

Thermodynamics :-

→ A branch of science which deals with the study of heat-energy into other forms of energy and vice-versa is thermodynamics.

→ mainly thermodynamics is concerned with the conversion of heat energy into mechanical work (or energy) and vice-versa.

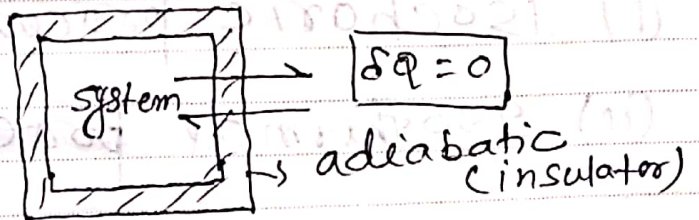
→ Efficiency of a heat engine

$$\eta = \frac{\text{Useful mechanical work}}{\text{Heat energy (input)}} \leq 55\%$$

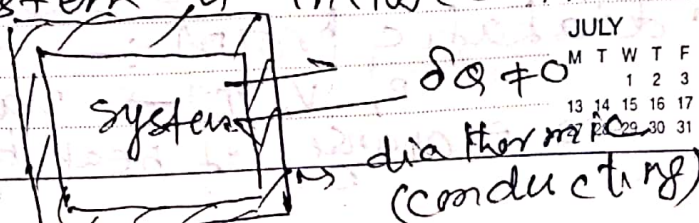
it means, complete conversion of heat energy into useful mechanical work is not possible without any other change.

① Thermodynamical system :- it is a collection of large no. of non-interacting particles having a certain value of pressure, volume, temp. etc.

(a) Isolated system :- it is a system which does not exchange heat energy with its surroundings for this, the system must be in an adiabatic enclosure.



(b) closed system :- This system exchanges heat energy with the surrounding without exchange of matter. This system is enclosed in a diathermic enclosure.



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(c) open system: - In this case exchange of both matter and energy takes place.

→ A thermodynamical system may be in solid state, liquid state, gaseous state or plasma state.

Thermodynamical variables: - These are parameters to describe a thermodynamical system.

→ In case of gaseous system - P, V, T, U (internal energy), S (entropy) are general thermodynamical variables.

WORK TO DO

→ for liquid system - $P, V, T, \text{density, surface tension etc}$ are thermodynamical variables.

→ for solid system - Temp. elasticity etc. are thermodynamical variables.

Thermodynamical process: -

A change in a thermodynamical state or variables is thermodynamical process.

PHONES

(i) Isochoric process: - $V = \text{const}$

(ii) Isothermal process: -

$$T = \text{const}$$

(iii) Isobaric process: -

$$P = \text{const}$$

(iv) Adiabatic process: -

$P, V, T \rightarrow \text{vary}$

No exchange of heat b/w the system & its surroundings.

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(V) Cyclic process :- if a system returns back to its initial state passing through different states then the process is cyclic.

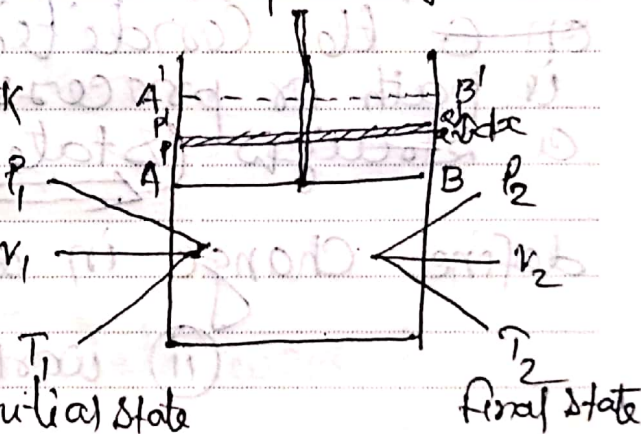
(VI) Reversible process :-

* FIRST LAW of thermodynamics :-

(Principle of conservation of energy)

Work done in a thermodynamical process
Let us consider a gaseous thermodynamical system in state (P_1, V_1, T_1) . The state of the system is changed to (P_2, V_2, T_2) .

We have to find, work done in this process. For this we take a state (P, V, T) of the system. When the piston is at V_1 .



After a small disp. dx the system is in the state $(P, V+dv, T+dT)$.

work done by the system in this process

$$\Delta W = \vec{F} \cdot d\vec{x}$$

$$= F dx \cos 0^\circ$$

$$\Delta W = F dx$$

$$\Rightarrow \Delta W = P A dx \quad ; \quad A = \text{Area of cross-section.}$$

$$\Rightarrow \Delta W = p dV \quad \text{--- (1), } dV = \text{change in volume.}$$

Hence, work done in the whole process

$$W = \int_{V_1}^{} p dV$$

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Sing. work is not a state function, so we can not give the limit during the finding the total work done. we can give the limit $\int_{V_1}^{V_2} PdV$ but it is not necessary.

$$W = \int_{V_1}^{V_2} PdV \quad \text{--- (2)}$$

WORK TO DO

(1) it is clear from eqⁿ. (2) that the work done W depends on the relation b/w P and V . this relation depends on the condition on the condition or process. Hence work is path or process dependent. so it is not a state function. Hence we can not define change in work.

(ii) work done in some particular process.

1. Isochoric process: -

$$\begin{aligned} V &= \text{const.} \\ \Rightarrow dV &= 0 \\ \Rightarrow PdV &= 0 \\ \Rightarrow \delta W &= 0 \\ \Rightarrow \int \delta W &= 0 \\ \Rightarrow W &= 0 \end{aligned}$$

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[2] Isoobaric process: -

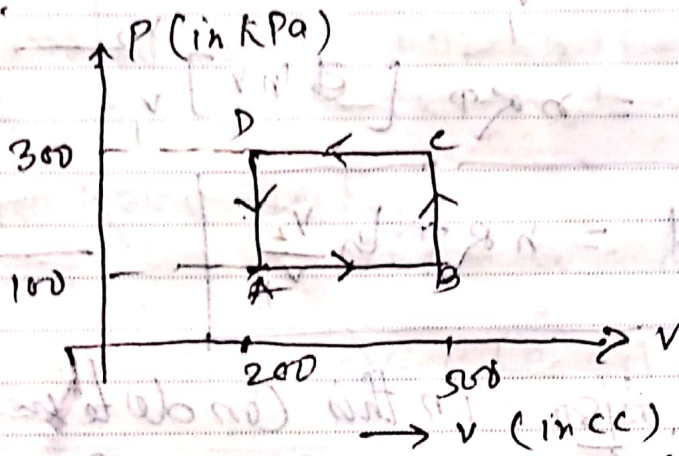
$P = \text{const.}$

$$W = \int_{V_1}^{V_2} P dV = P \int_{V_1}^{V_2} dV$$

$$= P [V]_{V_1}^{V_2} = P(V_2 - V_1)$$

⇒ $W = P(V_2 - V_1)$

Prob.



WORK TO DO

from the given fig., calculate work done in processes A → B, B → C, C → D, D → A.

soln: -

PHONES

(a) work done in process AB

$W_{A \rightarrow B} = P(V_2 - V_1)$

SUNDAY 7

$= 100 \times 10^3 (500 - 200) \times 10^{-6}$

$= 10^5 \times 300 \times 10^{-6} = 30 \text{ J.}$

(b) $W_{B \rightarrow C} = 0$

(c) $W_{C \rightarrow D} = -90 \text{ J}$

(d) $W_{D \rightarrow A} = 0$

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135-200

Ans.

$$\therefore W_{A \rightarrow B \rightarrow C \rightarrow D \rightarrow A} = 30 + 0 - 90 + 0 = -60 \text{ J.}$$

③ Isothermal process:-

$$T = \text{const.}$$

$$PV = nRT$$

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

Now

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

$$= nRT \left[\ln V \right]_{V_1}^{V_2}$$

$$W = nRT \ln \frac{V_2}{V_1} \quad \text{--- (1)}$$

Also in this condition,

$$P_1 V_1 = P_2 V_2$$

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

$$\therefore W = nRT \ln \frac{P_1}{P_2} \quad \text{--- (2)}$$

④ Adiabatic process:-

$$(i) \delta Q = 0 \quad dU + \delta W$$

in an adiabatic process

$$\delta Q = 0$$

$$\therefore dU + \delta W = 0$$

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$$\Rightarrow \delta w = -dU$$

$$\Rightarrow \delta W = -n C_v dT$$

Heat, work done when the state of the system is changed from (P_1, V_1, T_1) to (P_2, V_2, T_2)

$$W = -n C_v \int_{T_1}^{T_2} dT$$

$$\Rightarrow W = -n C_v (T_2 - T_1)$$

$$\Rightarrow W = n C_v (T_1 - T_2) \quad \text{--- (1)}$$

WORK TO DO

(11) We know that

$$C_p - C_v = R$$

only for ideal gas,
not for liquid or
solid, or
real gas

$$\Rightarrow C_v \left(\frac{C_p}{C_v} - 1 \right) = R$$

$$\Rightarrow C_v (\gamma - 1) = R$$

$$\Rightarrow C_v = \frac{R}{\gamma - 1} \quad \text{--- (2)}$$

PHONES

$$W = \frac{n R (T_1 - T_2)}{\gamma - 1} \quad \text{--- (3)}$$

$$pV = nRT$$

$$W = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1} \quad \text{--- (4)}$$

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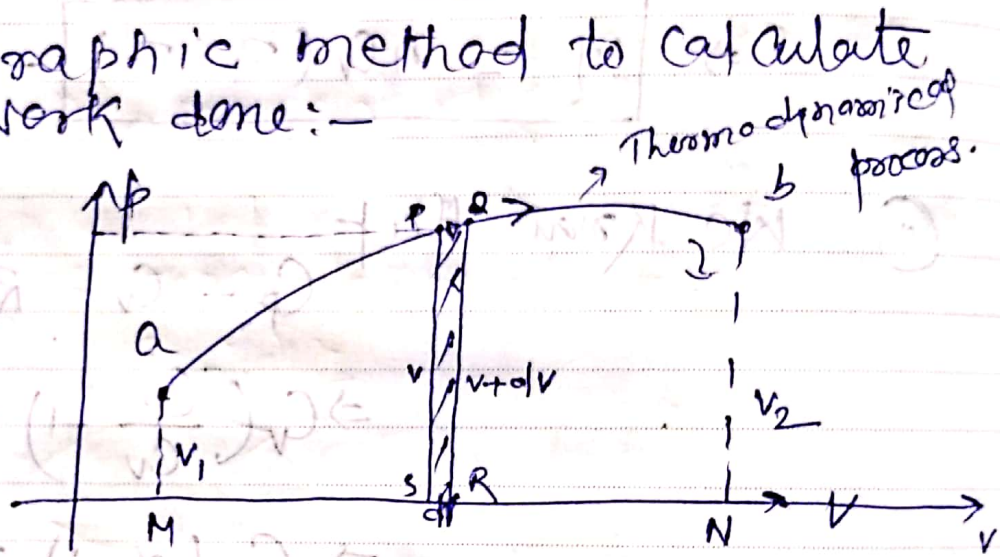
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Sign Convention :-

- (i) Work done by the system is taken positive when the system expands i.e. $V_f > V_i$, then (system) does work.
- (ii) Work done on the system is taken negative when the system is compressed i.e. $V_f < V_i$, then work is done on the system.

WORK TO DO

Graphic method to calculate work done :-



Consider, a thermodynamical process ab on PV diagram.

PHONES p and q are two very close points such that the pressure remains almost const. in the process pq. and volume is slightly changed by dv.

Now, work done in process pq

$$\delta W = PdV = p \times s \times R$$

$$\Rightarrow \delta W = \text{Area of } p \times R \times s \quad \text{--- (1)}$$

∴ work done in process ab

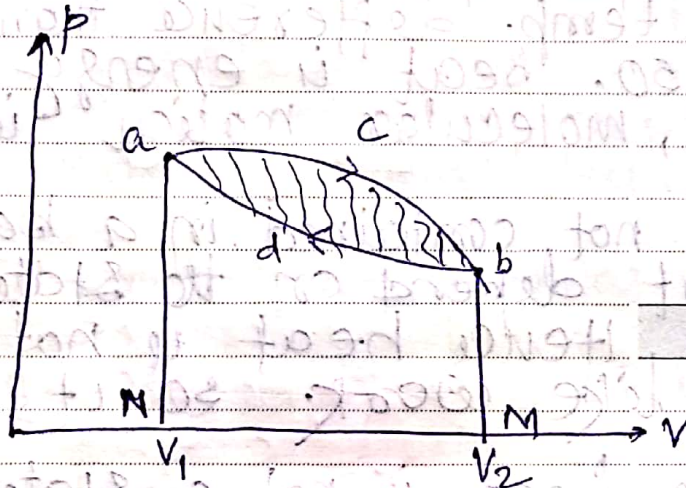
$$W = \int \delta W = \text{Area of } a b N M a$$

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→ In case of expansion curve work is +ve and
 In case of compression curve it is negative.

Work done in cyclic process:-



WORK TO DO

work done in cyclic process acbda.

$$W = W_{acb} + W_{bda} \quad \text{--- (1)}$$

$$\text{Now, } W_{acb} = \text{area of } acbMNa \quad \text{--- (2)}$$

$$W_{bda} = -\text{area of } bdaNNb \quad \text{--- (3)}$$

$$\therefore W = \text{area of } acbMNa - \text{area of } bdaNNb \quad \text{PHONES}$$

$$\Rightarrow W = \text{Area under cycle } acbda. \quad \text{--- (A)}$$

Sign Convention:-

if the sense of the cycle is clockwise then work done is positive and when it is anticlockwise then work is negative in a cyclic process.

Note:- If the P and V-axis are interchanged then sign convention is also reverse.

Heat :-

Heat

Heat

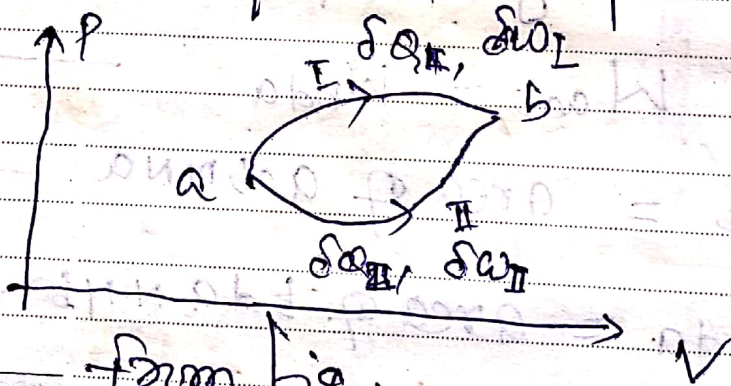
Q:- Heat is an energy X

(i) When a part of ~~a~~ internal energy flows due to temp. difference than it is called heat. so, heat is energy in motion. For it, molecular motion is responsible.

(ii) Heat is not contained in a body. so it does not depend on the state of the body. Hence heat is not a state function like work. so its change is not define.

WORK TO DO

As heat is not a state function so it is path or process dependent.



from fig :-

$$\delta Q_I \neq \delta Q_{II}$$

$$\delta W_I \neq \delta W_{II}$$

(iii) when heat is absorbed then it is taken positive. and when it is rejected then it is taken negative.

The sum total of internal kinetic energy, potential energy and rest mass energy is called internal energy of the system.

$$\text{i.e. } U = \sum E_{ki} + \sum E_{ij} + mc^2 \quad \text{--- (4)}$$

(iv) In case of an ideal gas

$$\sum E_{ij} = 0$$

$$\therefore U = \sum E_{ki} + mc^2 \quad \text{--- (5)}$$

WORK TO DO

for a monoatomic ideal gas translational kinetic energy is in the form of translational kinetic energy and for a molecule of it

$$E = \frac{3}{2} K T$$

if $N =$ no. of molecules in the system

then
$$E = \frac{3}{2} N K T \quad \text{--- (6)}$$

PHONES

$U = \frac{3}{2}$ internal energy of a monoatomic ideal gas

$$U = \frac{3}{2} N K T + mc^2 \quad \text{--- (7)}$$

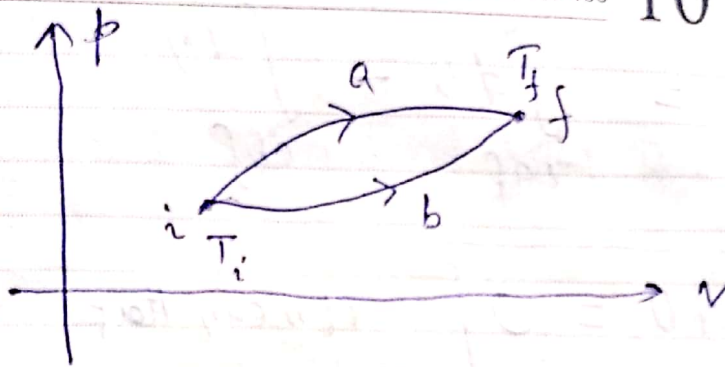
it is clear from these results that for a given mass of an ideal gas

$$U = f(T), \text{ only}$$

energy U is hence a state function so its change will be defined

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(v)



Internal energy of the system in state 'i' —

$$U_i = \frac{3}{2} NkT_i + mc^2$$

& in final state 'f'

$$U_f = \frac{3}{2} NkT_f + mc^2$$

∴ Change in internal energy

$$\Delta U = U_f - U_i$$

$$= \frac{3}{2} Nk(T_f - T_i) \quad \text{--- (8)}$$

It is clear from this result, that change in internal energy is independent of path.

i.e.
$$\int_{iaf} dU = \int_{ibf} dU$$

(vi) for a cyclic process change in internal energy is zero

$$\oint dU = \int_{iaf} dU + \int_{fbi} dU$$

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$$\oint dU = \int_{i \rightarrow f} dU - \int_{c \rightarrow b \rightarrow f} dU$$

$\therefore \boxed{\oint dU = 0}$ it means that $dU \neq 0$

Prob:- Change in internal energy in a cyclic process is zero as

WORK TO DO

- (a) change in internal energy is path independent.
- (b) initial and final states are same.
- (c) internal energy remains const.
- (d) All of the above.

In a cyclic process internal energy changes but for the complete cycle its change is zero.

PHONES

Prob:- An ideal gas passes from a state '1' to a state '2' by isothermal process. change in its internal energy is zero. because

- (a) internal energy remains const.
- (b) internal energy is path independent
- (c) initial and final internal energy are same
- (d) All of the above.

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$$U_1 = \frac{3}{2} N K T_1 + M C^2$$

if const.

FIRST LAW OF THERMODYNAMICS :-

According to first law of thermodynamics heat given to a system appears in max^m two forms

(1) A part of heat is used to increase internal energy of the system and

(2) Rest part of ~~heat~~ it is used by the system in doing mechanical work.

Let ΔQ = Heat given to the system

dU = Change in internal energy

ΔW = work done.

$$\Delta Q = dU + \Delta W$$

$$\Rightarrow \boxed{dU = \Delta Q - \Delta W} \quad \text{--- (i)}$$

$$\text{or, } \boxed{dU = dQ - dW}$$

$$\therefore \Delta W = p dV$$

$$\therefore \boxed{dU = \Delta Q - p dV}$$

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Application of 1st Law of thermodynamics

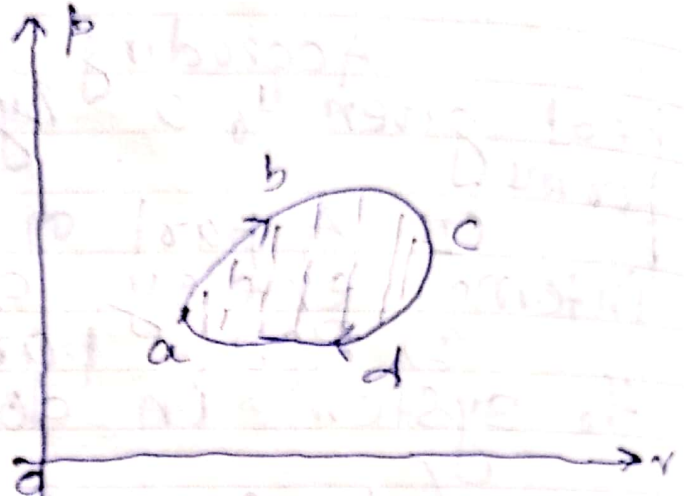
(A) Cyclic process :-

A/c to first law of thermodynamics

$$q = \Delta U + W$$

In cyclic process, $\Delta U = 0$

$$\therefore \boxed{q = W} = \text{Area under the cycle} \quad \text{--- (i)}$$



(B) Isochoric process :-

$$V = \text{const}$$

$$\Rightarrow dV = 0$$

$$\Rightarrow PdV = 0$$

$$\Rightarrow \int_{V_1}^{V_2} PdV = 0$$

$$\Rightarrow \boxed{W = 0}$$

So, from first law of thermodynamics

$$q = \Delta U \quad \text{--- (i)}$$

$$\text{Now, } \Delta U = \mu C_v (T_f - T_i)$$

$\mu = \text{no. of moles}$
 $C_v = \text{sp. heat capacity of const. volume}$
 $\gamma = \frac{C_p}{C_v}$

$$q = \Delta U = \frac{\mu R (T_f - T_i)}{\gamma - 1}$$

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$$\therefore Q = \frac{\mu R (T_f - T_i)}{\gamma - 1} \quad \text{--- (2)}$$

© Isothermal process :-

$$T = \text{Const.} \Rightarrow U = \text{Const.}$$

$$\Rightarrow \Delta U = 0$$

So, In isothermal process, first law of thermodynamics is

$$Q = W \quad \text{--- (i)}$$

Now,

$$W = \mu R T \ln \frac{V_f}{V_i}$$

$$= \mu R T \ln \frac{P_i}{P_f}$$

WORK TO DO

$$\therefore Q = \mu R T \ln \frac{V_f}{V_i} \quad \text{--- (2)}$$

$$\text{OR, } Q = \mu R T \ln \frac{P_i}{P_f} \quad \text{--- (3)}$$

① Adiabatic process :-

In an adiabatic process, $Q = 0$

\therefore from 1st law of thermodynamics

$$0 = \Delta U + W$$

$$\Rightarrow \Delta U = -W \quad \text{--- (i)}$$

Now,

$$W = \frac{\mu C_V (T_i - T_f)}{\gamma - 1} = \frac{\mu R (T_i - T_f)}{\gamma - 1}$$

$$= \frac{P_i V_i - P_f V_f}{\gamma - 1}$$

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$$\therefore \Delta U = - \mu c_v (T_i - T_f)$$

$$= - \frac{\mu R (T_i - T_f)}{\gamma - 1}$$

$$= - \left(\frac{P_i V_i - P_f V_f}{\gamma - 1} \right)$$

→ if $W \rightarrow +ve$, then $\Delta U = -ve$

WORK TO DO

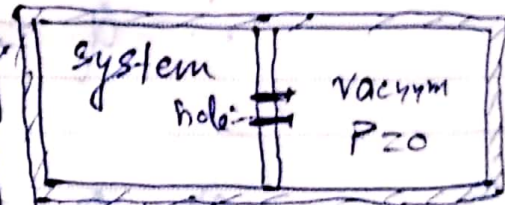
\Rightarrow adiabatic cooling.

→ if $W \rightarrow -ve$, then $\Delta U = +ve$.

\Rightarrow adiabatic heating.

[E] - free expansion:-

Adiabatic wall = Non-conducting



↓ Adiabatic wall.

Let us consider a thermodynamic system (say an ideal gas) is enclosed in half part of an adiabatic container. The remaining half part is vacuum. If a hole is made so that the gas expands in against of vacuum. Such an expansion is called free expansion.

Now, $W = \int_{V_i}^{V_f} p dV = 0$ as $p = 0$

$$Q = 0$$

\therefore from 1st law of thermodynamics

$$Q = \Delta U + W$$

$$\Rightarrow 0 = \Delta U + 0 \Rightarrow U = \text{const} \quad T = \text{const}$$

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