Lecture 2 1/18/2011

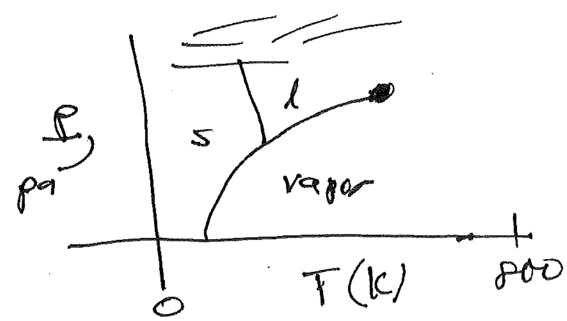
Please ask questions

Office hours on Wed: 2–3:15 } ask about homework material
5–6 pm

Read chapters ahead of time

Demo of phase transition: Na acetate heat pack
liquid → solid + heat
why metal disk needed?

slide on phase transitions for H_2O



note: degrees Celsius °C
but kelvin K no degree symbol
lower case upper case

room temp?
atm pressure
body temp?
boiling point of water?

Interesting Transitions

chemical soup → life — as # chemicals in soup increases?

cells → plants, animals — why so long? why did dinosaurs never develop tech?

neurons → brains — ~~cos~~ consciousness a phase transition as N increases?

computers → networks, Internet

Phase transitions help explain why thermal physics so interesting: <u>emergent behavior</u> rather than reductionism

Also means diff. approach: develop idealized conceptual models rather than solve exact fundamental equations

Back to "state" of physical system

key concept, tells you how much you need to know about a system.

mechanics: N particles require $6N$ #s.

electrodynamics: $\vec{E}(t_0,\vec{x})$, $\vec{B}(t_0,\vec{x})$ currents, charges, bcs

QM: $\psi(t_0,(\vec{x}_1,\vec{\sigma}_1),(\vec{x}_2,\vec{\sigma}_2)\cdots,\vec{x}_N,\vec{\sigma}_N))$

$\boxed{\text{Star Trek Slide}}$: inability to measure state of macroscopic object explains why teleportation unlikely: how to identify $\vec{x},\vec{v},|\psi\rangle$ for each atom? also need high-E photons to locate small objects, cause damage to bonds

State of equilibrium macroscopic system:
three numbers, e.g. E, T, N
V, T, N
S, V, N

Extraordinary simplification!!

Reason is subtle, consequence of conservation laws and statistical average, just accept for now.

Not true for glass, granular media.

Criteria for thermodynamic Equilibrium

- need macroscopic object of many pieces, concept doesn't apply to atom, molecule, photon
- ~~temp~~ time independent up to rigid rotation, rigid translation
- temp T constant and uniform everywhere (how to test this?)
- pressure P constant everywhere, unless external $\vec{E}$ or $\vec{G}$ field

} from maximi of entropy

- no relative motion
- properties independent of history of object
  technically wood not in equil
  but quantum tunneling implies everything is liquid over cosmological times

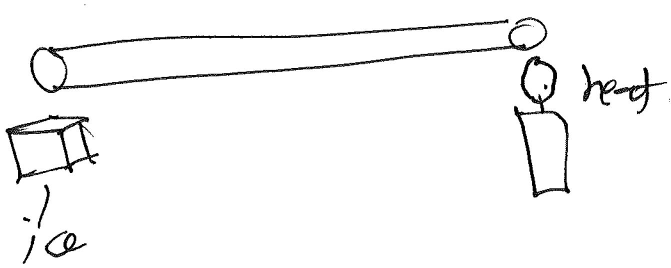
most of universe not in equil! Earth, stars, universe itself (space expands)

Discussion Question:

give example of nonequil. system that is

time indep.
motionless
pressure same everywhere?

answer: metal bar with one end hot, one end cold



slide of convection system, a spiral defect chaos state

consider static room, hot floor, cold ceiling...

Now begin Schroeder.

Where we are heading

Chapter 1: equilibrium
relaxation time
temperature via ideal gas
elementary kinetic theory
1st law of thermodynamics
heat capacity C

Chapter 2: entropy by counting states
ideal gas
Einstein solid (vibrations)
paramagnet
why spontaneous behavior

Chapter 3: temperature in terms of entropy
paramagnet: full properties
chemical potential

then → Chaps 6,7 back to 5 to finish

<u>Relaxation time</u>: how long to wait for equil. to be attained.

There are <u>multiple</u> relaxation times

- temperature diff $\Rightarrow$ thermal relaxation time
- pressure diff $\Rightarrow$ mechanical relaxation time
- conc. diff $\Rightarrow$ particle relaxation time
- non-uniform velocity $\Rightarrow$ viscous relaxation time

Key insight: all these times scale as L^2 where L is size of system.

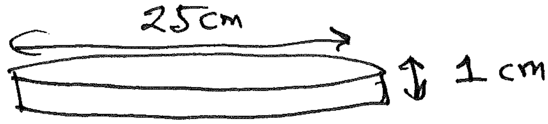
$$\tau \sim \frac{L^2}{C}$$

$C \leftarrow$ dissipation constant units m^2/s

thermal diffusivity $K \sim 2\cdot 10^{-5}\, m^2/s$ air
$2\cdot 10^{-7}\, m^2/s$ water

diffusion $D \sim 10^{-9} \frac{m^2}{s}$

Examples:



Petri dish filled with chemicals, how long to equilibrate?

minimum time scale is $\frac{L^2}{D}$

longest minimum time scale determined by broadest dimension

$$\tau \simeq \frac{\left(25\,\text{cm} \cdot 10^{-2}\,\text{m/cm}\right)^2}{\left(10^{-9}\,\frac{\text{m}^2}{\text{s}}\right)}$$

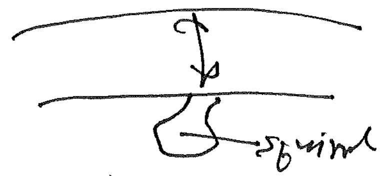
need to stir to mix

$10^6\,\text{s} \simeq 12$ days

$\simeq$ 1 year

Frostline:

K for rock $\simeq 10^{-6}\,\frac{\text{m}^2}{\text{s}}$



dig tunnel 2 m deep

$$\tau \simeq \frac{(2\,\text{m})^2}{10^{-6}\,\frac{\text{m}^2}{\text{s}}} \simeq 40 \text{ days}, \simeq 1.5 \text{ months}$$