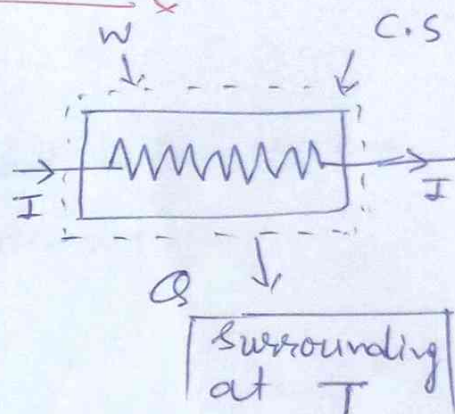


①

Isothermal dissipation of work

At steady state internal energy of resistor and its temp. remains constant.



hence, 1st law.

$$\Delta U = Q - W \Rightarrow Q = W$$

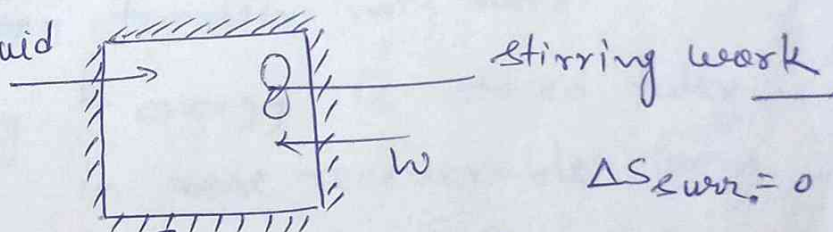
here, Flow of current represent work transfer at steady state.

$$\Delta S = \frac{Q}{T}, \quad \Delta S_{\text{wire}} = 0$$

$$\Delta S_{\text{univ.}} = \cancel{\Delta S_{\text{sur.}}}^{\neq 0} + \cancel{\Delta S_{\text{sys.}}}^{\neq 0} = \frac{Q}{T} > 0$$

Adiabatic dissipation of work

filled with viscous liquid



$$\Delta S_{\text{sur.}} = 0$$

Adiabatic wall

$$\Delta S_{\text{sys.}} = \int_{T_i}^{T_f} \frac{dQ}{T} = \int_{T_i}^{T_f} \frac{C_p dT}{T} = C_p \ln\left(\frac{T_f}{T_i}\right)$$

replace irreversible process with reversible one by considering heat transfer occur from reservoir having temp. from T_i to T_f (causing same change in state)

$$\Delta S_{\text{univ.}} = \Delta S_{\text{sys.}} + \Delta S_{\text{sur.}} = C_p \ln\left(\frac{T_f}{T_i}\right) > 0$$

heat capacity of liquid

$$T_f > T_i$$

$$\Rightarrow \Delta S_{\text{univ.}} = 0$$

Entropy transfer with heat flow

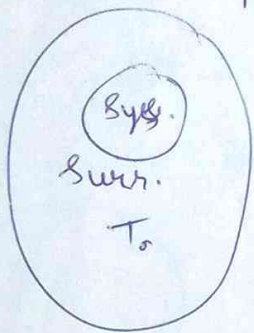
(2)

$$ds = \frac{dQ_{rev}}{T}$$

and $Q > 0 \Rightarrow$ heat added to the system,

$Q < 0 \Rightarrow$ heat removed

if Q removed reversibly.



$$\Delta S_{surroundings} = \frac{Q}{T_0}$$

then system temp. $= T_0$

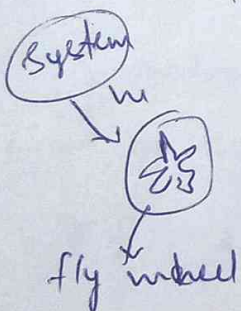
$$\Delta S_{sys.} = -\frac{Q}{T_0}$$

\Rightarrow System lost entropy & surrounding gain entropy.

hence, entropy transfer from system to surrounding.

No entropy transfer with work

\Downarrow meaning if energy is stored fully in ~~re~~ recoverable form.



\Downarrow if stored / work dissipated then entropy change.

entropy Generation in a closed system

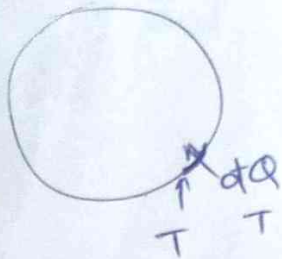
(3)

* Entropy of closed system can increase in two ways.

(a) heat transfer

(b) internal irreversibility or dissipation effect.
(e.g. K.E. is dissipated into internal energy).

$dQ \rightarrow$ infinitesimal amount of heat added to system
increase in system entropy.



$$dS = d_e S + d_i S$$

due to heat
interaction

irreversibility

$$dS = \frac{dQ}{T} + d_i S \quad \text{--- (A)}$$

$$0 \leq dS \geq \frac{dQ}{T} \quad \text{--- (B)}$$

(A) & (B)

$$\Rightarrow d_i S \geq 0$$

entropy increase due to internal irreversibility
is called entropy generation (S_{gen})

E.g. turbine

↓
entropy decrease due to heat
loss to surrounding ($\frac{dQ}{T}$)

may be
entropy increase due to irreversibility
(e.g. friction etc.)
($\int d_i S$)

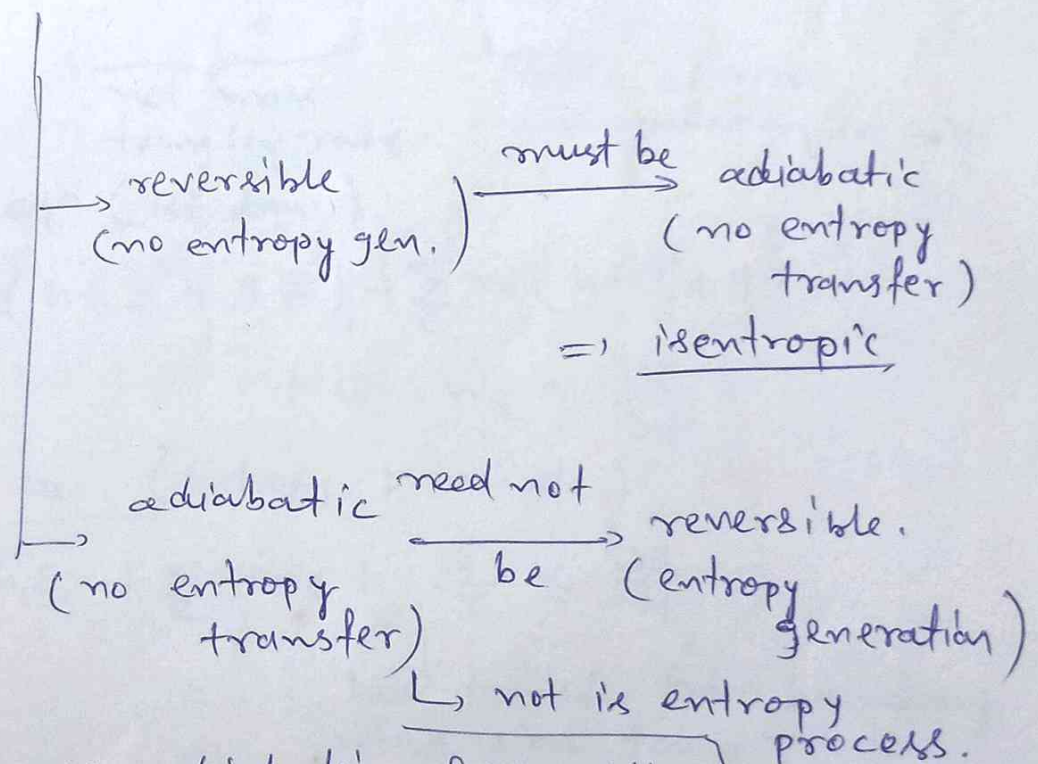
(4)

thus entropy before and after may or remain same.

$$\oint ds = 0$$

therefore
isentropic process need not be adiabatic or reversible.
 ??

but if isentropic process is reverse
 it must be adiabatic.



if a process adiabatic & reversible

\Rightarrow it must be isentropic.

infinitesimal reversible process.

$$dQ_R = dU_R + p dv$$

for irreversible process.

$$dQ_I = dU_I + W_I$$

as

$$dU_R = dU_I$$

④

$$\Rightarrow dQ_R - PdV = dQ_I - dW$$

$$\Rightarrow \left(\frac{dQ}{T} \right)_R = \left(\frac{dQ}{T} \right)_I + \frac{PdV - dW}{T}$$

$PdV - dW \rightarrow$ work lost due to irreversibility.

lost work $\rightarrow d(LW)$.

\downarrow
this approaches to 0.

\downarrow
process \rightarrow reversible

further

$$dS = d_e S + d_i S$$

\downarrow
addition

\downarrow
dissipation

For any process between equilibrium state ① & ②.

1st law

$$\Rightarrow \int_1^2 dQ - \int_1^2 dW = E_2 - E_1$$

$$Q_{1-2} = E_2 - E_1 + W_{1-2}$$

By second law

$$S_2 - S_1 \geq \int_1^2 \frac{dQ}{T}$$

$$S_2 - S_1 - \int_1^2 \frac{dQ}{T} = S_{gen}$$

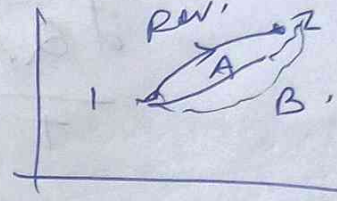
\downarrow
entropy
generation
due to irreversibility

S_{gen} is not a thermodynamic properties and depend on path.

however $S_2 - S_1 \rightarrow$ does n't depend on path

$$\Rightarrow dS_{gen} = ds - \frac{dQ}{T}$$

amount of S_{gen} amount of irreversibility



$$(S_{gen})_A > (S_{gen})_B$$

\Rightarrow A is more irreversible than B.
if heat transfer occur at several locati

$$(S_2 - S_1) = \sum_j \frac{Q_j}{T_j} + S_{gen}$$

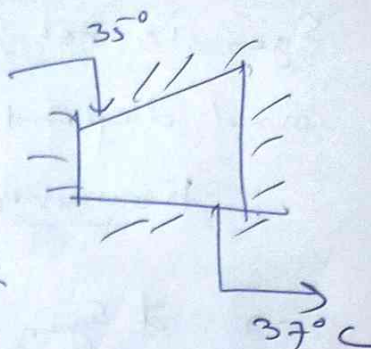
or

$$\frac{dS}{dt} = \sum_j \frac{\dot{Q}_j}{T_j} + \dot{S}_{gen}$$

①

Ex. 1

1 kg of water



$$T_2 = 37 + 273 = 310 \text{ K}$$

$$T_1 = 308 \text{ K}$$

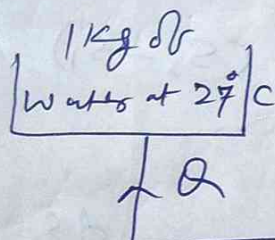
$$\frac{dQ_{rev}}{T} = ds \Rightarrow ds = \frac{m c_v dT}{T}$$

$$(C_v)_{\text{water}} = 4.187 \text{ kJ/kg}$$

$$= 1 \times 4.187 \ln \frac{T_2}{T_1}$$

$$= 0.0243 \text{ kJ/kg}$$

Ex. 2



entropy change of
at equil. system
& universe.

if we ~~not~~ don't want to change universe

entropy how water
should be heated

$$(\Delta S)_{\text{water}} = \int_{R(i)}^f \frac{dQ}{T} = \int_{R(i)}^f \frac{Q m c dt}{T}$$

$$= 4.187 \ln \frac{373}{300} \approx 0.91 \text{ kJ/K}$$

$$(\Delta S)_{\text{res.}} = -\frac{Q}{T_{\text{res.}}} = -\frac{1 \times 4.187 (73)}{373} = -0.82 \frac{\text{kJ}}{\text{K}}$$

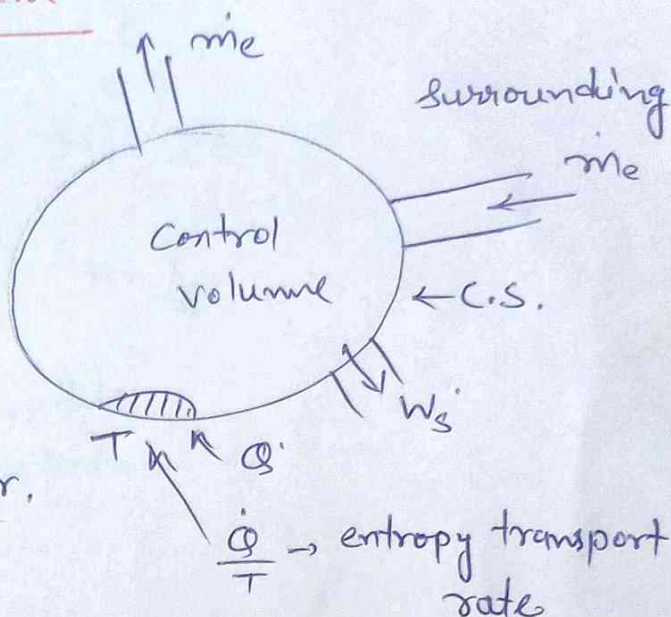
$$(\Delta S)_{\text{univ}} = 0.91 - 0.82 = 0.09 \text{ kJ/K} > 0$$

Entropy generation in an open system

(8)

Open system transfer of mass, energy & momentum.

Control surface can be rigid & it may be rigid & it may have one or more opening for mass transfer.



Continuity equation.

$$\underbrace{\sum_i \dot{m}_i - \sum_e \dot{m}_e}_{\text{net mass transfer rate}} = \underbrace{\frac{\partial M}{\partial t}}_{\text{rate of mass accumulation in C.V.}}$$

Energy eqⁿ (1st law)

$$\sum_i \dot{m}_i \left(h + \frac{V^2}{2} + gZ \right)_1 - \sum_e \dot{m}_e \left(h + \frac{V^2}{2} + gZ \right)_2 + \dot{Q} - \dot{W}_s = \frac{\partial \dot{E}}{\partial t}$$

Second law. (Entropy principle)

$$\sum_i \dot{m}_i s_i - \sum_e \dot{m}_e s_e + \frac{\dot{Q}}{T} \leq \frac{\partial S}{\partial t}$$

heat transfer from boundary which is at temp. T

net entropy transfer \leq entropy accumulation

$$\Rightarrow \dot{S}_{\text{gen.}} = \frac{\partial S}{\partial t} - \sum_i \dot{m}_i s_i + \sum_e \dot{m}_e s_e - \frac{\dot{Q}}{T}$$

second law $\dot{S}_{\text{gen.}} \geq 0$

(9)

For reversible process.

$$\dot{S}_{\text{gen.}} = 0$$

for irreversible $\dot{S}_{\text{gen.}} > 0$

$$\text{if } (\dot{S}_{\text{gen.}})_A > (\dot{S}_{\text{gen.}})_B$$

↓
more irreversible
at steady state

$$\dot{m}_e = \dot{m}_i$$

energy equation

$$0 = \dot{Q} - \dot{W}_{\text{sh}} + \sum \dot{m}_i \left(\quad \right) - \sum \dot{m}_e \left(\quad \right)$$

entropy eq.ⁿ

$$0 = \frac{\dot{Q}}{T} + \sum_i \dot{m}_i s_i - \sum_e \dot{m}_e s_e + \dot{S}_{\text{gen.}}$$

↑
how steady state.

rate of entropy in < rate of entropy out.

First & Second law combinedsecond law

$$dQ_{rev} = T ds$$

by first law, for closed system.

$$dQ = dU + \underbrace{pdv}_{\text{only } pdv \text{ work by piston}}$$

$$Tds = dU + pdv$$

Again, enthalpy -

$$H = U + PV$$

$$dH = dU + pdv + vdp$$

$$= Tds + vdp.$$

$$\boxed{Tds = dH - vdp} \quad \text{---} \quad (\times)$$

Summary.

$$dQ = dE + dw \quad \text{for, any process.}$$

* reversible & irreversible process.

$$dQ = dU + dw \rightarrow \text{any closed syst stationary system.}$$

$$dQ = dU + pdv \rightarrow \text{closed system with } pdv \text{ work only.}$$

($pdv \rightarrow$ work quasi-static reversible).

$$?? \left(\begin{array}{l} dQ = Tds \rightarrow \text{reversible system} \end{array} \right.$$

$$Tds = dU + pdv \rightarrow \text{closed, rev.}$$

from

$$Tds = dH - pdv$$

use of irreversible process $\xrightarrow{\text{doubtfull}} \text{no irreversible path}$

\downarrow more logical

change of state is irreversible.

(11)

Reversible adiabatic work in a steady flow system

SFEE per unit mass,

$$dq = dh + v dv + g dz + dw_x$$

for reversible process,

$$dq = T ds$$

$$\Rightarrow T ds = dh + v dv + g dz + dw_x \quad \text{--- (A)}$$

$$\text{for } \textcircled{x} \quad T ds = dh - v dp \quad \text{--- (B)}$$

$$\textcircled{A} \text{ \& } \textcircled{B} \Rightarrow$$

$$-v dp = v dv + g dz + dw_x$$

Integrating,

$$-\int_1^2 v dp = \int_1^2 v dv + g \Delta z + w_x$$

if K.E & P.E are negligible,

$$\Rightarrow -\int_1^2 v dp = w_x$$

$$\Rightarrow \boxed{w_x = -\int_1^2 v dp} \quad \text{--- (1)}$$

$$\text{if } dq = 0 \Rightarrow ds = 0$$

$$\int_1^2 dh = + \int_1^2 v dp$$

$$\Rightarrow h_2 - h_1 = \int_1^2 v dp \quad \text{--- (2)}$$

$$\Rightarrow \textcircled{1} \text{ \& } \textcircled{2} \Rightarrow \boxed{w_x = h_1 - h_2 = -\int_1^2 v dp} \quad \text{--- (C)}$$

Eqn (C) is valid for steady state reversible adiabatic process (turbine, engine, pump, compressor)

(12)

Reversible work done by piston (closed system)

$$W_{1-2}^c = \int_1^2 p dv$$

Reversible work flow system.

$$W_{1-2} = - \int_1^2 V dp$$

Entropy AND Disorder

$$\Delta S_{univ.} > 0$$

All spontaneous process is unidirectional.
(from higher potential to lower potential)

↓ Cause

$$\Delta S_{univ.} > 0$$

If potential difference is infinitesimal
($\Delta S_{uni.} \approx 0$)

changes stop when potential difference = 0
& equilibrium reaches.

$$S_0 \Rightarrow S_{max.}$$

work / K.E. \rightarrow co-ordinated movement of molecules, with
some average velocity.

macroscopic

P.E. \rightarrow deviation from initial position.

Heat / thermal energy \rightarrow random thermal motion
(completely disorder
avg. velocity ~ 0)

orderly energy can readily converted into
disorderly energy.

M.E. or E.E. $\xrightarrow{\text{to}}$ internal energy (and then heat)
via friction,

But limitation on conversion of disorderly energy
into orderly energy. (2nd law).

work $\xrightarrow{\text{to}}$ System (orderly energy $\xrightarrow{\text{to}}$ disorderly energy)

mixing of gas \rightarrow more disorder system.

\Rightarrow relation between disorder & entropy

Boltzmann (1877)

13

define disorder

expressed by the quantity w
(thermodynamic probability)

w higher \longrightarrow higher disorder

increase entropy \longrightarrow higher thermodynamic
probability

irreversible process goes on until most
probable state (equilibrium) reached.

Boltzmann assumed.

$$S = f(w)$$

entropy
additive

probability
multiplicative

$$S = S_A + S_B$$

$$w = w_A \cdot w_B$$

$$S(w) \neq S_A(w_A), S_B(w_B)$$

$$S(w) = S(w_A w_B) = S(w_A) + S(w_B)$$

\downarrow
well known

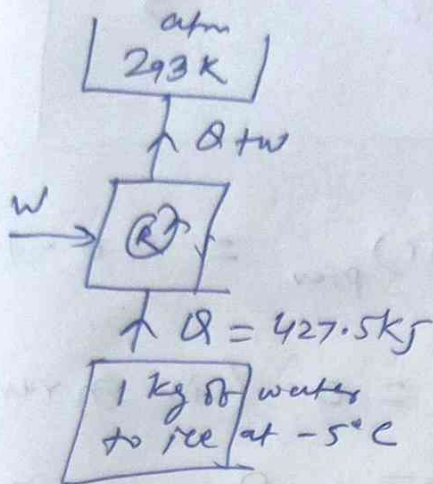
$$S = k \ln(w)$$

Ex

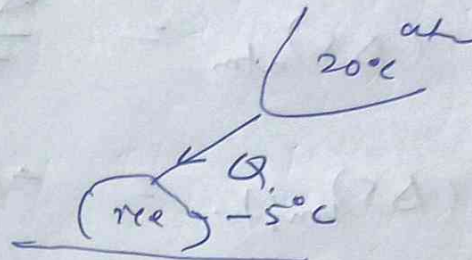
Convert 1 kg of water at 20°C

to -5°C ice ($\Delta Q = -427.5 \text{ kJ}$)

(b)



(a)



determine entropy at equil. (Plot T vs S),
increase.

What will be min. work to convert water
back to -5°C.

$$C_p(\text{water}) = 4.187 \text{ kJ/kg}.$$

$$C_p(\text{ice}) = 2.093 \text{ kJ/kg/K}.$$

$$L_{fs}(\text{water}) = 333.3 \text{ kJ/kg}.$$

$$Q = 1 \times 2.093 \times 25 + 1 \times 333.3 \text{ kJ/kg} \\ + 1 \times 4.187 \times 20 \\ = 427.5 \text{ kJ}$$

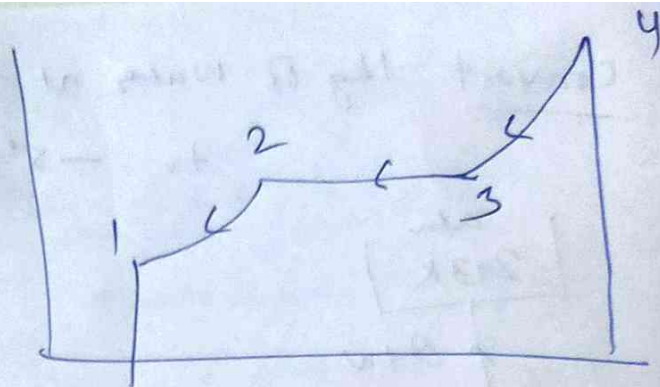
$$(\Delta S)_{\text{atm}} = -\frac{Q}{T} = -\frac{427.5}{293} = -1.46 \text{ kJ/K}$$

$$(\Delta S)_I = \int_{268}^{293} m_{cp} \frac{dT}{T} = \int_{268}^{273} + \int_{273}^{293} + \int_{268}^{273} \text{ melt}$$

$$= 0.389 + 1.22 + 0.296 \\ = 1.5549 \text{ kJ/K}$$

57.

15



$$(\Delta S)_{\text{sys.}} = -(\Delta S)_{\text{prev}} = 0 - 1.5549 \text{ kJ/K}$$

$$(\Delta S)_{\text{refrigerator}} = 0 \quad (\text{in a rev. cycle})$$

$$(\Delta S)_{\text{atm}} = \frac{Q + W}{T} = \frac{Q + W}{T}$$

$$(\Delta S)_{\text{unif.}} = -1.5549 + \frac{Q + W}{T} \geq 0$$

$$\Rightarrow \frac{Q + W}{T} \geq 1.5549$$

$$W_{\text{min}} = T(1.5549) - \frac{Q}{\cancel{0}}$$

$$= 293 \times 1.5549 - 427.5$$

$$= 28.5 \text{ kJ}$$