Syllabus

Course name: Statistical Mechanics II (PHYS40011)

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Hours: Monday 13:30-16:10

Place: H3108

Office hour: Flexible, but please text me in advance.

Prerequisites: Thermodynamics, Statistical Mechanics I, Quantum Mechanics

About the course:

This course offers a comprehensive introduction to quantum many-body systems, serving as a bridge between statistical mechanics and modern condensed matter physics. After reviewing the basics of Statistical Mechanics I, we delve into advanced concepts such as the density matrix formalism and Landau's Fermi liquid theory, before focusing on two central topics:

1. Superconductivity (BCS Theory) We develop the microscopic theory of superconductivity, starting from Cooper pairing and mean-field approximation to derive the Bogoliubov-de Gennes equations and gap equation. Key phenomena such as the Meissner effect, flux quantization, and thermodynamic properties (specific heat, quasiparticle excitations) are analyzed in depth.

2. Quantum Spin Systems We explore low-dimensional magnetism, particularly 1D antiferromagnetic spin chains and the Haldane conjecture. Topics include exact solutions via the Bethe ansatz, valence-bond states, the Lieb-Schultz-Mattis theorem, and the profound distinction between integer and half-odd-integer spin chains.

Course Schedule:

Week 1: Review of Thermodynamics and Basics of Equilibrium Statistical Mechanics
Week 2: Quantum Mechanics and Second Quantization
Week 3: Statistical Mechanics of Ideal Gases
Week 4: Density Matrices
Week 5: Hartree–Fock Equations and Landau's Fermi-Liquid Theory
Week 6: Attractive Interaction and Bound States
Week 7: Mean-Field Equations of Superconductivity
Week 8: BCS Theory
Week 9: Superfluidity, Meissner Effect, and Flux Quantization
Week 10: Introduction to Quantum Spin System
Week 11: 1D Antiferromagnetic Spin Chains
Week 12: Theoretical Understanding of the Haldane Conjecture
Week 13: Valence-Bond States

Week 14: Hidden Structures in Haldane Gap Systems

Lecture Notes: To help students concentrate fully during class and minimize the need for note-taking, I will prepare detailed lecture notes and provide recording videos for all sessions.

The part of superconductivity will primarily follow the treatment in [4], while the part of quantum spin systems will be based on [5].

Grading: Grades will be based on a combination of homework assignments and a final exam:

- Homework Assignments: 50% (5 sets, given every other week)
- Final Exam: 50%

References

[1] Pathria, R. K., & Beale, P. D. (2011). *Statistical Mechanics* (3rd ed.). Elsevier. (Note: The 2nd edition was published in 1996; 3rd edition is the most current) ISBN: 978-0123821881.

[2] Kardar, M. (2007). *Statistical Physics of Particles*. Cambridge University Press. ISBN: 978-0521873420.

[3] Coleman, P. (2015). *Introduction to Many-Body Physics*. Cambridge University Press. ISBN: 978-0521864886.

[4] Kita, T. (2015). *Statistical Mechanics of Superconductivity*. Springer. DOI: `https://doi.org/10.1007/978-4-431-55405-9` ISBN: 978-4431554042 (Hardcover), 978-4431554059 (eBook).

[5] Tasaki, H. (2020). *Physics and Mathematics of Quantum Many-Body Systems*. Springer. Series: Graduate Texts in Physics ISBN: 978-3-030-41264-8 (Hardcover) eISBN: 978-3-030-41265-5 (eBook) DOI: `https://doi.org/10.1007/978-3-030-41265-5`.

[6] Sachdev, S. (2011). *Quantum Phase Transitions* (2nd ed.). Cambridge University Press. ISBN: 978-0-521-51468-2 (Hardback) ISBN: 978-0-521-73264-8 (Paperback) DOI: `https://doi.org/10.1017/CBO9780511973765`.