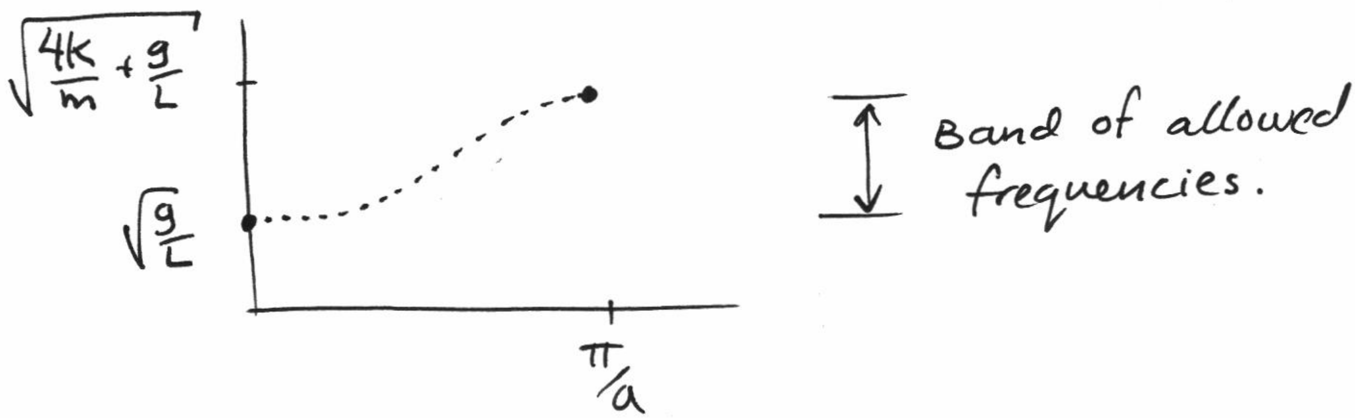
Discuss the forbidden freqs of the coupled pendulum system.

From HW #2

$$\omega = \sqrt{\frac{4K}{m}\sin^2\frac{ka}{2} + \frac{g}{L}}$$

Check limits $k=0$, $k=\pi/a$



Using the billiard ball demo:

Move the 8 ball very slowly $\left(\omega < \sqrt{\frac{g}{L}}\right)$

Move the 8 ball very fast $\left(\omega > \sqrt{\frac{4K}{m}+\frac{g}{L}}\right)$

Last time $\langle n_k \rangle = \dfrac{1}{e^{\hbar\omega_k/k_BT} - 1}$

Examples of exam questions:

- How many phonons occupy the highest freq mode of a diamond? (Approximation question)
- At what temperature does the highest freq mode of a diamond have $\langle n_k \rangle < 1/2$
  (Approx question)
- Show that $\langle n_k \rangle$ increases linearly with T for $k_BT \gg \hbar\omega_k$.
- How fast does a phonon move through a material if $\omega_k \ll \omega_{Debye}$?
  (Approximation question)

FINAL REMARKS ABOUT PHONONS

* Relationship to Noether's Thm:

  Once a phonon wave packet is launched in a "perfect crystal" it travels all the way across the crystal.

  The quantity $\hbar k$ is called the phonon momentum.

  The phonon momentum is conserved.

* In real systems, phonons are always being created and destroyed, keeping the system in thermal eqb such that

$$\langle n_k \rangle = \frac{1}{e^{\hbar\omega_k/k_BT} - 1}$$ for all modes.

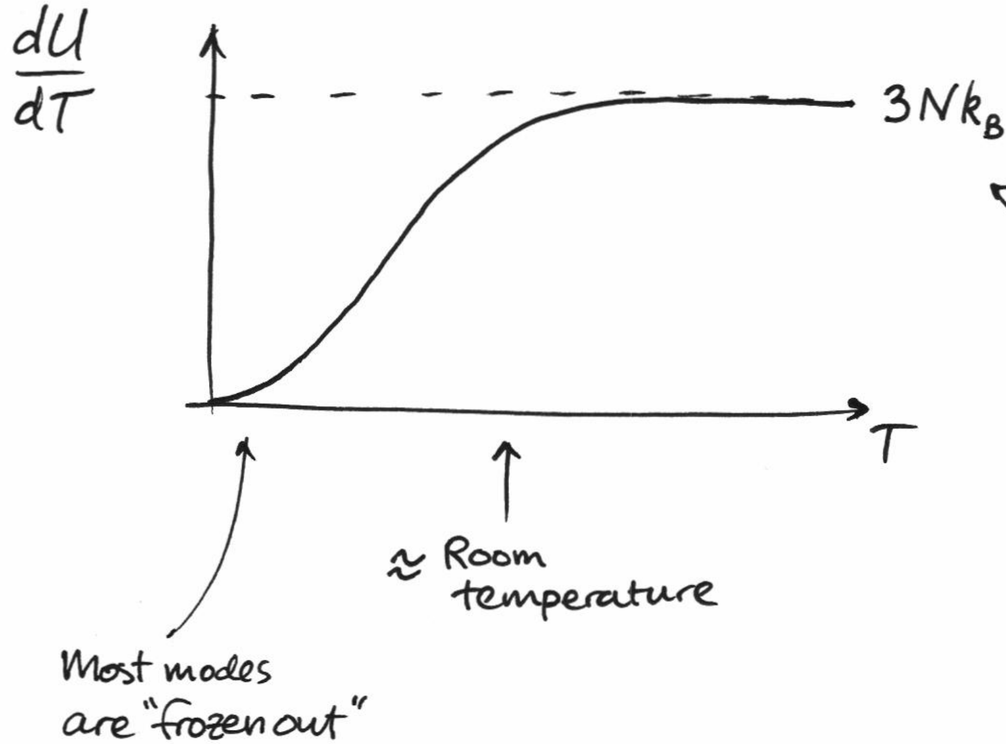
* SUMMARY OF LATTICE HEAT CAPACITY

Correct model for lattice vibrational energy

$$U(T) = \sum_{\text{all } k} \hbar\omega_k \left(n_k + \tfrac{1}{2}\right)$$

depends on T

Heat capacity (if we neglect small changes in ω_k as a function of temperature)



classical prediction of equipartition thm.

Every mode stores energy k_BT.