Reading: AM ch. 22-26.

Lattice thermal conductivity (phonon part):

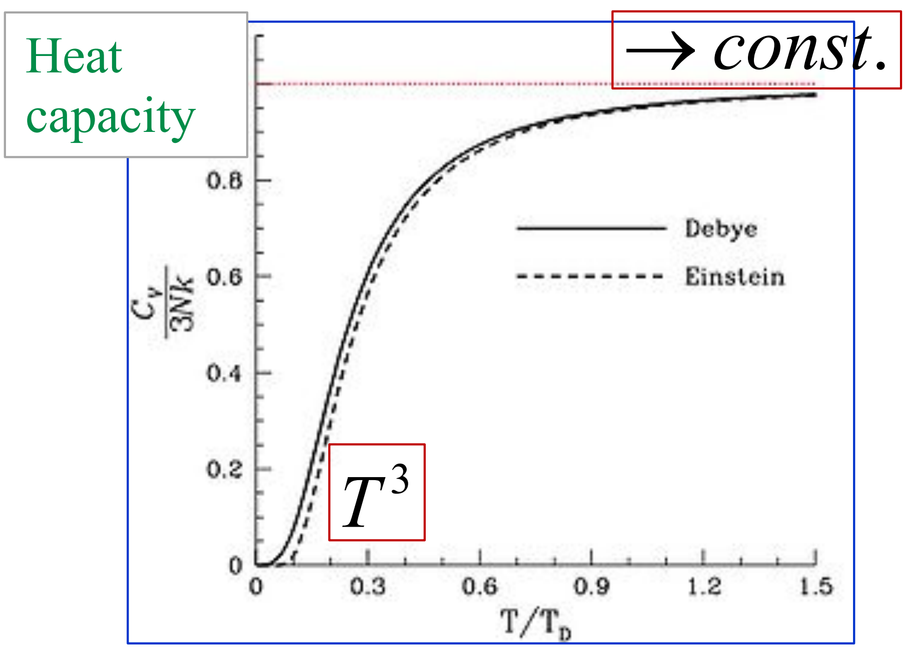
conductivity by phonon gas $\kappa = \frac{1}{3} C \ell v$

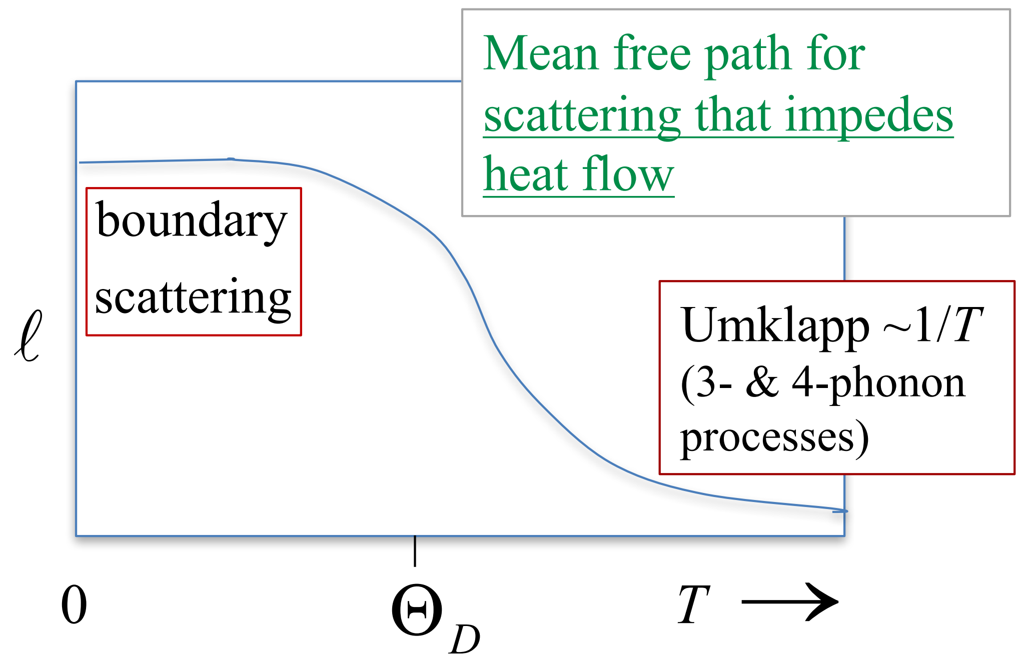
- C: Heat capacity
- ℓ: Mean free path
- v: Group velocity $\frac{\partial \omega}{\partial k}$

<u>Same</u> relationship we used for electron conductivity; phonon parallel conduction

(more generally would need a summation over all modes)

$n = kT / \hbar\omega$

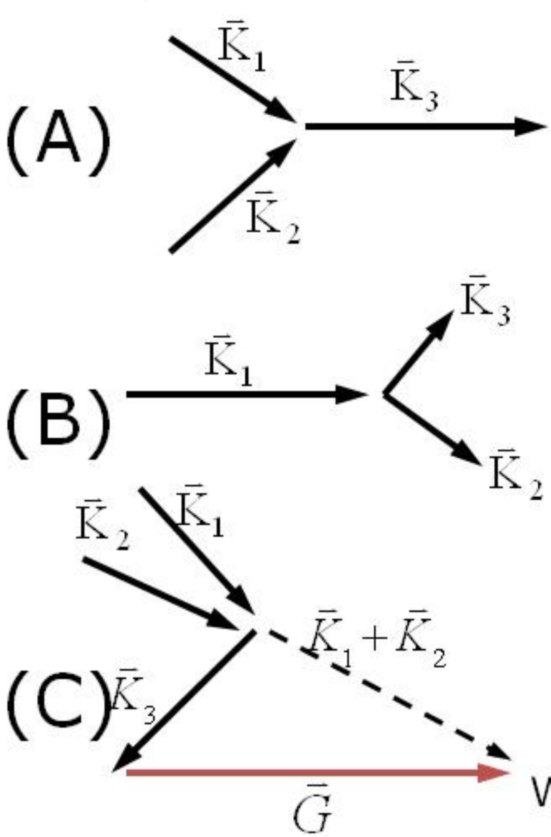




Non-Umklapp phonon scattering: generally <u>preserves heat flow</u>

Anharmonic lattice effects:

- 3-phonon interactions (phonon-phonon)



(A) $\vec{K}_1+\vec{K}_2=\vec{K}_3$ $\quad \omega_1+\omega_2=\omega_3$

(B) $\vec{K}_1=\vec{K}_2+\vec{K}_3$ $\quad \omega_1=\omega_2+\omega_3$

Normal (N)

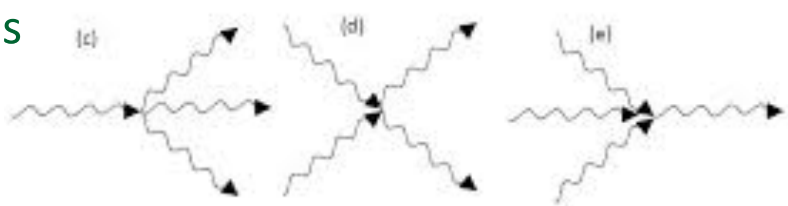
(C) $\vec{K}_1+\vec{K}_2=\vec{K}_3+\vec{G}$ $\quad \omega_1+\omega_2=\omega_3$

Where $\vec{G}$ is the reciprocal lattice vector

Umklapp (U)

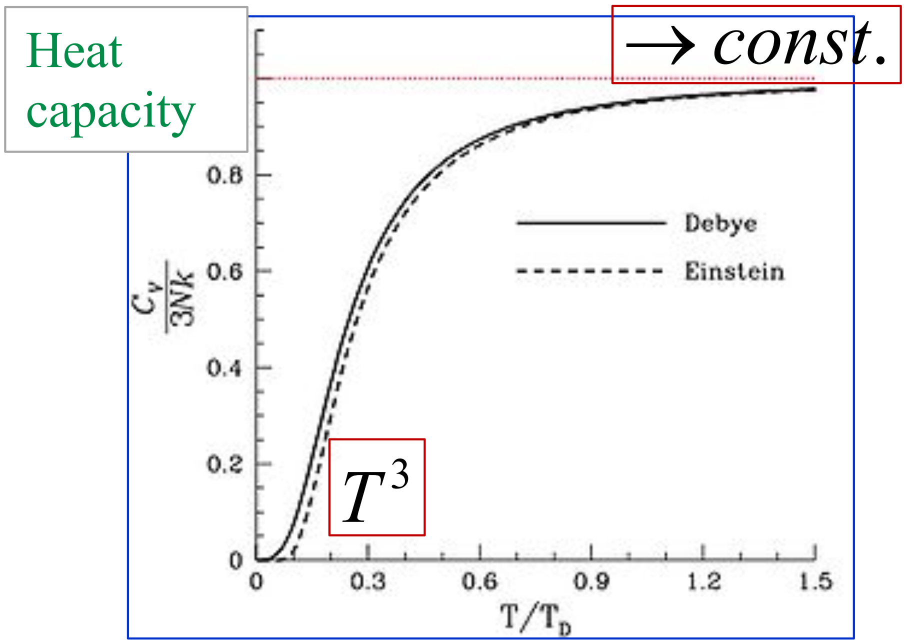
Umklapp dominates thermal conductivity

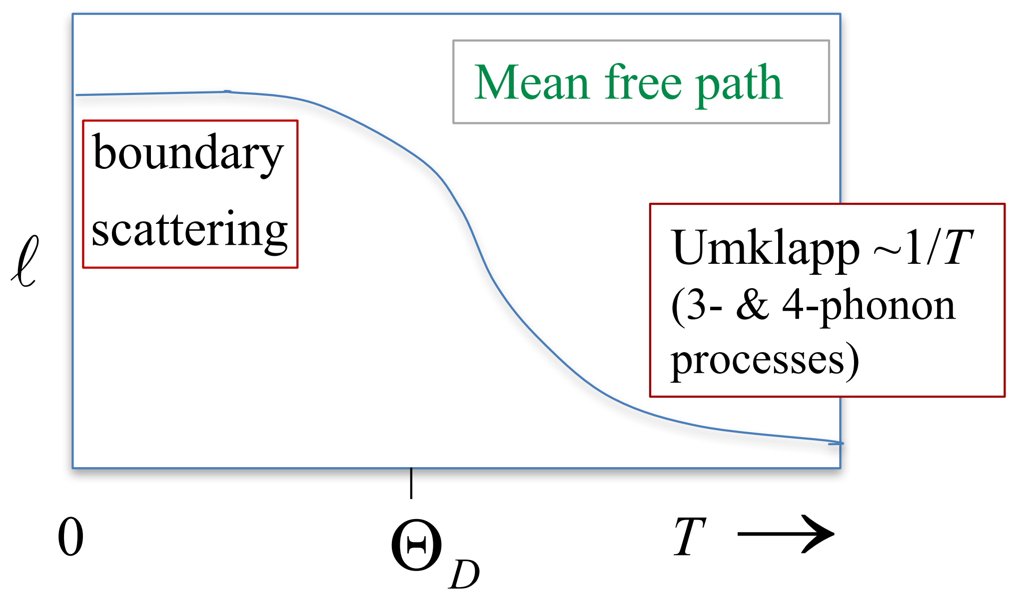
Other processes may be considered…

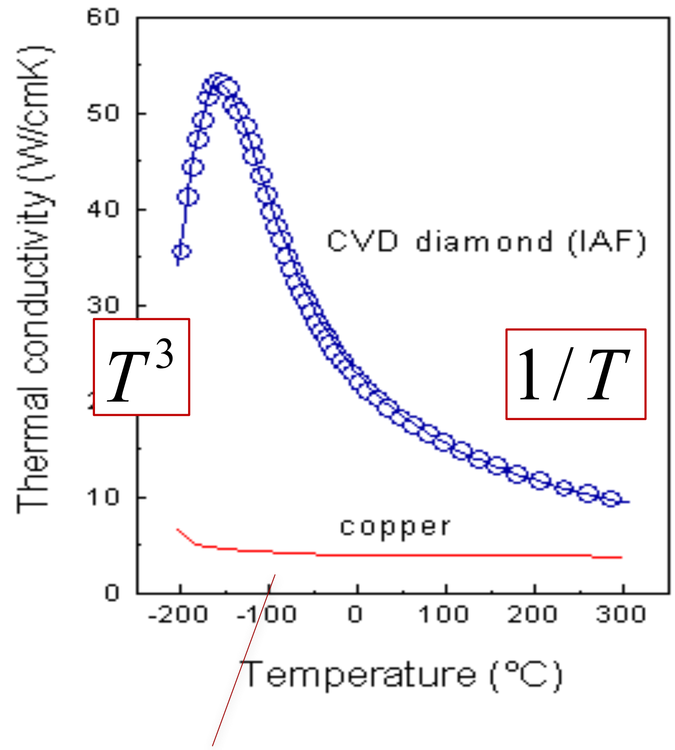


Lattice thermal conductivity:

$$\kappa = \tfrac{1}{3} C \ell v$$





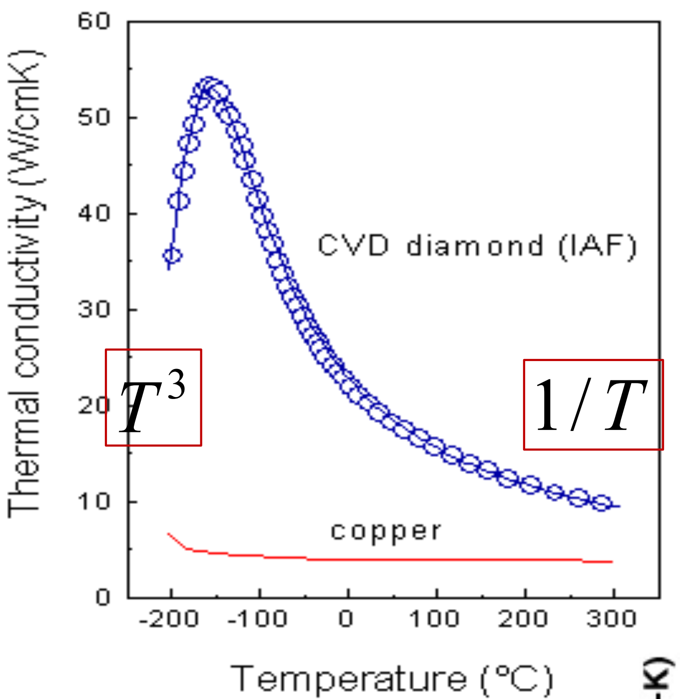


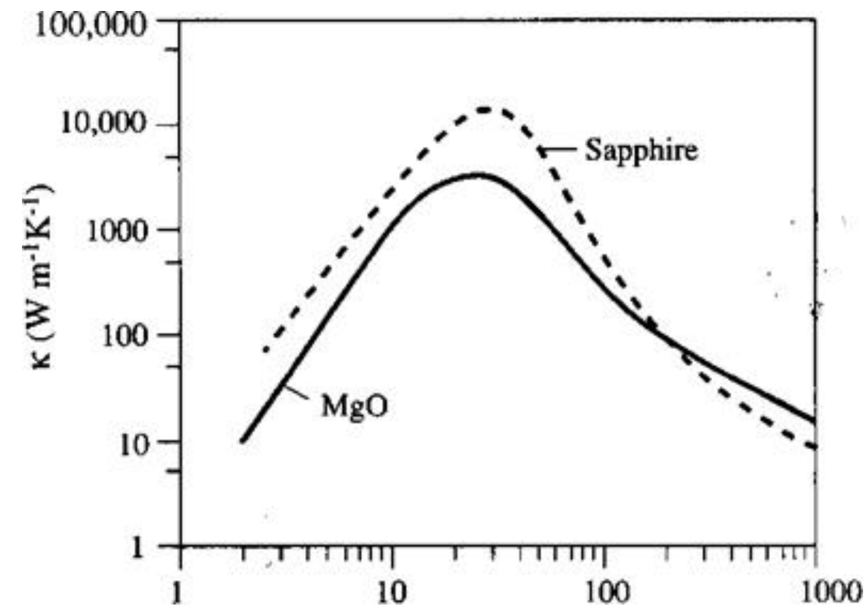
Note for metals,

$$\kappa = \kappa_\ell + \kappa_e$$

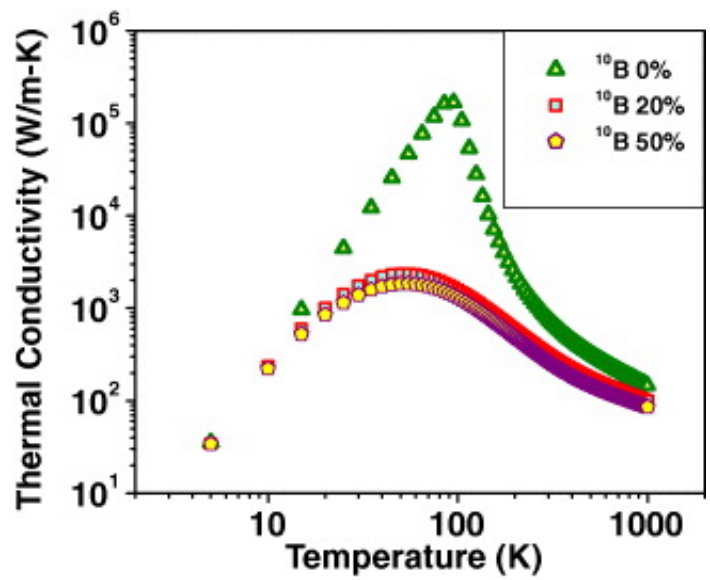
Lattice thermal conductivity:

- Large Θ_D generally large κ_L peak.
- Anharmonics decrease high-T κ_L.





Scattering from point defects analogous to Rayleigh scattering (long-wave case)
Negligible at low T leads to boundary scattering limit.



Boron nitride isotope effect

S. Barman, Europhys. Letters 2011

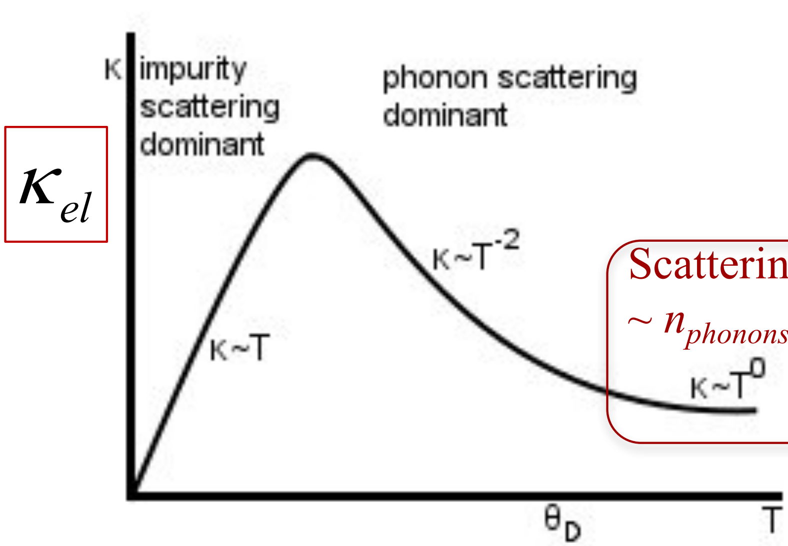
Glasses: "minimum thermal conductivity", mean free path ~λ.

Saw this slide before

Electron term (metals):

Thermal conductivity, $\kappa_{el} = \frac{1}{3} C \ell v$ (term added to κ_{phonon})

- $v =$ Fermi velocity for good metals.
- Specific heat we have seen: $C = \gamma T$
- Alloy or very strong disorder, peak may disappear.



Scattering rate $\sim n_{phonons} \sim T$

$$\frac{\kappa_{el}}{\sigma} = \frac{\pi^2}{3}\left(\frac{k_B}{e}\right)^2 T$$

Wiedemann-Franz law (see ch. 1, prefactor 3/2 for classical case; semiconductors)

$$c \cong \frac{1}{V} k_B T g(\varepsilon_F)\left(\frac{\pi^2}{3}\right) \equiv \gamma T \qquad \sigma = \frac{g(\varepsilon_F) v_F^2 e^2 \tau}{3}$$

Electrical resistivity of metals (ch. 26):

Matthiessen's rule: $$\frac{1}{\tau} = \frac{1}{\tau_{impurity}} + \frac{1}{\tau_{phonons}} + \ldots$$

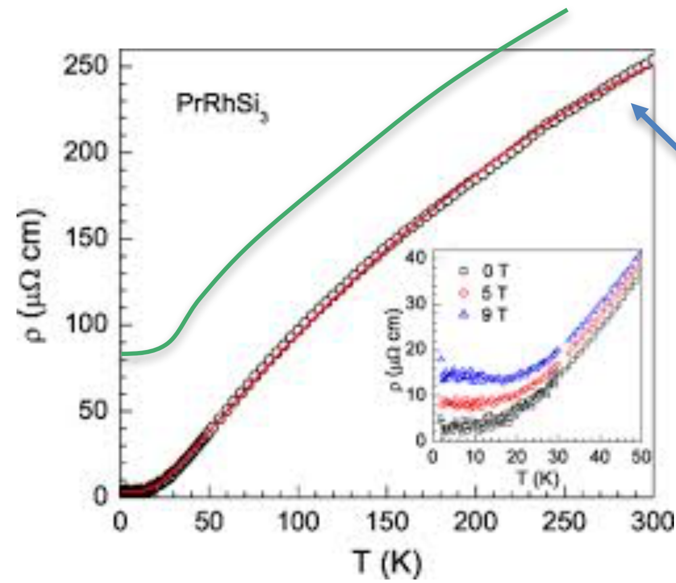
- Uncorrelated processes, metal resistivities add.
- Impurities always decrease mobility (increase resistivity)
- Alloy resistivity may be large & constant vs. *T*.
- Semiconductors resistivity normally <u>decrease</u> vs. *T*.

$$\mu = \frac{e\tau}{m} \qquad \sigma = ne\mu \equiv 1/\rho$$

mobility

$$\rho = \rho_{impurity} + \rho_{phonons} + \ldots$$

With impurities



$$\frac{1}{\tau} \propto n_{phonon}$$

High T,
Good metal
$\rho \sim T$.

Electrical resistivity of metals (ch. 26):

Matthiessen's rule

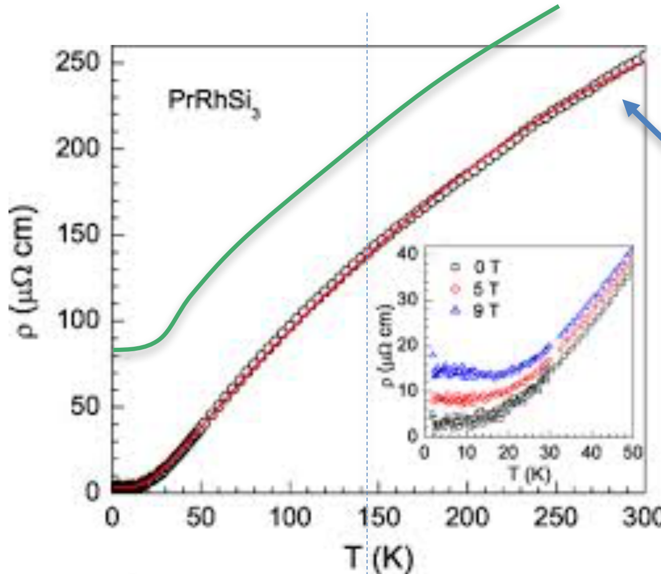
$$\frac{1}{\tau} = \frac{1}{\tau_{impurity}} + \frac{1}{\tau_{phonons}} + \ldots$$

Expect:

$$\sigma = ne\mu \equiv 1/\rho$$

$$\mu = \frac{e\tau}{m}$$

With impurities



$$\frac{1}{\tau} \propto n_{phonon}$$

High T,
Good metal
$\rho \sim T$.

Θ_D

- Low-T "Bloch T^5 law": multiple phonon scattering required to affect electron direction. Scattering rate in electrical conductivity formula not same as electron-phonon scattering rate.