Phonons and reciprocal lattice

inelastic light/x-ray/neutron scattering

ultrasound spectroscopy
infrared spectroscopy

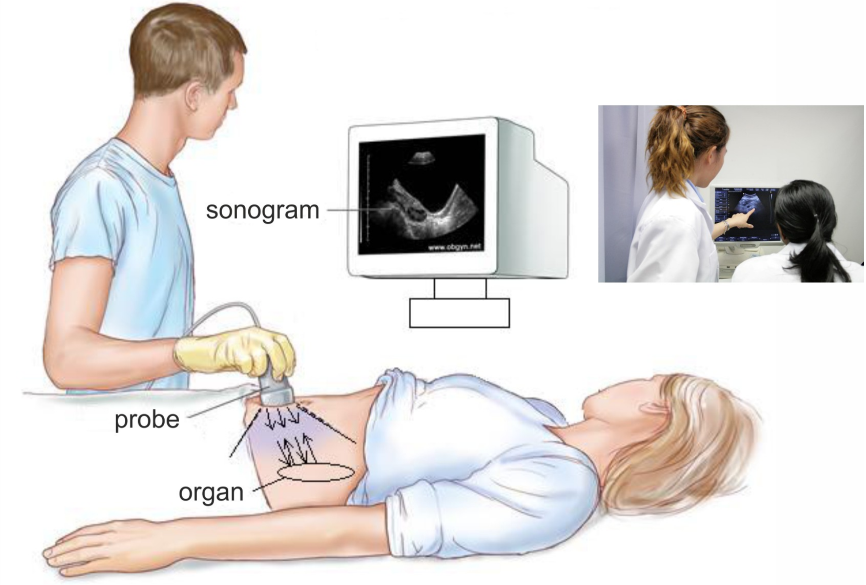
Léon Brillouin

by Alexander Tsirlin, Leipzig University

Lecture 13: November 23, 2023

Experimental technique

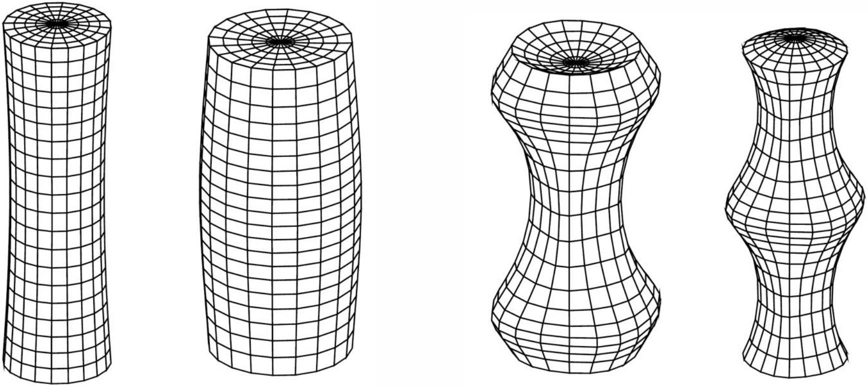
ultrasound spectroscopy


sonogram
www.obgyn.net
probe
organ

Acoustic resonance

Image credits: Brian0918 and Andy Dingley (CC-BY-SA)

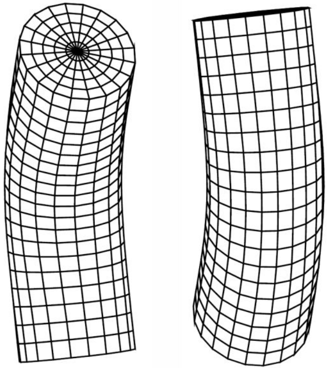
Mechanical resonance in solids



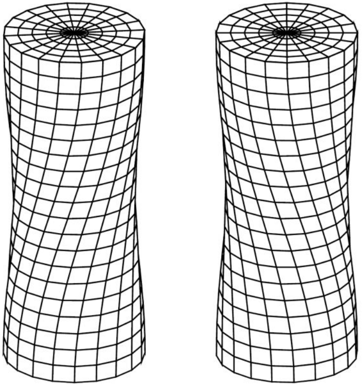
lowest extensional mode
36.85 kHz

first extensional overtone
69.94 kHz

Geophys. J. Int. 156, 154 (2004)

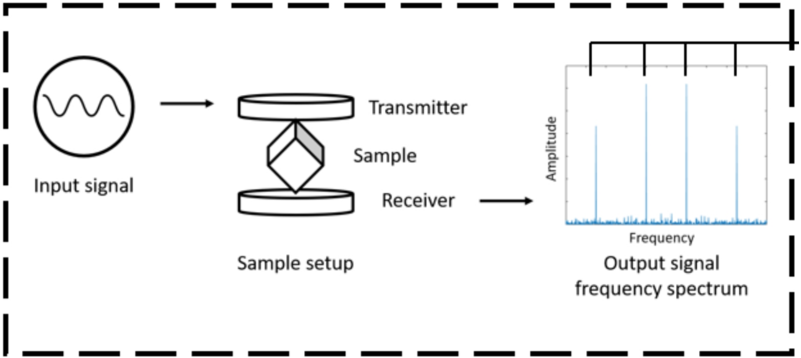


lowest flexural mode
20.49 kHz



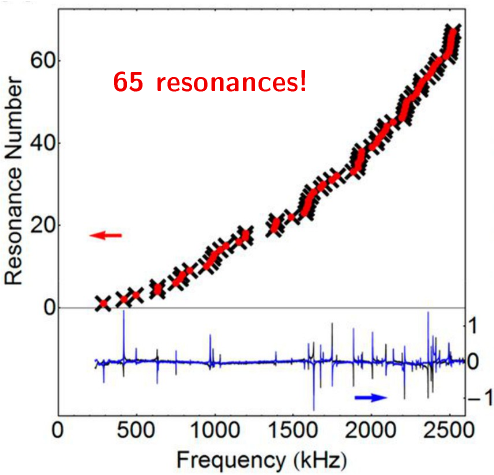
lowest torsional mode
22.66 kHz

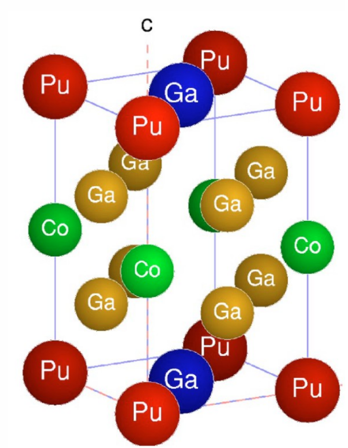
Geophys. J. Int. 156, 154 (2004)



Resonance frequencies depend on:

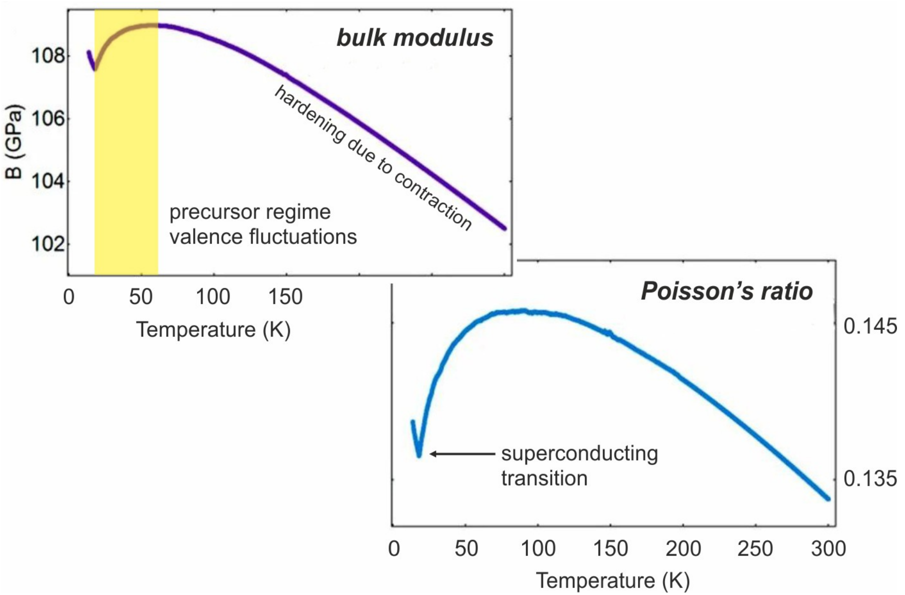
- elastic constants (C_{ij})
- sample shape
- sample dimensions





$PuCoGa_5$: tetragonal structure ($P4/mmm$), **6 elastic constants**

PNAS 112, 3285 (2015) and Phys. Rev. B 70, 104504 (2004)



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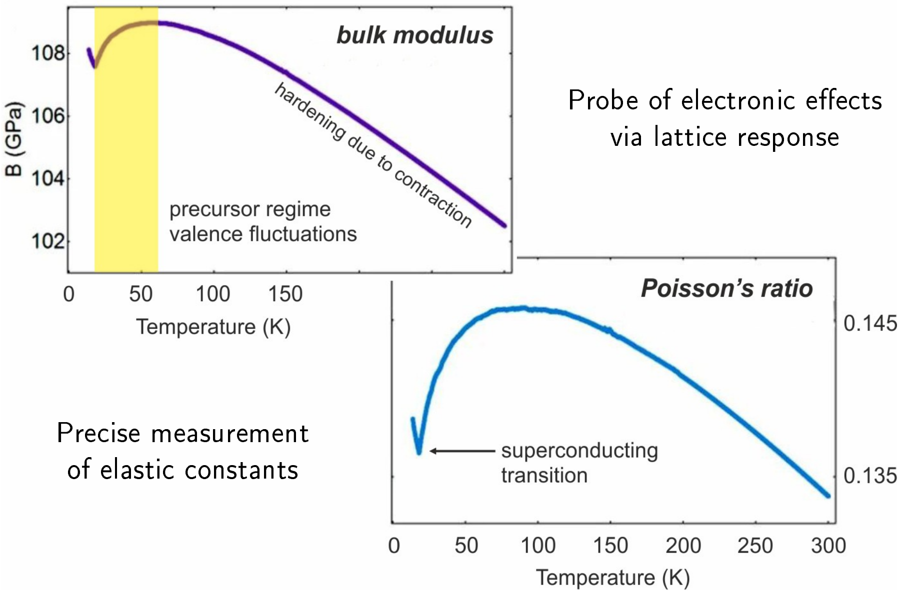


Probe of electronic effects via lattice response

Precise measurement of elastic constants

PNAS 112, 3285 (2015)

Experimental technique

infrared spectroscopy

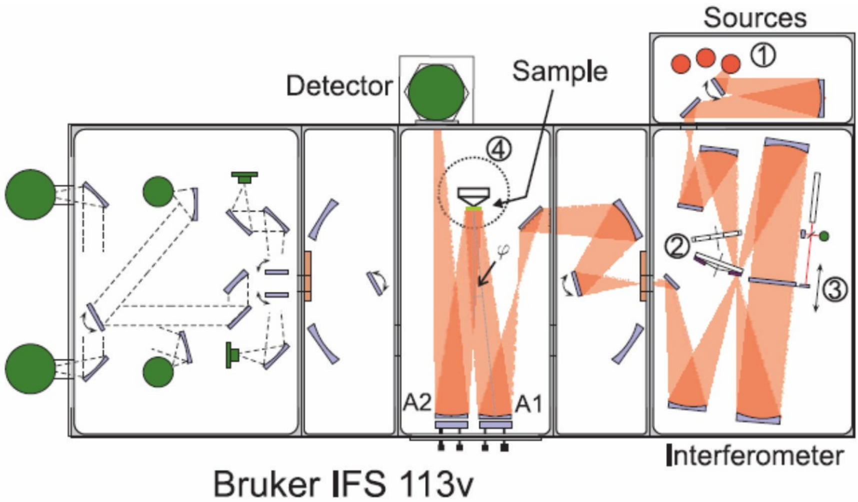


Image credit: David Neubauer, PhD thesis

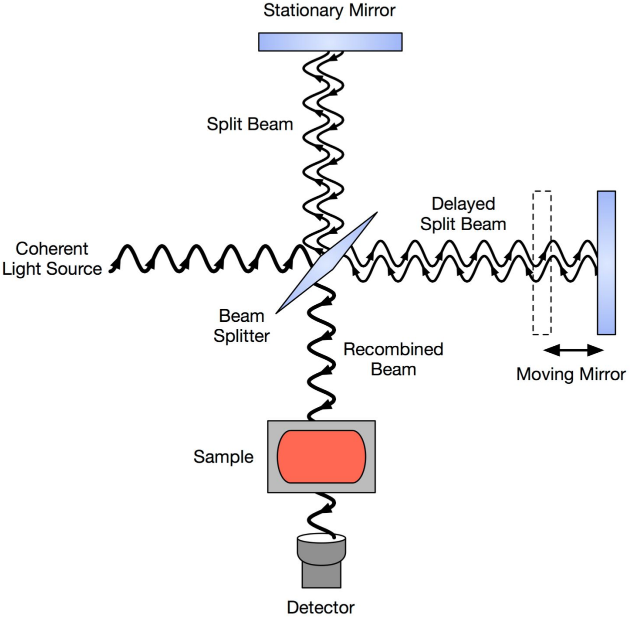
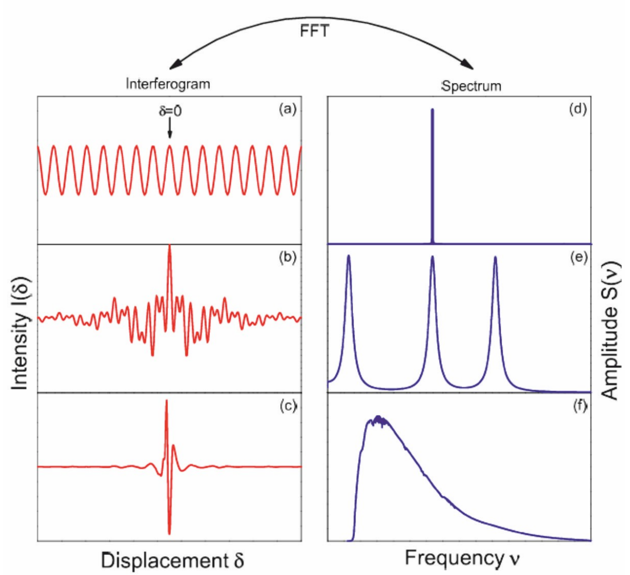


Image credit: Sanchonx (public domain)



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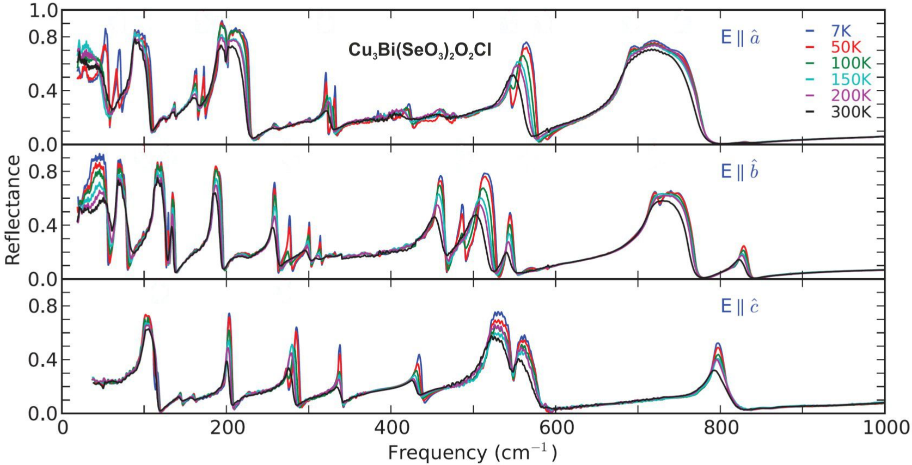
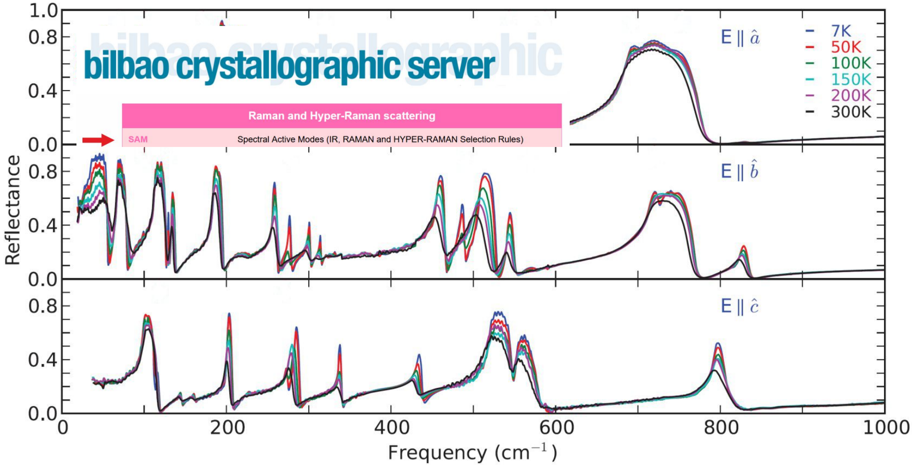


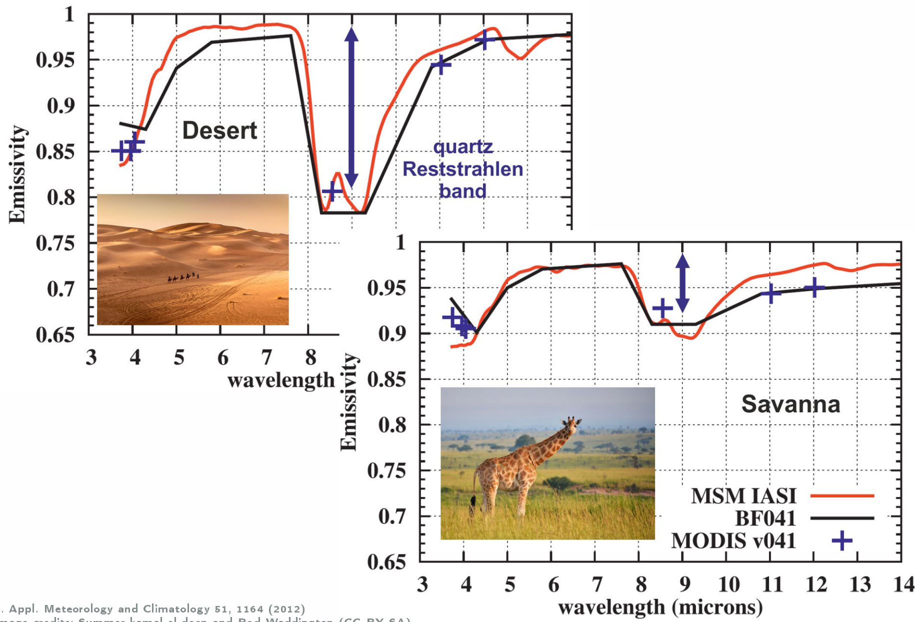
Phys. Rev. B 86, 174104 (2012)



Light polarization (direction of E) chooses different modes depending on their symmetry (orientation of μ_d)

Phys. Rev. B 86, 174104 (2012)

IR spectroscopy in geoscience



J. Appl. Meteorology and Climatology 51, 1164 (2012)
Image credits: Summer kamal el deen and Rod Waddington (CC-BY-SA)

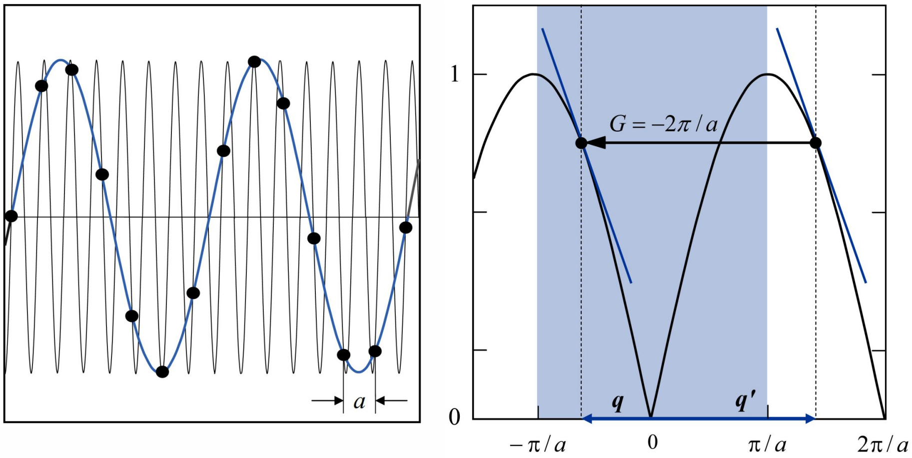
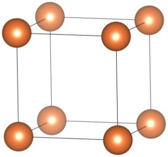
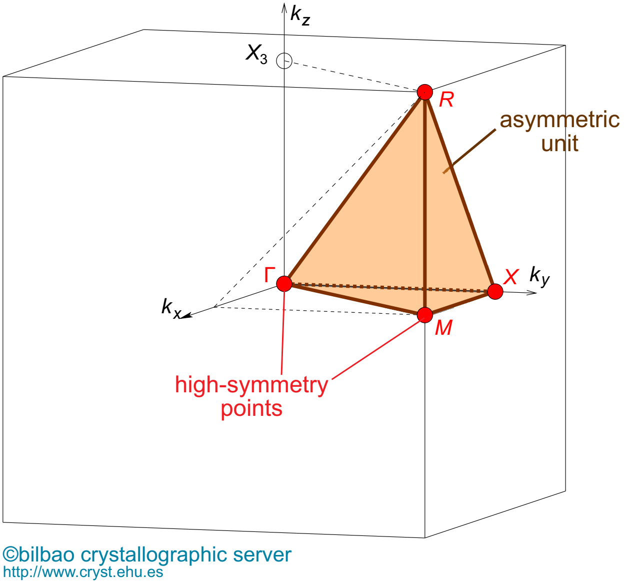


Image credit: S. Hunklinger, Festkörperphysik




k_z
X_3
R
asymmetric unit
Γ
X
k_y
k_x
M
high-symmetry points
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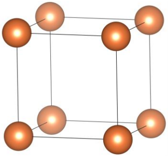

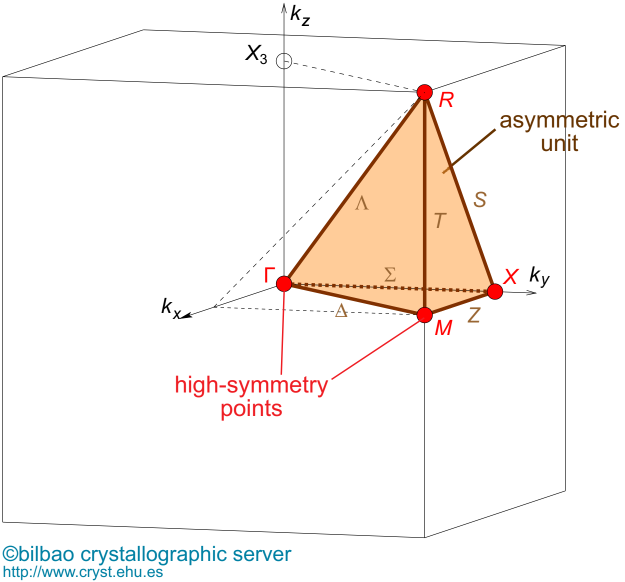

k_z
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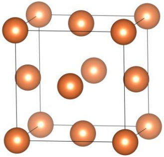
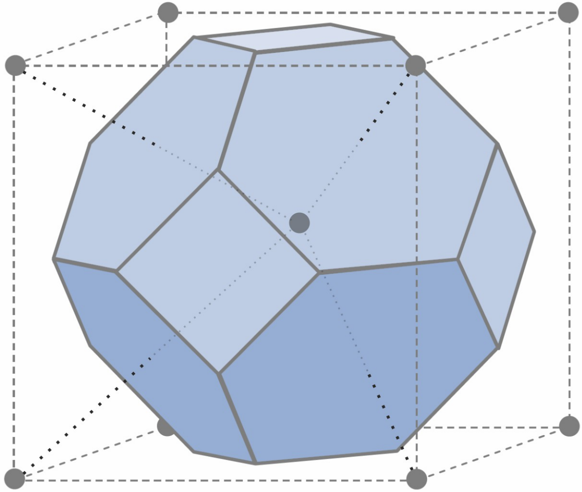
1^{st} Brillouin zone: fcc lattice





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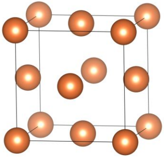
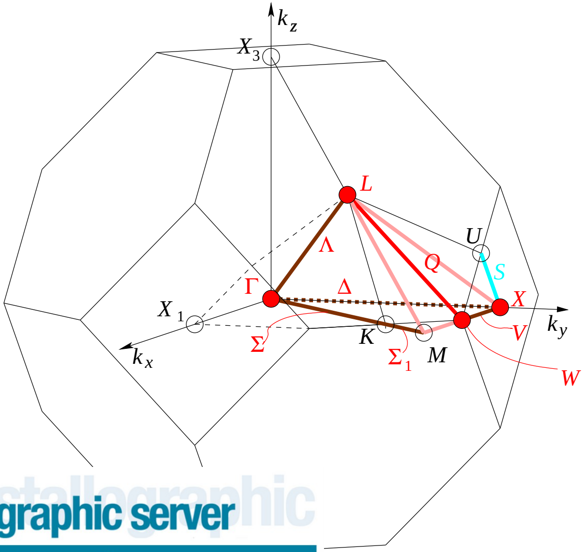
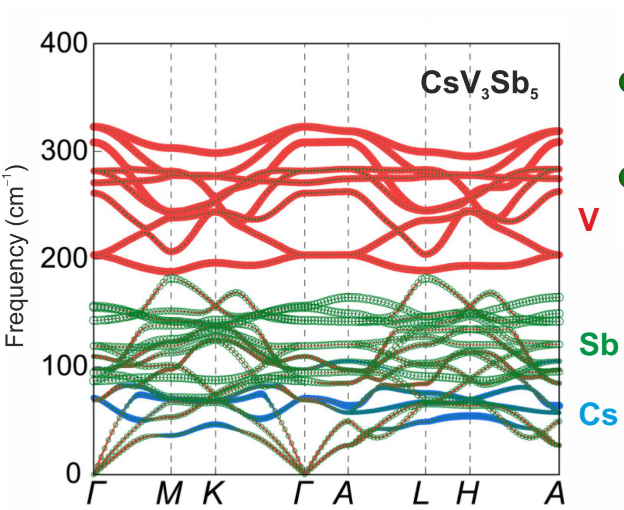
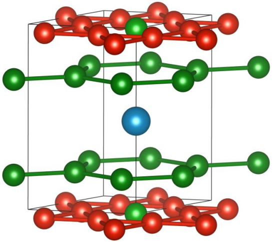




bilbao crystallographic server

Space-group symmetry	
KVEC	The k-vector types and Brillouin zones of Space Groups





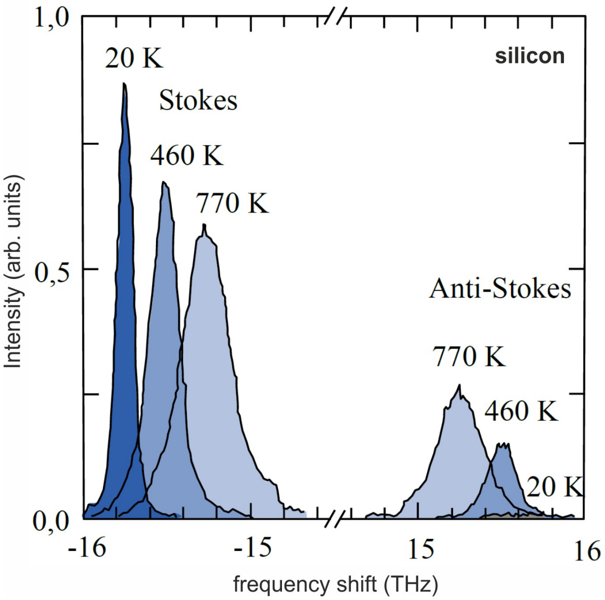
9 atoms
(per unit cell)

27 phonon bands

Phys. Rev. Materials 6, 094801 (2022)

Experimental technique

inelastic x-ray/neutron/light scattering



Low T

Stokes lines only

High T

anti-Stokes lines appear

Image credit: S. Hunklinger, Festkörperphysik

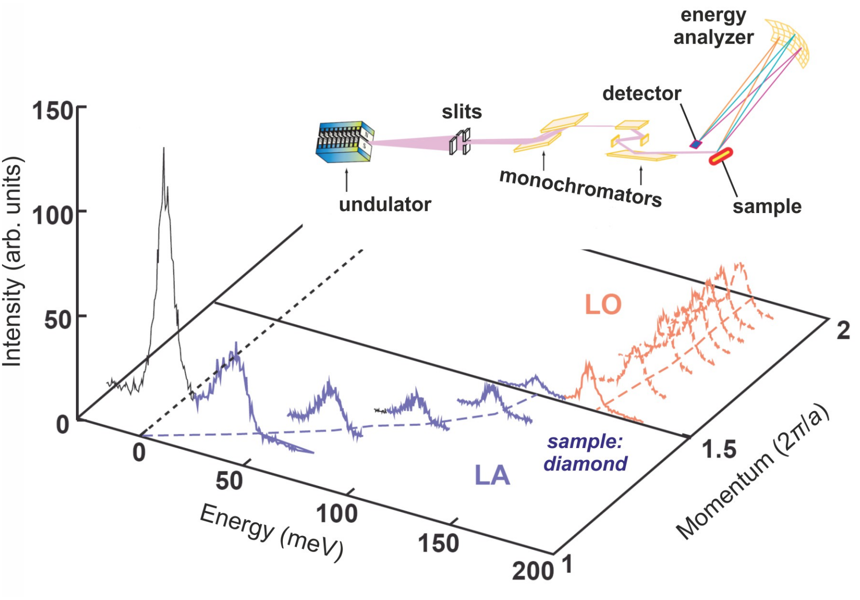
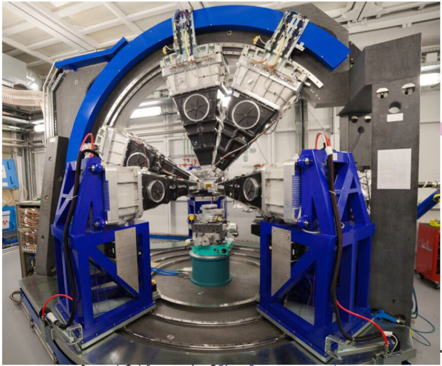
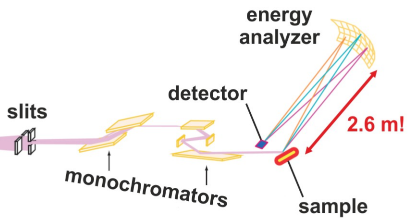


Image credit: Gross and Marx, Festkörperphysik





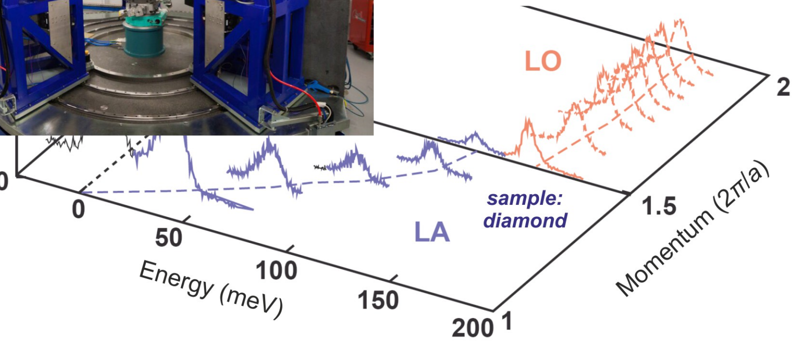
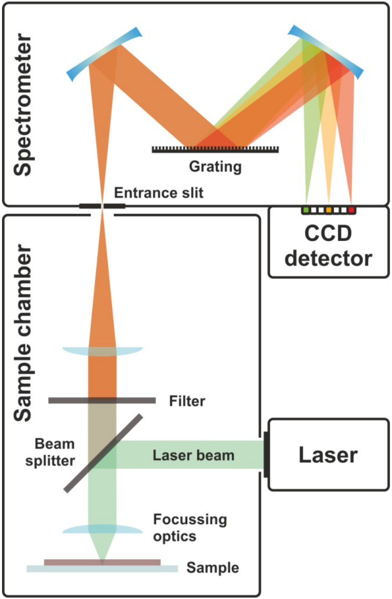
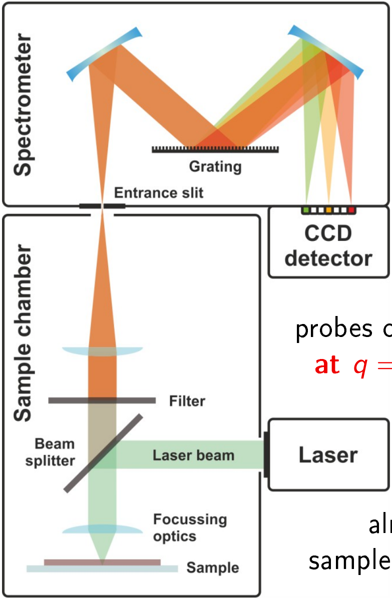


Image credit: Gross and Marx, Festkörperphysik and ESRF

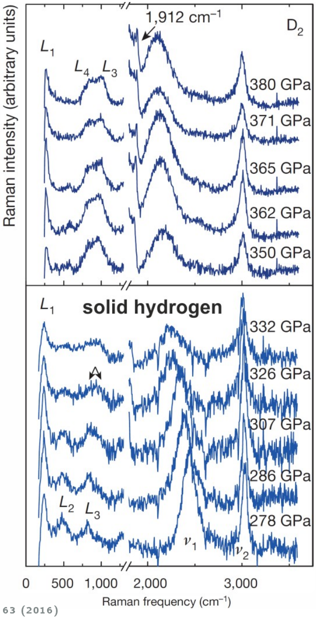
Raman (inelastic light) scattering





probes optical phonons
at $q = 0$ (Γ-point)

almost any
sample environment!



Person

Léon Brillouin

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1889–1969

- 1908–1912: study in Paris (Sorbonne and Collége de France)
- 1912–1913: internship in Munich with Arnold Sommerfeld

Sommerfeld: "Do you know Bessel functions? Calculate propagation of electromagnetic waves around Earth"

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Sommerfeld, 2 months later: "Well, I see that you don't have background for it. Then calculate propagation of electromagnetic waves in a crystal"

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1889–1969

- 1908–1912: study in Paris (Sorbonne and Collége de France)
- 1912–1913: internship in Munich with Arnold Sommerfeld
- 1920: PhD thesis, interaction between electromagnetic and elastic waves (**Brillouin scattering**)
- 1926: **WKB approximation**
- 1927: quantum theory of paramagnetism, **Brillouin function**
- 1930: concept of **Brillouin zones**

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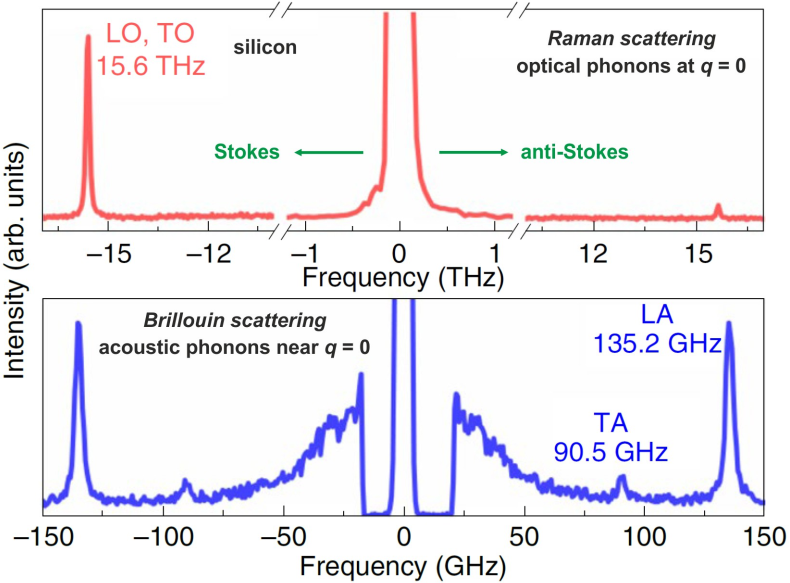

Nature Photonics 15, 720 (2021)