Basic/Essential Course Information	
Course title	Critical and non-equilibrium phenomena
Degree Course title	Physics
ECTS	6
Compulsory attendance	No
Course teaching language	ENGLISH

Teacher	Giuseppe Gonnella	gonnella@ba.infn.it

ECTS Details	**Disciplinary area/broad field:**	SSD	ECTS
	Characterizing	FIS/02	6

Time management and teaching activity type	Period	Year	lesson type
	IIst semester	I	Lessons (40h) Exercises (15h)

Time management	Total hours	in-class/in-lab study hours	out-of-class study hours
	150	55	95

Course calendar	Starting date	Ending date
	Last week of February	Last week of May

Syllabus	
Prerequisites	Theory of statistical ensembles, knowledge of the general characteristics of systems with phase transition, and of mean field and Landau theory, as studied in the preparatory course of statistical mechanics. Calculus and knowledge of general physics at the level of the three-year physics course. Thermodynamics at the level of undergraduate textbook.
Expected learning outcomes (according to Dublin Descriptors)	**Knowledge and understanding** Consolidation of statistical physics methods for the description of systems with many interacting particles and phase transitions. Knowledge and understanding of basic thermodynamic description for non-equilibrium systems and its derivation on the basis of microscopic methods and theory of stochastic processes. **Applying knowledge and understanding.** Knowledge of the foundations, paradigmatic models and techniques of analysis that make possible a description of systems with many degrees of freedom, even in absence of thermodynamic equilibrium. Development of the ability to apply theoretical methods acquired in the

	course to the study of equilibrium and non-equilibrium properties and phase behaviour of classical systems with interacting particles. **Making judgements.** Development of the ability to critically interpret and evaluate the most recent and significant scientific literature in the field of statistical mechanics for physical systems both in equilibrium and in the absence of thermodynamic equilibrium. Ability to analyse different research strategies for dynamical problems for systems with many interacting degrees of freedom. **Transferable Communication skills.** 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 and stochastic process. 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. **Lifelong learning skills.** Follow the current progress and further prospects within the areas of advanced statistical mechanics. Skills in the consultation of bibliographic material, databases and material on the web.
Course contents summary	Critical behaviour of systems at equilibrium: Renormalization group, models, and exact methods. Introduction to statistical mechanics of out of equilibrium systems. Non-equilibrium processes: mathematical description and basic models. Elements of non-equilibrium Thermodynamics. Non-equilibrium statistical mechanics basic theory.
detailed syllabus	**I Part: Critical behavior of systems at equilibrium** **Exact results**. Duality transformations and critical point for the Ising model in D=2. Transfer matrix method. Solution of the Ising model in D=1. Exact Solution of the Ising model in terms of random walks. Problems. **Renormalization group and critical phenomena**. Scale transformations (block, decimation, etc.). Scale symmetry of the free energy. The renormalization group method. The problem of the proliferation of interactions. Examples of calculation of critical exponents in lattice models. **Field theoretical approach to critical phenomena**. Mean field theory and Landau-Ginzburg approach. Linear approximation of the renormalization group equations and Gaussian fixed point. Φ^4 model. Perturbative series approach and Feynman diagrams expansion at eh first and second order in the coupling constant. ε-expansion. Renormalization group equations and non trivial fixed points. Flux of the renormalization group in the parameters space and critical exponents calculation.

Other applications of scaling theory.
Linear polymers. Fleury argument for the excluded volume interaction. de Gennes limit for spin models with O(n) symmetry and self-avoiding polymers. Critical exponents.

XY model and phase transitions mediated by topological defects. Vectorial model in D=2. Spin waves approximation. Elements of classification of topological defects. Kosterlitz-Thouless transition. Dislocation and disclinations. Phase transitions in hard-disk systems.

II Part: **Introduction to statistical mechanics of out of equilibrium systems.**

Non-equilibrium processes: mathematical description and basic models.

Non-equilibrium processes: mathematical description and basic models. Chapman-Kolmogorov equation. Fokker-Planck equation. Markov chains. Spectral properties and ergodicity. Monte Carlo methods. Examples of Markov chains.

Brownian motion. Diffusion equation and Einstein relation. Langevin equation. Kramers-Moyal expansion. Relation with Fokker-Planck equation. Kramers equation. Ito and Stratonovich stochastic integrals. Mean escape time from a potential well.

Elements of non-equilibrium Thermodynamics.

Continuous description of fluid systems. Conserved variables and balance equations. Continuity and Euler equations. The Navier-Stokes equations. Balance equation for energy and general heat equation. Local formulation of the second principle of thermodynamics and of entropy production.

Response and dissipation functions. Phenomenological relationships. Onsager theorem. The Curie principle. The complex response function. Dispersion relations. Sum rules.

Non-equilibrium statistical mechanics.
Origin of noise and memory terms in the Langevin equation. Generalized Brownian motion. Gaussian approximation. Critical slowdown and van Hove's theory.
Time reversal. Dynamic correlation function. Response function and linear susceptibility. (Kubo relations). Fluctuations-dissipation theorem. Onsager regression principle. Reciprocity relations. Effective temperature in systems with non-equilibrium steady-states.

books	L. Peliti, "Statistical Mechanics", Princeton University Press. R.K. Pathria, “Statistical Mechanics”, Butterworth&Heinemann. K. Huang, “Statistical Mechanics”, Zanichelli. S. Ma, “Modern Theory of Critical Phenomena”, Westview Press. De Groot , P. Mazur “Non-equilibrium thermodynamics”, Dover. P.M. Chaikin, T.C. Lubenski, “Principles of Condensed Matter”, Cambridge University Press. R. Kubo, M. Toda, N. Hashitsume, “Non Equilibrium Statistical Mechanics”, Springer. R. Zwanzig, “Nonequilibrium Statistical Mechanics”.
notes	Available for the whole program.
Teaching methods	Lectures and exercise on blackboard in classroom.
Assessment % of final mark	Oral exam (80%) and written proof (20%)
Evaluation criteria	Capability to discuss models, concepts and mathematical principles introduced in the course. Adequate comprehension, global and detailed knowledge of arguments and mathematical developments described throughout the course.