Mon. Aug. 27

- Let's think about a simple experiment
- We will add known quantities of heat, Q, to a solid object, then measure the change in temp. ΔT
- if we add Q_0 to the solid + measure ΔT, intuitively what would we measure if we added $2Q_0$?
- we expect there to be a constant of proportionality between Q + ΔT

$$\frac{Q}{\Delta T} \simeq \text{constant}$$

- We call $\frac{Q}{\Delta T}$ → "heat capacity" of the object (C)
- More generally,

$$\left(\frac{\partial Q}{\partial T}\right)_V = \left(\frac{\partial U}{\partial T}\right)_V = C_V$$

U → internal energy
V → const. volume

$$C_P - C_V = \frac{VT\alpha^2}{\beta_T}$$

$\alpha \equiv$ coef. of thermal exp.
α small for solids

- from the early 1800's, it was known

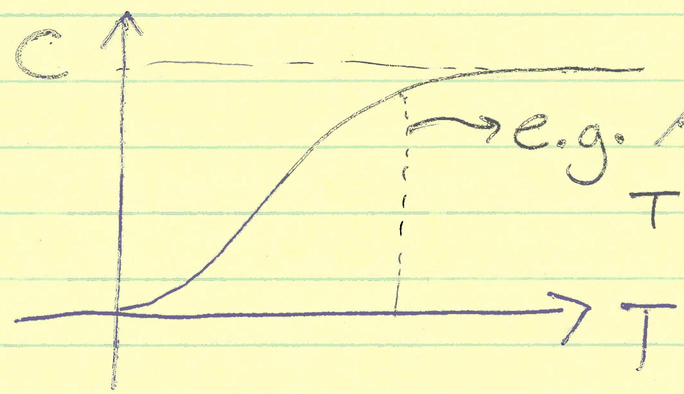
$$C = 3k_B \text{ per atom (for solids)}$$

$\rightarrow$ compare $C_V = \frac{3}{2}k_B T$ for gas

$k_B \equiv$ Boltzmann's constant

- this linearity agrees with our intuition
- However, we actually find something like:

$C \rightarrow C(T)$



$\rightarrow$ e.g. Ag gives $T \sim 120K$ $(\approx -150\,°C)$

- for "everyday" temperatures, C is effectively constant (+ most materials)
- for low temps., our intuition breaks down
- the solution was not discovered until 1907 by Einstein
- let's stop + think about the time period

- physics might seem primitive by today's standards, but it wasn't
- by this time we had EM waves, X-rays, radioactivity, Stat. mech., and special relativity (to name a few)
- with these advances, one might believe physicists would have figured out how an object heats up
- all things considered, this is a rather bland experiment, but we could not describe it (could be embarrassing)
- I see this as a bit of a need to get our house in order
- the solution to this problem will expose some deep secrets of physics + will help usher in a new area of science

→

- this class is solid state physics
- a branch of condensed matter physics which is the largest branch of physics
- this might not be surprising considering most objects we deal with on an everyday basis are solids
- it is remarkable that we have theories for solids since there are so many interacting parts coming together to make the macroscale object
- applications: semi-conductor industry which completely revolutionized electronics
- importantly, it is the physics of real systems & we combine many areas of physics into one: stat. mech., EM, quantum, etc.
- we get to see these theories in action to discover material properties
- discussion of syllabus & class structure (see syllabus)

- Recall the "partition function" Z, which encodes information about the thermodynamic variables of a system (equilibrium)

- For a classical system

$$Z = \frac{1}{h^3}\iint e^{-\beta H(q,p)}\, d^3q\, d^3p$$

$H \equiv$ Hamiltonian, $\beta \equiv 1/k_BT$, $h \equiv$ Plank's const.

$q \equiv$ position, $p \equiv$ momentum

- if we wanted to find the "internal energy" U of our solid, we assume this energy is held in the vibrations of the atoms

- classically, 3D simple harmonic oscillator spring const., k + mass, m

$$H = \frac{\vec{p}^{\,2}}{2m} + \frac{k}{2}\vec{x}^{\,2}$$

- if we can solve for Z, we can get U

- details of this calculation will be an assignment, but to get started

$$U = -\frac{1}{Z}\frac{\partial Z}{\partial \beta} = 3k_B T$$

$$\frac{\partial U}{\partial T} = C = 3k_B \quad \text{(Dulong-Petit law)}$$

• ind. of material

- solve for Z (first)

- our calculated partition function is for classical HO's in the solid

- We know from quantum that the energy eigenstates for the quantum harmonic oscillator

$$E_n = \hbar\omega(n + 1/2)$$

- recall $n = 0 \rightarrow$ ground state

- partition function for discrete energy levels

$$Z_{1D} = \sum_{n \geq 0} e^{-\beta\hbar\omega(n + 1/2)}$$