COURSE OF STUDY *Physics (LM-17)*

ACADEMIC YEAR *2023-2024*

ACADEMIC SUBJECT *Statistical Mechanics*

General information	
Year of the course	1st
Academic calendar (starting and ending date)	1st semester: September – December 2023
Credits (CFU/ECTS):	6
SSD	FIS/02
Language	English
Mode of attendance	Recommended, not compulsory

Professor/ Lecturer	
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Department and address	Dipartimento Interateneo di Fisica, Via Amendola 173, 70126 Bari (BA)
Virtual room	Teams Class "Statistical mechanics"
Office Hours (and modalities: e.g., by appointment, on line, etc.)	Monday and Tuesday, 11.00-13.00 by appointment

Work schedule			
Hours			
Total	Lectures	Hands-on (laboratory, workshops, working groups, seminars, field trips)	Out-of-class study hours/ Self-study hours
150	40	15	95
CFU/ECTS			
6	5	1	

Learning Objectives	- Justification of the statistical approach in the description of physical systems with many degrees of freedom; - Acquisition of basic notions of statistical ensembles and consequent theory, determination of the thermodynamic properties of macroscopic systems, classical and quantum, with a wide selection of examples; - Introduction to the theory of phase transitions and critical phenomena.
Course prerequisites	Calculus, general and modern physics, at first level physics courses. Thermodynamics at the level of undergraduate textbooks.

Teaching strategie	Lectures and exercises on the blackboard in classroom.
Expected learning outcomes in terms of	
Knowledge and understanding on:	● Understanding the scientific method, the nature, and the methods of research in Physics ● Knowledge of statistical mechanics and statistical methods ● Consolidation of knowledge of statistical physics for classical and quantum systems and understanding of the microscopic origin of the laws of thermodynamics.

Applying knowledge and understanding on:	● Ability to identify the essential elements of a phenomenon ● Ability to use analogy to apply known solutions to new problems (problem solving) ● Ability to use analytical and numerical mathematical computation tools ● Understanding of the foundations of the statistical description of many particle systems and theoretical elements useful for deriving thermodynamic equilibrium properties in classical and quantum contexts. Capability to apply the concepts learned to a wide variety of physical systems. Solve simple problems concerning thermal equilibrium statistical properties.
Soft skills	**Making informed judgments and choices:** ● Ability to work with increasing levels of autonomy, including taking responsibility in project planning and managing facilities. ● Knowledge and skills acquired in this course will develop the ability to critically interpret and evaluate the most recent and significant scientific literature in the field of statistical mechanics, having as reference point the concepts learned during the course and also discussing possible alternative research strategies. **Communicating knowledge and understanding:** ● Competence in communication in Italian and English in advanced fields of Physics ● Development of the ability to work in groups of 2-3 units, to whom it is proposed the solution of problems of statistical mechanics. **Capacities to continue learning:** ● Acquisition of basic knowledge tools for continuous learning and knowledge updates ● Follow the current progress and further prospects within the areas of statistical mechanics. ● Skills in the consultation of bibliographic material, databases and material on the web.
Syllabus	
Content knowledge	**Summary:** Foundation and principles of statistical physics. Classical statistical mechanics. Quantum statistical mechanics. Interacting systems, Phase transition and critical phenomena. **Detailed content:** I. **Foundations and principles of statistical physics.** Reversibility and irreversibility in physics. Loschmidt and Zermelo paradoxes. Macroscopic and microscopic points of view. Analogy with probability theory. Binomial distribution, large-number law and central limit theorem. Geometrical point of view. Kullback-Leibler entropy. Explanation of paradoxes. Ergodic hypothesis. Fundamental postulate of statistical mechanics. Equivalent expressions for the Boltzmann entropy. Additivity property. Intensive thermodynamic quantities. Derivation of thermodynamics. Classical ideal gas. Mixing entropy and Gibbs paradox. Microcanonical distribution. The ergodic problem. Rigorous results for ergodicity of extensive variables.

	2. **Classical statistical mechanics.** Canonical distribution. Derivation of thermodynamics and consistency with microcanonical distribution. Energy fluctuations and fluctuation-dissipation relation. Generalized Ensembles. The P-T ensemble and the hard-sphere gas in One Dimension. Gran-canonical distribution. Energy and particle number fluctuations. Gibbs variational principle. Energy equipartion and Virial theorems. Statistics of paramagnetism: Langevin and Brillouin models. Curie law. Negative temperatures. Virial for a system of classical particles. Pair distribution function. Cluster expansion for a classical fluid. Virial expansion of the state equation and first and second Virial coefficients. Problems. 3. **Quantum statistical mechanics.** General features of quantum systems with a large number of particles. Density matrix and statistical operator. Pure and mixed states. Liouville-von Neumann equations and stationary solutions. Microcanonical, canonical and gran-canonical distributions. Ideal gases in gran-canonical formalism. Thermodynamics of non-interacting fermions. State equation expansion at low and high temperature. Magnetic behavior of non-interacting fermions. Pauli paramagnetism and Landau diamagnetism. Non-interacting boson thermodynamics. Bose-Einstein condensation. Thermodynamics of boson gases. Problems. 4. **Interacting systems, Phase transition and critical phenomena.** Introduction. General observations on the problem of condensation. Van Hove, Lee e Yang results. Liquid-gas coexistence and critical point. Van der Waals equation. Critical exponents and singular behavior. Binary mixtures and lattice gas. Ising model. Simmetries, spontaneous symmetry breaking and order parameters. Peierls argument for phase transition in the Ising model in D=2. Duality and exact determination of the critical point. Mean field theory for Ising model. Variational formulation. Landau theory for phase transitions. Ginzburg criterium. Correlation functions. Scaling hypothesis for thermodynamic functions. Universal behavior at criticality.
Texts and readings	L. Peliti, "Statistical Mechanics", Princeton University Press. R.K. Pathria, “Statistical Mechanics”, Butterworth&Heinemann. K. Huang, “Statistical Mechanics”, Zanichelli. D. Dalvit, J. Frastai, I. Lawrie, “Problems on Statistical Mechanics”, Institute of Physics Publishing 1999. M. Falcioni, A. Vulpiani, “ Meccanica Statistica Elementare: I Fondamenti”, Springer 2014
Notes, additional materials	Notes avalaible for the whole program
Repository	Notes available on Team Class “Statistical Mechanics”

Assessment	
Assessment methods	

Assessment criteria	• **Knowledge and understanding** o Capability to discuss models, concepts and mathematical principles introduced in the course. • **Applying knowledge and understanding** o Adequate comprehension, global and detailed knowledge of arguments and mathematical developments described throughout the course. • **Autonomy of judgment** o Ability to critically interpret the relevance of specific results in the context of theoretical and statistical physics. • **Communication skills** o Capacity to clearly discuss topics discussed in the course and their relevance in a more general context.
Final exam and grading criteria	Oral exam based on the previous listed criteria (60%) and written description of specific models and topics (40%)
Further information	
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