## GE REVISED COURSE CONTENT

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|---|---|---|---|
| **Academic Year** | 2023 | **Semester** | 1 |
| **School/Programme** | SPMS | | |
| **Course Coordinator** | Asst Prof Yong Ee Hou | | |
| **Course Code** | PH7002 | | |
| **Course Title** | Concepts in Statistical Mechanics | | |
| **Pre-requisites** | For graduate students: No pre-requisites<br>For undergraduates: PH3201 Statistical Mechanics I or equivalent | | |
| **No of AUs** | 4 | | |
| **Contact Hours** | 52 contact hours<br>(3 hours lecture each week; 1 hour tutorial each week) | | |
| **Proposal Date**<br>***i.e. date proposal was drafted*** | Oct 2023 | | |
| **Expected Implementation date of new/revised course** | Aug 2024 | | |
| **Suggested Class Size** | 30 | | |
| **Any cross-listing?**<br>***Is course opened to all Postgraduate students (including IGP) or specific program (please indicate)?*** | Yes, SPMS Master by Research | | |

**Course Aims**

This course is an introduction to the physics of phase transitions. You will use knowledge from previous courses in non-interacting systems to develop the theoretical framework of interacting systems. Through the course, you will build foundational knowledge in key topics such as scaling, critical exponents, universality, fractal behavior, transfer matrix, Monte Carlo simulations, renormalization group, which are critical in the study of phase transitions. These concepts have wide applicability in different fields of studies and will be of interest to sophisticated students and researchers in mathematics, biology, engineering, computer science, and the social sciences.

**Intended Learning Outcomes (ILO)**

By the end of this course, you should be able to:

1. Apply the different statistical ensembles (e.g., microcanonical, canonical, grand canonical) to solve novel systems in Physics.
2. Explain how to use perturbative methods to calculate interacting system, e.g., cumulants, cluster expansion etc.
3. Apply approximation methods such as Mean Field Theory and Landau Theory in different novel systems.
4. Derive Ising model in 1 dimension using transfer matrix method.
5. Analyse problems numerically using Monte Carlo methods.
6. Explain the theory of abrupt and continuous phase transitions.
7. Explain scaling hypothesis, critical exponents and universality class.
8. Apply renormalization group techniques to different novel systems.

**Course Content**

- Introduction: review of statistical mechanics
- Introduction to magnetism: the Ising Model
- Approximate methods: Mean Field Theory
- Landau Theory: order parameters, broken symmetry, and topology
- Exact solution: Transfer Matrix methods
- Perturbative methods: linked cluster theorem, Feynman Diagrams, and Series expansions
- Critical Phenomena I: universality, Scaling hypothesis and critical points.
- Critical Phenomena II: Renormalization Group
- Monte Carlo methods: Markov processes, detailed balance, Metropolis algorithm.
- Optional advanced topics: Bose condensation, superfluidity, and superconductivity.

**Assessment (includes both continuous and summative assessment)**

*Note: It is advised that Group component and class participation should not be more than 40% and 20% respectively, unless with good justification.*

| Component | ILO Tested | Weighting | Team/Individual | Assessment Rubrics |
|---|---|---|---|---|
| 1. Final Project | ALL | 50% | Team | Appendix 1 |
| 2. Continuous Assessment 1 (CA1): Problem sets | ALL | 20% | Individual | Appendix 2 |
| 3. CA2: Midterm Test | 1-4 | 20% | Individual | Appendix 3 |
| 4. CA3: In-class participation | ALL | 10% | Individual | Appendix 4 |
| Total | | 100% | | |

**Description of Assessment Components:**

Final Project: You will be required to (1) write an essay ("Final essay" 35%), (2) Create an interactive numerical notebook ("interactive notebook:" 30%), and (3) give a ∼30 minutes presentation ("final presentation"35%) at a date to be arranged near the end of semester. A list of suggested topics will be provided at the start of school term. The critical essay should be typed in a journal paper format suitable for publication in Physical Review B (PRB), with proper documentation and citations, using Latex and the style files for PRB (details later).

The purpose of this assignment is multifold:

1. Give you something fresh to research on, related to statistical mechanics.
2. To give you an opportunity to develop the skills in doing a literature survey and digging up information from the library/online.
3. Demonstrate good taste, curiosity and ambition in your choice of subject.
4. Capable of distilling the most important and essential details from very technical papers.
5. Develop skills in numerical methods that are increasingly important for both academia and industry.

6. Develop your presentation skills.

Continuous Assessment 1 (CA1): 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 2.5 weeks.

Continuous Assessment 2 (CA2): There will be one in-class midterm. You will be allowed to bring a double-sided hand-written/printed formula sheet.

Continuous Assessment 3 (CA3): Lecture participations has a weighting of 10% of the course and will be done using WOOCLAP. The course coordinator will ask a few questions every lecture that will test and reinforce concepts covered during lecture.

**Formative feedback**

Because weekly class attendance and success in class are positively correlated, students are expected to participate in lectures and tutorials. The lectures are meant to be interactive. You will receive verbal feedback from me during in class participation questions using Wooclap, which provides real time assessment and feedback. You will also receive feedback through discussions during tutorials. Feedback will also be provided for each problem set, where any particularly problematic areas will be identified. Finally, feedback will be given after the midterm on the common mistakes and level of difficulty of the problems. Past exam questions and examiner's report are also made available for you.

**Learning and Teaching Approach**

*Note: Please include and indicate TEL component.*

| **Approach** | **How does this approach support you in achieving the learning outcomes?** |
|---|---|
| Problem solving | This is to develop your competence and perseverance in solving physics problems. |
| Hands-on group activities | This is to develop your physical intuition and competence in solving real-life problems. It also enables you to relate everyday phenomena to physics. |
| Lecture participation | This is to develop your communication skills and competence in physics. You are encouraged to discuss answers with your classmates so that you can learn from one another. |
| Technology-Enhanced Learning (TEL) | You will be answering in class participation questions using Wooclap from NTULearn which will provide real time assessment and feedback. |

**Reading and References**

The required textbooks for the course:

(A) J. Sethna, Statistical Mechanics Entropy, Order Parameters, and Complexity (ISBN-13: 978-0198865254).
(B) J. M. Yeomans, Statistical Mechanics of Phase Transitions (ISBN-13: 978-0198517306).

The course will cover parts of (A) and most of (B). Lectures are designed to be self-sufficient, and you are encouraged to take notes during class. Several useful reference books can be found in the library. These include:

(1) D. Chandler Introduction to modern statistical mechanics (ISBN-13: 978-0195042771).
(2) M. Plischke and B. Bergerson, Equilibrium Statistical Physics (ISBN-13: 978-9812561558).
(3) N. Goldenfeld, Lectures on Phase Transitions and The Renormalization Group (ISBN-13: 978-0201554090).
(4) M. Kardar, Statistical Physics of Particles (ISBN-13: 978-0521873420).
(5) M. Kardar, Statistical Physics of Fields (ISBN-13: 978-0521873413).

**Course Policies and Student Responsibilities**

(1) General

You are expected to attend all lectures punctually and complete scheduled assignments and project by due dates. You are expected to participate in all lecture/tutorial discussions and activities.

(2) Absenteeism
Absence from class without a valid reason will affect your overall course grade. Valid reasons include falling sick supported by a medical certificate and participation in NTU's approved activities supported by an excuse letter from the relevant bodies.

**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.

**Course Instructors**

| Instructor | Office Location | Phone | Email |
|---|---|---|---|
| Yong Ee Hou | SPMS-PAP 04-05 | (+65) 6316-2966 | eehou@ntu.edu.sg |
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**Industry Participation**

Nil. This is a theoretical course on the physics of phase transition. The focus is on student to learn knowledge and tools useful for research. In the final project, the students will learn how to work in a team to research and present a topic of interest to the class.

**Planned Weekly Schedule**

| Week | Topic | ILO | Readings/ Activities |
|---|---|---|---|
| 1 | Introduction and statistical ensembles | ILO1 | Sethna Chp 1,2 |
| 2 | Interacting systems, Mayer clusters | ILO1,2,6 | Sethna Chp 3 |
| 3 | Phase transitions | ILO3,4,6 | Yeomans Chp 1,2 |
| 4 | Mean field theory | ILO3,4 | Yeomans Chp 4 |
| 5 | Landau Theory | ILO6,7 | Sethna Chp 8,9 |
| 6 | Liquid-gas transitions | ILO1,2,6 | Sethna Chp 11 |
| 7 | Transfer methods | ILO1,4 | Yeomans Chp 5 |
| 8 | Series expansion | ILO1,6 | Yeomans Chp 6 |
| 9 | Monte Carlo simulations | ILO5 | Yeomans Chp 7<br>**midterm** |
| 10 | Scaling | ILO6,7 | Yeomans Chp 8 |
| 11 | Renormalization group I | ILO7,8 | Sethna Chp 12 |
| 12 | Renormalization group II | ILO7,8 | Yeomans Chp 9 |
| 13 | Student presentations | | - |

**Other information(s)**

Nil

## Appendix 1: Assessment Criteria for Final Project

There will be three components to the final project, namely, short essay (35%), interactive notebook (30%), and final presentation (35%). The course coordinator will give out a list of suggested topics at the start of the semester. Group size can be either one or two, depending on the size of enrollment.

**Component 1 (35%):** The purpose of your essay is to explain why the problem is interesting, what has been done, and what are the conclusions. The essay should be typed in a journal paper format suitable for publication in Physical Review B (PRB), using Latex and the style files for PRL. The paper should be double-columned, not exceeding 8 pages, including main text, figures, and references. Each group will submit a final essay to NTULearn where Turnitin will review for plagiarism automatically. The total similarity index from the Turnitin report should ideally be less than 10% and strictly less than 15%. Anything above 15% will result in a penalty that works as follows: if the similarity index is 20%, there will be a penalty of 2 x (20-15) = 10%; if the similarity index is 30%, the penalty becomes 2 x (30-15) = 30% and so on.

**Component 2 (30%):** Your interactive notebook should be fun for anyone trying to learn something about the topic. It should be a self-contained file that allows user to interact and learn from it. Proper references should be given from all the sources where you took the code from. Your interactive notebook should be free of bugs and executable by anyone without too much difficulties, e.g., at the start of the notebook, you should clearly state which version of python 3 it is tested on (e.g., python version 3.11) and the packages needed to run. The code should be written in python 3 in the format of jupyter notebook using common packages (such as numpy, scipy, scikit-learn, etc) and executable by anyone. Alternatively, you may write in Mathematica and the code should run on a free version of Wolfram Cloud account. Codes should produce accurate simulations/results and reproducible.

**Component 3 (35%):** The presentations will take place in-class during week 13 of semester 1. Each presentation should be ~20mins in duration, followed by ~5 minutes of Q&A. The talks must be attended by all students. You should prepare proper slides to explain the research topic as well as go through the interesting parts of your interactive notebook during the presentation. You should demonstrate the codes in your interactive notebook is executable by running parts (or all) of it during your presentation.

| Component | Weightage | Assessment |
|---|---|---|
| Final essay | 35% | Everyone in the group gets same grade |
| Interactive notebook | 30% | Everyone in the group gets same grade |
| Final presentation | 35% | Individual scoring based on quality of presentation |

During the final presentation, each group member will present the slides they are responsible for and will be awarded grade based on his/her presentation. They should do a demo of their interactive notebook and the highlights therein as part of their final presentation.

| **Final Essay (Group)** | | | | | |
|---|---|---|---|---|---|
| | **Pre-Structural** | **Uni-Structural** | **Multi-Structural** | **Relational** | **Extended-abstract** |
| Report structure, organization and discussions | No coherence | Content not well connected | Makes a series of points, but without synthesis. | Synthesizes points into a coherent argument. | Goes beyond synthesis to create a new, independent, point of view. |
| Information gathering on topic of interest | Lack of good reference | Some use of reference material, but without real relevance to the argument. | A range of relevant materials used uncritically to illustrate points. | A range of relevant materials used, critically integrated in argument. | A range of relevant material used, critically integrated to advance argument and to theorize. |
| Quality of report content | Knows nothing about a topic | Knows one thing about a topic | Knows a few (unconnected) things about a topic | Can connect ideas within a topic | Can make connections beyond the original topic |
| **Points** | **0-54** | **55-64** | **65-74** | **75-84** | **85-100** |

| **Interactive notebook (Group)** | | | | | |
|---|---|---|---|---|---|
| | **Pre-Structural** | **Uni-Structural** | **Multi-Structural** | **Relational** | **Extended-abstract** |
| Understanding of theory | Knows nothing about a topic | Knows one thing about a topic | Knows a few (unconnected) things about a topic | Can connect ideas within a topic | Can make connections beyond the original topic |
| Presentation of interactive notebook | No coherence | Content not well connected | Makes a series of points, but without synthesis. | Synthesizes points into a coherent argument. | Goes beyond synthesis to create a new, independent, point of view. |
| Correctness and efficiency of codes | Numerical results presented not relevant to topic. | One relevant result presented. | A few numerical results of subject matter implemented | Numerical results linked into coherent material | Numerical results linked into coherent material that goes beyond original topic |
| **Points** | **0-54** | **55-64** | **65-74** | **75-84** | **85-100** |

| **Final Presentation (Individual)** | | | | | |
|---|---|---|---|---|---|
| | **Pre-Structural** | **Uni-Structural** | **Multi-Structural** | **Relational** | **Extended-abstract** |
| Understanding of theory | Knows nothing about a topic | Knows one thing about a topic | Knows a few (unconnected) things about a topic | Can connect ideas within a topic | Can make connections beyond the original topic |
| Ability to explain concepts | Illogical and incoherent | Somewhat coherent | Makes a series of points, but without synthesis. | Synthesizes points into a coherent argument. | Goes beyond synthesis to create a new, independent, point of view. |
| Usefulness of visual aids | Slides and multimedia are not on point | Slides and multimedia are somewhat coherent | Slides and multimedia are somewhat coherent | Slides and multimedia are synergies with one another and help illustrate concepts | Slides and multimedia stimulate interest and promote learning |
| **Points** | **0-54** | **55-64** | **65-74** | **75-84** | **85-100** |

## Appendix 2: Assessment Criteria for (CA1) problem sets

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. You are strongly recommended to develop a regular schedule for doing these assignments, and do not wait until the due date before attempting the problems.

Each assignment will have a due date (always at the end of a Sunday night at 23:59:00), so do check the course website on NTULearn for more information. You are required to upload to NTULearn in ONE PDF file BEFORE with wordings in the proper upright position before the deadline. 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.). All the assignments will be graded online within NTULearn, and you will be able to see your score from the Grade Center in NTULearn. Your CA grades, which includes all the assignments, midterms, and participation score (from Wooclap), will be visible to you inside NTULearn. Be sure to monitor your grades and see how you are doing for the course.

## Appendix 3: Assessment Criteria for (CA2) midterm

There will be one in-class midterm around the middle of semester. You will be tested on ILO 1 to 4. The marks for each question are indicated at the beginning of each question. The midterm will be a RESTRICTED OPEN BOOK exam. You are only allowed to bring in ONE (1) sheet of A4 note HAND-WRITTEN/TYPED on both sides. Calculators may be used. However, you should write down systematically the steps in the workings.

## Appendix 4: Assessment Criteria for (CA3) in-class participation

Because weekly class attendance and success in class are positively correlated, students are expected to participate in lectures and tutorials. The course coordinator will ask a few questions (3-

5) every lecture that will test and reinforce concepts covered during lecture. The questions will be unevenly distributed over the duration of the lecture, with more questions asked towards the end of the class. There should be around 100 questions (of various nature, majority of which is MCQ) for the whole semester. Grading works as follows:

1. If you get > 50% of total questions from whole course correctly, you get the full 10%.
2. If you get between 0% to 50% of total points from whole course correctly, you will be awarded on a linear scale from 0% to 10%.