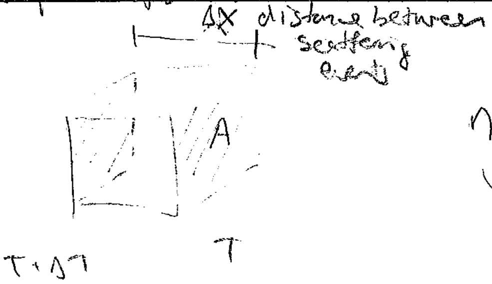
day 20 pg 1.



$n = \dfrac{\#\text{ phonons}}{\text{volume}}$ (like n for electrons)

poor label, but what [illegible]

$n v_x = \dfrac{\#}{\text{vol}} \cdot \dfrac{\text{[illegible]}}{\text{time}} \quad \dfrac{\#\text{ phonons}}{\text{area} \times \text{time}} = \text{"phonon flux"}$

Energy transport $\tilde{C}_V =$ heat cap. [illegible] for single phonon $= \dfrac{C_V}{N}$

ie. $Q = \tilde{C}_V \, \Delta T$

$$j_u = \frac{\text{energy lost from box}}{\text{area} \times \text{time}} = -\Big(\underbrace{n v_x}_{\frac{\#\text{ photons}}{\text{area time}}}\Big)\Big(\underbrace{\tilde{C}_V \Delta T}_{\frac{\text{energy}}{\text{phonon}}}\Big)$$

j_u energy flux

Also: $\Delta T =$ gradient $\times \Delta X$
$\frac{dT}{dx}$

$$\Delta T = \frac{dT}{dx} \cdot (v_x \tau)$$

$$j_u = -n v_x \tilde{C}_V \tau \frac{dT}{dx}$$

$$= -\frac{1}{3} n v^2 \tilde{C} \tau \frac{dT}{dx}$$

$v\tau = \ell$ mean free path

$n \tilde{C}_V = \dfrac{\text{phonons}}{\text{volume}} \cdot \dfrac{\text{heat cap}}{\text{phonon}}$

$= C = \dfrac{\text{heat cap}}{\text{volume}}$ ie $Q = VC\Delta T$

$$j_u = -\frac{1}{3} C v \ell \frac{dT}{dx}$$

compare w/ previous page, means that

$$\boxed{K_{\text{thermal}} = \frac{1}{3} C v \ell}$$

Table 2 pg 122 some representative values of C, K, and ℓ (for $v = 5000$ m/s as typical velocity)

What contributes to scattering?

- defects / surface → sidenote: in diamond, l is limited by isotopes, which seem to be "defects" to the phonons "isotope effect"
- electrons
- other phonons
- ...

Case 1: low temp, recall $C \sim T^3$

• not many other phonons present, l is limited by defects/surface, Expect l independent of temp

Then $K = \frac{1}{3} C v \underbrace{l}_{\text{const}}$

$K \sim C$

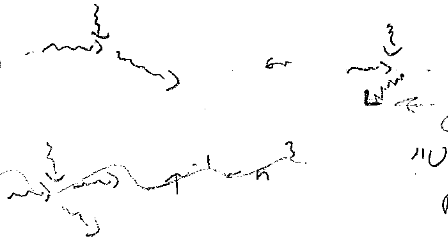
expect $\underline{K \sim T^3}$

seen in Fig 18, 19 pg 127 NaFl, Ge

Case 2 high temp, recall $C \sim$ const. But l is no longer const.

phonon-phonon scattering $l^{-1} \sim n^2$ (prob. of 2 phonons)

(3 phonon event) or



G

(4 phonon)

"Umklapp processes"

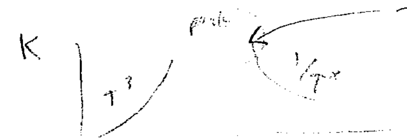
$$n = \frac{1}{e^{\hbar\omega/kT} - 1}$$

↳ if T is high, this is small

$$= \frac{1}{\cancel{1} + \frac{\hbar\omega}{kT} \cancel{-1}} = \frac{kT}{\hbar\omega}$$

$l \sim \frac{1}{T^x}$; $x \simeq 2$, possibly down to 1

$K = \frac{1}{3} C v l \Rightarrow K \sim \frac{1}{T^x}$



Again, seen in Fig 18, 19 pg 127

Not quite "high" → then Boltzmann factor governs how many phonons have high enough energy

$n \sim e^{-\text{const}/T}$ $K \sim l \sim \frac{1}{n^2} \sim e^{\text{const}/T}$ see here

Chapter 6 Electrons!

plan of attack

Ch 6 "Free electron Fermi gas" - no crystal structure
(mostly explains metals)

Ch 7 "Nearly free electron model" - bare minimum structure (periodic)

Ch 7, cont. more complete band structure

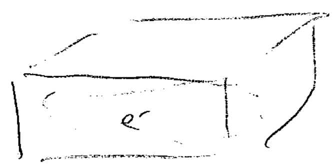
Ch 8 Semiconductors (and insulators)
↳ semiconductors that just don't know it yet :)

Then Exam 2

Then odds + ends - optical properties

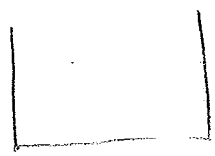
- etc.

Free electrons - Lorentz quote on pg 133



electrons confined in a box (the crystal)

Phys 222



infinite square well

$H\psi = E_n \psi$

$H \to -\frac{\hbar^2}{2m}\frac{d^2}{dx^2}$

(Eigenvalue eqn)

results: $\psi_n = A \sin \frac{\pi n x}{L}$ are wavefunctions (Eigenfunctions)

satisfies $\psi(x=0)=0$ and $\psi(x=L)=0$

Plug into eqn $-\frac{\hbar^2}{2m}\left(-\left(\frac{\pi n}{L}\right)^2\right)\psi = E\psi$

$$\boxed{E = \frac{\hbar^2}{2m}\frac{n^2\pi^2}{L^2}}$$