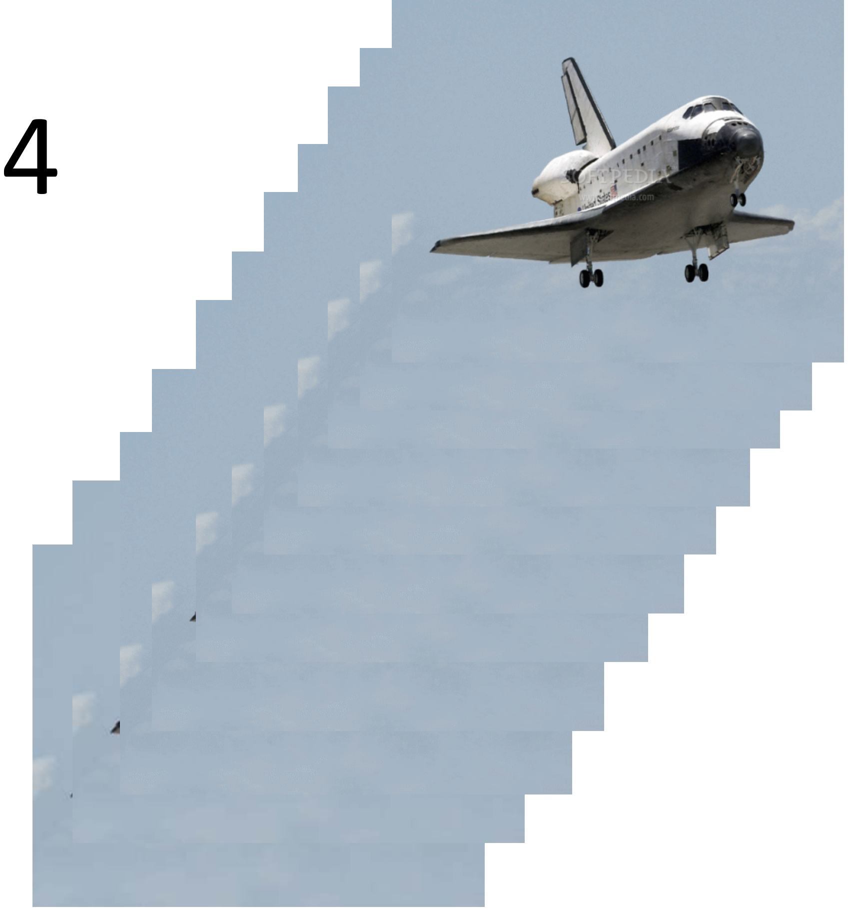
Unit 4



Second Law of thermodynamics

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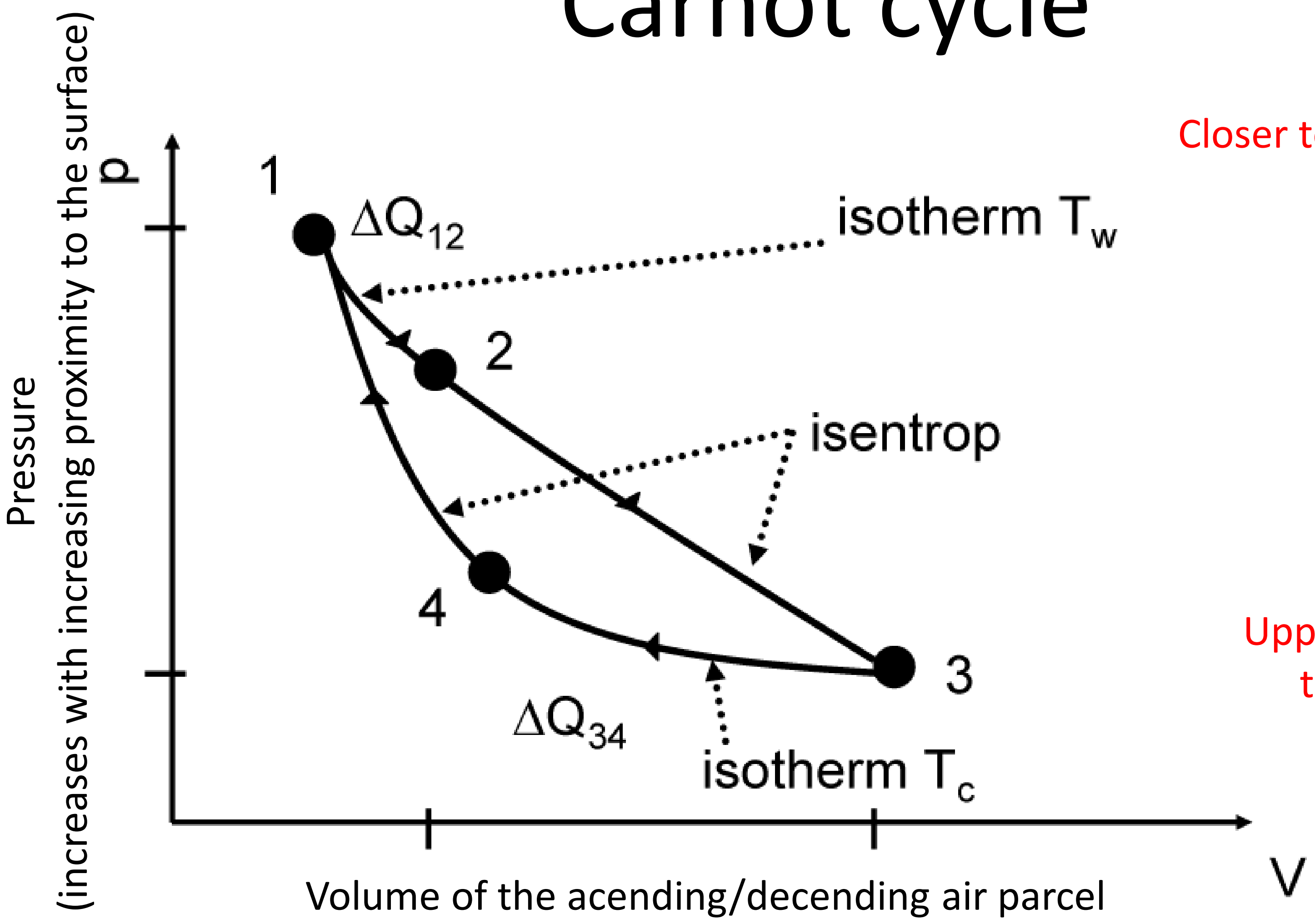
http://i1-win.softpedia-static.com/screenshots/365-Space-Shuttle-Screen-Saver_2.png

Carnot cycle



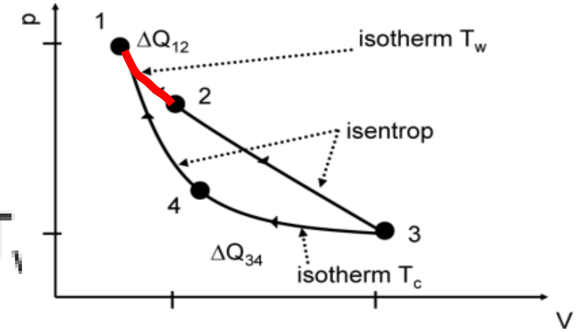
Closer to the Earth's surface

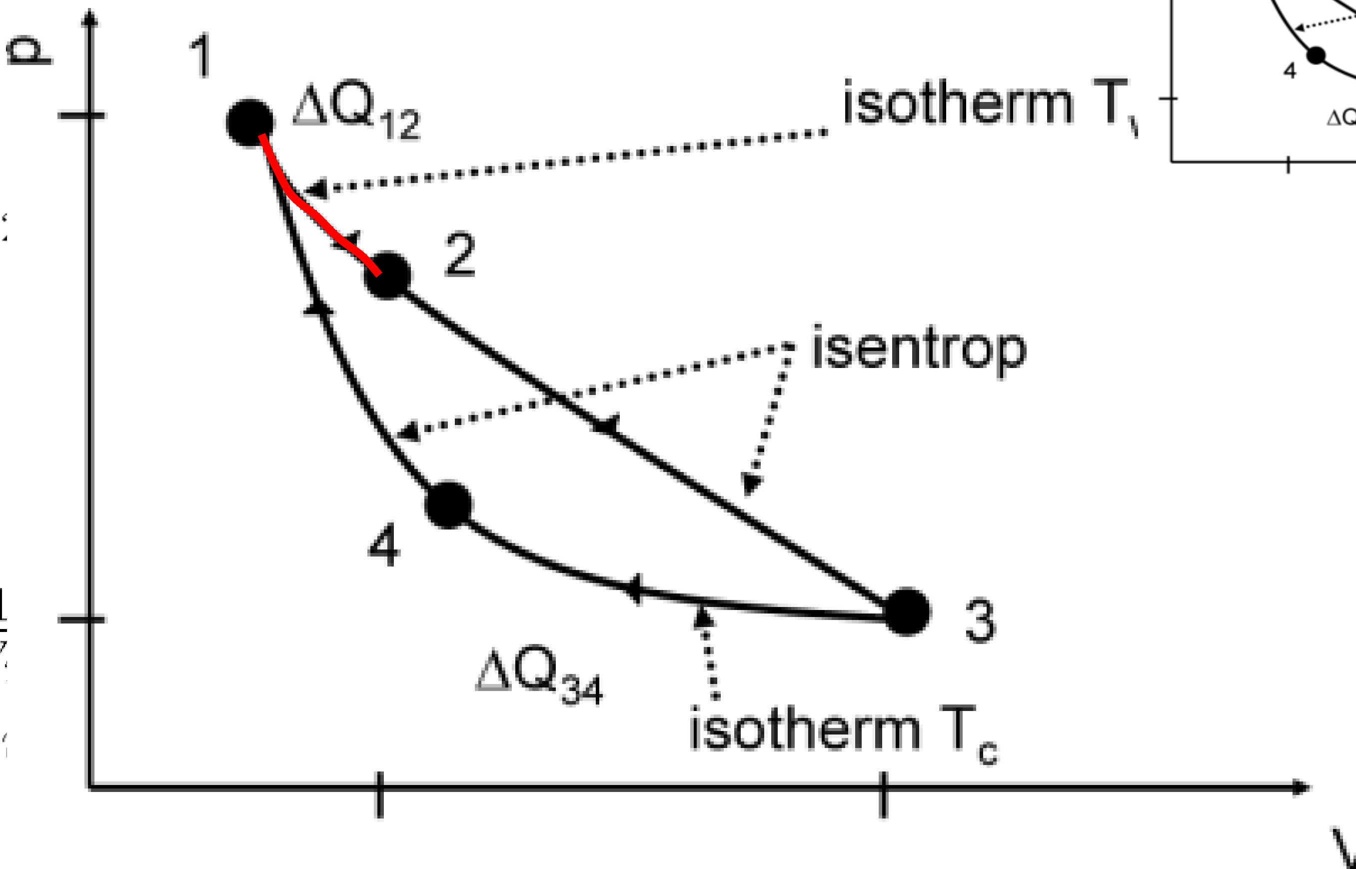
Upper levels in the troposphere

$$\Theta_1 = T_w\left(\frac{1000}{p_1}\right)^{\frac{R_d}{c_p}} = T_c\left(\frac{1000}{p_4}\right)^{\frac{R_d}{c_p}}$$

$$\Theta_2 = T_c\left(\frac{1000}{p_3}\right)^{\frac{R_d}{c_p}} = T_w\left(\frac{1000}{p_2}\right)^{\frac{R_d}{c_p}}$$

$1 \rightarrow 2$: Reversible isothermal expansion





w_1

$\frac{1}{V_1}$

$) = w_{12}$

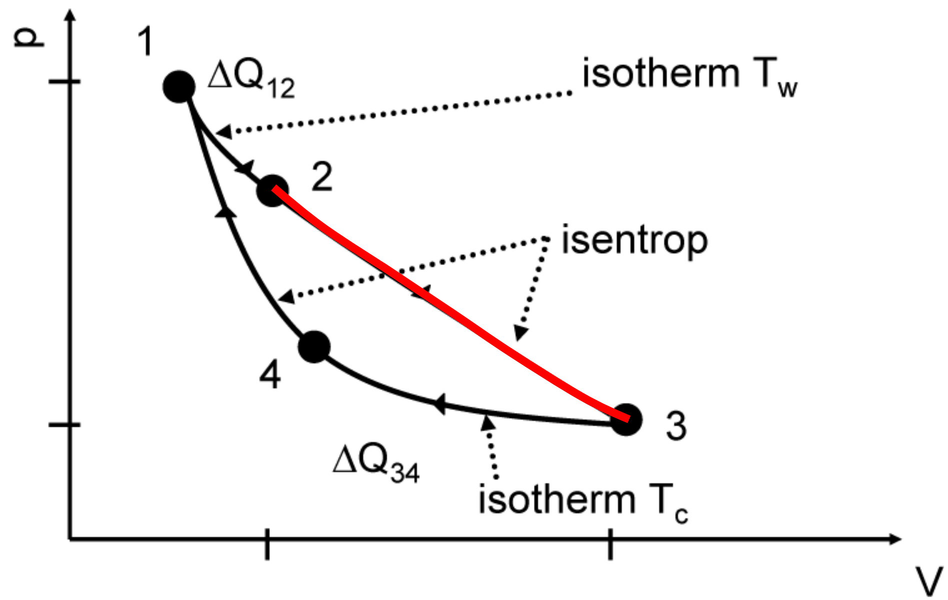
$V_2 > V_1,\ \Delta q_{12},\ w_{12} > 0$

THM: heat can be added without change in T!

2 → 3: Reversible adiabatic expansion

$$\Delta q_{23} = 0$$

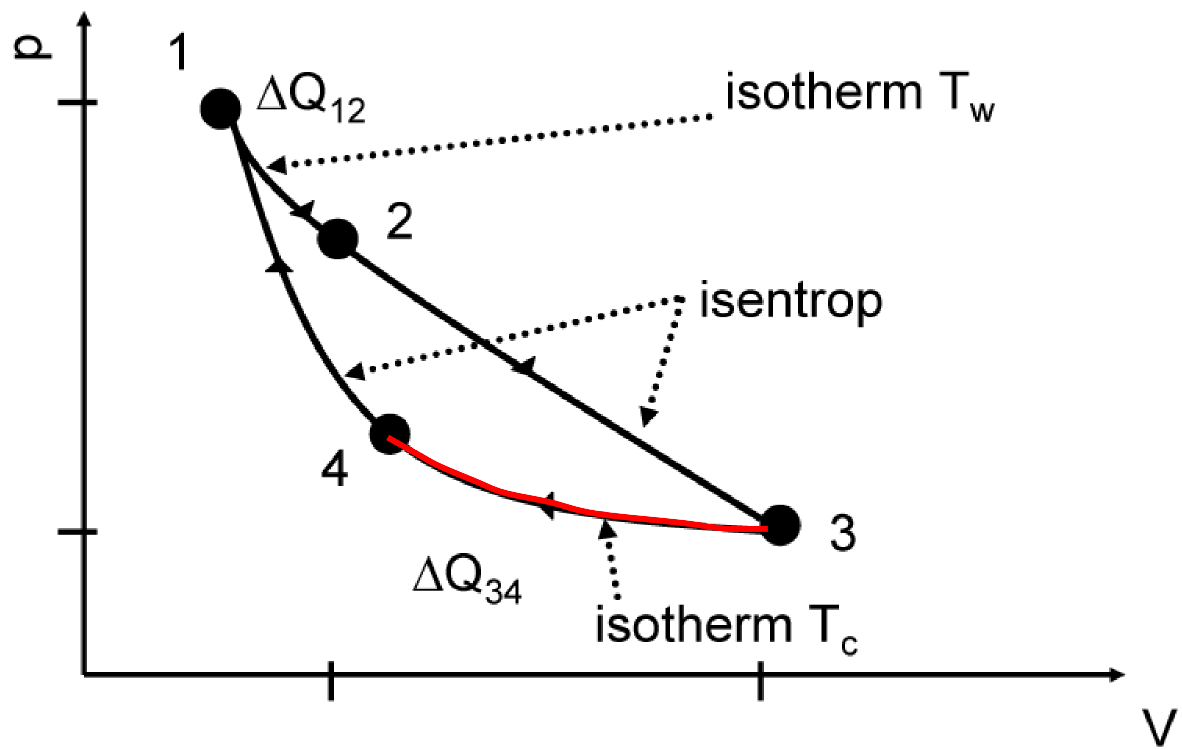
$$\Delta u_{23} = -c_v(T_w - T_c)$$
$$w_{23} = -\Delta u_{23} = c_v(T_w - T_c)$$



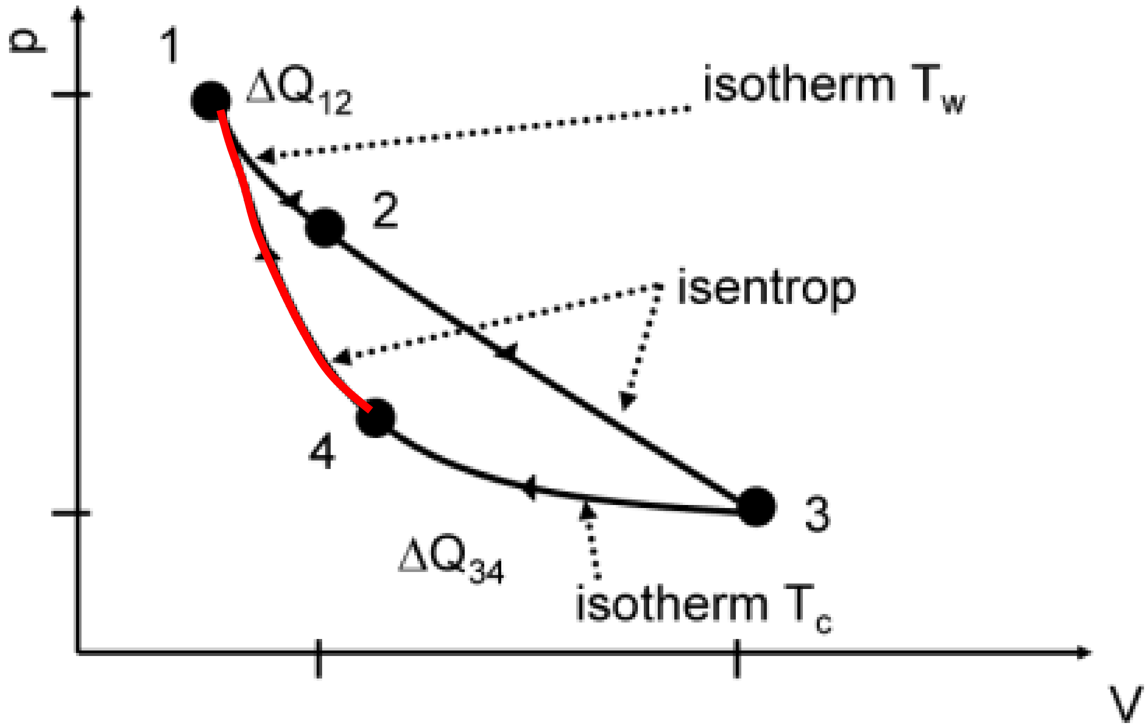
$3 \rightarrow 4$: Reversible isothermal compression

$$\Delta u_{34} = 0$$
$$w_{34} = -R_d T_c ln \frac{V_3}{V_4} = -R_d T_c ln(\frac{p_1}{p_3}(\frac{T_c}{T_w})^{\frac{cp}{R_d}})$$
$$q_{34} = -c_p T_c (\frac{\Theta_2}{\Theta_1})$$

$$q_{34} = W_{34}$$



$4 \rightarrow 1$: Reversible adiabatic compression



$$q_{41} = 0$$
$$\Delta u_{41} = c_v(T_c - T_w) > 0$$
$$w_{41} = -\Delta u_{41} = -c_v(T_w - T_c) < 0$$

Carnot cycle - THM

$$w = w_{12} + w_{23} + w_{34} + w_{41}$$
$$q = q_{12} + q_{23} + q_{34} + q_{41}$$

$$q = c_p(T_w - T_c)ln(\frac{\Theta_2}{\Theta_1})$$

$$w = q_{12} + q_{34} \text{ and } q_{34} < 0$$

$w=R_d(T_w-T_c)\ln(p_1/p_3(T_c/T_w)^{(cp/Rd)})$

$$\eta = \frac{\Delta q_{12} + \Delta q_{34}}{\Delta q_{12}} = 1 + \frac{\Delta q_{34}}{\Delta q_{12}} = 1 - \frac{T_c}{T_w}$$

THM: Carnot-cycle has maximum possible efficiency of all processes between T_w and T_c

Thermodynamics potentials

Potential	Variables
U **(*S*,*V*,*N*)**	***S*, *V*, *N***
H **(*S*,*P*,*N*)**	***S*, *P*, *N***
F **(*T*,*V*,*N*)**	***V*, *T*, *N***
G **(*T*,*P*,*N*)**	***P*, *T*, *N***

$$dU = T\,dS - P\,dV + \mu\,dN$$

$$dH = T\,dS + V\,dP + \mu\,dN$$

$$dF = -S\,dT - PdV + \mu dN$$

$$dG = -S\,dT + VdP + \mu dN$$

Maxwell relation: $\left(\dfrac{\partial T}{\partial V}\right)_{S,N} = -\left(\dfrac{\partial P}{\partial S}\right)_{V,N}, \quad \cdots$

Example: isolated air parcel

$$dU\left(S,V,N\right) = TdS - PdV + \mu dN$$

$$dU(S,V,N) = \left(\frac{\partial U}{\partial S}\right)_{V,N} dS + \left(\frac{\partial U}{\partial V}\right)_{S,N} dV + \left(\frac{\partial U}{\partial N}\right)_{S,V} dN$$

$$\left(\frac{\partial U}{\partial S}\right)_{V,N} = T \qquad \left(\frac{\partial U}{\partial V}\right)_{S,N} = -P \qquad \left(\frac{\partial U}{\partial N}\right)_{S,V} = \mu$$