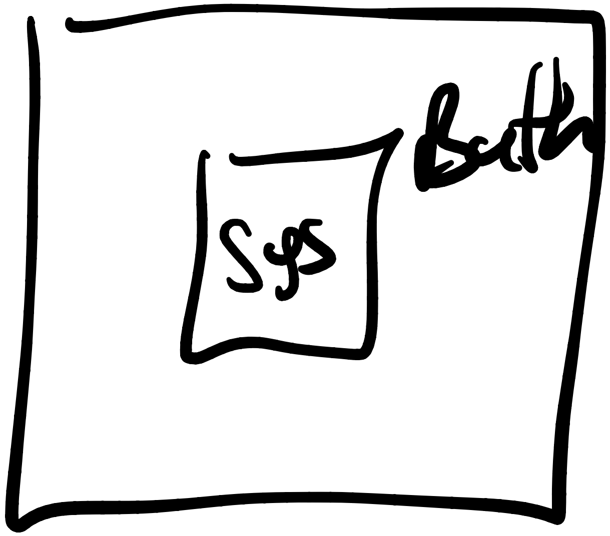
Lecture 5



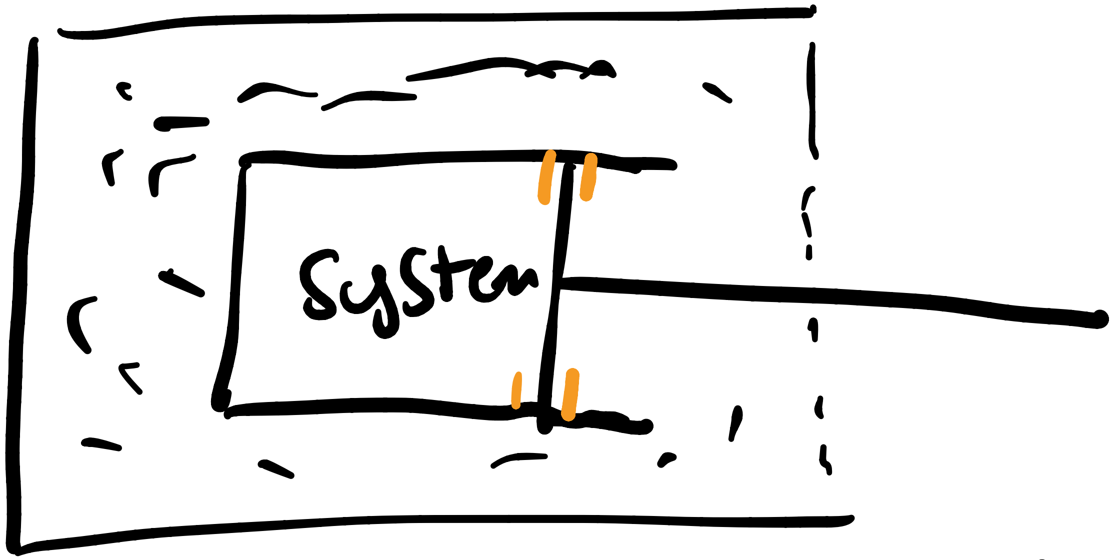
if no heat flow
$dq_{sys} = 0$

in that case, <u>State</u>

total energy

$N_{molecules}$, V_{olume}, E_{nergy}

State described by 2+# things



think about a gas...

Currently, fixed N, V, E,
with plunger, you can change V

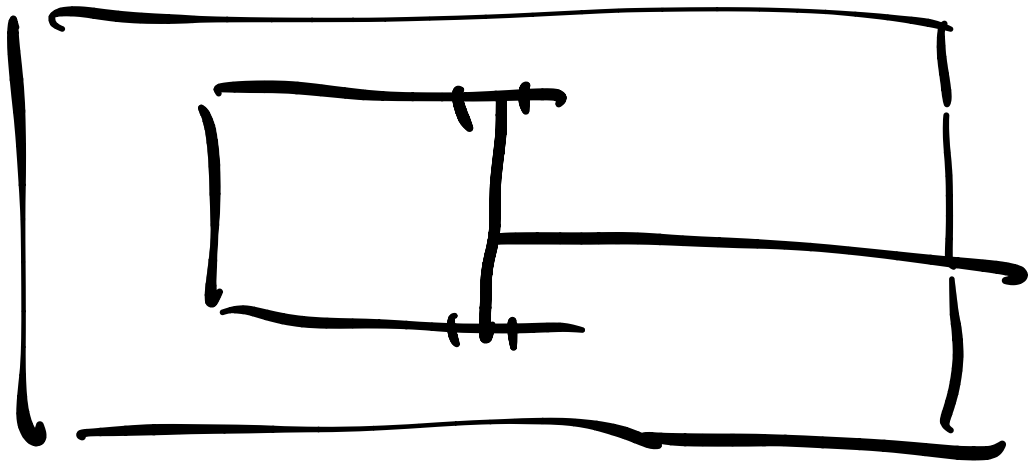
So change V

2 situations

$dq = 0$ ← expansion $T\downarrow$ $P\downarrow$

$dq \neq 0$ maybe T constant

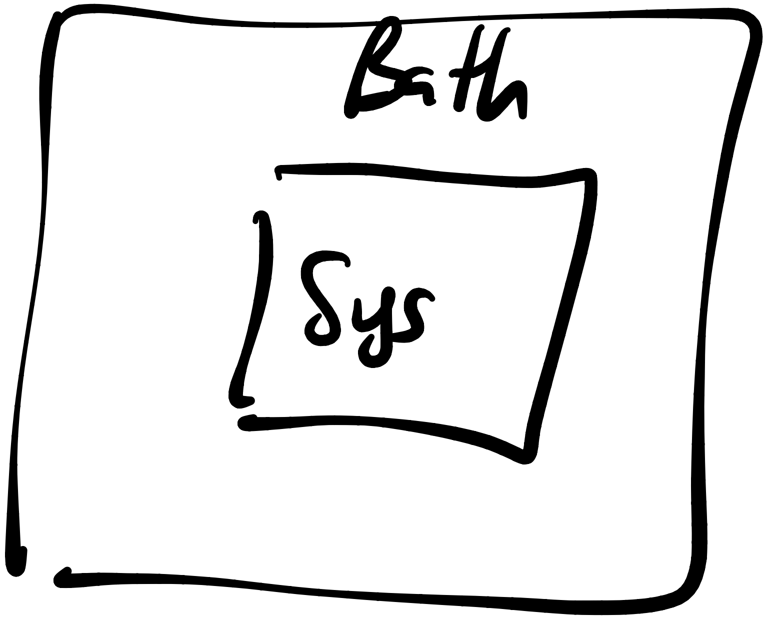
How do we change state:



Adiabatic change? so slow
every step is in equilibrium

Different from just free expansion/compression

Another example of adiabatic change



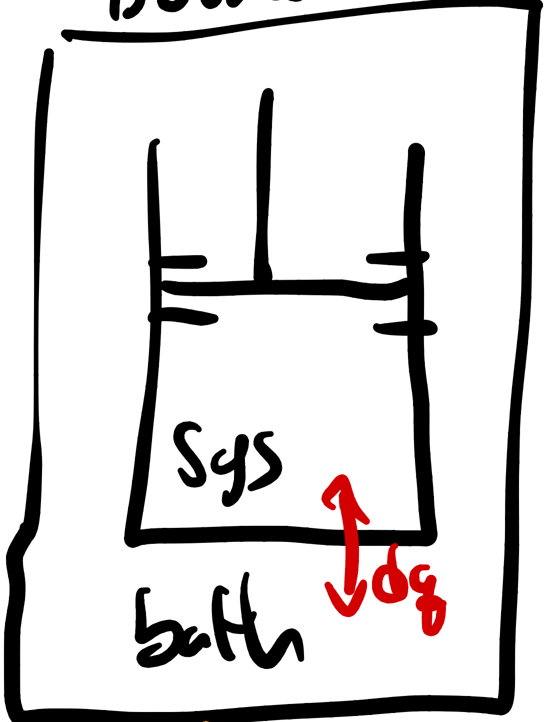
How do we get T_{sys} from $T_1 \to T_2$

Take $T_{bath} \to T_{bath} + \Delta T$

wait until $T_{sys} = T_{bath} + \Delta T$

"Reversible"

isothermal



State: N, V, T

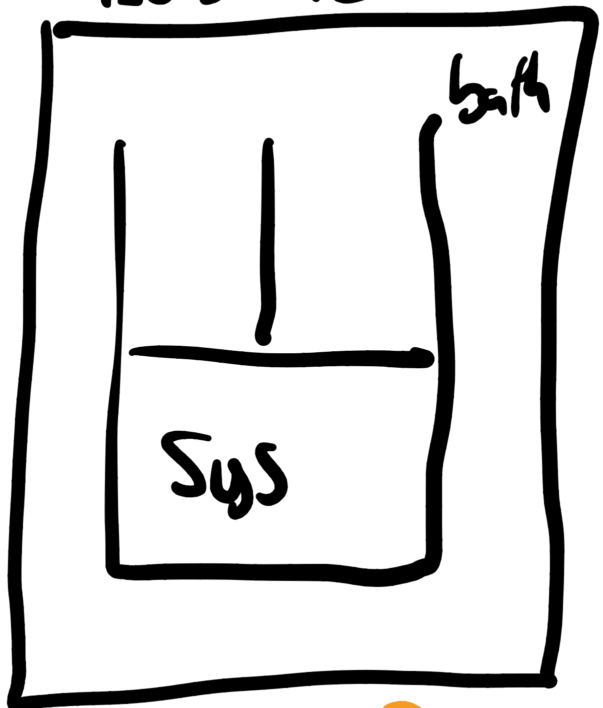
fix volume

@ Equilibrium

$T_{sys} = T_{bath}$

Heat flows until this is true

isobaric



State: N, $\underline{P}$, $\underline{T}$

@ equilibrium

Volume system changes until

$P_{sys} = P_{bath}$

open

State: μ, V, T

(μ, P, T)

@ eq

MC's flow until

$\mu_{sys} = \mu_{bath}$

Quantities can be intensive or extensive

Extensive - depends on size of the system

Examples - N, V, $\mathcal{E}_{total}$

Intensive examples don't depend on size

P, T, μ, $\frac{\mathcal{E}}{N}$, $\underbrace{\frac{V}{N}}_{1/\rho}$, ρ

Equation of state

Relationship between thermodynamic variables at equilibrium

Only need 3 things to describe state

Ideal gas law:

$$\underline{P}\,\underline{V} = \underline{n} R \underline{T} = \underline{N} k_B \underline{T}$$

$$P(N,V,T) = N k_B T / V$$

$$V(N,P,T) = N k_B T / P$$

E.O.S. examples

First law of thermodynamics

Energy conservation

For isolated system (incl. entire universe)

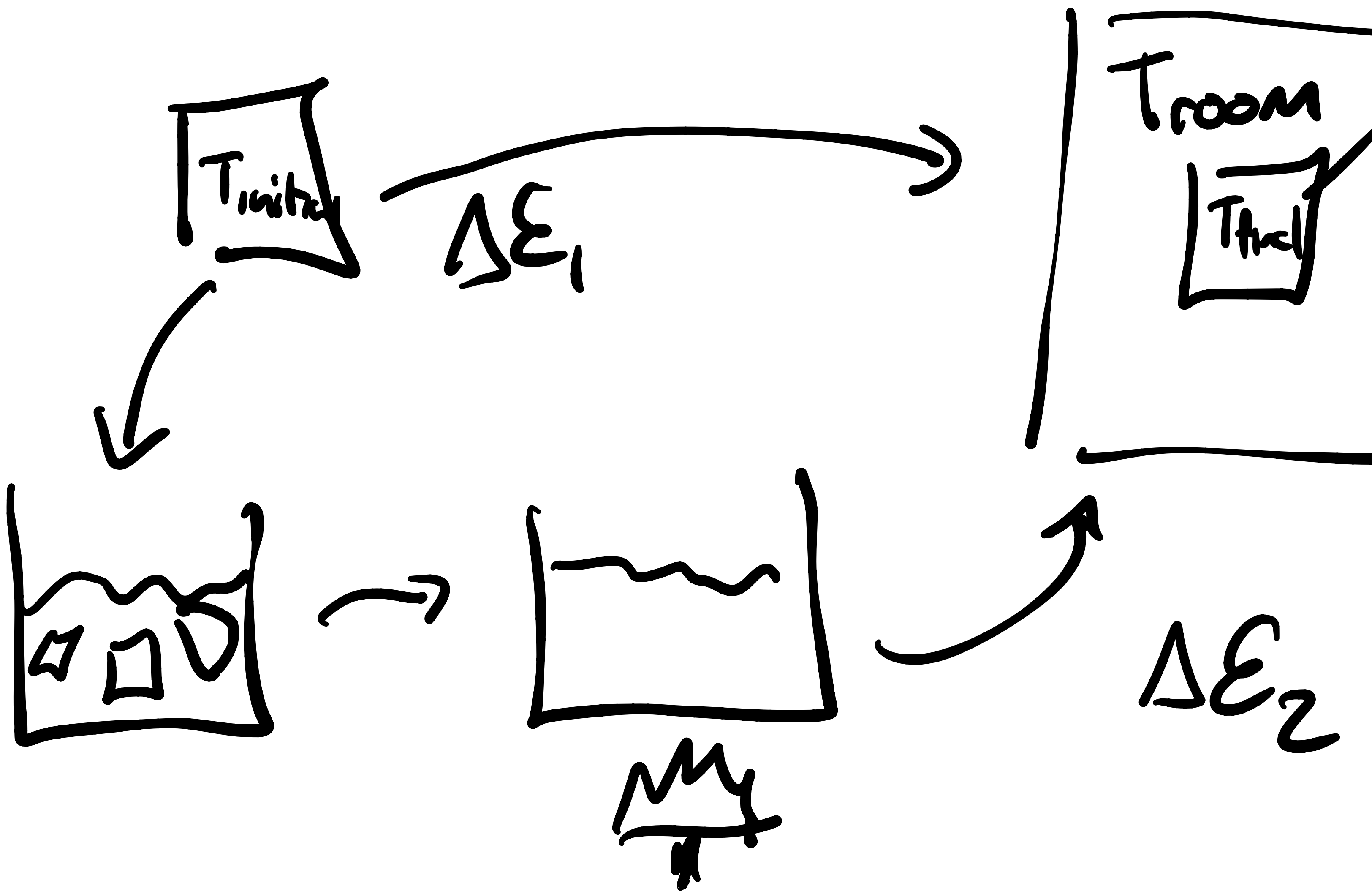
Energy total is constant

For not isolated system

$$\underset{\text{change in } E}{dE} = \underset{\text{change heat}}{đq} + \underset{\text{change in work}}{đw}$$

Energy is a <u>state</u> <u>function</u>

doesn't matter how you get to the current state



$\Delta E_1 = \Delta E_2$

$đq_1 \neq đq_2$

$đw_1 \neq đw_2$

sign of $đq$, $đw$ is a choice

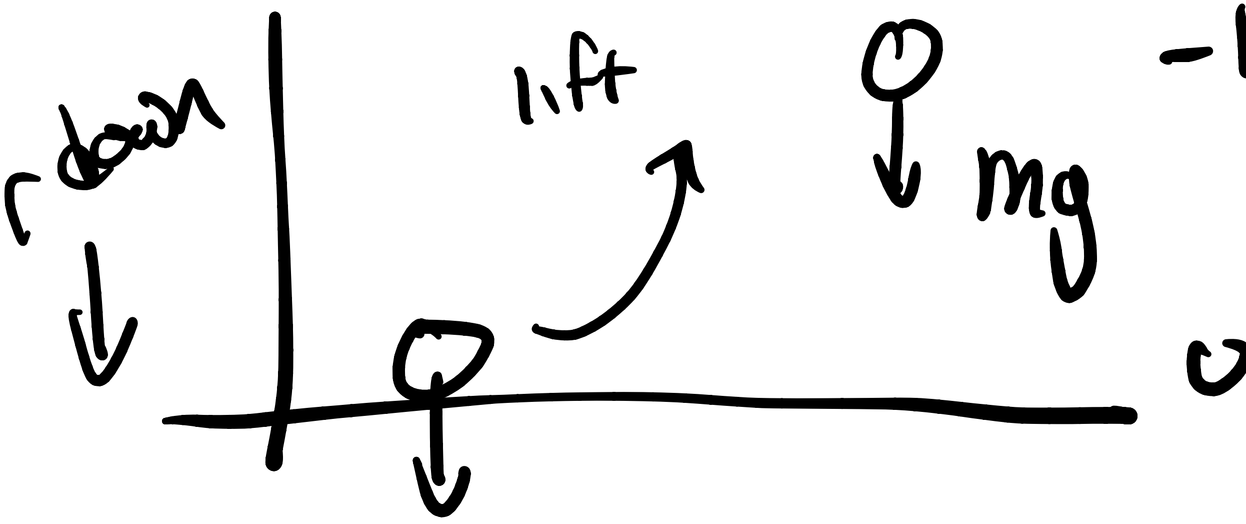
↳ $đq > 0$ heat in to system

$đw > 0$ work is done on system

What is work?

adding up force · distance for a lot of small changes

$$w = -\int \vec{F} \cdot \vec{dr}$$



$$F = ma$$

$$P = \frac{F}{A}$$

$$w = -\int_0^{-h} F\,dr$$

$$= Fh = mgh = \varepsilon_{final}$$

Here: $dw = -P_{bath}^{(external)}\,dV$

(work positive when $dV < 0$)

4 ways you can do work to change state

1. constant pressure $dP = 0$
2. constant volume $dU = 0$
3. constant temperature $dT = 0$
4. adiabatically $(dq = 0)$

will use an ideal gas to analyze these situations

Talked about work

What is "heat"? ← not a property of the system

Heat is amount of energy that flows as a result of difference in temperature

$$dq = C\,dT$$

heat capacity
specific heat

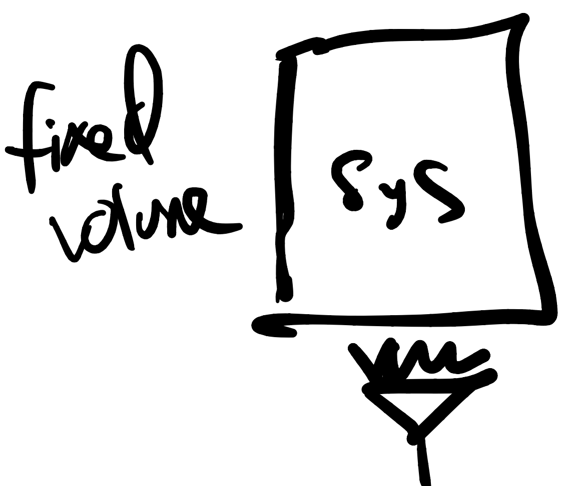
↑ response/sensitivity coefficient

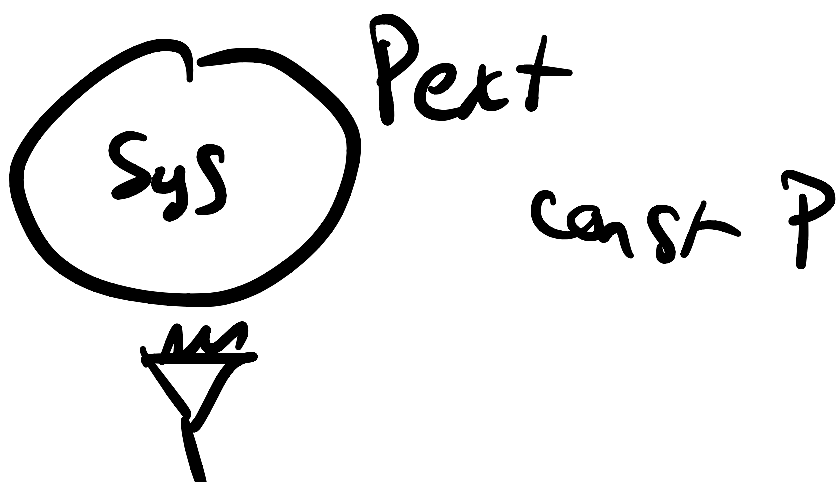
C – how much energy can a system store

2 specific heats ↙ which has more heat flow for same ΔT ?

$$C_V = \left(\partial q/\partial T\right)_V \qquad C_p = \left(\partial q/\partial T\right)_p$$

is $C_V > C_p$, $C_V = C_p$, $C_p < C_V$





$C(T)$ ← can depend on temperature

suppose it's constant for some range of Ts

How much heat does it take to change temp

$$dq = C\,dT$$

$$q = \int_{T_i}^{T_f} C\,dT = C(T_f - T_i)$$

$$= nC\Delta T$$