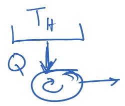
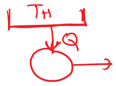
Second Law

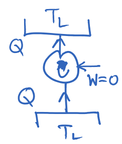
① KP statement



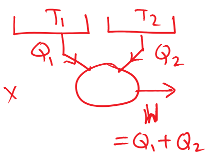
✗ ⟺ PMM II



② Clausius Statement

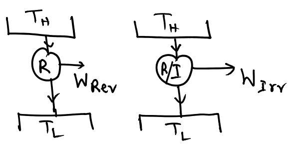


✗ $T_L < T_H$



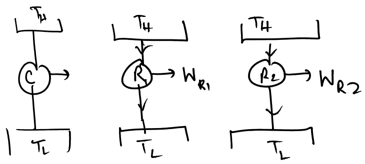
✗

Corr 1



$$\eta_{Rev} \geq \eta$$

Corr 2



$$\eta_{R1} = \eta_{R2} = \cdots = \left(1 - \frac{T_L}{T_H}\right)$$

$$(COP)_{R,Rev} = \frac{T_L}{T_H - T_L}$$

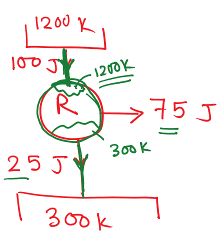
$$(COP)_{R,H} = \frac{T_H}{T_H - T_L}$$

Corr 3 / Clausius Inequality

$$\boxed{\oint \left(\frac{\delta Q}{T_b}\right) \leq 0}$$

[Proved it from Corr 1 & 2]

Rev. Cycles $\oint \left(\frac{\delta Q}{T_b}\right)_{Rev} = 0$ Irrev. $\oint \left(\frac{\delta Q}{T_b}\right)_I < 0$

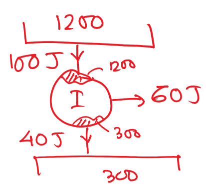


$$\oint \left(\frac{\delta Q}{T_b}\right) = \sum \left(Q/T_b\right)$$

$$= \frac{+100}{1200} + \frac{-25}{300}$$

$$= +0.08333 + (-0.08333)$$

$$= 0$$



$$\oint \left(\frac{\delta Q}{T_b}\right) = \sum \left(Q/T_b\right)$$

$$= \frac{+100}{1200} + \frac{-40}{300}$$

$$= 0.08333 - 0.1333 = -0.05$$

$$< 0$$

Clausius Inequality ⟹ **Entropy Change**

$$\oint \delta Q = \oint \delta W \quad \text{Cycle}$$

Process $Q - W = \Delta E$

↑ Change of Stored Energy

$$E = U + \tfrac{1}{2} m C^2 + m g z$$

$$e = u + \tfrac{1}{2} c^2 + g z$$

Let us assume internally rev. processes

$\{ e = u + \frac{1}{2}c^2 + gz$

Let us assume internally rev. process

T-S Diagram

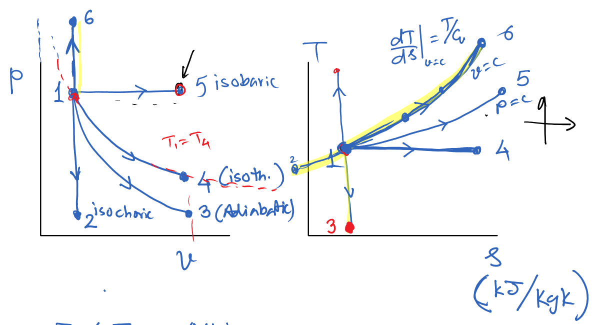
$$\boxed{\delta q = T\,ds}$$

1st Law

$$\delta q - \delta w = du$$

$$\delta q - p\,dv = du$$

$$\boxed{\delta q = du + p\,dv}$$



Const Vol.

$\delta q = du + p\,dv \to 0$

$T\,ds = du = C_v\,dT$

$$\Rightarrow \boxed{\frac{dT}{ds} = \frac{T}{C_v}}$$

$T_2 < T_1$, ΔU is $-$ve

$W = 0 \Rightarrow$ δQ is $-$ve

$T\,ds$ is $-$ve

+ve

$$\left.\frac{dT}{ds}\right|_{v=c} = \frac{T}{C_v}$$

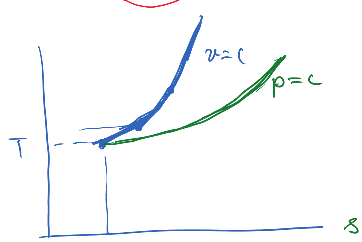
Const. pr. process

$\delta q = du + p\,dv$

$T\,ds = C_p\,dT$

$$\Rightarrow \boxed{\frac{dT}{ds} = \frac{T}{C_p}}$$

$$\left.\frac{dT}{ds}\right|_{p=c} = \frac{T}{C_p}$$



Calculation of Entropy of ideal gas

$pv = RT$

$p = \frac{RT}{v}$

$$\boxed{\delta q = du + p\,dv}$$

$$T\,ds = C_v\,dT + \frac{RT}{v}\cdot dv$$

$$\text{or}\quad ds = \frac{C_v\,dT}{T} + R\frac{dv}{v}$$

$$s_2 - s_1 = \int_1^2 C_v\frac{dT}{T} + R\ln v_2/v_1$$

If C_v is const.

$$\boxed{s_2 - s_1 = C_v \ln\frac{T_2}{T_1} + R\ln\frac{v_2}{v_1}}$$

$$\delta q = du + p\,dv + v\,dp - v\,dp$$

$$= du + d(pv) - v\,dp$$

$h = u + pv$

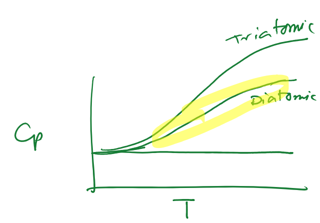
$dh = du + d(pv)$

$$\boxed{\delta q = dh - v\,dp}$$

$$T\,ds = C_p\,dT - \frac{RT}{p}dp$$

$$ds = \frac{C_p\,dT}{T} - R\frac{dp}{p}$$

$$\text{or}\quad \boxed{s_2 - s_1 = \int_{T_1}^{T_2}\frac{C_p\,dT}{T} - R\ln p_2/p_1}$$



if C_p = const. betn. T_1 & T_2 $\Rightarrow$

$$\boxed{s_2 - s_1 = C_p\ln T_2/T_1 - R\ln p_2/p_1}$$

If C_p = const. betn. T_1 & T_2 ⇒

$$s_2 - s_1 = C_p \ln T_2/T_1 - R \ln p_2/p_1$$

$$s_2 - s_1 = \int_{T_1}^{T_2} \frac{C_p dT}{T} - R \ln p_2/p_1$$

$$C_p(T) = a_0 + a_1 T + a_2 T^2$$

$$\int_{T_1}^{T_2} \left[\frac{a_0 + a_1(T) + a_2 T^2}{T}\right] dT =$$

TABLE A-22 Ideal Gas Properties of Air

T	h (kJ/kg)	u (kJ/kg)	s° (kJ/kg K)
200	199.97	142.56	1.29559
210	209.97	149.69	1.34444
220	219.97	156.82	1.39105
230	230.02	164.00	1.43557
240	240.02	171.13	1.47824
290	290.16	206.91	1.66802
295	295.17	210.49	1.68515
300	300.19	214.07	1.70203
305	305.22	217.67	1.71865
310	310.24	221.25	1.73498
350	350.49	250.02	1.85708
400	400.98	286.16	1.99194
450	451.80	322.62	2.11161
500	503.02	359.49	2.21952
550	554.74	396.86	2.31809

From Moran and Shapiro

Find the entropy of air at 400 K & 10 bar. Also find u & h for the same

u, h, s $\left[\begin{matrix} p = 10 \text{ bar} \\ T = 400 \text{ K} \end{matrix}\right]$ Air

For ideal gas h(T), u(T)

$h(T = 400\text{K}, p = 10 \text{ bar}) = h(T = 400\text{K}, p = 1 \text{ bar})$

$u(T = 400, p = 10 \text{ bar}) = u(T = 400)$

$s(T, p)$

$h_{400K, 10bar} = 400.98$ kJ/kg

$u_{400K, 10bar} = 286.16$ kJ/kg.

$$s(400K, 10 bar) = s^\circ(400K) - R \ln p_2/p_0 \quad (p_2 = 10,\ p_0 = 1)$$
$$= 1.99194 - 0.287 \ln 10$$
$$= 1.99194 - 0.66$$
$$= +1.33 \text{ kJ/kg K}$$

$$s(300K, 1 bar) = s^\circ(300K) - R \ln\left(\frac{p}{p_0}\right) \quad (p = 1 \text{ bar},\ p_0 = 1 \text{ bar} \Rightarrow 0)$$
$$= 1.702 \text{ kJ/kg K}$$

Calculate the change in entropy of a gas (Air) that is compressed for 300 K, 2 bar to 500 K, 10 bar

$$s_2 - s_1 = \int_{T_1}^{T_2} \frac{C_p dT}{T} - R \ln p_2/p_1$$

O_2, N_2, CO_2

$$= \left[\int_{T_0}^{T_2} \frac{C_p dT}{T} - R \ln p_2/p_0\right] - \left[\int_{T_0}^{T_1} \frac{C_p dT}{T} - R \ln (p_1/p_0)\right]$$

$$= \underbrace{\left[s^\circ(T_2) - R \ln p_2/p_0\right]}_{s_2} - \underbrace{\left[s^\circ(T_1) - R \ln (p_1/p_0)\right]}_{s_1}$$

$$s_2 - s_1 = \int^{T_2} \frac{C_p dT}{} - R \ln p_2/p_1$$

TABLE A-22 Ideal Gas Properties of Air

$s_2 \qquad s_1$

$$s_2 - s_1 = \int_{T_1}^{T_2} \frac{C_p dT}{T} - R \ln p_2/p_1$$

$$= \left[\int_{T_0}^{T_2} \frac{C_p dT}{T} - \int_{T_0}^{T_1} \frac{C_p dT}{T}\right] - R \ln p_2/p_1$$

$$= \left[s^0(T_2) - s^0(T_1)\right] - R \ln (p_2/p_1)$$

TABLE A-22 Ideal Gas Properties of Air

T	h	u	s°
200	199.97	142.56	1.29559
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450	451.80	322.62	2.11161
500	503.02	359.49	2.21952
550	554.74	396.86	2.31809

From Moran and Shapiro

$$s_2 - s_1 = (2.21952 - 1.70203) - 0.287 \ln \frac{10}{2}$$

$$= 0.51749 - 0.4619$$

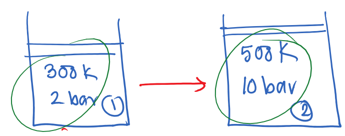
$$= 0.056 \text{ kJ/kg K}$$

If we used $C_{p_{air}} = 1.004$ kJ/kg

$$s_2 - s_1 = \int_{T_1}^{T_2} \frac{C_p dT}{T} - R \ln p_2/p_1 = 1.004 \ln \frac{500}{300} - R \ln 5$$

$$= 0.513 - 0.4619$$

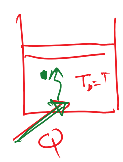
$$=$$



$$s_2 - s_1 = 0.056 \text{ kJ/kg.}$$

Find out the entropy generation if the change is brought about by

1) Supplying heat in a reversible manner
2) Using an electric heater placed inside the cylinder



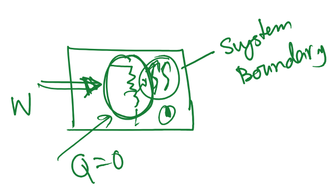
$$\Delta S = 0.056$$

Reversible process

$$S_2 - S_1 = \int \left(\frac{\delta Q}{T_b}\right)_{act} + S_{gen}$$

$$\int \left(\frac{\delta Q}{T_b}\right)_{Rev} = S_2 - S_1$$

$$S_{gen} = 0$$



$$S_2 - S_1 = \int \left(\frac{\delta Q}{T_b}\right)_{act} + S_{gen}$$

$$0.056 = 0 + S_{gen}$$

$$S_{gen} = 0.056 \text{ kJ/kg K}$$