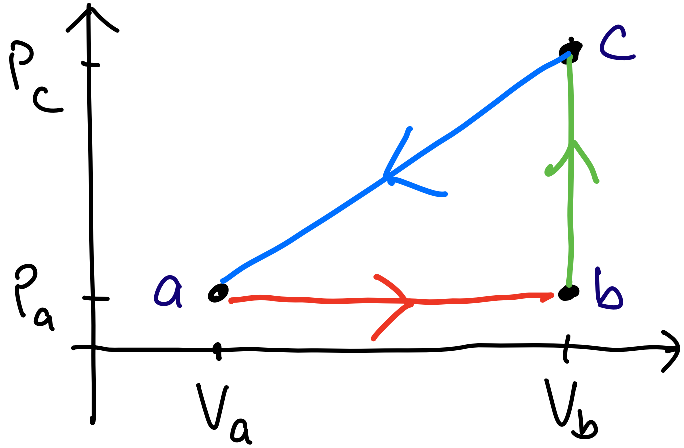
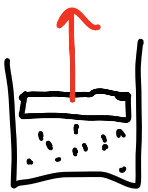


	W	ΔU	$Q=\Delta U - W$
$a\to b$	$-$	$+$	$+$
$b\to c$	0	$+$	$+$
$c\to a$	$+$	$-$	$-$
$a\to b\to c\to a$	$+$	0	$-$

Schroeder 1.33

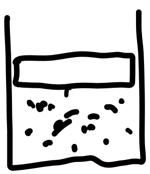
$U = \frac{f}{2} NkT$

$PV = NkT$



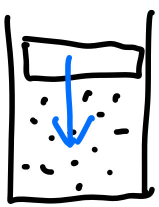
$a\to b$ $\quad W_{ab} = \int_{V_a}^{V_b} -P(V)\,dV = P_a(V_a - V_b) < 0$ $\quad V_b > V_a$, $P=\text{const} \Rightarrow (PV)_b > (PV)_a$

$\Rightarrow T_b > T_a \Rightarrow U_b > U_a$



$b\to c$ $\quad W_{bc} \int_{V_b}^{V_c} -P(V)\,dV = 0$ $\quad P_c > P_a$, $V=\text{const} \Rightarrow (PV)_c > (PV)_b \Rightarrow T_c > T_b$

$\Rightarrow U_c > U_b$



$c\to a$ $\quad W_{ca} = \int_{V_c}^{V_a} -P(V)\,dV = +(\text{area under } a\to c) = \frac{P_c - P_a}{2}(V_b - V_a) + P_a(V_b - V_a)$

$$W_{abca} = W_{ab} + W_{bc} + W_{ca} = \cancel{P_a(V_a - V_b)} + 0 + \frac{P_c - P_a}{2}(V_b - V_a) + \cancel{P_a(V_b - V_a)} = \frac{1}{2}(P_c - P_a)(V_b - V_a) > 0$$

positive work on gas

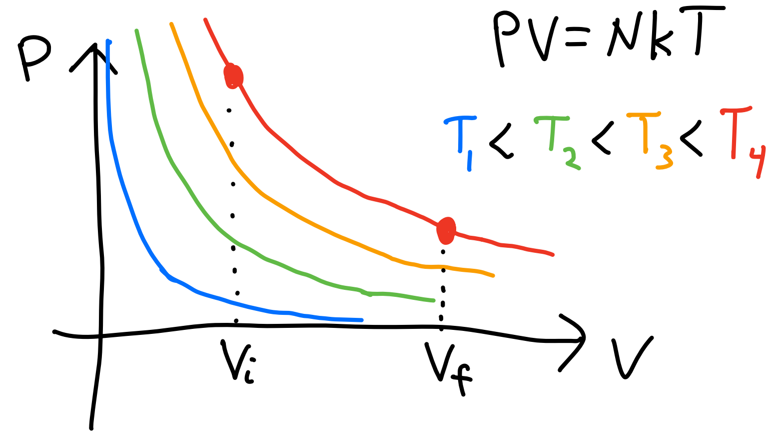
$$\Delta U_{abca} = 0 = W_{abca} + Q_{abca} \rightarrow Q_{abca} = -W_{abca} < 0$$

negative heat into gas

$\Rightarrow$ heat OUT of gas

isothermal compression/expansion
T = constant

$$
\begin{aligned}
W &= -\int_{V_i}^{V_f} P(V)\, dV \\
&= -\int_{V_i}^{V_f} \left(\frac{NkT}{V}\right)\, dV \\
&= -NkT \int_{V_i}^{V_f} \left(\frac{1}{V}\right)\, dV \\
&= -NkT\,[\ln V_f - \ln V_i] \\
&= NkT \ln \frac{V_i}{V_f}
\end{aligned}
$$



$\underbrace{\text{iso}}_{\text{same}}\underbrace{\text{therms}}_{\text{temperature}}$: PV curves of constant T

adiabatic compression/expansion
Q=0

$$dU = \frac{f}{2}Nk\,dT = -P(V)dV$$

$$\frac{f}{2}Nk\,dT = -\frac{NkT}{V}dV$$

$$\int_{T_i}^{T_f} \frac{f}{2}\frac{dT}{T} = -\int_{V_i}^{V_f} \frac{dV}{V}$$

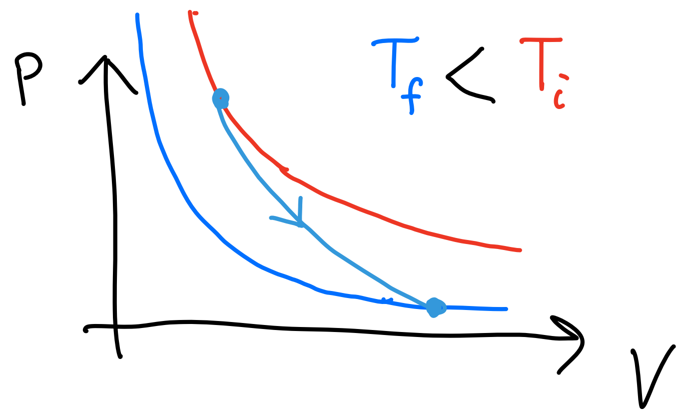
$$\frac{f}{2}\ln\frac{T_f}{T_i} = -\ln\frac{V_f}{V_i}$$

$$V_f {T_f}^{f/2} = V_i {T_i}^{f/2}$$

$$V_f\left(\frac{P_fV_f}{Nk}\right)^{f/2} = V_i\left(\frac{P_iV_i}{Nk}\right)^{f/2}$$

$$PV^{\frac{2+f}{f}} = PV^{\gamma} = constant$$

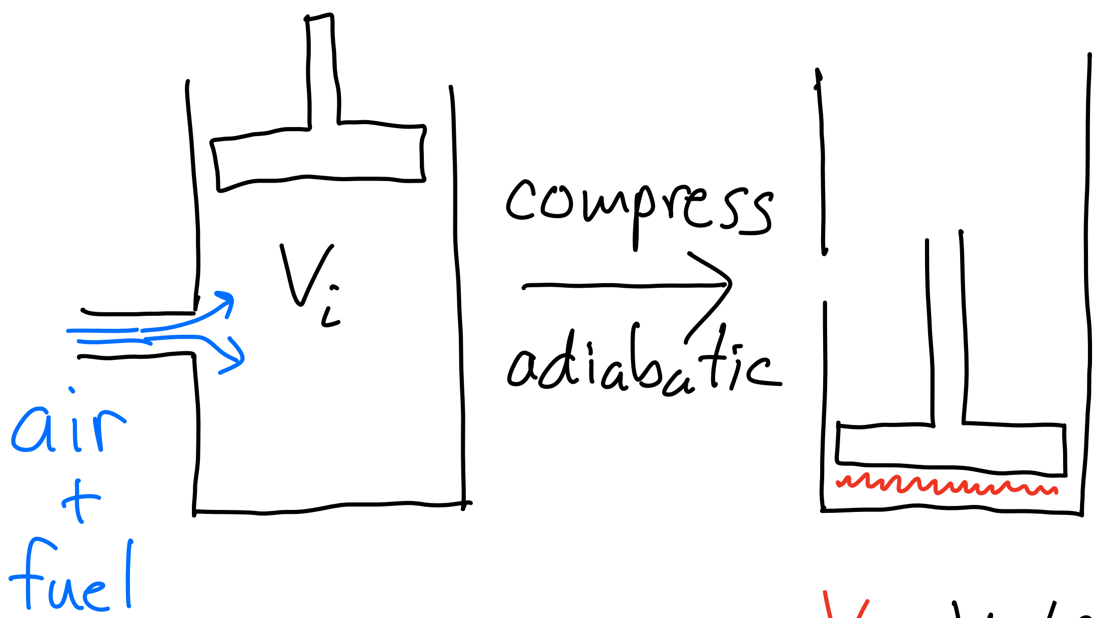
adiabatic exponent



adiabat : PV^{γ} = constant

with $Q=0$, T decreases faster than $\frac{1}{V}$ as V increases.

Diesel Engine



$$V_f = V_i / 20$$

$$V_f T_f^{f/2} = V_i T_i^{f/2}$$

$$\text{air: } f = \underbrace{3}_{\text{translation}} + \underbrace{2}_{\text{rotation}}$$

$$T_f = T_i \left(\frac{V_i}{V_f} \right)^{2/5}$$

$$= 300\,\text{K}\,(20)^{2/5}$$

$$\approx \underbrace{1000\ \text{K}}_{\text{high T ignites fuel w/o spark plug.}}$$

the piston compresses the air (with a litte diesel fuel), faster than Q can be transported, therefore it's adiabatic compression

Speed of thermodynamic processes

<u>quasistatic</u> $v \ll c_{sound}$ walls move slower than sound

<u>adiabatic</u> slow enough to be quasistatic, but fast enough that Q doesn't have time to flow (in appreciable quantity)

<u>isothermal</u> slower still – slow enough for Q to keep system in thermal equilibrium with environment.

Now just add heat

heat capacity $C \equiv \dfrac{Q}{\Delta T}$ ← heat into system to...
← change in temperature

depends on amount of stuff, so

Specific heat $c \equiv C/m$ heat capacity per mass

Really "thermal energy capacity" since Q isn't a state variable

$$C \equiv \frac{Q}{\Delta T} = \frac{\Delta U - W}{\Delta T}$$

ΔU depends on ΔT
so C is ambiguous
it depends on W

* No work, $V = \text{const}$: $C_V = \left(\dfrac{\Delta U}{\Delta T}\right)_V = \left(\dfrac{\partial U}{\partial T}\right)_V$

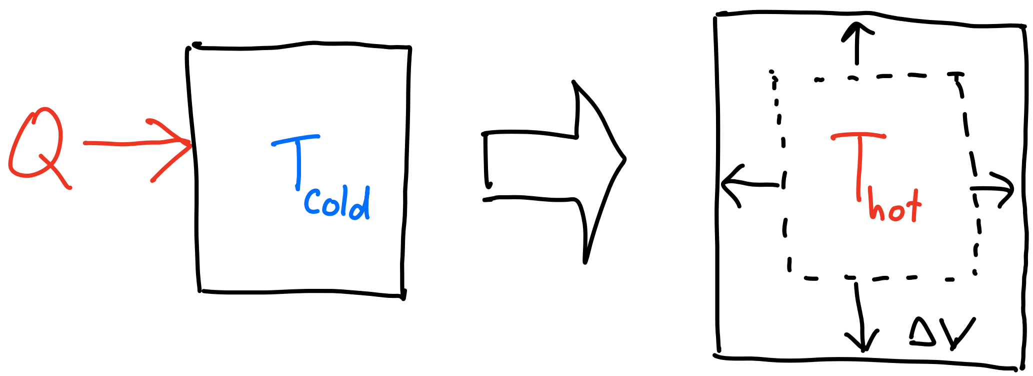
Water: $c_v = \frac{1\ \text{cal}/^\circ C}{g} = 4.186 \frac{J}{^\circ C \cdot g}$
specific heat

real materials change volume as T changes (V increases w/ T)

$\Rightarrow$ system does work on environment as T increases

$\Rightarrow$ $W < 0$

$\Rightarrow$ $Q = \Delta U - W$ is bigger & C is bigger



Q raised T, and thus U. Also had to supply W to expand

Constant pressure

$$C_p = \left(\frac{\Delta U - (-p\Delta V)}{\Delta T}\right)_p = \left(\frac{\partial U}{\partial T}\right)_p + \underbrace{p\left(\partial_T V\right)_p}_{\text{additional } Q \text{ for } W}$$

not quite the same as C_V

Suppose quadratic DoF $\quad U = \frac{f}{2}NkT$

$$C_V = \left(\partial_T U\right)_V = \partial_T\left(\underbrace{\tfrac{f}{2}}_{}NkT\right) = \frac{f}{2}Nk$$

independent of p, V so either can be fixed