Quantum Transport and Nanoscale Physics

Educational subject description sheet

Basic information

Study programme Fizyka **Speciality** INFORMACJA KWANTOWA I SPINTRONIKA **Organizational unit** Faculty of Physics **Study level** Second-cycle programme **Study form** Full-time **Education profile** General academic	**Didactic cycle** 2023/24 **Subject code** 04FIZIKSS.22S.04364.23 **Lecture languages** English **Course type** Elective **Block** specialty subjects
Subject coordinator	Ireneusz Weymann
Lecturer	Ireneusz Weymann, Kacper Wrześniewski

Period	**Activities and hours**	**Number of ECTS points**
Semester 2	• Lecture: 30, Exam • Laboratories: 30, Graded credit	6

Goals

Code	Goal
C1	The aim of this course is to present and discuss the main effects that emerge in the broad field of quantum transport and nanoscale physics, with an emphasize on effects and systems important for quantum information and spintronics.
C2	The second goal is to teach the students the basic formalism and methods that are used in the analysis of quantum effects in transport through various nanostructures, with a special focus on systems relevant for quantum information and spintronics.

Subject learning outcomes

Code	Outcomes in terms of	Learning outcomes	Examination methods
Knowledge – Student:			
W1	knows the basic trends in nanoscience in the context of quantum technologies	FIZ_K2_W01, FIZ_K2_W02, FIZ_K2_W03, FIZ_K2_W04	Written exam, Oral exam, Project, Report
W2	knows and understands the quantum effects that emerge in transport through nanoscale systems	FIZ_K2_W01, FIZ_K2_W02, FIZ_K2_W03	Written exam, Oral exam, Project, Report
W3	is familiar with the basic formalism describing quantum transport in nanostructures	FIZ_K2_W02, FIZ_K2_W03	Written exam, Oral exam, Project, Report
W4	knows and understands the role of quantum science in the development of new technologies	FIZ_K2_W05	Written exam, Oral exam, Project, Report
Skills – Student:			
U1	is able to solve basic problems and issues related to quantum transport with the aid of learnt theoretical tools/methods	FIZ_K2_U01	Project, Report
U2	is able to read and understand the specialized literature related to quantum transport and general quantum science	FIZ_K2_U05	Written exam, Oral exam
U3	is able to identify the current trends and challenges in the field of quantum transport and nanoscale physics	FIZ_K2_U02, FIZ_K2_U07	Written exam, Oral exam
U4	is able to program and use numerical methods to study transport properties of nanostructures	FIZ_K2_U01	Project, Report
Social competences – Student:			
K1	is ready to discuss contemporary challenges regarding development of new technologies and quantum science	FIZ_K2_K01, FIZ_K2_K02	Written exam, Oral exam

Study content

No.	Course content	Subject learning outcomes	Activities
1.	Nano-scale, dimensionality, different transport regimes and new effects emerging in nanoscale systems.	W1, W2, W3, W4, U2, U3, K1	Lecture
2.	Scattering formalism, Landauer formula, tunnel effect, tunneling through a double tunnel junction and the Breit-Wigner formula for resonant tunneling.	W1, W2, W3, W4, U1, U2, U3, U4, K1	Lecture, Laboratories
3.	Tunneling Hamiltonian, tunnel rates and current: orthodox theory of single-electron transport. Coulomb blockade, sequential tunneling, cotunneling, strong correlations.	W1, W2, W3, W4, U1, U2, U3, U4, K1	Lecture, Laboratories
4.	Equilibrium Green’s function theory: retarded, advanced, lesser and greater Green’s functions and their relation to physical quantities, free-electron Green’s functions, spectral function, fluctuation-dissipation theorem.	W1, W2, W3, W4, U1, U2, U3, U4, K1	Lecture, Laboratories

No.	Course content	Subject learning outcomes	Activities
5.	Nonequilibrium transport theory: nonequilibrium Green’s functions method and the Meir-Wingreen formula.	W1, W2, W3, W4, U1, U2, U3, U4, K1	Lecture, Laboratories
6.	Overview of recent advances in transport properties of nanoscale systems.	W1, W2, W3, W4, U2, U3, K1	Lecture

Additional information

Activities	Teaching and learning methods and activities
Lecture	Lecture with a multimedia presentation of selected issues, Conversation lecture, Discussion
Laboratories	Problem-based learning, Project method, Activating method - "brainstorming", Work in groups

Activities	Credit conditions
Lecture	The students have to pass the written exam, which will be followed by an optional oral exam and discussion. Assessment criteria: Very good (bdb; 5,0): 90-100% of final score Good plus (+db; 4,5): 80-89% of final score Good (db; 4,0): 60-79% of final score Satisfactory plus (+dst; 3,5): 60-69% of final score Satisfactory (dst; 3,0): 50-59% of final score Unsatisfactory (ndst; 2,0): 0-49% of final score
Laboratories	Preparation of a short project on a given quantum transport problem. This should include programming (in a language like C, C++, Python, Matlab, Mathematica, etc.), performing numerical calculations and analysis of the transport properties for a specific nanoscale model. Obtained results should be discussed in a short presentation or report, preferably prepared in latex. The mark (from 2.0 to 5.0) will take into account the implementation of the calculations, performed analysis and quality of the presentation.

Literature

Obligatory

1. Yuli Nazarov and Yaroslav Blanter, Quantum Transport (Cambridge 2009)
2. Tero Heikkila, The Physics of Nanoelectronics – Transport and Fluctuation Phenomena at Low Temperatures (Oxford Univ. Press 2013)
3. Hartmut Haug, Anti-Pekka Jauho, Quantum Kinetics in Transport and Optics of Semiconductors (Springer 2008) (chapter 3 and 12)

Optional

1. Massimiliano Di Ventra, Electrical Transport in Nanoscale Systems (Cambridge 2008)
2. Original research papers, references given during lecture

Calculation of ECTS points

Activities	Activity hours*
Lecture	30

Laboratories	30
Preparation for classes	30
Reading the indicated literature	30
Preparation of a project	30
Preparation for the exam	30
Student workload	**Hours** 180
Number of ECTS points	**ECTS** 6

* academic hour = 45 minutes

Efekty uczenia się dla kierunku

Kod	Treść
FIZ_K2_K01	The graduate is ready to critically evaluate own knowledge and received content
FIZ_K2_K02	The graduate is ready to recognize the importance of knowledge in solving cognitive and practical problems and seeking expert opinion (also from other scientific disciplines) to overcome difficulties during independent problem solving
FIZ_K2_U01	The graduate can use their knowledge to formulate and solve complex and unusual problems in the field of physical sciences; select and apply appropriate methods and tools necessary to solve a given problem (including advanced IT techniques), as well as adapt existing methods and tools or develop completely new ones
FIZ_K2_U02	The graduate can find the necessary information in the professional literature, databases and other sources, in particular in scientific journals basic to physics, and perform critical analysis, synthesis and creative interpretation of the collected information
FIZ_K2_U05	The graduate can use English in accordance with the requirements set out for level B2+ of the Common European Framework of Reference for Languages, as well as specialist English terminology in the field of physical sciences
FIZ_K2_U07	The graduate can independently determine the directions of further learning and implement a self-education program, learn throughout lifetime using the available international literature and be able to guide others in this regard
FIZ_K2_W01	The graduate knows and understands in-depth selected facts, phenomena, concepts and theories specific to physics and complex relationships between them (constituting advanced general knowledge in the field of physical sciences and representing both key and other selected issues in the field of advanced detailed knowledge in this discipline)
FIZ_K2_W02	The graduate knows and understands in-depth selected research methods and tools as well as mathematical models used in physics
FIZ_K2_W03	The graduate knows and understands in-depth selected computational methods and information technology tools and techniques used to solve complex problems in physics
FIZ_K2_W04	The graduate knows and understands main development trends in the discipline of physical sciences
FIZ_K2_W05	The graduate knows and understands the role of physical sciences in the context of fundamental dilemmas and challenges of modern civilization