10.01.12

Introduction

- Lecturer: Jon Andreas Støvneng, room E5-112.
- Reference group = whole class
- Homepage: amokk.phys.ntnu.no / TFY4340
- Timetable: Tuesdays 10:15 - 13:00, Fridays 08:15 - 10:00 } 3(4)F / 2(1)Ø

  Ca 42 lectures; 12 calculation exercises
- Exam: Written exam, Friday June 1, 09:00 - 13:00, or another day that suits you all.
- "Arbeider": Either a numerical project or an oral presentation of a scientific paper. (Pass / Fail.)
- Syllabus (Pensum): Lectured material, Calculation exercises, Selected scientific papers
- Supporting literature: Heinzel; Datta; Beenakker and van Houten
- Recommended background for TFY4340:

  Electromagnetism

  Thermodynamics

  Quantum mechanics

  Statistical mechanics

  Solid state physics

Contents (tentative, based on 2010/2011 lectures):

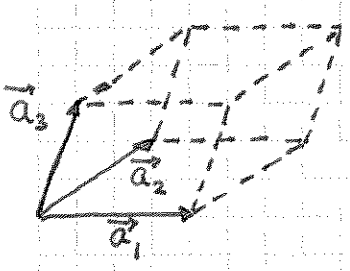
- Solid state physics update
  (Crystal structure, reciprocal lattice, electrons in crystals, density of states (DOS), periodic potential, Bloch's theorem, band structure, tight binding approximation, electron dynamics in crystals, semiconductors, carrier concentration, doping, surfaces, interfaces)
- Two-dimensional electron gas (2DEG) at SC-SC interface
- Contacts, gate electrodes, lateral patterns in 2DEG (lithography) ⇒ 1D and 0D structures (wires, dots)
- Transport theory (Drude model, Boltzmann equation, Einstein relations)
- Conductance in terms of transmission (Landauer formula)
- Magnetotransport (Drude model vs QM description, Landau levels, Büttiker-Landauer formalism, Onsager symmetry relations, multi-terminal devices, Quantum Hall Effect)
- Quantum interference effects (Aharonov-Bohm effect, weak localization, resonant tunneling)
- Single Electron Tunneling (Coulomb blockade, single electron transistor)
- Giant magnetoresistance ("Spintronics")
- Simple-minded presentation of physical phenomena at mesoscopic length scales ($\gg$ atomic scale, $\ll$ macroscopic scale)

Crystal structure

Bravais lattice: $\vec{R} = n_1\vec{a}_1 + n_2\vec{a}_2 + n_3\vec{a}_3$ $(n_i = 0, \pm 1, \pm 2, \ldots)$

Primitive vectors: $\vec{a}_i$; $i = 1, 2, \ldots, d$ $(d = \text{dimensionality})$

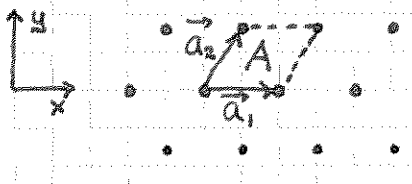
Primitive unit cell (several possibilities, but e.g. spanned by $\{\vec{a}_i\}$):



Volume: $V_3 = |(\vec{a}_1 \times \vec{a}_2)\cdot\vec{a}_3|$

(2D: $V_2 = A = |\vec{a}_1 \times \vec{a}_2|$)

Ex: 2D triangular lattice



$$A = \left| a\hat{x} \times \left(\frac{a}{2}\hat{x} + \frac{\sqrt{3}\,a}{2}\hat{y}\right)\right| = \left|\frac{\sqrt{3}}{2}a^2\hat{z}\right| = \underline{\frac{\sqrt{3}}{2}a^2}$$

Ex: 3D FCC Lattice (Face Centered Cubic)

$$\vec{a}_1 = \frac{a}{2}(\hat{x}+\hat{y}),\quad \vec{a}_2 = \frac{a}{2}(\hat{x}+\hat{z}),\quad \vec{a}_3 = \frac{a}{2}(\hat{y}+\hat{z})$$

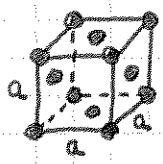
$$V = \left|\left((\hat{x}+\hat{y})\times(\hat{x}+\hat{z})\right)\cdot(\hat{y}+\hat{z})\right| \cdot \frac{a^3}{8}$$

$$= \left|(-\hat{y}-\hat{z})\cdot(\hat{y}+\hat{z})\right| \cdot \frac{a^3}{8}$$

$$= |-2| \cdot \frac{a^3}{8} = \frac{a^3}{4} = \text{volume pr lattice point}$$

i.e. 4 lattice points (e.g. atoms) occupy volume a^3,

OK:

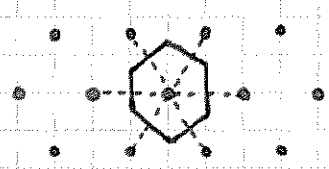


$8 \cdot 1/8 + 6 \cdot 1/2 = 4$

↑ corners ↑ faces

Wigner - Seitz cell: region of space around lattice point P closer to P than to all other lattice points

Ex: 2D triangular lattice



⇒ hexagonal W-S cell

Reciprocal Lattice

Defined as all wave vectors $\vec{K}$ such that $e^{i\vec{K}\cdot\vec{r}}$ has the periodicity of the Bravais lattice $\{\vec{R}\}$

$$\Rightarrow e^{i\vec{K}\cdot(\vec{r}+\vec{R})} = e^{i\vec{K}\cdot\vec{r}} \quad \Rightarrow \vec{K}\cdot\vec{R} = 2\pi\cdot l$$

$$\Rightarrow \vec{K} = \sum_{i=1}^{d} m_i \vec{b}_i \qquad (m_i = 0, \pm 1, \pm 2, \dots)$$

with $\vec{b}_i \cdot \vec{a}_j = 2\pi \cdot \delta_{ij}$ (δ_{ij} = Kronecker delta $= \begin{cases} 1; & i=j \\ 0; & i\neq j \end{cases}$)

If $d=3$:

$$\vec{b}_1 = \frac{2\pi}{V}(\vec{a}_2 \times \vec{a}_3)$$

$$\vec{b}_2 = \frac{2\pi}{V}(\vec{a}_3 \times \vec{a}_1)$$

$$\vec{b}_3 = \frac{2\pi}{V}(\vec{a}_1 \times \vec{a}_2)$$

$V = |(\vec{a}_1 \times \vec{a}_2)\cdot\vec{a}_3|$ = volume of primitive cell in direct space

$\tilde{V} = |(\vec{b}_1 \times \vec{b}_2)\cdot\vec{b}_3|$ = ——— " ——— reciprocal space

$$V\cdot\tilde{V} = (2\pi)^d$$

Brillouin zones

1. BZ = Wigner-Seitz cell in reciprocal space ("k-space") around $\vec{K} = 0$

n^{th} BZ = region of k-space with $\vec{K}=0$ as n^{th} nearest neighbour

FCC Bravais lattice $\Rightarrow$ BCC reciprocal lattice

BCC ——"—— $\Rightarrow$ FCC ——"——

Some common semiconductors:

Si, Ge: diamond lattice, i.e., two FCC lattices centered at $(0,0,0)$ and $\frac{a}{4}(1,1,1)$

GaAs etc: zincblende lattice, i.e., FCC Ga lattice centered at $(0,0,0)$ and FCC As lattice centered at $\frac{a}{4}(1,1,1)$

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Levi-Civita tensor (useful for multiple vector products)

$$\varepsilon_{ijk} = \begin{cases} +1 & \text{if } ijk = 123, 312, 231 \\ -1 & \text{if } ijk = 132, 312, 213 \\ 0 & \text{otherwise} \end{cases}$$

$$\varepsilon_{ijk}\,\varepsilon_{ilm} = \delta_{jl}\,\delta_{km} - \delta_{jm}\,\delta_{kl}$$

$$(\vec{A}\times\vec{B})_i = \varepsilon_{ijk}\,A_j\,B_k \equiv \sum_{j,k=1}^{3} \varepsilon_{ijk}\,A_j\,B_k ,$$

i.e., implicit summation over repeated indices

(Einstein summation convention)