1 Phonon

- Debye simplified the notation so that acoustic waves are treated as if they exist within a homogeneous elastic continuum, this followed by the requirement of periodic boundary conditions.
- This only permits certain wave vectors (numbers) $\vec{k}$ to exist.
- Einstein quantized lattice vibrations in terms of energy given by:
  \[ E = n\hbar\omega \]
- Each quantized energy is a phonon.
- For an average energy of a given wave, the number of phonons present are:
  \[ n = \frac{1}{\exp\left(\frac{\hbar\omega}{kT}\right) - 1} \]
- The high frequency vibrations produce optical phonons where the low, due to periodic boundary conditions induced quantization, are called acoustic phonons.
- Phonon waves produced by harmonic oscillators
- Ideal case phonons would not interact rather combine and separate via the superposition principle.
- Since interactions are not harmonic rather anharmonic and constricted by geometry. This causes phonons to scatter.
- This scattering results in thermal conductivity (or resistivity) and anharmonic vibrations result in thermal expansion.
- The De Broglie relation of phonons $p = \frac{\hbar}{\lambda} = \hbar\vec{k}$. 
• Momentum of phonons is important in indirect bandgap materials like silicon.

• Phonons are created or destroyed by changing the temperature of the crystal. Which corresponds to the energy of the crystal.

• In order to find the modes of vibration for harmonic oscillators in a crystal use of the Schrodinger equation yields,

\[ E = (n + \frac{1}{2})\hbar \omega \]

• Which for zero-point energy of vibration for \( E_0 = \frac{1}{2}\hbar \omega \) when \( n = 0 \) (at \( T = 0K \)). This has relevance to superconductivity phenomena.