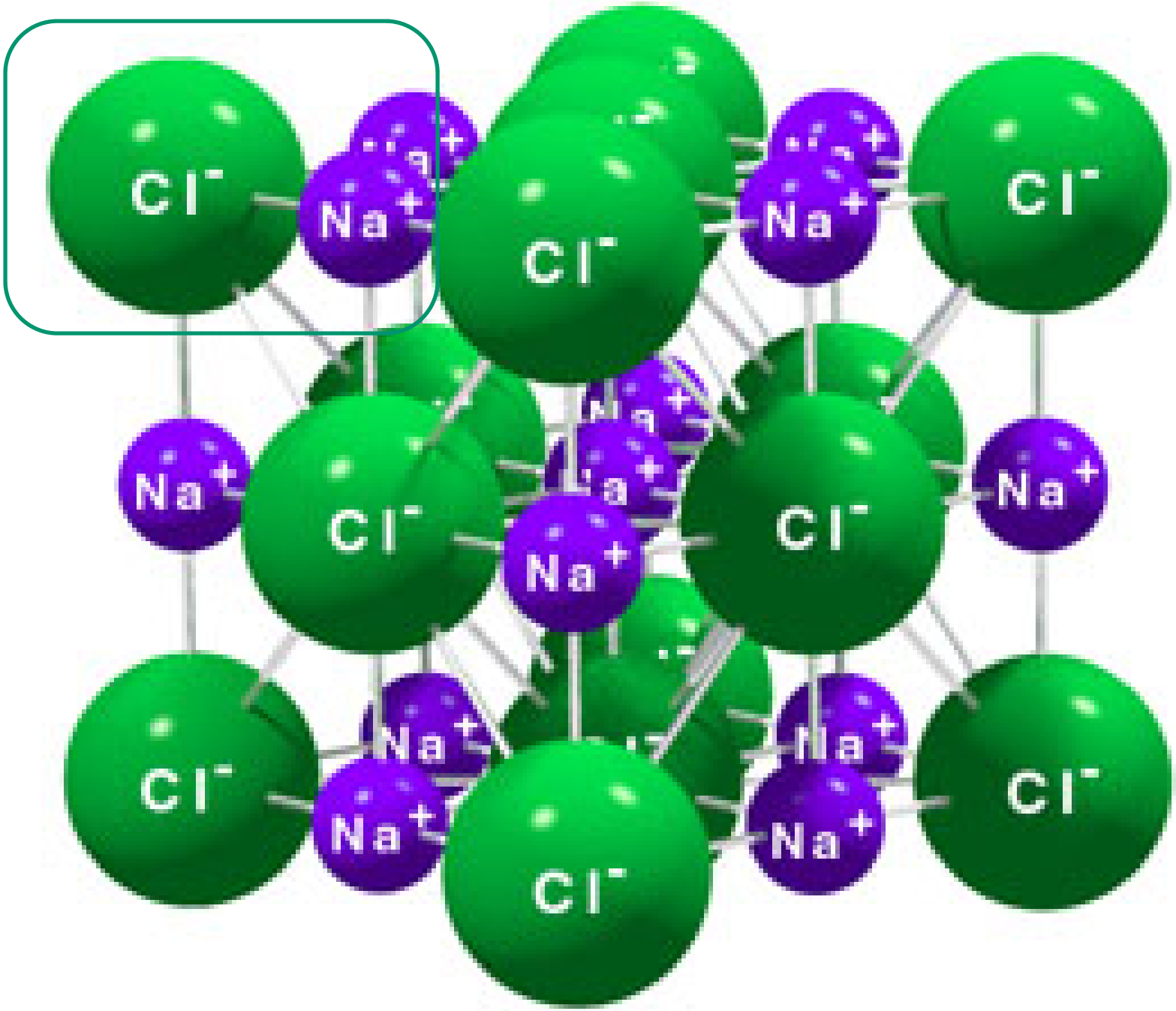
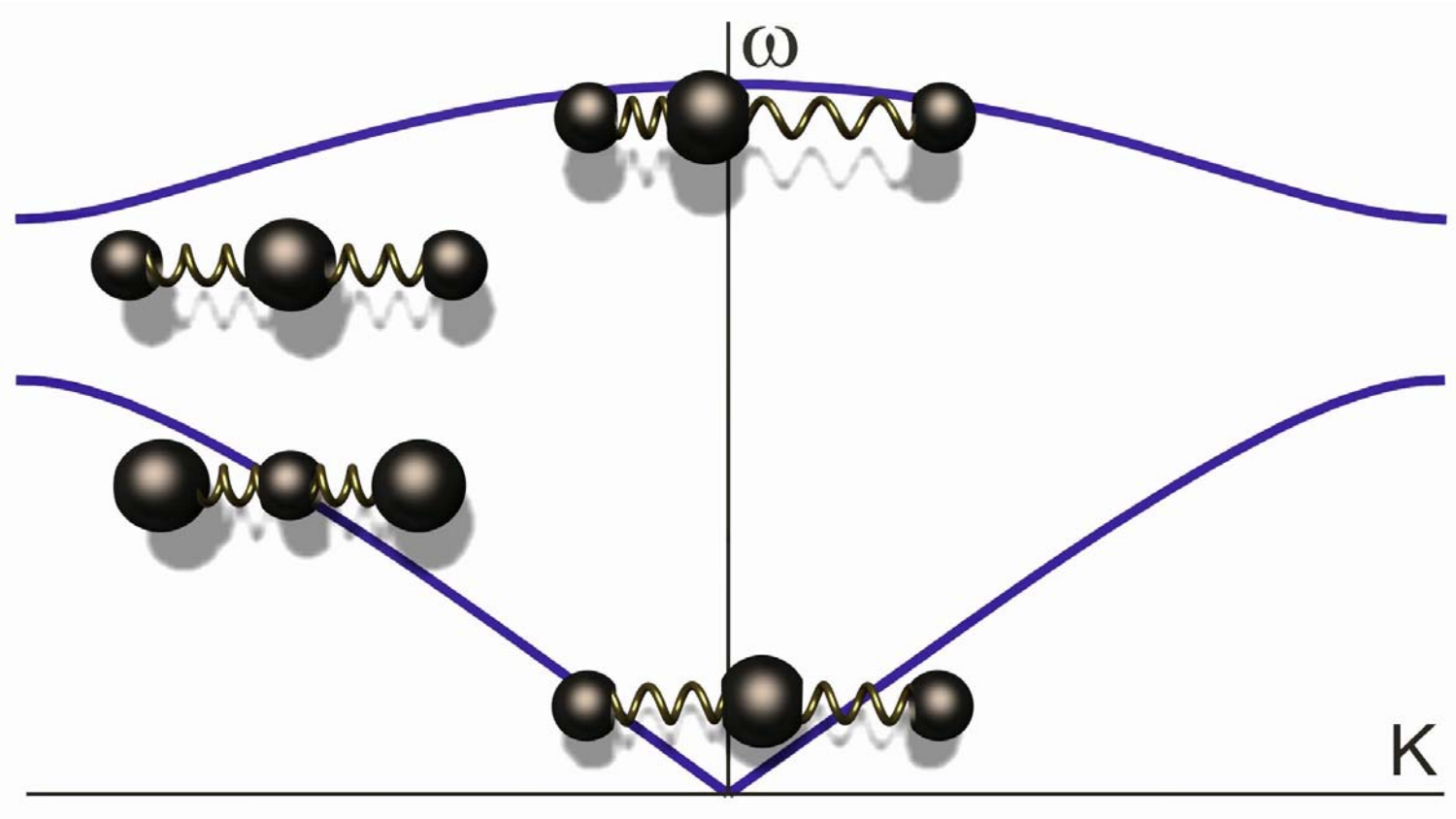
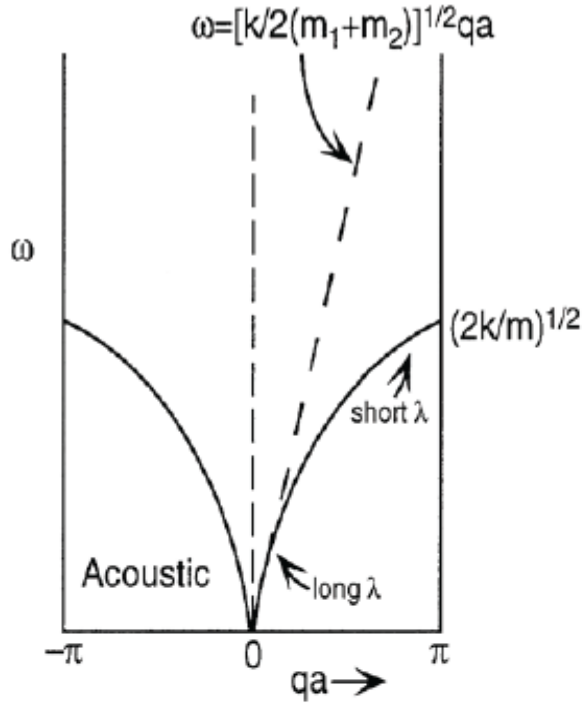
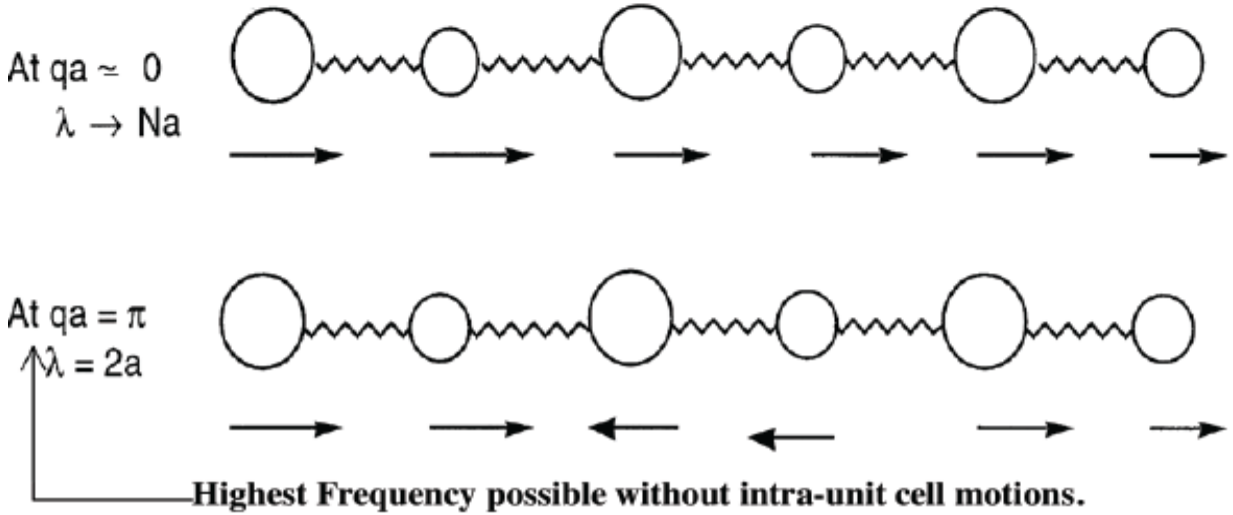
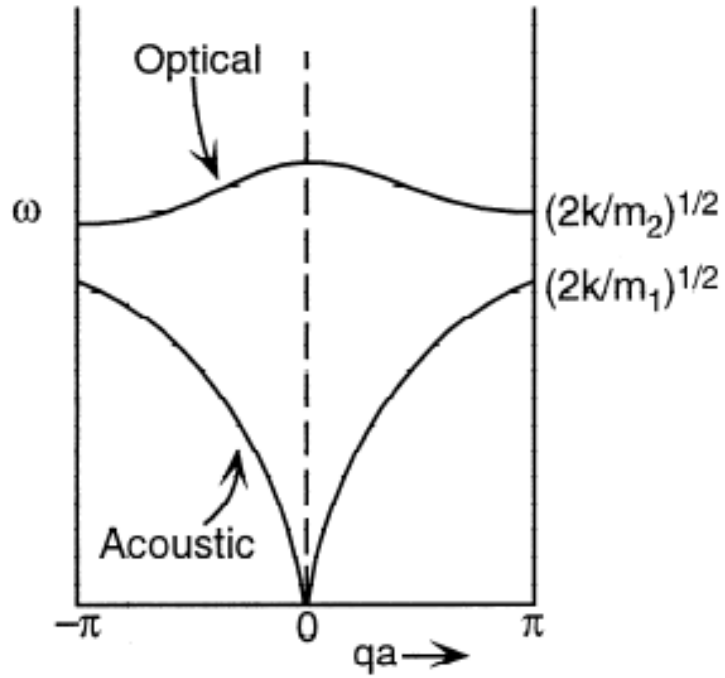

Cl⁻
Na⁺
Cl⁻
Na⁺
Cl⁻
Na⁺
Cl⁻
Na⁺
Cl⁻
Na⁺
Cl⁻
Na⁺
Cl⁻
Na⁺
Cl⁻


ω
K

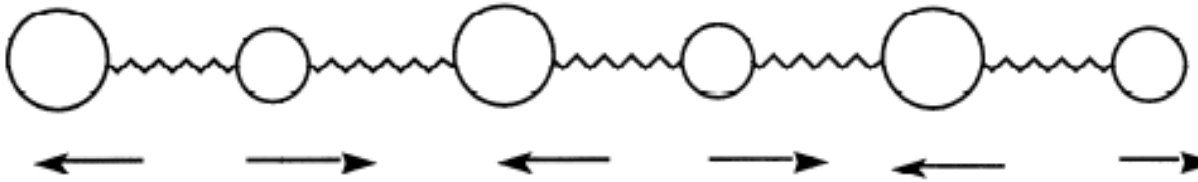




Highest Frequency possible without intra-unit cell motions.

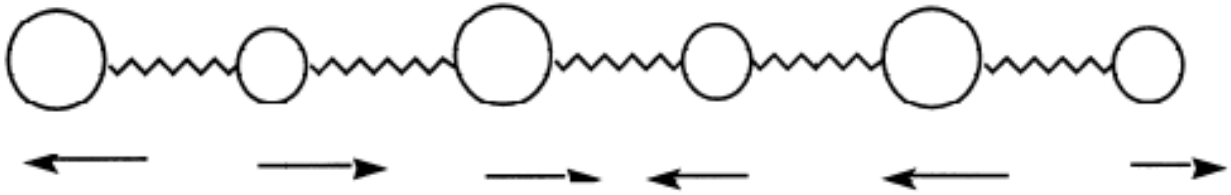


At qa = 0



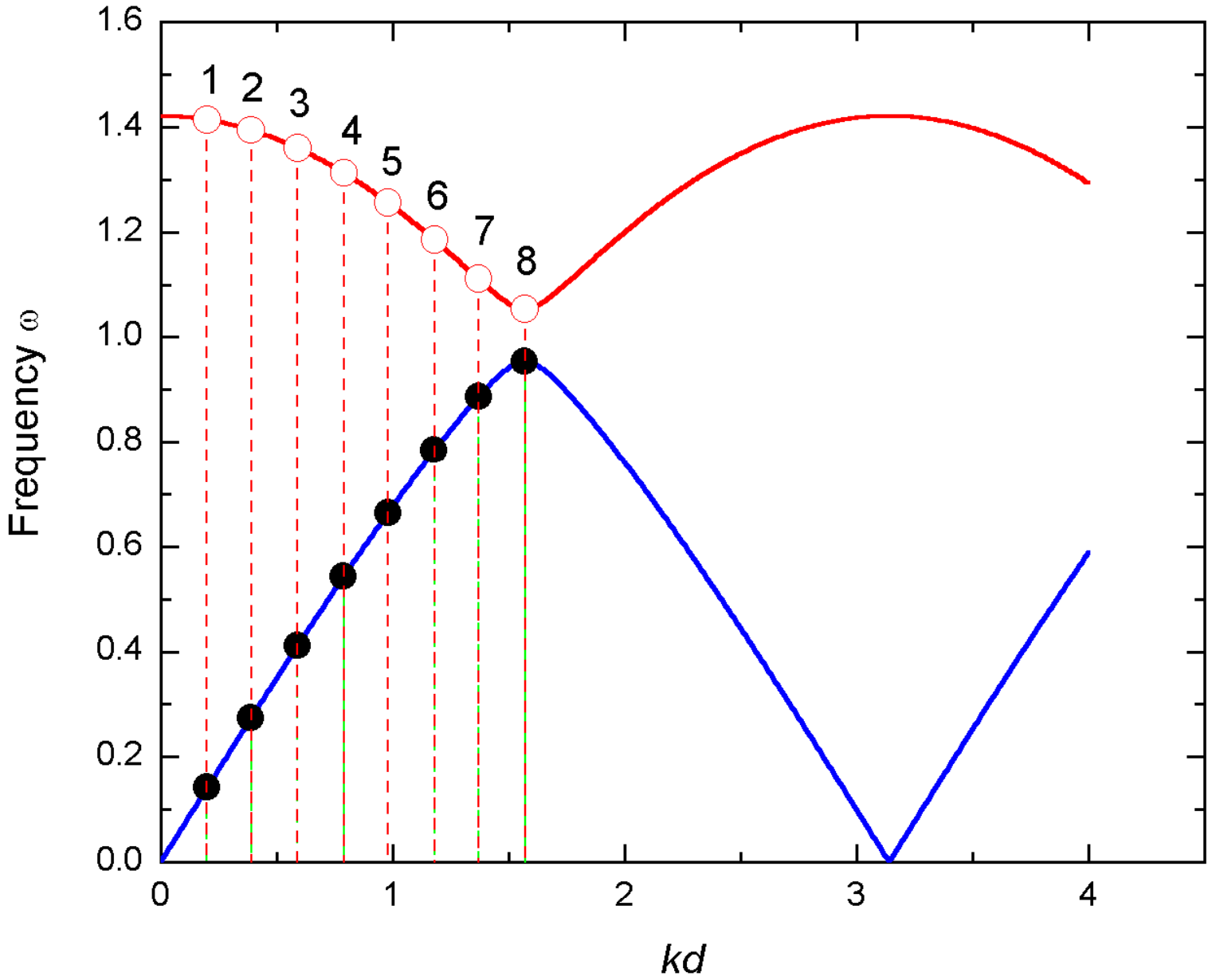
Atoms within each unit cell move out of phase but phases within each cell are identical

At qa = π

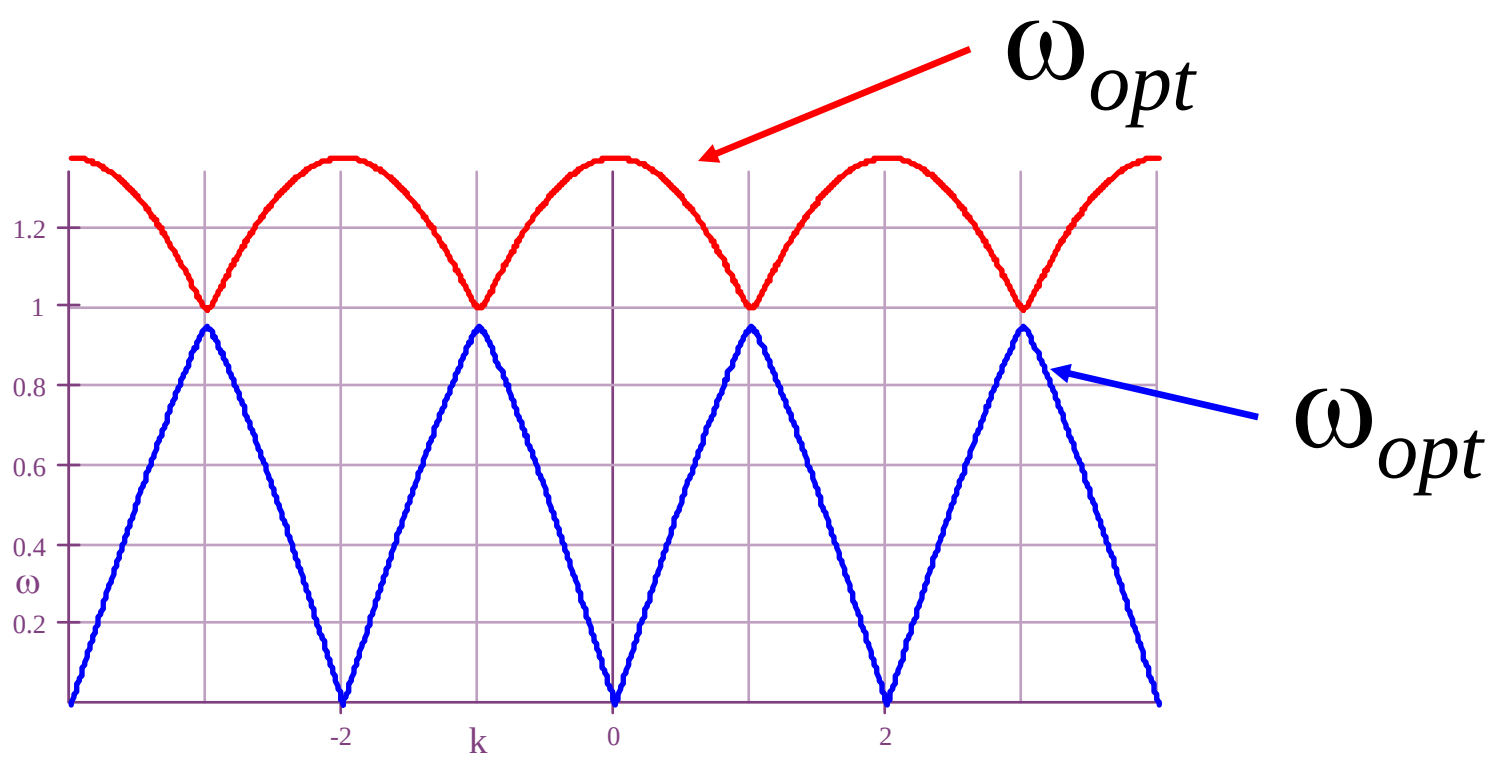


Atoms in each cell are out of phase and phase changes from cell to cell

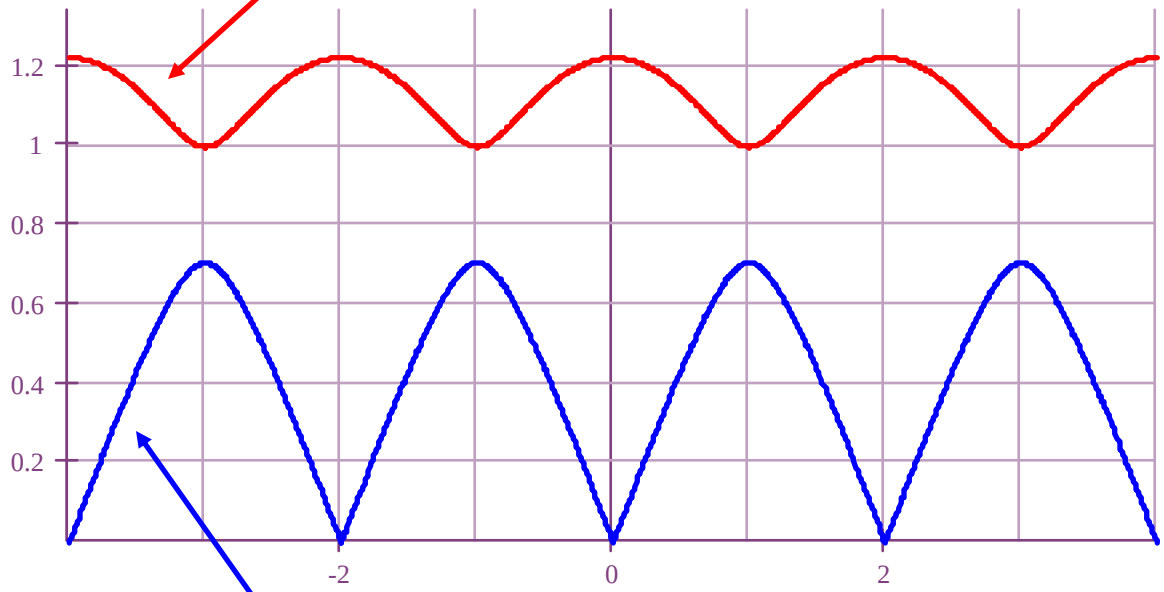
Diatomic chain, 16 masses, 8 unit cells



Dispersion Relation: diatomic

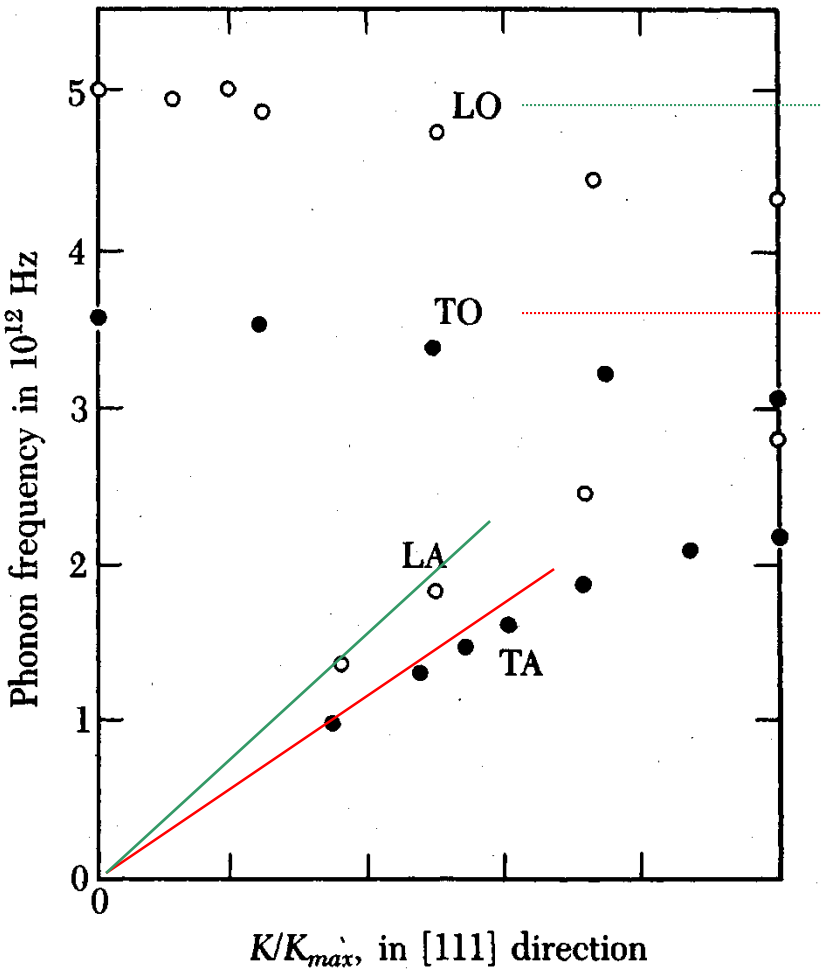


$$\omega_{opt} = \sqrt{\kappa\left(\frac{1}{M}+\frac{1}{m}\right)+\kappa\sqrt{\left(\frac{1}{M}+\frac{1}{m}\right)^2-\frac{4}{Mm}\left(\sin\left[k\frac{a}{2}\right]\right)2}}$$



$$\omega_{ac} = \sqrt{\kappa\left(\frac{1}{M}+\frac{1}{m}\right)-\kappa\sqrt{\left(\frac{1}{M}+\frac{1}{m}\right)^2-\frac{4}{Mm}\left(\sin\left[k\frac{a}{2}\right]\right)2}}$$

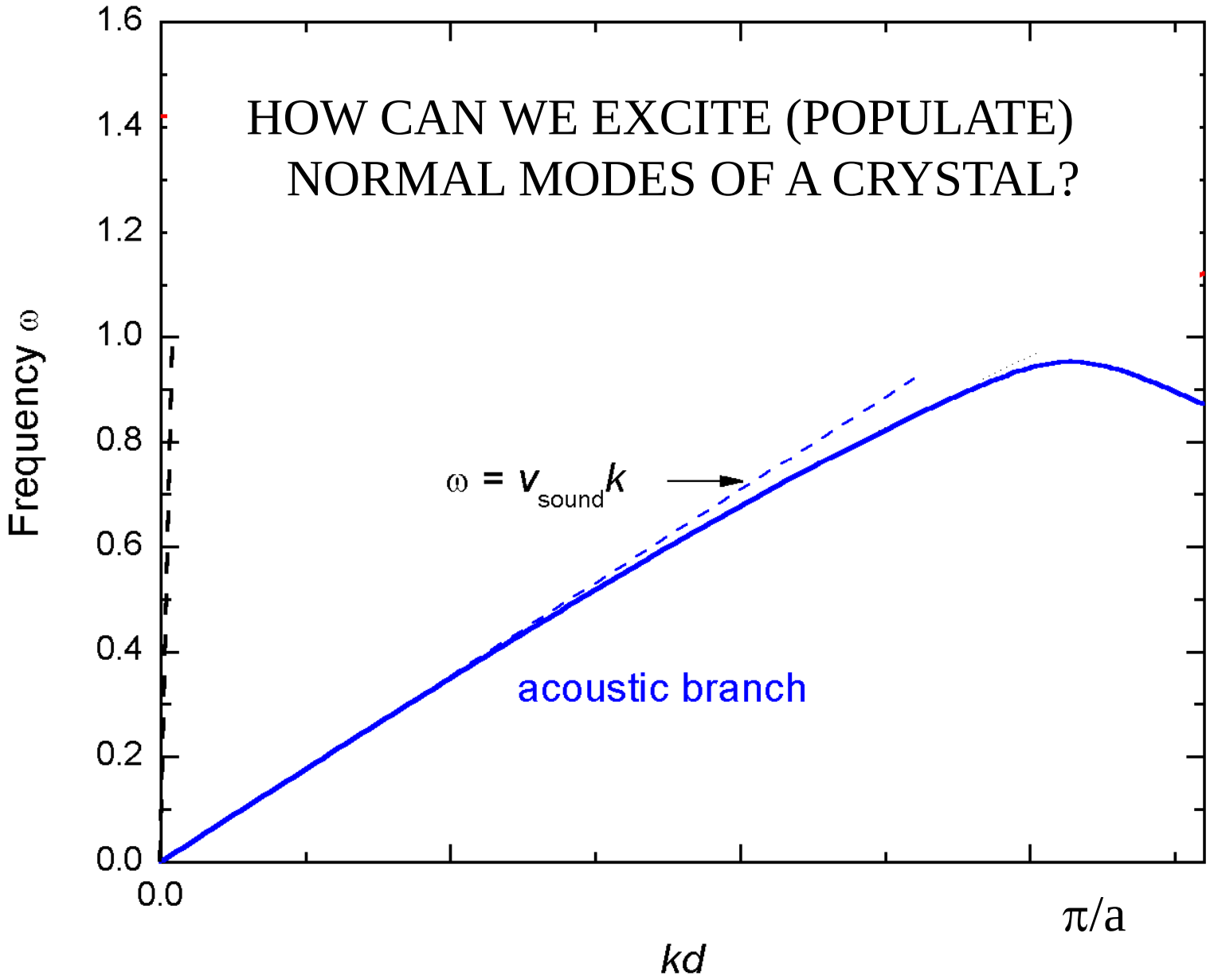
Dispersion Relation for KBr (measured by neutron scattering)



$\omega_{opt}/2\pi$ (longitudinal)

$\omega_{opt}/2\pi$ (transverse)

From C. Kittel, *Solid State Physics* after Woods, Brockhouse, Cowley and Cochran, Phys. Rev. **131**, 1025-1029 (1963)


HOW CAN WE EXCITE (POPULATE)
NORMAL MODES OF A CRYSTAL?
Frequency ω
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.0
π/a
kd
ω = v_sound k
acoustic branch

The 3 Distribution Functions

- Classical particles:
  - Maxwell-Boltzmann: $f_{MB}(n,T) = \exp(-E(n)/k_B T)$
- Fermions (half-integer spins, e.g. electrons)
  - Fermi-Dirac: $f_{FD}(n,T) = \frac{1}{\exp([E(n) - E_F]/k_B T) + 1}$
- Bosons (integer spins, e.g. photons, phonons)
  - Bose-Einstein: $f_{BE}(n,T) = \frac{1}{\exp(E(n)/k_B T) - 1}$