PH7002: Concepts in Statistical Mechanics

Course Outline (Sem 1 AY2023/2024)

No of AUs: 4

1 Course information

Course Coordinator: Assistant Professor Yong Ee Hou (eehou@ntu.edu.sg)
Office: SPMS-PAP-04-05
Office hour: Every Thursday 10am to 11am (week 2 to week 13, excluding recess week).

1.1 Lecture and Tutorial Schedule

- Tuesday: 10.30am-12.30pm (Lecture) (SPMS-TR+15)
- Wednesday: 1.30pm-2.30pm (Lecture) (SPMS-TR+15)
- Wednesday: 2.30pm-3.30pm (Tutorial) (SPMS-TR+15)

2 Course Aims

This course introduces the theoretical framework of statistical mechanics and applications to novel physical systems. Statistical mechanics concepts have wide applicability in many fields, including mathematics, biology, engineering, computer science, and the social sciences. Students are required to work on a final project to gain experience in research and critical thinking.

2.1 Intended Learning Outcomes

By the end of this course, you (as a student) should be able to:

1. Use the concept of Temperature and equilibrium in physical systems.
2. Use the different ensembles to solve novel systems in Physics.
3. Apply the concept of entropy and free energy in problem solving.
4. Use Monte Carlo methods in numerical simulations.
5. Apply approximation methods such as MFT and Landau theory in different novel systems.
6. Explain the theory of abrupt and continuous phase transitions.
7. Use scaling concepts in physical problems.
8. Apply renormalization group techniques in problem solving.

3 Course Content

I plan to cover topic 1 to topic 9 plus 1 or 2 optional topics over the whole semester.

1. Introduction: what is statistical mechanics?
2. Introduction to magnetism: the Ising Model
3. Approximate methods: Mean Field Theory and Landau Theory
4. Exact solution: Transfer Matrix methods
5. Series expansions and Mayer cluster
6. Markov processes, detailed balance and Monte Carlo simulations
7. Universality and Scaling hypothesis
8. Real Space Renormalization Group
9. Abrupt phase transitions
10. Percolation theory (optional)
11. Liquid-Gas Phase Transition (optional)
12. van der Waals gas (optional)
13. Gaussian model and momentum RG (optional)
14. Fluctuation and dissipation (optional)
15. Entropy and information theory (optional)
16. DNA modeling: Freely joint chain and the wormlike chain models (optional)

4 Grading

Homework is an essential major part of this course and you are expected to spend much time solving the problems before the tutorials. Group discussion is encouraged when attempting the homework problems. However, please complete the homework yourself. Homework assignments will be distributed regularly, about once in 2 weeks. I strongly recommend that you develop a regular schedule for doing these assignments, and do not wait until the due date before attempting the problems. I foresee the average time spent on each homework is $\sim$5-8 hours. Each assignment

will have a due date, with **late work counting** 0%. Please let me know in advance if you know that you will have a conflict with the due date (e.g. illness, scientific conferences, family issues, etc). There will be 6 assignments for the whole course, approximately once every 2 weeks, to be submitted to NTULearn.

Course	Homework sets	Class participation	Midterm Exam	Final Project
PH7002	20%	10%	20%	50%

5 References

The required textbooks for the course:

(1) J. Sethna, Statistical Mechanics Entropy, Order Parameters, and Complexity.

(2) J. M. Yeomans, Statistical Mechanics of Phase Transitions.

The course will cover part of (1) and most of (2). It will be supplemented by course notes and problems assigned will come from both (1) and (2). My lectures are designed to be self-sufficient. You are encouraged to take notes during class. A number of useful reference books may be found in the library. These include:

(1) D. Chandler *Introduction to modern statistical mechanics.*

(2) M. Plischke and B. Bergerson, *Equilibrium Statistical Physics.*

(3) N. Goldenfeld, *Lectures On Phase Transitions And The Renormalization Group.*

(4) M. Kardar, *Statistical Physics of Particles.*

(5) M. Kardar, *Statistical Physics of Fields.*

Also, for students who wishes to learn more on your own, there are also alot of useful resources online. Here are some that I like:

1. Lectures on statistical mechanics by Leonard Susskind: Link
2. Lecture notes by Michael Peskin: Link
3. Statistical Mechanics of Particles by Mehran Kardar: Link
4. Statistical Physics of Fields by Mehran Kardar: Link

6 PH7002 Final Project (50% of total grade)

For the final project, you will be required to do a research on a topic of interest and present your findings to the class. You should consult me regarding the choice of topic (ideally around 3rd to 5th week) to ensure it is suitable and also it is different from your classmates. Duplicate project topics should be avoided. There will be three components to the assessment, namely, **short essay (33.3%)**, **interactive notebook (33.3%)**, and **final presentation (33.3%)**. I will provide more information in a separate document.

7 Academic Integrity

Good academic work depends on honesty and ethical behaviour. The quality of your work as a student relies on adhering to the principles of academic integrity and to the NTU Honour Code, a set of values shared by the whole university community. Truth, Trust and Justice are at the core of NTU's shared values.

As a student, it is important that you recognize your responsibilities in understanding and applying the principles of academic integrity in all the work you do at NTU. Not knowing what is involved in maintaining academic integrity does not excuse academic dishonesty. You need to actively equip yourself with strategies to avoid all forms of academic dishonesty, including plagiarism, academic fraud, collusion and cheating. If you are uncertain of the definitions of any of these terms, you should go to the academic integrity website for more information. Consult your instructor(s) if you need any clarification about the requirements of academic integrity in the course.

8 Copyright Statement

and/or legal action if you are found to have committed any of the above or infringed the University's copyright.