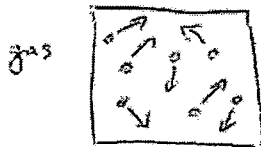


LAST WEEK:



Average microscopic properties:

NO. DENSITY: $\frac{N}{V}$

AVG. TRANSLATIONAL KINETIC ENERGY $E^{\text{avg}} = \frac{1}{2} m \langle v^2 \rangle_{\text{avg}}$

Macroscopic properties

Temperature: $T = \frac{2}{3k_B} E^{\text{avg}}$

Pressure: $P = \frac{2}{3} \left(\frac{N}{V} \right) E^{\text{avg}}$

determine
→

direct consequence: $PV = Nk_B T$

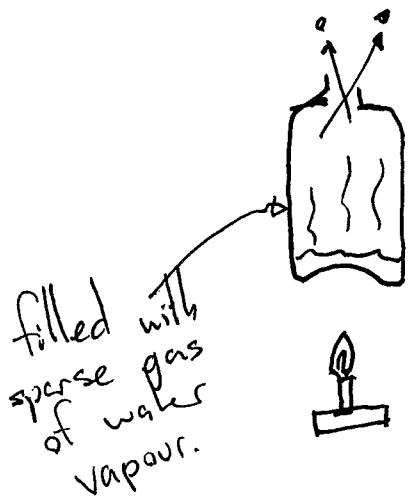
OR $PV = nRT$

IDEAL GAS LAW

N : # molecules
in # moles

- THERMODYNAMICS:
- define macroscopic variables to characterize complicated systems.
 - understand how these are related to microscopic physics
 - determine relations between microscopic variables that follow from micro-physics

Can Crushing Demo:

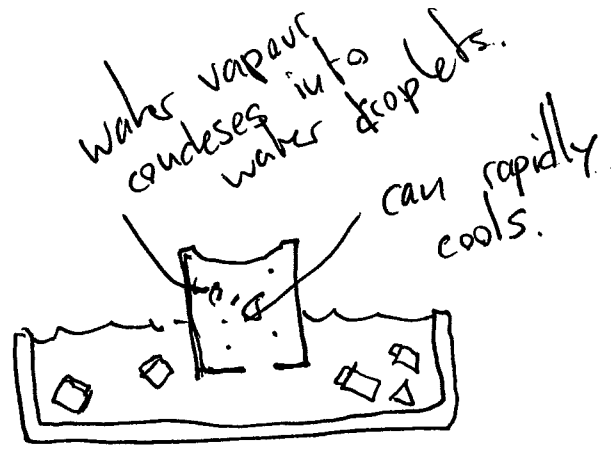


① Boiling water causes energetic molecules to replace the air. The air gets pushed out of the can.

$$PV = nRT \leftarrow \text{increases!}$$

these stay the same ↑ this must decrease

② Turning the can over into the water means that # molecules stays constant. The temperature drops and the pressure inside drops.

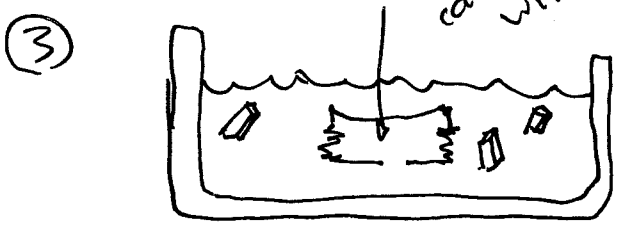


$$PV = nRT$$

constant ↓ these drop.

can is crushed inside as pressure inside can wants to equilibrate with pressure outside can.

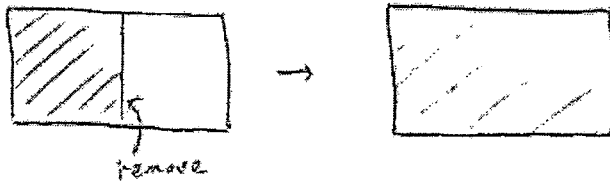
At some point pressure wants to equilibrate. The temp of the system is about const.



$$PV = nRT$$

goes up ↓ decreases. const

Exercise:



Ideal gas: no temperature change
(energy conservation)
Real gas: temperature goes down.

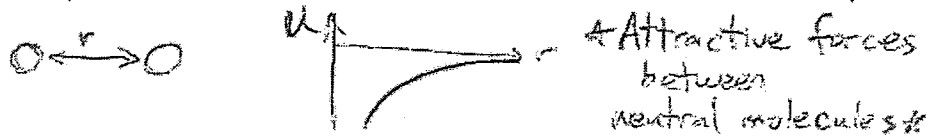
Q: Why?

energy cons \Rightarrow total energy unchanged

temp \downarrow \Rightarrow kinetic energy decreases

energy must go to potential energy

- more potential energy to have molecules further apart.

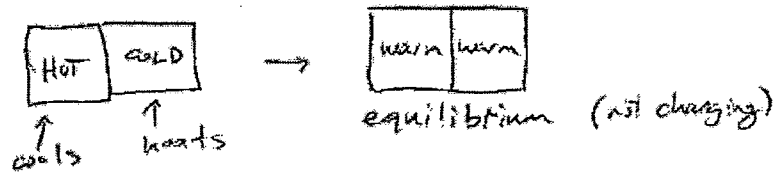


Responsible for formation of liquids/solids at low T.

Aside: how is temperature defined macroscopically?

- way to quantify how hot or cold something is.

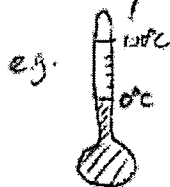
- observation:



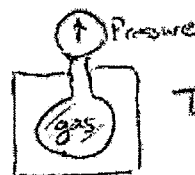
- if $A+B$ in equilibrium & $A+C$ in equilibrium, then $B+C$ in equilibrium.

- crucial property: ^{can define} temperature ^{to be} same for any two systems in equilibrium.

- use a reference system that changes in a quantifiable way as it is heated to define a temperature scale



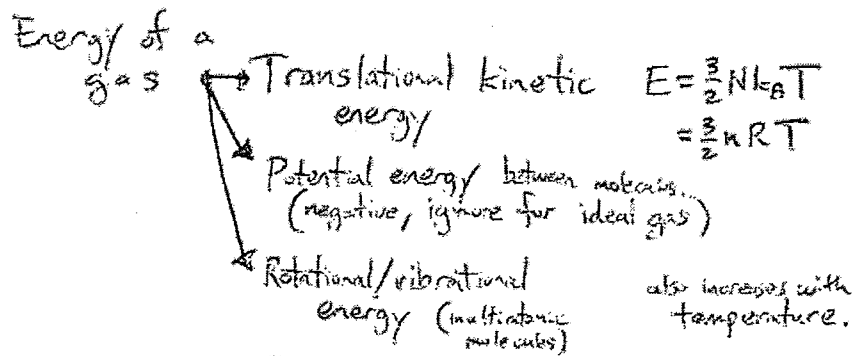
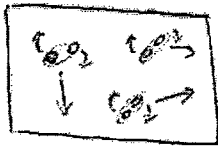
or



$$T = 273.16 \text{ K} \cdot \frac{P}{P_0}$$

\uparrow
611.3 Pa

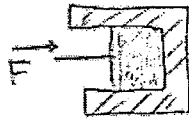
WHERE IS THE ENERGY STORED?



Can change energy by

① HEATING: define HEAT Q : energy entering gas via non-mechanical process
(-ve Q if energy goes out)

② WORK: define W = work done ON gas
 \nearrow +ve compression
 \searrow -ve expansion



$$\begin{aligned} W &= F \Delta x \\ &= P \times (\text{Area of piston}) \times \Delta x \\ &= -P \Delta V \end{aligned}$$

Energy conservation: $\Delta E = Q + W$

1ST LAW OF THERMODYNAMICS

clicker

Ideal monatomic gas:

- added energy goes to translational kinetic energy

$$\Delta E = \frac{3}{2} n R \Delta T$$

Generally: part of energy goes to rotations, vibrations. Define c_v by

$$\Delta E = n c_v \Delta T \quad (\text{for small } \Delta T)$$

examples: ① constant volume

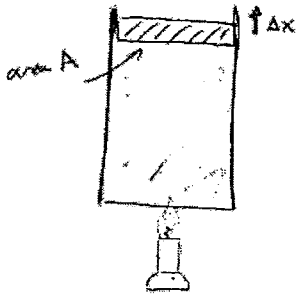


$W = 0$ so $\Delta E = Q$
for temperature increase ΔT
require $Q = \Delta E = nC_v \Delta T$

Ideal gas Law \Rightarrow Pressure \propto Temperature.

$\frac{P}{T}$ stays constant

② constant pressure:



Ideal gas law \Rightarrow $\frac{\text{Volume}}{\text{Temperature}}$ stays constant.

- gas expands as it is heated.

$$W = - \underbrace{P \cdot A}_{\text{force}} \cdot \Delta x$$

$$W = - P \Delta V$$

Work done on gas
for fixed pressure.

Heat required to increase temp. by ΔT :

have: $\Delta E = nC_v \Delta T$

$$W = -P\Delta V = -nR\Delta T$$

$$Q = \Delta E - W = nC_v \Delta T + nR\Delta T$$

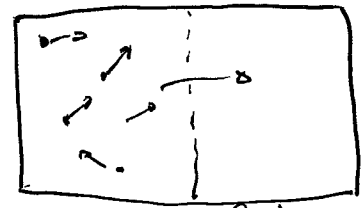
$$= n(C_v + R)\Delta T$$

defined to be C_p

More heat required to increase T at constant
pressure than constant volume

③ constant temperature.

$$\Delta E = n C_v \Delta T = 0$$



gas freely expands.

from ideal gas law

$$PV = nRT$$

stays constant

$$P_1 V_1 = P_2 V_2$$

The change in heat is given by the work

$$Q + W = 0$$

$$\Rightarrow Q = -W$$

$$\begin{aligned} W &= \int_{V_1}^{V_2} P dV \\ &= \int_{V_1}^{V_2} \frac{nRT}{V} dV \\ &= nRT \ln\left(\frac{V_2}{V_1}\right) \end{aligned}$$

④ Adiabatic process:

$$Q = 0$$

$$\Rightarrow \Delta E = W.$$

This occurs in well insulated systems, or for rapidly changing systems where heat doesn't have time to be exchanged.

$$\frac{PV}{T} \text{ is constant.}$$