Physics of low-dimensional systems

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Richting	Eysica
Jaar	MFYS

Bespreking

De vorm van het examen kan je zelf vrij kiezen, het is zoizo een apart theorie- en oefeningenexamen, maar of ze open/gesloten boek zijn is jullie vrije keuze !

De meest populare keuze is theorie gesloten boek en oefeningen openboek.

(bij een openboek theorieexamen moet je afleidingen doen parallel aan die uit de theoriecursus om zo een nieuw fenomeen te beschrijven).

Tip van de dag: Ziet da ge u grafiekskes goe kent, den Peeters is daar verzot op !

Puntenverdeling

Theorie: 10/20

Oefeningen: 10/20

Examenvragen

Academiejaar 2015-2016 1ste zit

Theorie

1. **Wigner crystallization.**
    - Plot the phase diagram (make use of two limits).
    - Give the relevant scales of temperature and denstity.
    - Indicate the classical and auantum regime.
2. **Einstein relation.**
    - Give the derivation.
    - Give the physical interpretation of this relation.
3. **Explain coherent backscattering peak.**
    - What is the equivalent phenomena for electrons?
    - Give one example of an experimernt how to measure this (for electrons).

Oefeningen

1. **Quantum well.** Electron is confined in a quantum well with witdh a in the z-direction, and there is also a potential $V_y(y)=m\hbar\omega^2y^2/2$. Write down the energy dispersion and calculate the DOS. Sketch the DOS for
   - $1/a^2 \ll \hbar\omega$
   - $1/a^2 \gg \hbar\omega$
2. **Coulomb barrier.** Similar to exc. 28.
3. **Graphene.** Show that there is a band gap in the dispersion when the symmetry of the sublattices is broken (e.g. $V_A=-V_B$). Do the same for double layer graphene with a perpendicular electrical potential ($V_1 \neq V_2$). Draw both dispersion relations.

Academiejaar 2014-2015 1ste zit

Theorie

1. The Hall effect.
   - What is the integer quantum Hall effect? How can it be measured? And give a physical explanation of it.
   - What is the fractional quantum Hall effect? And what is the physics behind it?
2. Derive the Schrödinger equation for electro-magnetic waves. How can you reconcile the energy-momentum relation in the Schrodinger equation with the linear dispersion relation of photons?
3. Explain persistent current and Aharonov-Bohm effect.
   - Derive the resonance equations for both effects and explain why they are different.
   - How can they be measured?

Oefeningen

1. Find the electron density per unit area for two cases ($T=0$):

   - a 2D semiconductor with parabolic energy bands, valley degeneracy 2 and an effective mass $m*$,

   - graphene.

   Express the two answers in terms of the Fermi energy and show that they are different. Express them in terms of the Fermi wave-vector and show that they are the same.

2. Consider the five-terminal Hall bar in a 2DEG, shown in the figure (http://i.imgur.com/nqsxelt.gif), in the presence of a strong magnetic field, electrons can be transported from one contact to the other only by edge states. The configuration is such that the main channel is pinched by top-gates and a quantum point contact (QPC) is formed. Consider that MM is the total number of (spin-degenerate) edge channels and KK is the number of channels reflected at the point contact. Show that:

    - The longitudinal resistance is RL=h2e2KM(M−K)RL=h2e2KM(M−K).
    - The Hall resistance between probes on the two sides of the QPC is RH=h2e21M−KRH=h2e21M−K.
    - The Hall resistance between probes on one side of the QPC is RH=h2e21MRH=h2e21M.

3. It is known that due to lattice symmetries, both single and bilayer graphene are **zero-gap** semiconductors. Show how this intrinsic property can be broken, i.e. show how can a gap be induced in the electronic spectrum?

4. Consider a quantum wire with a rectangular cross-section, Lx=aLx=a, Ly=bLy=b. Find the energy dispersion and the density of states of free electrons confined inside the wire. How do these quantities change as the aspect ratio of the wire changes from square, to thin-film, i.e. from Lx=LyLx=Ly to Lx≫LyLx≫Ly.

Academiejaar 2013-2014 1^ste zit

Theorie

1. Construct the phase diagram for Wigner crystallisation in 2D.
2. Fractional Quantum Hall Effect. What is it? Give a theoretical explanation for this effect.
3. Skyrmions in a 2DEG. Under which conditions can they be observed?
4. Persistent current. What is it? Give a physical explanation for it. How can it be observed?
5. Coherent back scattering. What is it? Give one experiment how it can be observed. What is the equivalent effect for electrons?

Academiejaar 2012-2013 1^ste zit

Theorie

Gesloten boek, schriftelijke voorbereiding met achteraf mondelinge verdediging.

1. Explain Coulomb blockade.

    What are the conditions under which this effect can be observed?

2. What is weak localization?
   - Give one experiment how to measure this effect.
   - What is the equivalent effect for light?
   - Give one example of an experiment how to measure this with light.
3. Give (and derive) the phasediagram for Wigner crystallization for a two dimensional electron gas. Indicate where the classical and the quantum regime are located.
   Derive the Landauer formula.
4. What is the quantum Hall effect?
   Compare this effect for a 2DEG and graphene. Explain the differences.

Oefeningen

De oefeningen werden dit jaar door Lucian Covaci gegeven en waren openboek, waarbij zowel cursus als eigen notities van de oefeningen gebruikt mochten worden.

1. Optical absorption in quantum wells. Consider a heterostructure consisting of a thin GaAs layer sandwiched between to thick AlGaAs layers such that a quantum well is achieved. Assume that the quantum well can be approximated as an infinite quantum well of width aa.
   - Find the electron and hole wave-functions and the energy levels inside the well.
   - Consider different thicknesses for the GaAs layer, aa is 9.4 nm and 1 nm. Is the infinite well approximation for the lowest energy states still realistic if the depth of the well is V_0 = 0.3 eV?
   - Find the maximal wavelength of absorbed radiation seen in the optical absorption for a well of width a=9nma=9nm.
   - Sketch the dependence of the maximal wavelength on the well thickness. Consider that the effective mass of the electrons is m_e = 0.067 m_0 and that there are two hole species, the heavy holes with effective mass m_{hh} = 0.5 m_0 and the light holes with effective mass m_{lh} = 0.082 m_0, where m_0 is the mass of the free electron.
2. Potential step (Schrödinger and Dirac). Consider an electron impinging on a potential step of height V0V0 at an angle of incidence θθ. Find the angle dependent reflection and transmission probabilities for:
   - an electron in a two dimensional electron gas,
   - an electron in a graphene sheet, as a function of energy of the incoming electron, EE, with respect to the potential step height, U0U0. Write down the equivalent of Snell's law for both cases and find the condition for total reflection.

3. Landauer formula. Consider a ballistic channel connecting two reservoirs with Fermi energies EF,L=EF−eVEF,L=EF−eV and EF,R=EFEF,R=EF.
    - Derive the Landauer formula for the conductance, assuming the Fermi-Dirac distribution function and the conditions
      |eV|≪|EF|
      $$|eV| \ll |E_F|$$
      and T→0T→0.
    - Find the number of conducting modes if the channel is considered to be a nanowire with a rectangular cross-section (a×ba×b).
    - Show that in the presence of scatterers the transmission probability for a long wire of length LL can be written as:
      T(L)=L0L+L0
      $$T(L)=\frac{L_0}{L+L_0}$$
      where L0=ν−1T/(1−T)L0=ν−1T/(1−T) is a characteristic length and νν is the linear density of scatterers.
    - Using the previous formula show that in the limit of a large wire, Ohm's law, R∼L/AR∼L/A, is recovered.
4. Hall bar. Quantum Hall effect. Find the Hall resistance $R_{13,24}$ and the two-point resistance, $R_{13,13}$ for the 2DEG Hall bar with four terminals. Show that in the presence of a perpendicular magnetic field and when the Fermi levels lies between two Landau levels, the Hall resistance is quantized while the two-point resistance is zero. Assume that the width of the contacts is large such that the current is transmitted only through edge currents due to skipping orbits.

Academiejaar 2011-2012 1ste zit

Theorie

1. Consider an electron moving in 2D in the presence of a perpendicular magnetic field.
    - Calculate the energy spectrum.
    - Calculate the density of states.
    - Do the same calculation for an electron moving in 3D.
2. What is the Aharonov-Bohm effect?
    - Give a derivation of this effect.
    - What is the difference with the persistent current in a ring?
3. Einstein relation.
    - Give a derivation.
    - Give the physical interpretation of this relation.
4. Explain coherent backscattering peak.
    - What is the equivalent phenomena for electrons?
    - Give one example of an experiment how to measure this for electron.
    - Give one example of an experiment how to measure this with light.

Oefeningen

1. Consider a tree-dimensional analogue of graphene for which the low-energy excitations described by the following Hamiltonian $\hat{H}=v_F\vec{\sigma}\cdot\vec{p}$ with v_F the Fermi-velocity and $\vec{\sigma}=(\sigma_x,\sigma_y,\sigma_z)$ the Pauli-vector.
    - Calculate the energy spectrum for this system.
    - Calculate the density of states and make a figure
    - Calculate the Fermi-vector as a function of the carrier density
2. Consider the perfectly symmetric quantum Hall probe as given in the figure. Due to the large size of the applied magnetic field, only transport at the edges is possible through skipping orbits (as shown in the figure). This also implies there is perfect transmission in these edge channels. in the experiment a current is driven from contact 1 to 4 whereas the other contacts are used for voltage measurements. Use the Landauer-Buttiker formalism to calculate the following quantities assuming 1 available conduction channel:
    - The current I between contact 1 and 4.
    - The Hall resistance $R_{26,14}$
    - The longitudinal resistance $R_{65,14}$
    - What happens to the above quantities if more than one conduction channel is present (say n)?

Fout bij het aanmaken van de miniatuurafbeelding: Bestand is zoek

Categorieën:
- Fysica
- MFYS