}\right) = 2.303RT\log_{10}\left(\frac{P_1}{P_2}\right)$$

Isothermal change: The process in which the thermodynamic system undergoes the changes at constant temperature is called isothermal change.

In this process gases obeys Boyle's law i.e. pv = constant.

Work done by the gas in isothermal process is

$$W = \int_{v_1}^{v_2} pdv = \int_{v_1}^{v_2} \frac{RT}{V} dv = RT\int_{v_1}^{v_2} \frac{dv}{v}$$

$$\Rightarrow W = RT\left[\log v\right]_{v_1}^{v_2}$$

$$\Rightarrow W = RT\left[\log v_2 - \log v_1\right]$$

$$\Rightarrow W = RT\log_e \frac{v_2}{v_1}$$

$$W = 2.303RT\log_{10}\left(\frac{v_2}{v_1}\right)$$

As $p_1v_2 = p_2v_2$

$$\Rightarrow \frac{v_2}{v_1} = \frac{p_1}{p_2} \Rightarrow W = 2.303RT\log_{10}\left(\frac{p_1}{p_2}\right)$$

4. Write down the expression for the work done by an ideal gas during an adiabatic change and explain.

A. The expression for work done by an ideal gas during adiabatic change is

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

The process in which no exchange of heat takes place between system and surroundings (i.e. $\Delta Q = 0$) is called adiabatic change.

In adiabatic change, pv^{γ} = constant. Where $\gamma = \frac{C_p}{C_v}$

The work done by the gas during the volume expansion from v_1 to v_2 is written as

$$W = \int_{v_1}^{v_2} pdv$$

$$\Rightarrow W = \int_{v_1}^{v_2} \frac{K}{v^{\gamma}} dv \qquad \left[\because pv^{\gamma} = K\right]$$

$$\Rightarrow W = K \int_{v_1}^{v_2} v^{-\gamma} dv$$

$$\Rightarrow W = K \left[\frac{v^{1-\gamma}}{1-\gamma}\right]_{v_1}^{v_2}$$

$$\Rightarrow W = \frac{K}{(1-\gamma)} \left[v_2^{1-\gamma} - v_1^{1-\gamma}\right]$$

on simplification

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

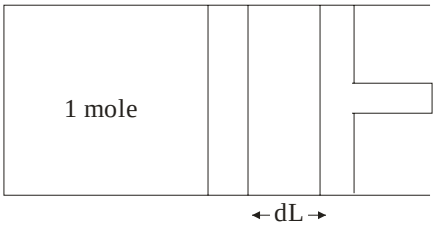
5. What is the difference between second law of thermodynamics and the law of conservation of energy?

A. 1) According to the law of conservation of energy total energy always remains constant. i.e. energy neither be created nor destroyed but it can be converted from to another form.

2) But according to second law of thermodynamics, all the heat cannot be converted to work. It gives the idea of the direction of flow of heat between the bodies. If prohibit the flow of heat in a particular direction.

6. Show that $C_p - C_v = R$ in the case of one mole of ideal gas.

A. relation between C_p and C_v:



1) Consider one mole of an ideal gas in a cylindrical vessel with tight piston.

2) Let 'A' be the area of cross section of the piston.

3) At constant pressure, let the temperature of the gas is increased through 1°C, then let 'dL' is the displacement in the piston.

$\therefore$ Force exerted by the gas on the piston, F = PA

$\therefore$ Work done by the gas on the piston, dW = F.dl

$$\Rightarrow dW = PAdl$$

$$\Rightarrow dW = PdV \quad \ldots\ldots\ldots\ldots\ldots(1)$$

Also $C_p = \frac{1}{m}\frac{dQ}{dT}$

$$\Rightarrow C_P = dQ \quad \ldots\ldots\ldots\ldots\ldots(2) \qquad \left[\because m = 1\,\text{mole}, dT = 1^{o}C\right]$$

Substitute (1), (2) in Ist law of thermodynamics dQ = dU+dW

$$\Rightarrow C_p = dU + PdV \ldots\ldots\ldots\ldots(3)$$

Also from PV = RT

$$\Rightarrow PdV = RdT$$

$$\Rightarrow PdV = R \quad \ldots\ldots\ldots\ldots(4) \quad \left[\because dT = 1^{o}C\right]$$

Substitute (4) in (3)

$$\therefore C_P = dU + R \ldots\ldots\ldots\ldots(5)$$

At constant volume

$$C_v = \frac{1}{m}\frac{dQ}{dT}$$

$$\Rightarrow C_v = dQ \quad \left[\because dT = 1^{o}C, m = 1\,\text{mole}\right]$$

Also from Ist law of thermodynamics, $dQ = dU$ ……. (7) $\left[\because dW = 0\right]$

From (6) and (7) $dU = C_v$ …….(8)

Substitute (8) in (5)

$\therefore C_p = C_v + R$

$\Rightarrow C_p - C_v = R$

7. Write a short note on triple point of water.

A. Triple point of water:

- The equilibrium temperature at which 3 states of matter exist simultaneously is called triple point.
- The value of triple point of water is 610.42pas pressure and 273.16 k temperature.
- Taking temperature on x-axis and pressure on y – axis for water in different states is as shown in the graph.
- In the graph S_1 is called triple point and S_1I is called 'Ice line' and it is having –ve slope.
- On the left side of this line ice exists and on the right side water exists.
- Along this line, if the temperature is increased ice converts into water.
- In the graph S_1S is called steam line. It is having +ve slope. It the temperature is increased along this line water is converted into steam.
- S_1H is called hoarfrost line it is having +ve slope. If the temperature is increased along this line ice covert into steam i.e. sublimation takes place.

8. Why $C_P > C_V$

A. The amount of heat energy supplied at C_P is utilized to increase internal energy and also do external work. But in the case of C_V the heat energy supplied is utilized only to increases the internal energy. Hence $C_P > C_V$.

The ratio of C_P and C_V is represented by 'γ' i.e. $\gamma = \frac{C_P}{C_V}$

9. Explain a Quasi – static process.

A. Quasi – static process : An infinitesimally slow process in which at each and every intermediate state, the system remains in thermal and thermodynamics equilibrium with the surroundings throughout the entire process is called Quasi – static process.

Explanation:

1) Consider a gas enclosed in a cylinder by piston. If suddenly the piston pushed down words, the gas inside will undergo sudden compression during the compression, the gas inside the cylinder passes through several states, that are not in equilibrium states. This is because of the pressure and

temperature of the system will rapidly change. But after certain time, the gas will attain the thermodynamic equilibrium with surroundings.

2) Instead of pushing the piston in a sudden manner, let us lower it down in infinitely slow manner such that at every stage of the system, the pressure difference and temperature difference between system and surroundings should be infinitesimally small. It is called Quasi – static.

10. Explain a cyclic process.

A. Cyclic process: The process in which the system after passing through various stages (of pressure, volume and temperature changes) returns to its initial state is called cyclic process. Internal energy (U) of the system only depends on the state of the system and not on the path followed.

It cyclic process, $dU=0$ Hence $dQ = dW$

P - V graph for a cyclic process is a closed curve.

11. Explain Reversible process.

A. Reversible process: A process that can be retraced back in opposite direction in a such away that the system passes through the same states as in the direct process and finally the system and surroundings return to their original states is called reversible process.

12. Explain Irreversible process.

A. Irreversible process: A process that cannot be retraced back in opposite direction is called irreversible process.

Eg: 1) diffusion of gases 2) Magnetisation of material

3) Work done against friction

4) Joule heating – heat produced in a conductor by passing a current through it.

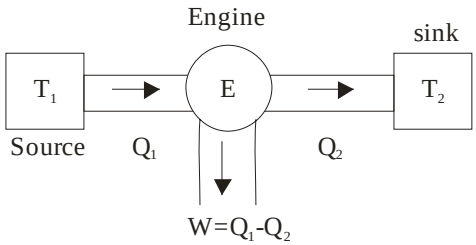
13. Explain the working of a heat engine.

A. Heat Engine: Heat engine is a device used to convert heat energy into work. Heat engine consists of 1) Heat engine consists of (1) a body at higher temperature (J_1), heat Q_1 is extracted from this body called source [Hot reservoir]

2) A body of the engine containing working substance. In a steam engine working substance is stem.

3) A body at a lower temperature T_2. Heat Q_2 is rejected by the working substance to this body called ‘sink’ (or cold reservoir)

4) Working by the system, $W= Q_1 – Q_2$.

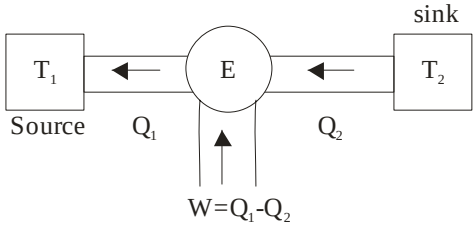


5) The efficiency of a heat engine is defined as ratio of work done by the engine to the amount of heat absorbed by the engine.

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

14. Explain the working of a refrigerator.

A. Refrigeration: If is just the reverse of heat engine. In this working substance extracts heat from sink and amount of work done on the working substance and finally heat is rejected to hot reservoir.



15. Under what conditions a process can be considered as a reversible process?

A. Conditions for a process to be reversible:

1) The process should be Quasi-static.

2) No amount of heat is to be conversed into electric (or) magnetic forms of energy.

3) There should be no loss of energy due to conduction, convector (or) dissipation of energy against any resistance like friction, viscosity etc.,

Example: 1) pettier effect and see beck effect

2) Fusion of ice and vapourisation of water.

16. What is an isothermal process? State the conditions to be fulfilled by an isothermal process.

A. The process in which the pressure and volume changes taking place at constant temperature is called isothermal process.

Conditions:

1) The cylinders should be good conductors of heat.

2) The process should be quasi-static.

3) As the temperature is constant, gases obeys Boyles law i.e., PV = constant.

17. What is an adiabatic process? State the conditions to be fulfilled by an adiabatic process.

A. The process in which there is no exchange of heat between system and surroundings (i.e. dQ=0 is called adiabatic process.

Conditions:

1) The cylinder should be bad conduction of heat

2) As temperature is not constant, Boyle's law does not valid. Hence PV^{γ} = constant.

3) The cylinder – gas system is well insulated thermally.

VERY SHORT ANSWER QUESTIONS:

1. What is heat capacity? What is specific heat?

Ans. Heat capacity: The amount of heat required per unit rise of temperature is called heat capacity.

$$\text{Heat capacity} = \frac{\Delta Q}{\Delta t}$$

Specific heat: "As the quantity of heat required by unit mass of the material to rise its temperature by one degree" is called specific heat.

$$\text{Specific heat s} = \frac{\Delta Q}{m\Delta t}$$

2. State Zeroth law of thermodynamics. What is its significance?

(or)

State the Zeroth law of thermodynamics.

Ans: Zeroth law of thermodynamics: "If two systems are in thermal equilibrium with a third system then they must be in thermal equilibrium with each other" is called the Zeroth law of thermodynamics.

It forms the basis of concept of temperature.

3. Define calorie and standard calorie.

Ans: calorie is the amount of energy required to raise the temperature of 1 gram of water through $1^{o}C$. It depends on temperature range. calorie is defined for a limited range of temperatures usually from $14.5^{0}C$ *to* $15.5^{0}C$.

Standard calorie:

Definition: Mean Calorie is the amount of heat required to the temperature of 1 gm of water $14.5^0 C$ *to* $15.5^0 C$.

4. Define latent heat of fusion and latent heat of vaporization.

Ans: **Latent heat of fusion**: The amount of heat required by unit mass of substance to convert from solid state to liquid state at constant temperature is called latent heat of melting.

Latent heat of vaporization: The amount of heat required to convert unit mass of substance from liquid state to vapour state is called latent heat of vaporization.

5. What is the principle used determining the specific heat of a substance?

Ans: Method of mixtures.

Heat lost by hot body = Heat gained by cold body.

6. What is the relation between work and heat?

Ans: When is done on a system its internal energy increases the energy which is transferred by a non mechanical way is called heat

When work is done against friction, heat is generated.

The amount of heat generated (Q) is directly proportional to the work done (W).

$\therefore W = Q \Rightarrow W = JQ$

Where J is called joules constant (or) mechanical equivalent of heat

7. When a gas expands through ΔV at constant pressure P. What is the work done?

Ans: Work done dW = P.dV

8. What is the specific heat of a gas in (a) an isothermal change (b) an adiabatic change?

Ans: Molar specific heat of a gas $C = \frac{1}{n}.\frac{dQ}{dT}$

Where dQ = Heat supplied

dT = Change in temperature

a) In isothermal process $dT = 0 \Rightarrow C = \frac{1}{n}.\frac{dQ}{0} \Rightarrow C = \infty$

b) In adiabatic process $dQ = 0 \Rightarrow \frac{0}{dT} \Rightarrow C = 0$

9. A thermos flask containing a liquid is shaken vigorously what happens to its temperature?

Ans: When liquid is shaken in a thermos flask, work is done on the liquid which gets converted into internal energy of the liquid. Hence, temperature of liquid increases.

10. When can we treat a process as a quasi-static process?

Ans: Any process taking place sufficiently slowly, not involving accelerated motions and large temperature gradients can be treated as quasi-static process.

11. What is the relation between the total heat absorbed and work done by a system in a cycle process?

Ans: In a cyclic process, Internal energy is constant, i.e., dU = 0

From 1st law of thermodynamics dQ = dU + dW

$\Rightarrow dQ = dW$. for a cyclic process.

$\therefore$ *Inacyclicprocess, the total heat absorded by the system equals the work done by the system.*

12. When will be a heat engine having maximum efficiency?

Ans: Heat extracted Q_1 from the source is more and heat rejected Q_2 to the sink less

13. What are 'source' and 'sink' in a heat engine?

Ans. Source: A body at a higher temperature T_1.*Heat* Q_1 is extracted from this body by the working substance and hence it is called a 'source'

Sink: A body at a lower temperature T_2.*Heat* Q_2 is rejected by the working substance to this body and hence is called a 'sink'.

14. Briefly state the functioning of a heat engine.

Ans: "A device used to convert heat energy into work is called a heat engine".

It extracts heat Q_1 from the source and rejects a heat Q_2 to the sink

Efficiency, $\eta = \frac{w}{Q_1} = 1 - \frac{Q_2}{Ql1}$

15. Briefly state the functioning of a refrigerator.

Ans: The refrigerator is just the reverse of a heat engine.

In this the working substance extracts an amount of heat Q_2 from the sink and after doing work rejects an amount of heat Q_1 to the source which is at a higher temperature T_1 .

16. Define the efficiency of an engine.

Ans: The efficiency (η) of a heat engine is defined as the ratio of the work done (W) by the engine to the amount of heat absorbed (Q_1) by the engine.

$$\eta = \frac{W_1}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1}$$

17. Give a few examples for reversible process.

Ans: 1) An isothermal and adiabatic changes are reversible if they are performed very slowly.

2) Peltier effect and Seebeck effect.

3) Fusion of ice and vaporization of water.

18. Give a few examples for irreversible processes.

Ans: 1) All the processes occurring in the natural are irreversible.

2) Work done against friction.

3) Joule heating.

4) Diffusion of gases.

ASSESS YOURSELF

1. Should a quasi – static process be reversible?

A. No, it need not be

2. Should a cyclic process be reversible?

A. No, it need not be

3. Water is heated by using an immersion heater. Can the process be reversed?

A. No, it is an irreversible process.

4. Is evaporation of water a reversible process?

A. No, it is an irreversible process

5. An ideal gas is allowed to expand at constant temperature in a quasi static process. Can you reverse the process?

A. No, it is an irreversible process

6. Suppose you keep you two hands on two bodies simultaneously and feel them equally cold or hot. What is your inference?

A. The are at the same temperature as your body (Thermal equilibrium).

7. If you place your hands on a wooden and a metal chair at the same temperature. Lower than your body temperature, which of them do you find hotter?

A. The wooden chair

8. In the above question, if your body temperature is lower what will be your feeling?

A. The metal chair will be felt hotter.

9. A sound wave is sent into a gas pipe. Does its internal energy change?

A. Yes,

10. What happens when a metal spring dissolves in an acid?

A. The internal energy of the acid increases followed by increase in temperature.

11. Which types of energy of the following given to a system changes its internal energy? (a) Electromagnetic (b) electrical (c) Nuclear

A. All the three

12. When water boils at a complaint temperature of 100°C, it there any change in the internal energy?

A. Yes, the internal energy of steam at 100°C is always greater than the internal energy of the same quantity of water at 100°C.

13. Can you find an example of decrease in internal energy at constant temperature?

A. Freezing water at 0°C.

14. A small bottle of an ideal gas is brought into a thermally insulated room and it is broken in the room. What happens to the temperature of the room?

A. It remains constant as free expansion of the gas does not work, $dW = 0$ and no heat is supplied $dQ = 0$ $\therefore dU = 0$ or U = constant.

15. When two ice blocks are rubbed against each other some ice melts in between the two. Which law can explain the process?

A. Joule's law

16. Two identical bodies at temperature T_1 and T_2 are brought into thermal contact. Under what conditions they came to thermal equilibrium at the mean temperature?

A. When their heat capacities are same.

17. Equal masses of two liquids at different temperature are mixed if the resultant temperature is equal to the mean of their temperature, what is your inference about their specific heats?

A. Their specific heats are equal.

18. Two bodies A and B have their specific heat as S_A and S_B respectively. If $S_B < S_A$, which of the two would you use as a coolant?

A. The liquid A

19. If the difference in the molar specific heats of a gas is equal to R what will be the difference in the molar specific heats if there are n mole?

A. R.

20. From Fig. 15.6 whether more work is done in the isothermal process or adiabatic process?

A. Isothermal process.

21. Why in Fig 15.6 adiabatic is sleeper than isothermal?

A. Since the pressure and volume change quickly.

22. In which process (isothermal or adiabatic) there is a greater change in internal energy?

A. Adiabatic

23. Equal quantities of ice at 0°C and steam at 100°C are mixed up. What will be the resultant temperature?

A. 100°C

24. You cannot get something for no-thing. Do you think this statement is equivalent to any law of thermodynamics?

A. Yes, 1st law of thermodynamics

25. Why is not possible to cool down a room on a hot summer day by leaving the refrigerator open?

A. Because it violates second law of thermodynamics.

PROBLEMS

|l. A piece of lead falls from a height of 100 m on a fixed non-conducting slab which brings it to rest. If the specific heat of lead is 30.6 cal/kg^{0}C find the increase in temperature of the slab immediately after collision,

Sol. Height (h) = 100 m

Specific heat of lead (s) = 30.6 cal/kg^{o}C

Increases in temperature (Δt) = ?

$mgh = ms\Delta t$

$$\Delta t = \frac{mgh}{ms} = \frac{gh}{s} = \frac{9.8\times100}{30.6\times4.2} = \frac{980}{128.52} = 7.625 = 7.63°C$$

2. A lead bullet of mass 42 g travelling at a speed of 20O ms^{-1} comes to rest in a wooden block. If no heat is taken away by the wood, find the temperature of the bullet. (Specific heat of lead = 0.03 cal/g°C).

Sol. Mass of bullet (m) = 42 g

Speed (v) = 200 m/s

Temperature of bullet = ?

Specific heat (s) = 0.03 cal/g°C

KE of bullet = heat gained by bullet

$$\frac{1}{2}mv^2 = ms\Delta t \Rightarrow \Delta t = \frac{v^2}{2s}$$

$$\Delta t = \frac{200\times200}{2\times0.03\times4.2\times1000} = \frac{40}{0.252} = 158.7°C$$

3. A steel ball of mass 0.1 kg falls from a height of 10 m and bounces to a height of 5.4 m from the ground. If the dissipated energy in this process is absorbed by the ball, find the rise in temperature of the ball. (Specific heat of steel = 460 J kg^{-1} K^{-1}

Sol. Mass of ball (m) = 0.1 kg

Height (h_1) = 10 m

Bounced height (h_2) = 5.4 m

$\Delta h = h_1 - h_2 = 4.6m$

Temperature of ball (Δt) = ?

Specific heat (s} $= 460Jkg^{-1}k^{-1}$

$g = 10m/s^2$

$mgh = ms\Delta t \Rightarrow gh = s\Delta t$

$$\Delta t = \frac{gh}{s} = \frac{10 \times 4.6}{460} = \frac{1}{10} = 0.1°C$$

4. A lead bullet of 10 g. traveling at 300 ms^{-1} strikes against a block of wood and comes to rest. Assuming 50% of heat is absorbed by the bullet; find the increase in its temperature. (Specific heat of lead is 150 J kg^{-1} K^{-1}).

Sol. Bullet mass (m) $= 10 \times 10^{-3} kg$

Velocity (v) = 300 m/s

50% of heat absorbed by bullet increase temperature (Δt) = ?

Lead specific heat $(s) = 150 JKg^{-1}k^{-1}$

$$\frac{1}{2}mv^2 = ms\Delta t$$

$$\Delta t = \frac{v^2}{2s} = \frac{300 \times 300}{2 \times 150} = 300°C$$

50% heat is absorbed by bullet so The increase in temperature = 150°C

5. Hailstones fall from a certain height. If only 1% of the hailstones melt on reaching the ground, find the height from which they fall, (g = 10 ms^{-2}, L = 80 calorie/g and J = 4.2 J/calorie.

Sol. Height (h) = ?

$g = 10 m/s^2$

$L = 80 cal/g = 80 \times 4.2 \times 1000 J/Kg.k$

Loss potential energy= Heat energy required for melting

$$mgh = mL = h = \frac{L}{g} = \frac{1\%L}{g} = \frac{80 \times 4.2 \times 10}{10}$$

$h = 336m$

6. A bullet moving with a uniform velocity V stops suddenly after hitting the target and the whole mass melts. If the mass of the bullet is m, specific heat is S, initial temperature is 25°C, melting point is 475°C and latent heat is L, find the velocity of the bullet in terms of S and L in SI units.

Sol. Velocity (v) = ?, mass of the bullet = m

Specific heat = s

Initial temperature $(t_1) = 25°C$

Final temperature $(t_2) = 475°C$

Latent heat = L

KE of bullet converts into heat and ice melts $KE = ms\Delta t + mL$

$$\frac{1}{2}mv^2 = ms\Delta t + mL$$

$$\frac{v^2}{2} = s\Delta t + L = 450.s + L$$

$$v^2 = 2(450.s + L) \Rightarrow v = \sqrt{2(450.s + L)}$$

7. A metal sphere of radius r and specific heat s is rotated, about an axis passing through its centre at a speed of n rotations per second. It is suddenly stopped and 50% of its energy is used in increasing its temperature. Find the increase in temperature of the sphere.

Sol. Radius of sphere = r

Rotational KE of the metal sphere = heat gained

$$\frac{1}{2}I\omega^2 = ms\Delta t$$

$$50\% \text{ of } \frac{1}{2}I\omega^2 = ms\Delta t$$

$$\frac{50}{100} \times \frac{1}{2}I\omega^2 = ms\Delta t$$

$$\Delta t = \frac{I\omega^2}{4ms} = \frac{I(2\pi n)^2}{4ms} = \frac{4\pi^2 n^2 . \frac{2}{5}mr^2}{4ms}$$

$$\Delta t = \frac{2}{5}\frac{\pi^2 n^2 r^2}{s}$$

8. A copper block of mass 1 kg slides down on a rough inclined plane of inclination 37° at a constant speed. Find the increase in the temperature of the block as it slides down through 60 cm assuming that the loss in mechanical energy goes into the copper block as thermal energy. (Specific heat of copper = 420 J kg^{-1} K^1, g = 10 ms^{-2}.)

Sol. Mass of copper block = 1 kg

Angle of inclination = 37°

$\Delta T = ?$

Distance (l) = $= 60\times10^{-2}$ m

Specific heat = 420 J/kg K

g = 10 m/s^2

KE loss by the block = Heat gained by the block

$$\frac{1}{2}mv^2 = ms\Delta t$$

$$\Delta t = \frac{v^2}{2s} = \frac{(2gl\sin\theta)}{2s} \qquad \left[\because v = \sqrt{2gl\sin\theta}\right]$$

$$= \frac{2\times10\times60\times10^{-2}\times\sin 37}{2\times420} = \frac{6\times0.6018}{420} = 0.008597$$

$\Delta t = 8.6\times10^{-3}$°C

9. The densities of two substances are in the ratio 5: 6 and the specific heats are in the ratio 3:5 respectively. Find the ratio of their thermal capacities per unit volume.

Sol. Ratio of the densities $(d_1 : d_2) = 5:6$

Ratio of specific heats $(s_1 : s_2) = 3:5$

$$\frac{\text{Ratio of thermal capacities}}{\text{Volume}} = ?$$

Thermal capacity = $\frac{dQ}{dT}$

Thermal capacity/Volume = specific heat × density

Ratio of thermal capacities = $\frac{3}{5}\times\frac{5}{6} = \frac{1}{2}$

10. Two lead spheres at the same temperature have radii in the ratio 1:2. What is the ratio of their heat capacities?

Sol. Ratio of radii of two spheres $(r_1 : r_2) = 1:2$

Ratio of their heat capacities = ?

Heat capacity $\frac{dQ}{dT} = ms \Rightarrow \frac{dQ}{dT} = Vds$

$$\frac{dQ}{dT} \propto v \Rightarrow \frac{dQ}{dT} \propto \frac{4}{3}\pi r^3 \Rightarrow \frac{dQ}{dT} \propto r^3$$

$$\frac{\left(\frac{dQ}{dT}\right)_1}{\left(\frac{dQ}{dT}\right)_2} = \frac{r_1^3}{r_2^3} = \frac{1^3}{2^3} = \frac{1}{8}$$

11. The thermal capacity of 10 g of a substance is 8 calories. What is the specific heat ? (J = 4.2 J/Cal.)

Sol. Mass = 10g = 10×10^{-3} kg

Thermal capacity $\frac{\Delta Q}{\Delta T} = 8\text{cal}$

Specific heat (s) =?

$$\frac{\Delta Q}{\Delta T} = ms \Rightarrow \text{specific heat}(s) = \frac{1}{m}.\frac{\Delta Q}{\Delta T}$$

$$s = \frac{1}{10\times10^{-3}} \times 8 \times 4.2 = 3360 J/kgK$$

12. A liquid of mass m and specific heat s is heated to a temperature T. Another liquid of mass m/2 and specific heat 2 s is heated to a temperature 2T. If these two liquids are mixed, find the resultant temperature of the mixture.

Sol. One liquid — an other liquid

Mass (m_1) = m — mass (m_2) $= \frac{m}{2}$

Specific heat (s_1) = 2s — specific heat (s_2) = 2S

Temperature (t_1) = T — Temperature (t_2) = 2T

$$\text{Resultant temperature of mixture} = \frac{m_1 s_1 t_1 + m_2 s_2 t_2}{m_1 s_1 + m_2 s_2}$$

$$\theta = \frac{msT + \frac{m}{2}.2s.2T}{ms + \frac{m}{2}.2s} = \frac{msT + 2msT}{ms + ms}$$

$$\theta = \frac{3msT}{2ms} = \frac{3}{2}T$$

13. The temperatures of equal masses of three different liquids A,B and C are 12ºC, 19ºC and 28ºC respectively. The temperature when A and B are mixed is 16ºC and when B and C are mixed, it is 23ºC. What will be the temperature when A and C are mixed?

Sol. Let s_1, s_2 and s_3 be the specific heats of A,B and C liquids

Temperature of 3 different liquids is 12ºC, 19ºC and 28ºC.

Heat gained by A = Heat loss by B

$$ms_1(16-12) = ms_2(19-16)$$

$$4s_1 = 3s_2 \Rightarrow s_1 = \frac{3}{4}s_2$$

When 'B' and 'C' are mixed

Heat gained by 'B' = Heat loss by 'C'

$$ms_2(23-19) = ms_2(28-23) \Rightarrow 4s_2 - 5s_2$$

$$s_2 = \frac{5}{4}s_3 \text{ and } \frac{5}{4}s_3 = \frac{4}{3}s_1$$

When 'A' and 'C' are mixed then 't' is the resultant temperature.

$$ms_1(t-12) = ms_3(28-t) = \frac{15}{16}s_3(t-12) = s_2(28-t)$$

$$15t - 180 = 448 - 16t \Rightarrow 31t = 628$$

$$t = \frac{628}{31} = 20.26 = 20.3°C$$

14. In an experiment to determine the specific heat of a solid using the method of mixture, 102g of water is used in a copper calorimeter of mass 80g. The initial temperatures of the water and solid are 16.0ºC and 100ºC respectively and the temperature of the mixture of the mixture is 24.1ºC. If the mass of the solid is 49.8g calculate its specific heat. (Specific heat of water = 1 cal/gºC)

Sol. Let s_1 be the specific heat of solid $\Rightarrow s_1 = ?$

$t_1 = 16°C, t_2 = 100°C$ and $t_3 = 24.1°C$

Mass of the solid $(m_s) = 49.8gr$

Mass of water $(m_w) = 102gr$

$s_w = 1cal/gr°C$

Heat loss by solid = heat ground by water

$$m_s s(t_2 - t_3) = m_w s_w (t_3 - t_1)$$

$$49.8 \times s \times (100 - 24.1) = 102 \times 1 (24.1 - 16)$$

$$s = \frac{102 \times 8.1}{49.8 \times 75.9} = \frac{826.2}{3779.82} = 0.2185 \text{cal/gr}$$

15. Calculate the masses of silver iron and aluminium which have the same thermal capacity as a litre of water. Their specific heats are 235.2 J/kg K, 130.2 J/kg K and 924 J/kg K respectively.

Sol. $s_S = 235.2 \text{J/kg k}; s_I = 130.2 \text{J/kg k}$

$s_A = 924 \text{J/kg k}$

Thermal capacities are equal

$$\frac{dQ}{dT} = 1$$

$$\text{Specific heat (s)} = \frac{1}{m} . \frac{dQ}{dT}$$

$$\text{mass of silver } m_S = \frac{1}{235.2} = 0.00425 \times 4200 = 17.85 \text{kg}$$

$$\text{Mass of iron } m_I = \frac{4200}{130.2} = 32.25 \text{kg}$$

$$\text{Mass of aluminium } m_A = \frac{4200}{924} - 4.545 \text{kg}$$

16. A piece of metal of mass 112 g is heated to 100°C and dropped into a copper calorimeter of mass 40 g containing 200 g of water at 16°C. Neglecting heat loss, calculate the specific heat of the metal if the equilibrium temperature reached is 24.1°C. {Specific heat of water = 1 cal/g°c.)

Sol. Mass of substance (M_S) = 112 gr.

Mass of calorimeter (M_C) = 40 gr.

Mass of water (M_W) = 200 gr

$t_1 = 16°; t_2 = 100°\text{C}; t_3 = 24.1°\text{C}$

Specific heat of water = 1 cal/g°c

Specific heat of substance = s = ?

Heat gained by (water + calorimeter) = Heat loss by the substances

$$(t_3 - t_1)[m_w s_w + m_c s_c] = m_s s(t_2 - t_3)$$

$$(24.1-16)[200\times1+40\times0.1] = 112\times s\times(100-24.1)$$

$$8.1(204) = 112\times s\times 78.9$$

$$s = \frac{8.1\times204}{112\times75.9} = \frac{1652.4}{8500.8} = 0.194 \text{cal/gr°C}$$

17. The specific heat of air at constant pressure is 1.005 kJ/kg K and the specific heat of air at constant volume is 0.718 kJ/kg K. Find the specific gas constant.

Sol. At constant pressure $C_p = 1.005 \text{kJ/kg K}$

At constant volume $C_v = 0.718 \text{kJ/kg K}$

Specific gas constant (r) = ?

We know $C_p - C_v = r$

r = 1.005 – 0.718 = 0.287

r = 0.287 kJ/k mole K

18. The specific heat of air at constant pressure is 1.005 kJ/kg K and the specific heat of air at constant volume is 0.718 kJ/kg K. If the universal gas constant is 8.314 kJ/k mole K. Find the molecular weight of air.

Sol. At constant pressure $C_p = 1.005 \text{kJ/kg K}$

At constant volume $C_v = 0.718 \text{kJ/kg K}$

Universal gas constant (R) =8.314 kJ/k mole K

Molecular weight of air (m) = ?

We know $r = C_p - C_v$

$$\frac{R}{M} = C_p - C_v$$

$$M = \frac{R}{C_p - C_v} = \frac{8.314}{1.005-0.718} = \frac{8.314}{0.287}$$

19. The specific heat of argon at constant volume is 0.3122 kJ/kg K. Find the specific heat of argon at constant pressure if R = 8.314 kJ/k mole K. (Molecular weight of argon = 39.95)

Sol. At constant volume = $C_p = 0.3122\,kJ/kg\,K$

At constant pressure Cp = ?

R= 8.314 kJ/k mole K, M = 39.95

We know $C_p - C_v = \frac{R}{M}$

$$C_p = \frac{R}{M} + C_v = \frac{8.314}{39.95} + 0.3122 = 0.2081 + 0.3122$$

$$C_p = 0.5203\,kj/kg\,K$$

20. If the specific heats of carbon dioxide at constant pressure and constant volume are 0.846 kJ/kg K and 0.657 kJ/kg K, respectively find the ratio of specific heats of gases.

Sol. At constant 'P' $C_p = 0.846 kJ/kgK$

At constant 'V' $C_v = 0.657\,kJ/kgK$

Ration $\frac{C_p}{C_v} = ?$

$$\gamma = \frac{C_p}{C_v} = \frac{0.846}{0.657} = 1.2876 = 1.288$$

21. Calculate the specific heat of a gas at constant volume from the following data. Density of the gas at N.T.P. = 19×10^{-2} kg/m^3, (C_p/C_v) = 1.4, J = 4.2×10^3 J/k.cal; atmospheric pressure = 1.013×10^5 N/m^2.

Sol. At constant 'V' $\rho_v = ?$

Density of gas at N.T.P. = 19×10^{-2} kg/m^3

$$\frac{C_p}{C_v} = 1.4J = 4.2\times10^3\,J/k\,cal$$

Atmospheric pressure (P) = 1.013×105 N/m2

We know $\rho_v = \frac{R}{\gamma - 1}$ where $R = \frac{P}{J\rho t}$

$$C_v = \frac{1.013\times10^5}{87141.6} = 1.162$$

$C_v = 1.162\,k\,Cal/kg\,K$

22. The specific heat of helium at constant pressure and constant volume are 4.949 k cal/k mole K and 2.969 k cal/k mole K, respectively. If the density of helium at N.T.P is 0.178 g/litre find J.

Sol. At constant 'P' $C_p = 4.949\,k\,cal/k\,mole\,K$

At constant 'V' $C_v = 2.969\,K\,cal/kmole\,K$

Density of Helium at NTP = 0.178 g/litre

J = ?, M = 4, $n = \frac{1000}{4} = 250$

$$C_p - C_v = \frac{P}{J\rho T} \Rightarrow J = \frac{P}{(C_p - C_v)\rho TN} = \frac{1.013\times10^5}{1.98\times0.178\times273\times250}$$

$$J = 0.042\times10^5 = 4200\,J/k.cal$$

23. Calculate the difference between the two specific heats of ammonia, given that the density of ammonia at N.T.P. is 0.769 gram/litre and J = 4200 J/K cal. Express it in k cal / kg K.

Sol. Density of Ammonia at NTP $(\rho) = 0.769\,gram/litre$

J = 4200 J/k.cal

$P = 1.013\times10^5\,N/m^2, T = 273k$

$$\rho = 0.769\times\frac{10^{-3}kg}{10^3cm^3} = \frac{0.769\times10^{-3}}{10^3\times10^{-6}}$$

$$\rho = 0.769\,kg/m^3$$

$$C_p - C_v = R \Rightarrow C_p - C_v = \frac{P}{\rho T}$$

$$= \frac{1.013\times10^5}{0.769\times273} = \frac{101300}{209.937} = 482.525\,J/kg.K$$

$$C_p - C_v = \frac{482.525}{4210} = 0.1146\,k\,cal/kg\,K$$

24. The specific heat of methane at constant pressure is 2.2537 kJ/kg K. If the ratio of its specific heats is 1.299, find the universal gas constant, given that the molecular weight of methane is 16.043.

Sol. At constant 'P' $C_p = 2.2537\,kJ/kg\,K$

Ration of specific heat (r) $= \dfrac{C_p}{C_v} = 1.299$

R = ?

Molecular weight of methane (M) = 16.043

$C_p = 2.2537\times10^3\,J/kg\,K$

We know

$$C_p = \frac{\gamma R}{M(\gamma-1)} \Rightarrow R = \frac{C_p(\gamma-1)M}{\gamma}$$

$$R = \frac{2.2537\times10^3(1.299-1)\times16.043}{1.299}$$

$$= \frac{2.2537\times10^3\times0.299\times16.043}{1.299}$$

$$= 8.322\times10^3 = 8322\,J/k\,mole\,K$$

25. The molar heat capacities of carbon monoxide at constant pressure and constant volume are 29.13 kJ/k mole K and 20.84 kJ/k mole K respectively. Find molecular weight of carbon monoxide. (Density of carbon monoxide at N.T.P = 1.25 kg/m^3 and atmospheric pressure = 1.013×10^5 N/m^2.)

Sol. At constant 'P' $C_p = 29.13\,kJ/k\,mole\,K$

At constant 'V' $C_v = 20.84\,kJ/k\,mole\,K$

Molecular weight (m) =?

Density at NTP $(\rho) = 1.25kg/m^3$

$P = 1.013\times10^5\,N/m^2$

$$C_p - C_v = R = \frac{MP}{\rho T} \Rightarrow M = \frac{(C_p - C_v)\rho T}{P}$$

$$M = \frac{(29.13-20.84)\times1.25\times273\times10^3}{1.013\times10^5}$$

$$= \frac{8.29\times10^3\times1.25\times273}{1.013\times10^5} = \frac{2828.963}{101.3} = 27.926 = 27.93$$

26. If the ratio of the specific heats of steam is 1.33 and R = 8312 J/k mole K, find the molar heat capacities of steam at constant pressure and constant volume.

Sol. $\gamma = \frac{C_p}{C_v} = 1.33$

R = 8312 J/k mole K

$C_p = ?, C_v = ?$

$$C_p = \frac{\gamma R}{\gamma - 1} = \frac{1.33 \times 8312}{1.33 - 1} = \frac{1.33 \times 8312}{0.33} = \frac{11054.96}{0.33}$$

$$= 33499.8 = 33.50\,\text{kJ / K mole K}$$

$$C_v = \frac{R}{\gamma - 1} = \frac{8312}{1.33 - 1} = \frac{8312}{0.33} = 25187.87 = 25.187\,\text{kJ / k mole K}$$

27. If the ratio of specific heat of neon is 1.667 and R = 8312 J/K mole K, find the specific heats of neon at constant pressure and constant volume. (Molecular weight of neon = 20.183)

Sol. $\gamma = 1.667, R = 8312\,\text{J / k mole K}$

$m = 20.183, C_p = ?, C_v = ?$

$$C_p = \frac{\gamma R}{(\gamma - 1)m} = \frac{1.667 \times 8312}{(1.667 - 1) \times 20.183}$$

$$= \frac{1.667 \times 8312}{0.667 \times 20.183} = 1.667 \times 617.44 = 1029.27 = 1.029\,\text{kJ / k mole K}$$

$$C_v = \frac{R}{(\gamma - 1)m} = \frac{8312}{(1.667 - 1) \times 20.183} = \frac{8312}{0.667 \times 20.183} = 617.44$$

$$= 0.6174\,\text{kJ / k mole K}$$

28. 2 kg of air is heated at constant volume. The temperature of air is increased from 293 K to 313 K. If the specific heat of air at constant volume is 0.718 kJ/kg K, find the amount of heat absorbed in kJ and k cal. (J = 4.2 kJ/k.cal).

Sol. Mass (m) = 2kg

$T_1 = 293k,\ T_2 = 313k, C_v = 0.718\,\text{kJ / kg K}$

dQ = ?

$$(dQ)_v = mC_v dT = 2 \times 0.718 \times (313 - 293) = 1.436 \times 20 = 28.72\text{kJ}$$

In k.Cal $\Rightarrow \frac{28.72}{4.2} = 6.838\,\text{k.Cal}$

29. 2 moles of hydrogen is heated at constant volume. The temperature of the gas is increased from 280 K to 320 K. If the specific heat of hydrogen at constant volume is 10.183 kJ/kg K. Find the amount of heat absorbed in kJ. (Molecular weight of hydrogen = 2.016)

Sol. n = 2

$T_2 = 280$ K, $T_2 = 320$ K

$C_v = 10.183$ kJ/kg K

m = 2.016

$(dQ)_v = ?$

$(dQ)_v = nC_v dTm = 2\times10.183\times10^3\times(320-280)\times2.016$

$= 2\times10.183\times10^3\times40\times2.016 = 1.642\times10^3 = 1.642\text{kJ}$

30. Five kilo moles of oxygen is heated at constant pressure. The temperature of the oxygen gas is increased from 295 K to 305 K. If the molar heat capacity of oxygen at constant pressure is 6.994 k cal/ k mole K. Calculate the amount of heat absorbed.

Sol. $n = 5\times10^3$

$T_1 = 295\text{K}, T_2 = 305\text{K}$

$C_p = 6.994\,\text{k cal / k mole K}$

$(dQ)_p = ?$

$(dQ)_p = nC_p dT = 5\times10^3\times6.994\times10 = 349.7\text{k.Cal}$

31. Find the change in internal energy in joule, when 10g of air is heated from 30ºC to 40ºC. (Cv = 0.172 k cal/kg K, J = 4200 J/k cal)

Sol. Change in internal energy (in Joule) = ?

M = 10g = 10×10^{-3} kg

$t_1 = 30°\text{C}, t_2 = 40°\text{C} \Rightarrow \Delta T = 313-309 = 10\text{K}$

$C_v = 0.172\,\text{kcal / kg K}$

$J = 4200\,\text{J / k.cal}$

$(dQ)_v = mC_v dT = 10\times10^{-3}\times0.172\times10^3\times4.2\times10 = 17.2\times4.2 = 72.24\text{J}$

32. The molar heat capacities of nitrogen at constant pressure and constant volume are 29:11 kJ/k mole K respectively. When 5 gram of nitrogen is heated from 290 K to 310 K find (i) the increase in its internal energy and (ii) the external work done. (Molecular weight of Nitrogen = 28)

Sol. $C_p = 29.11 kJ/k\,mole\,K$

$C_v = 20.81 kJ/k\,mole\,K$

$m = 5\times10^{-3} kg$

$T_1 = 290K, T_2 = 310K$

$\Delta T = T_2 - T_1 = 310 - 290 = 20K$

Molecular weight (m) = 28

i) Change in internal energy (dU) = $\frac{m}{M}C_v dT$

$$= \frac{5\times10^{-3}}{28}\times20.81\times10^3\times20 = 74.32J$$

ii) External work done (dW) = dQ – dU

$$\frac{m}{M}C_p dT - dU = \frac{5\times10^{-3}}{28}\times29.11\times10^3\times20 - 74.32$$

$$= 103.96 - 74.32 = 29.64J$$

33. The specific heats of hydrogen at constant pressure and constant volume are 14.307 kJ/kg K and 10.183 kJ/kg K respectively. When one mole of hydrogen is cooled from 0ºC to – 20ºC find (i) the decrease in its internal energy and (ii) the ratio of the decrease in its internal energy to the total energy lost.

Sol. $C_p = 14.307 kJ/kg\,K$

$C_v = 10.183 kJ/kgK$

$n = 1 \Rightarrow m = 2$

$t_1 = 0°C; t_2 = -20°C \Rightarrow \Delta t = -20°C$

i) Change in internal energy = Heat supplied at constant volume

$dU = mC_v dT = 2\times10^{-3}\times10.183\times10^3\times-20 = -407.32J$

'-ve' sign represent the decrease in du

ii) Total energy lost = $mC_p dT = 2\times10^{-3}\times14.307\times20\times10^3 = 40\times14.307 = 572.28$

$$\frac{\text{Decrease in 'dU'}}{\text{Total energy lost}} = \frac{407.32}{572.28} = 0.7117$$

34. The molar heat capacities of oxygen at constant pressure and constant volume are 6.994 k cal/k mole K and 5.013 k cal k mole K respectively. When one kilo mole is heated from 290 K to 310 K Calculate (i) the external work done and (ii) the ratio of the external work done to the total energy gained. (J = 4200 J/k cal.)

Sol. $C_p = 6.994\,\text{k.cal/k.mole K}$

$C_p = 6.994\,\text{cal/mole K S}$

$C_v = 5.013\,\text{cal/mole K}$

$n = 1\,\text{kilo mole}$

$T_1 = 290\text{K}, T_2 = 310\,\text{K}$

$C_p - C_v = R \Rightarrow ndT\left(C_p - C_v\right) = nRdT$

i) $\therefore dW = ndT\left(C_p - C_v\right) = \left(6.994 - 5.013\right)\times10^3\times20\times1$

$dW = 1.981\times10^3\times20 = 39620\,\text{cal (or)}$

$= 39620\times4.2 = 166404 = 1.664\times10^5\,\text{Jou}$

ii) Total energy $\left(dQ\right) = nC_p dT\times J = 6.994\times10^3\times20\times4.2$

$= 5.8749\times10^5\,\text{J} = 5.875\times10^5$

$$\frac{dw}{dQ} = \frac{1.664\times10^5}{5.875\times10^5} = 0.2832$$

35. Two moles of air, when heated through 10K expands by an amount of $1.66\times10^{-3}m^3$ under a constant pressure of $10^5 N/m^2$. If C_v = 20.81 J/mole K, find C_p.

Sol. n = 2 mo**les;** $\Delta T = 10k$

$p = 10^5\,\text{N/m}^2; C_v = 20.81\,\text{J/mole K}$

$dV = 1.66\times10^{-3}\,\text{m}^3, C_p = ?$

$\left(C_p - C_v\right) = R \Rightarrow ndT\left(C_p - C_v\right) = nRdT \Rightarrow ndT\left(C_p - C_v\right) = PdV$

$$C_p - C_v = \frac{PdV}{ndT} = \frac{10^5 \times 1.66 \times 10^{-3}}{2 \times 10} = \frac{16.6}{2} = 8.3$$

$$C_p = C_v + 8.3 = 20.81 + 8.3 = 29.11 J / mole\,K$$

36. Four moles of a perfect gas heated to increase its temperature by 2ºC absorbs heat of 40 cal at constant volume. If the same gas is heated at constant pressure find the amount of heat supplied. (R = 2 cal/ mole K.)

Sol. n = 4, $\Delta T = 2°C$

$$(dQ)_v = nC_v dT = 40\,cal$$

$$(dQ)_p = ?$$

R = 2 cal/mole K

$$(dQ)_v = du = nC_v dT = 4 \times C_v \times 2 = 40 \qquad \ldots\ldots\ldots\ldots(1)$$

$$(dQ) = nC_p dT, Q = 4 \times C_p \times 2 \qquad \ldots\ldots\ldots\ldots(2)$$

(2) – (1)

$$8C_p - 8C_v = Q - 40 \Rightarrow 8(C_p - C_v) = Q - 40$$

$$8 \times 2 = Q - 40 \Rightarrow Q = 40 + 16 = 56\,cal$$

37. The gas fitted in a cylinder fitted with a frictionless piston is heated. It expands by 1.670×10^{-3} m^3 under a constant pressure of 10^5 N/m^2. Find the external work done.

Sol. dv = 1.670×10^{-3} m^3

P = 10^5 N/m^2

dW = ?

External work dW = P dV $= 10^5 \times 1.670 \times 10^{-3} = 167J$

38. Five moles of hydrogen is heated through 20K under constant pressure. If R = 8.312 J/mole K, find the external work done.

Sol. n = 5; dT = 20 k

P – Constant

R = 8.312 J/mole K

External work (dW) = pdV = nRdT = 5×8.312×20 = 831.2 J

39. Find the external work done by the system in k cal when 20 k cal of heat is supplied to the system the increase in its internal energy is 8400 J. (J = 4200 J/k cal)

Sol. External work done (dW) = ?

$$dU = 8400J = \frac{8400}{4200} = 2k\,cal$$

$$dQ = 20\,k.cal = 20\,k.cal$$

According to 1st law of thermodynamics

$$dQ = dU + dW \Rightarrow dW = dQ - dU$$

$$dW = 20 - 2 = 18\,k.cal$$

40. Heat of 30 k cal is supplied to a system and 4200 J of external work is done on the system so that its volume decreases at constant pressure. What is the change in its internal energy ? (J = 4200 J/k cal).

Sol. $dQ = 30$ k.cal $= 30\times10^3$ cal

External work done (dW) = 4200 J

V – Decreases at constant 'P'

dU = ?

We know

$$dQ = dU + dW \Rightarrow dU = dQ - dW = dU - (dW)$$

$$dU = 30 + \frac{4200}{4200}\,k.cal$$

$$dU = 31\,k.cal = 31\times4200 = 130200J = 1.302\times105J$$

41. The volume of 1 kg of hydrogen gas at N.T.P is 11.2 m^3. Specific heat of hydrogen at constant volume is 10046 $Jkg^{-1}\,K^{-1}$. Find the specific heat at constant pressure.

Sol. m = 1 kg

Volume at NTP = 11.2 m^3

$C_v = 10046\ Jkg^{-1}\,k^{-1}$

C_p = ?

$P = 1.013\times10^5\ N/m^2$

T = 273 K

Density $(\rho) = \frac{m}{V} = \frac{1}{11.2} = 0.0893$

$C_p - C_v = \frac{R}{m} = \frac{P}{\rho T}$

$C_p - C_v = \frac{1.013 \times 10^5}{0.0893 \times 273} = 4155.2$

$C_p = 10046 + 4155.2 = 14201.2\,J/kg.K$

42. A gas at 10°C temperature and 1.013×10^5 Pa pressure in compressed adiabatically to half of its volume. If the ratio of specific heats of the gas is 1.4, what is the final temperature?

Sol. $t_1 = 10°C \Rightarrow T_1 = 273 + 10 = 283K$

$P = 1.013 \times 10^5 Pa$

$V_1 = V \Rightarrow V_2 = \frac{V}{2}$

$\gamma = 1.4, T_2 = ?$

In Adiabatic process $TV^{\gamma-1} = Constant$

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

$283(V)^{\gamma-1} = T_2 \left(\frac{V}{2}\right)^{\gamma-1}$

$283 = T_2 \times \frac{1}{2^{\gamma-1}}$

$T_2 = 283 \times 2^{1.4-1} 283 \times 2^{0.4} = 491.1K$

Final temperature $t_2 = 491 - 1 = 273 = 219.1°C$

43. Find the work done by a gas when it expands isothermally at 37°C to four times its initial volume.

Sol. $V_1 = V, V_2 = 4V$

$T_1 = 37° + 273 = 310\ K$

In isothermal process

Work done $dW = 2.303RT \log \frac{V_2}{V_1}$

$$dW = 2.303 \times 8.314 \times 310 \log \frac{4V}{V}$$

$$= 5935.61 \times \log 4 = 5935.61 \times 0.6021 = 3573.83 J$$

44. At 27ºC and pressure of 76 cm of Hg the volume of a diatomic gas is 2000 cm^3. If it is compressed adiabatically to a volume of 1000 cm^3, what are its pressure and temperature?

Sol. $T_1 = 27 + 273 = 300$ K

$T_2 = ?$

$P_1 = 76$ cm of Hg

$V_1 = 2000\ cm^3$

$V_2 = 1000\ cm^3$

$P_2 = ?,\ \gamma = 1.4 (\text{for di})$

In adiabatic process PV^y = constant

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

$$P_2 = P_1 \left(\frac{V_1}{V_2} \right)^{1.4} = 76 \times \left(\frac{2000}{1000} \right)^{1.4}$$

$$P_2 = 76 \times 2^{1.4}$$

$$P_2 = 200.5\, cmHg$$

$$TV^{\gamma - 1} = constant$$

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

$$T_2 = T_1 \left(\frac{V_1}{V_2} \right)^{\gamma - 1} = 300 \times 2^{0.4} = 300 \times 2^{2/5}$$

$$T_2 = 122.9°C$$

45. Find the efficiency of a heat engine if the temperature of the source is 100ºC and sink is 27ºC.

Sol. $T_1 = 1000 + 273 = 373K, T_2 = 27 + 273 = 300K$

Efficiently $(n) = 1 - \frac{T_2}{T_1}$

$$\eta = 1 - \frac{300}{373} = \frac{73}{373} = 0.1957$$

46. 50g of steam at 100ºC is passed into 250g of ice at 0ºC. Find the resultant temperature if latent heat of steam is 540 cal/g. Latent heat of ice is 80 cal/g and specific heat of water is 1 cal / gºC.

Sol. Mass of steam (m_s) = 50gr

t_2 = 100ºC

Mass of ice (m_c) = 250gr

t_1 = 0ºC

Resultant temperature = t = ?

$L_{steam} = 540 cal/gr$

$L_{ice} = 80 cal/gr$

$S_{water} = 1 cal/g°C$

According to method of mixtures

$$m_s L_s + m_s S(100 - t) = m_C L_C + m_s S(t - 0)$$

$$50 \times 540 + 50 \times 1(100 - t) = 250 \times 80 + 250 \times 1 \times t$$

$$27000 + 5000 - 50t = 20000 + 250t$$

$$300t = 12,000$$

$$t = \frac{12000}{300} = 40°C$$

47. 1g of steam at 100ºC is passed into a calorimeter of water equivalent 10g containing water of mass 90g. Find the resultant temperature of the mixture if the initial temperature of water is 27ºC.

Sol. mass of steam (m) = 1 gr

Find temperature = 100ºC

Initial temperature = 27ºC

Mass of water = 90gr

t = resultant temperature = ?

Heat loss by steam = heat gained by water.

$$mL + m_s(100 - t) = m_w s(t - 27)$$

$$1 \times 540 + 1 \times 1(100 - t) = 90 \times 1 \times (t - 27)$$

$$540 + 100 - t = 90(t - 27) = 90t - 90 \times 27$$

$$91t = 3070 \Rightarrow t = \frac{3070}{91} = 33.74°C$$