Wed 18 Feb

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Plan

Otto cycle → Diesel

ST diagrams

Heat capacity of solids → Einstein model (quantized but classical)

Otto cycle

Check both $\eta = \frac{W_{out} - W_{in}}{Q_{in}} = 1 - \frac{Q_{out}}{Q_{in}}$ match

$W = -\int P\,dV = 0$ for const. volume

$Q = \int T\,dS = 0$ for adiabatic

$$\left.\begin{aligned} \therefore\ W_{out} &= -W_{34} = -\Delta\langle E\rangle_{34} = -\tfrac{3}{2}N(T_4 - T_3) \\ W_{in} &= W_{12} = \tfrac{3}{2}N(T_2 - T_1) \end{aligned}\right\} \text{same as Carnot adiabatic stages}$$

$$Q_{in} = Q_{23} = \Delta\langle E\rangle_{23} = \tfrac{3}{2}N(T_3 - T_2)$$

$$Q_{out} = -Q_{41} = -\tfrac{3}{2}N(T_1 - T_4)$$

$$\eta = \frac{T_3 - T_4 - T_2 + T_1}{T_3 - T_2} = 1 - \frac{T_4 - T_1}{T_3 - T_2} \quad \text{match} ✓$$

Adiabatic stages: $\left.\begin{aligned} V_1 T_1^{3/2} &= V_2 T_2^{3/2} \\ V_1 T_4^{3/2} &= V_2 T_3^{3/2} \end{aligned}\right\} \quad \frac{T_1}{T_4} = \frac{T_2}{T_3}$

$$\eta = 1 - \frac{T_4(\cancel{1 - T_1/T_4})}{T_3(\cancel{1 - T_2/T_3})} = 1 - \frac{T_4}{T_3} = 1 - \left(\frac{V_2}{V_1}\right)^{2/3} = 1 - \frac{1}{r^{2/3}}$$

Also $\left(\frac{V_2}{V_1}\right)^{2/3} = \frac{T_1}{T_2}$

so $\eta = 1 - \frac{T_1}{T_2} < 1 - \frac{T_1}{T_3} = \eta_c$

$T_2 < T_3$

Maximize η by increasing $r = \frac{V_1}{V_2}$

In practice $\eta \sim 20\% - 30\%$

Obstruction: large $r \to$ auto-ignition ("knock")

Diesel: Only compress air (non-combustible)

Then <u>inject</u> (diesel) fuel

η depends on both compression ratio $r = \frac{V_1}{V_2}$

and cutoff ratio $c = \frac{V_3}{V_2}$

$1 < c < r$

Can have larger $r \to$ higher $\eta \sim 40\%$

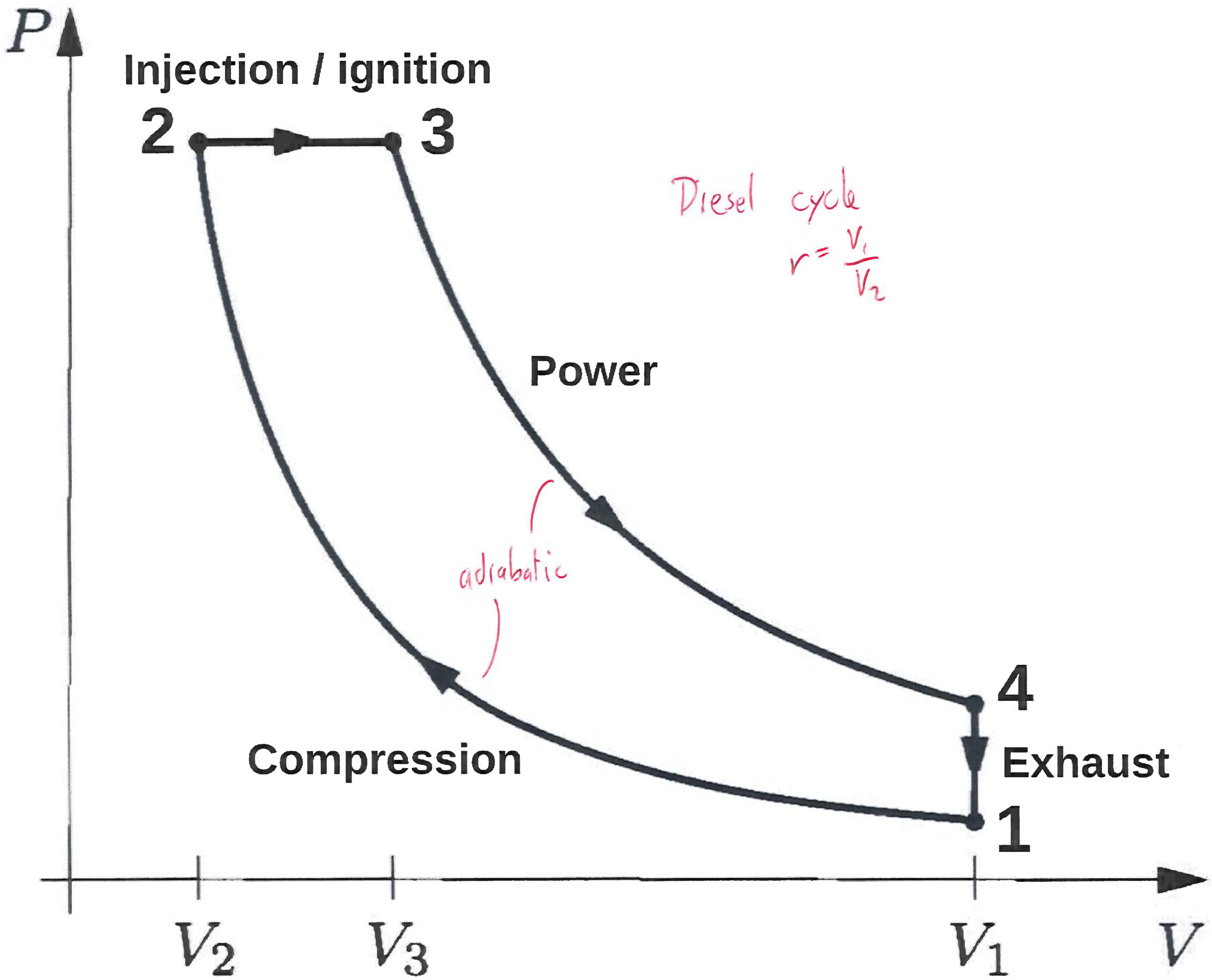
<u>ST diagrams</u>

Can swap PV for different pair

$\to$ entropy and temperature

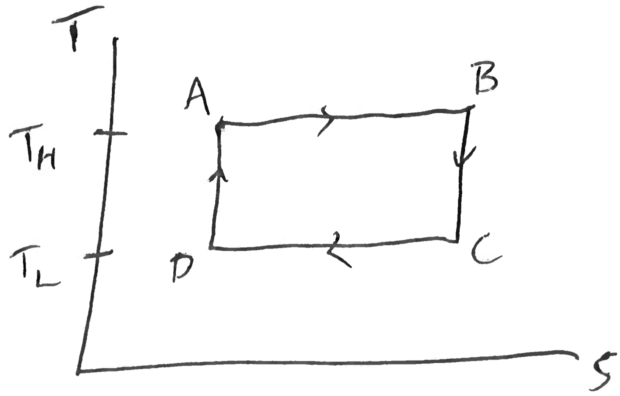
Why? Adiabat $\to$ vertical line (fixed S)

Isothermal $\to$ horizontal line (fixed T)



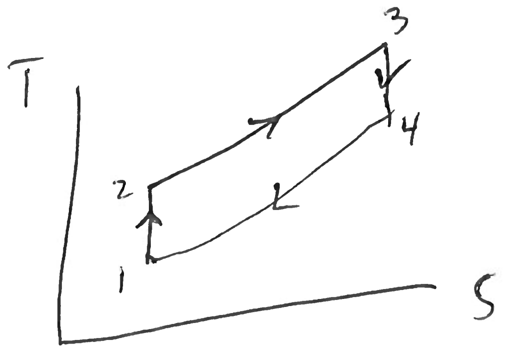
P
Injection / ignition
2
3
Power
4
Exhaust
1
Compression
adiabatic
Diesel cycle
$r = \frac{V_1}{V_2}$
V_2
V_3
V_1
V

Carnot:



Area under curve $\rightarrow \int T\, dS = Q$

Otto:



Heat capacity of solids

$C_V \rightarrow 0$ as $T \rightarrow 0$ (third law)

C_V increases to a constant for high T

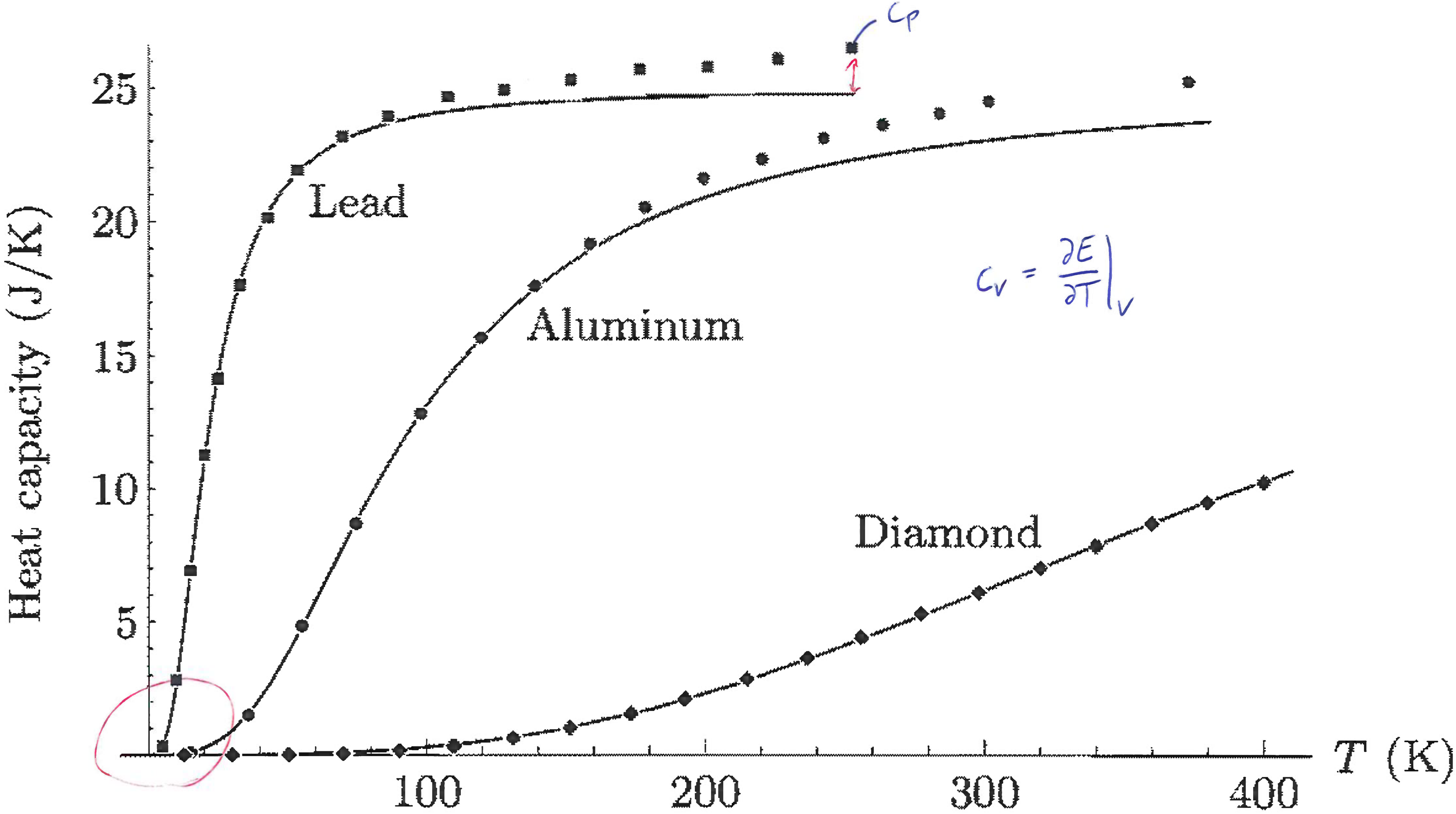
Ideal gas $C_V = \frac{\partial E}{\partial T} = \frac{\partial}{\partial T}\left(\frac{3}{2} N T\right) = \frac{3}{2} N$

What about dist'able spins? $\uparrow \downarrow \uparrow$ H

$\downarrow \uparrow \uparrow$

Better: "Einstein solid"

Atoms held in place by oscillators with discrete energy levels


Heat capacity (J/K)
25
20
15
10
5
100
200
300
400
T (K)
Lead
Aluminum
Diamond
C_p
$C_V = \frac{\partial E}{\partial T}\Big|_V$