Advanced Statistical Physics

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ECTS credits: 6

Language of instruction: English

Examination: written exam (%) and/or oral (%)

Description:

0. **Preliminaries** *(mathematical notions, exercises for the summer)*

1. **Introduction** *(1st Lecture, coupled with TD1)*
   Importance of Statistical Mechanics. Classical and quantum. Short reminder of the ergodic hypothesis and the ensembles' definition. The concept and modelization of a bath.

2. **Phase transitions** *(Six lectures)*
   a. Classical and quantum physical (and beyond) realizations.
   b. Concepts (the thermodynamic limit, order parameters, symmetries and their breaking, ergodicity breaking, pinning fields).
   c. Energy vs. entropy, the Peierls argument.
   d. Classification (2nd order, 1st order & infinite order) and main differences.
   e. Critical phenomena and scaling. (Mean-field methods. Correlations and susceptibilities, the FDT. Landau theory and Ginzburg-Landau criterium. Renormalization group ideas.)
   f. First order phase transitions. (Spinodal and binodal. Metastability. The bubble argument, surface vs. volume.)
   g. Topological phase transitions. (The 2d XY model and some quantum realizations. Mermin-Wagner theorem. Spin waves and vortices.)
   h. Finite size scaling (complemented by TD3).
   i. Some words on quenched randomness and how it can modify everything we explained until now.

   TD1 One session A harmonic oscillator bath. Phonons. Its integration and the reduced partition function. The extension to Newton dynamics and a way to derive the Langevin equation.

   TD2 Two sessions In-equivalence of ensembles. The fully-connected Blume-Capel model solved in the canonical and microcanonical ensembles. Second order vs. first order transition.

   TD3 Two sessions Data analysis and finite size scaling.

TD4 One session Quenched randomness. Self-averageness. The Imry-Ma argument.

3. **Quantum statistical physics** *(Six lectures)*
    a. Density matrix and quantum statistical physics. General properties: KMS, FDT, etc.
    b. The fully-connected quantum Ising model and its quantum phase transition.
    c. Quantum spin chains. (The usual tricks. Jordan-Wigner transformation & mapping to fermions. Bogoliubov transformation & diagonalization in Fourier space. Phase transition.)
    d. From classical to quantum fields. The quantum harmonic oscillator (as in Altland-Simons, for example)
    e. Imaginary-time representation of the partition function and the d dimensional quantum - d+1 dimensional classical mapping. (Matsubara frequencies. Semiclassical limit.)
    f. Classical and quantum Monte Carlo methods. (The sign problem.)
    g. Anderson localization.

References

Phase Transitions

– H. E. Stanley, Introduction to phase transitions and critical phenomena (Oxford University Press, New York, 1971).
– N. Goldenfeld, Lectures on phase transitions and the renormalization group (Addison-Wesley, 1992).
– J. Cardy, Scaling and renormalization in Statistical Physics, Cambridge Lecture notes in physics (Cambridge University Press, Cambridge UK, 1996).
– D. J. Amit, Field theory, the renormalization group and critical phenomena (World Scientific, Singapore, 1984).
– G. Parisi, Statistical field theory (Addison-Wesley, 1988).
– B. Simon, Phase Transitions and Collective Phenomena (Cambridge University Press, Cambridge UK, 1997).
– I. Herbut, A modern approach to critical phenomena (Cambridge University Press, Cambridge UK, 2006).
– A. M. Tsvelik, Quantum field theory in condensed matter, 2nd ed. (Cambridge University Press, Cambridge UK, 2007).
– M. Kardar, Statistical Physics of Fields, (Cambridge University Press, Cambridge UK, 2007).

Quantum

– A. Altland and B. Simons, Condensed Matter Field Theory 2nd ed. (Cambridge University Press, Cambridge UK, 2001).
– P. M. Chaikin and T. C. Lubensky, Principles of Condensed Matter Physics (Cambridge University Press, Cambridge UK, 1995).
– P. Coleman, Introduction to Many Body Physics (Cambridge University Press, Cambridge UK, 2015).
– C. Di Castro and R. Raimondi, Statistical Mechanics and Applications in Condensed Matter (Cambridge University Press, Cambridge UK, 2015).
– T. Giamarchi, Quantum Physics in One Dimension (Oxford University Press, Oxford UK, 2003).
– S. Sachdev, Quantum Phase Transitions, (Cambridge University Press, Cambridge UK, 2001).