Subject card

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| Subject name and code | Quantum Thermal Machines, PG_00159206 | | | | | |
| Field of study | Quantum Information Technology | | | | | |
| Date of commencement of studies | October 2025 | | Academic year of realisation of subject | | 2026/2027 | |
| Education level | Master’s studies | | Subject group | | | |
| Mode of study | full-time studies | | Mode of delivery | | at the university | |
| Year of study | 2 | | Language of instruction | | English | |
| Semester of study | 3 | | ECTS credits | | 6.0 | |
| Learning profile | academic | | Assessment form | | exam | |
| Conducting unit | Faculty of Mathematics, Physics and Informatics -> Rector | | | | | |
| Name and surname of lecturer (lecturers) | Subject supervisor | dr Borhan Ahmadi | | | | |
| | Teachers | | | | | |
| Lesson types | Lesson type | Lecture | Tutorial | Laboratory | Project | Seminar | SUM |
| | Number of study hours | 30.0 | 30.0 | 0.0 | 0.0 | 0.0 | 60 |
| | E-learning hours included: 0.0 | | | | | | |
| Learning activity and number of study hours | Learning activity | Participation in didactic classes included in study plan | Participation in consultation hours | Self-study | SUM | |
| | Number of study hours | 60 | 0.0 | 30.0 | 90 | |
| Subject objectives | The aim of the course is to apply thermodynamics of non-dissipative and dissipative quantum systems in studying efficiency of energy transfer in the microscopic systems. | | | | | |

| Learning outcomes | | | |
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| | Course outcome | Subject outcome | Method of verification |
| | [QITL3_W02] has in-depth knowledge in the field of advanced mathematics and mathematical and computer methods, necessary to solve physical problems of medium complexity, and advanced knowledge in the area of quantum information and its technological aspects | Student has in-depth knowledge about open system methods. | [SW4] test/exam - oral or written |
| | [QITL3_W04] knows advanced methods of theoretical and mathematical physics necessary in creating models of quantum mechanics | Student knows advanced analytical techniques to model physical systems for thermodynamic purposes. | [SW4] test/exam - oral or written |
| | [QITL3_U01] is able to apply the scientific method in solving physical problems and reasoning in the field of quantum information theory | Student has the ability to apply the scientific method in studies of energy transfer in quantum physical systems. | [SU4] test/exam - oral or written |
| | [QITL3_U05] has the ability to synthesize methods and ideas from various areas of physics and other branches of science; is able to notice that distant phenomena are sometimes described by similar models | Student has the ability to connect analytical methods of open quantum systems and techniques for their numerical simmulation with tools used in different areas of physics | [SU4] test/exam - oral or written |
| | [QITL3_W03] knows advanced experimental, observational and numerical techniques allowing to plan and perform a complex physical experiment or computer simulation | Student knows how to do numerical calculations and simulations to solve many-body differential equations. | [SW4] test/exam - oral or written |
| | [QITL3_W05] knows the theoretical foundations of computational methods and IT techniques used to model and simulate physical systems considered in quantum information theory | methods used to simulate many-body systems | [SW4] test/exam - oral or written |
| | [QITL3_K02] is aware of the decisive role of experiment in the verification of physical theories; is aware of the existence of the scientific method in acquiring knowledge | Student knows the importance of the experimental implementation of quantum thermal systems in veryfying theoretical predictions based on approximations | [SK4] test/exam - oral or written |
| | [QITL3_W01] has extended knowledge in the field of general physics and advanced knowledge in the area of quantum information theory; knows the history of the development of quantum information theory and its importance for the progress of science, knowledge of the world and social development | Student has extended knowledge in the field of thermodynamics and advanced knowledge in dissipative systems. | [SW4] test/exam - oral or written |
| | [QITL3_W06] has knowledge of current directions in the development of physics, in particular in the field of quantum information theory | Student is familiar with the present literature in the field of quantum thermal machines. | [SW4] test/exam - oral or written |
| | [QITL3_U02] has the skills to plan and conduct basic and advanced research and calculations in the area of quantum information theory or its applications | Student is capable of assesing regime of validity of approximations used in modelling of quantum open systems. | [SU4] test/exam - oral or written |
| Subject contents | Quantum thermodynamic variables: Work and heat, Non-dissipative and dissipative quantum systems, Quantum thermal machines, Quantum transistors, Quantum Batteries. | | |
| Prerequisites and co-requisites | | | |
| Assessment methods and criteria | Subject passing criteria | Passing threshold | Percentage of the final grade |
| | tutorial part: test | 51.0% | 50.0% |
| | lecture part: exam | 51.0% | 50.0% |

<table>
<tr><td rowspan="3">Recommended reading</td><td>Basic literature</td><td>Quantum Thermodynamics: Emergence of Thermodynamic Behavior Within Composite Quantum Systems by Jochen Gemmer , M. Michel, Günter Mahler (2012)</td></tr>
<tr><td>Supplementary literature</td><td>None.</td></tr>
<tr><td>eResources addresses</td><td></td></tr>
<tr><td>Example issues/<br>example questions/<br>tasks being completed</td><td colspan="2">1. Work and Heat in Quantum Systems<br><br>• Definitions of work and heat in quantum mechanics.<br>• Internal energy and the quantum first law of thermodynamics.<br>• Two-point measurement (TPM) protocol for work statistics.<br>• Work fluctuations and quantum fluctuation theorems.<br>• Physical examples illustrating the distinction between work and heat.<br><br>2. Dynamics of Dissipative and Non-Dissipative Quantum Systems<br><br>• Closed versus open quantum systems.<br>• Unitary and non-unitary time evolution.<br>• Density matrix formalism and quantum master equations.<br>• Lindblad equation and its physical interpretation.<br>• Thermalization, decoherence, and steady states.<br><br>3. Quantum Thermal Machines<br><br>• Quantum heat engines and refrigerators.<br>• Quantum Otto and Carnot cycles.<br>• Efficiency, power, and performance optimization.<br>• Role of coherence and quantum correlations in thermal machines.<br>• Comparison between classical and quantum thermal machines.<br><br>4. Quantum Thermal Transistors<br><br>• Concept and operating principles of a quantum thermal transistor.<br>• Heat currents and thermal amplification.<br>• Three-terminal quantum thermal devices.<br>• Physical implementations (e.g., quantum dots, superconducting circuits, trapped ions).<br>• Applications in thermal management and quantum technologies.<br><br>5. Quantum Batteries<br><br>• Definition and motivation for quantum batteries.<br>• Charging and discharging dynamics.<br>• Collective versus local charging protocols.<br>• Quantum advantage: the role of entanglement and collective interactions.<br>• Experimental implementations and current challenges.</td></tr>
<tr><td>Work placement</td><td colspan="2">Not applicable</td></tr>
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