FYS3410 - Vår 2010 (Kondenserte fasers fysikk)

http://www.uio.no/studier/emner/matnat/fys/FYS3410/index-eng.xml

Based on Introduction to Solid State Physics by Kittel

Course content

- Periodic structures, understanding of diffraction experiment and reciprocal lattice
- Crystal binding, elastic strain and waves
- Imperfections in crystals: point defects and diffusion
- **Crystal vibrations: phonon heat capacity and thermal conductivity**
- Free electron Fermi gas: density of states, Fermi level, and electrical conductivity
- Electrons in periodic potential: energy bands theory classification of metals, semiconductors and insulators
- Semiconductors: band gap, effective masses, charge carrier distributions, doping, pn-junctions
- Metals: Fermi surfaces, temperature dependence of electrical conductivity

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FYS3410 lecture schedule and exams: Spring 2010

M/18/1/2010:	Introduction and motivation. Periodicity and lattices	2h
W/20/1/2010:	Index system for crystal planes. Crystal structures	1h
M/25/1/2010:	Reciprocal space, Laue condition and Ewald construction	2h
W/27/1/2010:	Brillouin Zones. Interpretation of a diffraction experiment	1h
M/01/2/2010:	Crystal binding, elastic strain and waves	2h
W/03/2/2010:	Elastic waves in cubic crystals; defects in crystals	1h
M/08/2/2010:	Defects in crystals; case study - vacancies	2h
W/10/2/2010:	Diffusion	1h
M/15/2/2010:	Crystal vibrations and phonons	2h
W/17/2/2010:	Crystal vibrations and phonons	1h
M/22/2/2010:	Planck distribution and density of states	2h
W/24/2/2010:	Debye model	1h
M/01/3/2010:	Einstein model and general result for density of states	2h
W/03/3/2010:	Thermal conductivity	1h
M/08/3/2010:	Free electron Fermi gas in 1D and 3D – ground state	2h
W/10/3/2010:	Density of states, effect of temperature – FD distribution	1h
M/15/3/2010:	Heat capacity of FEFG	2h
W/17/3/2010:	Repetition	1h
22/3/2010:	Mid-term exam	

M/14/4/2010:	Electrical and thermal conductivity in metals	2h
W/12/4/2010:	Bragg reflection of electron waves at the boundary of BZ	1h
M/19/4/2010:	Energy bands, Kronig - Penny model	2h
W/21/4/2010:	Empty lattice approximation; number of orbitals in a band	1h
M/26/4/2010:	Semiconductors, effective mass method, intrinsic carriers	2h
W/28/4/2010:	Impurity states in semiconductors and carrier statistics	1h
M/03/5/2010:	p-n junctions and heterojunctions	2h
W/05/5/2010:	surface structure, surface states, Schottky contacts	2h
M/10/5/2010:	no lectures	
W/12/5/2010:	no lectures	
W/19/5/2010:	Repetition	2h
W26/5/2010:	Repetition	2h
27-28/5/2010:	**Final Exam (sensor: Prof. Arne Nylandsted Larsen at the Aarhus University, Denmark, http://person.au.dk/en/anl@phys.au.dk)**	

Lecture 10: Crystal vibrations and phonons

- **Summary of vibrations based on harmonic oscillator approximation**
- **Born – von Karmer cyclic boundary conditions**
- **Interpretation in terms of phonons resulting from comparison of one harmonic oscillator (single atom) with a set of N synchronized harmonic oscillators (solid)**
- **Examples of phonon-assisted processes: photoluminescence in semiconductors**

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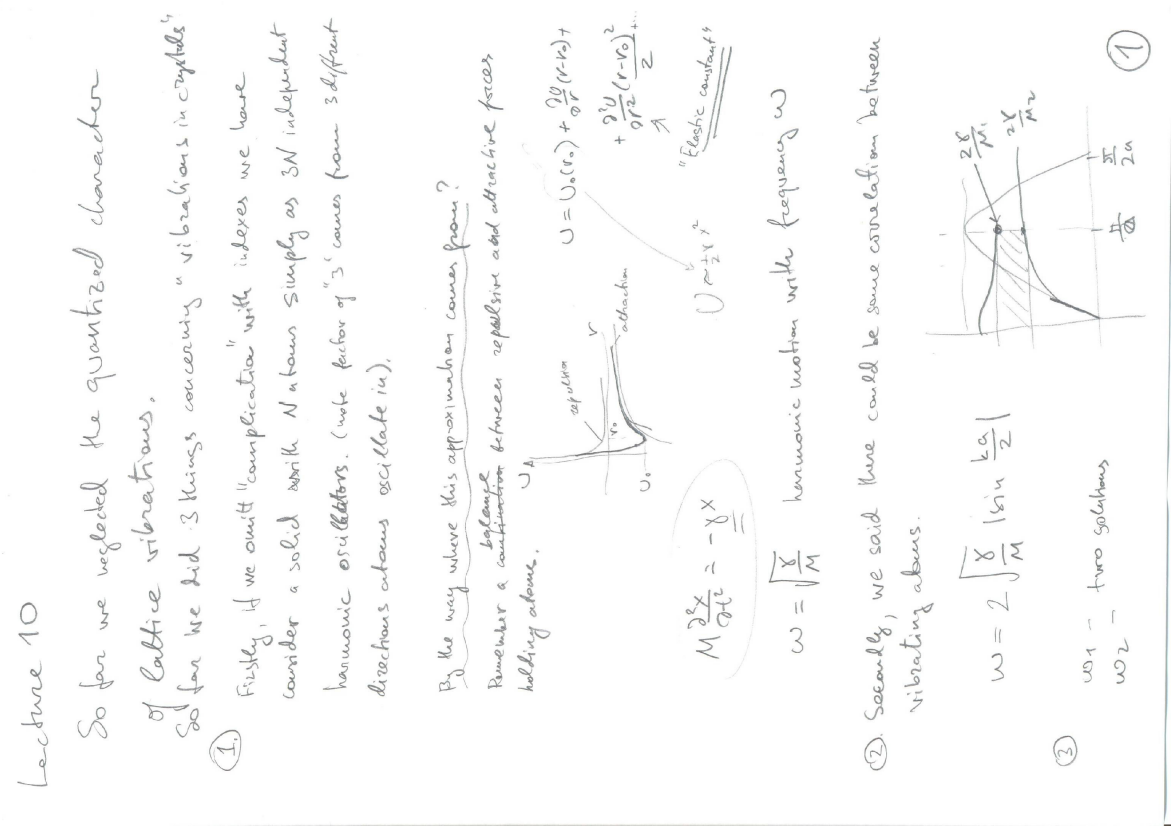
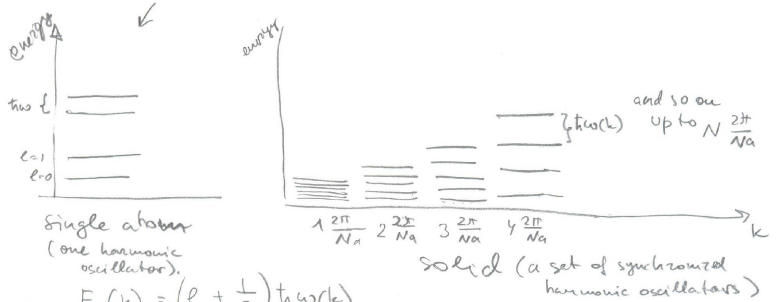


Coming back to the harmonic oscillator.

The energy levels are quantized with

$$E_\ell = \left(\ell + \frac{1}{2}\right)\hbar\omega \qquad E = \frac{1}{2}\gamma x^2$$

$\ell = 0, 1, \ldots \quad \omega = \sqrt{\frac{\gamma}{m}}$



Single atom (one harmonic oscillator).

solid (a set of synchronized harmonic oscillators)

$$(*) \rightarrow E_\ell(k) = \left(\ell + \frac{1}{2}\right)\hbar\omega(k)$$

number of k is limited $k = \frac{2\pi}{aN} m$ and just as ℓ takes only discrete values so that "k" can be used to "label" different oscillations.

! The combination of k and ℓ describes one vibrational state of a solid.

We can also come up with an alternative view of the whole vibrationalspectrum. We have started to look at the vibrational motion of a single atom but for a system of many atoms we have found vibrational modes in which <u>all</u> atoms participate Still, the Eq.(*) formally looks like the energy levels of many harmonic oscillators but these oscillators are <u>not</u> localized on any particular atom. All atoms participate. Often a single exitation of this oscillator spectrum is called a phonon.

Are there other problems we didnt think of so far?

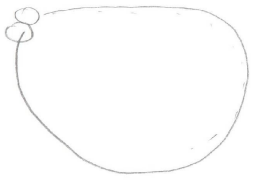
Yes! the chain of atoms (or solid in general) is not infinite.

we can just fix the ends of the chain

or

connect end to the beginning

Born - von Karman



$$U_{N+n}(t) = U_n(t)$$

Born - von karman restricts the possible k-values for the waves in the crystals.

First of all the longst possible wave for a chain of "N" atoms with a spacing of "a" is restricted to "Na"

More precisely, we have to require $U_n(t) = U_0 \exp[i(kna - \omega t)]$

$$e^{ikan} = e^{ika(N+n)} \Rightarrow e^{ikNa} = 1$$

$e^{ix} = (\cos x + i \sin x)$

$\cos 2\pi = 1$

$$ikNa = 2\pi \cdot m$$

$$\Downarrow$$

$$k = \frac{2\pi}{Na} \cdot m$$

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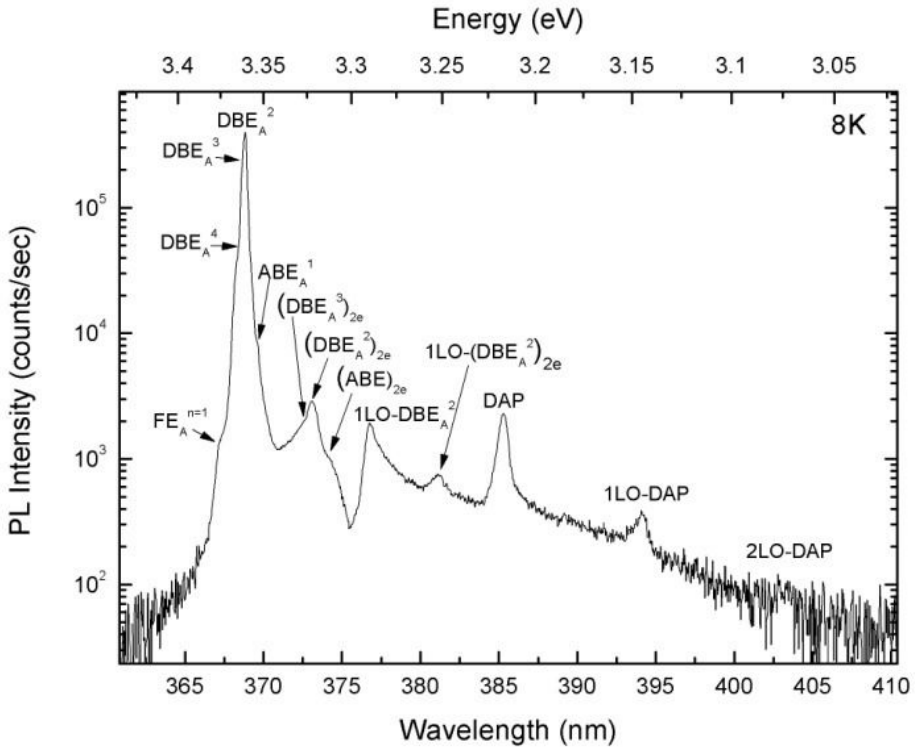
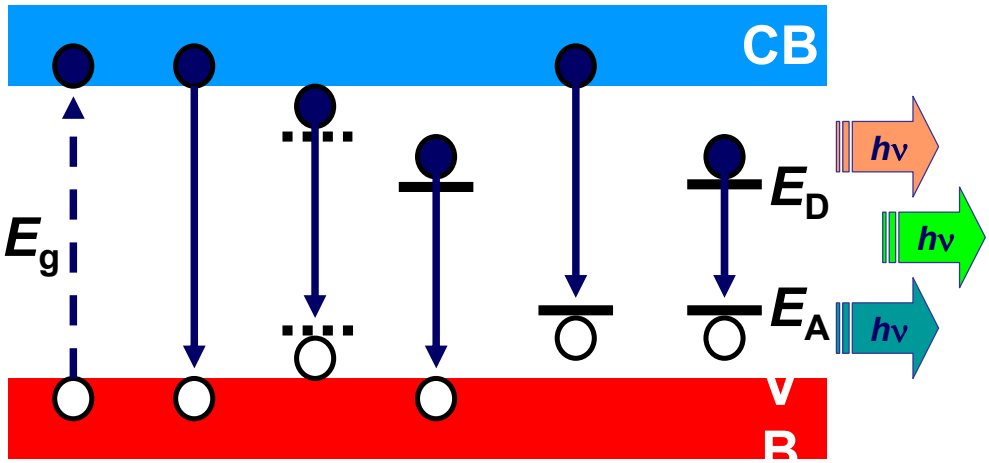
- **Examples of phonon-assisted processes: photoluminescence in semiconductors**

Photoluminescence



Recombination radiation



BAND-TO-BAND RECOMBINATION

$h\nu = E_g - nE_P$

Inelastic Scattering by Phonons

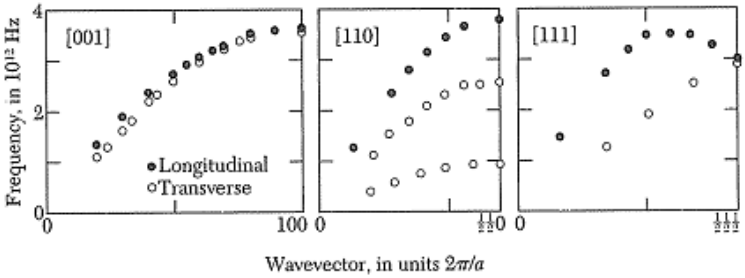
Neutron scattering:

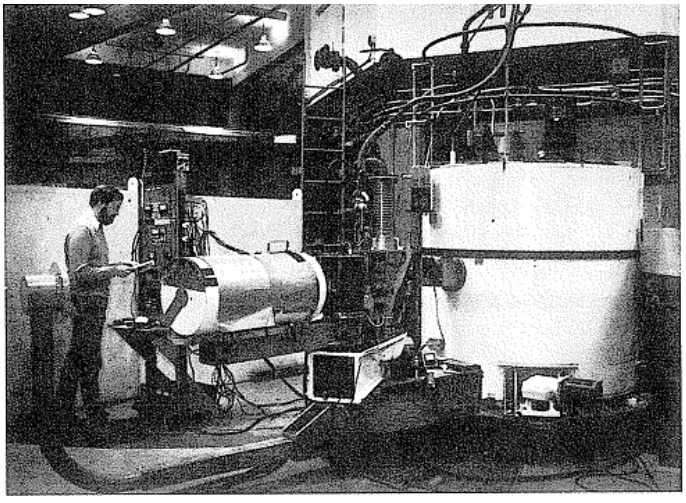
Conservation of momentum:

$$\mathbf{k}' \pm \mathbf{K} = \mathbf{k} + \mathbf{G}$$

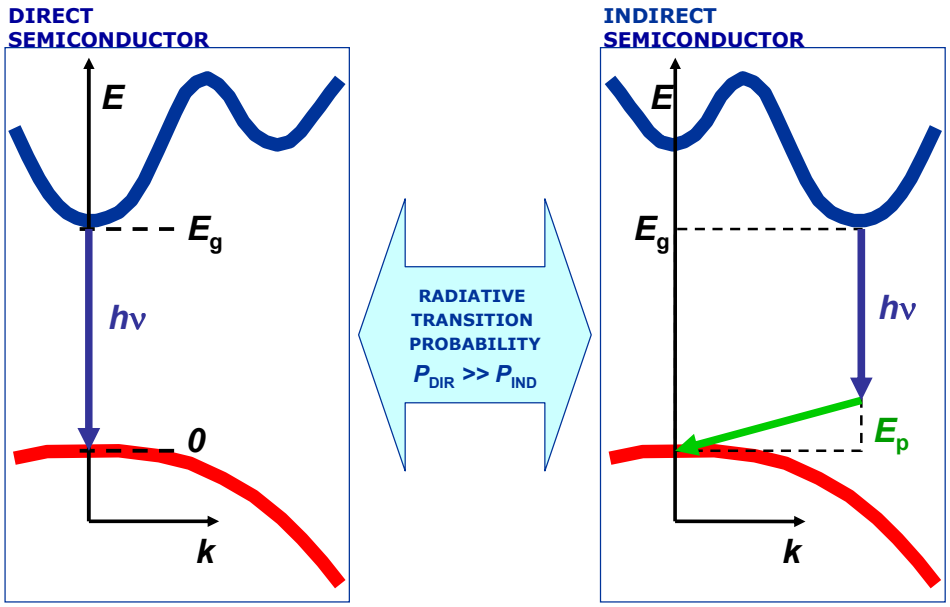
Conservation of energy:

$$\frac{\hbar^2 k^2}{2M_n} = \frac{\hbar^2 k'^2}{2M_n} \pm \hbar\omega$$





Radiative transitions



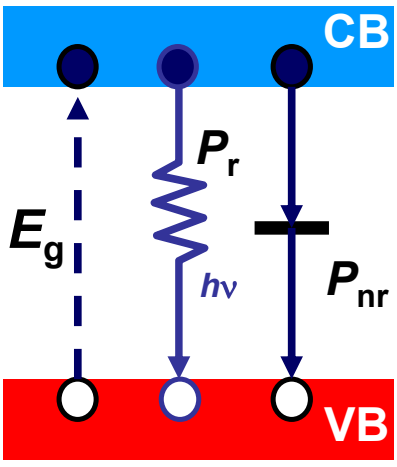
EMISSION SPECTRUM

$I(\nu) = B(h\nu - E_g)^{1/2}$

$h\nu = E_g - nE_p$

$I(\nu) = B(h\nu - E_g + E_p)^2$

Emission efficiency



COMPETITION OF RADIATIVE AND NONRADIATIVE RECOMBINATION

Quantum Efficiency

$$\eta = P_r / (P_r + P_{nr})$$

P_r - probability of **radiative** transitions

P_{nr} - probability of **nonradiative** transitions

$P_{nr} = P_{nr0} \exp(-E^*/kT)$

Thermal Quenching

$$\eta = [1 + C \exp(-E^*/kT)]^{-1}$$

where $C = P_{nr} / P_r = \tau_r / \tau_{nr}$