UNIVERSITÀ DEGLI STUDI DI PALERMO

DEPARTMENT	Fisica e Chimica - Emilio Segrè
ACADEMIC YEAR	2022/2023
MASTER'S DEGREE (MSC)	PHYSICS
INTEGRATED COURSE	QUANTUM THERMODYNAMICS
CODE	22748
MODULES	Yes
NUMBER OF MODULES	2
SCIENTIFIC SECTOR(S)	FIS/03
HEAD PROFESSOR(S)	NAPOLI ANNA Professore Associato Univ. di PALERMO
OTHER PROFESSOR(S)	MILITELLO BENEDETTO Professore Associato Univ. di PALERMO PATERNOSTRO MAURO Professore Ordinario Univ. di PALERMO
CREDITS	6
PROPAEDEUTICAL SUBJECTS	
MUTUALIZATION	
YEAR	2
TERM (SEMESTER)	1° semester
ATTENDANCE	Not mandatory
EVALUATION	Out of 30
TEACHER OFFICE HOURS	**MILITELLO BENEDETTO** Tuesday 14:30 16:00 Stanza 122, Dip. Fisica e Chimica, Via Archirafi 36. Thursday 14:30 16:00 Stanza 122, Dip. Fisica e Chimica, Via Archirafi 36. **NAPOLI ANNA** Monday 15:00 16:30 Dipartimento di Fisica e Chimica, stanza 122, Via Archirafi 36 Friday 14:30 16:00 Dipartimento di Fisica e Chimica, stanza 122, Via Archirafi 36

DOCENTE: Prof.ssa ANNA NAPOLI

PREREQUISITES	The students are supposed to be familiar with basic concepts of classical physics, quantum mechanics and statistical mechanics. In particular, students must know the principles of (classical) thermodynamics, the quantum mechanical description of simple microscopic systems (free particle, particle in a quadratic potential, spins and few-level systems). Moreover, they should be familiar with statistical mechanics and with concepts such as phase space, ergodicity, partition function, microcanonical, canonical and gran canonical ensembles. Students are also supposed to have some mathematical skills especially concerning multiple integrals, partial derivatives and matrix algebra.
LEARNING OUTCOMES	Knowledge and understanding: The course is meant to provide an introduction to open questions concerning the link between thermodynamics and quantum mechanics. It introduces ideas and methods in the grasp of the students who attended the courses of the first year of the second cycle course in Physics. Applying knowledge and understanding: lectures will be organized in such a way to make the students fruitfully participate to extensive discussions aimed at a deep understanding of thermodynamic concepts such as entropy and temperature. The role of entanglement in the emergence of thermodynamics from quantum mechanics will be particularly explored. Students will be stimulated to familiarize with qualitative and quantitative aspects of the concepts developed in the course, by addressing important conceptual problems and open questions concerning quantum thermodynamics. Making Judgements: Students will be stimulated to independently process the concepts introduced in the lectures, the aim being twofold: to offer a training in understanding problems and to provide motivations for finding new problems which could deserve an in-depth study, even at a research-activity level. Communication skills: Students must acquire the ability to present in a clear way the problems discussed during the course. To facilitate the acquisition of such ability, students will be stimulated to discuss about the meaning and resolution of problems proposed by the teacher. Learning skills: Detailed suggestions about the relevant bibliography (books and scientific papers) will be provided by the teacher, which will allow the students to get the highest profit from the lectures.
ASSESSMENT METHODS	The final examination consists of a short oral presentation on a topic previously agreed with the teachers and of an oral examination during which the candidate will be requested to demonstrate his/her knowledge of the contents of the course, even on topics different from that related to his oral presentation. The final assessment will be based on the following criteria: -Insufficient (exam not passed) if the candidate does not show an acceptable knowledge of the contents of the course. -Sufficient (mark 18-20) if the candidate shows a sufficient knowledge of the contents of the course but a limited ability of both presenting the concepts and applying the methods described in the course. -Satisfactory (mark 21-23) if the candidate exhibits sufficient knowledge of the contents, sufficient ability of presenting the concepts and applying the methods. -Good (mark 24-26) if the candidate exhibits good knowledge of the contents, sufficient ability of presentation and sufficient ability to apply the methods. -Very good (mark 27-29) if the candidate exhibits good knowledge of the contents, good ability of presentation, and fairly good ability of application of the methods. -Excellent (mark 30-30 cum laude) if the candidate exhibits excellent knowledge of the concepts, excellent ability of presentation and the ability to apply autonomously the methods.
TEACHING METHODS	The didactic activity is organized in lectures. The lectures aim at bringing to light open problems related to the connection between classical thermodynamics (CT) and quantum mechanics (QM), at providing new tools and methods which are typical of quantum thermodynamics (QT) and showing how they can be used to construct a direct link between CT and QM. These tools are also useful in the study of systems out of equilibrium. Moreover simple examples will be discussed in order to make the students familiar with the methods of QT and able to apply such methods to the study of simple systems.

MODULE
QUANTUM THERMODYNAMICS

Prof. BENEDETTO MILITELLO

SUGGESTED BIBLIOGRAPHY	
J. Gemmer, M. Michel, G. Mahler, Quantum Thermodynamics: Emergence of Thermodynamic Behavior Within Composite Quantum Systems, (2nd Edition), Springer. ISBN: 978-3-540-70509-3 - ISBN eBook: 978-3-540-70510-9 Altro materiale fornito dal docente / Additional material provided by the teacher	
AMBIT	20901-Attività formative affini o integrative
INDIVIDUAL STUDY (Hrs)	51
COURSE ACTIVITY (Hrs)	24
EDUCATIONAL OBJECTIVES OF THE MODULE	
1) Understanding of the meaning of studying thermodynamic properties in the realm of quantum mechanics. Understanding of the conceptual and methodological differences between statistical mechanics and quantum thermodynamics. 2) Quantum thermodynamics at equilibrium for systems under microcanonical, canonical and grand canonical conditions, and in the strong-coupling limit. 3) Method of averages in the “accessible regions” applied to at-equilibrium or out-of-equilibrium systems.	

SYLLABUS

Hrs	Frontal teaching
1	Problematic aspects of the foundations of thermodynamics. The problem of using thermodynamics at a microscopic level.
1	H-Theorem and its consequences.
2	Density operator: definition and general properties, purity and von Neumann entropy, scalar products and distances.
14	The concept of typicality and the key role of the environment and system-environment correlations. Accessible regions and Hilbert-space averages. Typicality under microcanonical, canonical and grand canonical conditions.
2	Energy degeneracy of modular environments.
2	Strong-coupling limit and typicality of the reduced state of the system.
2	Brief discussion on the Hilbert-space average methods applied to non-equilibrium systems.

MODULE
NON-EQUILIBRIUM QUANTUM THERMODYNAMICS

Prof. MAURO PATERNOSTRO

SUGGESTED BIBLIOGRAPHY	
H.-P. Breuer and F. Petruccione, The Theory of Open Quantum Systems (Oxford University Press, Oxford, UK, 2002). Materiale didattico fornito dal docente	
AMBIT	20901-Attività formative affini o integrative
INDIVIDUAL STUDY (Hrs)	51
COURSE ACTIVITY (Hrs)	24
EDUCATIONAL OBJECTIVES OF THE MODULE	
Traditional and non-traditional approaches to non-equilibrium evolutions. Thermodynamic processes at a microscopic scale and quantum thermal machine	

SYLLABUS

Hrs	Frontal teaching
3	Out-of-equilibrium systems interacting with their environment: completely positive maps, Lindblad master equations
7	Markovian Master Equations: microscopic derivation. Kubo-Martin-Schwinger relation. Thermal state. Heat- and work terms in a master equation.
2	Stationary states in presence of many baths. Heat transfer
4	Out of equilibrium systems and non-Hermitian operators. Spectral analysis of Lindblad operators. Non Hermitian hamiltonian.
6	Microscopic thermodynamic transformations and quantum thermal machines
2	Steepest entropy ascent approach for out-of-equilibrium systems