PhD COMPLEX EXAM
STATISTICAL PHYSICS AND THERMODYNAMICS

11. Quantum statistical physics

- Density matrices and density operators. (Neumann equation, equilibrium, entanglement, principle of maximal entropy).
- Quantum gases, Bose-Einstein condensation and superfluidity.
- Correlations and linear response (Kubo formula, fluctuation-dissipation theorem, Kramers-Kronig relation).
- Second quantization.
- Principles of quantum Monte-Carlo methods (Trotter formula, discussion on some simple system).

12. Non-equilibrium systems and chaotic dynamics

- Brownian motion and diffusion (Langevin vs. Fokker-Planck equation).
- Markov processes and relaxation to equilibrium (H-theorem, maximum entropy principle and basic principles of Monte Carlo simulation).
- Pattern formation, and fractal growth, multifractals.
- Ergodicity and classical chaos (dynamical systems, attractors, Lyapunov exponents, integrable vs. non-integrable systems, Hamiltonian systems and Liouville's equation).
- Classically integrable/chaotic systems at the quantum level (Wigner-surmise, Poisson vs. Wigner-Dyson statistics, Gutzwiller's trace formula).

13. Complex systems

- Small world networks vs. Erdős-Rényi model, network growth models.
- Network motifs. Communities. Directed, weighted and signed networks. Spreading. Temporal networks. Social, economic and ecological networks.
- Basic concepts of traditional game theory. Potential games. Evolutionary games.
- Disordered systems: Percolation, basic spin glass properties and models. Fractals and multifractals.

14. Computational methods and phase transitions

- Molecular dynamics. Interactions, solution methods. Event directed MD, instabilities.
- The Monte Carlo method (detailed balance, Metropolis algorithm, importance sampling, averaging) and simulated annealing.
- Second-order phase transitions and universality (critical exponents, critical correlations, scaling laws).
- Wilson's renormalization group concept and its implications (finite size scaling, scaling of free energy).
- Finite size scaling, and critical dynamics (critical slowing down, speed-up techniques).