

Unit - 8

Thermodynamics

THERMOMETRY, THERMAL EXPANSION AND CALORIMETRY

8.1 Heat

The energy associated with configuration and random motion of the atoms and molecules within a body is called heat.

- (1) Units : Joule (S.I.) and calorie (Practical unit)
- (2) The ratio of work done (W) to heat produced (Q) is constant.

$$\frac{W}{Q} = J \text{ or } W = JQ$$

J is called mechanical equivalent of heat and has value 4.2 J/cal.

$$1 \text{ calorie} = 4.186 \text{ Joule} = 4.12 \text{ Joule}$$

- (3) Heat is a path dependent and is taken to be positive if the system absorbs it and negative if releases it.

8.2 Temperature

Temperature is defined as the degree of hotness or coldness of a body. Heat flows from higher temperature to lower temperature.

Two bodies are said to be in thermal equilibrium when both the bodies are

at the same temperature. Temperature \propto kinetic energy $\left[\text{As } E = \frac{3}{2} RT \right]$

8.3 Scales of Temperature

The Kelvin temperature scale is also known as thermodynamic scale. The S.I. unit of temperature is kelvin and is defined as $(1/273.16)$ of the temperature of the triple point of water. The triple point of water is that point on a P-T diagram where the three phases of water, the solid, the liquid and the gas,

can coexist in thermal equilibrium.

To construct a scale of temperature, two fixed points are taken. First is the freezing point of water, it is called lower fixed point. The second is the boiling point of water, it is called upper fixed point.

Name of the scale	Symbol for each degree	Lower fixed point (LFP)	Upper fixed point (UFP)	Number of divisions on the scale
Celsius	°C	0°C	100°C	100
Fahrenheit	°F	32°F	212°F	180
Reaumer	°R	0°R	80°R	80
Rankine	°Ra	460 Ra	672 Ra	212
Kelvin	K	273.15 K	373.15 K	100

Temperature on one scale can be converted into other scale by using the following identity.

$$\frac{\text{Reading on any scale} - \text{Lower fixed point (LFP)}}{\text{Upper fixed point (UFP)} - \text{Lower fixed point (LFP)}} = \text{Constant for all scales}$$

8.4 Thermal Expansion

When matter is heated, it expands.

(i) Coefficient of linear expansion $\alpha = \frac{\Delta L}{L} \times \frac{1}{\Delta T}$

(ii) Coefficient of superficial expansion $\beta = \frac{\Delta A}{A} \times \frac{1}{\Delta T}$

(iii) Coefficient of volume expansion $\gamma = \frac{\Delta V}{V} \times \frac{1}{\Delta T}$

(iv) The value of α , β and γ depends upon the nature of material. All have dimension $[\theta^{-1}]$ and unit per °C.

(v) $\Delta L = L\alpha\Delta T$, $\Delta A = A\beta\Delta T$ and $\Delta V = V\gamma\Delta T$

(vi) Final length $L' = L + \Delta L = L(1 + \alpha\Delta T)$

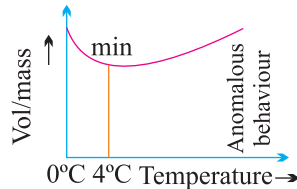
Final area $A' = A + \Delta A = A(1 + \beta\Delta T)$

Final volume $V' = V + \Delta V = V (1 + \gamma \Delta T)$

(vii) $\beta = 2 \alpha$ and $\gamma = 3 \alpha$

8.5 Anomalous Expansion of Water

- (1) In case of water, it expands on heating if its temperature is greater than 4°C. In the range 0°C to 4°C water contracts on heating and expands on cooling, *i.e.*, negative.



- (2) At 4°C, density of water is maximum while its specific volume is minimum.

8.6 Expansion of Gases

Gases have no definite shape, therefore gases have only volume expansion.

8.7 Thermal Capacity and Water Equivalent

- (1) **Thermal capacity** : It is defined as the amount of heat required to raise the temperature of the whole body (mass, m) through 1°C or 1 K.

$$\text{Thermal capacity} = m c = \mu C = \frac{Q}{\Delta T}$$

Dimension : $[ML^2T^{-2}\theta^{-1}]$, Unit : call °C (practical) Joule K (S.I.)

- (2) **Water Equivalent** : Water equivalent of a body is defined as the mass of water which would absorb or evolve the same amount of heat as is done by the body in rising or falling through the same range of temperature. It is represented by W .

If m = Mass of the body, c = Specific heat of body

$$\therefore \text{Water equivalent (W)} = mc \text{ gm}$$

8.8 Specific Heat

- (1) **Gram specific heat** : The heat required to raise the temperature of one gram mass of a body through 1°C (or 1 K) is called gram specific heat of the material of the body.

$$\text{specific heat, } c = \frac{Q}{m\Delta T}$$

Units : Calorie/ $gm^{\circ}C$ (Practical), J/kg K(S.I.)

Dimension : $[L^2T^{-2}\theta^{-1}]$

- (2) **Molar specific heat** : Amount of heat required to raise the temperature of one gram mole of the substance through a unit degree it is represented by (capital) C.

$$\therefore C = \frac{Q}{\mu\Delta T}$$

Units : Cal $\text{mol}^{-1} \text{ }^{\circ}C^{-1}$ (Practical), J $\text{mol}^{-1} \text{ K}^{-1}$ (S.I.)

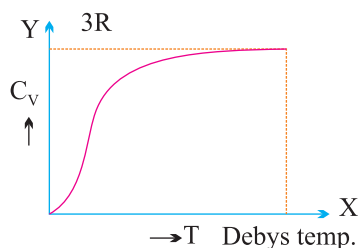
Dimension : $[ML^2T^{-2}\theta^{-1}\mu^{-1}]$

8.9 Specific Heat of Solids

Specific heat of a solid is specific heat at constant volume C_v .

With rise in temperature, C_v increases and becomes constant = $3R$

Dulong and Petit law : Average molar specific heat of all metals at room temperature is constant and is equal to $3R$. This statement is known as Dulong and Petit law.



8.10 Latent Heat

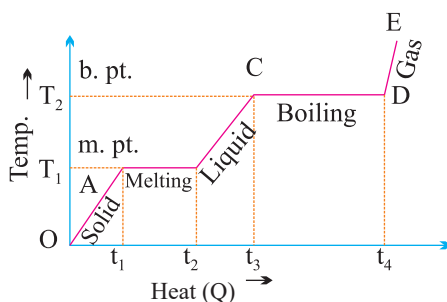
- (1) When a substance changes from one state to another state then energy is either absorbed or liberated. This heat energy is called latent heat.
- (2) No change in temperature is involved when the substance changes its state.
- (3) $\Delta Q = mL$, where L is the latent heat.
- (4) Unit : cal/gm or J kg and Dimension : $[L^2T^{-2}]$
- (5) Any material has two types of latent heats
 - (i) **Latent heat of fusion** : The heat required to change 1 kg of the material in its solid state to its liquid state, latent heat of fusion (or latent heat of ice) is $L_F = L_{ice} \approx 80 \text{ cal/g}$.

- (ii) **Latent heat of vaporisation** : The heat energy required to change 1 kg of the material in its liquid to 1 kg of the material in its gaseous state. Latent heat of vaporisation (latent heat of steam) is $L_v = L_{\text{steam}} \approx 540 \text{ cal/gm}$.

8.11 Principle of Calorimetry

Heat lost = Heat gained

i.e., principle of calorimetry represents the law of conservation of heat energy.



8.12 Heating Curve

Thermodynamic Processes

- (1) **Thermodynamics** : It is a branch of science which deals with exchange of heat energy between bodies and conversion of the heat energy into mechanical energy and vice versa.
- (2) **Thermodynamic system** : A collection of an extremely large number of atoms or molecules confined within certain boundaries such that it has a certain value of pressure, volume and temperature is called a thermodynamic system. Anything outside the thermodynamic system to which energy or matter is exchanged is called its surroundings.

Thermodynamic system may be of three types :

- (i) **Open system** : It exchanges both energy and matter with the surrounding.
- (ii) **Closed system** : It exchanges only energy (not matter) with the surroundings.
- (iii) **Isolated system** : It exchanges neither energy nor matter with the surrounding.

- (3) **Thermodynamic variables and equation of state :** Pressure, volume, temperature, internal energy and the number of moles are called thermodynamic variables.

For μ moles of an ideal gas, equation of state is $PV = \mu RT$.

Thermodynamic State Variables :

- (i) Intensive variables
- (ii) Extensive variables.

8.13 Zeroth Law of Thermodynamics

If systems A and B are each in thermal equilibrium with a third system separately C, then A and B are in thermal equilibrium with each other.

The zeroth law leads to the concept of temperature.

8.14 Quantities Involved in First Law of Thermodynamics

- (1) **Heat (ΔQ) :** It is the energy that is transferred between a system and its environment.

- (i) Heat is a form of energy so it is a scalar quantity with dimension $[ML^2T^{-2}]$.
- (ii) Unit : Joule (S.I.), Calorie (1 calorie = 4.2 Joule)
- (iii) Heat is a path dependent quantity.
- (iv) $\Delta Q = mL$ [For change in state] and $\Delta Q = mc\Delta T$ [For change in temperature]

$(\Delta Q)_v = \mu C_v \Delta T$ [For constant volume] and $(\Delta Q)_p = \mu C_p \Delta T$ [For constant pressure]

- (2) **Work (ΔW) :**

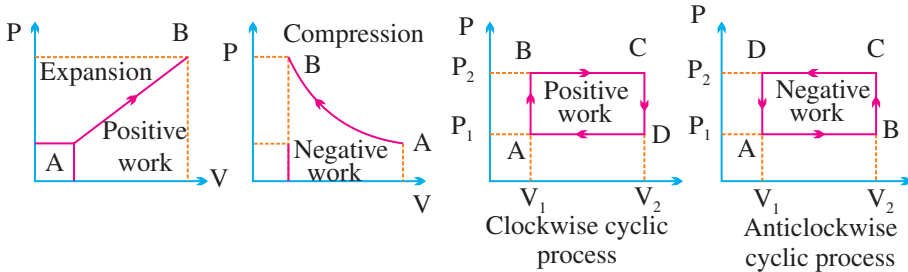
$$\therefore \text{Work done } \Delta W = \int dW = \int_{V_i}^{V_f} p dV = P(V_f - V_i)$$

- (i) Like heat, work is also a path dependent, scalar physical quantity with dimension $[ML^2T^{-2}]$
- (ii) $\Delta W =$ positive if $V_f > V_i$ i.e., system expands
 $\Delta W =$ negative if $V_f < V_i$ i.e., system contracts

(iii) $W = \text{area under } P - V \text{ diagram}$

It is positive if volume increases (for expansion)

It is negative if volume decreases (for compression)



It is positive if the cycle is clockwise.

It is negative if the cycle is anticlockwise.

(3) Internal energy (U) : Internal energy of a system is the energy due to molecular motion and molecular configuration.

The energy due to molecular motion is called internal kinetic energy U_k and that due to molecular configuration is called internal potential energy U_p .

i.e., Total internal energy $U = U_k + U_p$

(i) Internal energy of an ideal gas is totally kinetic $U = U_k = \frac{3}{2} \mu RT$

(ii) In case of gases whatever be the process

$$\Delta U = \int P \, dV$$

(iii) Change in internal energy does not depend on the path.

$$\Delta U = U_f - U_i$$

(iv) Change in internal energy in a cyclic process is always zero.

8.15 First Law of Thermodynamics

It is a statement of conservation of energy. According to it $\Delta Q = \Delta U + \Delta W$

(1) First law introduces the concept of internal energy.

(2) Sign conventions

ΔQ	Positive	When heat is supplied to a system
	Negative	When heat is drawn from the system
ΔW	Positive	When work done by the gas (expansion)
	Negative	When work done on the gas (compression)
ΔU	Positive	When temperature increases, internal energy increases
	Negative	When temperature decreases, internal energy decreases

- (3) **Limitation** : First law of thermodynamics does not indicate the direction of heat transfer. It does not tell anything about the conditions, under which heat can be transformed into work and also it does not indicate as to why the whole of heat energy cannot be converted into mechanical work continuously.

8.16 Isothermal Process

In this process, P and V change but $T = \text{constant}$ *i.e.*, change in temperature $\Delta T = 0$.

(1) Condition for isothermal process :

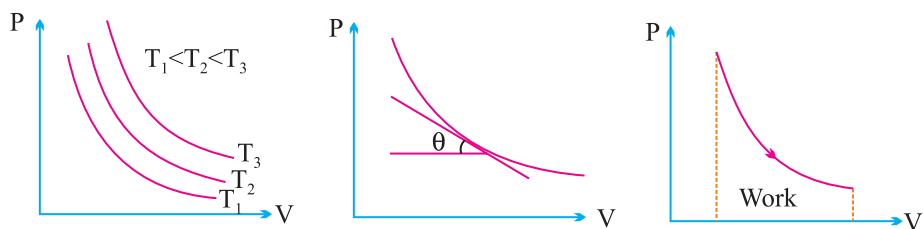
- The walls of the container must be perfectly conducting.
- The speed of process should be very slow.

- (2) **Equation of state** : In all isothermal process Boyle's law is obeyed. Hence equation of state is $PV = \text{constant}$.

(3) Example of isothermal process :

- Melting process [Ice melts at constant temperature 0°C]
- Boiling process [water boils at constant temperature 100°C]

(4) Indicator diagram



$$(5) \quad \text{Work done } W = \mu RT \log_e \left(\frac{V_f}{V_i} \right) = 2.303 \mu RT \log_{10} \left(\frac{V_f}{V_i} \right)$$

$$W = \mu RT \log_e \left(\frac{P_i}{P_f} \right) = 2.303 \mu RT \log_{10} \left(\frac{P_i}{P_f} \right)$$

(6) **Heat supplied in isothermal process :** $\Delta Q = \Delta W$ *i.e.*, heat supplied is used to do work against external surrounding.

8.17 Adiabatic Process

In this process P, V and T changes but $\Delta Q = 0$.

(1) **Essential conditions for adiabatic process :**

- (i) All walls of the container and the piston must be perfectly insulating.
- (ii) The speed of process should be fast.

(2) **Example of some adiabatic process :**

- (i) Sudden bursting of the tube of bicycle tyre.
- (ii) Propagation of sound waves in air and other gases.

(3) **Energy in adiabatic process :** For adiabatic process

$$\Delta Q = 0, \therefore \Delta U + \Delta W = 0$$

If $\Delta W =$ positive then $\Delta U =$ negative *i.e.*, adiabatic expansion produce cooling.

If $\Delta W =$ negative then $\Delta U =$ positive *i.e.*, adiabatic compression produce heating.

(4) **Equation of state :**

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

It can also be re-written as

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

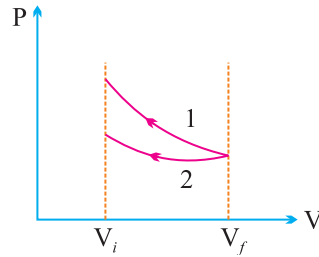
and
$$\frac{T^\gamma}{P^{\gamma-1}} = \text{constant}$$

(5) **Indicator diagram :**

- (i) Curve obtained on PV graph are called adiabatic curve.

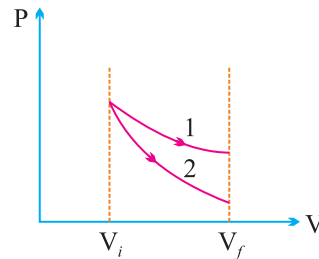
(ii) Slope of adiabatic curve

$$\tan \phi = -\gamma \left(\frac{P}{V} \right)$$



(6) Work done :

$$W = \frac{[P_i V_i - P_f V_f]}{(\gamma - 1)} = \frac{\mu R (T_i - T_f)}{(\gamma - 1)}$$



(7) **Free expansion :** Free expansion is adiabatic process in which no work is performed on or by the system. The final and initial energies are equal in free expansion.

8.18 Reversible and Irreversible Process

(1) **Reversible process :** A reversible process is one which can be reversed in such a way that all changes occurring in the direct process are exactly repeated in the opposite order and inverse sense. The conditions for reversibility are :

- (i) There must be complete absence of dissipative forces. (friction, viscosity etc.)
- (ii) The speed of process should be infinitely slowly.
- (iii) The temperature of the system must not differ appreciably from its surroundings.

Examples of reversible process are :

- (a) All slow isothermal and adiabatic changes are reversible.

- (b) Very slow evaporation or condensation.
- (2) **Irreversible process** : Any process which is not reversible exactly is an irreversible process. Examples of irreversible processes are :
- (i) Sudden expansion or contraction
 - (ii) Heat transfer between bodies

8.19 Cyclic and Non-cyclic Process

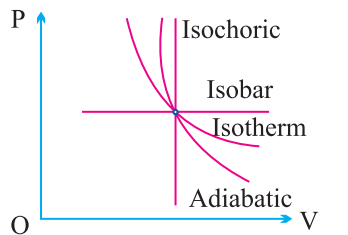
A cyclic process consists of a series of changes which return the system back to its initial state.

In non-cyclic process the series of changes involved do not return the system back to its initial state.

- (1) In cyclic process change in internal energy is zero and temperature of system remains constant.
- (2) Heat supplied is equal to the work done by the system.
- (3) For cyclic process P–V graph is a closed curve and area enclosed by the closed path represents the work done.

If the cycle is clockwise work done is positive and if the cycle is anticlockwise work done is negative.

8.20 Graphical Representation of Various Processes



Heat engine is a device which converts heat into work continuously through a cyclic process.

The essential parts of a heat engine are :

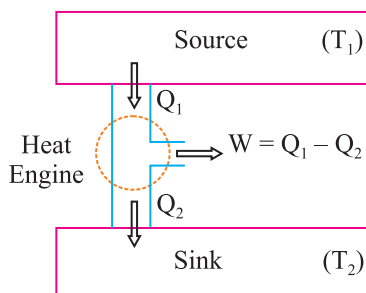
Source : Working substance : Steam, petrol etc.

Sink : “efficiency” η is given by

$$\eta = \frac{\text{Work done}}{\text{Heat input}} = \frac{W}{Q_1}$$

also

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



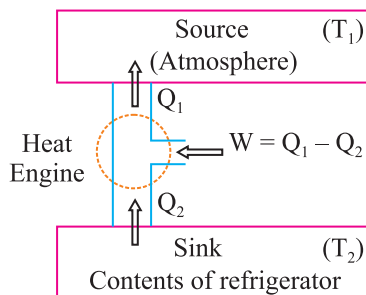
A perfect heat engine $\eta = 1$. Practically efficiency is always less than 1.

8.21 Refrigerator or Heat Pump.

A refrigerator or heat pump is basically a heat engine run in reverse direction.

It essentially consists of three same parts.

The performance of a refrigerator is expressed by means of “coefficient of performance” β which is defined as the ratio of the heat extracted from the cold body to the work needed to transfer it to the hot body.



i.e.,

$$\beta = \frac{\text{Heat extracted}}{\text{work done}} = \frac{Q_2}{W} = \frac{Q_2}{Q_1 - Q_2}$$

A perfect refrigerator

$W = 0$ so that $Q_1 = Q_2$ and hence $\beta = \infty$.

(1) Carnot refrigerator :

$$\text{For carnot refrigerator} = \frac{Q_1}{Q_2} = \frac{T_1}{T_2}$$

$$\text{coefficient of performance } \beta = \frac{T_2}{T_1 - T_2}$$

where T_1 = temperature of surrounding, T_2 = temperature of cold body

- (2) Relation between coefficient of performance and efficiency of refrigerator

$$\beta = \frac{1-\eta}{\eta}$$

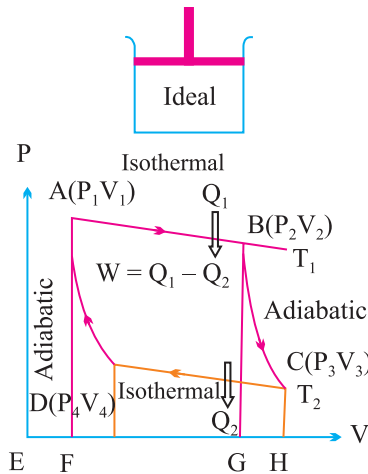
8.22 Second Law of Thermodynamics

- (1) **Clausius statement** : It is impossible for a self acting machine to transfer heat from a colder body to a hotter one without the aid of an external agency.
- (2) **Kelvin's statement** : It is impossible for a body or system to perform continuous work by cooling it to a temperature lower than the temperature of the coldest one of its surroundings.
- (3) **Kelvin-Planck's statement** : It is impossible to design an engine that extracts heat and fully utilises into work without producing any other effect.

8.23 Carnot Engine

Carnot designed a theoretical engine. This engine cannot be realised in actual practice.

- (1) **Carnot cycle** : The working substance of the engine undergoes a cycle known as Carnot cycle. It consists of the following four strokes.
- (i) Isothermal expansion :



- (ii) Adiabatic expansion :
- (iii) Isothermal compression :
- (iv) Adiabatic compression :

(2) Efficiency of Carnot cycle :

$$\eta = \frac{\text{Work done}}{\text{Heat input}} = \frac{W}{Q_1}; \eta = 1 - \frac{T_2}{T_1}, T_1 \text{ and } T_2 \text{ are in Kelvin.}$$

- (i) Efficiency of a heat engine depends only on temperatures.
- (ii) Efficiency of a heat engine is always lesser than unity, *i.e.*, whole of heat can never be converted into work which is in accordance with second law.

(3) **Carnot theorem** : Carnot's reversible engine working between two given temperature is considered to be the most efficient engine.

TRANSMISSION OF HEAT

8.24 Introduction

The transfer of heat from one body to another may take place by one of the following modes.

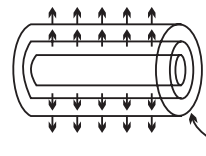
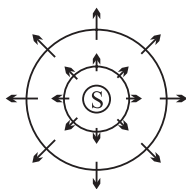
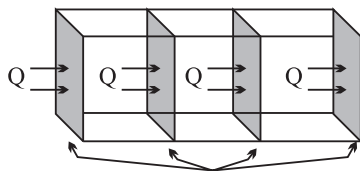
Conduction	Convection	Radiation
Heat flows from hot end to cold end. Particles of the medium simply oscillate but do not leave their place.	Each particle absorbing heat is mobile.	Heat flows without any intervening medium in the form of electromagnetic waves.
Medium is necessary for conduction.	Medium is necessary for convection.	Medium is not necessary for radiation.
It is a slow process.	It is also a slow process.	It is a very fast process.
Path of heat flow may be zig-zag.	Path may be zig-zag or curved.	Path is a straight line.
Conduction takes place in solids.	Convection takes place in fluids.	Radiation takes place in gaseous and transparent media.
The temperature of the medium increases through which heat flows.	In this process also the temperature of medium increases.	There is no change in the temperature of the medium.

8.25 Conduction

(1) **Variable and steady state** : If temperature of every cross-section of the rod goes on increasing, hence rod is said to exist in variable state.

The state of the rod in which no part of rod absorbs heat is called steady state. (Temperature of every cross-section of the rod remains constant.)

(2) **Isothermal surface** : Any surface having its all points at the same temperature, is called isothermal surface.



Plane Isothermal surfaces

Spherical Isothermal surfaces

Cylindrical Isothermal surfaces

(3) **Temperature Gradient** : The rate of change of temperature with distance between two isothermal surface is called temperature gradient.

$$\text{Temperature gradient} = \frac{(\theta - \Delta\theta) - \theta}{\Delta x} = \frac{-\Delta\theta}{\Delta t}$$

The negative sign show that temperature θ decreases as the distance x increases in the direction of heat flow.

(4) **Coefficient of thermal conductivity** : If L be the length of the rod, A the area of cross-section and θ_1 and θ_2 are the temperature of its two faces, then the amount of heat flowing from one face to the other face in time

$$t \text{ is given by } Q = \frac{KA(\theta_1 - \theta_2)t}{l}$$

Where K is coefficient of thermal conductivity of material of rod.

(i) Units = $\text{Js}^{-1}\text{m}^{-1}\text{k}^{-1}$ or $\text{Wm}^{-1}\text{k}^{-1}$ (S.I.) CGS unit = $\text{cal s}^{-1} \text{cm}^{-1} \text{°C}^{-1}$

(ii) Dimension : $[\text{MLT}^{-3}\theta^{-1}]$

(iii) The magnitude of K depends only on nature of the material.

(iv) For perfect conductors, $K = \infty$ and for perfect insulators, $K = 0$

(v) The thermal conductivity of pure metals decreases with rise in temperature but for alloys thermal conductivity increases with increase of temperature.

(vi) Human body is a bad conductor of heat.

8.26 Combination of Conductors

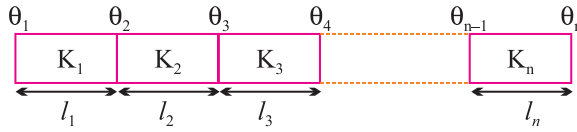
(1) **Series combination** : Let n slabs each of cross-sectional area A are connected in the series Heat current is the same in all the conductors.

$$\text{i.e., } \frac{Q}{t} = H_1 = H_2 = H_3 \dots\dots\dots = H_n$$

(i) Equivalent resistance $R = R_1 + R_2 + R_3 + \dots\dots\dots R_n$

(ii) If K_s is equivalent conductivity,

$$\therefore \text{then } K_s = \frac{l_1 + l_2 + l_3 + \dots + l_n}{\frac{l_1}{K_1} + \frac{l_2}{K_2} + \frac{l_3}{K_3} + \dots + \frac{l_n}{K_n}}$$



(2) **Parallel Combination** : Let n slabs each of length/are connected in parallel then.

(i) Equivalent resistance $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n}$

(ii) Temperature gradient across each slab will be same.

(iii) Heat current in each slab will be different.

$$\therefore K = \frac{K_1 A_1 + K_2 A_2 + K_3 A_3 + \dots + K_n A_n}{A_1 + A_2 + A_3 + \dots + A_n}$$

8.27 Convection

Mode of transfer of heat by means of migration of material particles of medium is called convection. It is of two types.

(1) **Natural convection** : This arise due to difference of densities at two places on account of gravity.

(2) **Forced convection** : If a fluid is forced to move then it is called forced convection. In this case Newton's law of cooling holds good. According to which rate of loss of heat from a hot body is directly proportional to the surface area of body and excess temperature of body over its surroundings.

$$i.e., \frac{Q}{t} \propto A(T - T_0)$$

where T = Temperature of body and T_0 = Temperature of surrounding

(i) Natural convection takes place from bottom to top while forced convection in any direction.

(ii) Natural convection is not possible in a gravity free region such as a free falling lift or an orbiting satellite.

8.28 Radiation

The process of the transfer of heat from one place to another place without heating the intervening medium is called radiation.

Properties of thermal radiation

- (1) Thermal radiations are also called infra-red radiations.
- (2) Medium is not required for the propagation of radiations.
- (3) Every body whose temperature is above zero Kelvin emits thermal radiation.
- (4) Their speed is equal to that of light.
- (5) They follow laws of reflection refraction, interference diffraction and polarisation.

QUESTIONS

1. Why spark is produced when two substances are struck hard against each other?
2. What is the specific heat of a gas in an isothermal process ?
3. On what factors, does the efficiency of Carnot engine depend ?
4. What are two essential features of Carnot's ideal heat engine ?
5. Plot a graph between internal energy U and Temperature (T) of an ideal gas.
6. Refrigerator transfers heat from cold body to a hot body. Does this violate the second law of thermodynamics ?
7. Is it possible to increase the temperature of gas without giving it heat ?
8. Can the specific heat of a gas be infinity ?
9. Out of the parameters : temperature, pressure, work and volume, which parameter does not characterise the thermodynamics state of matter ?
10. Why a gas is cooled when expanded ?
11. Why does air pressure in car tyre increases during driving ?
12. Heat is supplied to a system, but its internal energy does not increase. What is the process involved ?
13. Under what ideal condition the efficiency of a Carnot engine be 100%.

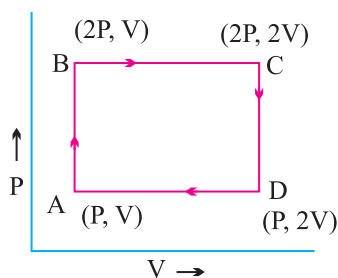
14. Which thermodynamic variable is defined by the first law of thermodynamics ?
15. Is coefficient of performance of a refrigerator a constant quantity ?
16. What is the efficiency of carnot engine working between ice point and steam point ?
17. Heat cannot flow itself from a body at lower temperature to a body at higher temperature is a statement or consequence of which law of thermodynamics ?
18. What is the specific heat of a gas in an adiabatic process ?

SHORT ANSWER TYPE QUESTIONS (2 MARKS)

19. Heat system based on circulation of steam are more efficient in warning a building than those based on circulation of hot water why ?
20. Write two limitation of the first law of thermodynamics.
21. Write the expressions for C_v and C_p of a gas in terms of gas constant R and γ where

$$\gamma = C_p / C_v$$

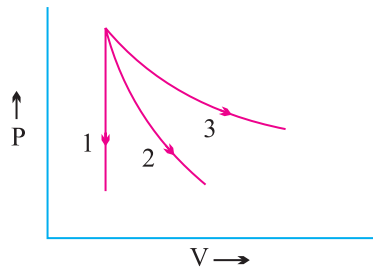
22. No real engine can have an efficiency greater that of a carnot engine working between the same low temperatures. Why ?
23. Why water at the base of a waterfall is slightly warmer than at the top ?
24. When ice melts, the change in internal energy is greater than the heat supplied. Why ?
25. Give two statements for the second law of thermodynamics.
26. An ideal monatomic gas is taken round the cycle ABCDA as shown. Calculate the work done during the cycle.



27. Can a room be cooled by opening the door of refrigerator in a closed room ?
28. Explain what is meant by isothermal and adiabatic operations.
29. Two bodies at different temperatures T_1 and T_2 , if brought in thermal contact do not necessarily settle to the mean temperature $(T_1 + T_2)/2$ Explain.

SHORT ANSWER TYPE QUESTIONS (3 MARKS)

30. Obtain an expression for work done in an isothermal process.
31. Identify and name the Thermodynamic processes 1, 2, 3 as shown in figure.



32. Two samples of gas initially at the same temperature and pressure are compressed from volume V to $V/2$ one sample is compressed isothermally and the other adiabatically in which case the pressure will be higher ? Explain ?
33. Explain briefly the principle of a heat pump. What is meant by coefficient of performance ?
34. (a) Why a gas has two principal specific heat capacities ?
(b) Which one is greater and why ?
(c) Of what significance is the difference between these two specific heat capacities and their ratio ?
35. Is it a violation of the second law of thermodynamics to convert
(a) Work completely into heat
(b) Heat completely into work
Why or why not ?
36. State first law of thermodynamics. On its basis establish the relation between two molar specific heat for a gas.

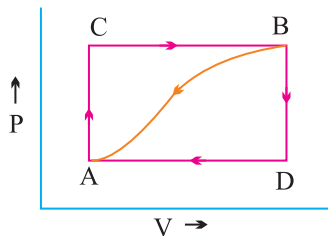
37. Explain briefly the working principle of a refrigerator and obtain an expression for its coefficient of performance.
38. State zeroth law of thermodynamics. How does it lead to the concept of temperature ?
39. What is a cyclic process ? Show that the net work done during a cycle process is numerically equal to the area of the loop representing the cycle.
40. A gas has two specific heats *i.e.*, C_p and C_v which one is greater and repeated why ?
41. What is an isothermal process ? Derive an expression for work done during an isothermal process.

LONG ANSWER TYPE QUESTIONS (5 MARKS)

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

NUMERICALS

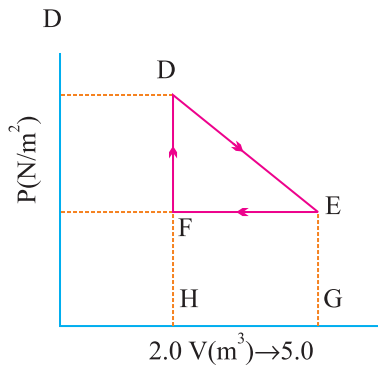
45. When a system is taken from state A to state B along the path ACB, 80 k cal of heat flows into the system and 30 k cal of work is done.
 - (a) How much heat flows into the system along path ADB if the work done is 10 k cal ?
 - (b) When the system is returned from B to A along the curved path the work done is 20 k cal. Does the system absorb or liberate heat.
 - (c) If $U_A = 0$ and $U_D = 40$ k cal, find the heat absorbed in the process AD



46. $\frac{1}{2}$ mole of helium is contained in a container at S.T.P. How much heat energy is needed to double the pressure of the gas, keeping the volume constant ? Heat capacity of gas is $3 \text{ J g}^{-1} \text{ K}^{-1}$.

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

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



48. What is the coefficient of performance (β) of a carnot refrigerator working between 30°C and 0°C ?
49. Calculate the fall in temperature when a gas initially at 72°C is expanded suddenly to eight times its original volume. ($\gamma = 5/3$)
50. Refrigerator is to maintain eatables kept inside at 9°C . If room temperature is 36°C calculate the coefficient of performance.
51. A perfect carnot engine utilizes an ideal gas the source temperature is 500 K and sink temperature is 375 K. If the engine takes 600 k cal per cycle from the source, calculate
- The efficiency of engine
 - Work done per cycle
 - Heat rejected to sink per cycle
52. Two carnot engines A and B are operated in series. The first one A receives heat at 900 K and reject to a reservoir at temperature T K.
- The second engine B receives the heat rejected by the first engine and in turn rejects to a heat reservoir at 400 K calculate the temperature T when
- The efficiencies of the two engines are equal
 - The work output of the two engines are equal

57. Consider two containers A and B containing identical gases at the same pressure, volume and temperature. The gas in container A is compressed to half of its original volume isothermally while the gas in container B is compressed to half of its original value adiabatically. The ratio of final pressure of gas in B that of gas in A is

- (a) $2^{\gamma-1}$ (b) $\left(\frac{1}{2}\right)^{\gamma-1}$
(c) $\left(\frac{1}{1-\gamma}\right)^2$ (d) $\left(\frac{1}{\gamma-1}\right)^2$

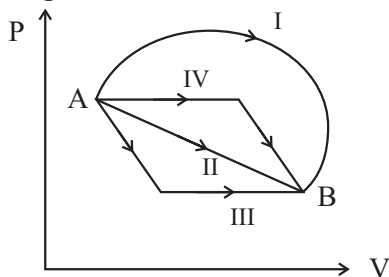
58. Which of the process described below are irreversible?

- (a) The increase in temperature of an iron rod by hammering it
(b) A gas in a small container at a temperature T_1 is brought in contact with a big reservoir at a higher Temperature. T_2 which inverses the temperature of the gas
(c) A quasi - state isothermal expansion of an ideal gas in cylinder fitted with a frictionless piston
(d) An ideal gas is enclosed in a piston cylinder arrangement with adiabatic Walls. A weight W is added to the piston, resulting in compression of a gas

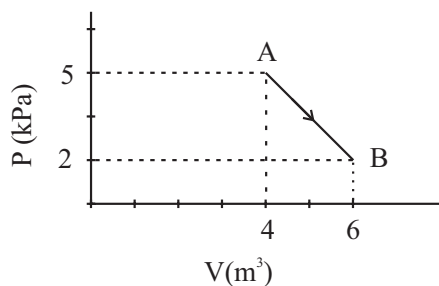
59. An ideal gas undergoes isothermal process from some initial state i to final state f. Choose the correct alternative

- (a) $dU = 0$ (b) $d\theta = 0$
(c) $d\theta = dU$ (d) $dw = dw$

60. Fig. shows the P-V diagram of an ideal gas undergoing a change of state from A to B. from different process I, II, III & IV as shown in figure may lead to the same change of state



- (a) Change in internal energy is same in IV and III cases but not in I and II
- (b) Change in internal energy is same in all the four cases
- (c) Work done is maximum is Case I
- (d) Work done is minimum in case II
61. A mono-atomic gas at a pressure P , having a volume V expand isothermally to a volume $2V$ and then adiabatically to a volume $16V$. The final pressure of the gas is ($\gamma = 5/3$)
- (a) $64 P$ (b) $32 P$
- (c) $P/64$ (d) $16 P$
62. One mole of an ideal diatomic gas undergoes a transition from A to B along a path AB as shown in fig. The change in internal energy of the gas during the transition is ($\gamma = \frac{3}{5}$)

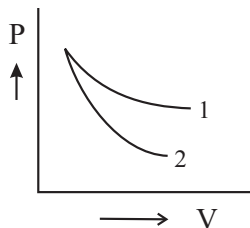


- (a) -20 KJ (b) 20 J
- (c) -12 KJ (d) 20 KJ
63. At 27°C two moles of an ideal mono-atomic gas occupy a volume V . The gas expands adiabatically to a volume $2V$. The final temperature of the gas is [Take $\gamma = \frac{5}{3}$]
- (a) 179 K (b) 189 K
- (c) 213 K (d) 219 K

64. In the above question, change in internal energy of the gas is

- (a) -2660.23 J (b) -2777.23 J
(c) -2767.23 J (d) -2600 J

65. P-V plots for two gases during adiabatic process are shown in fig. Plots 1 & 2 should correspond respectively to

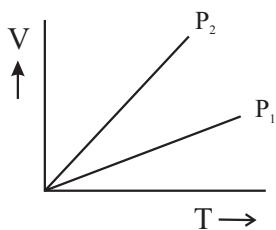


- (a) He and O_2 (b) O_2 and He
(c) He and Ar (d) O_2 and N_2

66. The work of 146 KJ is performed in order to compress one kilomole of a gas adiabatically, and in this process, the temperature of the gas increase by 7°C . The gas is

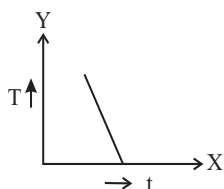
- (a) Triatomic (b) Monoatomic
(c) Diatomic
(d) Mixture of monoatomic & diatomic

67. In V-T diagram shown in fig., what is the relation between P_1 and P_2 ?

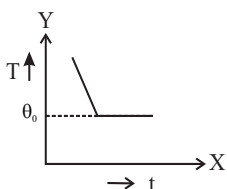


- (a) P_2 and P_1 (b) $P_2 > P_1$
(c) $P_2 < P_1$ (d) Cannot say

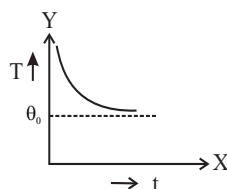
72. A Carnot engine, having an efficiency of $\eta = \frac{1}{10}$ as heat engine is used as a refrigerator. If the work done on the system is 10J the amount of energy absorbed from the reservoir at lower temperature is
- (a) 99 J (b) 90 J
(c) 1 J (d) 100 J
73. The door of a running refrigerator inside a room is left open. The correct statement out of the following ones is
- (a) The room will be cooled slightly
(b) The room will be warmed up gradually
(c) The room will be cooled to the temperature inside the refrigerator
(d) The temperature of the room will remain unaffected.
74. If Metal is heated to temperature θ and then allowed to cool in a room which is at temperature θ_0 , the graph between the temperature T of the metal and time t will be closest to :



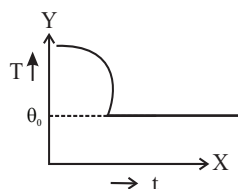
(a)



(b)



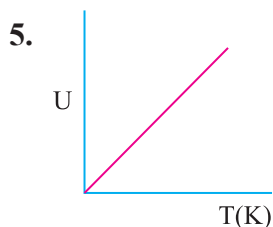
(c)



(d)

SHORT ANSWERS (1 MARK)

- Work is converted into heat.
- Infinite.
- $\eta = 1 - T_2/T_1$. On the temperature of sink and source.
- (i) Source and sink have infinite heat capacities.
(ii) Each process of the engine's cycle is fully reversible.



6. No, External work is done.
7. Yes, it happens during an adiabatic process.
8. Yes.
9. Work.
10. Decrease in internal energy.
11. $PV = nRT$
 $V = \text{constant}, T = \text{increases. So, } P \text{ also increases } P \propto T$
12. Isothermal expansion.
13. If the temperature of sink is zero kelvin.
14. Internal energy.
15. No. As the inside temperature of the refrigerator decreases, its coefficient of performance decreases.
16. $\eta = 1 - T_2/T_1 = 1 - 273/373 = 26.8\%$
17. Second law of thermodynamics.
18. Zero.

SHORT ANSWERS (2 MARKS)

19. Because steam at 100°C has more heat than water at 100°C .
20. (i) It does not give the direction of flow of heat.
 (ii) It does not explain why heat cannot be spontaneously converted into work.

21.
$$\gamma = C_p/C_v$$

$$C_p - C_v = R$$

$$C_p = \gamma C_v$$

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

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

22. In carnot engine.

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

(ii) Working substance is an ideal gas

In real engine these condition cannot be fulfilled.

23. Potential energy converted into kinetic energy, some part of kinetic energy is converted into heat.

24. $dq = du + dw$

$$du = dq - pdv.$$

26. PV

27. No, It is a violates seconds law.

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

Isothermal Process : Pressure, volume changes temperature remain constant.

29. Heat flows from higher temperature to lower temperature until the temperature become equal.

Two bodies

$$m_1 = \text{mass of 'A'} \quad \boxed{T_1} \quad \boxed{T_2} \quad m_2 = \text{mass of 'B'}$$

$$c_1 = \text{specific heat of A} \quad c_2 = \text{specific heat of B}$$

Let $T_1 > T_2$ Heat will be lost by 'A' and gained by 'B' According to principle of calorimetry,

$$\text{Heat lost} = \text{Heat gained}$$

Let their common temperature attained be 'T',

$$m_1 c_1 (T_1 - T) = m_2 c_2 (T - T_2)$$

$$m_1 c_1 T_1 - m_1 c_1 T = m_2 c_2 T - m_2 c_2 T_2$$

$$m_1 c_1 T_1 + m_2 c_2 T_2 = (m_1 c_1 + m_2 c_2) T$$

$$T = \frac{m_1 c_1 T_1 + m_2 c_2 T_2}{(m_1 c_1 + m_2 c_2)}$$

It is possible only,

If $m_1 = m_2 = m$, $C_1 = C_2 = C$,

$$T = \frac{T_1 + T_2}{2}.$$

45. (a) $dw_{ADB} = +10 \text{ k cal}$

Internal energy is path independent

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

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

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

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

$$\begin{aligned} dQ_{BA} &= du_{BA} + dw_{BA} \\ &= -50 - 20 = -70 \text{ k cal} \end{aligned}$$

(c) $U_A = 0, U_D = 40 \text{ k cal}$

$$du_{AD} = 40 \text{ k cal}$$

$$dw_{ADB} = 10 \text{ k cal}$$

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

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

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

$$C_v = MC_v = 12 \text{ J/mole } k, M \rightarrow \text{Molecular mass}$$

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

$$\Delta T = 2T_1 - T_1 = 273 \text{ k}$$

$$\Delta Q = nC_v \Delta T = 1638 \text{ J}$$

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

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

$$= \text{Area of trapezium DEGHD} - \text{Area of rectangle EFHG}$$

$$= \text{Area of triangle DEF}$$

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

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

$$= 450 \text{ J.}$$

$$48. \beta = \frac{T_2}{T_1 - T_2} = \frac{273}{303 - 273} = 9.1$$

$$49. \quad T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$$

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

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

50. Here $T_1 = 273 + 36 = 309 \text{ K}$,

$$T_2 = 273 + 9 = 282 \text{ K}.$$

Coefficient of performance.

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

51. $T_1 = 500 \text{ K}$, $T_2 = 375 \text{ K}$

$Q_1 = \text{Heat absorbed} = 600 \text{ k cal}$

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

$$= 25\%$$

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

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

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

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

$$= 450 \text{ k cal}$$

52. $W_A = W_B$

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

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

$$Q_2 \left(1 - \frac{T_3}{T_2}\right) = Q_1 \left(1 - \frac{T_2}{T_1}\right)$$

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

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

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

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

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

$$\eta_A = \eta_B$$

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

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

$$= 600 \text{ k}$$

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

mass of gas = 10 mole

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

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

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

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

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

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

$$T_1 = 1873 \text{ k}$$

$$T_2 \text{ Remain constant } T_2 = 773 \text{ k}$$

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

(ii) T_1 remain constant = 1500°C

$$T_1 = 1500 + 273 = 1773 \text{ k}$$

T_2 is decreased by 100 *i.e.*, 400°C

$$T_2 = 400 + 273 = 673 \text{ k}$$

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

$$\eta_2 > \eta_1.$$

SOLUTION (MCQ)

55. (c) In curve 1, V is constant : It represents isochoric process. In curve 4, P is constant. It represents isobaric process. Out of curves 2 & 3, one is isothermal and other is adiabatic process. As slope of curve 2 is more than the slope of 3, therefore. Curve 2 represents adiabatic process.

56. (b) Work done by the gas is equal to area of rectangle ABCDA fig.
= $AB \times BC$

$$= (2V_0)P_0 = 2 P_0V_0$$

As the trace is anticlockwise, the work is done on the gas. Work done by the gas = $-2P_0V_0$

57. (a) When the compression is isothermal for gas in A $P_2 V_2 = P_1 V_1$

$$P_2 = \frac{P_1 V_1}{V_2} = P_1 = \frac{V_1}{V_1/2} = 2 P_1$$

For gas in B, when compression is adiabatic

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

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

$$\text{So } \frac{P_2}{P_1} = \frac{2^\gamma P_1}{2 P_1} = 2^{\gamma-1}$$

58. (a, b, d)

59. (a,d) In isothermal process $dU = 0$

From $d\theta = dU + dW$ when $dU = 0 \rightarrow d\theta = dW$

60. (b,c) From the given initial state A to final state B change in internal energy is same in all the four Cases as it is independent of the path from A to B.

As work done = area under P-V curve therefore, work done is maximum in Case I.

61. (c) If P_2 is pressure after isothermal expansion, then

$$P_2 V_2 = P_1 V_1 \quad ; \quad P_2 = P_1 \frac{V_1}{V_2} = P \times \frac{V}{2V} = \frac{P}{2}$$

If P_3 is pressure after adiabatic expansion, then

$$P_2 V_2^\gamma = P_3 V_3^\gamma$$

$$\begin{aligned} P_3 &= P_2 \left(\frac{V_2}{V_3} \right)^\gamma = \frac{P}{2} \left(\frac{2V}{16} \right)^{5/3} = \frac{P}{2} \left(\frac{1}{8} \right)^{5/3} \\ &= \frac{P}{2} \left(\frac{1}{2^3} \right)^{5/3} = \frac{P}{2} \times \frac{1}{2^5} = \frac{P}{64} \end{aligned}$$

62. (a) Change in internal energy

$$\Delta U = nC_v \Delta T \quad \text{and} \quad T = \frac{PV}{nR}$$

$$\Delta T = T_2 - T_1 = \frac{P_2 V_2 - P_1 V_1}{nR}, \quad C_v = \frac{R}{\gamma - 1}$$

$$\begin{aligned} \Delta U &= \frac{nR}{\gamma - 1} \left(\frac{P_2 V_2 - P_1 V_1}{nR} \right) = \frac{P_2 V_2 - P_1 V_1}{\gamma - 1} \\ &= \frac{5 \times 4 - 2 \times 6}{\frac{3}{5} - 1} = \frac{20 - 12}{-2/5} = \frac{-8}{2/5} = -20 \text{ KJ} \end{aligned}$$

63. (b) In an adiabatic change $T_2 V_2^{\gamma-1} = T_1 V_1^{\gamma-1}$

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

$$T_2 = 300 \left(\frac{V}{2V} \right)^{\frac{5}{3}-1} = 300 (0.5)^{3/2}$$

$$T_2 = 189.03 \text{ K.}$$

64. (c) Change in internal energy $\Delta U = nC_v\Delta T$, n = No of moles

$$C_v = \frac{R}{\gamma-1} \therefore \Delta U = \frac{nR}{\gamma-1} \Delta T$$

$$\Delta U = \frac{2 \times 8.31 \times (189 - 300)}{\frac{5}{3} - 1} = -2767.23 \text{ J}$$

65. (b) In an adiabatic process, slope of P-V graph $= \frac{dP}{dV} = -\gamma \frac{P}{V}$
 i.e. slope $\propto \gamma$ (with -ve sign)
 So $(\text{slope})_2 > (\text{slope})_1 \therefore \gamma_2 > \gamma_1$
 \therefore plot 1 corresponds to O_2 ($\gamma = 1.4$) and Plot 2 corresponds to He ($\gamma = 1.67$). Choice (b) is correct.

66. (c) Here $W = -146 \text{ KJ} = -146 \times 10^3 \text{ J}$

$$T_2 - T_1 = 7^\circ\text{C}, R = 8.31 \text{ mole}^{-1} \text{ K}^{-1}$$

$$= 8.3 \times 10^3 \text{ J kilomole}^{-1} \text{ K}^{-1}$$

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

$$-146 \times 10^3 = \frac{8.3 \times 10^3 \times 7}{1 - \gamma}$$

$$\gamma - 1 = \frac{8.3 \times 10^3 \times 7}{146 \times 10^3} = 0.40$$

$\gamma = 1.40$ The gas must be diatomic.

67. (c) In an isobaric process $P = \text{constant}$ and

$$V \propto T \text{ or } V = \left(\frac{nR}{P} \right) T$$

V-T graph is a straight line with slope $\propto \frac{1}{P}$

$$(\text{slope})_2 > (\text{slope})_1 \therefore P_2 < P_1$$

68. (d) The incorrect statement is (d). This is because in going from B to C or D to A ; $dV = 0$

$$\therefore dW = p.dV = 0$$

69. (a) The equation of adiabatic change is

$$P_V^\gamma = \text{constant which gives}$$

$$P^{1-\gamma} T^\gamma = \text{constant}$$

$$P^{1-\gamma} \propto \frac{1}{T^\gamma} \quad \text{or} \quad P \propto T^{\left(\frac{\gamma}{\gamma-1}\right)}$$

$$\text{As } P \propto T^3 \quad \therefore \frac{\gamma}{\gamma-1} = 3 \quad \text{or} \quad \gamma = \frac{3}{2}$$

$$\text{Hence } \frac{C_p}{C_v} = \gamma = \frac{3}{2}$$

70. (d) As $Q = e \sigma T^4 At$

$$\text{So } e = \frac{Q}{\sigma T^4 At} = \frac{300}{(5-67 \times 10^{-8}) \times (1001)^4 \times (5 \times 10^4) \times 60} \\ = 0.18$$

$$71. (c) \quad \eta_1 = 1 - \frac{273+0}{200+273} = \frac{200}{473}$$

$$\eta_2 = 1 - \frac{-200+273}{0+273} = \frac{200}{273}$$

$$\text{Hence } \eta_2 / \eta_1 = 0.577$$

72. (b) Here $\eta = \frac{1}{10}$, $W = 10 \text{ J}$, $\theta_2 = ?$

$$\beta = \frac{1-\eta}{\eta} = \frac{1-\frac{1}{10}}{\frac{1}{10}} = 9$$

$$\text{As } \beta = \frac{\theta_2}{W} \quad \text{or} \quad \theta_2 = 90 \text{ J}$$

73. (b) $\text{C.O.P} = \frac{Q_2}{W} = \frac{T_2}{T_1 - T_2}$

when door is left open $T_2 \rightarrow T_1$, Hence C.O.P. \uparrow i.e. $\theta_2 \uparrow$. So heat energy given to the room increases.
