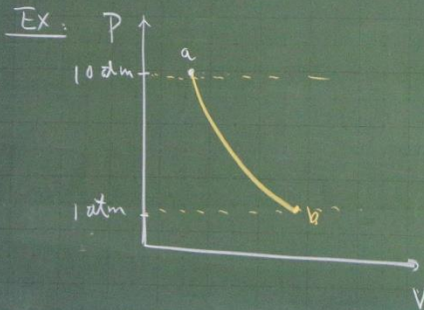


Ideal Gas

Rev. { Isothermal
Adiabatic } Expansion
 $P_1 \rightarrow P_2 (< P_1)$



a. $\begin{cases} V_a = 10 \text{ l} \\ P_a = 10 \text{ atm} \\ T_a = 298 \text{ K} \end{cases} \rightarrow P_b = 1 \text{ atm}$

Monatomic Ideal Gas

Q1. (Rev. + Isothermal) Expansion
 $\Delta U, \Delta Q, \Delta W, \Delta H$?

a. $\begin{cases} V_a = 10 \text{ l} \\ P_a = 10 \text{ atm} \\ T_a = 298 \text{ K} \end{cases} \rightarrow P_b = 1 \text{ atm}$

Monatomic Ideal Gas

Q1. (Rev. + Isothermal) Expansion
 $\Delta U, \Delta Q, \Delta W, \Delta H$?

Sol1:

$T_b = 298 \text{ K}$

$n = \frac{P_a V_a}{R T_a} = 4.09 \text{ (moles)}$

Ideal Gas: $U = U(T)$!
indep of P, V .

\therefore const. $T, \Delta U = 0$

$$\Delta W = \int_a^b \delta W_{rev} = \int P \cdot dV = \int_{V_a}^{V_b} \frac{nRT}{V} \cdot dV$$

$$= nRT \ln\left(\frac{V_b}{V_a}\right) = 23.3 \text{ (KJ)}$$

$V_b = \frac{nRT}{P_b} = 100 \text{ (l)}$

$\Delta U = \Delta Q - \Delta W \quad \therefore \Delta Q = \Delta W$

Sol 1:

$$T_b = 298 \text{ K}$$

$$n = \frac{P_a V_a}{RT_a} = 4.09 \text{ (moles)}$$

Ideal Gas: $U = U(T)$!
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$$\Delta W = \int_a^b \delta W_{rev} = \int P \cdot dV = \int_{V_a}^{V_b} \frac{nRT}{V} \cdot dV$$
$$= nRT \ln\left(\frac{V_b}{V_a}\right) = 23.3 \text{ (KJ)}$$

$$V_b = \frac{nRT}{P_b} = 160 \text{ (L)}$$

$$\Delta U = \Delta Q - \Delta W \quad \therefore \Delta Q = \Delta W$$

$H \equiv U + P \cdot V$ \star enthalpy (K^2)

$$\Delta H = (H_b - H_a) = (U_b + P_b V_b) - (U_a + P_a V_a)$$
$$= \underbrace{(U_b - U_a)}_{\Delta U = 0} + (P_b V_b - P_a V_a) = 0$$

\star Ideal Gas. $H = H(T)$
indep of P, V

$$\therefore dT = 0 \Rightarrow \Delta H = 0$$

$$\Rightarrow \therefore dU = C_v dT \Rightarrow \Delta U = \int_{T_1}^{T_2} C_v dT$$

Sol 1:

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$$\therefore dT = 0 \Rightarrow \Delta H = 0$$

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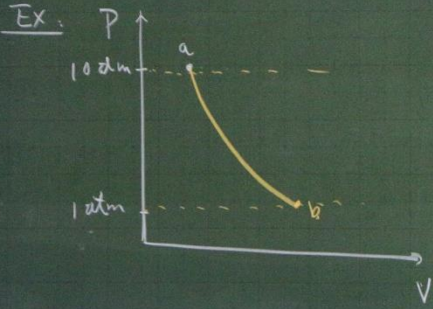
$$dH = C_p dT \Rightarrow \Delta H = \int_{T_1}^{T_2} C_p dT$$

\star Monatomic Ideal Gas

$$C_v = \frac{3}{2} R, \quad C_p = \frac{5}{2} R, \quad \gamma = \frac{5}{3}$$

Ideal Gas

Rev. { Isothermal
Adiabatic } Expansion
 $P_1 \rightarrow P_2 (< P_1)$

Ex: 

a. $\begin{cases} V_a = 10 \text{ l} \\ P_a = 10 \text{ atm} \\ T_a = 298 \text{ K} \end{cases} \rightarrow P_b = 1 \text{ atm}$

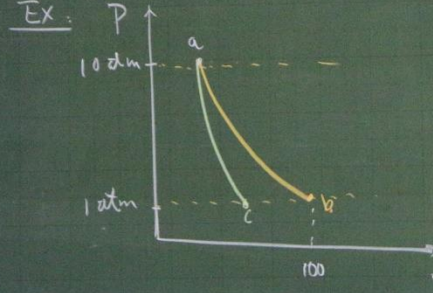
Monatomic Ideal Gas

Q1: (Rev. + Isothermal) Expansion
 $\Delta U, \Delta Q, \Delta W, \Delta H = ?$

Q2: (Rev. + Adiabatic)
 $\Delta U, \Delta Q, \Delta W, \Delta H = ?$

Ideal Gas

Rev. { Isothermal
Adiabatic } Expansion
 $P_1 \rightarrow P_2 (< P_1)$

Ex: 

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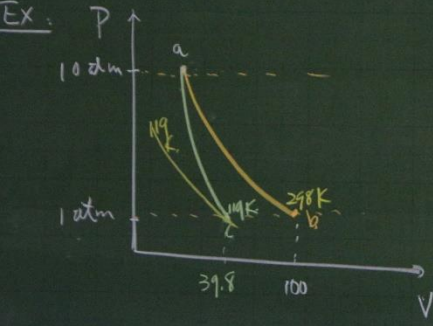
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Ideal Gas

Rev. { Isothermal
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 $P_1 \rightarrow P_2 (< P_1)$

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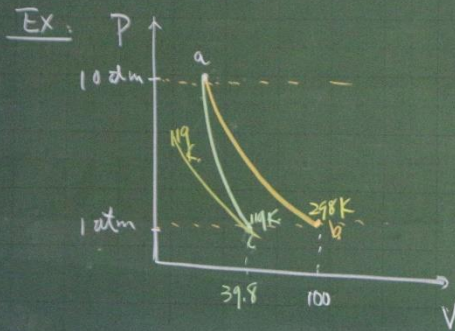
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Ideal Gas

Rev. { Isothermal
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 $P_1 \longrightarrow P_2 (< P_1)$



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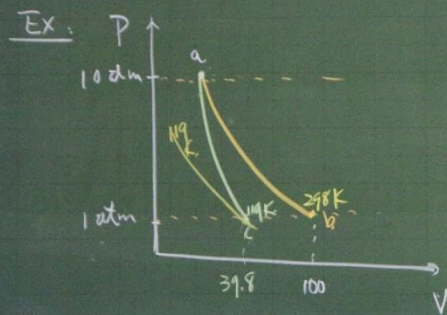
Monatomic Ideal Gas

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Ideal Gas

Rev. { Isothermal
Adiabatic Expansion
 $P_1 \longrightarrow P_2 (< P_1)$



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Monatomic Ideal Gas

Q1: (Rev. + Isothermal) Expansion
 $\Delta U, \Delta Q, \Delta W, \Delta H = ?$

Q2: (Rev. + Adiabatic)
 $\Delta U, \Delta Q, \Delta W, \Delta H = ?$

4.09 (moles)

$U = U(T)$!
of P, V .

$U = 0$

$w = \int P dv = \int_{V_a}^{V_b} \frac{nRT}{V} dV$

$w = \frac{V_b}{V_a} = 23.3 \text{ (KJ)}$

(a)

$\Delta Q = \Delta W$

$H \equiv U + P \cdot V$ \star enthalpy (KJ)

$\Delta H = (H_b - H_a) = (U_b + P_b V_b) - (U_a + P_a V_a)$

$= \frac{(U_b - U_a)}{\Delta U = 0} + (P_b V_b - P_a V_a) = 0$

\Rightarrow Ideal Gas. $H = H(T)$
indep of P, V

$\therefore dT = 0 \Rightarrow \Delta H = 0$

$\Rightarrow \therefore dU = C_v dT \Rightarrow \Delta U = \int_{T_1}^{T_2} C_v dT$

$dH = C_p dT \Rightarrow \Delta H = \int_{T_1}^{T_2} C_p dT$

\star Monatomic Ideal Gas

$C_v = \frac{3}{2} R, C_p = \frac{5}{2} R, \gamma = \frac{5}{3}$

Solz:

Adiabatic

Adiabatic

$P_a V_a^\gamma = P_b V_b^\gamma$

$T_c = \frac{P_c V_c}{nR}$

$\Delta U = n \int_{T_1}^{T_2} C_v dT$

$\Delta U = \Delta Q$

$\Delta H = (H_c - H_a)$

$\gamma \cdot \Delta H =$

9 (moles)

$U(T)$!
 P, V .

$U = 0$

$w = \int P dv = \int_{V_a}^{V_b} \frac{nRT}{V} dV$

$w = 23.3 \text{ (KJ)}$

$\Delta Q = \Delta W$

$H \equiv U + P \cdot V$ \star enthalpy (KJ)

$\Delta Q_p = \Delta H_p$

$\Delta H = (H_b - H_a) = (U_b + P_b V_b) - (U_a + P_a V_a)$

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\star Monatomic Ideal Gas

$C_v = \frac{3}{2} R, C_p = \frac{5}{2} R, \gamma = \frac{5}{3}$

Solz:

Adiabatic

Adiabatic

$P_a V_a^\gamma = P_b V_b^\gamma$

$T_c = \frac{P_c V_c}{nR}$

$\Delta U = n \int_{T_1}^{T_2} C_v dT$

$\Delta U = \Delta Q$

$\Delta H = (H_c - H_a)$

$\gamma \cdot \Delta H = n \int_{T_1}^{T_2} C_p dT$

analyse ($\frac{1}{3}$)

$$-\Delta H_p$$

$$-(U_a + P_a V_a)$$

$$-P_a V_a = 0$$

$$H = H(T)$$

$$P \cdot V$$

$$\Delta U = \int_{T_1}^{T_2} C_{v,d} dT$$

$$\Delta H = \int_{T_1}^{T_2} C_{p,d} dT$$

Gas

$$\gamma = \frac{5}{3}$$

solz

$$\text{Adiabatic: } \delta Q = 0, \Delta Q = 0$$

$$\text{Adiabatic: } P \cdot V^\gamma = \text{const} = C$$

$$P_a V_a^\gamma = P_c V_c^\gamma \Rightarrow V_c = 39.8 \text{ (L)}$$

$$T_c = \frac{P_c V_c}{nR} = 119 \text{ (K)}$$

$$\Delta U = n \int_{T_a}^{T_c} C_{v,d} dT = n C_{v,d} (T_c - T_a) = -9.13 \text{ (KJ)}$$

$$\Delta U = \Delta Q - \Delta W \quad \therefore \Delta W = -\Delta U = +9.13 \text{ (KJ)}$$

$$\Delta H = (H_c - H_a) = \Delta U + (P_c V_c - P_a V_a) = -15.2 \text{ (KJ)}$$

$$\text{? } \Delta H = n \int_{T_a}^{T_c} C_{p,d} dT = n C_{p,d} (T_c - T_a)$$

analyse ($\frac{1}{3}$)

$$-(U_a + P_a V_a)$$

$$-P_a V_a = 0$$

$$H = H(T)$$

$$P \cdot V$$

$$U = \int_{T_1}^{T_2} C_{v,d} dT$$

$$H = \int_{T_1}^{T_2} C_{p,d} dT$$

$$\gamma = \frac{5}{3}$$

solz

$$\text{Adiabatic: } \delta Q = 0, \Delta Q = 0$$

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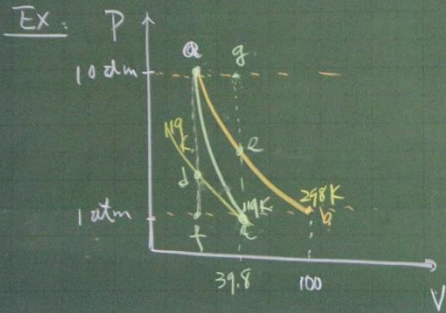
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Ideal Gas

Rev. { Isothermal
Adiabatic Expansion
 $P_1 \rightarrow P_2 (< P_1)$



a. $\begin{cases} V_a = 10 \text{ l} \\ P_a = 10 \text{ atm} \\ T_a = 298 \text{ K} \end{cases} \rightarrow P_b = 1 \text{ atm}$

Monatomic Ideal Gas

Q1. (Rev. + Isothermal) Expansion

$\Delta U, \Delta Q, \Delta W, \Delta H$?

Q2. (Rev. + Adiabatic)

$\Delta U, \Delta Q, \Delta W, \Delta H$ = ?

Q3. ΔU , indep of path

| |
|--|
| $\text{a} \rightarrow \text{e} \rightarrow \text{c}$ |
| $\text{a} \rightarrow \text{d} \rightarrow \text{c}$ |
| $\text{a} \rightarrow \text{b} \rightarrow \text{c}$ |
| $\text{a} \rightarrow \text{f} \rightarrow \text{c}$ |
| $\text{a} \rightarrow \text{g} \rightarrow \text{c}$ |

$\Delta U_1, \textcircled{1}, \textcircled{2}, \textcircled{3}, \textcircled{4}, \textcircled{5}$

Sol 3.

$\textcircled{1} \begin{cases} \text{a} \rightarrow \text{e} : dT=0, \Delta U=0 \\ \text{e} \rightarrow \text{c} : dV=0, \Delta U = n \int_{T_e}^{T_c} C_V dT \\ -9.13 \text{ (KJ)} = n \cdot C_V (T_c - T_e) \end{cases}$

$\textcircled{2} \begin{cases} \text{a} \rightarrow \text{d} : dV=0 \Rightarrow \Delta U = n C_V (T_d - T_a) \\ \text{d} \rightarrow \text{c} : dT=0 \Rightarrow \Delta U=0 \end{cases}$

$T_d = T_c = 119 \text{ K}$
 $T_a = T_e = 298 \text{ K}$

$\Delta U = n \int_{T_i}^{T_f} C_V dT = n \cdot C_V (T_2 - T_1)$

$\Delta H = n \cdot C_P (T_2 - T_1)$

=0

$\textcircled{2}$

9.13 (KJ)

$\Delta U = +9.13 \text{ (KJ)}$

$\Delta W = -15.2 \text{ (KJ)}$

Ch

\star Ist
 $\Delta U = \dots$
d

Ch. 2

1st Law

$$\Delta U = \Delta Q - \Delta W$$
$$dU = \delta Q - \delta W$$

$C \equiv ?$

$H \equiv ?$

Ch. 3 - 2nd Law

§ Introduction

* Irreversible, Reversible

* Degree of Irreversibility

* "Entropy": S (熵)

* Carnot Engine

* Equilibrium: $S_{\text{universe}} = S_{\text{max}}$

§ system

✓ Isolated system: \leftrightarrow universe (x)
constant, U, V, M_i

✓ Closed system:
constant M_i
energy transfer

✓ Open system:
mass transfer
energy transfer

* Equilibrium: rest

Non-Equil. \rightarrow Equil.

Spontaneous?
(自发)

* Spontaneous

Irreversible

e.g.



§ system

- ✓ Isolated system: \leftrightarrow universe (x) constant, U, V, M_i
- ✓ Closed system: $\left[\begin{array}{l} \text{constant } M_i \\ \text{energy transfer} \end{array} \right.$
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Ir

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 Non-Equil. \longrightarrow Equil.
 Spontaneous?
 (自然)

* Spontaneous



Irreversible

e.g.



UNIVERSE (x)
 constant, U, V, M_i
 constant, M_i
 energy transfer
 mass energy transfer
 rest
 Equil.
 ous?

* Spontaneous reaction
 Irreversible!

e.g.

A

B

⇒

A+B

T₁

T₂

⇒

T

T

T₁ < T₂ T₁ < T < T₂

(Max. S) ⇌ (Min. E)

Degree of
Heat Res

UNIVERSE (x)
 constant, U, V, M_i
 constant, M_i
 energy transfer
 mass energy transfer
 rest
 Equil.
 ous?

* Spontaneous reaction
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e.g.

A

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⇒

A+B

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T₂

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UNIVERSE (x)
 constant, U, V, M_i
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 energy transfer
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 Irreversible!

e.g.

A

B

⇒

A+B

T₁

T₂

⇒

T

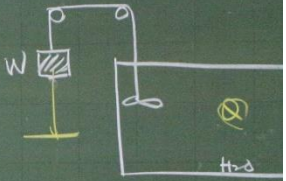
T

T₁ < T₂ T₁ < T < T₂

(Max. S) ⇌ (Min. E)

Degree of
Heat Res

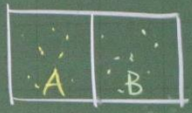
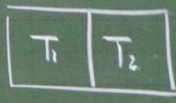
idea: $\left(\frac{Q}{T}\right)_S$



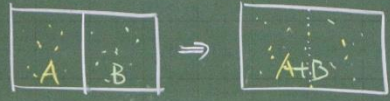
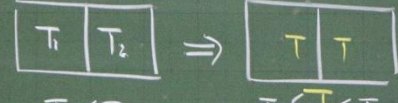
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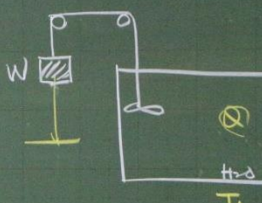
* Equilibrium: rest
 Non-Equil. \rightarrow Equil.
 Spontaneous? (自然)

* Spontaneous
 Irreversible
 e.g. 

 $T_1 < T_2$
 (Max. S)

UNIVERSE (x)
 constant, U, V, M_i
 constant, M_i
 energy transfer
 mass transfer
 rest
 Equil.
 us?

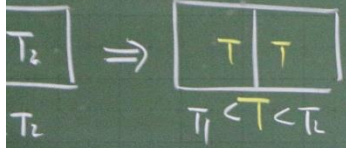
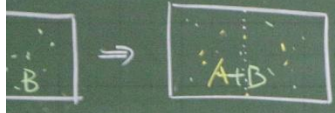
(Natural)
 * Spontaneous reaction
 Irreversible!
 e.g. 

 $T_1 < T_2$ $T_1 < T < T_2$
 (Max. S) \Leftrightarrow (Min. E)

§ Degree of
 Heat Res. T_1
 idea: $\left(\frac{Q}{T} \right)_S$



(Natural' reaction

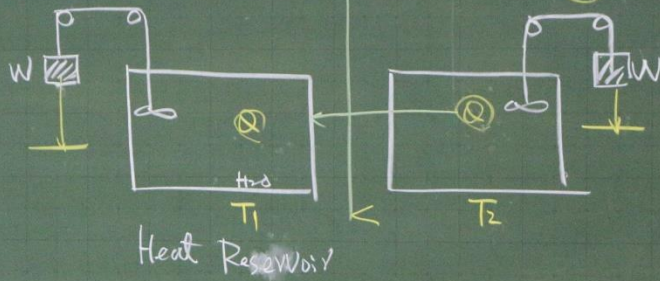
versible!



$\Delta S \Leftrightarrow (M, n, E)$

§ Degree of Irreversibility

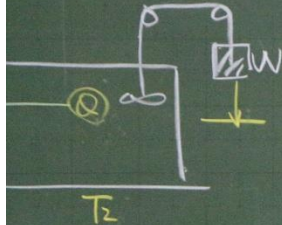
$\Leftrightarrow \Delta S$ "Entropy" $\left(\frac{Q}{T}\right)$



idea: $\left(\frac{Q}{T}\right)$ Index of Irreversibility
 $\Delta S \Leftrightarrow \left(\frac{Q}{T}\right)$

vs: bility

"Entropy" $\left(\frac{Q}{T}\right)$



of Irreversibility

§ Reversible Process

- * Imaginary
- * infinitesimally small change
- * continuum of equil. states
- * No Degradation Heat

§ Reversible versus Irrev. Process
Example

§ Reversible Process

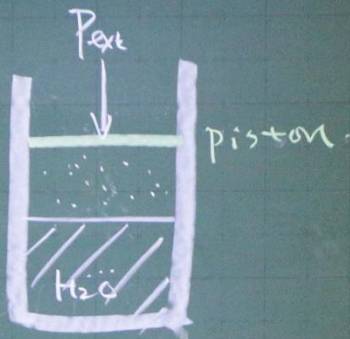
* Imaginary

* infinitesimally small change

* continuum of equil. states

* No Degradation Heat

§ Reversible versus Irrev. Process
Example



process 1: sudden decrease ΔP

$$\textcircled{1} (P_{ext} - \Delta P)$$

H₂O: evaporation \Rightarrow volume \uparrow
increase

: work done "by" system: $(P_{ext} - \Delta P) \cdot \Delta V = W_{11}$

(2) (

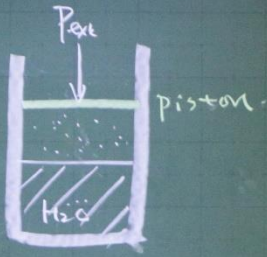
H₂O vap

\Rightarrow

work d

W_2

$$\Delta W = ($$



process 1: sudden decrease ΔP

① $(P_{ext} - \Delta P)$ one mole

H₂O: evaporat: on \Rightarrow volume V increase

work done "by" system: $(P_{ext} - \Delta P) \cdot V = W_1$

② $(P_{ext} - \Delta P) \rightarrow P_{ext}$

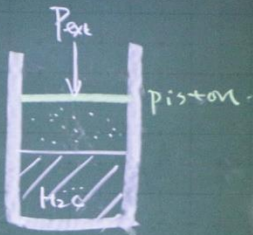
H₂O vapor condensation

$\Rightarrow V$ decreases

work done "on" system

$W_2 = -P_{ext} \cdot V$

$\Delta W = (W_1 + W_2) = -\Delta P \cdot V$
permanent change



process 1: sudden decrease ΔP

① $(P_{ext} - \Delta P)$ one mole

H₂O: evaporat: on \Rightarrow volume V increase

work done "by" system: $(P_{ext} - \Delta P) \cdot V = W_1$

② $(P_{ext} - \Delta P) \rightarrow P_{ext}$

H₂O vapor condensation

$\Rightarrow V$ decreases

work done "on" system

$W_2 = -P_{ext} \cdot V$

$\Delta W = (W_1 + W_2) = -\Delta P \cdot V$
permanent change

Irreversible

$S: \left(\frac{Q}{T}\right)$

$\rightarrow P_{ext}$
 condensation
 rev
 system
 V
 $S: \left(\frac{Q}{T}\right)$
 $-\Delta P: V$
 change
 ble

process: infinitesimal change $\delta p \rightarrow 0$
 $\sum (P_{ext} - dp) \rightarrow \sum P_{ext}$

$$W_i = (P_{ext} - \delta p) \cdot V \cong + P_{ext} \cdot V$$

$$W_o = (P_{ext} + \delta p) \cdot V \cong - P_{ext} \cdot V$$

$\Delta W_{\text{net}} \cong 0$ (No change)
 Reversible

Evaporation Only
 work done "By" system

Irrev: $W_{\text{irrev}} = (P_{ext} - \Delta P) \cdot V$
 Rev: $W_{\text{rev}} = P_{ext} \cdot V = W_{\text{max}}$

same final state

$$\Delta U_{\text{Irrev}} = Q_{\text{Irrev}} - W_{\text{Irrev}}$$

$$\Delta U_{\text{Rev}} = Q_{\text{Rev}} - W_{\text{Rev}}$$

$\therefore (Q_{\text{Rev}} - Q_{\text{Irrev}}) = (W_{\text{Rev}} - W_{\text{Irrev}}) > 0$
 $Q_{\text{Rev}} > Q_{\text{Irrev}}$

process
 H₂O
 work done

Define degradation heat: Q_{deg}

$$Q_{deg} \equiv (Q_{rev} - Q_{irrev}) > 0$$

* Reversible process:

$$\Delta S_{reservoir} = - \frac{Q_{rev}}{T}$$

$$\Delta S_{cylinder} = + \frac{Q_{rev}}{T}$$

$$\Delta S_{total} = 0$$

Evaporator
work done

{ Irrev: $W_{irrev} =$
Rev: $W_{rev} =$
same

$$\begin{cases} \Delta U_{Irrev} = \\ \Delta U_{rev} = \end{cases}$$

$$\therefore (Q_{rev} - Q_{irrev})$$

Q_{deg}

Define degradation heat: Q_{deg}

$$Q_{deg} \equiv (Q_{rev} - Q_{irrev}) > 0$$

* Reversible process:

$$\Delta S_{reservoir} = - \frac{Q_{rev}}{T}$$

$$\Delta S_{cylinder} = + \frac{Q_{rev}}{T}$$

$$\Delta S_{total} = 0$$

Evap
work a

{ Irrev: W
Rev: W

$$\begin{cases} \Delta U_{Irrev} = \\ \Delta U_{rev} = \end{cases}$$

$$\therefore (Q_{rev} - Q_{irrev})$$

Define degradation heat: Q_{deg}

$$Q_{deg} \equiv (Q_{rev} - Q_{irrev}) > 0$$

* Reversible Process:

$$\Delta S_{reservoir} = - \frac{Q_{rev}}{T}$$

$$\Delta S_{cylinder} = + \frac{Q_{rev}}{T}$$

$$\Delta S_{total} = 0$$

Evaporator work done
 Irrev: W_{irrev}
 Rev: W_{rev}

ΔU_{irrev}
 ΔU_{rev}

$(Q_{rev} - Q_{irrev})$

Irreversible Process

$$\Delta S_{reservoir} = - \frac{Q_{irrev}}{T}$$

$$\Delta S_{cylinder} = \frac{Q_{irrev}}{T} + \left(\frac{Q_{deg}}{T} \right)$$

$$\Delta S_{total} = \frac{Q_{deg}}{T} > 0$$

Define degradation

$$Q_{deg} \equiv (Q_{rev} - Q_{irrev})$$

* Reversible

$$\Delta S_{reservoir} = - \frac{Q_{rev}}{T}$$

$$\Delta S_{cylinder} = + \frac{Q_{rev}}{T}$$

$$\Delta S_{total} = 0$$

If consider:
cylinder only

Irreversible:

$$\left(\frac{Q_{\text{irr}} + Q_{\text{rev}} - Q_{\text{rev}}}{T} \right) = \Delta S_{\text{cylinder}} = \frac{Q_{\text{irr}}}{T} + \left(\frac{Q_{\text{deg}}}{T} \right)$$

Reversible:

$$\Delta S_{\text{cylinder}} = \frac{Q_{\text{rev}}}{T}$$

Irreversible Process

$$\Delta S_{\text{reservoir}} = -$$

$$\Delta S_{\text{cylinder}} = 0$$

$$\Delta S_{\text{tot}} = \frac{Q_{\text{deg}}}{T}$$

consider:
cylinder only

Irreversible Process

$$\Delta S_{\text{reservoir}} = - \frac{Q_{\text{irr}}}{T}$$

$$\Delta S_{\text{cylinder}} = \frac{Q_{\text{irr}}}{T} + \left(\frac{Q_{\text{deg}}}{T} \right)$$

$$\Delta S_{\text{tot}} = \frac{Q_{\text{deg}}}{T} > 0$$

Define $Q_{\text{deg}} =$

* Reversible

$$\Delta S_{\text{reservoir}}$$

$$\Delta S_{\text{cylinder}}$$

$$\Delta S_{\text{tot}}$$

$\Delta S_{\text{tot}} > 0$ $\Delta S_{\text{tot}} \uparrow$ $(S) \left(\frac{Q}{T} \right)$
 system $\Delta S_{\text{irr}} = \Delta S_{\text{rev}}$ condition

sider:

for only

$$\Delta S_{\text{reservoir}} = \frac{Q_{\text{irrev}}}{T} - \left(\frac{Q_{\text{deg}}}{T} \right)$$

$$\Delta S_{\text{cylinder}} = \frac{Q_{\text{rev}}}{T}$$

Irreversible Process

$$\Delta S_{\text{reservoir}} = - \frac{Q_{\text{irrev}}}{T}$$

$$\Delta S_{\text{cylinder}} = \frac{Q_{\text{irrev}}}{T} + \left(\frac{Q_{\text{deg}}}{T} \right)$$

$$\Delta S_{\text{tot}} = \frac{Q_{\text{deg}}}{T} > 0$$

$$\therefore \Delta S_{\text{tot}} > 0$$

$$\Delta S_{\text{tot}} \uparrow$$

(S) $\left(\frac{Q}{T} \right)$
condition

system $\Delta S_{\text{irrev}} = \Delta S_{\text{rev}}$

sider:

for only

$$\Delta S_{\text{reservoir}} = \frac{Q_{\text{irrev}}}{T} - \left(\frac{Q_{\text{deg}}}{T} \right)$$

$$\Delta S_{\text{cylinder}} = \frac{Q_{\text{rev}}}{T}$$

Irreversible Process

$$\Delta S_{\text{reservoir}} = - \frac{Q_{\text{irrev}}}{T}$$

$$\Delta S_{\text{cylinder}} = \frac{Q_{\text{irrev}}}{T} + \left(\frac{Q_{\text{deg}}}{T} \right)$$

$$\Delta S_{\text{tot}} = \frac{Q_{\text{deg}}}{T} > 0$$

$$\therefore \Delta S_{\text{tot}} > 0$$

$$\Delta S_{\text{tot}} \uparrow$$

(S) $\left(\frac{Q}{T} \right)$
condition

system $\Delta S_{\text{irrev}} = \Delta S_{\text{rev}}$

side:
for only

$$Q_{rev} = \frac{Q_{irrev}}{T} - \left(\frac{Q_{deg}}{T} \right)$$

$$\Delta S_{cylinder} = \frac{Q_{rev}}{T}$$

Irreversible Process

$$\Delta S_{reservoir} = - \frac{Q_{irrev}}{T}$$

$$\Delta S_{cylinder} = \frac{Q_{irrev}}{T} + \left(\frac{Q_{deg}}{T} \right)$$

$$\Delta S_{tot} = \frac{Q_{deg}}{T} > 0$$

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

$$\therefore \Delta S_{tot} > 0 \quad \Delta S_{tot} \uparrow \quad (S) \left(\frac{Q}{T} \right)$$

system $\Delta S_{irrev} = \Delta S_{rev}$

condition

Define $Q_{deg} \equiv$

$$Q_{deg} \equiv$$

* Reversible

$$\Delta S_{reserv}$$

$$\Delta S_{cylinder}$$

$$\Delta S_{total}$$

side:
for only

$$Q_{rev} = \frac{Q_{irrev}}{T} - \left(\frac{Q_{deg}}{T} \right)$$

$$\Delta S_{cylinder} = \frac{Q_{rev}}{T}$$

Irreversible Process

$$\Delta S_{reservoir} = - \frac{Q_{irrev}}{T}$$

$$\Delta S_{cylinder} = \frac{Q_{irrev}}{T} + \left(\frac{Q_{deg}}{T} \right)$$

$$\Delta S_{tot} = \frac{Q_{deg}}{T} > 0$$

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

$$\therefore \Delta S_{tot} > 0 \quad \Delta S_{tot} \uparrow \quad (S) \left(\frac{Q}{T} \right)$$

system $\Delta S_{irrev} = \Delta S_{rev}$

condition

Define $Q_{deg} \equiv$

$$Q_{deg} \equiv$$

* Reversible

$$\Delta S_{reserv}$$

$$\Delta S_{cylinder}$$

$$\Delta S_{total}$$