Solid State Physics

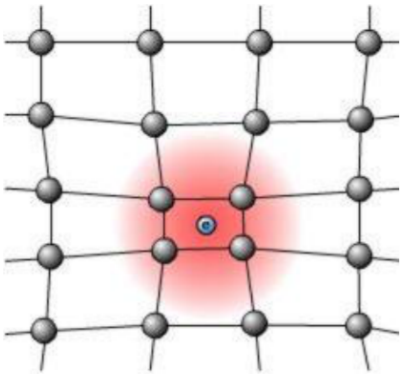
Summary Lecture 6

What are phonons?

- A *phonon* is a quasiparticle used to better describe the properties of lattice vibrations in crystals (www.chemie.de).
- *"[...] a phonon is a collective excitation in a periodic, elastic arrangement of atoms or molecules in condensed matter, like solids and some liquids"* (Wikipedia).

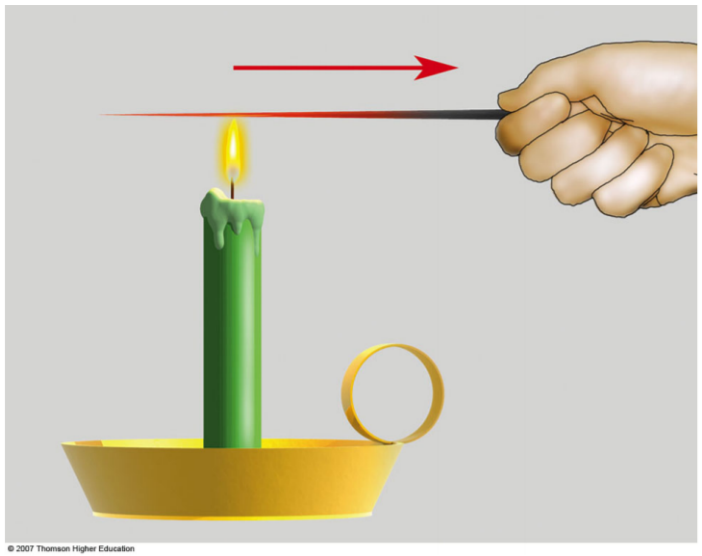
Why are phonons important?

- Phonons can make superconductivity



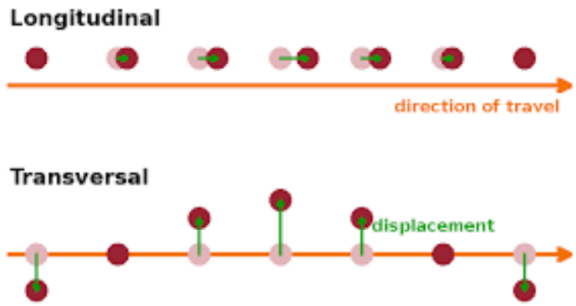
http://www.chm.bris.ac.uk/webprojects2000/igrant/theory.html

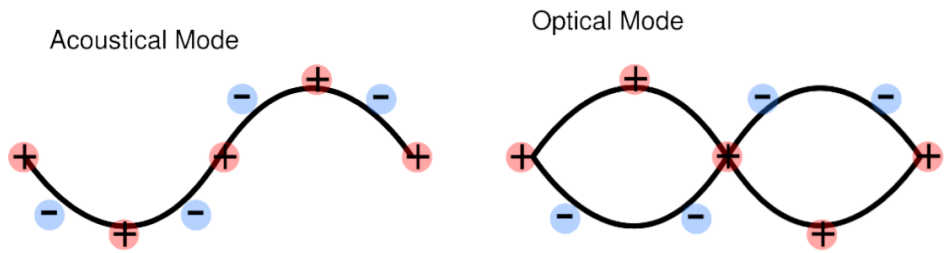
- Phonons can conduct heat



What types of phonons are there?

- Longitudinal Acoustic **(LA)**
- Longitudinal Optical **(LO)**
- Transversal Acoustic **(TA)**
- Transversal Optical **(TO)**



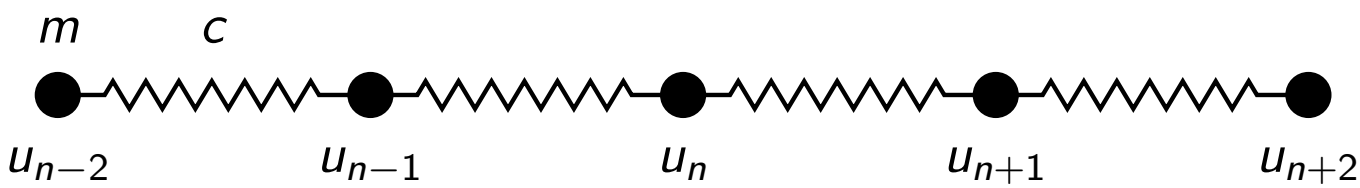


Number N of phonon branches

- $N_{acoustic} = 3$
- $N_{optical} = 3 \cdot p - 3$
- $N_{total} = 3p$

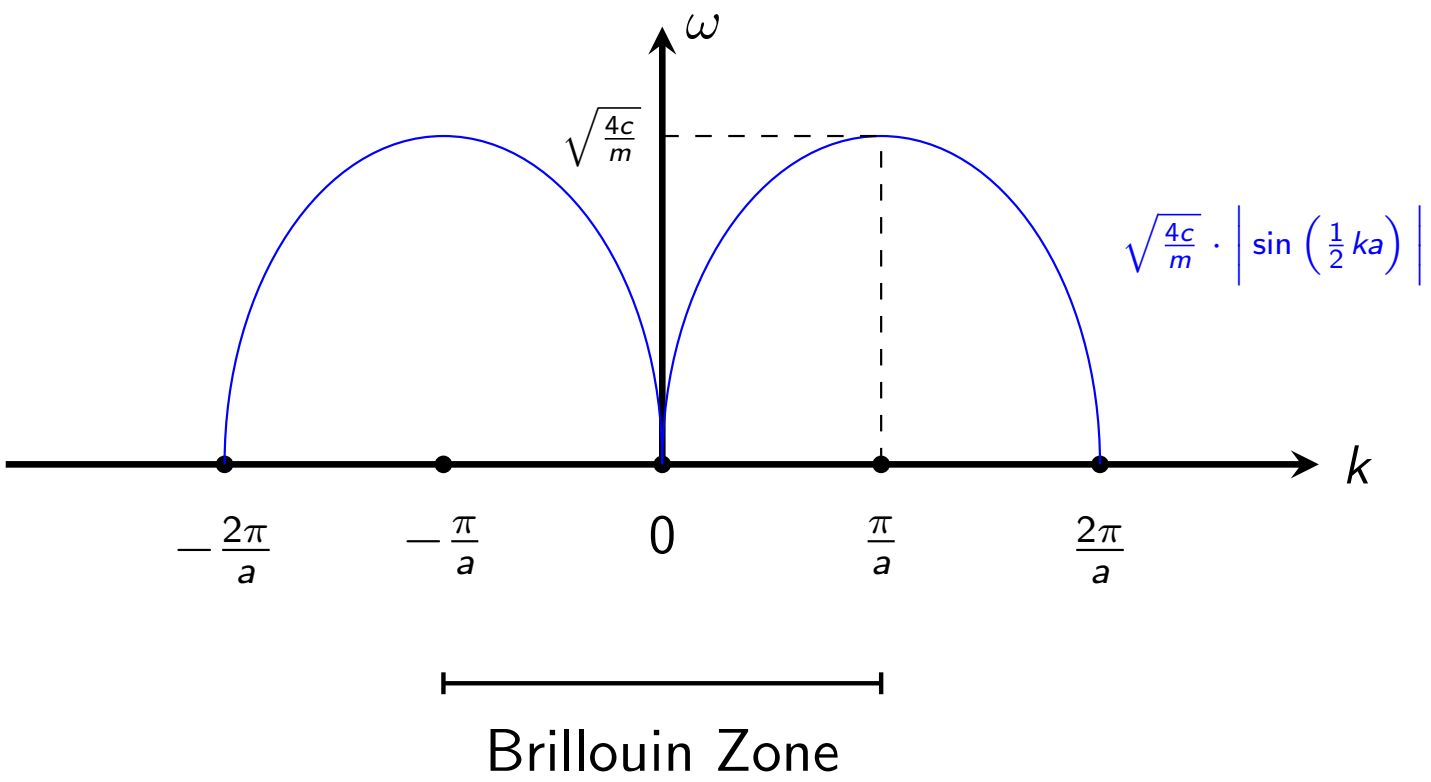
where p is the number of atoms in the primitive cell

Phonon dispersion ω
of a 1-atomic linear chain

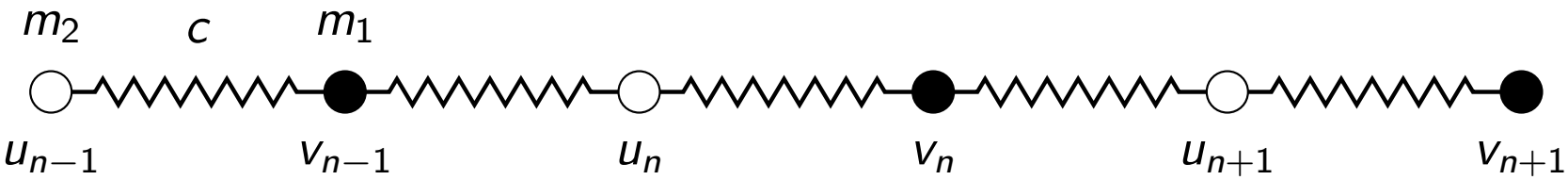


- $F_n = c(u_{n+1} + u_{n-1} - 2u_n) = m \cdot \frac{\mathrm{d}^2 u_n}{\mathrm{d}t^2}$
- $\omega^2 = \frac{4c}{m} \cdot \sin^2\left(\frac{1}{2}ka\right) \quad \Rightarrow \quad \omega = \sqrt{\frac{4c}{m}} \cdot \left|\sin\left(\frac{1}{2}ka\right)\right|$

Phonon dispersion ω
of a 1-atomic linear chain



Phonon dispersion ω
of a 2-atomic linear chain



- $F = m_i \cdot a \Rightarrow m_2 \cdot \frac{\mathrm{d}^2 u_n}{\mathrm{d}t^2} = c(v_n + v_{n-1} - 2u_n)$

$$\Rightarrow m_1 \cdot \frac{\mathrm{d}^2 v_n}{\mathrm{d}t^2} = c(u_n + u_{n-1} - 2v_n)$$

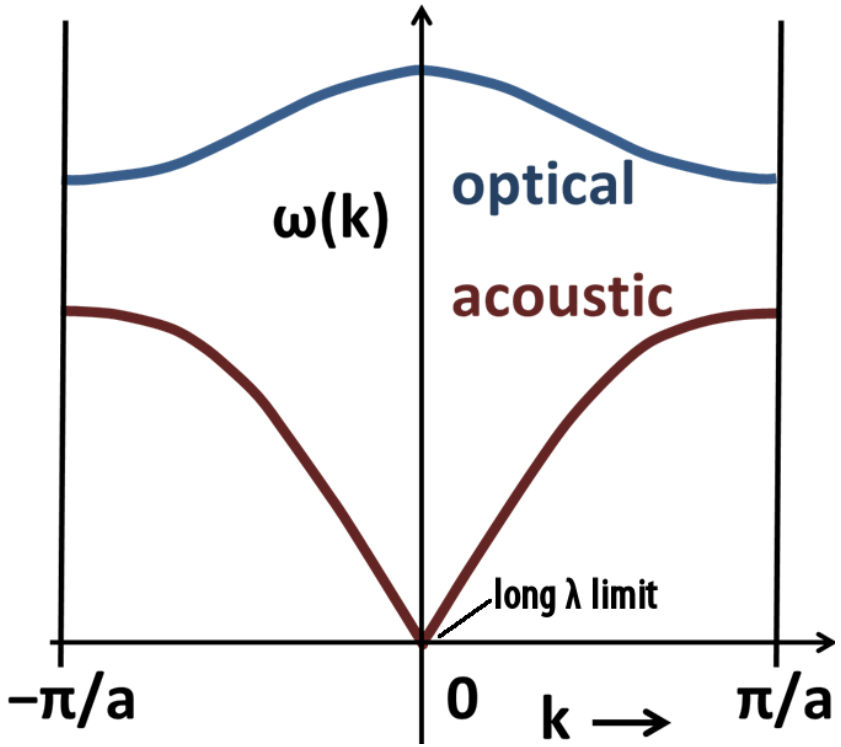
Phonon dispersion ω
of a 2-atomic linear chain

- Case 1: $ka \ll 1$
  - $\begin{cases} \omega_1^2 \simeq 2c\left(\frac{1}{m_1}+\frac{1}{m_2}\right) \\ \omega_2^2 \simeq \frac{1/2 \cdot ck^2a^2}{m_1+m_2} \end{cases}$
- Plug in ω_1:
  - $\frac{u}{v} = -\frac{m_2}{m_1} \Rightarrow u = -v$

    $\rightarrow$ *optical*
- Case 2: $k = \pm\frac{\pi}{a}$
  - $\begin{cases} \omega_1^2 = \frac{2c}{m_2} \\ \omega_2^2 = \frac{2c}{m_1} \end{cases}$
- Plug in ω_2:
  - $\frac{u}{v} = 1 \Rightarrow u = v$

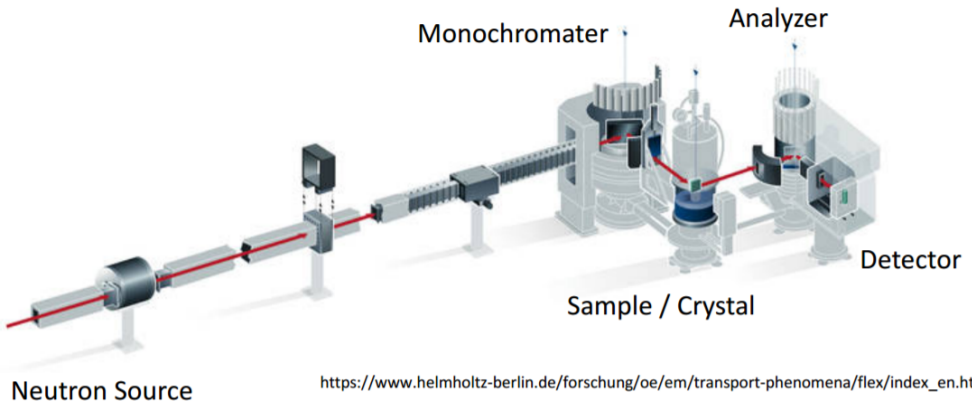
    $\rightarrow$ *acoustic*

Phonon dispersion ω
of a 2-atomic linear chain

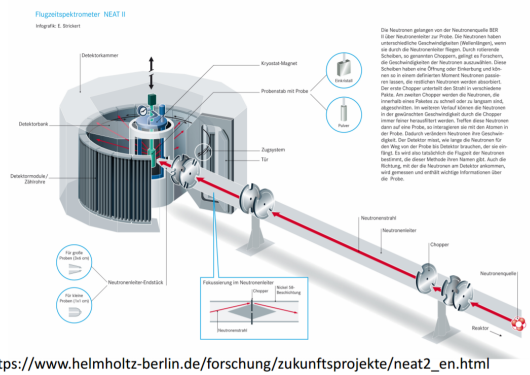


(https://en.wikipedia.org/wiki/Phonon)

How to measure phonons
Triple axis spectrometer and time-of-flight spectrometry



https://www.helmholtz-berlin.de/forschung/oe/em/transport-phenomena/flex/index_en.html

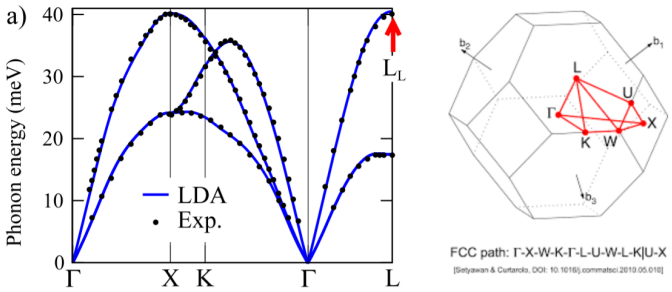


https://www.helmholtz-berlin.de/forschung/zukunftsprojekte/neat2_en.html

Triple axis spectrometer

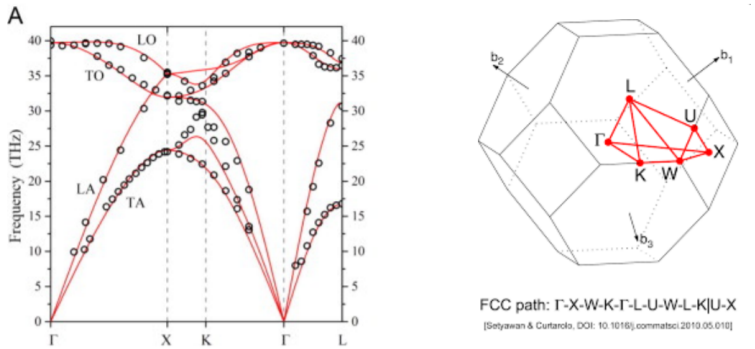
Time-of-flight spectrometry

Examples
Phonons in aluminium and diamond



http://iopscience.iop.org/article/10.1088/0953-8984/24/5/053202

Aluminium



1 THz = 4.14... meV

Diamond