THERMODYANAMICS

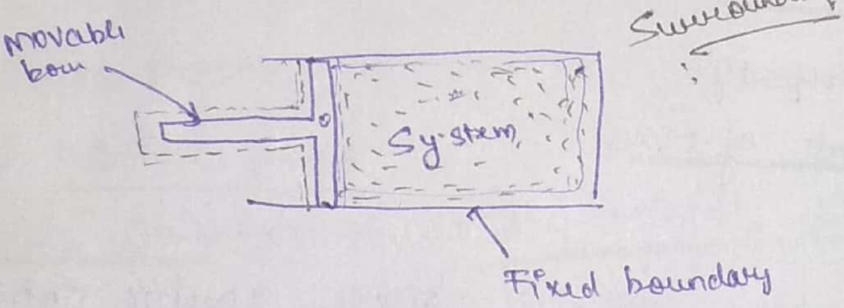
- Thermodynamic's is the branch of science which deals with energy and it's interaction with system and Sourrounding.

Energy → Ability to cause changes

System → It is a fixed mass or fixed region in space where study is focused

Sourrounding → Everything the except system

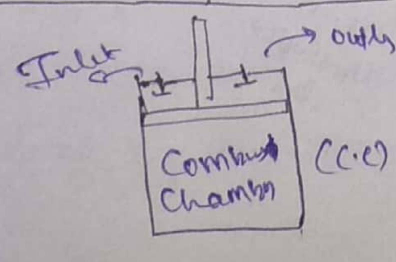
The part of the which is affected by the system is called Immidiate Sourroundin



Boundary → A Imagionary or Real Surface that's seprates system from sourrounding

Boundary can be fixed or movable.

System	Mass	Energy	Example
1) closed system	×	✓	Piston cylinder arrangement without valves
2) open system	✓	✓	P.C.A with valves
3) ~~closed~~ Isolated System	×	×	Universe



① microscopic approach
In which we deals with property each and every molecule and concentrate & consider of molecules

② Macroscopic. approach.
We focused avg. system property. Instead, of particular molecule behaviour

Properties
Any characteristics which gives the Information of about the system

1) Intensive property
Independent of mass eg → viscosity, Thermal con

2) Extensive property
Dependent of Mass

Note
specific enthalpy, specific volume, specific entropy specific energy, are Intensive property.

which of the following property Intensive property.

(a) Volume → Extensive
(b) Pressure → Intensive
(c) density → Intensive
(d) Kinetic energy → Intensive
(e) Specific enthalpy → Intensive
(f) thermal conductivity → Intensive
(g) Viscosity. → Intensive
(h) Refractive Index. → Intensive, due to dimensionless

State Variably

When we are changing the property ~~that~~ then state changes.

Or

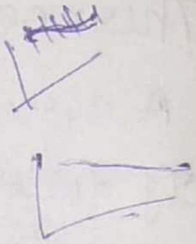
Any condition of the system is known as state of the system for the particular all the property will have fixed value

As any changing of property state of system changes.

Change of state of a system is known as process

Path Variable

The Infinite state through which system passes while going from Intial state to final state is called path variable or process path.



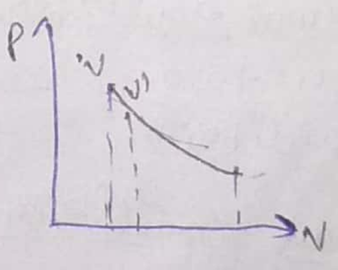
Thermodynamic process

- Quasi - Static process

A process which occurs at very infinitly slow rate Quasic - static process

It is represented by solid line ~~or~~ or joined line.

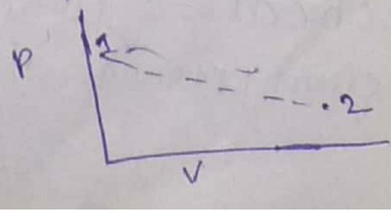
In Quasi - static Process, each state through which system passes is an equilibrium state



Non-
- Quasi - static process

A process which is Not Quasi-static process

It is represented by dashed line.



Reversible and Irreversible process.

~~When we are changing~~

When reversed in direcn follows the same path as of the ~~pro~~ forward process and leaves no change in System and sourroundiy. It is called reversible

when the change in System and sourrounding It is called Irreversible.

Thermodyamical equilibrium → If the property of the system at all points become

A system is said to be in thermodyanimical equilibrium If following types of equilibrium are satisfied

(1) Mechanical equilibrium
when all the force are balanced.

(2) chemical equilibrium
when all the chemical eqn are balanced or No unbalanced chemical eqn.

(3) Thermal equilibrium.
when two bodies are in same temp. these body are in thermal equilibrium

(4) Phase equilibrium
when the phase are equal proportion or Mass of per unit ~~area~~ time cost.

Electrical ⇒ When there exist an ~~??~~ uniformity of electric potential throughout they

Pure Substance

It is substance in which the chemical composition through out the volume. Air, $O_2 + N_2$, Gaseous air, H_2O + steam, etc.

Pressure — molecular interaction

$Pa = N/m^2$

$1\ bar = 10^5\ N/m^2$

$Psi = 6894.75\ Pa$

The pressure exerted by a system is defined as the force exerted normal to unit area of the boundary.

Pound / $inch^2$

Gibb's – phase rule → It provides the theoretical foundation of the thermodynamic

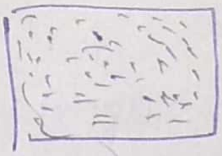
$$P + F = C + 2$$

P = No. of phase, F = D.O.F, C = No. of Compont

In the room thermodynamic There is only 1 No. of compont

based in characterizing the chem catt system and equilibrium relation of the phase present as physical condition

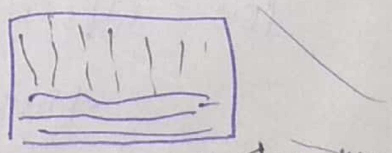
F = degree of free = No. of Independent Internal property required of fixed of the system



$N_2 + O_2$

$F = -1 + 2 + 2$

$\boxed{F = 3}$



liquid water & water vapor mix

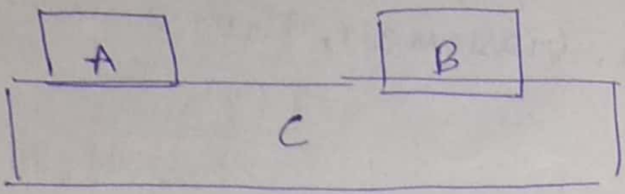
$F = 1 + 2 - 2$

$\boxed{F = 1}$

$\boxed{L_f = \text{Lentent heat} = \frac{Q}{m}}$

The amount of heat required to change the phase of 1 Kg water is called that.

Zeroth law of thermodynamic's



If $T_A = T_C$

& $T_B = T_C$

then $\boxed{T_A = T_B}$

When any two bodies of different temp A & B the attaching the body C in both they All the system are in thermal equilib. then body A = B of temp

	Ice pt	Steam pt
C	0	100
F	32	21
K	273.15	373.15

$$\boxed{\frac{C}{5} = \frac{F-32}{9} = \frac{K-273.15}{5}}$$

(Hg → thorough expansion of temp normally)

How to find the eq^n of temp.

$T = ap + b$ — ①

for ice pt

$0 = ap_i + b$ — ②

for steam pt

$100 = ap_s + b \longrightarrow$ ③

then ① − ②

$T - 0 = a(P - P_i)$ — ④ $\Rightarrow a = \frac{T}{P - P_i}$

then ② − ③

$-100 = a(P_i - P_s)$ — ⑤

Put the value of a in eqⁿ 5

$$-100 = \frac{T}{P-P_i}(P_i - P_s)$$

$$\frac{T_c}{100} = \frac{P-P_i}{P_s-P_i} \quad \text{— (A)}$$

For degree F

$$T = ap + b \quad \text{— (1)}$$

$$32 = ap_i + b \quad \text{— (2)}$$

$$212 = ap_s + b \quad \text{— (3)}$$

1 − 2

$$T - 32 = a(P - P_i) \quad \text{— (4)}$$

$$a = \frac{T-32}{P-P_i}$$

2 − 3

$$-180 = a(P_i - P_s) \quad \text{— (5)}$$

then, Put the value of a in eqⁿ 5

$$-180 = \frac{T-32}{P-P_1}(P_i - P_s)$$

$$\frac{T_F - 32}{100} = \frac{P-P_i}{P_s-P_1} \quad \text{— (B)}$$

From eqⁿ A & B

$$\frac{T_c}{100} = \frac{T_F-32}{180}$$

$$\boxed{\frac{T_c}{5} = \frac{T_F-32}{9}}$$

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For K

$T = ap + b$ — ①

$273.15 = ap_i + b$ — ②

$373.15 = ap_s + b$ — ③

$T - 273.15 = a(p - p_i)$ — ④

$-100 = a(p_i - p_s)$ — ⑤

$a = \frac{T - 273.15}{p - p_i}$

then put in eqⁿ ⑤

$-100 = \frac{T - 273.15}{p - p_i}(p_i - p_s)$

$\frac{-100}{T - 273.15} = \frac{p_i - p_s}{p - p_i}$

$\frac{T - 273.15}{100} = \frac{p_s - p_i}{p - p_i}$

$\frac{T - 273.15}{100} = \frac{p - p_i}{p_s - p_i}$ — (C)

then equal A = C

$\frac{T_K - 273.15}{100} = \frac{T_c}{100}$

$\boxed{T_K = T_c + 273.15}$

equal B = C

$\frac{T_F - 32}{\cancel{180}\,9} = \frac{T_K - 273.15}{\cancel{100}\,5}$

$\boxed{\frac{T_F - 32}{9} = \frac{T_K - 273.15}{5}}$

$$\boxed{\frac{P-P_i}{P_s-P_i} = \frac{T-T_i}{T_s-T_i}}$$

Energy interaction :-

(1) Internal energy (U)

These are all the microscopic form of energy which can't be realise from Naked eyes. comes into the internal energy

Macroscopic enlisted

These all the realised in Naked eyes.

Work

It is said to be done by the system If the sole effect on the thing's external to the system can be reduced to raise the weight. Though, weight may not be actually raised.

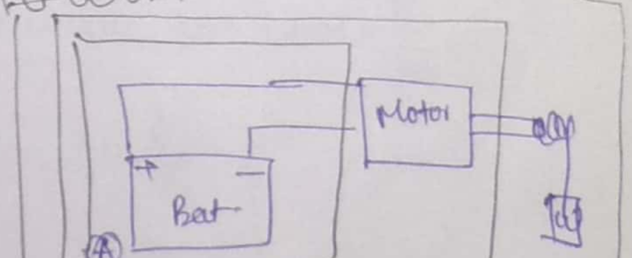
Work is a boundary phenomenan.

Workdone by the system $\Rightarrow$ Positive

work done on the system $\longrightarrow$ Negative

Important point with respect to Work

- Work is not a property
- It is a path funch
- It is a boundary phenom
- It is an inexact differential
- It is a transiant phenomenan (Unstudyable)



A & B $\Rightarrow$ work

C $\Rightarrow$ Not work

~~Closed system Analysis~~

$\cancel{T = ...}$

$\cancel{R - P_i = P_s - P_T}$

Phase

If a quantity of matter is homogenous or uniform throughout in physical structure and chemical composition is termed as phase

pressure

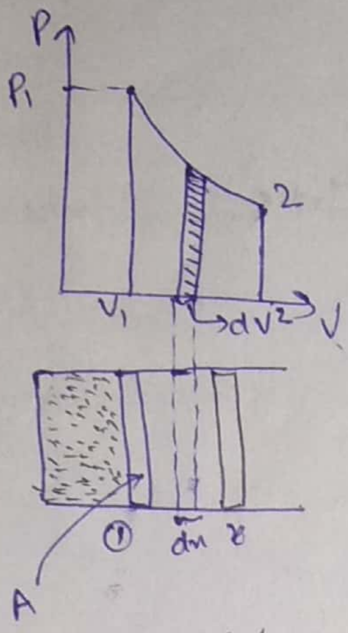
- Atmosphere: pressure exerted by the atmosphere air
- Gauge ↓ pressure measured from gauge and instrument (Bourdon / Mano meter)
- Absolute: pressure measured from level of absolute zero press
- Vacuum: pressure of fluid to be measured is less than atm press
  - Static press: when pressure sensed by a measuring device moving with same velocity as the fluid stream
  - Impact / Stagnation: Force per unit area to the direction of force when fluid is brought to rest reversibly (pitot tube)
  - Velocity press: velocity or dynamic head is termed as velocity pressure

$$\boxed{P_{abs} = P_{gauge} + P_{atm}}$$

$$\boxed{P_{abs} = P_{atm} - P_{vac}}$$

- 76cm of Hg = 101.3 kN/m²
- ~~40mm~~ 13.6 mm of water column = 1 mm of Hg

Closed System Analysis



Work = force × displace

Work = P × A × dx

$\delta W = P\,dV$

$$\boxed{W = \int P\,dV}$$

PdV workdone, ~~Workdone~~ - displacement
Boundary work

① Isochoric (Volume const)
② Isobaric (Pressure const)
③ Isothermal ($T = C$)
④ Adiabatic ($\Delta Q = 0$)
⑤ Polytropic proc. ξ

Isentropic

Isochoric $\boxed{V = C} \Rightarrow dV = 0$

then, $\boxed{W = 0}$

Isobaric $\boxed{P = C}$

$$W = \int_1^2 P\,dV = P(V_2 - V_1)$$

Isothermal ($T = C$)

$PV = mRT$ $\quad R$ = characteristic gas const $= \dfrac{\bar{R}}{M}$

$PV = C$

$P = \dfrac{C}{V}$ — ①

$$W = \int_1^2 \frac{C}{V}\,dV$$

$W = C \ln(V_2 - V_1)$

$$\boxed{W = C \ln \frac{V_2}{V}}$$

$W = P_1 V_1 \ln \dfrac{V_2}{V_1}$

$W = P_2 V_2 \ln \dfrac{V_2}{V_1}$

$W = mRT \ln \dfrac{V_2}{V_1}$

$$\boxed{W = 2.303\, mRT \log_e \frac{V_2}{V}}$$

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(4) Adiabatic Process

$$PV^{\gamma} = C$$

$$P = \frac{C}{V^{\gamma}} \qquad \gamma = 1.4$$

$$W = \int_1^2 \frac{C}{V^{\gamma}}\, dV \qquad \gamma = \text{Adiabatic Index.}$$

$$W = C\left[\frac{V^{-\gamma+1}}{-\gamma+1}\right]_1^2$$

$$\frac{C}{-\gamma+1}\left[V_2^{-\gamma+1} - V_1^{-\gamma+1}\right]$$

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

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

$$\boxed{W = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}} \text{ Joule.}$$

(5) Poly tropic process

$PV^{n} = C$ where ~~no~~ definite value of n = Polytropic Index

$n = 0 \Rightarrow$ Isobaric

$n = \infty \Rightarrow$ Isochoric $\qquad \boxed{-\infty < n < +\infty}$

$n = 1 \Rightarrow$ Isothermal

$n = \gamma = \frac{C_P}{C_V}$

If $PV^{-1} = C$, $PV^{-2} = C$, $PV^{2} = C$ } Polytropic

$$W_{1-2} = C\int P\,dV = C\left(\frac{V_2^{1-n} - V_1^{1-n}}{1-n}\right)$$

$$C = P_1 V_1^{n} = P_2 V_2^{n}$$

$$W_{1-2} = \frac{P_2 V_2 V_2^{1-n} - P_1 V_1 V_1^{1-n}}{1-n} = \frac{P_1 V_1 - P_2 V_2}{n-1} \text{ kJ}$$

Process	Representation	Workdone
① Isochoric	$V=c$	$W=0$
② Isobaric	$P=c$	$W=P(V_2-V_1)$
③ Isothermal	$T=0$	$W=2.303\, PV \ln\left(\frac{V_2}{V_1}\right)$
④ Adiabatic	$Q=0$	$W=\frac{P_1V_1-P_2V_2}{\gamma-1}$
⑤ Polytropic	$PV^n=c$	$\boxed{W=\frac{P_1V_1-P_2V_2}{n-1}}$

* If the adiabatic process has to be carried out without Insulation It should be carried in a very fast manner.

- If an Isothermal process has to be carried out during phase change of the substance.

Slope of Isothermal and adiabatic's process

$PV^{\infty}=c$

Isothermal

$PV=c$

$d(PV)=dc$

$VdP+PdV=0$

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

Adiabatic

$PV^{\gamma}=c$

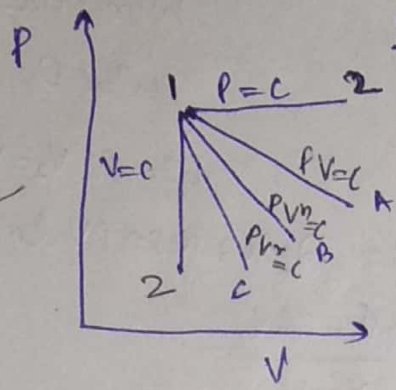
$d(PV^{\gamma})=dc$

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

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

$$=-\gamma PV^{-1}=-\gamma\frac{P}{V}$$

then, Adiabatic



Expansion

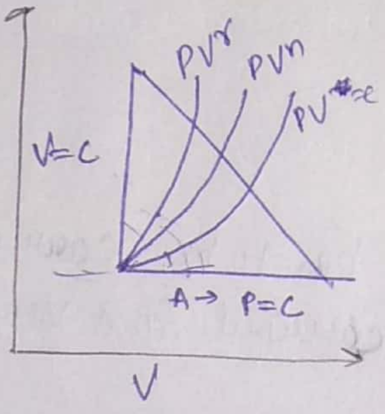
- Adiabatic is C because
- slope is more as compared to Isothermal
- Isothermal is A because γ=1 min val
- Any b/w (n).

• Adiabatic curve is more vertical than Isothermal curve.

: the slope of adiabatic curve is 'γ' times the slope of Isothermal curve.

Compression

$(Q = -ve, W = -ve)$



Isothermal	Adiabatic
$\frac{dP}{dV} = -\frac{P}{V}$	$\frac{dP}{dV} = -\frac{\gamma P}{V}$
during com $\frac{dP}{dV} = \frac{P}{V}$	$\frac{dP}{dV} = \frac{\gamma P}{V}$

expansion $(Q = +ve, W = +ve)$

Ideal Gas Behaviour for Different Process

$PV = mRT \longrightarrow$ Ideal gas

$R \rightarrow$ characteristic gas eqn

① Isochoric $V = C$

$PV = mRT$

$\frac{P}{T} = C$

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

(2) Isobaric $(P=C)$

$PV = mRT$

$\frac{V}{T} = C$

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

(3) Isothermal $PV=C$

$PV = mRT$

$$\boxed{P_1V_1 = P_2V_2}$$

(4) Adiabatic process

$PV^\gamma = C$

$P_1V_1^\gamma = P_2V_2^\gamma$

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

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

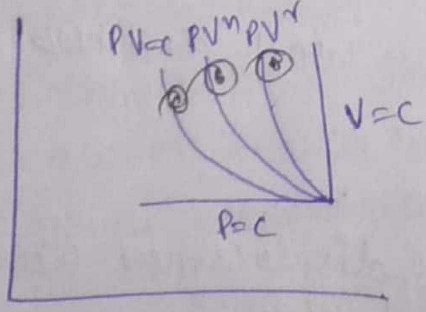
$\frac{T_2V_1}{T_1V_2} = \left(\frac{V_1}{V_2}\right)^\gamma$

By closed system
Quasi-static proc
Ideal gas

$\frac{PV}{T} = \text{const}$

$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

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



A is more vertical then it is adiabatic

A Gas expand from intial state with $P_1 = 340 kpa$ and $V_1 = 0.0425\ m^3$ to a final state where $P_2 = 136 kpa$ If the Pressure Volume relation ship during the process is $\boxed{PV^2 = C}$ then determine in KJ.

$$P_1 V_1^2 = P_2 V_2^2$$

$$340 \times 10^3 \times (0.0425)^2 = 136 \times 10^3 \times V_2^2$$

$$\frac{340 \times (4.25)^2}{136} = V_2^2$$

$$= 0.675\ m^3$$

$$W = \frac{P_1V_1 - P_2V_2}{n-1}$$

~~340×10³×0·0425 − 136×10³×~~ 3'

$$\boxed{W = \frac{340 \times 0.0425 - 136 \times 0.675}{2-1}}\ KJ$$

$$\boxed{W = 5.3103}\ J$$

Q. What are the other forms of work explain briefly

Work ⇒ It is the sole effect external to the System boundary has been the rise weight.

Sole effect ⇒ differentiate b/w work and heat

Work forms

1) Work of fluid (Mechanical work) or displacement work

~~It is the work when we are~~ forcing

It is the work can be defined by when the external force can be applied at the molecule and thing's that's displace at one place to another place is called displacement or fluid workdone.

$$F = P \cdot A$$

$$W = F \cdot dx$$

$$\delta W = P \cdot A \cdot dx$$

$$W = \int_1^2 P\, dV$$

$$\boxed{W = P(V_2 - V_1)}$$ 5

During compression = $\boxed{W = -P(V_2 - V_1)}$ 5

Work done in moving an electric charge through electric field.

When the charge moving in electric field and experience a force by the electric field ~~them~~, that electric force (E) can be formed the potential difference across the charge (q) that's called work done

$\cancel{E = -\frac{\partial V}{\partial q}}$ $\boxed{W = V dq}$

It is valid only for reversible

Paddle- wheel work or stirring work

As the weight is lowered and the paddle wheel turns thus is a work tranfer into the fluid system which get stirred since the volume of the system remains const.

$$\delta W = \int_1^2 mg\, ds = \int_1^2 T d\theta$$

Paddle wheel ⇒ It is a device which is converted into rotary motion into linear motion

Shaft work → A rotating shaft work is commly encountred in machin element

often the torque T applied to the shaft is const.
For specific const. torque, the workdone during n revolution is determined as follw

$$F = \frac{T}{r}$$

$$S = 2(\pi r n)$$

$$W = F \cdot S$$

$$\boxed{W = 2\pi n T}$$

Heat

~~It is the form of energy~~ which is transferred ~~by virtue of temp diff.~~

- It is the not property
- It is the path func^n
- It is boundary phenomena
- It is transient

$$\boxed{Q = mc\Delta T}$$

Specific heat (C)

~~the~~ when the ~~energy~~ ~~that~~ energy required to raise the temp of unit mass substance by unit degree temp. diff ~~mass by the 1K temp.~~

$$\boxed{C = \frac{Q}{m\Delta T}}$$

Why $C_p > C_v$

~~As~~ because there is work done of $C_p = P(V_2 - V_1)$

& In C_v workdone $= 0$

So, energy = microscopic + macroscopic
~~Internal energy~~ + work

So, the work in the C_p is more required
So heat is more required so,
C_p is lar

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because C_p includes Internal energy & Wordone. Where as C_v includes only Internal energy.

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

At the Molecular level: At room temp.
Both C_p and C_v are increases but there ratio γ ~~dep~~ decrease.
But this ~~gas~~ is not applicable for Monoatomic (Inert)

- At the molecular level at high temp when we are braked the bond of molecule then, required the more Heat so, C_p and C_v are also Incre

$\gamma = 1.67$ (monoatomic)
$\gamma = 1.4$ (Diatomic)
$\gamma = 1.33$ (Polyatomic)

- Heat supplied by the system (+)
  on the system (−)

First law of ~~en~~ thermodynamics

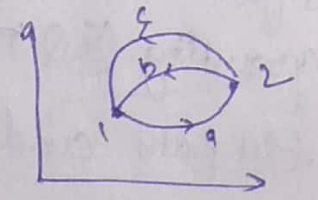
By professor (Joule)

$$\boxed{E_{in} - E_{out} = E_{stored}}$$

For a closed system Undergoing a cycle net heat transfer is equal to net works transfer

Consequences

① Heat is the path function



1−a−2−b−1

$$Q_{1a2} + Q_{2b1} = W_{1a2} + W_{2b1} \quad \text{— ①}$$

1-a-2-c-1

$Q_{1a2} + Q_{2c1} = W_{1a2} + W_{2c1}$ — ②

eq1 - eq2

$Q_{2b1} - Q_{2c1} = W_{2b1} - W_{2c1}$ — Ⓐ

$x \neq 0$ $x \neq 0$

→ so, it is path funtion

Though, path b and c are different but the end points are same in the heat transfer in path b and c is differenu and hence, heat transfer depend's on path and is a path funcⁿ

② Energy is a property

From eqⁿ A

$$\underbrace{Q_{2b1} - W_{2b1}}_{\text{energy}} = \underbrace{Q_{2c1} - W_{2c1}}_{\text{energy}}$$

It is equal so, it is pro

$$\boxed{\delta Q - \delta W = dE}$$

Though path b and c are different and the end points are same but the quantity ($\delta Q - \delta W$) will alsy be same for both the pam and heny it does not depends on path and must represent a change in property.

And, that property know as energy.

(3). Energy is a point funcⁿ

- Energy is an exact differential (dE)

$$E = \text{Micro} + \text{Macro}$$
$$\quad U \qquad\qquad K.E \,\&\, P.E$$

Assumption

$\Delta K.E$ and $\Delta P.E = 0$. (For closed system)

$\boxed{dE = dU}$ $\longrightarrow$ $E = \text{micro}$

$$\delta Q - \delta W = dE$$

$$\boxed{\delta Q = dU + \delta W}$$

$$\boxed{W = W_{boundary} + W_{other}}$$

$$\delta Q = dU + \delta W_b + \cancel{\delta W_o}^{\,0}$$ • There is no other form of work.

$$\boxed{\delta Q = dU + PdV}$$

For An Isolated system energy remains const

$$\cancel{\delta Q}^{\,0} = dE + \cancel{\delta W}^{\,0}$$

$$dE = 0$$

$$\boxed{E = \text{Const}}$$

(9) PMM-I Perpetual Motion Machine of I^{st} kind

According to first law of thermodynamics there can be no machine which produces work continously without absorbing any other form of energy such a device know as PMM-I

$C_p =$ $C_v =$ ~~R~~ 2.87 ... 8.314

Heat transfer for Various process

(a) Iso-choric Process

$$\delta Q = dU + \delta W$$

first Assum $\delta W_b = 0$

$\delta W_b = 0$

$$\delta Q = dU$$

$$\boxed{mC_v dT = dU}$$

Isochoric, Valid for all substance

For Ideal gas Valid for all process

(b) Iso baric Process

$$\delta Q = dU + \delta W$$

$$\delta Q = dU + PdV + \cancel{\delta W_o}^{0}$$

$$mC_p dT = dU + PdV$$

$$mc_p dT = dU + d(PV)$$

$$mc_p dT = d(U + PV)$$

$$\boxed{mC_p dT = dH}$$

H = enthalpy = U+PV

Isobaric, Valid for all subst

Ideal gas valid for all process

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(3) For Isothermal process

$$\delta Q = dU + \delta W$$

for Ideal gas

$$U = f(T)$$

$$\delta Q = \cancel{dU}^{0} + \delta W$$

$$\boxed{\delta Q = \delta W}$$

In Isothermal process the total heat supplied to the Ideal gas is converted into work and it is ~~tho'~~ not a violation of 2nd law of thermodynamics since, 2nd law is for a cycle Not for a process

(4) Adiabatic Process

$$\delta Q = dU + \delta W$$

$$\boxed{dU = -\delta W}$$

Polytropic and first law of opening

Heat transfer for Polytropic process

$$C_p - C_v = R \quad -(1) \quad ☆☆☆$$

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

$$\boxed{C_p = \gamma C_v} \quad -(2)$$

Putting eqn (1) in (2)

$$\gamma C_v - C_v = R$$

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

$$\boxed{C_v = \frac{R}{\gamma - 1}} \quad \text{and} \quad \boxed{C_p = \frac{\gamma R}{\gamma - 1}}$$

$$\boxed{\delta Q = dU + \delta W}$$

$$\delta Q = mc_v dT + \frac{P_1V_1 - P_2V_2}{n-1}$$

$$= mc_v(T_2 - T_1) + \frac{P_1V_1 - P_2V_2}{n-1}$$

$$= \frac{mR}{\gamma-1}(T_2 - T_1) + \frac{P_1V_1 - P_2V_2}{n-1}$$

$$= \frac{1}{\gamma-1}(mRT_2 - mRT_1) + \frac{P_1V_1 - P_2V_2}{n-1}$$

For Ideal gas $\quad P_1V_1 = mRT_1 \qquad P_2V_2 = mRT_2$

$$= \frac{1}{\gamma-1}(P_2V_2 - P_1V_1) + \frac{P_1V_1 - P_2V_2}{n-1}$$

$$\delta Q = \frac{P_1V_1 - P_2V_2}{n-1}\left[-\frac{(n-1)}{\gamma-1} + 1\right]$$

$$\delta Q = \frac{P_1V_1 - P_2V_2}{n-1}\left[\frac{-n+\cancel{1}+\gamma-\cancel{1}}{\gamma-1}\right]$$

$$\delta Q = \frac{P_1V_1 - P_2V_2}{n-1}\left[\frac{\gamma-n}{\gamma-1}\right]$$

$$\boxed{(\delta Q)_{poly} = (\delta W)_{poly}\left[\frac{\gamma-n}{\gamma-1}\right]}$$

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$$(\delta Q)_{poly} = \frac{P_1V_1 - P_2V_2}{n-1}\left(\frac{\gamma - n}{\gamma - 1}\right)$$

$$\frac{mRT_1 - mRT_2}{\gamma - 1}\left(\frac{\gamma - n}{n-1}\right)$$

$$\frac{mR}{\gamma - 1}\left(\frac{\gamma - n}{n-1}\right) \cdot (T_2 - T_1)$$

$$m\underbrace{\left(-C_v\left(\frac{\gamma - n}{n-1}\right)\right)}(T_2 - T_1)$$

Specific heat for polytropic process $= -C_v\left(\frac{\gamma - n}{n-1}\right)$

The specific heat of polytropic process is negative i.e, even though the heat supply temp. decreases because work done by the gas exceeds the heat supplied.

To prove $C_p - C_v = R$

For Ideal Gas

$$\Rightarrow \boxed{dH = dU + dPV}$$

$$mC_p dT = mC_v dT + d(mRT)$$

$$\cancel{m}C_p \cancel{dT} = \cancel{m}C_v \cancel{dT} + \cancel{m}R\cancel{dT}$$

$$\boxed{C_p = C_v + R}$$

Open System Analysis (Mass responsible for energy transfer)

There are two principles that flows by open system

- Conservation of mass (Mass in = Mass out)
- Conservation of energy ($E_{in} = E_{out}$)

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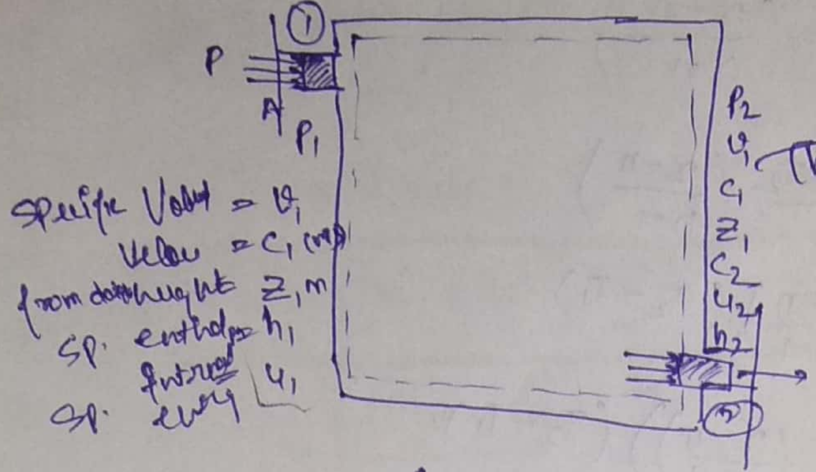


There is no accumulation of energy and Mass

$$\delta W = P_1 A \, dx$$

$$\delta W = P_1 \, dV$$

$$\frac{\delta W}{\delta m} = P_1 \frac{dV}{\delta m}$$

$$\delta W_1 = P_1 v_1$$

$$\delta W_2 = P_2 v_2$$

open system = Control Volume

Closed = Control Mass

$$\boxed{P_1 \frac{dV}{\delta m} = P_2 \frac{dV}{\delta m}}$$

Inlet work on C.V (control volume) $= -P_1 V_1$

Outlet " " " $= +P_2 V_2$

Steady state → when properties donot change with time

when properties donot change with space is called Uniform

Unsteady state – when properties do change with time and when properties do change with the space. Non Uniform

SFEE Study flow Energy equation

Study flow energy equation

Question

$\dot{m} = \rho \dot{Q}$ → Discharge

$\boxed{Q = \frac{dV}{dt}}$ ⇒ discharge

$E_{in} = E_{out}$

$$\boxed{H_1 + \frac{C_1^2}{2} + g z_1 + Q = H_2 + \frac{C_2^2}{2} + g z_2 + W_{CV}}$$

$\boxed{\dot{m}_{in} = \dot{m}_{out}}$

W_{CV} ⇒ control volume work in watts

$$\dot{m}_1 (h_1 + \frac{C_1^2}{2} + g z_1 + q) = \dot{m}_2 (h_2 + \frac{C_2^2}{2} + g z_2 + W_{CV})$$

$\boxed{\dot{m}_1 = \dot{m}_2}$

$$h_1 + \frac{C_1^2}{2} + g z_1 + \dot{q} = h_2 + \frac{C_2^2}{2} + g z_2 + \dot{W}_{CV}$$

for $\boxed{K.E \ \& \ P.E = 0}$

$$h_1 + \dot{q} = h_2 + W_0 = \text{other form}$$

$\dot{w} = \frac{W}{m}$

$$u_1 + P_1 V_1 + \dot{q} = u_2 + P_2 V_2 + W_0$$

$$\dot{q} = (u_2 - u_1) + (P_2 V_2 - P_1 V_1) + W_0$$

$$= \Delta U + \underbrace{W_{bo} + W_0}$$

$$\boxed{\dot{q} = \Delta U + \dot{w}}$$

This is the first law of thermodynamics for open syst

Workdone and Q and ΔE for different system

- Water and its vapour in a rigid boil

rigid boiler $\Rightarrow$ $\int p\,dV = 0$ $\quad W = 0$

$Q = +ve$

$\Delta E = Q - W = +ve$

- Water and steam circulating through various component of steam power plant

workdone $\Rightarrow$ Turbine Input work < Output work
+ve

Q_t = Heat added in the boil > Heat rejected to cond
+ve

$\boxed{\Delta E = 0}$

- Hydrogen and oxygen in the form of combustible mixture within a rigid ~~bod~~ and insulated wall.

Insulated $Q = 0$
Rigid $W = 0$

$\boxed{\Delta E = 0}$

- In gasolin mixture
  - Q $\Rightarrow$ ~~heat~~ chemical Energy $\rightarrow$ Mechanical energy by the mixture of air and gasoline.
    then Temp ↑ & Inter ↑
    Internal energy on the System = +ve

$Q = -ve$

- $W \Rightarrow$ Work done by the system = +ve

$\Delta E = Q - W$
$-Q - W = \underline{-ve}$

Capacitor → Work done by the system

(W) → Input w ≤ output work

Discharging (boundary) Capacitor receive wr

$$\boxed{W = +VI}$$

Q = Adiabatic system ⇒ 0

$$\Delta E = -VI$$

Block → Q=0 → Block (Non conductivity)

⇒ W = Capacity = +VI due to friction

⇒ $\Delta E = -VI$

Plane ⇒ Q ⇒ No Heat transfer = 0

W = −VI due to block

$\Delta E = +VI$

Block & plane ⇒ Q=0

W=0

$\Delta E = 0$

Falling body does not produce any work.

Thermal efficiency = $\dfrac{\text{Net Work done}}{\text{Heat supply}}$

अवश्य आया

During winter season a room measuring $5 \times 6 \times 3\ m^3$ heated electrically from initial temp. of $0°C$ to $20°C$. The air pressure inside the room is the same as that of surround and is equal to 74 cm of Hg. The pressure remains const. during this process. The heat capacity of furniture and walls is 32 kJ/K. The sp. heat of air is 1005 kJ/kg K. Calculate the amount of electric energy needed for heating the room. How much air escapes through gaps and windows during this period.

$$V = 5 \times 6 \times 3 = 90\ m^3 \qquad 76\ mP = 1.013 \times 10^2$$

$$74 = \frac{1.013 \times 10^2 \times 74}{76} = \underrightarrow{0.9863 \times 10^2}\ Pa$$

$$m_1 = \frac{PV}{RT} = \frac{0.9863 \times 10^2 \times 90}{0.287 \times (273+0)} =$$

$$m_2 = \frac{0.9863 \times 10^2 \times 90}{0.287 \times 273+20} =$$

air esc $\Rightarrow m_1 - m_2 = 7.7314$

$$m = \frac{m_1 + m_2}{2} = \underline{\qquad}$$

$$Q_1 = m \cdot c_p (T_2 - T_1)$$

$$Q_2 = 32 \times (20 - 0)$$

$$= 32 \times 640$$

$$Pe = \frac{Q_1 + Q_2}{1\,hour} = \quad 64$$

• Thermodynamics Process

Thermodynamics process is that process ~~when the~~ ~~temp or heat transferred~~ .

transition in which a system changes from one initial state to final state

Reversible process

When ~~the~~ ~~system~~ reversed in the direcn follows a same path there is no change system and surrounding is called reversible

(a) Frictionless relative motion, electrolo, Isothermal expan ...

Irreversible

When the reversed in the direcn follows a same path there is change system and sour. is called Irrevers

(a) Fluid flows with friction

(b) Free expansion

(c) diffusion of gas

Flow work

Those work which is associated in the flow process. Hence it has absent of closed system. The flow work is work require to cause the flow of fluid in any passage

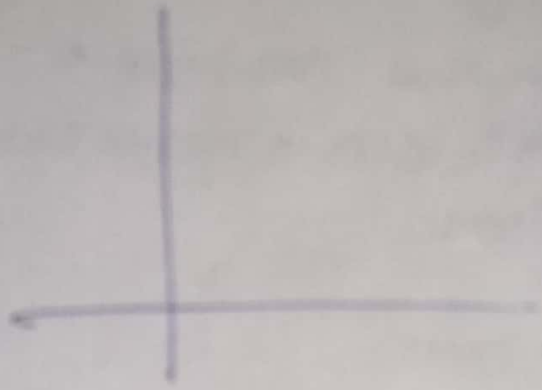
Nozzle or Turbine

(v) ⇒ Constant Volume ⇒ Isochoric process

PV^{n} = polytropic

$Q = mC_v \Delta T$

Given $P = 1.5$ bar



Workdone for $\int PdV$ ⇒ Constant pressure
Isobaric process

Application of Steady flow energy equation

Conversion of Unit

$$h_1 + \underbrace{\left(\frac{C_1^2}{2} + gz\right)\times 10^{-3}}_{\text{KJ/kg}} + \dot{q} = h_2 + \underbrace{\left(\frac{C_2^2}{2} + gz\right)\times 10^{-3}}_{\text{KJ/kg}} + \dot{q}$$

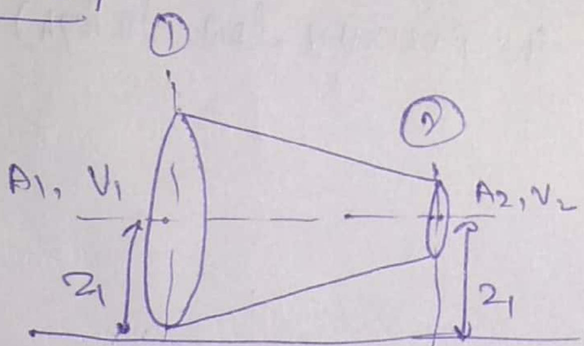
then it

① Nozzle velocity

Assumption

① Steady state
② Adiabatic Nozzle.
③ Change potential energy 0
④ $\boxed{W_{CV} = 0}$

For brams we are uses super sonic Nozzle



$A_1V_1 = A_2V_2$

$Q = \frac{m^3}{s}$

discharging

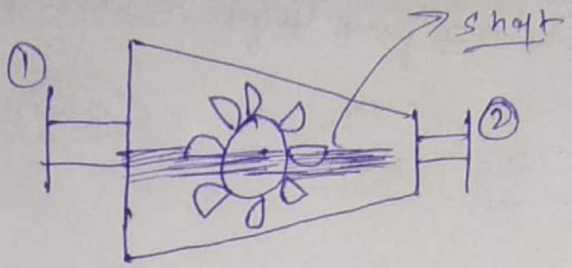
$$h_1 + \frac{C_1^2}{2} + \cancel{gz_1} + \cancel{q} = h_2 + \frac{C_2^2}{2} + \cancel{gz_1} + \cancel{W}$$

$$h_1 + \frac{C_1^2}{2} = h_2 + \frac{C_2^2}{2}$$

$C_2 >>>> C_1$

$$\boxed{C_2 = \sqrt{2(h_1 - h_2)}} \text{ m/s}$$

Turbine



Assumption

1. Steady state
2. Adiabatic
3. Kinetic energy & P.E = 0

$$h_1 + \cancel{\frac{C_1^2}{2}} + \cancel{gz_1} + \cancel{\dot{q}}^{\,0} = h_2 + \cancel{\frac{C_2^2}{2}} + \cancel{gz_2} + \dot{w}_{cv}$$

$$h_1 - h_2 = \dot{w}_{cv}$$

Compressor (Compressed the pressure low to high)

Assumption

1. steady state
2. Adiabatic
3. Change in K.E & P.E = 0

$$h_1 + \frac{C_1^2}{2} + gz_1 + \dot{q} = h_2 + \frac{C_2^2}{2} + gz_2 + w_{cv}$$

$$\boxed{h_1 - h_2 = -\dot{w}_{cv}}$$

-ve because workdone on the system.

Limitation of first law of thermodynamics.

① First discuss about energy transfer only it quantity., doesn't discuss the grade of energy & the quality of energy.

② First law does not discuss about the direcⁿ of energy transfer.

~~Example of limitation of first law~~

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(6) $h_1 + \frac{C_1^2}{2} + q = h_2 + \frac{C_2^2}{2} + W_{cv}$

(8) <u>Axial flow comp</u>

$P_1 = 1$ bar | $P_2 = 5$ bar
$T_1 = 300K$ | $T_2 = 475.15$ $\leftarrow \frac{T_2}{T_1} = \left(\frac{P_1}{P_2}\right)^{\frac{\gamma-1}{\gamma}}$
$C_1 = 300$ m/s | $C_2 = 100$ m/s

$PV = mRT$

$P = \rho RT$

$P_1 = \rho_1 R T_1$

$\boxed{\rho_1 =}$ $\boxed{\rho_2 =}$

$20 = \rho_1 A_1 V_1$

$h_1 + \frac{C_1^2}{2} + g\cancel{z_1}^{0} + \cancel{q}^{0} = h_2 + \frac{C_2^2}{2} + g\cancel{z_2}^{0} + W_{cv}$

$W_{cv} = -(h_2 - h_1) + \left(\frac{C_1^2}{2} - \frac{C_2^2}{2}\right) \times 10^{-3}$

$W_{cv} = -C_p(T_2 - T_1) + \left(\frac{C_1^2}{2} - \frac{C_2^2}{2}\right) \times 10^{-3}$

$= -1.005(475.15 - 300) + \left(\frac{(300)^2 - (100)^2}{2}\right) \times 10^{-3}$

$= -1.05 \times 175.15 +$

$= -176.020 +$

$= \underline{136} \times \frac{kJ}{kg}$

$20 \times 136 = $ ______ kW

Problem solving for closed system

If ~~P~~ $p = f(V)$ known

- Yes
  - $\boxed{\text{Linear}}$ → Use graphical approach
  - $\boxed{\text{Non-linear}}$ → $W = \int P\,dV$
- No → first law data known
  - Yes → $\boxed{Q = \Delta E + W}$
  - No → $\boxed{\text{Use practic appro}}$

(14)

26/9/17

Second law of thermodynamics

Thermal energy reservoir (TER) → It is a large body of infinite heat capacity capable of absorbing and rejecting infinite amount of heat without any considerable change in thermodyanamics Co-ordinate.

Source is a TER from which we can gain an infinite amount of Heat without any temp. change in source.

Sink is a TER from which we can absorb infinite amount of heat without undergoing any change in temp.

$Q_S \rightarrow$ Heat Supplied

$Q_R \rightarrow$ Heat Rejected

$Q_H \rightarrow$ Heat transfer at High Temp

$Q_L \rightarrow$ " " " Low Temp

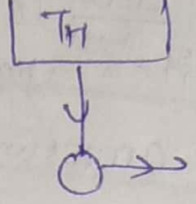
$T_H \rightarrow$ Body of temp which is at Higher temp

$T_L \rightarrow$ " " temp of which is at lower temp.

According to second law of thermodyanamics it is impossible to construct a device working on a cycle which converts { low grade energy, (random energy or disorganised energy example:- thermal energy, Heat) into { High grades (organised energy ex→ work)

Statement of Kelvin or plancle

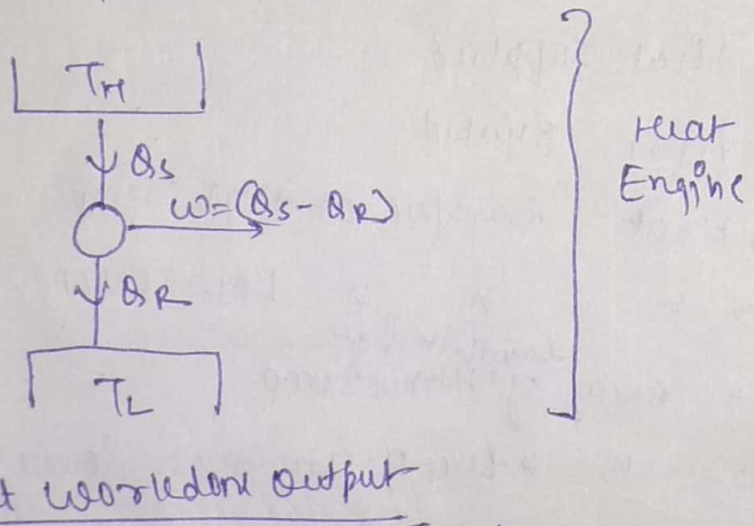
"It is impossible developed a device working on a cycle which produces work by exchanging heat with a single reservoir.



Heat engine cycle

It is a thermodyanamics cycle which produces work by the expanse of Heat

According to Kelvin plank of second law, No Heat engine can have an efficient of 100%.



$$\eta = \frac{\text{Net workdone output}}{\text{Net Heat Input}}$$

$$\eta = \frac{W}{Q_S} = \frac{Q_S - Q_R}{Q_S} = 1 - \frac{Q_R}{Q_S}$$

$$\boxed{\eta = 1 - \frac{Q_R}{Q_S}}$$

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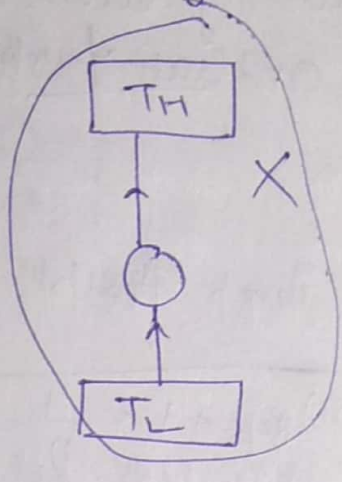
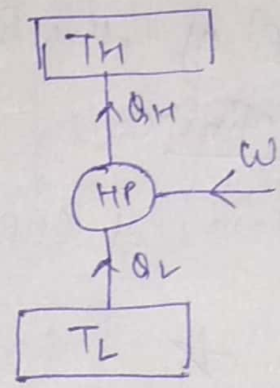
Heat engine is based on concept of Kelvin Plancle statement of second law of thermodynamics an it produces work both exchanging heat with two thermal energy reservoir.

Statement of Clausis of second law

It is impossible to developed a device working on a cycle which transfer heat from lower temp. to High temp. without any energy input.



But,



HP ⇒ Heat pump

Coefficient of performance (COP) =

$$COP = \frac{(\text{desired effect})}{(\text{work input})}$$

$$(COP)_{\text{Heat pu}} = \frac{Q_H}{W}$$

$$E_{in} = E_{out}$$

$$Q_L + W = Q_H$$

$$\boxed{W = Q_H - Q_L}$$

$$\boxed{(COP)_{HP} = \frac{Q_H}{Q_H - Q_L}}$$

$$(COP)_{Refri} = \frac{Q_L}{W_{in}}$$

$$\boxed{(COP)_{Refri} = \frac{Q_L}{Q_H - Q_L}}$$

According to Clausius statement of second law. The (COP) of the Refrigerator or Heat pumps can't be infinite

- The Relation of COP of Heat Pump & Refri

$$\star \quad \boxed{(COP)_{HP} = (COP)_{Refr} + 1 = \frac{1}{\eta_E}}$$

$$\frac{Q_H}{Q_H - Q_L} =$$

Refrigerator

It device which maintains the temp. of the system lower than that of surrounding.

Heat Pump

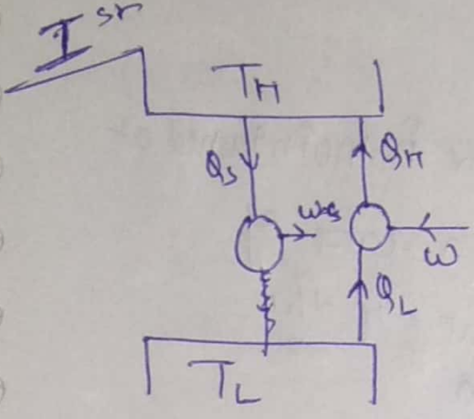
It is a device which maintains the temp. of the system Higher than that of surrounding.

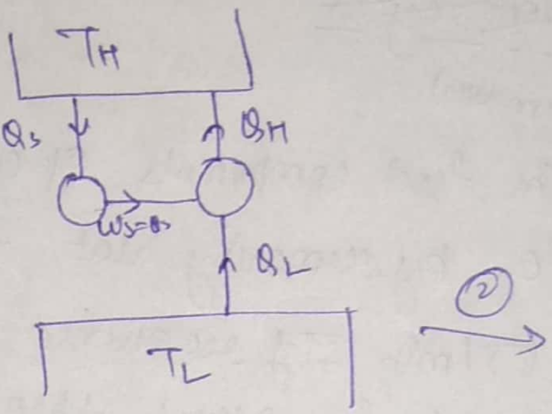
Also

A Heat engine cycle is a thermodynamics cycle in which there is net heat transfer to the system and net work transfer from the System. The system which executes heat engine cycle is a heat engine

Equivalance of kelvin planck statement and Clausius statement of

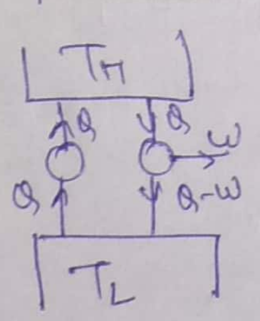
I st

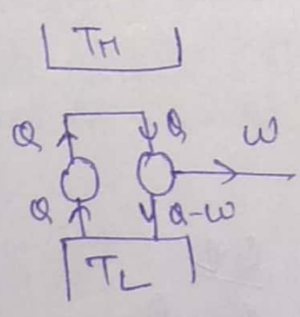




"Merge the device that violet's kelvin planck statement with the device Calusius stat"

"As we violet's kelvin plancks statement the calusius statement get's violeted automatically because after merging devices there is no need of external energy input to transfer Heat from lower temp. to higher temp.





" As we violets calusius statement kelvin plancks statements gets automatically violeted because after merging the devices there is no need to interact heat or transfer heat from source (TER).

"The ~~voi~~ violation of kelvin planck statement leads to violation of clausius statement and vice - versa".

Hence, These statements are called as <u>parallel</u>
<u>statement of second law of thermodyanami.</u>

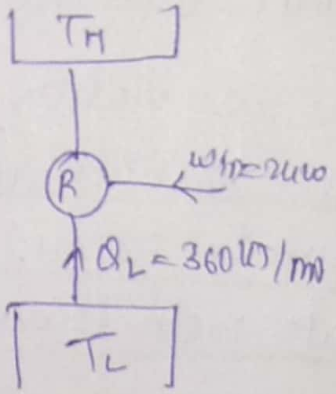
~~Carnot cycle~~

Numerical

Q The food components of a refrigerator is maintained at $4°C$ by removing heat from it at a rate of 360 KJ/min If required power input to the refrigerator is 2KW then determine

(i) COP of refrigerator

(ii) the rate of heat rejected that Houses the refrigerator



COP

$Q_L = 360 \frac{kJ}{min} = \frac{\overset{6}{360}}{60} = 6\ \underline{KW}$

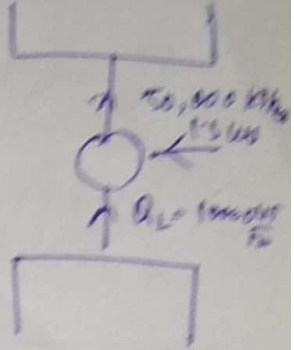
$COP = \frac{Q_L}{W} = \frac{6kw}{2kw} = 3\ kw$

$\boxed{COP = 3}$

$COP = \frac{Q_H}{Q_H - Q_L}$

$(Q_H - Q_L)3 = 6 \qquad = 8\ kw$

Q A commercial heat pump removes 10,000 KJ/hour of heat from the source and rejects 50,000 KJ/hour to the sink and requires 1.5 KW of power. What is COP of Heat pump



1. $Q_H = \frac{\cancel{10,000}}{60 \times 60} = \frac{500}{36}$

$Q_L = 10,000 KJ/hr$

$(COP)_{Ref} = \frac{Q_L}{Q_H - Q_L} = \frac{10,000}{\cancel{40,000}} = \frac{1}{4} \quad 2$

$\frac{10,000}{5000} = 2$

$(COP)_{Pu} = \frac{2}{4} + 1$

$\boxed{(COP)_{Pu} = 3}$

$36 \overline{)500}$ 13.9 ; 36, 140, 108, 320, 4

$\frac{50,000}{1.5}$

$(COP) = \frac{15,000 / 3600}{1.5}$

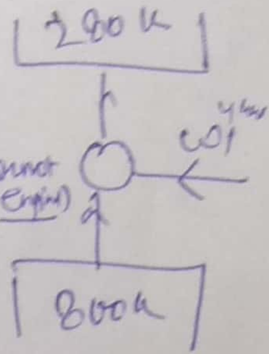
$\frac{15000}{5000} = 3$

Q_1 150

$\frac{10000}{3600} = 2.778$

A completely reversible heat engine operates with a source at 800 K and sink at 280 K and requires at what rate heat must be supplied to the engine in KJ/hour for producing a power of 4 KW.

22153 .846 KJ/hr



Carnot engine Note: for reversible engine efficiency is a funcn of temp. only) $\left(\eta = 1 - \frac{Q_R}{Q_S}\right)\left(1 - \frac{T_L}{T_H}\right)$ (Carnot Engine)

$\eta = 1 - \frac{280}{280} = 1 - \frac{280}{281}$

$\eta = 1 - \frac{280}{800} =$

$\eta = .65$

$Q_H = W + Q_L$

$\frac{Q_R}{Q_S} = \frac{T_L}{T_H} \Rightarrow \boxed{Q_R = Q_S \frac{T_L}{T_H}}$

$$\boxed{Q_s = \frac{\eta}{\omega}}$$

$$\boxed{Q_s = \frac{\cancel{\cdot 63}}{\cancel{4}}} \quad Q_s = \frac{4}{\cdot 63}$$

$$\boxed{Q_s = \frac{4}{\cdot 63} \times 3600}$$

Tu

Carnot are reversible engine
But In the daily life Irrev

In a Carnot Engine the ratio of minimum to max^m temp. 0.8 If a heat pump is operated b/w b/w same limit what is its C.O.P.

$$\frac{T_{max}}{T_{min}} = \frac{T_{sink}}{T_{source}} = 0.8$$

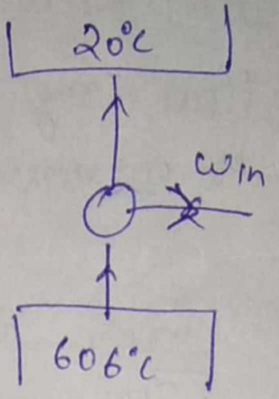
$$COP = \frac{1}{\eta_E}$$

$$\eta = 1 - \frac{T_L}{T_H} =$$

$$1 - 0.8$$

$$COP = \frac{1^0}{0.2} \underline{5}$$

A Reversible heat engine operating under a source temp. of 606°C and sink temp 20°C what will be the work done per KJ heat supplied to the engine.



$\eta = 1 - \frac{T_L}{T_H}$

$1 - \frac{293}{879}$

$\frac{879 - 293}{879}$

$\boxed{\eta = 0.667}$

$\frac{T_L}{T_H} = \frac{293}{879}$

$Q_s = \frac{W}{\eta}$

$W =$

$\eta \times Q_s = W$

$Q_s = 1$ for per KJ

$\boxed{W = 0.667 \text{ KJ}}$

A Refrigeration system rejects heat at a rate of 120kW and consume 30kW, then find the COP of refrigerator

$(COP)_R = \frac{1}{\eta} =$

$Q_R = 120W$

$Q_S = 30$

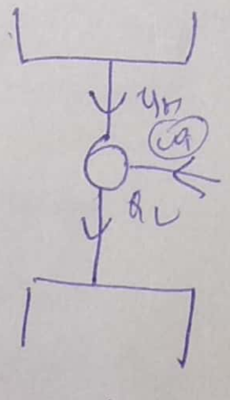
$\eta = \frac{W}{Q_{in}} = \frac{120K}{30K}$

$= 1 + \frac{1}{4} = 5$

$1 - \frac{Q_R}{Q_S} =$

$\frac{30}{120}$ $\frac{1}{4}$

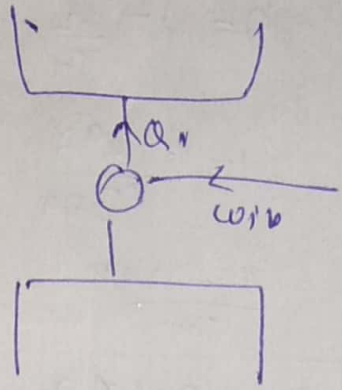
$= 1 + \frac{1}{4} = \frac{5}{4}$



$(COP)_R = \frac{Q_L}{Q_H - W} = \frac{120 - 30}{30}$

$\boxed{(COP)_R = 3}$

A Refrigerator used for cooling food in a grossary store is to produced 10,000 KJ/hour cooling effect and (COP) is Ref = 1.35 How many K. Watts of power will require to operate the refrigerator.



$$\frac{10,000}{3600} \text{ KJ/s}$$

$$= 2.7 \text{ KJ}$$

$$(COP)_R = \frac{Q_H}{W}$$

$$= \frac{2.7}{1.35} = \underline{2.0376}$$

Q A domestic refrigerator which follows reverse carnot cycle set as 2°C and ~~Ambient~~ Ambiant temp is 30°C find the reverse carnot cycle Q_H, Q_L, COP of Refrig (NOTE: for a reverse carnot cycle COP is a func^n of temp. only)

~~$(COP)_R =$~~

$$COP = \cancel{T_C}\ 1 - \frac{T_L}{T_H} = \frac{2}{30}$$

$$\frac{30-2}{30} = \underline{0.93}$$

$$(COP)_3 = \cancel{Q_3}\ \frac{Q_L}{Q_H - Q_L} = \frac{T_L}{T_H - T_L} = \frac{2+273}{30-2}$$

$$\frac{275}{293-275} = \frac{275}{18}$$

Reversible process is an ideal process and all natural process are considered as irreversible process.

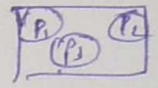
All Reversible process are quasistatic But the conversed is not true.

Causes of Irreversiblitity

a) Lack of equilibrium with in system or ~~with~~ b/w system and sourroundings.

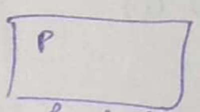
~~b)~~ Dissiapative effects:

a) i). Heat transfer through a finite temp. differenu.
ii) Lack of pressure equilibrium with in system
iii) Free expansion.

(iii) 

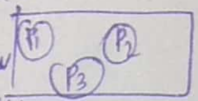
$P_1 \neq P_2 + P_3$
↓, equ

b) i) Friction
(ii) Paddle wheel work
~~(iii)~~ Energy transfer through resistor etc.

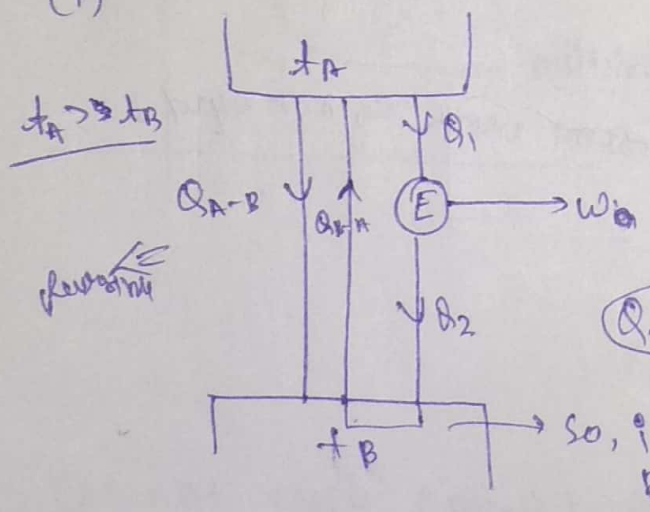


$P_1 = P_2 = P_3 = P$

But we arrow, not make it pressure gradient then, ~~is~~ to do some work so, it is going on irreversible.



(i)



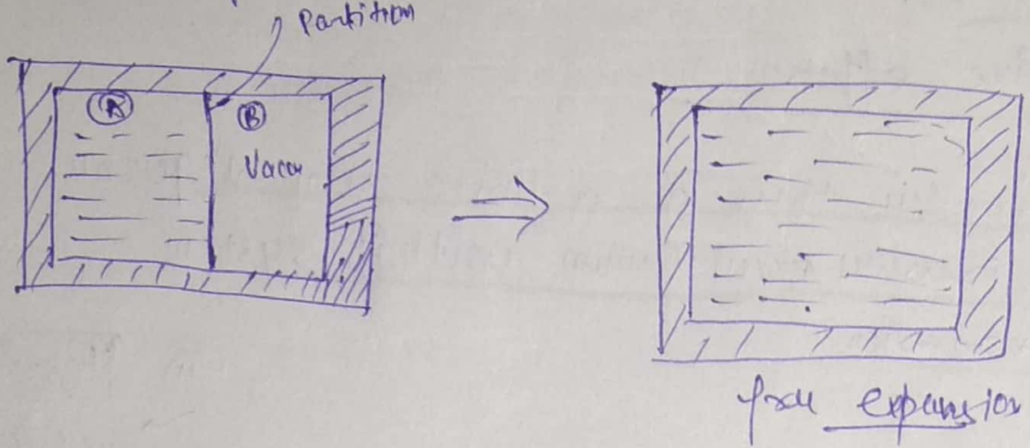
$$Q_2 = Q_{B-A}$$

→ So, it voilates Kelvin plank statement So, ~~it~~ Q_{A-B} is Reversible

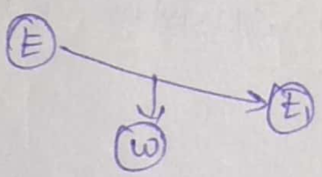
(A)

Let Suppose (A) As we can see figure (A) If we considered Q_{A-B} as Reversible. We can reversed its direction and assuming Heat rejected by the engine is equals to Heat transfer from B-A (Q_{B-A}) that means E produces work by the exchanging heat with a single reservoir and that is the violation of "Kelvin plancks" statement so, we can say heat transfer through a finite temp diff is an irreversible process.

(iii) Expension of gases against the vaccum in an insulating room is known as free expansion. It is an highly irreversible process

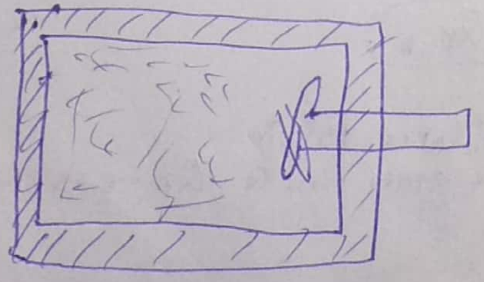


(ii) a)



$\boxed{W + E_1 \neq E}$ due to friction the dos dome work So, not equal

b)



c)

Carnot cycle (Reversiable cycle)

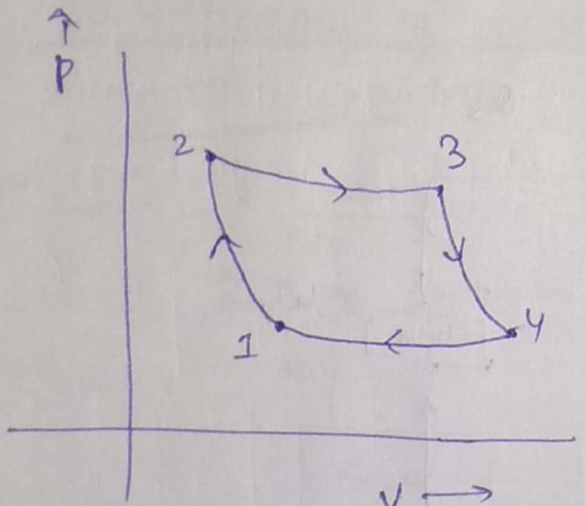
It is

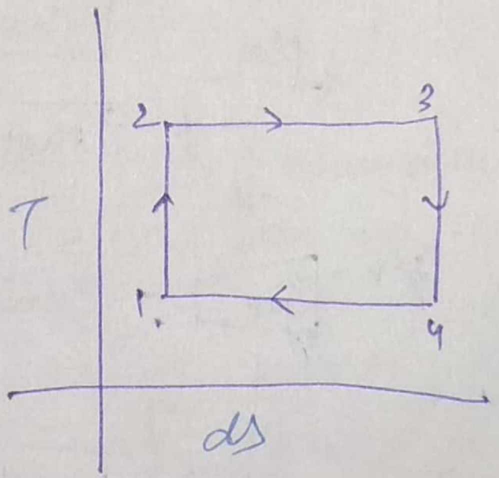
Process 1-2
Reversiable, adiabtic compression

2-3
Reversiable Isothermal Heat addition

3-4
Reversiable ~~Isothermal~~ adiabtic expansion

4-1
Reversiable Isotherm Heat rejection

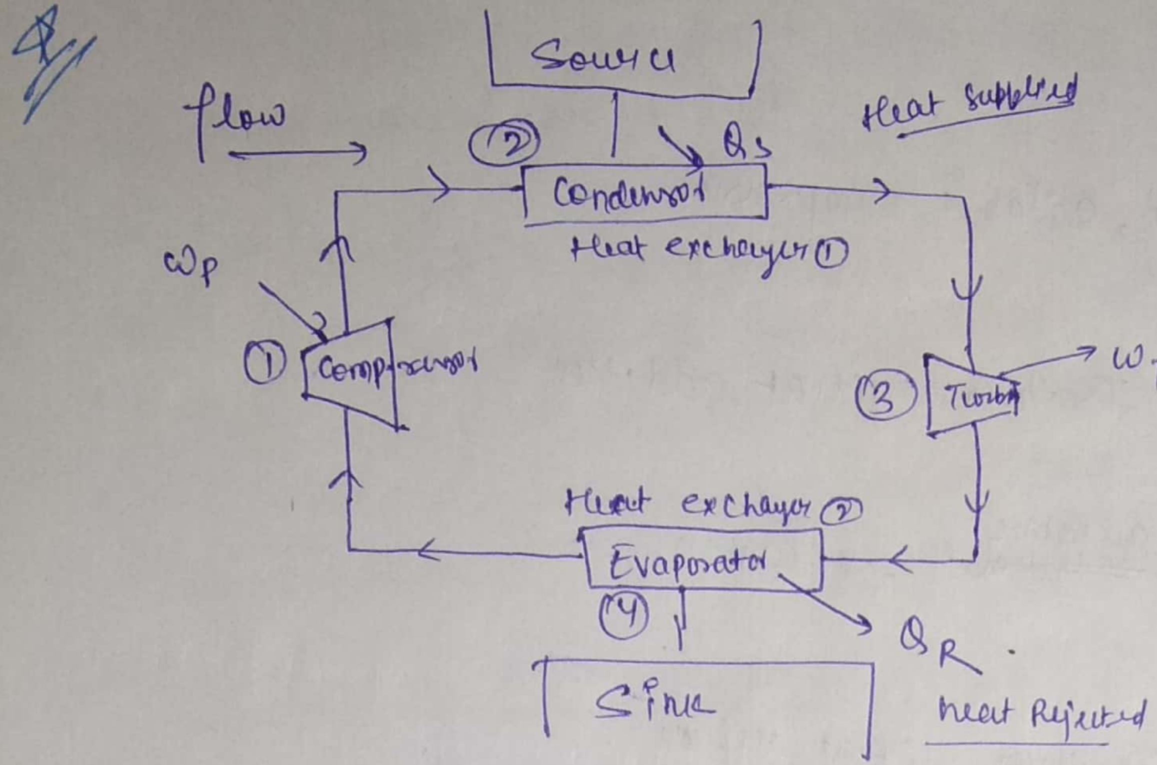




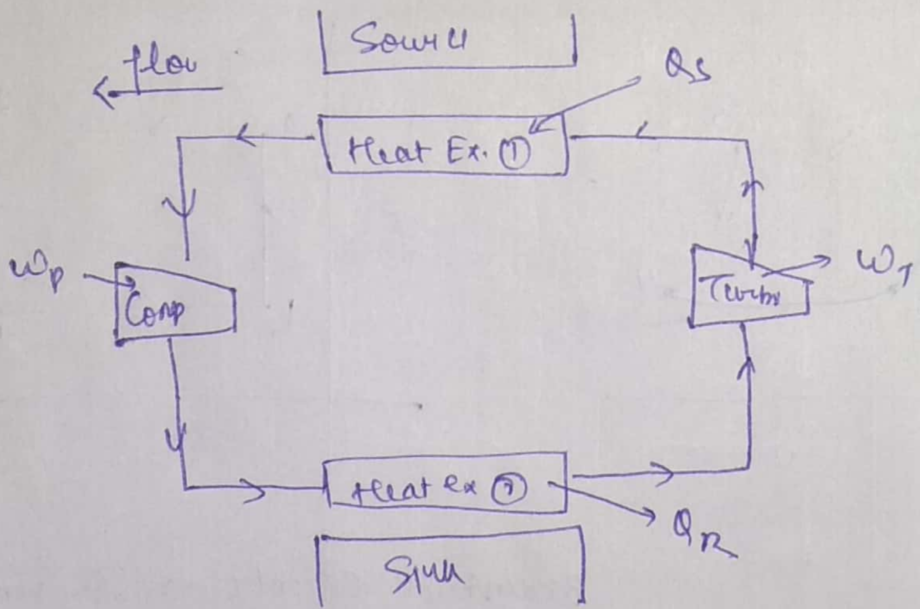
Reversiable adiabtic → Isosentric

Carnot cycle consist of two adiabtic two isotherms process to realise adiabtic with out Insulation it must be carried out in a very fast manner and to realise Isothermal condition in single phase it must be very slow Hence, these combination are not possible in a cycle thus being Carnot cycle is not practically feasible.

Reverse Carnot cycle



Carnot cycle



Reverse Carnot cycle

For engine

In cyclic process

$$(\Sigma Q)_{net} = (\Sigma W)_{net}$$

$$Q_{net} = Q_S - Q_R, \quad W_{net} = W_T - W_P$$

$$\boxed{\eta = \frac{W_{net}}{Q_s}}$$

COP For Reversed carnot cycle.

$$(COP) = \frac{D.E}{W_{net}} = \frac{D.E}{W_P - W_T}$$

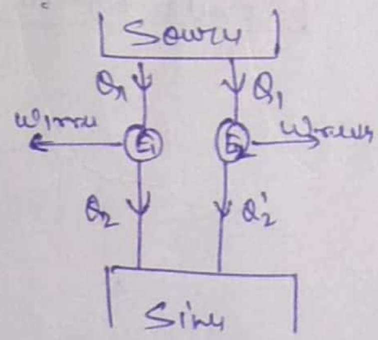
$$W_P - W_T \Rightarrow \underline{W_P >>> W_T}$$

Carnot theorem

1) The efficiency of all reversible heat engine operating b/w same two reservoir will always the same.

2) The efficiency of an irreversible engine cannot exceeds the efficiency of a reversible engine operating b/w the same two reservoirs.

proof of 2nd

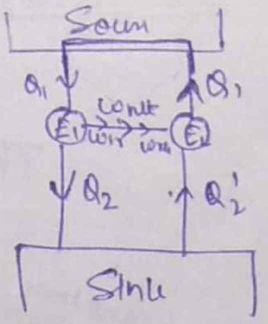


Assuming $\eta_{rev} < \eta_{irrev}$

$$\frac{W_{rev}}{Q_1} < \frac{W_{irrev}}{Q_1}$$

$$\boxed{W_{irr} > W_{rev}}$$

Since, E_2 is a reversible engine So, we can reversed it direc^n.



$$\boxed{W_{net} = W_{irr} - W_{rev}}$$

So, it violates the kelvin plank statement. because we have no need of source.

After reversing the direc^n of E_2 reversible $W_{reversible}$ requirement can be fullfilled by $W_{irreversible}$ (work) since $\boxed{W_{irreversible} > W_{reversible}}$ and there is net work output (W_{net}).

- Heat rejected by engine (E_2) is equal to the Heat supplied to engine (E_1) so, we can supply Heat rejected by E_2 into E_1 and thus we do not require source. and engine is capable of producing work by exchanging heat with a single i.e, the voilation of Kelvin plank statement. The Assumption is wrong. efficiency of engine is greater than η_{irrev} operating under same temp

$$\boxed{\eta_{rev} > \eta_{irrev}}$$

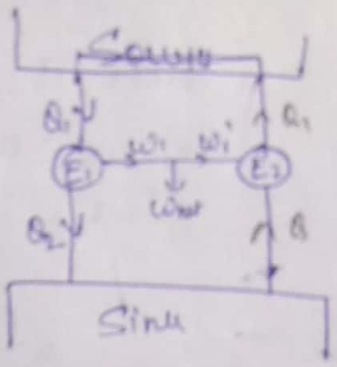
Thermodyanamic Temp scale.

proof of 7th

$\eta_1 > \eta_2$

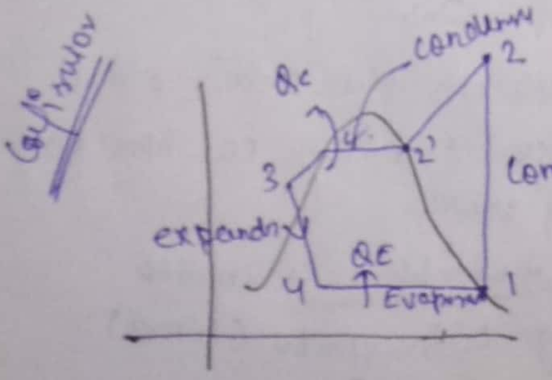
$\frac{W_1}{Q_1} > \frac{W_1'}{Q_1}$

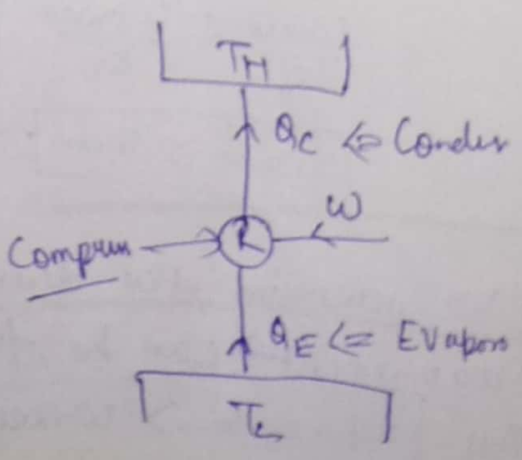
$\boxed{W_1 > W_1'}$



$\boxed{W_{net} = W_1 - W_1'}$

Then $Q_1 = Q_1'$ ⇒ it is violets as an plank st





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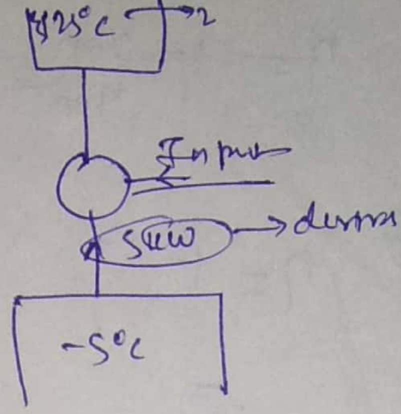
Tutorial sheet

(7) $Q_S = 5\,kW$



$$(COP)_{R_4} = \frac{\text{desired}}{\text{Input}} = \frac{1}{\eta}$$

I

$$\eta = 1 - \frac{268}{298}$$

$$\eta = \frac{298-268}{298}$$

$$\eta = \frac{30}{298} = \frac{298}{30}$$

$$\boxed{COP = 9.9}$$

II

$$COP = \frac{\text{desired}}{\text{Input}}$$

~~9.8 × 5 kW = Win~~

~~$\boxed{49.6\ kW = W_{in}}$~~

$$9.9 = \frac{5}{W_{in}}$$

$$W_{in} = \frac{5}{9.9}$$

$W_{in} = 0.505\,kW$

---

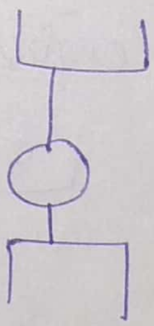
(8) $(COP)_R = \frac{273}{18}$

$= 15.1667$

10°C ⟶ 0°C ⟶ 0°C

mcΔT   mL

C = 4.18   L.O



$$(COP)_R = \frac{Q_E}{W_{in}}$$

$$Q_E = m \times L$$

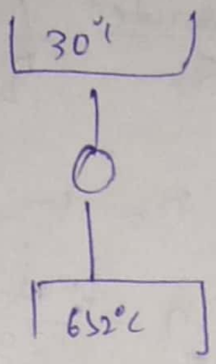
$$= \frac{1000 \times 333.5}{3600} \frac{kJ}{hr}$$

$\boxed{Q_E = 92.6382}$ kWh.

$$W_{in} = \frac{92.638}{15.1667} = 6.108\ kWh$$

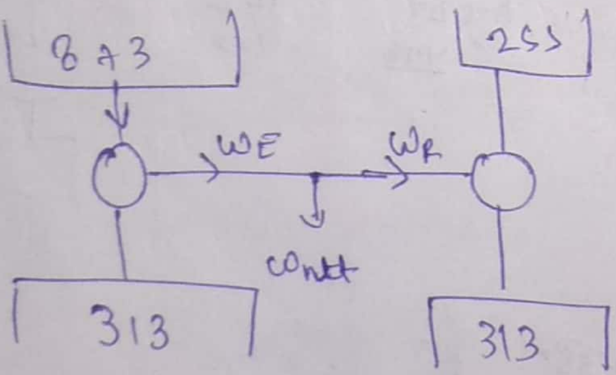
$\eta = 1 - \frac{200}{400} = 0.5$

(13) $\eta = 1 -$



$Q_S =$

A Reversible heat engine operation b/w 600°C and 40°C. The engine drives a refrigerator which operates b/w 40°C and -18°C still, there is net work output 370 kJ find out the cooling effect of the refrigerator If heat supplied to the engine 2100 kJ



$$\eta = \frac{873 - 313}{873} = .642 = \frac{W_E}{Q_i}$$

$$.642 \times 2100 = W_E$$

$$1348.2 = W_E$$

$W_R = W_E - W_{net}$
$= 1348.2 - 370$
$= \underline{978.2}$

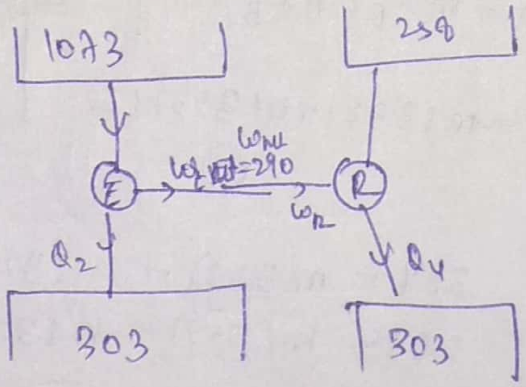
$(COP)_R = \frac{253}{313-253} = \frac{253}{60} = \cancel{16.86}\ 4.3$

I. $\cancel{16.86}\ 4.3 = \frac{Q_3}{W_R}$

$\boxed{\cancel{4.38} \times 978.2 = Q_3} =$

KS.

A Reversible heat engine operating b/w thermal reservoirs at 800°C and 30°C drives a reversible refrigerator which operates b/w −15°C and 30°C still, the heat supplied to the engine is 1900 KJ and a net work output 290 KJ determine
(i) refrigerating effect of the refrigerator
(ii) the total ammount of heat supplied to 30°C reservoirs



$\frac{273}{-15}{258}$

$\eta = \frac{1073 - 303}{\cancel{1078}} = \frac{770}{1073} = \underline{0.717}$

$\eta = 0.71 = \frac{W_E}{1900}$

$W_E = 0.71 \times 1900 = \underline{1363.46}$

$W_R = 1363.46 = \underline{1073.46}$

$(COP)_R = \frac{258}{45} = \cancel{17.2}\ 5.7$

$17.2 = \frac{D.t}{1363.46}$

$5.7\ \cancel{17.2} \times 1363.46 = P.L$ 5.7

6154.3

$\cancel{2}\ 3411.31$
$= 7812.7$

$\eta = 1 - T_1$

$\boxed{Q_2 + Q_4}$

$\eta = 1 - \frac{Q_2}{Q_1}$ ЛЛ, $\eta_E = 1 - Q$

Tutorial sheet

Q1

$T = a \ln(\theta) + b$

$273 = a \ln 1.83 + b \Rightarrow 273 = a(0.6) + b$

$373 = a \ln 6.78 + b \quad - \; 373 = a(1.91) + b$

$-100 = a(0.6 - 1.91)$

$-100 = -1.31 a$

$\boxed{a = 76.3}$

$T = a \ln 2.42 + b$

$273 = 76.3 \times 0.6 + b$

$T = 76.3 \times 0.88 + 227.22$

$273 = 45.78 + b$

$273 - 45.78 = b$

$T = 294.364$

$\boxed{T = 21.3°C}$

$\boxed{227.22 = b}$

Q2

$t_A = 0°C = 273 K$

$t_B = 373 K$

Acc to Ques

$t_A = 51°C = 324 K$

$t_B = 50°C = 323 K$

$t_A = m t_B + n t_B^2 + L$

$324 = m(323)K + n(323)^2 K + L$ — (2)

$273 = m(373) + n(373)^2 + L$ — (1)

$324 = m(323) + n(323)^2 + L$

$273 = m(373) + n(373)^2 + L$

$51 = -m(50) - n(50)^2$ (3)

$t_A = m($

$t_A =$

③ $0 = \cancel{m} L + 0 + 0$

$\boxed{L = 0}$ ← ①

$100 = 0 + 100m + 10^4 n$ — ②

$51°C$ & $50°C$

$51 = 50m + 2500n$ ← ③

$$\begin{array}{l} 100 = 100m + 10000 \\ -51 \times 2 = \cancel{50m} \times 2 \quad 2500 \times 2 \end{array}$$

$$\begin{array}{l} 102 = 100m + 5000n \\ -100 = 100m + 5000n \end{array}$$

$2 = -5000m$

$m = \frac{-2}{5000} = \frac{1}{2500}$

$\boxed{n = -\frac{1}{2500}}$

$\boxed{m = 1.04}$

$dA = \cdot$

By the define the construction of metal.

1 Bar = 101.3 Pa

④ $P_1 V_1 = P_2 V_2$

$3 \times 0.13 = 0.6 \times V_2$

$\frac{3 \times (0.13)^2}{0.6} = V_2^2$ $\quad \sqrt{.09} = .4032$

$\boxed{V_2 = .4032} = \underline{.402}$

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

$\frac{3 \times 0.13 - 0.6 \times .4032}{2-1}$

0.6×4.032

$.4032$
$\times .6$
$.24192 \times 10$

$= .29808 \times 10^5 \text{ N/m}$ $.54$

$.54$
$.24192$
29808

$= 29808 \text{ N/m}$

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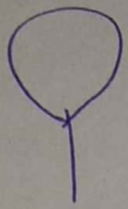


1m = diam

$r = \frac{1}{2}m$

$P_1 = 150\,kPa$

$V_1 = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi\left(\frac{1}{2}\right)^3$

$P_2 = 450\,kPa$

$V_2 =$

$P_1V_1 = P_2V_2$

$150\times10^3 \times \frac{4}{3}\pi\left(\frac{1}{2}\right)^3 = 450\,kPa \times V_2$

$W = P_1V_1 - P_2V_2$

$= P(V_2 - V_1)$

$V \propto d^3$

$\frac{V_1}{V_2} \propto \frac{d_1^3}{d_2^3}$

$P \propto d_1$

$\frac{P_1}{P_2} = \frac{d_1^3}{d_2^3}$

$\frac{450}{150} = \frac{d_1}{d_2}$

$3 = \frac{\left(\frac{1}{2}\right)^3}{d_2^3}$

$24 = d_2^3$

$d_2 = \sqrt[3]{24}$

$W = 150\left(\frac{4}{3}\pi(3)^3 - \frac{4}{3}\pi\left(\right.\right.$

$150 \times \frac{4}{3}\pi\left[\left(\frac{1}{2}\right)^3 - 24\right]$

$\left[\frac{1}{8} - \frac{1}{24}\right]$

$\times\left(\frac{24-8}{24}\right)$

$P_1 = 150\,kPa$

$P_2 = 450\,kPa$

$P \propto$

$V_1 = \left(\frac{\pi}{6}\right)\times(1)^3 = \frac{\pi}{6}$

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

$V_2 = \frac{\pi}{6}D^3$

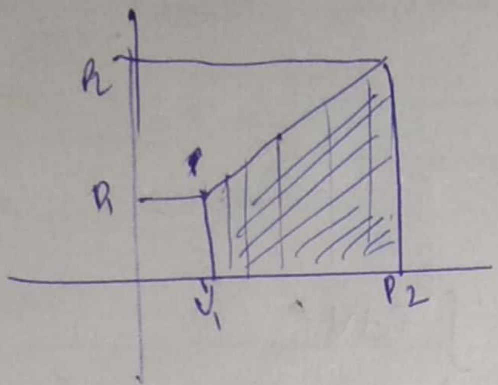
$V \propto D^3$, $P \propto D^3$

$\boxed{P \propto V} \Rightarrow$ ∴

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

$PV^{-1} = C$

$$W = \frac{P_1V_1 - P_2V_2}{n-1}$$



$\frac{1}{2}(150$

② $W = \int_{0.6}^{V} (8-4V)\,dV$

~~150 = 8(0.6 − V) − 4(0.6)V²~~

$150 = 8(V - 0.6) - \frac{4}{2}(V^2 - (0.6)^2)$

$150 = 8V -$

Previous Year Question's

① For a closed system derive an expression for work transfer in a poly tropic

According to the Question $PV^n = C$ —①

then, $P = \frac{C}{V^n}$

then, workdone $= \int_1^2 P\,dV$

$$W = \int_1^2 \frac{C}{V^n}\,dV$$

$$= \int_1^2 C V^{-n}\,dV$$

$$\frac{C\left[V^{-n+1}\right]_1^2}{-n+1}$$

$$= \frac{C}{(n+1)}\left[V_2^{-n+1} - V_1^{-n+1}\right]$$

$$P_1V_1^n = P_2V_2^n = C$$

$$\boxed{W = \frac{P_1V_1 - P_2V_2}{n-1}}$$ Joule.

② A Non flow reversible process can be written down by an eqn $P = V^2 + \frac{a}{V}$ bar Determine the workdone If volume Changes from $1m^3$ to $3m^3$

Tutorial

Power = 60 W   Volume = 86.4 m3

For Ideal Gas

$C_p = 1.005$ kJ/kgK

$C_V = 0.718$ kJ/kgK

$R = 0.287$ kJ/kgK

$\frac{P}{t} = \frac{W}{t}$

$24 \times 60 \times 60$

$60 = \frac{W}{4 \times \cancel{6} \times 60 \times 60}$

$P = 100$ kPa

$P = 100 \times 10^3$ Pa

$\boxed{6 \times 4 \times \cancel{6} \times 60 \times 60 = W}$

$V = \cdot$

$\frac{P_1V_1 - P_2V_2}{\gamma - 1}$

$24 \times 3600 = W$

~~864000 = W~~

864 kJ

$Q = W + \cancel{\Delta E}^{\,0}$

$Q = W$

$864\ kJ = mC_v\Delta T$

$PV = mRT$

$m = \frac{PV}{RT}$

$m = \frac{100 \times 86.4}{0.287 \times 303}$

273
+30
303

~~$mC_v\Delta T$~~

$864\ kJ = m \times 0.718 \times \Delta T$

$864 \times 10^3 = 98.7 \times 0.718 \times (T_2 - T_1)$

$\frac{864}{98.7 \times 0.718} = T_2 - 303$

$\frac{86 \times 10^3}{98.7 \times 0.718} + 303 = dT_2$

$12.19 = dT$

$P_0 = 100$ kPa

$V_0 = 20$ m3

$P = P_0 + 2(V - V_0)^2$

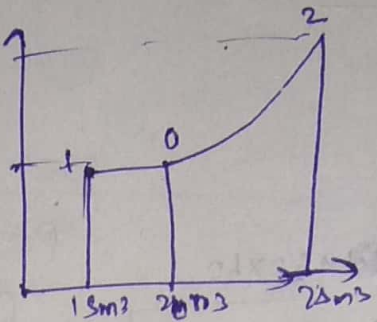
$P_1 = 100$ kPa	$P_2 = 150$ kPa
$V_1 = 15$ m3	$V_2 = 25$ m3
$T_1 = 20°C$	$T_2 = ??$

$\frac{100 \times 15}{293} = \frac{150 \times 25}{T_2} \Rightarrow T_2 = \frac{150 \times 25}{100 \times 15} \times 293$

$\frac{25}{10} \times 293 = 733$ K

$W =$ $P = P_0 + 2(V - V_0)^2$

$W =$



$P(V_2 - V_1)$

$= \int_{20}^{25} P_0 + \int_{20}^{25} \frac{(V-20)^3}{3}$

$= P_0(25-20) + \frac{(25-20-20)^3}{3} \frac{(25-20)}{2}$

$P_0\ 100 \times 5 + \frac{(5-20)^3}{3} * \frac{5}{2}$

$500 + \frac{125}{3} \times \frac{5}{2}$

$500 + \frac{625}{6}$

$\frac{3000 + 625}{6} =$

$W = W_{1-0} + W_{0-2}$

$W_{10} = 5 \times 100 = 500$

$W_{0-2} = \int_{20}^{25} P_2 dV$

$= \int_{20}^{25} P_0 + 2(V-20)^2$

$100(25-20) + 2\frac{(V-20)^3}{3}$

$= 100 \times 5 + 2\frac{((25-20)^2 - 20)^3}{3}(25-20)$

$= 500 + \frac{2}{3}[(5)^2 - 20]^3$

$500 + \frac{2}{3}[25-20]^3$

$500 + \frac{125}{3}$

$\frac{1500+125}{3} = \frac{1560}{3} = 503$

$= 500 + 83.35$

$= 583.3$

$\frac{125}{3}$ 916

$\frac{1025}{3}$

$500 + 83$

583

~~Q+W = DE~~

~~0+4340 = DE~~

$Q = W + DE$

$Q = 4340 + DE$

$DE = -4340$

$\sum Q = Q_{12} + Q_{23} + Q_{34} + Q_{41}$

$(-340 \times 200) = Q_4$

(2-3) $42000 = 0 + DE$

Process	Q (KJ/min)	W (KJ)	DE (KJ)
1-2	0	4340	-4320
2-3	42000	0	42000
3-4	-4200	69000	-73200
4-1			

$(\sum E)_{cycle} = 0$

$\sum Q = Q_{12} + Q_{23} + Q_{34} + Q_{41}$

$-340 \times 200 = 0 + 42000 + 4200 + Q_{41}$

$-68000 = 42000 + 4200 = Q_{41}$

$-105800 = Q_{41}$

$\boxed{\sum Q = \sum W}$

$-68000 = W_{12} + W_{23} + W_{34} + W_{41}$

$-68000 + 4340 - 69000 = W_{41}$

$-141340 = Q_{41}$

$(\sum E)_{cycle} = 0$

$E_{12} + E_{23} + E_{34} + E_{41} = 0$

$-4340 + 42000 - 73200 + E_{41} = 0$

$E_{41} = 35540$

Radial wo $= \frac{-141340}{-340}$

closed system

Note For an cyclic process area enclosed on P.V diagram is equal net work transfer.

For closed system in cyclic process $(E) = 0$

Ex

$\dot{m} = \rho A V$

$\boxed{\frac{V^2}{2} = \sqrt{2(h_1 - h_2)}}$

$\dot{Q} = \dot{m}(h_2 - h_1)$

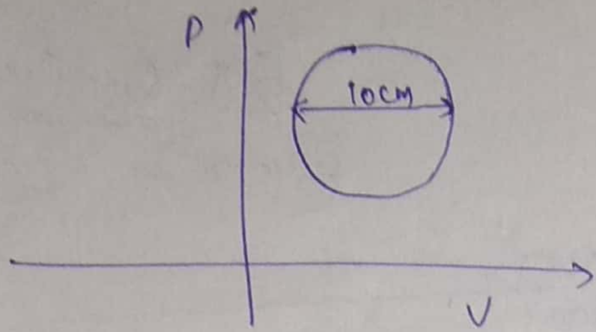
$-W = -(h_2 - h_1)$

$A_1 V_1 = A_2 V_2$

$A_1 V_1 = A_2 V_2$

$A_2 = 9$

(8)



1 cm = 300 kPa

1 cm = 0.1 m3

1 cm² = 30 kJ (a)

Area $= \frac{\pi}{4} D^2$

$= 78.5$

1 cm2 = 30

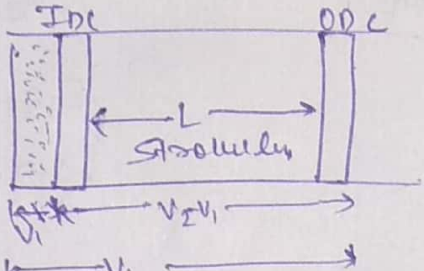
78.5 cm2 = 30 × 78.5

$\boxed{= 2356.1 \text{ kJ}}$

(9) $A = 0.12 m^2$

$P_1 = 1.5 MPa$

$P_2 = 0.15 MPa$



$(V_2 - V_1) =$ Area of Piston × L

=

Ar of tr $= \frac{1}{2}(P_1 + P_2)(V_2 - V_1)$

$= \frac{1}{2}(1.5 + 0.15) \times 10^6 (0.12) \times 0.30$

$= \frac{1}{2}(1.65) \times 0.12 \times 10^6$

(10) $P = \frac{5}{V} + 1.5$

$\int W = \int_{0.15}^{0.05} P\,dV$

$\frac{5}{V} + 1.5 V$

$\cancel{(-)\frac{5}{(0.05)^2 - (0.15)^2} + \frac{1.5}{2}}$

$W = 5 \log V + 1.5 \frac{V^2}{2}$

$5 \log \frac{0.05}{0.15} + \frac{1.5}{2}[(0.05)^2 - (0.15)^2]$

$-5 \times 0.48 + 0.75 [0.0025 - 0.0225]$

$\cancel{0.0224} +$

$-5 \times 1.10 + 1.5 \times 0.1$

$= -5.54 + 1.5 \times 0.1 = -5.54 + 0.15 = 5.64$

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$-5.643 \text{ bar } m^3$

$$-\frac{5.64 \times 10^5}{10^3}$$

$= -5.643 \times 10^2 = 564.3 \text{ KJ}$

$Q = -45 \text{ KJ}$

$-45 + 564.3 = \Delta U$

$\boxed{519.3 \text{ KJ} = \Delta U}$

$\Delta H = \Delta U + \Delta(PV)$

$\Delta H = 519.3 + P_2V_2 - P_1V_1$

$P_1 = \frac{5}{0.05} + 1.5 \qquad P_2 = \frac{5}{0.15} + 1.5$

$101.5 \times 10^2 \qquad = 33.3 + 1.5 = 34.8 \times 10^2$

$\Delta H = 519.3 + (34.8 \times 0.15 - 101.5 \times 0.05)10^2$

$= (5.22 - 0.507)$

$\cdot 4.71$

$519.3 + 471$

$= 50445$

(11) $C_p = 1.5 + \frac{75}{T+45}$

$dH = \int_{T_1 = 20°C}^{T_2 = 260°C} C_p dT \qquad dQ = \int_{T_1 = 20°C}^{T_2 = 260°} C_p dT$

$Q = \Delta U + W$

(12)

$V = 0.2\,m^3$

$P_1 = 4\,ka$ $\quad P_2 = 1.02$ $\quad \gamma = \frac{c_p}{c_v} = \frac{1}{0.714}$

$T = 130°C$

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

$4 \times (0.2)^{1.4} = 1.02\, V_2^{1.4}$

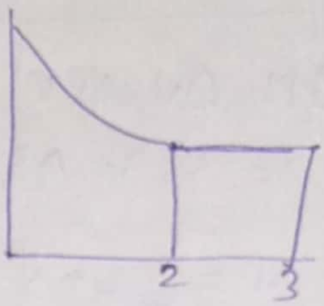
$\frac{4}{1.02}(0.2)^{1.4} = V_2^{1.4}$

$3.92 \times 0.105 = V_2^{1.4}$

$\boxed{V_2 = \sqrt[1.4]{3}}$

P_2

V_2



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

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

$\boxed{T_2 = 272.32\,k}$ $\quad m = \frac{P_1 V_1}{R T_1}$

$h_3 - h_2 = m\,c_p\,(T_3 - T_2)$

$72.5 = 0.694 \times 1 \times (T_3 - 272.32)$

$\boxed{T_3 = 376.79\ k}$

$\frac{V_2}{T_2} = \frac{V_3}{T_3}$

$\boxed{V_3 = 0.733\,m^3}$

$\omega_{1-2} = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1} =$

$W_{2-3} = P_2 (V_3 - V_2) = 1.02 \times 10^3 ($

$W = 83454$

for poly tropic process

$$W_{1-2-3} = \frac{P_1V_1 - P_2V_2}{n-1}$$

$$85454 = \frac{4\times10^5\times0.53 - 1.02\times10^5\times0.733}{n-1}$$

$$n-1 = \frac{4\times10^5\times0.53 - 1.02\times10^5\times0.733}{85454}$$

$$n = 1 + \frac{4\times10^5\times0.53 - 1.02\times10^5\times0.732}{85454}$$

$PV = mRT$

$$\boxed{V = \frac{mRT}{P}}$$

(13) $PV^{1.3}$

$P_1V_1^{1.3} = P_2V_2^{1.3}$

$P_1V_1^{1.3} = P_2V_2^{1.3}$

$$\boxed{V_2^{1.3} = \frac{P_1V_1^{1.3}}{P_2}}$$

$$\boxed{T_2 = T_1\left(\frac{V_1}{V_2}\right)^{\gamma-1.3}}$$

$$\boxed{R = \frac{8314}{30}}$$

$$W = \frac{P_1V_1 - P_2V_2}{1.3-1}$$

$C_P - C_V = R$

$C_P - R = C_V$

$$\boxed{1.73 - R = C_V}$$

$$\cancel{\boxed{\Delta H = mC_P(T_2 - T_1)}}$$

$$\boxed{\frac{C_P}{C_V} = \gamma}$$

$\Delta Q = \Delta U + W$

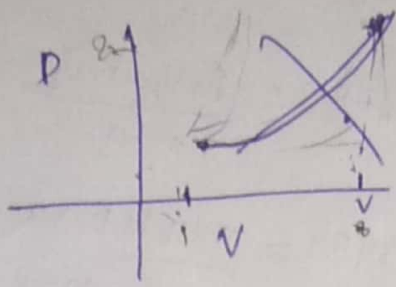
$\Delta Q -$

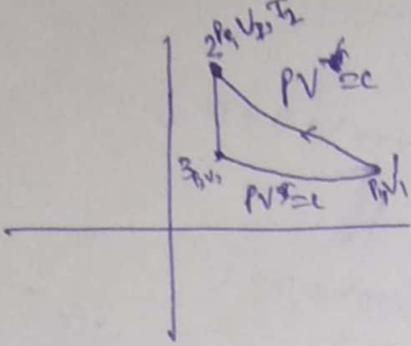
$$\boxed{(\delta Q)_{poly} = \delta W \times \left(\frac{\gamma - n}{\gamma - 1}\right)}$$

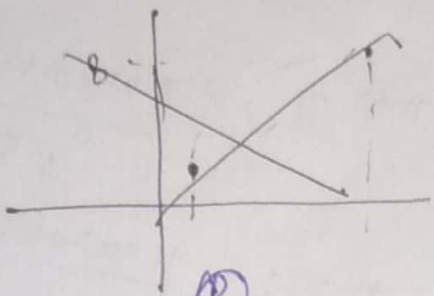
(14) $V_1 = 0.1 m^3$

$T_1 = 300 K$

$P_1 = 1 bar$







$$102 \overline{)143} \quad 1$$
$$102$$

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

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

$$1 \times (0.1)^{1.4} = V_2^{\gamma}$$

$$\boxed{V_2 = .023 \ m^3}$$

$R = (KJ) \rightarrow$ (P) Kg Pa

$$\gamma = \frac{C_p}{C_V} = \frac{143}{102} =$$

$PV = mRT$

$C_p - C_V = R$

$143 - 102$

$4.1 = R$

$$\frac{10^2 V_1}{4.1 \times 300} = m$$

$$\frac{10^2 \times 0.1}{0.287 \times 300} = m$$

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

$$\boxed{T_2 = 543.43 \ K}$$

$$\frac{100}{0.287 \times 300} = m$$

$$\boxed{m = 0.1161 \ kg}$$

Sol:

$$W_{1-2} = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$$

$$W_{2-3} = 0$$

$$W_{3-1} = P_1 V_1 \ln\left(\frac{V_3}{V_1}\right)$$

$$W = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1} + P_1 V_1 \ln\left(\frac{V_3}{V_1}\right)$$

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$$W = \frac{100 \times 0.1 - 300 \times .023}{1.4 - 1} + 0.1 \times 0.23 \times \ln\left(\frac{0.018}{.023}\right)$$

$$= \frac{-21 + 14.85}{-6.31}$$

$P_3 V_3 = P_1 V_1$ or $\frac{P_3}{T_3} = P_2$

$\boxed{P_3 = \frac{P_1 V_1}{V_3}} \Rightarrow 4.73$ bar.

$V_3 = V_2$

$= \frac{1 \times 0.1}{0.023}$

$C_p - C_v = R$

$C_p = 0.005$

$R = 0.287$

$C_v = 282$

$\Delta H = m C_v dT$

$= 0.1161 \times 0.718 \times (T_3 - T_2)$

$= 0.1161 \times 0.718 \times (543 - 300)$

$= 0.1161 \times 0.718 \times 243$

$\Delta H = 0.1161$

0.718

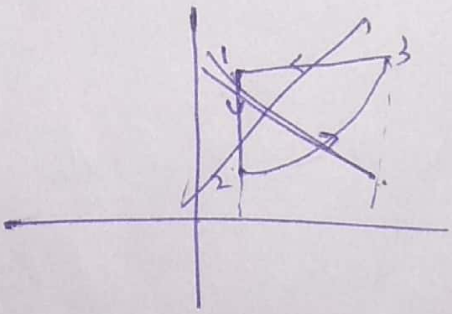
By cyclic process

$\boxed{\Sigma Q = \Sigma W} \Rightarrow 5.43 kJ$

(16) $T_1 = 300$

$T_2 = 1050$ K

$T_2 = T_3 = 1050$ K (Isotherm



$W_{net} = \cancel{W_{12}}^{0} + W_{23} + W_{31}$

$P_2 V_2 \ln\left(\frac{V_3}{V_2}\right) + P_1(V_2 - V_3)$

$P_3 V_3 \ln\left(\frac{V_3}{V_2}\right) + P_1(V_2 - V_3)$

$mRT_2 \ln\left(\frac{V_3}{V_2}\right) + P_1(V_2 - V_3)$