Thermodynamics & Statistical Mechanics (0321-4110)

Graduate Level Course, Semester A, 2017

School of Physics & Astronomy, Tel Aviv University

Lecturer: Prof**. Yacov Kantor** Teaching Assistant: **Tom Levy**

Detailed syllabus

1. Concepts: thermodynamic system, thermostat, isolated system, closed/open system, thermodynamic contact (thermal, mechanical, material), equilibrium.
2. 0^{th} ,1^{st} & 2^{nd} postulates of thermodynamics, Carnot cycle, temperature, entropy. Reversibility, maximal entropy principle.
3. Thermodynamic potentials: energy, Helmholtz free energy, enthalpy, Gibbs free energy. Intensive and extensive quantities. Natural variables. Maxwell relations. Gibbs-Durhem equation.
4. Minimax principles in thermodynamics. Stability criteria.
5. Thermodynamics of classical ideal gas, Tonks gas, van der Waals gas, black-body radiation. Maxwell construction.
6. Gibbs theory of phase transitions. Phase diagrams. Order of phase transitions.
7. Black-body radiation, quantization, 3^{rd} postulate of thermodynamics.
8. Analytical mechanics as basis for classical statistical mechanics: Laplacian and Hamiltonian formulation, canonical variables, Poisson brackets, phase space, volume conservation. Density function. Liouville theorem.
9. Shannon entropy. Constrained entropy maximization.
10. Microcanonical, canonical, grand canonical and *p-T* ensembles.
11. Relation between statistical sums and thermodynamic functions.
12. Time-dependence of entropy. “Coarse-grained” entropy. Boltzmann entropy.
13. Equipartition and virial theorems. Pair correlation function.
14. Quantum mechanics as basis for quantum statistical mechanics: Density matrix and its evolution equation. Relation between classical and quantum “counting” of states.
15. Ideal quantum gases: Bose-Einstein and Fermi-Dirac. Bose-Einstein condensation. Statistical attraction/repulsion between particles. Photons and phonons.
16. One-dimensional systems. Ising & Heisenberg models. Transfer matrix method.
17. Cluster expansions. Virial coefficients. Justification of van der Waals equation.
18. Debye-Hückel theory of electrolytes.
19. Approximate methods: Peierls inequality, Gibbs inequality.
20. Monte Carlo method.
21. 2^{nd} order phase transitions: Landau function, scaling, critical exponents.
22. Renormalization group. Real space renormalization. Universality.

Administrative information

1. The course relies on the knowledge acquired at undergraduate level courses on Statistical Mechanics, Analytical Mechanics and Quantum Mechanics.
2. Timely submission of 75% of the problems assigned as homeworks is required to take the final exam. (Either session; no exceptions.)

Supplementary academic information

Textbooks (any edition of the books can be used)

Main texts that will be used throughout the course:

1. Kerson Huang. *Statistical Mechanics*. Wiley, New York.
2. Raj K. Pathria. *Statistical Mechanics*. Butterworth-Heinemann, Oxford.
3. Linda E. Reichl. *A Modern Course in Statistical Physics*. Wiley, New York.

Texts that will be used only in some parts of the course:

1. Ryogo Kubo. *Thermodynamics*. North-Holland, Amsterdam [and Mir, Moscow (in Russian)].
2. Ryogo Kubo. *Statistical Mechanics*. North-Holland, Amsterdam [and Mir, Moscow (in Russian)].
3. Herbert B. Callen. *Thermodynamics and an Introduction to Thermostatics*. Wiley, New York.
4. Mehran Kardar. (a) *Statistical Physics of Particles*; (b) *Statistical Physics of Fields*, Cambridge U. Press.
5. Dmitry N. Zubarev. *Nonequilibrium Statistical Thermodynamics*. Consultants Bureau, New York [and Nauka, Moscow (in Russian)].
6. Lev D. Landau and Evgeny M. Lifshitz. *Statistical Physics: Part 1*. Vol. 5 in Series "Course of Theoretical Physics." Elsevier, Amsterdam [and Nauka, Moscow (in Russian)].
7. William D. McComb. *Renormalization Methods.* Clarendon Press, Oxford.
8. Nigel Goldenfeld. *Lectures on Phase Transitions and Renormalization Group*. Addison-Wesley, Advanced Book Program, Reading, Massachusetts.

Texts on specific subjects:

1. Richard P. Feynman. *Statistical Mechanics*. Benjamin, Reading, Mass. [and Mir, Moscow (in Russian)].
2. Franz Mandl. *Statistical Physics*. Wiley, New York.
3. Radu Balescu. *Equilibrium and Nonequilibrium Statistical Mechanics.* Wiley, New York [and Mir, Moscow (in Russian)].

Models & systems

1. Ideal classical and quantum gas
2. Van der Waals gas
3. Tonks gas and general one-dimensional gases
4. Photons and black-body radiation
5. Phonons
6. Ideal quantum gases (Fermi-Dirac and Bose-Einstein)
7. One-dimensional Ising model
8. Two-dimensional Ising model
9. General Ising model and related models (lattice gas, binary alloy)
10. Lattice models on Bethe lattice and on fractals
11. Percolation
12. Heisenberg model & other O(n) models
13. Two-dimensional Coulomb system
14. Classical plasma and strong electrolytes
15. Ideal polymers

Methods

1. Exact solutions of selected models
2. Partition function evaluations in various ensembles
3. Transfer matrix
4. Mean field approximations
5. Variational methods
6. Perturbative methods, series expansions
7. Monte Carlo
8. Renormalization group