Physics 489 S 04 Lecture 11
Measurement of Dispersion $\omega(k)$, Scattering, Anharmonicity (A& M chs 24,25)

1. Conservation laws for scattering
   phonon creation $k_{in} = k_{out} + k_{phonon} + G \quad E_{in} = E_{out} + \hbar\omega_{phonon}$
   phonon creation $k_{in} = k_{out} - k_{phonon} + G \quad E_{in} = E_{out} - \hbar\omega_{phonon}$

2. Experimental measurement of dispersion curves
   Scattering waves which interact weakly with solids: neutrons, photons
   Thermal neutron scattering: **k** over full BZ; energies $\approx k_B T$
   X-rays: **k** over full BZ; energies $\approx KeV$
   Visible, IR light: $\mathbf{k} \approx 0$; energies $\approx eV$

3. Neutron Scattering: Triple Axis Spectrometer.
   Elastic Diffraction - Bragg scatering from static lattice
   Inelastic Diffraction - Bragg scatering from dynamic lattice
   0 phonon - Bragg; 1 phonon - sharp peak; 2 phonon - broad background
   Example: Pb from A&M

4. X-rays: Very difficult to analyze energies to find small energy differences
   Current research area using synchrotrons

5. Light scattering. $\mathbf{k} \approx 0$
   Raman scattering sees optic modes. Independent of angle.
   Brillouin scattering sees acoustic modes. Depend on scattering angle.

6. Infrared light absorption. Optically active phonons.

7. Thermal motion and Bragg scattering:
   Sharp Bragg peaks exist for elastic scattering, with the intensity reduced by the Debye-Waller Factor

8. Scattering and electrical resistivity
   Scattering of electrons in metals gives resistivity - Drude theory, lecture 3
   $\sigma = (ne^2/m)\tau$, $\rho = (m/ne^2)(1/\tau)$, $1/\tau$ = scattering rate
   Electrons scatter from vibrations $\propto u^2$ (Golden rule)
   At high T ($T >> \Theta_D$), $u^2 \propto T$, and $\rho \propto T$; $\sigma \propto T^{-1}$
   At low T, thermal phonons have small k and u^2 is small; leads to $\rho \propto T^5$

9. Anharmonicty illustrated with pair potential.
   $E = E_0 + (1/2)A_2(r - r_0)^2 + (1/6)A_3(r - r_0)^3$ with $A_3 < 0$. Measurements give Gruneisen parameter $\gamma = -d(ln\omega)/d(lnV) \propto -A_3 r_0/A_2$
   Thermal expansion $\alpha = \frac{1}{r_0}\frac{d<r-r_0>}{dT} \propto \frac{\gamma}{B}C_V$
   Hence $\alpha \propto T^3$ at low temperature, constant at high temperature.

10. Phonon-phonon scattering due to anharmonicity

11. Thermal conductivity - finite because of phonon scattering
    Just as for electrons (A&M Chapt. 1, lecture 3), thermal conductivity for phonons is given by $\kappa = \frac{1}{3}v^2\tau c_V = \frac{1}{3}v\ell c_V$
    Thus $\kappa \propto T^{-1}$ at high T; $\kappa \propto T^3$ at low T
    Examples: LiF, diamond