DIPARTIMENTO
INTERUNIVERSITARIO DI FISICA

General information		
Academic subject	Statistical Mechanics	
Degree course	Master Physics	
Academic Year	2022-23	
European Credit Transfer and Accumulation System (ECTS)		6
Language	English	
Academic calendar (starting and ending date)	19 settembre – 16 dicembre 2023	
Attendance	Non compulsory	

Professor/ Lecturer	
Name and Surname	Giuseppe Gonnella
E-mail	gonnella@ba.infn.it
Telephone	0805442435
Department and address	*Dipartimento di Fisica via Amendola 173*
Virtual headquarters (Microsoft Teams code)	
Tutoring (time and day)	Monday 11.00 – 13.00

Syllabus	
Learning Objectives	- Justification of the statistical approach in the description of physical systems with many degrees of freedom; - Acquisition of the 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 level of undergraduate textbooks.
Contents	**Summary:** Foundation and principles of statistical physics. Classical statistical mechanics. Quantum statistical mechanics. Interacting systems, Phase transition and critical phenomena. **Detailed content:** **1. 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.

Books and bibliography	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
Additional materials	*Notes avalaible for the whole program*

Work schedule			
Total	Lectures	Hands on (Laboratory, working groups, seminars, field trips)	Out-of-class study hours/ Self-study hours
Hours			
	55		95
ECTS			
	6		

Teaching strategy	
	Lectures and exercise on blackboard in classroom.

Expected learning outcomes	
Knowledge and understanding on:	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:	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** 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** Development of the ability to work in groups of 2-3 units, to whom it is proposed the solution of even complex problems of statistical mechanics. Communication skills are also developed through the presentation of seminars, proposed to students on a voluntary basis, on subjects complementary to those of the course.

	• **Capacities to continue learning** 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.

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