



SWAMI VIVEKANANDA SCHOOL OF

ENGINEERING & TECHNOLOGY

SUBJECT NOTE – THERMAL ENGINEERING

SEMESTER – 3RD

LECTURER NAME – ER. ABHIJIT CHAND

① Thermodynamics:

② Definition of energy:

It is defined as the ability to do work. It is measured by multiplying the force applied on an object (measured in newtons) with the distance moved by that object. The unit of energy is Joule or Joules (J).

Energy is required for doing any type of work in life. It is required for cooking, heating, cooling, lighting etc. In our home, it is required to run our machines and other mechanical equipment in industry. It is required to run our locomotives or transport.

③ Source of energy:

④ Conventional energy:

The conventional energy sources are called non-renewable available in nature (Stock of the land & sea, fossil of the earth). They are finite but some natural energy of the earth (like wind, solar, hydro, etc.) are produced continuously in nature (This is the natural energy of the stored water and energy of the dam).

⑤ Non-conventional energy:

The non-renewable energy sources are those energy sources which have accumulated in nature over a long time (billions of years) and cannot be replenished in hundred years. These sources are like, fossils in quantity and cannot be replaced. They are like this that to be exchanged with time. The energy sources include: fossil fuels, coal & oil, natural gas, nuclear fuel and nuclear energy like Uranium-235.

- 1) Solar energy is solar based energy.
 - 2) Wind energy is wind based energy.
 - 3) Tidal energy is hydro based.
- } Renewable energy
A non-conventional energy.

- 4) Geothermal energy.
 - 5) Thermal power.
 - 6) Nuclear power.
- } Non-renewable energy
A conventional energy.

① Various Thermodynamic System:

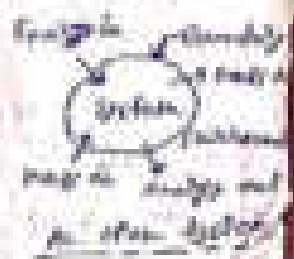
① closed system:

There is no mass transfer across the system boundary. There may be energy transfer into or out of the system. A certain quantity of matter is a system bounded by a system constitutes a closed system. A diagram of a closed system is shown below.



② Open system:

The open system is one in which matter crosses the boundary of the system. There may be energy transfer also. Matter of the surrounding enters and leaves the system, as in all processes in which matter enters at one place and leaves at other places and there are energy transfers across the system boundary.



③ Isolated system:

The isolated system is one in which there is no interaction between the system and the surroundings. It is a closed system and energy and there is no mass transfer across system boundary.



Thermodynamic Equilibrium:

A system is said to exist in a state of thermodynamic equilibrium when no change in any macroscopic property is registered, if the system is isolated from its surroundings.

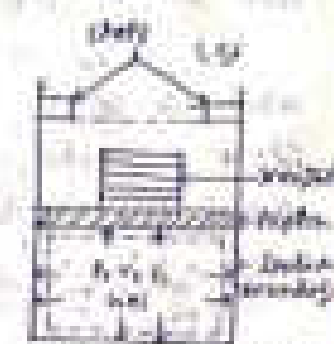
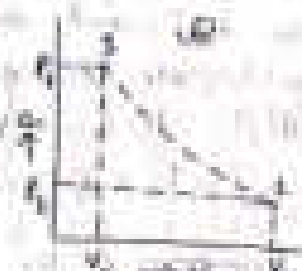
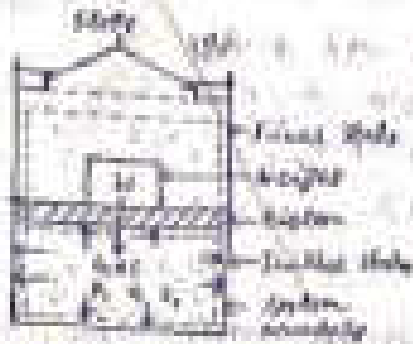
When there are various inhomogeneities over the part of a isolated system, the inhomogeneities at every point disappear with time. This rate of change decreases and eventually stop, when no further changes are observed. The system is said to be in thermal equilibrium.

A system will be in a state of thermodynamic equilibrium, if the conditions for the following three types of equilibrium are satisfied.

- 1) Mechanical equilibrium
- 2) Chemical equilibrium
- 3) Thermal equilibrium

Quasi-Static Process:

Let us consider a system of gas contained in a cylinder. The system initially is in equilibrium state, represented by the parameters P_1, V_1, T_1 . The weight on the piston just balances the upward force exerted by the gas. If the weight is removed, there will be an unbalanced force between the system and the surroundings, and under this pressure, the piston will move up till it gets the state. The system again comes to an equilibrium state, being described by the parameters P_2, V_2, T_2 . But the intermediate



Transition between two equilibrium states by an unbalanced force

The following is the graph for the quasi-static process.

Transition from one state to another by a quasi-static process

States passed through by the system are not equilibrium states, which cannot be described by thermodynamic coordinates, since the piston moves a small distance in the initial and final equilibrium states which is a dotted line, which has got no thermodynamic sense. If the weight on the piston is made up of many very small pieces of weights and removed one by one very slowly, then the list of the states and any instant of the upward travel of the piston, if the system is isolated, the definition of the state of the system then the thermodynamic equilibrium state will be microscopically well so every state passed through by the system will be an equilibrium state, but a process which is not a locus of all equilibrium states passed through by the system, is even quasi-static process. Quasi means almost infinite number of the characteristic values of a quasi-static process. It is also called reversible process.



Thermodynamic Properties:

The physical properties of the system are the internal energy, pressure, volume, temperature etc. The definition of the property of a system is the amount of work done by the system in a process. The unit of work is Joule.

↓ Work

Thermodynamic Process

... with ...
... of a ...
... of ...



Thermodynamic Cycle

... cycle ...
... of ...
... of ...

... cycle ...
... of ...
... of ...

Adiabatic Process

The ... of the system ...
... of ...
... of ...
... of ...

Isobaric Process

The ... of the system ...
... of ...
... of ...
... of ...

Internal Energy

... energy ...
... of ...
... of ...

... energy ...
... of ...
... of ...

... energy ...
... of ...
... of ...

$$E = \frac{1}{2}mv^2$$

Temperature: by the word temperature

call a body is

Temperature may be defined as the natural condition of a body when which denotes its capacity or propensity to heat to other bodies at touching that other body.

In SI units, temperature is measured in degree Celsius ($^{\circ}C$).

"Absolute temperature" is based upon "absolute zero" Absolute zero is the temperature at which the volume of a given mass of a gas becomes nil. Absolute zero is equivalent to $-273^{\circ}C$.

Internal energy: Molecules possess energy in several ways. Kinetic energy, potential energy, vibrational energy, etc. The total energy of a molecule is called internal energy. As temperature of the molecules is increased, their total internal energy also increases which increases their internal energy. Internal energy is a function of temperature.

Enthalpy: Summation of internal energy and pressure energy is called enthalpy.

Enthalpy is given by $H = U + PV$

where, U = internal energy of a gas, P = pressure of the gas,

V = volume of the gas.

① Heat:

Energy transferred without transfer of matter between a system and its surroundings due to temperature difference, is called heat.

Heat is a form of energy which flows from one body to another when a temperature difference exists between them.

In SI units, heat is measured in joules (J).

② Work:

Work is said to be done by a force when that force acting on a body moves the body through some distance.

Work is measured as the product of the force and the distance travelled by the body in the direction of the force applied.

So, $Work = F \times S$

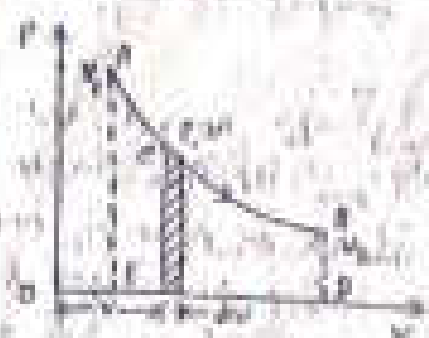
Unit of work will be joule (J) or newton meter ($N \cdot m$).

Q1 Mechanical Equivalent of heat or Joule's experiment :

Mechanical equivalent of heat or Joule's experiment is the quantity of mechanical energy which raised the unit quantity of heat. It is usually denoted by 'J'. In most cases $J = 4.18 \text{ J/cal}$ (SI unit), $J = 3.71 \text{ J/cal}$, $J = 8.3 \text{ J/cal}$.

Q2 P-V work done on P-V diagram :

or Work done by expansion of a gas during compression or expansion of a gas :



Let AB represent pressure-volume diagram of a gas during its expansion from volume V_1 at A to volume V_2 at B. Let the gas be contained in a cylinder filled with a piston in it and let $c =$ cross-sectional area of the piston.

Let us consider an infinitesimal volume ΔV of the piston and let ΔV be the volume of the gas at A. From this infinitesimal ΔV , let the volume increase by a very small amount Δv . Then the length through which the piston moves during this increase in volume $= \frac{\Delta v}{c}$.

Work done by the piston at $c = P \Delta v$.
 Change in volume is so small that at this stage, pressure of the gas may be assumed to be constant at P .
 Very small amount of work done by the gas during this small increase in volume is that of $dW = P \Delta v = P \frac{dV}{c} = P dV$.

But P or density is not same of the whole time in P-V diagram.

Therefore, integrating both sides we get

$$\int_a^b P dV = \int_a^b P dV = \int_a^b P dV$$

 where $W =$ total work done by the gas when volume changes from V_1 to V_2 .
 But $\int_a^b P dV$ denotes the area under curve AB in P-V diagram as shown with area is also given by the area under the P-V diagram.

In case of expansion, we will take +ve value of work and in case of compression, we will take -ve value of work.

① Specific heat :

Specific heat of a substance is the quantity of heat required to raise unit mass of the substance through one degree.

Specific heat of water is $1 \text{ cal/deg}^\circ \text{C}$ or $4.187 \text{ J/deg}^\circ \text{C}$.

Let, $m = \text{mass of a substance}$, $s = \text{Specific heat of the substance}$, $\Delta T = \text{Rise of temperature in } ^\circ \text{C}$ or $^\circ \text{F}$.

$Q = \text{Heat added to the substance}$

Then, $Q = m \cdot s \cdot \Delta T$ or $s = \frac{Q}{m \cdot \Delta T}$

② Specific heat of a gas at constant pressure :

Specific heat of a gas at constant pressure is the quantity of heat required to raise unit mass of the gas through one degree Celsius (or one degree Fahrenheit) when the gas is heated at constant pressure. It is usually denoted by C_p .

Specific heat of a gas at constant pressure is constant for a particular gas but is different for different gases.

Specific heat of air at constant pressure is given by $C_p = 1.01 \text{ cal/deg}^\circ \text{C}$ or $4.187 \text{ J/deg}^\circ \text{C}$.

Let, $T_1 = \text{Initial absolute temperature in } ^\circ \text{K}$

$T_2 = \text{Final absolute temperature in } ^\circ \text{K}$

Then heat added to the gas at constant pressure is given by

$$Q = m \cdot C_p (T_2 - T_1) \text{ cal}$$

③ Specific heat of a gas at constant volume :

Specific heat of a gas at constant volume is the quantity of heat required to raise unit mass of the gas through one degree Celsius (or one degree Fahrenheit) when the gas is heated at constant volume. It is usually denoted by C_v .

For air, $C_v = 0.714 \text{ cal/deg}^\circ \text{C}$ or $2.98 \text{ J/deg}^\circ \text{C}$.

Specific heat of a gas at constant volume is constant but is different for different gases.

Let, T_1 and $T_2 = \text{Initial and final absolute temperature in } ^\circ \text{K}$

Then heat added to the gas at constant volume is given by

$$Q = m \cdot C_v (T_2 - T_1) \text{ cal} = m \cdot C_v (T_2 - T_1) \text{ J}$$

② Relation between C_p and C_v

(1) The difference of two specific heats is equal to the constant R .

(2) The ratio of two specific heats (C_p/C_v) is known as adiabatic index and it is denoted by a Greek letter γ .

We know that $C_p - C_v = R$ i.e. $\frac{C_p}{C_v} = 1 + \frac{R}{C_v}$

Since C_p is always greater than C_v , therefore the value of γ is always greater than unity.

The value of γ is 1.4 .

Let atmospheric air, C_p and C_v are both unknown.

③ Law of Thermodynamics

① Zeroth Law of Thermodynamics

This law states that when two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other.

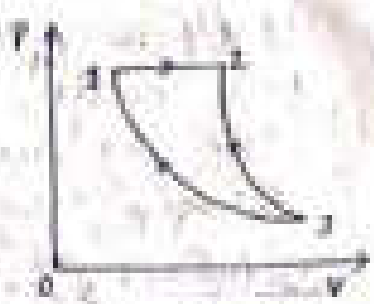
Explanation: Let A and B are two systems which are in thermal equilibrium with a third system C. This means no heat transfer takes place between systems A and C, and no heat transfer will take place between systems B and C. Thus no heat transfer will take place between systems A and B. This implies that temperature of both the systems A and B will be the same.

② First Law of Thermodynamics

This law states that the heat and mechanical work are mutually convertible. According to this law, a definite amount of mechanical work is needed to produce a definite amount of mechanical work heat and vice versa.

This law also states that the energy can neither be created nor destroyed, though it can be transferred from one form to another.

Explanation: Let a gas undergo cyclic process along the lines 1-2, 2-3 and 3-1.



Also let u_1 = internal energy of the gas when it expands along the line 1-2.

u_2 = work done by the gas when it expands along the line 1-2.

u_3 = work done when the gas when it compressed along the line 2-3.

q_1 = heat added to the gas when it expands along the line 1-2.

q_2 = heat added to the gas when it expands along the line 2-3.

q_3 = heat rejected from the gas when it is compressed along the line 3-1.

Then change in work done is given by $W = u_2 + u_3 - u_1$ and net heat furnished is given by $Q = q_1 + q_2 - q_3$.

According to the first law of thermodynamics, $W = Q$, where W is a constant known as mechanical equivalent of heat or joule's equivalent.

$\therefore J = 1$, because 1 cal unit work.

② Thermodynamics:

Definition:

The thermodynamics is that branch of Engineering science deals with the energies possessed by gases and vapors. It also includes the conversion of these energies in terms of heat and mechanical work and their relationships and their relationships with properties of the system.

Example: A 10000 rupee deposit in a bank is withdrawn by a public school. How much is the public school liable to pay to the bank? The bank's balance is 10000 rupees.

Solution: It is said that liability to pay is the amount of the deposit.

∴ $Q = 10000$ rupees

∴ $Q = 10000$ rupees

∴ $Q = 10000$ rupees

∴ $Q = 10000$ rupees

∴ $Q = 10000$ rupees

Note: Since the amount is 10000 rupees, the bank has to pay 10000 rupees as interest.

(2) During withdrawal of a sum of money, if the bank is liable to pay the public school, and 10000 rupees is deposited to the bank.

Determine the net liability to pay to the public school.

Solution: Let x be the required sum to be paid to the public school.

∴ $x = 10000 - 10000$

∴ $x = 0$ rupees

∴ $x = 0$ rupees

∴ $x = 0$ rupees

∴ $x = 0$ rupees

∴ $x = 0$ rupees

∴ $x = 0$ rupees

∴ $x = 0$ rupees

$V(t)$ is the volume of water in the tank at time t . The volume of water in the tank at time t is $V(t)$. The volume of water in the tank at time t is $V(t)$.

Solution: (i) Let $V(t)$ be the volume of water in the tank at time t .

The volume of water in the tank at time t is $V(t)$.

$$\frac{dV}{dt} = \text{rate in} - \text{rate out} = 20 - \frac{V}{100}$$

$$\frac{dV}{dt} + \frac{V}{100} = 20$$

(ii) Let $V(t)$ be the volume of water in the tank at time t .

$$\frac{dV}{dt} = 20 - \frac{V}{100}$$

$$\frac{dV}{dt} + \frac{V}{100} = 20$$

$$\frac{d}{dt} \left(V e^{\frac{t}{100}} \right) = 20 e^{\frac{t}{100}}$$

$$V e^{\frac{t}{100}} = 200 e^{\frac{t}{100}} + C$$

$$V = 200 + C e^{-\frac{t}{100}}$$

A closed system receives a heat transfer of 100 kJ and does 40 kJ of work. Calculate the change in internal energy.

Solution: For a closed system,

$$Q = \Delta U + W$$

A heat transfer of 100 kJ is added (into the system) and 40 kJ of work is done by the system (out of the system).

$$100 = \Delta U + 40$$

$$\Delta U = 100 - 40 = 60 \text{ kJ}$$

Since the system is closed, there is no mass transfer across the boundary.

(iii) A piston-cylinder device is initially at 1 bar and 200 K. The piston is moved to a final state of 10 bar and 300 K. The process is such that the pressure remains constant during the process. There is a transfer of 100 kJ of heat from the system during the process. Calculate the change in internal energy of the system.

(iv) A piston-cylinder device is initially at 1 bar and 200 K. The piston is moved to a final state of 10 bar and 300 K. The process is such that the pressure remains constant during the process. There is a transfer of 100 kJ of heat from the system during the process. Calculate the change in internal energy of the system.

Solution: First we set up a continuity equation in a control volume

$$Q_1 = Q_2 = Q_3$$

$$V_1 A_1 = V_2 A_2 = V_3 A_3$$

$$\text{Hence, } V_2 = \left(\frac{A_1}{A_2} \right) V_1 = \left(\frac{0.10}{0.05} \right) 10 = 20 \text{ m/s}$$

$$V_3 = \left(\frac{A_1}{A_3} \right) V_1 = \left(\frac{0.10}{0.20} \right) 10 = 5 \text{ m/s}$$

$$\text{Hence, } V_3 = 5 \text{ m/s}$$

Substituting in equation (1)

$$-20(0.05) + V_2(0.05) - 5(0.20) = 0$$

$$-1.0 + 0.05 V_2 - 1.0 = 0$$

$$0.05 V_2 = 2.0 \Rightarrow V_2 = 40 \text{ m/s}$$

The initial velocity of the jet is calculated by 40 m/s

in the process.

Q. 10) A fluid is confined in a cylinder by a spring loaded, frictionless piston so that the pressure in the fluid is a linear function of the volume ($P = a + bV$). The initial state of the fluid is given by the following equation; $10 = 10 + 0.001 V$

where V is in m^3 , P is in N/m^2 , and V is in m^3 . The fluid changes from an initial state of 100 kPa , 0.001 m^3 to a final state of 400 kPa , 0.002 m^3 , with no other heat that does in the piston, find the direction and magnitude of the work and heat transfer.

Solution: The change in the internal energy of the fluid

during the process

$$u_2 - u_1 = 0.15 (1000 + 0.001 \times 1000) - 0.15 (1000 + 0.001 \times 1000) = 50 \text{ J/kg}$$

$$\text{Hence, } P = a + bV \quad \text{So, } 100 = a + 0.001 \times 100$$

$$400 = a + 0.002 \times 100$$

From these two equations $a = 50 \text{ kPa/m}^3$ and $b = 200 \text{ kPa/m}^3$

With proper analysis during the process

$$W_{1-2} = \int_{V_1}^{V_2} P dV = \int_{V_1}^{V_2} (a + bV) dV =$$

$$= a(V_2 - V_1) + \frac{b}{2} (V_2^2 - V_1^2) = (50 - 10) \left[0.002 - 0.001 \right]$$

$$= 0.02 \left[-50 \times 0.001 + \frac{200}{2} (0.002^2 - 0.001^2) \right] = 100 \text{ J/kg}$$

Now if done by the system, the magnitude being 100 J/kg

$$\text{Heat transfer involved is given by, } Q_{1-2} = u_2 - u_1 + W_{1-2}$$

$$= 50 + 100 = 150 \text{ J/kg}$$

150 J/kg is done into the system during the process.

Q. (i) The internal energy of a certain substance is given by the following equation, $u = 7.5 PV + 14$,

where u is given in kJ/kg, P is in MPa and v is in m³/kg.

A system consisting of 1 kg of this substance expands from an initial pressure of 10 MPa and a volume of 0.12 m³ to a final pressure 1 MPa in a process in which pressure and volume are related by $Pv^{1.2} = \text{constant}$.

(a) If the expansion is quasi-static, find Q , ΔU and W for the process.

(b) In another process the same system expands according to the same pressure-volume relationship as in part (a) and reaches the same initial state to the same final state as in part (a), but the heat transfer in this case is 10 kJ.

Find the work transfer for this process.

(c) Explain the difference in work transfer in parts (a) and (b).

Solution: $u = 7.5 PV + 14$

$$\Delta u = u_2 - u_1 = 7.5P_2V_2 - 7.5P_1V_1$$

$$\Delta U = 7.5(P_2V_2 - P_1V_1)$$

Now, $P_1V_1^{1.2} = P_2V_2^{1.2}$

$$P_2V_2 = P_1V_1 \left(\frac{P_1}{P_2}\right)^{1/1.2} = 0.12(10)^{1/1.2}$$

$$= 0.12 \times 7.92 = 0.9504 \text{ m}^3$$

$$\therefore \Delta U = 7.5(10 \times 0.9504 - 10 \times 0.12)$$

$$= -71.43 \text{ kJ} \quad \underline{\text{Ans}}$$

For a quasi-static process,

$$W = \int P dV = \frac{P_2V_2 - P_1V_1}{1-1.2}$$

$$= \frac{(10 \times 0.9504 - 10 \times 0.12) \times 10^3}{1-1.2}$$

$$= 100.7 \text{ kJ} \quad \underline{\text{Ans}}$$

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

$$= -71.43 + 100.7 = 29.27 \text{ kJ} \quad \underline{\text{Ans}}$$

Now, Here $Q = 29.27$

(b) Since the end states are the same, ΔU would remain the same as in (a). $W = Q - \Delta U = 30 - (-71.43) = 101.43 \text{ kJ} \quad \underline{\text{Ans}}$

(c) The work transfer is not equal to $\int P dV$ since the process is not quasi-static.

Constant Pressure Process:

Heating causes increase in volume and temperature and external work is done.

$$dQ = dU + dW = \gamma dU + dW = d(PV) = dW$$

When addition of heat increases temperature and does work, the ratio of increase in internal energy to the corresponding increase in temperature is called γ .

Constant Volume Process:

In case of gas in rigid process, addition of heat increases its temperature and does internal work. For this process, $dQ = dU + dW = dU$ (since work done = 0).

The ratio of increase of internal energy to the corresponding increase of temperature is called the specific heat at constant volume.

Constant Temperature Process or Isothermal Process:

A process in which the temperature of the working substance remains constant during its expansion or compression is called a constant temperature process or isothermal process. This will happen when the working substance remains in contact with a large thermal contact with the surroundings so that heat "goes in" or "comes out" is compensated exactly for the mechanical work done by, or on, the gas respectively. It is this way, really, that an isothermal process:

- (i) There is no change in temperature.
- (ii) There is no change in internal energy.

We know that $P_1 V_1 = P_2 V_2 = P_3 V_3 = \dots = nRT$ (since $dQ = 0$)

When being isothermal expansion of a gas,

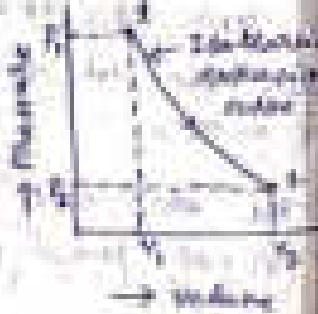
Heat added = Work done by the gas.

Similarly, during isothermal compression of a gas,

Heat extracted = Work done on the gas.

A little consideration will show that the isothermal process is governed by Boyle's Law. Thus the isothermal equation of a perfect gas is $PV = \text{constant}$.

Now consider a certain quantity of a perfect gas being expanded isothermally, which is shown by the curve ABC in figure.



- Let, V_1 = Initial volume of gas,
- P_1 = Initial Pressure of gas,
- V_2 = Final volume of gas,
- P_2 = Final Pressure of gas.

The following is the mathematical expression for Boyle's Law:

$$P_1 V_1 = P_2 V_2$$

$$P_1 \times 100 \text{ cm}^3 = 1.5 \text{ atm} \times 200 \text{ cm}^3$$

$$P_1 = \frac{1.5 \times 200}{100} = 3 \text{ atm} \quad \dots (1)$$

In general, $P \propto \frac{1}{V}$ or $PV = \text{constant}$

where V is the volume (when P is held) and constant is $P_1 V_1$ (when P is held)

where V is the volume (when P is held) and constant is $P_1 V_1$ (when P is held)

$$\text{Boyle's Law: } P_1 V_1 = P_2 V_2$$

$$\text{where } P_1 = \text{Initial Pressure, } V_1 = \text{Initial Volume}$$

$$P_2 = \text{Final Pressure, } V_2 = \text{Final Volume}$$

Adiabatic Process or Isothermal Process:

A process in which the working substance neither receives nor gives out heat to its surroundings, during its expansion or contraction is called an adiabatic process. This will happen when the working substance remains thermally insulated, so that no heat enters or leaves it during the process. It is also called that as an adiabatic process.

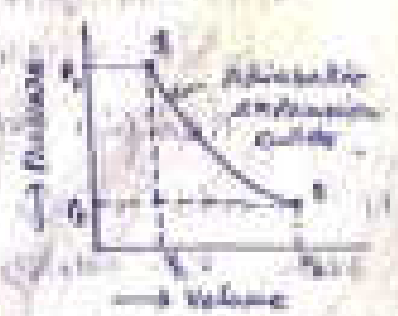
- (i) No heat is exchanged with the surroundings.
- (ii) The temperature of the gas changes as the work is done at the cost of internal energy.
- (iii) The change in internal energy is equal to the work done.

It is noted that $Q_{int} = \Delta U + W_{ext}$ and, for adiabatic process ($Q_{int} = 0$)

where Q_{int} indicates heat, ΔU increase in internal energy, work must be done by the gas ($W_{ext} = -W$), work must be done by the gas. Similarly, if decrease in internal energy, work must be done by the gas.

Now consider a certain quantity of a perfect gas being expanded adiabatically which is shown by the curve $1-2$ in figure.

- Let, V_1 = Initial volume of gas,
- P_1 = Initial Pressure of gas,
- V_2 = Final volume of gas and
- P_2 = Final Pressure of gas.



The potential energy associated through it is given by,

$$U = \frac{\rho g V z}{2} = \frac{\rho g A L z}{2} \quad \text{--- (1st relation)}$$

$$= \frac{\rho g z}{2} \times \frac{\rho g A L z}{\rho g} \quad \text{--- (2nd relation)}$$

Point: If for adiabatic process, $P_1 V_1^\gamma = P_2 V_2^\gamma = \text{constant}$, slope of is, the adiabatic curve.

(ii) Case: $P_1 = P_2$ and $h_1 = h_2$, therefore the curve is a horizontal line & is called as,

$$\left(\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + z_1\right) = \left(\frac{P_2}{\rho g} + \frac{v_2^2}{2g} + z_2\right)$$

Steady state process:

'Steady state' means that the rates of flow of mass and energy remain the constant values are constant.

In most engineering devices, there is a constant rate of flow of mass and energy through the control surface, and the control volume in course of time attains a steady state. At the steady state of a system, any thermodynamic property will have a fixed value at a particular location, and will not alter with time.

Control energy equation for a jet at a steady state process:

Let a jet flow steadily through a fluid volume within a boundary. Since it is assumed that the flow is steady, the mass flow rate of the jet at inlet = mass flow rate of the jet at outlet = \dot{m} kg/s.

The jet may have following types of energies at inlet.

(i) Potential energy = $\dot{m} z_1$ Joules

Where, z_1 = height of entrance above the ground level in meters.
 \dot{m} = mass flow rate of jet in kg/s.

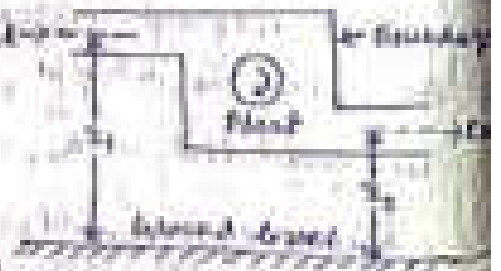
So, Potential energy for 1 kg fluid = z_1 Joules

(ii) Kinetic energy = $\frac{1}{2} \dot{m} v_1^2$ Joules

Where, v_1 = velocity of flow at inlet in m/s.

(iii) Pressure energy = $\dot{m} v_1$ Joules

Where, P_1 = Pressure of the jet at inlet in N/m²
 v_1 = Volume of 1 kg mass of the jet at inlet in m³



(d) Initial energy = U_1 , Kinetic energy = $\frac{1}{2} \rho V_1^2 A_1 \Delta x$

(e) $\rho \Delta x$ = mass added in volume Δx of mass ρ of the fluid at inlet in time Δt .

Then total energy at Δx inlet of the fluid at inlet is

$$E_1 = p_1 A_1 \Delta x + \frac{1}{2} \rho V_1^2 A_1 \Delta x + U_1 + \rho \Delta x$$

and at outlet

$$E_2 = p_2 A_2 \Delta x + \frac{1}{2} \rho V_2^2 A_2 \Delta x + U_2 + \rho \Delta x$$

Let $\rho \Delta x$ = volume in pipe of Δx mass of the fluid in the fluid within the boundary

Then $E_1 = E_2$ and a heat transfer losses

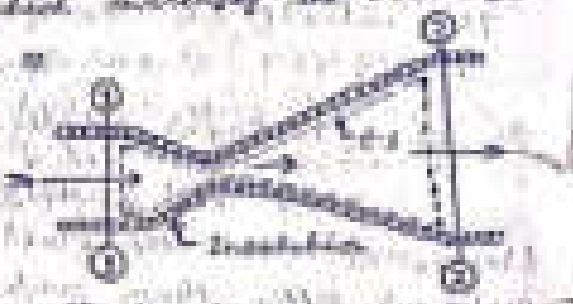
$$p_1 A_1 \Delta x + \frac{1}{2} \rho V_1^2 A_1 \Delta x + U_1 + \rho \Delta x = p_2 A_2 \Delta x + \frac{1}{2} \rho V_2^2 A_2 \Delta x + U_2 + \rho \Delta x + \text{heat transfer losses}$$

$$\text{or } p_1 A_1 + \frac{1}{2} \rho V_1^2 A_1 + \rho U_1 + \rho \Delta x = p_2 A_2 + \frac{1}{2} \rho V_2^2 A_2 + \rho U_2 + \rho \Delta x + \text{heat transfer losses} \quad [A_1 V_1 = A_2 V_2]$$

Application of Bernoulli's law of conservation of energy to study flow through a pipe with a diameter change:

Example and Diagram:

A pipe of a device which increases the velocity of a fluid at the entrance of its nozzle. The nozzle is a tapered section of a pipe. The velocity of the fluid at the nozzle is constant. The fluid is incompressible. The flow is steady and the pipe is insulated.



The steady flow energy equation of the fluid at the inlet and outlet of the pipe is

$$h_1 + \frac{V_1^2}{2g} + z_1 + \frac{p_1}{\rho g} = h_2 + \frac{V_2^2}{2g} + z_2 + \frac{p_2}{\rho g} + \text{losses}$$

Here $\frac{dh}{dx} = 0$, $\frac{dz}{dx} = 0$, and the change in potential energy is zero.

The equation reduces to $h_1 + \frac{V_1^2}{2g} = h_2 + \frac{V_2^2}{2g}$

The continuity equation gives

$$V_1 A_1 = V_2 A_2$$

When the inlet velocity is the velocity of approach V_1 is small compared to the exit velocity V_2 , equation becomes

$$h_1 = h_2 + \frac{V_2^2}{2g} \quad \text{or } V_2 = \sqrt{2g(h_1 - h_2)}$$

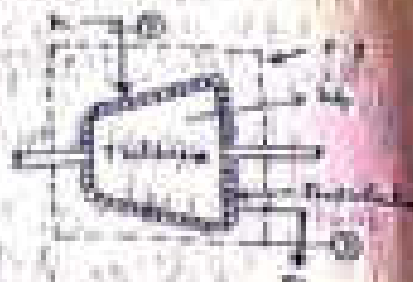
where $(h_1 - h_2)$ is the head.

Equation (1) and (2) hold good for a liquid as well.

Parallel and counterflow

Parallel flow: fluid enters both pipes from the same end, and exits from the other end. The temperature difference between the two fluids decreases as they flow through the heat exchanger.

Counterflow: fluid enters one pipe from one end and the other pipe from the opposite end. The temperature difference between the two fluids remains relatively constant throughout the heat exchanger.



Flow through a Parallel

$$Q = m_1 c_p (T_{1i} - T_{1o}) = m_2 c_p (T_{2o} - T_{2i})$$

It is seen that cold fluid is heated to the point of the reference of the inlet.

Similarly, for counterflow heat exchanger, cold fluid is heated to the point of the reference of the inlet.

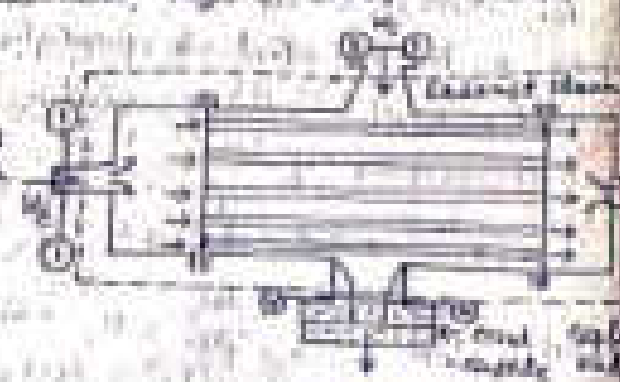
$$T_{1o} = T_{2o} - \frac{Q}{m_2 c_p}$$

$$m_2 \frac{Q}{c_p} = m_1 (T_{1i} - T_{1o})$$

The outlet of the fluid increases by the amount of heat input.

Heat exchanger of steam condenser

A steam condenser is a device in which heat is transferred from the steam to the cooling water. The steam condenses into water, and the cooling water is heated. The heat exchanger is usually a shell and tube type.



$$m_1 c_p (T_{1i} - T_{1o}) = m_2 c_p (T_{2o} - T_{2i})$$

Note the hot and cold water are considered small, but if no external work done, and energy exchange in the form of heat is considered only between the two fluids, i.e. there is no external heat interaction at heat exchanger.

For a steam condenser, the steam is at a higher temperature than the cooling water. The heat exchanger is usually a shell and tube type. The steam condenses into water, and the cooling water is heated. The heat exchanger is usually a shell and tube type.

② Limitations to the 1st law of thermodynamics:

- (1) First law of thermodynamics states only about conservation of heat and not about the direction of heat flow. That is, it does not specify whether heat will flow from hot body to cold body or vice versa and why.
- (2) While mechanical work can be fully converted into heat energy, heat energy cannot be converted into mechanical energy, unless the conversion is partial, i.e., availability of heat and a mechanical work is not only there.

First examples showing limitations of 1st law:

(i) If hot water cools by giving out its heat to the system surrounding, but vice versa is not, it can never be heated by taking heat from the water surrounding.

(ii) When flames are applied to start a car, chemical energy is converted into heat energy. The heat and heat energy cannot be used to cause the car to move.

③ Second law of thermodynamics:

This law states that there is a definite limit to the amount of mechanical energy, which can be obtained from a given quantity of heat energy.

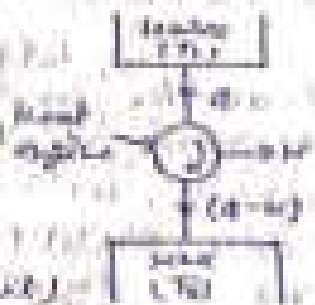
④ Kelvin-Planck statement:

It is impossible to construct a heat engine working on cyclic process which will convert all the heat supplied to it into equivalent amount of mechanical work.

Explanation:

Let, Q_1 = heat supplied to a heat engine from a high temperature heat reservoir called source in any time t .

W = work done by the heat engine (in heat unit) in the same time t .



According to Kelvin-Planck statement, $W < Q_1$.

This according to the law of conservation of energy, heat rejected to the low temperature heat reservoir, called sink $Q_2 > 0$.

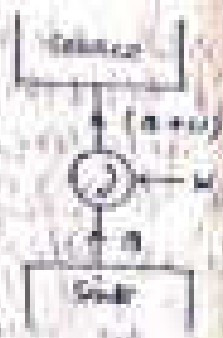
⑤ Clausius statement:

It is impossible for a self-acting machine, which is not aided by an external agency to transfer heat from a body at lower temperature, to a body at higher temperature, i.e., from sink to the source.

Examination 1

Let Q_1 be heat to be transferred from the "source" to the "sink" delivered through engine with sink the reservoir and will do work with the working medium through which heat is rejected from place where the "sink" is the sink.

Let Q_2 = heat to be transferred from sink to the source at "2" place.



Then according to Kelvin's statement, some internal mechanical work is to be done when the working medium through which heat is rejected from place.

Let W = work to be done when the working medium in the cycle.

Then according to law of conservation of energy, heat delivered to the source in line (2) will be $Q_1 + W$.

Examination 2: Assumptions and classical statement:

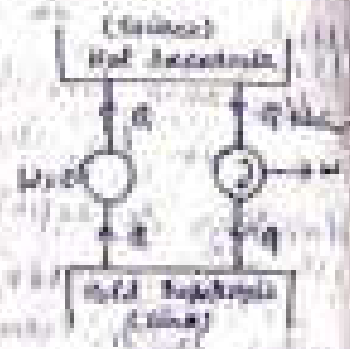
It is possible to transfer heat from one place to another place with a cold reservoir to a hot reservoir without any work being done when the working medium is some mechanical system.

Let Q_1 = quantity of heat received by a system from cold reservoir. The quantity of heat of conservation of energy, and our assumption Q_1 will also be delivered to the hot reservoir.

Let it now assumed that a heat engine operates between the two hot and cold reservoirs separated, then

Let $Q_2 + W$ = heat received by the heat engine from the hot reservoir, and also done by the heat engine. Then according to the law of conservation of energy, Q_1 = heat rejected by the heat engine to the cold reservoir.

Combining the two systems together we get the following result:



Total heat received by the combined system

$= Q_1 + Q_2 + W = W$

Total heat done by the combined system

$= W + 0 = W$

Total heat rejected to the cold reservoir by the combined system $= Q_1 - Q_1 = 0$

Thus the combined system becomes a perpetual motion of the second kind which is impossible according to

Refer to statement, since an assumption that least one
 item at its own would have only happened to not happened
 is wrong, since classifying statement is true in this way,
 classis statement is flawed by our knowledge of nature about
 statement. Here say the equivalence of nature about and
 classis statement regarding least one of them.

Example: 1000 items for amount of money is calculated as a
 function of an initial amount of 100000 = 100000. Multiple of
 1000 items, multiple of 1000 at each and end of the process
 are respectively 1000000 and 1000000, representing calculated money
 and number items are least amount, and the value of the
 function is 100000.

Relation: 1000 items = 1000000 = 1000000
 According to the stated steps, multiple at the process,

$$2000 = \frac{1000000}{1000} + 1000 = 1000 + 1000 = 2000$$

Given: $2000 = 1000 + 1000$, $4000 = 2000 + 2000$, $8000 = 4000 + 4000$

Items also are as calculated. In the process, the least of items is added to the
 the process.

It is also to be added in the case of items.

When the slope of items becomes

$$M_1 = M_2 + 1000$$

Given: $M_1 = 2000 + 1000$, $M_2 = 1000 + 1000$
 $M_1 = 3000$, $M_2 = 2000$

$$\text{With slope of 1000 items, slope} = 1000 \times 1000 = 1000000$$

$$= 1000000 \times 1000$$

Required total described by the following (the output of
 the function) = 1000000000

$$= 1000000000 / 1000 = 1000000 \text{ items}$$

Notes:

When a function is a refer to statement, it becomes
 least from the least value where that is added to the
 least value of addition in generating items.

Refer to statement in classis statement, when atmosphere of
 the 'scale' and depth of the 'line' is the 'line'.
 A classis note being the context of the 'line'.

Heat exchanger

In a heat exchanger, there is a fluid on each side of the pipe. The fluid on one side is heated by the heat exchanger, and the fluid on the other side is cooled. The heat exchanger is a device that transfers heat from one fluid to another without mixing them.



The performance of a heat exchanger is measured by its efficiency. The efficiency of a heat exchanger is the ratio of the actual heat transfer to the maximum possible heat transfer.

$$\eta = \frac{Q_{actual}}{Q_{max}} = \frac{Q_1}{Q_2} = \frac{Q_1 - Q_1'}{Q_2 - Q_1'}$$

Refrigerator

A refrigerator is a device that transfers heat from a cold space to a warm space. It works by using a cycle of compression and expansion of a refrigerant. The refrigerant is compressed, then it expands and cools, then it is compressed again and the cycle repeats.



The performance of a refrigerator is measured by its coefficient of performance (COP). The COP of a refrigerator is the ratio of the heat removed from the cold space to the work done on the refrigerant.

$$COP = \frac{Q_1}{W} = \frac{Q_1}{Q_2 - Q_1}$$

Heat pump

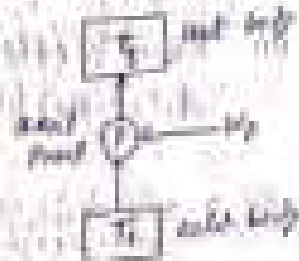
A heat pump is a device that transfers heat from a cold space to a warm space. It works by using a cycle of compression and expansion of a refrigerant. The refrigerant is compressed, then it expands and cools, then it is compressed again and the cycle repeats.

In the similar way, as discussed in refrigerator we have $Q_1 = Q_2 - W$, where Q_1 is the heat removed from the cold space, Q_2 is the heat added to the warm space, and W is the work done on the refrigerant.

The magnitude of a unit gain is subjected to the ratio of the amount of load subjected to the total load to the amount of load subjected to the flow in the system.

$$(G(s))_{T=1} = \frac{G(s)}{1+s} = \frac{1 \cdot \omega_p}{s - \omega_p}$$

$$= \frac{T_1}{s - \omega_p} = \frac{\omega_p}{s - \omega_p} + 1$$



The cost of unit flow is always smaller.

Problem: A machine working in a closed cycle between two end points. Determine the cost when it is started at a particular point, the cost per unit.

Solution: Assume $T = \text{time}$ and $\omega_p = \text{frequency}$.

(1) Cost of a unit flow is $\frac{T_1}{s - \omega_p} = \frac{\omega_p}{s - \omega_p} + 1$

(2) Cost of a unit flow is $\frac{T_1}{s - \omega_p} = \frac{\omega_p}{s - \omega_p} + 1$

(3) Cost of a unit flow is $\frac{T_1}{s - \omega_p} = \frac{\omega_p}{s - \omega_p} + 1$

Remarks: A feedback system is the total cost is reduced in the steady state. To find the total cost, we require the flow through steady state. The flow state is not steady or in the steady state, the flow is not steady and mechanical energy is not. This should be steady, except in a feedback system, there should be any loss of cost due to variation. Radiation and conduction, etc. of gas, which is available at the position, including the gas, are available. This is a feedback system, the total cost is not reduced at the end of the gas.

Following are the conditions of availability of a gas:
 (1) The pressure and temperature of the gas, system, must not drop, otherwise, the loss of the availability of the gas is the process.

- (2) All the processes, taking place in the cycle of plant, must be extremely slow.
- (3) The working parts of the engine must be frictionless.
- (4) There should be no loss of energy during the cycle of operation.

Irreversible Process:

A process, in which change in the thermodynamic state of a system is called irreversible process. In an irreversible process there is a loss of heat, due to friction, induction or deduction.

In an actual process, most of the processes are irreversible to some degree. The main causes for the irreversibility are: (i) friction and fluid friction, (ii) unbalanced expansion, (iii) heat transfer with a finite temperature difference, (iv) electrical resistance, (v) mechanical work into heat. This heat cannot be fully converted into work, which would increase the efficiency of the process. Thus, if state of the system is changed in the process, it cannot be reversed. Thus, a reversible process, by itself, satisfies the first, second and third laws of thermodynamics.

Scope of Irreversibility:

The irreversibility of a process may be due to either one or more of the following:

- (i) Loss of equilibrium during the process.
- (ii) Friction and dissipation effects.

Irreversibility due to loss of equilibrium:

The loss of equilibrium (mechanical, thermal or electrical) between the system and its surroundings, or between two systems, or two parts of the same system, causes a spontaneous change which is irreversible. The following are various examples in this regard:

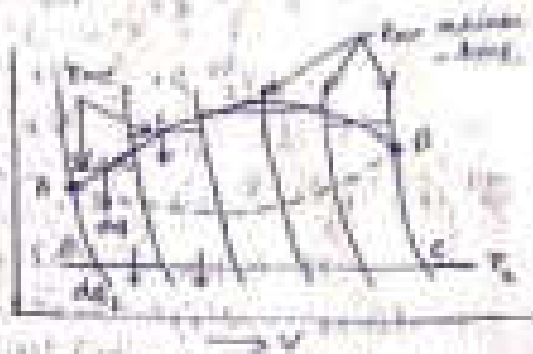
- (i) Heat transfer through a finite temperature difference.
- (ii) Loss of electrical equilibrium with in the interior of the system or between the system and surroundings.
- (iii) Free expansion.

Irreversibility due to dissipative effects:

It may be due to the dissipative effects in which work is done without producing an equivalent increase in the kinetic or potential energy of any system. The dissipation of work into molecular internal energy called as the friction or the irreversible losses take through the change of such phenomena as friction, viscosity, conductivity, electrical resistance, and magnetic hysteresis.

Classing reversibility:

Let us consider a cycle ABCD in figure. Let AB be a constant pressure curve reversible or irreversible, while the other processes in the cycle are irreversible. Let the cycle be divided into a number of elementary cycles.



Let $\eta = 1 - \frac{Q_2}{Q_1}$ be the efficiency of the cycle. While η is not greater than η_{rev} , the efficiency of a cycle will be equal to or less than the efficiency of a reversible cycle.

$$\eta_1 = \frac{Q_1}{Q_2} > \left(\frac{Q_1}{Q_2}\right)_{rev}$$

$$\eta_2 = \frac{Q_1}{Q_2} \leq \left(\frac{Q_1}{Q_2}\right)_{rev}$$

Since $\left(\frac{Q_1}{Q_2}\right)_{rev} = \frac{T_1}{T_2}$

$$\frac{Q_1}{Q_2} \leq \frac{T_1}{T_2}$$

$$\eta_2 = \frac{Q_1}{Q_2} \leq \frac{T_1}{T_2}$$

Let η_{rev} be the efficiency of a reversible process.

$$\eta_{rev} = \frac{Q_1}{Q_2} = \frac{T_1}{T_2}$$

Hence, for any process $\eta < \eta_{rev}$

Then for any cycle:

$$\oint \frac{dQ}{T} < \oint \frac{dQ}{T}$$

Since the system is in a state of equilibrium at the initial and final states, the net change in entropy is zero.

Heat capacity of a diatomic gas is $\frac{5}{2} R$ at room temperature.

This equation is based on the assumption of additivity of degrees of freedom & the equipartition theorem.

- 1) If $\frac{dQ}{dT} = 0$, the gas is ideal.
- 2) If $\frac{dQ}{dT} < 0$, the gas is non-ideal and attractive.
- 3) If $\frac{dQ}{dT} > 0$, the gas is non-ideal and repulsive.

Entropy:

It is an important thermodynamic property of a system - substance, which increases with the addition of heat and decreases with its removal. It is a statistical property to define the level of disorder. But it is not statistically easy to define degree of disorder of a system. Over small range of temperature, the increase of entropy, which is multiplied by the absolute temperature, gives the heat absorbed or rejected by the working substance, which is equal to the change in internal energy.

$$dQ = T dS$$

where, T = absolute temperature,

dS = increase of entropy in entropy.

Theoretically, the entropy of a substance is zero at absolute zero temperature. However, in entropy calculations, some convenient datum should be selected than which measurement may be made.

It may be noted that entropy at 0°K is arbitrary to have zero entropy.

Principle of increase of entropy:

For any spontaneous process undergone by a system the equation for the total mass

$$dS \geq \frac{dQ}{T}$$

For an isolated system which does not undergo any energy interaction with the surroundings, $dQ = 0$.

Relationship of ideal gas

$$PV = nRT$$

For a compressible fluid

For an incompressible fluid

It is clear from the above that the behavior of an isolated system can be described, at various pressures and densities, except only when the pressure is appreciable. This is shown by the possibility of expansion of matter at any pressure. It is the transition from the gaseous state to the liquid state that is the most interesting.

③ Parasit of ideal gas:

A parasit of (or an ideal gas) may be defined as a state of a substance, whose constitution from its normal state is complete. A volume contains some particles of ideal gas. The behavior of such a volume is similar to that of a parasit gas.

④ Physical Properties:

- 1) Pressure exerted by the gas
- 2) Volume exerted by the gas
- 3) Temperature of the gas

⑤ Gay law:

In a gas law process (in which the gas does not react with itself and in which the mass of the gas remains constant) the behavior of a gas is described by the following laws:

- (i) Boyle's law, (ii) Charles's law, (iii) Avogadro's law,
- (iv) Joule's law, (v) Gay-Lussac's law,
- (vi) Dalton's law of partial pressure.

⑥ Boyle's law:

The absolute pressure of a given mass of a parasit gas varies inversely as its volume when the temperature remains constant.

$$P \propto \frac{1}{V}, \quad P_1 V_1 = P_2 V_2$$

The mass of a given mass of gas varies directly as its absolute temperature, when the volume remains constant.

$$P, V, \text{ and } n = \text{constant}$$

Charles's Law:

(i) The volume of a given mass of a perfect gas varies directly as its absolute temperature, when the pressure remains constant.

$$P, n, \text{ and } \rho = \text{constant}$$

$$\text{or } \frac{V_1}{T_1} = \frac{V_2}{T_2} = \frac{V_3}{T_3} = \dots = \text{constant}$$

(ii) All perfect gases change in volume by 1/273 of its original volume at 1°C for every 1°C change in temperature when the pressure remains constant.

Let V_1 = volume of a given mass of gas at 0°C and
 V_2 = volume of the same mass of gas at $t^\circ\text{C}$

Then, according to the above statement,

$$V_2 = V_1 + \frac{1}{273} V_1 t = V_1 \left(\frac{273+t}{273} \right) = V_1 \frac{T}{273}$$

$$\text{or } \frac{V_2}{T} = \frac{V_1}{273}$$

where, Absolute zero corresponding to $0^\circ\text{C} = 273^\circ\text{K}$

Absolute zero corresponding to $0^\circ\text{C} = 273^\circ\text{K}$

The zero (-273°C) at which the volume of a gas becomes zero is called absolute zero temperature.

Gay-Lussac's Law:

This law states "The absolute pressure of a given mass of a perfect gas varies directly as its absolute temperature, when the volume remains constant."

$$V, n, \text{ and } \rho = \text{constant}$$

$$\text{or } \frac{P_1}{T_1} = \frac{P_2}{T_2} = \frac{P_3}{T_3} = \dots = \text{constant}$$

General Gas Equation or Equation of State:

The gas laws which give us the relation between the two variables when the third variable is constant, but in actual practice, all the three variables i.e. pressure, volume and temperature, change simultaneously. To deal with all practical cases, the Boyle's and Charles's laws are combined together, which give us a general gas equation.

According to Boyle's law, $P \propto \frac{1}{V}$ at constant T and n .
 $P \propto \frac{1}{V}$ or $PV \propto \frac{1}{1}$ or $PV = \text{constant}$
 and according to Charles's law,

$V \propto T$ at constant P and n .
 $V \propto T$

$\therefore PV \propto T$ or $\frac{PV}{T} = \text{constant}$

The constant value depends upon the nature and quantity of the gas concerned.

The more exact value of the gas constant R is

$$\frac{R}{J} = \frac{8.314}{1} = 8.314 \text{ J mol}^{-1} \text{ K}^{-1}$$

② Characteristic Equation of a gas:

It is a mathematical form of physical gas equation. If the volume (V) in the ideal gas equation is taken as that of 1 kg of gas (known as specific volume v), then the constant c is represented by universal constant R .

Thus, the ideal gas equation may be written as

$$P v = RT$$

where R is known as characteristic gas constant or simply gas constant.

For any mass m of a gas the characteristic gas constant becomes

$$\begin{aligned} \text{or } P v_1 &= mRT \\ \text{or } P V &= mRT \end{aligned} \quad [\because m v_1 = V]$$

Notes: (i) In SI units, the unit of R is $\text{J kg}^{-1} \text{ K}^{-1}$.

(ii) The value of R is different in different gases. Its value in atmosphere air is known as $R_{\text{air}} = 287 \text{ J kg}^{-1} \text{ K}^{-1}$.

③ Universal gas constant or molar constant:

It is generally denoted by R_u if a gas is product of the gas constant and the molecular weight of the gas.

Mathematically, $R_u = MR$

where, M = molecular mass of the gas in kg-mole mass
 R = gas constant

In Joules, if n_1, n_2, n_3 are the number of molecules in different parts and T_1, T_2, T_3 are the temperatures respectively, then

$$n_1 T_1 = n_2 T_2 = n_3 T_3 = \dots = n T$$

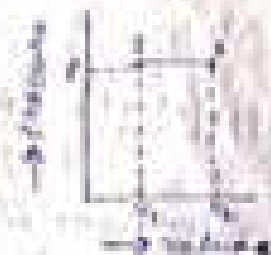
where T is the value of T at any given time.

10. In all units, the value of P is known by Boyle's law, i.e. $P \propto 1/V$.

② Boyle's Law of Isothermal Expansion:

When gas is heated at a constant pressure, its temperature and volume both increase. When there is a change in its volume, the heat supplied is utilized in increasing the internal energy of the gas, and also in doing some external work. It may be noted that this process is possible by slowly heat.

They consider a gas in a cylinder being heated at a constant pressure from an initial temperature T_1 to a final temperature T_2 . This process is shown in the P-V diagram in figure.



to show that heat supplied to the gas at

Boyle's Law:

$$Q_{12} = n C_p (T_2 - T_1)$$

Increase in internal energy,

$$U_2 - U_1 = n C_v (T_2 - T_1)$$

and work done during the process is by the gas,

$$W_{12} = P(V_2 - V_1) = nRT(T_2 - T_1)$$

$$= nR(T_2 - T_1)$$

where T is the temperature of the gas. Pressure, which will be a constant. The temperature and volume both decrease during cooling, and work is said to be done by the gas.

Heat rejected by the gas, $Q_{21} = n C_p (T_1 - T_2)$

Increase in internal energy, $U_{21} = n C_v (T_1 - T_2)$

and work done on the gas, $W_{21} = P(V_1 - V_2) = nR(T_1 - T_2)$

(b) During contraction of cooling process, work is done by the gas (n, V_1, T_1), internal energy of the gas increases (n, V_2, T_2) and heat is supplied to the gas (n, V_2, T_2).

- The heat capacity, the number of moles of gas, and the volume of the gas are constant.
- The heat capacity, the number of moles of gas, and the volume of the gas are constant.

③ Constant Volume Process or Isochoric Process:

When the gas is heated at constant volume, its temperature and pressure will increase. Since there is no change in its volume, the external work is done by the gas. All the heat supplied is stored in the body of the gas in the form of internal energy. It may be noted that this process is possible only for a gas.



Let us consider a gas at a certain pressure being heated at a constant volume from an initial temperature T_1 to a final temperature T_2 . This process is shown in the $p-V$ diagram, volume diagram, in figure.

We know that $Q_{12} = nC_v(T_2 - T_1)$ and $W_{12} = 0$.
 We also know that the internal energy $U_2 - U_1 = nC_v(T_2 - T_1)$.
 Heat supplied, $Q_{12} = nC_v(T_2 - T_1) = U_2 - U_1$.

④ Isothermal Process:

A quasistatic adiabatic process of a gas is called an isothermal process (at constant temperature).

⑤ Polytropic Process:

The polytropic process is any process of a gas that can be described by the relation $pV^n = \text{constant}$.

where n is polytropic index. When $n = 0$, the process is isobaric, when $n = 1$, the process is isothermal, when $n = \gamma$, the process is adiabatic, and when $n = \infty$, the process is isochoric. The various equations for expansion or compression for these processes, the various equations for polytropic process may be obtained by changing the value of n in the adiabatic process.

The total amount of expansion during this process is given by $\int_{V_1}^{V_2} p \, dV$

$$Q = \int_{V_1}^{V_2} p \, dV = \int_{V_1}^{V_2} \frac{p_0 V_0}{V} \, dV = \frac{p_0 V_0}{\gamma - 1} \left[\frac{V_2}{V_1} - 1 \right]$$

$$= \frac{p_0 V_0}{\gamma - 1} \left[\frac{V_2}{V_1} - 1 \right] \quad \text{[The expansion]}$$

Notes: (i) When a gas expands, the heat is supplied by the gas.

(ii) When a gas expands, the total heat is supplied by the gas.

(iii) The polytropic index is γ .

$$\gamma = \frac{C_p}{C_v}$$

② Flow expansion (or unimpeded expansion) process

A gas contained inside a vessel is allowed to expand suddenly into a vacuum chamber through an orifice of a large dimension. In this process, no heat is supplied or rejected and no external work is done, hence the total heat of the gas remains constant. This type of expansion is also called by constant total heat expansion. It is a free expansion process,

$$Q_{12} = 0, \quad W_{12} = 0 \quad \text{and} \quad \Delta U = 0$$

③ Throttling Process:

When a perfect gas is contained inside a cylinder of finite dimensions, such as a cylinder fitted with a slightly closed valve, the process is called by throttling process. During this process, no heat is supplied or rejected and also, no external work is done. However, there is no change in temperature, and the total heat of the gas remains constant.

During the throttling process, the volume of a perfect gas is under constant total heat condition and is equal to the external process. This is a throttling process,

$$Q_{12} = 0, \quad W_{12} = 0 \quad \text{and} \quad \Delta U = 0$$

② Dalton's Molecular Weight Theory and Graham's Law

Q. No.	Theory	Proof
1.	Equal no. of molecules of all the gases occupy equal volumes at constant temp. and pressure.	Equal no. of molecules of all the gases occupy equal volumes at constant temp. and pressure.
2.	Equal no. of molecules of all the gases occupy equal volumes at constant temp. and pressure.	Equal no. of molecules of all the gases occupy equal volumes at constant temp. and pressure.
3.	Equal no. of molecules of all the gases occupy equal volumes at constant temp. and pressure.	Equal no. of molecules of all the gases occupy equal volumes at constant temp. and pressure.

③ Avogadro's Law
According to Avogadro's law, equal volumes of all gases at the same temperature and pressure contain equal number of molecules.

At STP, 1 mole of any gas occupies 22.4 litres. This is known as molar volume. The volume of 1 mole of any gas at STP is 22.4 litres.

④ Avogadro's Law
If equal volumes of all gases at the same temperature and pressure contain equal number of molecules, then the molecular weight of all gases is directly proportional to their density. The molecular weight is directly proportional to the density of the gas at STP.

⑤ Dalton's Law of Partial Pressures
According to Dalton's law, the total pressure exerted by a mixture of ideal gases is equal to the sum of the partial pressures of the constituents.

Partial pressure of each constituent is defined as the pressure it would exert if it alone occupied the volume of the mixture at the same temp. as that of the mixture.
Dalton's law of ideal gas, $P = P_1 + P_2 + P_3 + \dots = \sum (n_i R T / V)$
or $PV = nRT$

(2) The initial pressure and temperature of certain mass of air contained in a closed vessel are 10^5 Pa and 30°C respectively. It is heated until its temperature rises to 100°C . Calculate the final pressure.

Solution: Given: $P_1 = 10^5 \text{ Pa}$, $T_1 = 30^\circ\text{C}$, $T_2 = 100^\circ\text{C}$, $P_2 = ?$
 $T_1 = 30 + 273 = 303 \text{ K}$

Since the vessel is a closed one, $V_1 = V_2$. According to Boyle's law, at constant volume, $P \propto T$.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \quad \text{Since } V_1 = V_2$$

$$10^5 \times \frac{1}{303} = \frac{P_2}{373}$$

$$P_2 = 10^5 \times \frac{373}{303} = 1.23 \times 10^5 \text{ Pa}$$

(3) A quantity of air having a mass of 10 kg and temperature of 30°C occupies a volume of 0.3 m^3 . Find the final pressure and also the volume of the gas when the temperature is 100°C and pressure is 10^5 Pa . Assume $R = 0.287 \text{ kJ/kg}^\circ\text{K}$.

Solution: Given: $m = 10 \text{ kg}$, $T_1 = 30^\circ\text{C}$, $V_1 = 0.3 \text{ m}^3$, $T_2 = 100^\circ\text{C}$, $P_2 = 10^5 \text{ Pa}$.

$$V_1 = 0.3 \text{ m}^3, T_1 = 30 + 273 = 303 \text{ K}, P_1 = ?$$

$$R = 0.287 \text{ kJ/kg}^\circ\text{K} = 287 \text{ J/kg}^\circ\text{K}$$

Let P_1 = Initial absolute pressure of the gas in N/m^2 .

Now, $P_1 V_1 = mRT_1$

$$P_1 \times 0.3 = 10 \times 287 \times 303$$

$$P_1 = \frac{10 \times 287 \times 303}{0.3} = 2.87 \times 10^6 \text{ Pa}$$

Required initial gauge pressure = Initial absolute pressure - Atmospheric pressure

$$= 2.87 \times 10^6 - 1.01325 \times 10^5$$

$$= 2.768675 \times 10^6 \text{ Pa}$$

Let V_2 = Required final volume in m^3 .

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$\frac{2.87 \times 10^6 \times 0.3}{303} = \frac{10^5 \times V_2}{373}$$

$$V_2 = \frac{2.87 \times 10^6 \times 0.3 \times 373}{10^5 \times 303} = 1.35 \text{ m}^3$$

∴ $V_2 = 1.35 \text{ m}^3$ and $P_2 = 10^5 \text{ Pa}$

∴ Final pressure = 10^5 Pa and final volume = 1.35 m^3

(8) The density of a certain gas is 1.25 kg m^{-3} at 20°C and under atmospheric pressure. What volume of gas must be collected when the following physical data are given: $T_2 = 100^\circ\text{C}$, $P_2 = 1.013 \times 10^5 \text{ Pa}$, $m = 1 \text{ kg}$.

Solution: Given: $\rho_1 = 1.25 \text{ kg m}^{-3}$, $T_1 = 20^\circ\text{C} = 293 \text{ K}$, $P_1 = 1.013 \times 10^5 \text{ Pa}$
 $T_2 = 100^\circ\text{C} = 373 \text{ K}$, $P_2 = 1.013 \times 10^5 \text{ Pa}$, $m = 1 \text{ kg}$
 Let, $V_1 = \text{Initial volume}$, $V_2 = \text{Final volume}$

$$V_2 = \frac{P_1 V_1 T_2}{P_2 T_1}$$

$$= \frac{1.25 \times 293 \times 373}{1.013 \times 10^5 \times 1.013 \times 10^5} = 1242.49 \text{ m}^3$$

Required volume of gas which must be collected at the given conditions is 1242.49 m^3 .

Note: If the density of the gas is given, the volume of gas is calculated by using the ideal gas equation. The density of a gas is always constant at a certain temperature and pressure.

(9) 1 kg of air at NTP occupies a volume of 700 litres. What will be the volume and density of this air at 20°C and at an absolute pressure of $2 \times 10^5 \text{ Pa}$?

Solution: Given: $m = 1 \text{ kg}$, $T_1 = 0^\circ\text{C} = 273 \text{ K}$, $P_1 = 1.013 \times 10^5 \text{ Pa}$
 $V_1 = 700 \text{ litres} = 0.7 \text{ m}^3$, $T_2 = 20^\circ\text{C} = 293 \text{ K}$
 $P_2 = 2 \times 10^5 \text{ Pa}$ [∵ $1 \text{ litre} = 10^{-3} \text{ m}^3$]

$$V_2 = \frac{P_1 V_1 T_2}{P_2 T_1} = \frac{1.013 \times 10^5 \times 0.7 \times 293}{2 \times 10^5 \times 273} = 0.407 \text{ m}^3$$

$$\rho_2 = \frac{m}{V_2} = \frac{1}{0.407} = 2.45 \text{ kg m}^{-3}$$

Required density is 2.45 kg m^{-3} .

(10) The internal volume of a closed vessel containing air at a temperature of 20°C is 5 m^3 . A vacuum pump is used to evacuate a quantity of 200 kg of air. The atmospheric pressure is $1.013 \times 10^5 \text{ Pa}$. Find the mass of air contained in the vessel. Take $R = 287 \text{ J kg}^{-1} \text{ K}^{-1}$.

Solution: Given: $V_1 = 5 \text{ m}^3$, $T_1 = 20^\circ\text{C} = 293 \text{ K}$
 $P_1 = 1.013 \times 10^5 \text{ Pa}$, $m = 200 \text{ kg}$
 $P_2 = 1.013 \times 10^5 \text{ Pa}$, $T_2 = 293 \text{ K}$

Given: $R = 287 \text{ J kg}^{-1} \text{ K}^{-1}$
 Let, $m = \text{Required mass of the air} = ?$

$$P_1 V_1 = m R T_1$$

$$1.013 \times 10^5 \times 5 = m \times 287 \times 293$$

$$m = \frac{1.013 \times 10^5 \times 5}{287 \times 293} = 59.4 \text{ kg}$$

(6) An automobile tyre contains carbon dioxide at 21 atm pressure and is inflated to 30 atm. The atmospheric pressure is 1.013 x 10⁵ Pa. If the tyre is kept at constant temperature, what will be the gauge pressure? Assume that the tyre does not stretch due to mechanical pressure.

Solution: [Note: we will use the gauge and absolute pressure and absolute temperature]

Atmospheric Pressure = $\frac{1}{10}$ x 760 mm = 0.76 x 10⁵ Pa

Absolute Pressure $P_1 = 0.76 \times 10^5 + 21 = 2.76 \times 10^5$ Pa

$T_1 = 27^\circ\text{C} = 300\text{K}$

Given: $V_1 = V_2$

So the gauge pressure $\frac{P_1}{T_1} = \frac{P_2}{T_2}$

$\Rightarrow \frac{2.76 \times 10^5}{300} = \frac{P_2}{300}$

$\Rightarrow P_2 = 2.76 \times 10^5$ Pa = gauge absolute pressure

Required gauge pressure = $2.76 \times 10^5 - 0.76 \times 10^5 = 2.0 \times 10^5$ Pa

(7) When 0.1 mol of a gas is heated slowly at 1 atm, it is observed that the gas expands 10% and does work at constant pressure and 10% of heat when heated at constant volume. Find (i) adiabatic index, (ii) the constant and (iii) molecular weight.

Solution: Heat is a specific heat of the gas at constant volume is $\frac{1}{2} nR$

$n = 0.1$ mol of the gas $\therefore Q = 0.05 nR$

Heat lost when at constant pressure is $\frac{1}{2} nR$

$Q_1 = nC_p(T_2 - T_1) = nC_p(T_1 - T_2)$

$100 = nC_p(100 - 80) = nC_p \times 20$

At constant volume $Q_2 = nC_v(T_2 - T_1) = nC_v(T_1 - T_2)$

Similarly $100 = nC_v(100 - 80) = nC_v \times 20$

$\frac{100}{20} = \frac{C_p}{20} \Rightarrow C_p = 100$ [where C_p is the specific heat]

$\therefore C_p = 100 = \frac{f}{2} nR = \frac{f}{2} \times 0.1 \times 8.314 = 4.157 f$

Q. 819. Let n gms. of a gas be contained in a cylinder of length l cm. The temperature of the gas is T K. The pressure of the gas is P N/m².
 $\therefore n = \frac{PV}{RT} = \frac{P \times \pi r^2 l}{RT}$ [where r is the radius of the cylinder]

(14) A plastic bottle of capacity 1.5 l is completely filled with a gas at 100 kPa and temperature of 30°C . Calculate

- (i) mass of nitrogen contained in the bottle
 - (ii) molar volume of the gas
 - (iii) density of the gas
 - (iv) molar density of the gas
- Take molecular weight of nitrogen as 28 .

Solution: (i) Let m = mass of N_2 contained
 R = characteristic gas constant of N_2
 We know that universal gas constant = 8.314 J/kg mol K.
 $R = \frac{R_u}{M}$ where M = molecular weight of $N_2 = 28$ (g/mol)
 $\therefore R = \frac{8.314}{28} = 0.297$ J/kg mol K
 $\therefore m = \frac{PV}{RT} = \frac{100 \times 10^3 \times 1.5 \times 10^{-3}}{0.297 \times 303} = 1.66$ kg

According to the formula, $P = \frac{mRT}{V}$ we get,
 $100 \times 10^3 \times 1.5 \times 10^{-3} = 1.66 \times 0.297 \times 303$

(ii) molar volume = volume occupied by one mole of gas
 Again, the P mole molar volume is V_m
 Let V_m = required molar volume

Then $P V_m = RT$ (1) (2)
 $\therefore V_m = \frac{RT}{P} = \frac{0.297 \times 303}{100 \times 10^3} = 9.0 \times 10^{-4} \text{ m}^3$

(iii) Density of the gas = $\frac{m}{V}$
 $= \frac{1.66}{1.5 \times 10^{-3}} = 1106.67 \text{ kg/m}^3$

(iv) molar density = $\frac{m}{V} \times \frac{1}{M}$
 $= \frac{1.66}{1.5 \times 10^{-3}} \times \frac{1}{28} = 39.52 \text{ mol/m}^3$

Q1) A vessel of 10 m³ capacity contains 1 kg mole of O₂ at 10 bar. Determine the pressure of O₂ by the van der Waals equation. Calculate the van der Waals, change of specific internal energy and specific enthalpy. Assume value of specific heat to be real molecular weight of O₂ to be 32.

Solution: [mole: 10, internal energy and sp. enthalpy values internal energy and enthalpy of unit mole]

Given: $V = 10 \text{ m}^3$, $T = 10 + 273 = 283 \text{ K}$
 $V_1 + 30 + 273 = 283 \text{ K}$, $10/32 = 0.3125 \text{ kmol}$, $n = 10$

We know that van der Waals gas constant is given by,

$$R^* = 8.314 \text{ kJ/kmol K}$$

$$a = 1.36 \text{ m}^6 \text{ kmol}^{-2} \text{ bar}$$

$$b = 0.037 \text{ m}^3 \text{ kmol}^{-1}$$

Let, P_1 = Realized initial pressure of O₂ in vessel.

Then, $P_1 \times 10^3 \times 10 = 10 \times 8.314 \times 283 - \frac{10^2 \times 1.36}{10} + \frac{10 \times 10 \times 0.037^2}{10}$

Let, P_1 = Realized initial pressure.

Then, $\frac{P_1 \times 10^4}{10} = 23087 - 136 + 13.6$

Let, ΔU = Realized change of internal energy per unit mole of O₂.

Then, $\Delta U = n C_v (T_2 - T_1) + \frac{a}{V} (n^2 - n_1^2)$

Given: $\frac{\Delta U}{n} = 14$ and $C_v = 14.308 \text{ kJ/kmol K}$

We know that, $\Delta U = n C_v (T_2 - T_1) + \frac{a}{V} (n^2 - n_1^2)$

$14 = 14.308 (T_2 - 283) + \frac{1.36}{10} (10^2 - 10^2)$

$14 = 14.308 (T_2 - 283)$

[mole: 10, sp. enthalpy but there is a change of internal energy]

Also, $\Delta H = n C_p (T_2 - T_1) + \frac{a}{V} (n^2 - n_1^2)$

[mole: 10, also we give the change of enthalpy]

Q2) Determine the gas constant of hydrogen if the specific volume of hydrogen at 1 bar and 100 K is 10 m³/kg. Also find the specific heat of the gas if the value of the gas specific heat is 1.407.

Solution: [sp. volume, value volume, pressure of unit mass of gas]

Given: $P = 1 \text{ bar}$, $T = 100 \text{ K}$, $v = 10 \text{ m}^3/\text{kg}$, $n = 1 \text{ kmol}$

We know, $Pv = RT$ or $1 \times 10 = 8.314 \times T$

Also, $C_p = 1.407 \text{ kJ/kg K}$

Again, $C_p - C_v = R$, $1.407 - C_v = 8.314$

or, $C_v = 1.407 - 8.314 = -6.907 \text{ kJ/kg K}$

and $C_p = 1.407 \times 10^{-3} = 14.07 \text{ kJ/kmol K}$

100 A vessel of capacity 100 m³ contains air at a pressure of 101 kPa and temperature of 27°C. Additional air is pumped into the vessel until the pressure rises to 200 kPa and the temperature to 30°C. Determine the mass of air pumped in, if the vessel is allowed to cool until the temperature is again 27°C. Calculate the pressure in the vessel, also determine the mass of air transferred during the change of state.

Solution: Let m_1 = mass of air initially contained in the vessel
 Then, $P_1 = 101 \text{ kPa}$, $V_1 = 100 \text{ m}^3$, $T_1 = 27^\circ\text{C}$, $T_1 = 27 + 273 = 300 \text{ K}$

$$\therefore P_1 V_1 = m_1 R T_1 \quad \dots (1)$$

$$m_1 = \frac{P_1 V_1}{R T_1} = \frac{101 \times 100}{0.287 \times 300} = 117.4 \text{ kg}$$

Let m_2 = mass of air in the vessel when additional air has been pumped into it

$$P_2 V_2 = m_2 R T_2 \quad \dots (2)$$

$$m_2 = \frac{P_2 V_2}{R T_2} = \frac{200 \times 100}{0.287 \times 300} = 228.2 \text{ kg}$$

$$\therefore m_2 - m_1 = 228.2 - 117.4 = 110.8 \text{ kg}$$

Required mass of air pumped into the vessel = 110.8 kg

Let P_3 = Required pressure in 100 m³ when the vessel has been cooled.

$$\text{Then, } P_3 V_3 = m_2 R T_3 \quad \text{Here, } V_3 = 100 \text{ m}^3, T_3 = 27^\circ\text{C} = 300 \text{ K}$$

$$P_3 \times 100 = 228.2 \times 0.287 \times 300$$

$$P_3 = \frac{228.2 \times 0.287 \times 300}{100} = 197.8 \text{ kPa}$$

Required final pressure during the change of state is 197.8 kPa

$$\therefore P_3 = 197.8 \text{ kPa}$$

Since the degree of freedom is 1, it is a case of heat rejection and heat into the volume $\frac{P}{\gamma}$ is not applicable because $\gamma > 1$

A vessel contains 100 m³ of a gas at a pressure of 101 kPa and the rate of air is reduced by an air pump, total mass in the vessel of the remaining gas, the temperature being unaltered.

Solution: Let m_1 = mass of air initially contained in the vessel

$$\text{Then, } P_1 V_1 = m_1 R T_1 \quad \dots (1)$$

Final mass of air in the vessel = $m_2 = \frac{1}{2} m_1 = \frac{1}{2} m_1$

Let P_2 = Required final pressure in 100 m³

$$\text{Then, } P_2 V_2 = m_2 R T_2 \quad \dots (2)$$

Dividing eqn (2) by eqn (1), we get,

$$\frac{P_2 V_2}{P_1 V_1} = \frac{m_2 R T_2}{m_1 R T_1} = \frac{1}{2}$$

$$\therefore P_2 = \frac{1}{2} P_1 = \frac{1}{2} \times 101 = 50.5 \text{ kPa}$$

(14) Density of hydrogen gas at 20°C and 1 atm is 0.0899 g/l. Find the characteristic gas constant of hydrogen gas and its specific heat at constant pressure and at constant volume.

Solution: Given: $P_1 = 1.0132 \times 10^5 \text{ N/m}^2$, $T = 293 \text{ K}$, $\rho = 0.0899 \text{ kg/m}^3$
 Let, $R = \text{characteristic gas constant}$
 $m = 2 \text{ kg}$, $V = 22.7 \text{ m}^3$ at constant pressure and constant temperature
 $m_1 = 2 \text{ kg}$, $V_1 = 22.7 \text{ m}^3$
 $m_2 = 4.1888 \text{ kg}$, $V_2 = 22.7 \text{ m}^3$

Given: $\frac{m_1}{m_2} = \frac{V_1}{V_2}$, where ρ is constant at constant pressure and constant temperature.
 $\rho = 0.0899 \text{ kg/m}^3$

Again, $P = \rho R T$
 $1.0132 \times 10^5 = 0.0899 R \times 293$
 $R = \frac{1.0132 \times 10^5}{0.0899 \times 293} = 370.4 \text{ J/kg}^\circ\text{C}$

From value of R , we get
 $C_p = R + C_v$
 $370.4 = 10.2 + C_v$
 $C_v = 360.2 \text{ J/kg}^\circ\text{C}$

(15) 0.15 m³ of a gas at a pressure of 10 atm undergoes a process at 200 atm, the final volume being 0.2 m³. Calculate the change in internal energy of the gas. Take $C_p = 24 \text{ kJ/kg}^\circ\text{C}$ and $R = 287 \text{ J/kg}^\circ\text{C}$.

Solution: Given: $V_1 = 0.15 \text{ m}^3$, $V_2 = 0.2 \text{ m}^3$
 $P_1 = 10 \text{ atm} = 1.0132 \times 10^6 \text{ N/m}^2$, $P_2 = 200 \text{ atm} = 2.0264 \times 10^7 \text{ N/m}^2$
 $C_p = 24 \text{ kJ/kg}^\circ\text{C}$, $R = 287 \text{ J/kg}^\circ\text{C}$

Change in internal energy of a gas is given by
 $\Delta U = m C_v (T_2 - T_1)$
 we know, $P_1 V_1 = P_2 V_2 = m R T_1 = m R T_2$
 $\frac{P_1 V_1}{P_2 V_2} = \frac{T_1}{T_2}$
 $\frac{1.0132 \times 10^6 \times 0.15}{2.0264 \times 10^7 \times 0.2} = \frac{T_1}{T_2}$
 $T_2 = 20 T_1$

Again, $P_1 V_1 = m R T_1$
 $1.0132 \times 10^6 \times 0.15 = m \times 287 \times T_1$
 $m = \frac{1.0132 \times 10^6 \times 0.15}{287 \times T_1} = \frac{528.25}{T_1}$

Putting these values of m and T_2 in $\Delta U = m C_v (T_2 - T_1)$, we get
 $\Delta U = 0.15 \times 287 \times (20 T_1 - T_1) = 0.15 \times 287 \times 19 T_1$
 $= 840.45 T_1$

From $P_1 V_1 = m R T_1$
 $1.0132 \times 10^6 \times 0.15 = \frac{528.25}{T_1} \times 287 \times T_1$
 $T_1 = \frac{528.25 \times 287}{1.0132 \times 10^6 \times 0.15} = 118.860$

Therefore, $\Delta U = 840.45 \times 118.860 = 99.9 \text{ kJ}$

(19) A tank having a capacity of 15 m^3 contains air at 10°C and atmospheric pressure. The tank is evacuated at constant temperature until the vacuum is 740 mm Hg . Find the mass of air which is left in the vessel if the mass of air pumped out, 15 g of the air left in the tank is equal to 5°C , what is the pressure of the air if for air $R = 287 \text{ J/kg}^\circ\text{K}$

Solution: Given: $V_1 = 15 \text{ m}^3$, $T_1 = 10 + 273 = 283 \text{ K}$

Let, $m_1 =$ mass of air initially contained in the tank

$$P_1 V_1 = m_1 R T_1 \quad \text{and} \quad P_2 V_2 = m_2 R T_2$$

$$\therefore \frac{P_1 V_1}{T_1} = \frac{m_1 R}{1} \quad \text{and} \quad \frac{P_2 V_2}{T_2} = \frac{m_2 R}{1}$$

Let, $m_2 =$ mass of air remaining contained in the tank

$$P_1 V_1 = m_1 R T_1 \quad \text{and} \quad P_2 V_2 = m_2 R T_2$$

$$1.01325 \times 10^5 \times 15 = m_1 \times 287 \times 283$$

$$m_1 = \frac{1.01325 \times 10^5 \times 15}{287 \times 283} = 19.17 \text{ kg}$$

Let, $m_2 =$ mass of air left in the tank

$$P_2 V_2 = m_2 R T_2 \quad \text{Here, } T_1 = T_2 = 273 \text{ K and } V_2 = 15 \text{ m}^3$$

$$\therefore 0.81325 \times 10^5 \times 15 = m_2 \times 287 \times 273$$

$$m_2 = \frac{0.81325 \times 10^5 \times 15}{287 \times 273} = 15.17 \text{ kg}$$

Resulted mass of air pumped out

$$m_1 - m_2 = 19.17 - 15.17 = 4 \text{ kg}$$

Let, $P_2 =$ final pressure of air in 15 m^3 vessel if the tank cooled

$$P_2 V_2 = m_2 R T_2 \quad \text{Here, } V_2 = V_1 = 15 \text{ m}^3, T_2 = 5 + 273 = 278 \text{ K}$$

$$P_2 \times 15 = 15.17 \times 287 \times 278 \quad \text{or } P_2 = \frac{15.17 \times 287 \times 278}{15} = 7.4 \times 10^5 \text{ Pa}$$

(20) A tank containing compressed air at a pressure of 50 bar and 30°C . A portion of the air is released when the tank and the pressure and temp. is decreasing with the final 10 bar and 20°C respectively. If the released air measured 10 m^3 at standard atmospheric pressure and 15°C , what is the volume of the tank & mass remaining gas contained in air at 10°C and 10 bar .

Solution: Let m_1 be the mass of 10 m^3 of air at standard atmospheric pressure = $1.01325 \times 10^5 \text{ Pa}$ and $15 + 273 = 288 \text{ K}$

$$10 \text{ m}^3 = \frac{m_1 R T_1}{P_1} = \frac{m_1 \times 287 \times 288}{1.01325 \times 10^5} = 10 \text{ m}^3$$

$$m_1 = \frac{10 \times 1.01325 \times 10^5}{287 \times 288} = 12.28 \text{ kg}$$

According to the ideal gas law, we get

$$P_1 V_1 = m_1 R T_1 \quad \text{and} \quad P_2 V_2 = m_2 R T_2$$

$$10 \times 1.01325 \times 10^5 = 12.28 \times 287 \times 288$$

$$m_2 = \frac{10 \times 1.01325 \times 10^5}{287 \times 288} = 12.28 \text{ kg}$$

Let, $V =$ required volume of the tank in 10 bar

$m_2 =$ mass of air left in the tank

$$\text{Then, } 10 \times 1.01325 \times 10^5 = m_2 \times 287 \times 288 \quad [T_1 = 20 + 273 = 293 \text{ K}]$$

$$\text{or, } m_2 = \frac{10 \times 1.01325 \times 10^5}{287 \times 293} = 12.28 \text{ kg}$$

Total mass of gas by the time it flows to

$$m = \rho V = 1.2 \times 10^{-3} \times 1.5 \times 10^{-3} \text{ kg}$$

$$m = 1.8 \times 10^{-6} \text{ kg}$$

$$m = 1.8 \times 10^{-6} \text{ kg} = 1.8 \times 10^{-6} \text{ kg}$$

$$m = 1.8 \times 10^{-6} \text{ kg} = 1.8 \times 10^{-6} \text{ kg}$$

Using constant Absolute Pressure (isobaric):

(a) work done $w = \int_{V_1}^{V_2} p \, dV = p(V_2 - V_1)$

[note: In case of expansion, work done will be obtained and in case of contraction, work done will be obtained]

(b) heat delivered $Q = nC_p(T_2 - T_1)$

(c) change of internal energy $\Delta U = nC_v(T_2 - T_1) = \frac{5}{2} nR(T_2 - T_1)$

(d) change of enthalpy $\Delta H = nC_p(T_2 - T_1)$

(e) change of enthalpy $\Delta H = nC_p(T_2 - T_1) = 2nC_p(T_2 - T_1)$

$$\left. \begin{aligned} \frac{P_1 V_1}{T_1} &= \frac{P_2 V_2}{T_2} \\ P_1 V_1 &= P_2 V_2 \\ P_1 T_1 &= P_2 T_2 \end{aligned} \right\} \text{Here } P_1 = P_2$$

A gas of 10^{-3} m^3 at a pressure of 10^5 Pa expands isobarically to a volume of $2 \times 10^{-3} \text{ m}^3$. Initial temperature of the gas is 27°C , and $n = 1 \text{ mol}$, and $C_p = 29 \text{ J/mol}^\circ\text{C}$.

Find its change of internal energy of the gas, the heat delivered to the gas and the change of enthalpy.

Solution: Given: $V_1 = 10^{-3} \text{ m}^3$, $V_2 = 2 \times 10^{-3} \text{ m}^3$, $T_1 = 27^\circ\text{C} + 273 = 300^\circ\text{C}$

$T_2 = ?$, $n = 1 \text{ mol}$, $C_p = 29 \text{ J/mol}^\circ\text{C}$ and $C_v = 20 \text{ J/mol}^\circ\text{C}$

(a) change of internal energy of the gas, $\Delta U = nC_v(T_2 - T_1)$ [at this volume is $2 \times 10^{-3} \text{ m}^3$]

now, $P_1 V_1 = P_2 V_2$

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

we know that $P = \frac{nR}{V} T$ $\Rightarrow P_1 = \frac{nR}{V_1} T_1$ $\Rightarrow 10^5 = \frac{1 \times 8.314}{10^{-3}} T_1$

from eqn (1) we get $10^5 \times 10^{-3} = 10^5 \times 2 \times 10^{-3}$ $\Rightarrow T_2 = 300^\circ\text{C}$

from eqn (2) we get $\Delta U = 1.0823 \times 20 \times (300 - 300) = 0$

again, $\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$ $\Rightarrow T_2 = \frac{P_2 V_2}{P_1 V_1} T_1$

$\therefore \frac{T_2}{T_1} = \frac{V_2}{V_1}$ $\Rightarrow T_2 = \frac{V_2}{V_1} T_1 = \frac{2 \times 10^{-3}}{10^{-3}} \times 300 = 600^\circ\text{C}$

from eqn (3) we get $\Delta H = 1.0823 \times 29 \times (600 - 300) = 94.496 \text{ J}$ Ans

20) Let air expanded from 100°C to 10°C at constant pressure. The work done is 100 J. Find the change of internal energy of air.

Work done $W = P(V_2 - V_1) = 100 \text{ J}$ (at 10°C) state
 $= 100 \text{ J}$

Change of internal energy $= m C_v (T_2 - T_1)$
 $= 1.00 \text{ kg} \times 1.00 \text{ kJ/kg} \cdot \text{K} \times (10 - 100) \text{ K}$
 $= -90 \text{ kJ}$

21) 5 kg of air at 10°C and at atmospheric pressure is heated at constant pressure to 100°C. Determine the final volume of air. (i) work done, (ii) change of internal energy of air and (iii) change of internal energy of air. Assume suitable value of C_v and C_p for air.

Assume suitable value of C_v and C_p for air.

Solution: Given: $m = 5 \text{ kg}$, $T_1 = 10^\circ\text{C} = 283 \text{ K}$
 $T_2 = 100^\circ\text{C} = 373 \text{ K}$

(i) work done, $W = \frac{P}{\gamma - 1} (V_2 - V_1) = \frac{P}{\gamma - 1} V_1 \left(\frac{T_2}{T_1} - 1 \right)$
 $\frac{P V_1}{\gamma - 1} = \frac{P V_2}{\gamma - 1}$
 $V_1 = \frac{P V_2}{P}$
 $V_2 = \frac{P V_1}{P}$
 $V_2 = \frac{1.01325 \times 10^5 \times 5}{1.01325 \times 10^5} = 5 \text{ m}^3$

(ii) work done by air, $W = P(V_2 - V_1) = 1.01325 \times 10^5 (5 - 5) = 0 \text{ J}$
 $= 1.01325 \times 10^5 \times 0 = 0 \text{ J}$
 $= 0 \text{ J}$

(iii) change of internal energy of air, $\Delta U = m C_v (T_2 - T_1)$
 $\Delta U = 5 \times 0.718 (100 - 10) = 359.5 \text{ kJ}$

(iv) change of internal energy of air, $\Delta U = m C_v (T_2 - T_1)$
 $\Delta U = 5 \times 1.00 (100 - 10) = 450 \text{ kJ}$

③ constant volume of diatomic process (reversible)

- (i) Heat absorbed, $Q = n C_V (T_2 - T_1)$
 (ii) change of internal energy, $\Delta U = n C_V (T_2 - T_1) = Q$
 (iii) change of entropy, $\Delta S = n C_V \ln \frac{T_2}{T_1} = n C_V \ln \frac{P_2}{P_1}$

(iv) $\frac{Q_2}{Q_1} = \frac{\Delta U_2}{\Delta U_1} = \frac{T_2}{T_1} = \frac{P_2}{P_1}$ [$\because C_V = \frac{5}{2} R$]

(v) $\frac{Q_2}{Q_1} = \frac{P_2}{P_1}$; here, $n = 5, \therefore \frac{Q_2}{Q_1} = \frac{P_2}{P_1}$
 $\frac{Q_2}{Q_1} = \frac{P_2}{P_1}$

(vi) 1.2 m^3 of air at 100°C is heated at constant volume while the final temperature is 150°C . Assuming $\gamma = 1.4$ calculate $T_2 = ?$ the change of
 (i) mass of air, (ii) final pressure & volume
 (iii) amount of heat supplied, (iv) external work done
 (v) change of internal energy.

Solution: (i) Let P_1 characteristic for constant vol air

Then, $P_1 V_1^{\gamma} = P_2 V_2^{\gamma} = 1.01 \times 10^5 \times (1.2)^{1.4} = 1.01 \times 10^5 \times 1.91$

Let, $P_2 = 0.5 \text{ MPa} = 5 \times 10^5 \text{ Pa}$, $V_2 = 1.2 \text{ m}^3$

$T_1 = 273 + 100 = 373 \text{ K}$, $n = \text{mass of air} / \text{molar mass}$

$\therefore P_1 V_1 = n R T_1$

$n = \frac{P_1 V_1}{R T_1} = \frac{1.01 \times 10^5 \times 1.2}{8.314 \times 373} = 3.91 \text{ moles}$

(ii) $\frac{Q_2}{Q_1} = \frac{P_2}{P_1}$; here, $\frac{Q_2}{Q_1} = \frac{P_2}{P_1} = \frac{5 \times 10^5}{1.01 \times 10^5} = 4.95$

$\therefore \frac{Q_2}{Q_1} = \frac{P_2}{P_1}$

$n C_V T_2 = \frac{P_2 V_2}{\gamma - 1} = \frac{5 \times 10^5 \times 1.2}{0.4} = 1.5 \times 10^6 \text{ J}$
 $\therefore T_2 = \frac{1.5 \times 10^6}{3.91 \times \frac{5}{2} \times 8.314} = 201.72 \text{ K}$
 $= 201.72 - 273 = -71.28^\circ\text{C}$

(iii) Let $Q =$ heat supplied

Then, $Q = n C_V (T_2 - T_1) = 3.91 \times \frac{5}{2} \times 8.314 \times (201.72 - 373)$

$= -607.52 \text{ J}$

(iv) External work done = 0, because it is a constant volume process.

(v) change of internal energy of 1.2 m^3 of air

$\Delta U = n C_V (T_2 - T_1) = 0$

$= 3.91 \times \frac{5}{2} \times 8.314 \times (201.72 - 373) = -607.52 \text{ J}$

$= -607.52 \text{ J}$

(23) 1000 cc of air at constant pressure, at 27°C is a gas at 27°C and at atmospheric pressure. To during the process of heat addition, the volume remains constant, find the final temperature and pressure. Take, R as the gas constant and $\gamma = 1.418$ as the ratio.

Solution: Given: $V = 1000 \text{ cc}$, $V_1 = 1000 \text{ cc}$, $T_1 = 27^\circ\text{C} = 300 \text{ K}$
 $P_1 = 1.01325 \text{ bar} = 1.01325 \times 10^5 \text{ Pa}$ [RHS] $\gamma = 1.418$
 $1.01325 \times 10^5 \times 1000 \times 10^{-6} = n \times 8.314 \times 300$
 $n = 4.01 \text{ mol}$

For constant volume process, $Q = nC_v(T_2 - T_1)$
 $1000 = 4.01 \times 12.47 \times (T_2 - 300) = 5000$
 $T_2 - 300 = \frac{5000}{4.01 \times 12.47} = 98.5$
 $T_2 = 398.5 \text{ K}$
 $\frac{P_2}{P_1} = \frac{T_2}{T_1}$ as $V_1 = V_2$
 $P_2 = P_1 \times \frac{T_2}{T_1} = 1.01325 \times 10^5 \times \frac{398.5}{300} = 1.34 \times 10^5 \text{ Pa}$

(24) 10 m³ of air at a pressure of 100 kPa is heated at constant volume until the pressure becomes 150 kPa. Find the heat added and work done.

Solution: Given: $V_1 = V_2 = 10 \text{ m}^3$, $P_1 = 100 \text{ kPa}$, $P_2 = 150 \text{ kPa}$
 $n = \frac{P_1 V_1}{R T_1} = \frac{100 \times 10}{8.314 T_1}$
 For constant volume process, $Q = nC_v(T_2 - T_1)$
 $Q = nC_v(T_2 - T_1) = \frac{P_2 V_2 - P_1 V_1}{\gamma - 1}$
 $Q = \frac{150 \times 10 - 100 \times 10}{1.418 - 1} = 1125 \times 10 \text{ J}$
 $Q = 11250 \text{ J}$

For constant volume process, heat added is given by
 $Q = nC_v(T_2 - T_1) = C_v(P_2 V_2 - P_1 V_1)$

From eqn (1) and (2) we get
 $P_2 V_2 - P_1 V_1 = \frac{Q}{C_v}$ and $nC_v(T_2 - T_1) = \frac{Q}{C_v}$

From eqn (3)
 $Q = C_v \left(\frac{P_2 V_2 - P_1 V_1}{C_v} - \frac{P_1 V_1}{C_v} \right)$
 $= \frac{C_v}{R} (P_2 V_2 - P_1 V_1) = \frac{C_v}{R} (P_2 V_2 - P_1 V_1)$
 $= \frac{C_v}{R} (150 \times 10 - 100 \times 10) = \frac{C_v}{R} (5000)$
 $= \frac{C_v}{R} \times 5000 = 11250 \text{ J}$

Q. Estimation of adiabatic exponent of a diatomic gas [10 marks]

- (i) Characteristics $\gamma = 1.4$, $\rho = 1.25 \text{ kg/m}^3$, $\mu = 1.8 \times 10^{-4} \text{ Pa}\cdot\text{s}$
- (ii) Change of velocity, $\rho_2 = 0.625 \text{ kg/m}^3$, $\mu_2 = 1.8 \times 10^{-4} \text{ Pa}\cdot\text{s}$
- (iii) $\frac{P_2}{P_1} = \frac{\rho_2}{\rho_1}$
- (iv) $P_1 V_1 = P_2 V_2$
- (v) $P_1 V_1^\gamma = P_2 V_2^\gamma$

Q. A gas of air under a pressure of 100 kPa is compressed to a pressure of 200 kPa, isothermally. Find the amount of work done by the gas, the change in internal energy and the quantity of heat to be rejected during compression.

Solution: Given: $P_1 = 100 \text{ kPa}$, $P_2 = 200 \text{ kPa}$, $T_1 = T_2$
 Process: Isothermal process, work done by gas is

Let V_1, V_2 be the initial and final volumes respectively.

From continuity we get $\rho_1 V_1 = \rho_2 V_2$

$V_2 = \frac{\rho_1}{\rho_2} V_1 = \frac{1.25}{0.625} V_1 = 2 V_1$

Work done by gas is $W = \int_{V_1}^{V_2} P dV$

$W = P_1 V_1 \ln \frac{V_2}{V_1} = 100 \times 10^3 \times V_1 \ln 2$

$W = 100 \times 10^3 \times V_1 \times 0.693 = 69.3 \times 10^3 V_1 \text{ J}$

The sign indicates that work has been done by the gas.

Q. A gas of air under a pressure of 100 kPa and volume of 1 m³ expands isothermally to a volume of 2 m³. Calculate:

- (i) Initial temperature of air.
 - (ii) Final temperature of air.
 - (iii) External work done by air.
 - (iv) Change in internal energy.
- For air $C_p = 1.005 \text{ kJ/kg}\cdot\text{K}$ and $C_v = 0.718 \text{ kJ/kg}\cdot\text{K}$

[Note: If not otherwise stated, take air as an ideal gas.]

Solution: Given: $P_1 = 100 \text{ kPa}$, $V_1 = 1 \text{ m}^3$, $V_2 = 2 \text{ m}^3$, $T_1 = T_2$

(i) Let $\gamma = \text{characteristic gas constant for air}$

$\gamma = C_p - C_v = 1.005 - 0.718 = 0.287 \text{ kJ/kg}\cdot\text{K}$

Let $T_1 = \text{Initial absolute temperature}$

Now, $P_1 V_1 = \mu R T_1$

1) In Isothermal process, $W = nRT \ln \frac{V_2}{V_1}$

2) $W = nRT \ln \frac{V_2}{V_1} = 847 \text{ J}$

3) $W = nRT \ln \frac{V_2}{V_1} = 174 \text{ J}$

(ii) Since it is an isothermal process, final temp $T_2 = T_1 = 300 \text{ K}$

(iii) For isothermal process, work done is given by

$W = nRT \ln \frac{V_2}{V_1}$

$= 8.314 \times 300 \times \ln \frac{2}{1} = 174 \text{ J}$

$= 174 \text{ J}$

(iv) For isothermal process, final temp $T_2 = T_1 = 300 \text{ K}$

$W = 174 \text{ J}$

(v) Change of internal energy for isothermal process is given by

$\Delta U = nC_v(T_2 - T_1)$

In isothermal process, $T_2 = T_1$ so $\Delta U = 0$

3) Adiabatic or Quasistatic Process (Reversible):

(i) Law of adiabatic process, $PV^\gamma = \text{const}$ where $\gamma = \frac{C_p}{C_v}$

(ii) Work done, $W = \int P dV = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$

(iii) Heat transfer, $Q = 0$

(iv) change of internal energy, $\Delta U = nC_v(T_2 - T_1)$

$W = -\Delta U = -nC_v(T_2 - T_1) = nC_v(T_1 - T_2)$

(v) For adiabatic, $\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1} = \left(\frac{P_1}{P_2}\right)^{\frac{\gamma-1}{\gamma}}$

(vi) change of entropy, $\Delta S = nC_p \ln \frac{T_2}{T_1}$

(vii) $\frac{P_1 V_1^\gamma}{T_1} = \frac{P_2 V_2^\gamma}{T_2}$

(viii) $P_1 V_1 = nRT_1$

$P_2 V_2 = nRT_2$

$\frac{P_1 V_1^\gamma}{T_1} = \frac{P_2 V_2^\gamma}{T_2} \Rightarrow \frac{P_1 V_1^\gamma}{nRT_1} = \frac{P_2 V_2^\gamma}{nRT_2} \Rightarrow \frac{P_1 V_1^\gamma}{T_1} = \frac{P_2 V_2^\gamma}{T_2}$

$\left(\frac{P_1}{P_2}\right)^\gamma = \left(\frac{V_2}{V_1}\right)^\gamma \left(\frac{T_1}{T_2}\right)$

(b) 0.15 m^3 of air at a temperature of 20°C and pressure of 10^5 Pa is compressed to a volume of 0.01 m^3 at a pressure of 10^6 Pa . Calculate the work done.

(i) the initial volume
 (ii) the final volume
 (iii) the initial temperature
 (iv) the final temperature

Solution: Given: $V_1 = 0.15 \text{ m}^3$, $P_1 = 10^5 \text{ Pa}$, $T_1 = 20^\circ\text{C}$
 $V_2 = 0.01 \text{ m}^3$, $P_2 = 10^6 \text{ Pa}$, $T_2 = ?$

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

$\left(\frac{10^6}{10^5}\right)^{\frac{1}{1.4}} = \left(\frac{0.15}{0.01}\right)^{\frac{1}{1.4}}$

$10^{\frac{1}{1.4}} = \left(\frac{0.15}{0.01}\right)^{\frac{1}{1.4}}$

$10 = \left(\frac{0.15}{0.01}\right)^{\frac{1}{1.4}}$

$10^{1.4} = \frac{0.15}{0.01}$

$25.1188643150958 = 15$

-ve sign indicates that heat is rejected

(b) 0.15 m^3 of air at a pressure of 10^5 Pa and temperature of 20°C is compressed to a volume of 0.01 m^3 at a pressure of 10^6 Pa . Calculate the work done.

(i) the initial volume
 (ii) the final volume
 (iii) the initial temperature
 (iv) the final temperature

Solution: Given: $P_1 = 10^5 \text{ Pa}$, $P_2 = 10^6 \text{ Pa}$, $V_1 = 0.15 \text{ m}^3$
 $V_2 = 0.01 \text{ m}^3$, $T_1 = 20^\circ\text{C}$, $T_2 = ?$

(i) For isothermal process, work done is given by

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

$= \frac{10^6 \times 0.01 - 10^5 \times 0.15}{1.4 - 1}$

$= -11.57 \text{ kJ}$

-ve sign indicates that heat is rejected

(ii) Heat transfer due to ...

$$Q = \frac{kA \Delta T}{L}$$

... where ...

... where ...

$$Q = \frac{kA \Delta T}{L}$$

HEAT TRANSFER

(i) Conduction:

Heat transfer ...

... molecular ...

(ii) Modes of heat transfer:

- (i) Conduction, (ii) Convection, (iii) Radiation.

Conduction: Conduction is the transfer of heat ...

Convection: Convection is the transfer of heat ...

Radiation: Radiation is the transfer of heat ...

② Fourier's Law of Conduction:

This is the fundamental law based on conduction and it states that the rate of flow of heat through a single layer may be said to directly proportional to the area of the surface at right angles to the direction of heat flow, and the change of temperature will depend on the depth of the plate of the heat flow.

It is represented by the equation,

$$Q = -kA \frac{dt}{dx}$$

where, k = coefficient of conductivity and A = area of surface conductivity of the body (W/mK).

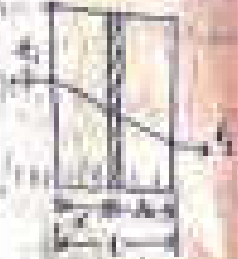
$\frac{dt}{dx}$ = Temperature gradient.

③ Thermal conductivity:

Thermal conductivity of a material is the amount of heat conducted through the material per unit time having unit area of heat exchange area, and unit distance of temperature.

$$\text{Rate of heat flow } Q = \frac{kA(t_1 - t_2)}{l}$$

$$k = \frac{Ql}{A(t_1 - t_2)}$$



④ Heat exchanger:

A device used for transferring heat from fluid to another is called a heat exchanger. It is used to transfer heat between two or more fluids, gases, liquids and vapors, condensate and boiler in steam plants, condenser and evaporator in refrigeration and air conditioning units. The following are types of heat exchangers are common in use:

(i) Parallel flow heat exchanger:

In parallel flow heat exchanger, the fluid flow in the same direction. The least difference of temperature at inlet and respectively the rate of flow of fluid and the rate of exchange of temperature are maximum here.

(ii) Counter current flow heat exchanger:

In counter current flow heat exchanger, the fluid flow in the opposite direction.

① Reversible isobaric expansion:

According to Boyle's law, the product of the pressure P and volume V of a gas is constant if the temperature T is constant. This is the condition for a reversible isobaric expansion.

② Slowness condition:

According to the slowness condition, the change in pressure of a gas is small compared to the total pressure. Mathematically, $\frac{dP}{P} \ll 1$.

Mathematically, condition for a slow process

$$\frac{dP}{P} \ll 1$$

Note, $k = \text{slowness constant} = 10^{-2} \text{ sec}^{-1} \text{ atm}^{-1}$

③ Adiabatic expansion:

If no heat is exchanged with the surroundings, the process is adiabatic. Mathematically, $Q = 0$.

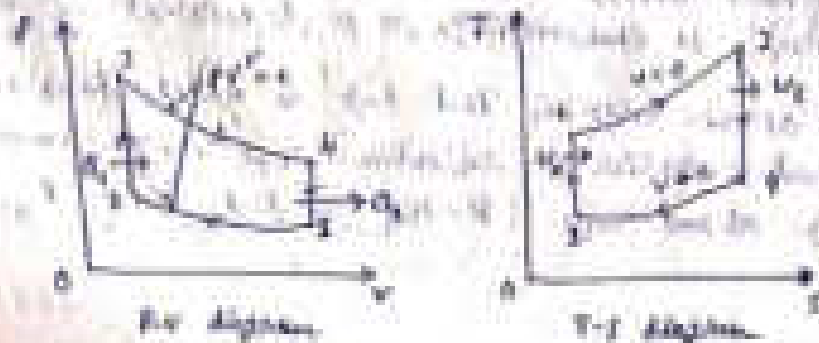
$$Q = \frac{\text{Heat supplied} - \text{Heat rejected}}{\text{Heat supplied}}$$

This quantity is known as the efficiency of the process.

In order to compare the efficiency of the isobaric and adiabatic processes, we consider a gas expanding from a volume V_1 to a volume V_2 . In the isobaric process, the pressure is constant. In the adiabatic process, the pressure changes. The efficiency of the isobaric process is less than that of the adiabatic process.

④ Isothermal expansion:

In isothermal expansion, the temperature of the gas remains constant. The work done by the gas is equal to the heat supplied to it.



② The following is the sequence of operation of Otto cycle:

- (1) Process 1-2 is isentropic compression of gas during which pressure and temperature of the gas rise from P_1 and T_1 to P_2 and T_2 respectively.
- (2) Process 2-3 is isochoric constant volume heating of the gas during which pressure and temperature further rise from P_2 and T_2 to P_3 and T_3 respectively.
- (3) Process 3-4 is isentropic expansion of the gas during which pressure and temperature further rise from P_3 and T_3 to P_4 and T_4 respectively.
- (4) Process 4-1 is isochoric constant volume rejection of heat until the original condition at 1 is restored.

③ Thermal efficiency of Otto cycle in terms of compression ratio:

Let: Q_1 = heat added during cycle,
 Q_2 = heat rejected during cycle.

Then heat utilised during the cycle is $Q_1 - Q_2$.
 Now, thermal efficiency is given by

$$\eta_{th} = \frac{\text{heat utilised}}{\text{heat supplied}} = \frac{Q_1 - Q_2}{Q_1} \quad \text{--- (1)}$$

Now, $Q_1 = m c_p (T_3 - T_2)$

where, m = mass of gas added during a cycle
 c_p = specific heat at constant pressure of the gas used
 or the working medium.

Similarly $Q_2 = m c_p (T_4 - T_1)$ [$T_4 > T_1$]

$$\eta_{th} = \frac{m c_p (T_3 - T_2) - m c_p (T_4 - T_1)}{m c_p (T_3 - T_2)}$$

$$\eta_{th} = \frac{T_3 - T_2}{T_3 - T_2} = 1 - \frac{T_4 - T_1}{T_3 - T_2}$$

For the isentropic process 1-2, $P_1 V_1^\gamma = P_2 V_2^\gamma$ and $T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$
 we get, $\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^\gamma$ [where, $r_c = \frac{V_1}{V_2}$ = compression ratio]

Similarly for isentropic process 3-4, $T_3 V_3^{\gamma-1} = T_4 V_4^{\gamma-1}$
 we get, $\frac{T_3}{T_4} = \left(\frac{V_3}{V_4}\right)^\gamma$ [where, $r_e = \frac{V_3}{V_4}$ = expansion ratio]

$$T_2 = T_1 r_c^\gamma \quad \text{and} \quad T_3 = T_4 r_e^\gamma$$

Therefore, $\frac{T_2}{T_1} = \frac{T_3}{T_4}$

Pulling force = value of σ at t_2 - value of σ at t_1

$$F = \frac{E A (t_2 - t_1)}{L}$$

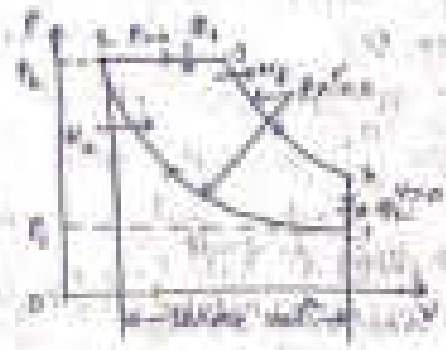
Ratio of contraction ratio = $\frac{\text{value at beginning of contraction}}{\text{value at the end of contraction}}$

(ii) Extension ratio = $\frac{\text{value at the end of extension}}{\text{value at the beginning of extension}}$

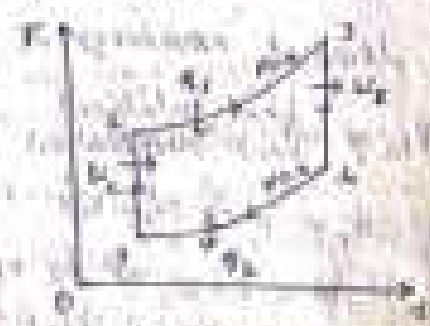
(iii) In case of the cycle, contraction ratio is a extension ratio.

③ Diesel cycle :

In an diesel cycle, a perfect gas of volume V_1 is at initial pressure P_1 and temperature T_1 . In diesel cycle, the gas is first compressed isothermally from P_1, V_1, T_1 to P_2, V_2, T_1 . Then it is heated at constant volume from P_2, V_2, T_1 to P_3, V_2, T_2 . Then it is expanded isothermally from P_3, V_2, T_2 to P_4, V_3, T_2 . Finally it is cooled at constant volume from P_4, V_3, T_2 to P_1, V_1, T_1 .



P-V diagram



P-T diagram

① Process 1-2 isothermally isothermal compression of the gas

which constant and temperature of the gas also same T_1 and T_2 so P_1 and T_1 respectively.

② Process 2-3 isothermally constant pressure heating of the gas which temperature of the gas isothermal higher than T_1 to T_2 pressure remaining constant at P_2 .

③ Process 3-4 isothermally isothermal expansion which constant and temperature that same T_2 and T_1 to P_3 and T_2 respectively.

④ Process 4-1 isothermally constant volume cooling of the gas which constant the original condition at 1 is obtained.

Thermal efficiency of diesel cycle in terms of compression ratio and cut-off ratio

Let Q_1 = heat added during a cycle
 Q_2 = heat rejected during a cycle

Then, heat utilised during the cycle = $Q_1 - Q_2$

Now, $\eta_{th} = \frac{\text{heat utilised by the cycle during the cycle}}{\text{heat added to the cycle during the cycle}}$
 $= \frac{Q_1 - Q_2}{Q_1}$ (1)

Now, $Q_2 = mc_p(T_4 - T_1)$

where, m = mass of gas taken during a cycle
 c_p = specific heat of the gas at constant pressure.

$Q_1 = m c_p (T_3 - T_2)$

From eqn (1), we get

Now, $\eta_{th} = \frac{m c_p (T_3 - T_2) - m c_p (T_4 - T_1)}{m c_p (T_3 - T_2)}$

Let $\gamma = \frac{c_p}{c_v}$ and $r = \frac{V_2}{V_1}$ (compression ratio)
 $\eta_{th} = \frac{(T_3 - T_2) - (T_4 - T_1)}{(T_3 - T_2)}$

where, $\gamma = \frac{c_p}{c_v}$ is the ratio of specific heats and $r = \frac{V_2}{V_1}$ is the compression ratio.

$\frac{T_3}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1} = r^{\gamma-1}$

where, $r = \frac{V_2}{V_1}$ = compression ratio

or, $T_3 = T_2 r^{\gamma-1}$

again, as the process between 2-3 is isentropic, we get

$\frac{T_3}{T_2} = \frac{V_2}{V_3} \gamma$ [Charles's law]

or, $\frac{T_3}{T_2} = \frac{V_2}{V_3} \gamma = \frac{V_2}{V_3} \gamma$

where, $\frac{V_2}{V_3}$ is the cut-off ratio and γ is the ratio of specific heats.

$r_c = \frac{\text{volume of the cylinder at expansion}}{\text{volume of the cylinder at compression}} = \frac{V_3}{V_2}$

where, r_c is the cut-off ratio and γ is the ratio of specific heats.

$\frac{T_3}{T_2} = \frac{1}{r_c} \gamma$

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

Again use the isobaric process 2-3, we get

$$\frac{T_3}{T_2} = \left(\frac{V_3}{V_2}\right)^{\gamma-1} = \left(\frac{V_3}{V_2}\right)^{\gamma-1}$$

$$\therefore T_3 = T_2 \left(\frac{V_3}{V_2}\right)^{\gamma-1} = T_1 \left(\frac{V_2}{V_1}\right)^{\gamma-1} \left(\frac{V_3}{V_2}\right)^{\gamma-1} = T_1 \left(\frac{V_3}{V_1}\right)^{\gamma-1}$$

Substituting these values of T_2 , T_3 and T_1 in eqn (1) we get

$$\eta_{Carnot} = 1 - \frac{T_4}{T_1} = \frac{T_1 \left(\frac{V_2}{V_1}\right)^{\gamma-1} - T_4}{T_1}$$

$$= 1 - \frac{T_4}{T_1} = \frac{\left(\frac{V_2}{V_1}\right)^{\gamma} T_4}{\left(\frac{V_2}{V_1}\right)^{\gamma} T_1}$$

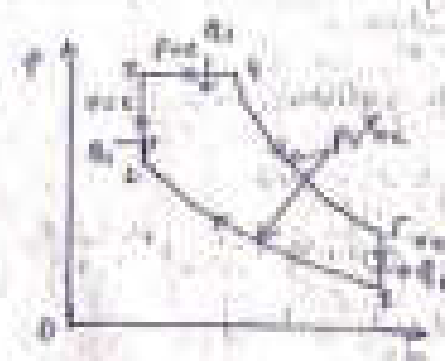
$$= 1 - \frac{T_4}{T_1} = \frac{\left(\frac{V_2}{V_1}\right)^{\gamma} T_4}{\left(\frac{V_2}{V_1}\right)^{\gamma} T_1}$$

② Real Carnot Cycle:

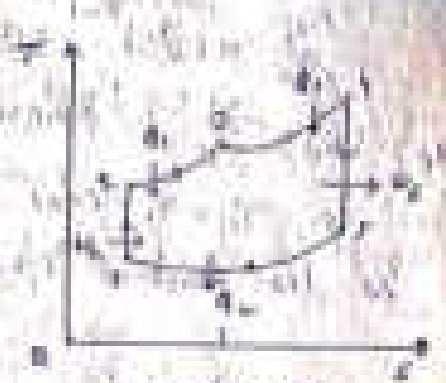
A real Carnot cycle is a combination of two isobaric and two isochoric cycles.

Large space Diesel engine acts as real Carnot cycle.

In this engine when the space of the engine is above certain value it is necessary to start fuel injection hence the temperature of compressed air is dependent to start it.



P-V Diagram



T-V Diagram

③ Real Carnot cycle consists of the following process & are

(i) Process 1-2 isobaric isothermal expansion of gas during which temperature stays same T_1 to T_2 , pressure stays same P_1 to P_2 and volume increases from V_1 to V_2 .

(ii) Process 2-3 isochoric constant volume heating of gas during which temperature further increases from T_2 to T_3 and pressure further increases from P_2 to P_3 .

(i) Process 1-2: Isothermally expand, pressure constant at P_1 , during which temperature starts from T_1 to T_2 and volume increases from V_1 to V_2 .

(ii) Process 2-3: Isothermally compress, pressure constant at P_2 , during which temperature starts from T_2 to T_3 , volume starts from V_2 to V_3 and volume increases from V_3 to V_4 .

(iii) Process 3-4: Isothermally expand, pressure constant at P_3 , during which temperature starts from T_3 to T_4 , volume starts from V_3 to V_4 and volume increases from V_4 to V_1 .

(iv) Process 4-1: Isothermally compress, pressure constant at P_4 , during which temperature starts from T_4 to T_1 , volume starts from V_4 to V_1 and volume increases from V_1 to V_2 .

(v) Process 1-2: Isothermally expand, pressure constant at P_1 , during which temperature starts from T_1 to T_2 , volume starts from V_1 to V_2 and volume increases from V_2 to V_3 .

(vi) Process 2-3: Isothermally compress, pressure constant at P_2 , during which temperature starts from T_2 to T_3 , volume starts from V_2 to V_3 and volume increases from V_3 to V_4 .

(vii) Process 3-4: Isothermally expand, pressure constant at P_3 , during which temperature starts from T_3 to T_4 , volume starts from V_3 to V_4 and volume increases from V_4 to V_1 .

(viii) Process 4-1: Isothermally compress, pressure constant at P_4 , during which temperature starts from T_4 to T_1 , volume starts from V_4 to V_1 and volume increases from V_1 to V_2 .

(ix) Process 1-2: Isothermally expand, pressure constant at P_1 , during which temperature starts from T_1 to T_2 , volume starts from V_1 to V_2 and volume increases from V_2 to V_3 .

(x) Process 2-3: Isothermally compress, pressure constant at P_2 , during which temperature starts from T_2 to T_3 , volume starts from V_2 to V_3 and volume increases from V_3 to V_4 .

(xi) Process 3-4: Isothermally expand, pressure constant at P_3 , during which temperature starts from T_3 to T_4 , volume starts from V_3 to V_4 and volume increases from V_4 to V_1 .

(xii) Process 4-1: Isothermally compress, pressure constant at P_4 , during which temperature starts from T_4 to T_1 , volume starts from V_4 to V_1 and volume increases from V_1 to V_2 .

(xiii) Process 1-2: Isothermally expand, pressure constant at P_1 , during which temperature starts from T_1 to T_2 , volume starts from V_1 to V_2 and volume increases from V_2 to V_3 .

(xiv) Process 2-3: Isothermally compress, pressure constant at P_2 , during which temperature starts from T_2 to T_3 , volume starts from V_2 to V_3 and volume increases from V_3 to V_4 .

(xv) Process 3-4: Isothermally expand, pressure constant at P_3 , during which temperature starts from T_3 to T_4 , volume starts from V_3 to V_4 and volume increases from V_4 to V_1 .

(xvi) Process 4-1: Isothermally compress, pressure constant at P_4 , during which temperature starts from T_4 to T_1 , volume starts from V_4 to V_1 and volume increases from V_1 to V_2 .

(xvii) Process 1-2: Isothermally expand, pressure constant at P_1 , during which temperature starts from T_1 to T_2 , volume starts from V_1 to V_2 and volume increases from V_2 to V_3 .

(xviii) Process 2-3: Isothermally compress, pressure constant at P_2 , during which temperature starts from T_2 to T_3 , volume starts from V_2 to V_3 and volume increases from V_3 to V_4 .

(xix) Process 3-4: Isothermally expand, pressure constant at P_3 , during which temperature starts from T_3 to T_4 , volume starts from V_3 to V_4 and volume increases from V_4 to V_1 .

(xx) Process 4-1: Isothermally compress, pressure constant at P_4 , during which temperature starts from T_4 to T_1 , volume starts from V_4 to V_1 and volume increases from V_1 to V_2 .

(xxi) Process 1-2: Isothermally expand, pressure constant at P_1 , during which temperature starts from T_1 to T_2 , volume starts from V_1 to V_2 and volume increases from V_2 to V_3 .

(xxii) Process 2-3: Isothermally compress, pressure constant at P_2 , during which temperature starts from T_2 to T_3 , volume starts from V_2 to V_3 and volume increases from V_3 to V_4 .

(xxiii) Process 3-4: Isothermally expand, pressure constant at P_3 , during which temperature starts from T_3 to T_4 , volume starts from V_3 to V_4 and volume increases from V_4 to V_1 .

(xxiv) Process 4-1: Isothermally compress, pressure constant at P_4 , during which temperature starts from T_4 to T_1 , volume starts from V_4 to V_1 and volume increases from V_1 to V_2 .

(xxv) Process 1-2: Isothermally expand, pressure constant at P_1 , during which temperature starts from T_1 to T_2 , volume starts from V_1 to V_2 and volume increases from V_2 to V_3 .

(xxvi) Process 2-3: Isothermally compress, pressure constant at P_2 , during which temperature starts from T_2 to T_3 , volume starts from V_2 to V_3 and volume increases from V_3 to V_4 .

(xxvii) Process 3-4: Isothermally expand, pressure constant at P_3 , during which temperature starts from T_3 to T_4 , volume starts from V_3 to V_4 and volume increases from V_4 to V_1 .

(xxviii) Process 4-1: Isothermally compress, pressure constant at P_4 , during which temperature starts from T_4 to T_1 , volume starts from V_4 to V_1 and volume increases from V_1 to V_2 .

(xxix) Process 1-2: Isothermally expand, pressure constant at P_1 , during which temperature starts from T_1 to T_2 , volume starts from V_1 to V_2 and volume increases from V_2 to V_3 .

(xxx) Process 2-3: Isothermally compress, pressure constant at P_2 , during which temperature starts from T_2 to T_3 , volume starts from V_2 to V_3 and volume increases from V_3 to V_4 .

(B) Thermal efficiency of heat engine cycle:

Let, Q_1 = heat added during a cycle.

Q_2 = heat rejected during a cycle.

Then heat utilised during a cycle = $Q_1 - Q_2$.

Now, thermal efficiency is given by

$$\eta_{th} = \frac{\text{Heat utilised}}{\text{Heat supplied}} = \frac{Q_1 - Q_2}{Q_1} \quad \text{--- (1)}$$

$$\text{Now, } Q_1 = m C_v (T_2 - T_1) + m C_p (T_3 - T_2)$$

where, $m C_v$ = mass of gas utilised during a cycle,

C_v = specific heat at constant volume,

C_p = sp. heat at constant pressure,

$$Q_2 = m C_v (T_4 - T_3)$$

From eqn (1) we get,

$$\eta_{th} = \frac{m C_v (T_2 - T_1) + m C_p (T_3 - T_2) - m C_v (T_4 - T_3)}{m C_v (T_2 - T_1) + m C_p (T_3 - T_2)}$$

$$= \frac{C_v (T_2 - T_1) + C_p (T_3 - T_2) - C_v (T_4 - T_3)}{C_v (T_2 - T_1) + C_p (T_3 - T_2)}$$

$$= 1 - \frac{C_v (T_4 - T_3)}{C_v (T_2 - T_1) + C_p (T_3 - T_2)} \quad \left[\text{where } \gamma = \frac{C_p}{C_v} \right]$$

For the adiabatic process 1-2 we get,

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

$$\text{or, } T_2 = T_1 (r)^{\gamma-1} \quad \text{--- (ii)}$$

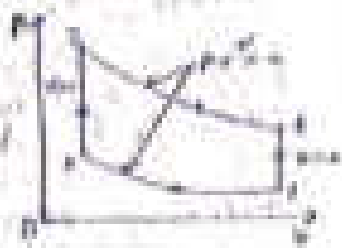
For the constant volume process 2-3 we get,

$$\frac{T_3}{T_2} = \frac{P_3}{P_2} = r_{c,r}$$

where, $r_{c,r} = \frac{P_3}{P_2} = \text{compression ratio.}$

(1) In an isobaric process, the pressure and temperature of air at the beginning of compression are 1 bar and 30°C. respectively. If 1000 J of heat is added to 10 cm³ of oxygen volume, determine the pressure and temperature at the end of such process. Assume expansion ratio of 4.

Solution: Given, $P_1 = 1 \text{ bar}$, $T_1 = 30^\circ\text{C} = 303 \text{ K}$



Volume, $V_1 = 10 \text{ cm}^3$, $V_2 = 40 \text{ cm}^3$

$$\frac{V_2}{V_1} = 4$$

For the adiabatic process, we use relation $P_1 V_1^\gamma = P_2 V_2^\gamma$

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

$$\frac{P_2}{1} = 1 \left(\frac{10}{40}\right)^\gamma$$

$$P_2 = 1 \times 0.375 = 0.375 \text{ bar}$$

$$P_1 V_1^\gamma = P_2 V_2^\gamma \Rightarrow T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$$

Again, $P_1 V_1^\gamma = P_2 V_2^\gamma \Rightarrow T_1 V_1^\gamma = T_2 V_2^\gamma$

$$P_2 = P_1 \left(\frac{V_1}{V_2}\right)^\gamma = 1 \times 0.375 = 0.375 \text{ bar}$$

$$Q_1 (\text{heat added}) = n C_V (T_2 - T_1)$$

$$1000 = n C_V (T_2 - T_1)$$

$$1000 = 1 \times 2.5 R (T_2 - 303)$$

$$T_2 = 200.52 \text{ K}$$

$$Q_2 = 200.52 - 303 = -102.48 \text{ J}$$

Again, for the process 2-3, we get:

$$\frac{P_3}{P_2} = \left(\frac{V_2}{V_3}\right)^\gamma$$

$$\frac{P_3}{0.375} = \left(\frac{40}{10}\right)^\gamma$$

$$P_3 = 0.375 \times \frac{1}{4} = 0.09375 \text{ bar}$$

For the adiabatic process 3-4, we get: $P_3 V_3^\gamma = P_4 V_4^\gamma$

$$\frac{P_4}{0.09375} = \left(\frac{10}{40}\right)^\gamma \Rightarrow P_4 = 0.09375 \times 4 = 0.375 \text{ bar}$$

$$T_4 = 303 \text{ K}$$

Again, $P_3 V_3^\gamma = P_4 V_4^\gamma \Rightarrow T_3 V_3^\gamma = T_4 V_4^\gamma$

$$P_4 = P_3 \left(\frac{V_3}{V_4}\right)^\gamma = 0.09375 \times \left(\frac{1}{4}\right)^\gamma$$

$$P_4 = 0.0234 \text{ bar}$$

1. The system consists of two masses m_1 and m_2 connected by a string over a pulley. The masses are on inclined planes with angles α and β respectively.

Initial velocity $v_0 = 0$.
 Displacement $s = \frac{1}{2} a t^2$.
 Velocity $v = a t$.
 Acceleration $a = \frac{m_2 \sin \beta - m_1 \sin \alpha}{m_1 + m_2}$.

When $t = 0$, $v = 0$.
 When $t = t_1$, $v = a t_1$.
 When $t = t_2$, $v = a t_2$.

At $t = t_1$, $v_1 = a t_1$.
 At $t = t_2$, $v_2 = a t_2$.

At $t = t_3$, $v_3 = a t_3$.
 At $t = t_4$, $v_4 = a t_4$.

At $t = t_5$, $v_5 = a t_5$.
 At $t = t_6$, $v_6 = a t_6$.

At $t = t_7$, $v_7 = a t_7$.
 At $t = t_8$, $v_8 = a t_8$.

At $t = t_9$, $v_9 = a t_9$.
 At $t = t_{10}$, $v_{10} = a t_{10}$.

Let, area under the line 1-2 = Area under the line 2-3
 $\therefore (P_1 V_1 - P_2 V_2) = (P_2 V_2 - P_3 V_3)$
 Now, area under the line 1-2 = Work done by air during
 adiabatic expansion along the line 1-2 = $\frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$

$$W_1 = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$$

where, W_1 = work done by air during adiabatic expansion

Now, let the adiabatic process 2-3 be given by

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

$$\therefore P_3 = P_2 \left(\frac{V_2}{V_3}\right)^\gamma = 1 \times (2)^{1.4} = 2.639 \text{ bar}$$

$$\therefore P_3 = 2.639 \text{ bar} = 263.9 \text{ kPa}$$

$$= 263.9 \times 10^3 \text{ N/m}^2 \text{ (with units)}$$

Again, let the adiabatic process 2-3 be given by

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

$$\therefore P_3 = P_2 \left(\frac{V_2}{V_3}\right)^\gamma = P_2 \left(\frac{2}{1}\right)^\gamma$$

$$\therefore P_3 = 1014 \times \left(\frac{1}{2}\right)^{1.4} = 38.9 \text{ kPa}$$

$$\text{Given: } V_2 = 20 \times 10^{-3} \text{ m}^3 = \frac{20 \times 10^{-3}}{10^3} = 20 \times 10^{-6} \text{ m}^3$$

Again, given: $\frac{V_3}{V_2} = 2$

$$V_3 = 2V_2 = 2 \times 20 \times 10^{-6} = 40 \times 10^{-6} \text{ m}^3$$

$$W_2 = W_1 = \frac{P_2 V_2 - P_3 V_3}{\gamma - 1}$$

$$\therefore W_2 = \frac{263.9 \times 20 \times 10^{-6} - 38.9 \times 40 \times 10^{-6}}{1.4 - 1}$$

$$= 1.34 \text{ J}$$

Now, under the line 1-2 = Work done by air during constant
 Let, W_c = Work done with air during compression

$$\text{Then, } W_c = \frac{P_2 V_2 - P_1 V_1}{\gamma - 1} \text{ (compression)}$$

$$P_2 = 10.14 \text{ bar} = 10.14 \times 10^5 \text{ N/m}^2 = 1014 \text{ kPa}$$

$$V_2 = V_1 = 20 \times 10^{-6} \text{ m}^3$$

$$P_1 = 1 \text{ bar} = 10^5 \text{ N/m}^2 = 100 \text{ kPa}$$

$$W_c = \frac{1014 \times 20 \times 10^{-6} - 100 \times 20 \times 10^{-6}}{1.4 - 1}$$

$$= 0.645 \text{ J}$$

$$\therefore W = W_1 + W_2 = 1.34 \text{ J} + 0.645 \text{ J} = 1.985 \text{ J} \text{ Ans}$$

2. I.C. engine, Introduction:

The term 'internal combustion engine' is applied to all heat engines having combustion of the fuel taking place inside the engine cylinder and the working medium consists of the products of combustion of the fuel and intake air. The force on the piston is due to the pressure of the products of combustion in the cylinder. The I.C. engine working cycle is the other side of the products of combustion which expansion are exhausted into the atmosphere at the end of each cycle. It is the most common type engine.

The most outstanding application of I.C. engine is the automobile. The I.C. engine has low cost, simplicity of construction and high thermal efficiency. It is used in transport, agriculture, aviation, marine, power, etc. I.C. engines are used in locomotive, etc.

Classification of I.C. engine:

- (i) According to the type of fuel used:
 - (a) Gasoline engine
 - (b) Diesel engine
 - (c) Heavy oil engine
- (ii) According to the intake system:
 - (a) Otto cycle or constant volume combustion cycle
 - (b) Diesel cycle or constant pressure combustion cycle
 - (c) Dual combustion cycle
- (iii) According to the stroke of engine:
 - (a) Single stroke engine
 - (b) Double stroke engine
- (iv) According to the method of ignition:
 - (a) Spark plug ignition
 - (b) Compression ignition
- (v) According to the arrangement of cylinder:
 - (a) Single cylinder engine
 - (b) Multi cylinder engine

Conduct Heat Loss:

It is the heat transferred to the air through the surface of the body of animal above the skin surface.

① Conduct Heat Loss:

It is the transfer of heat required to raise the temperature of body parts into the surrounding medium at the same temperature.

② Insulation:

The heat insulation is obtained by the body of animals. The heat insulation is obtained by the body of animals which depends on the nature of the insulation. The amount of insulation mainly depends on the nature of the body and type of surface of the body. The insulations are getting in the body from three sources. Part of the insulation are provided by the body, a part of the insulation are provided by the surrounding insulation are provided through the body.

③ Insulation: Surface absorption:

Surface insulation of a body is the insulation heat absorbed by the body.

④ Surface Radiation:

Surface radiation is the heat of the radiation heat radiated by the body.

⑤ Surface Transmission:

Surface transmission is the heat of radiation heat transmitted by the body.

⑥ Blow body:

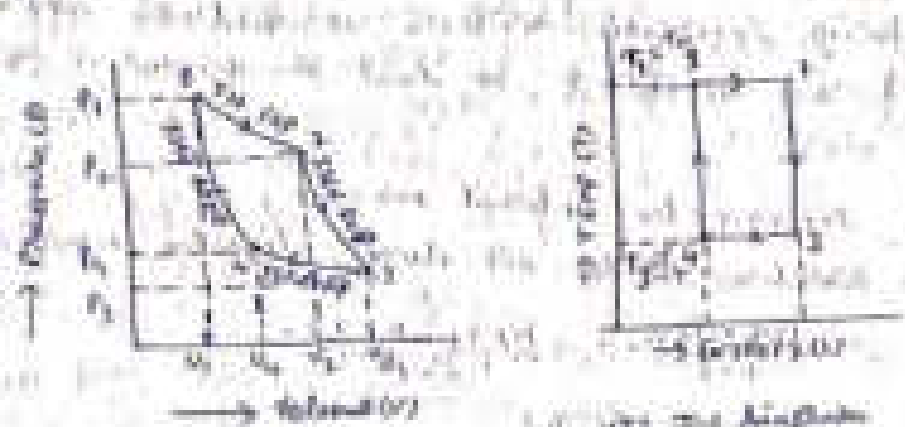
A blow body absorbs all the radiation heat and is that conductivity of a blow body is 1, and insulations are insulations and also not. Blow body does not only a nature.

⑦ Newton's law of cooling:

It is an important law in the field of heat transfer which states that the rate of heat loss of a body is directly proportional to the surface area and difference of temperature between the body and the medium.

① Carnot Cycle :

This cycle was devised by Nicolas Carnot and consists of four stages of the expansion of a heat engine. In a Carnot cycle, the working substance is a perfect gas consisting of two isotherms and two reversible adiabats or (isentropes) expansion. The two end states of this cycle is shown in figure. It can be understood that the engine produces work as it goes all at its original condition is restored by heat to it, say in a cold bath.



② P-V diagram

① During isothermal expansion of gas by 1.0 m³ at 300 K, the heat supplied is fully equal to the work done by the gas.

Heat supplied = $Q_1 = nRT \ln \frac{V_2}{V_1}$

where $n = \frac{P_1 V_1}{RT_1} = \frac{1.0 \times 10^5}{8.314 \times 300} = 40.0$ moles

② During reversible adiabatic expansion of gas by 1.0 m³ at 300 K, the heat supplied is zero.

Work done = $W = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$

③ During adiabatic compression of gas by 1.0 m³ at 300 K, the heat supplied is zero.

Heat rejected = $m c_p (T_2 - T_1)$
 Heat input = $m c_p (T_2 - T_1)$
 Efficiency = $\frac{W}{Q_{in}} = \frac{m c_p (T_1 - T_2)}{m c_p (T_2 - T_1)}$
 = $\frac{T_1 - T_2}{T_2 - T_1}$

Note: The efficiency and compression ratio must be equal otherwise the cycle would not close.

(4) Being reversible indicates a frictionless compression process by which the volume is halved or reduced to 1/2 of its initial value.

∴ Increase in internal energy = Heat added during adiabatic compression

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

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

We can show the above discussion that the change in internal energy during reversible adiabatic compression is equal to the increase in internal energy during reversible adiabatic expansion. Hence there is no net work done during the whole cycle if there is no heat input.

Work done = Heat supplied - Heat rejected

$$= m R T_2 \log_e T - m R T_1 \log_e T$$

$$= m R \log_e T (T_2 - T_1)$$

∴ Efficiency $\eta = \frac{\text{work done}}{\text{heat supplied}}$

$$= \frac{m R \log_e T (T_2 - T_1)}{m R T_2 \log_e T}$$

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

Note: (3) From the above equation, the efficiency of a cycle is independent of T_1 and T_2 is dependent on T_2/T_1 (which is the heat sink to work in at a high temperature of supply, and rejected at a low temperature of supply). It may be noted that 100% efficiency can be