Course Requisites (if applicable)

Pre-requisites	For graduate students: No pre-requisites For undergraduates: PH3201 Statistical Mechanics I or equivalent
Co-requisites	
Pre-requisite to	
Mutually exclusive to	
Replacement course to	
Remarks (if any)	

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.

Course's Intended Learning Outcomes (ILOs)

Upon the successful completion of this course, you (student) would be able to:

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

Reading and References (if applicable)

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).

Planned Schedule

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
1	Introduction and statistical ensembles	1	Sethna Chp 1,2		
2	Interacting systems, Mayer clusters	1, 2, 6	Sethna Chp 3		
3	Phase transitions	3, 4, 6	Yeomans Chp 1,2		
4	Mean field theory	3, 4	Yeomans Chp 4		
5	Landau Theory	6, 7	Sethna Chp 8,9		
6	Liquid-gas transitions	1, 2, 6	Sethna Chp 11		
7	Transfer methods	1, 4	Yeomans Chp 5		
8	Series expansion	1, 6	Yeomans Chp 6		
9	Monte Carlo simulations	5	Yeomans Chp 7		**midterm**
10	Scaling	6, 7	Yeomans Chp 8		
11	Renormalization group I	7, 8	Sethna Chp 12		
12	Renormalization group II	7, 8	Yeomans Chp 9		
13	Student presentations				

Learning and Teaching Approach

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.

Assessment Structure

Assessment Components (includes both continuous and summative assessment)

No.	Component	ILO	Related PLO or Accreditation	Weightage	Team/Individual	Rubrics	Level of Understanding
1	Continuous Assessment (CA): Project(Final Project)	All		50	Team	Analytic	Multistructural
2	Continuous Assessment (CA): Others(Continuous Assessment 1 (CA1): Problem sets)	All		20	Individual	Analytic	Multistructural
3	Continuous Assessment (CA): Others(CA2: Midterm Test)	1-4		20	Individual	Analytic	Multistructural
4	Continuous Assessment (CA): Class Participation(CA3: In-class participation)	All		10	Individual	Holistic	Relational

Description of Assessment Components (if applicable)

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:

Give you something fresh to research on, related to statistical mechanics.

To give you an opportunity to develop the skills in doing a literature survey and digging up information from the library/online.

Demonstrate good taste, curiosity and ambition in your choice of subject.

Capable of distilling the most important and essential details from very technical papers.

Develop skills in numerical methods that are increasingly important for both academia and industry.

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.

NTU Graduate Attributes/Competency Mapping

This course intends to develop the following graduate attributes and competencies (maximum 5 most relevant)

Attributes/Competency	Level
Collaboration	Intermediate
Communication	Advanced
Creative Thinking	Advanced
Learning Agility	Intermediate
Problem Solving	Advanced

Course Policy

Policy (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. On the use of technological tools (such as Generative AI tools), different courses / assignments have different intended learning outcomes. Students should refer to the specific assignment instructions on their use and requirements and/or consult your instructors on how you can use these tools to help your learning. Consult your instructor(s) if you need any clarification about the requirements of academic integrity in the course.

Policy (General)

You are expected to complete all assigned pre-class readings and activities, attend all seminar classes punctually and take all scheduled assignments and tests by due dates. You are expected to take responsibility to follow up with course notes, assignments and course related announcements for seminar sessions they have missed. You are expected to participate in all seminar discussions and activities.

Policy (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.

If you miss a lecture, you must inform the course instructor via email prior to the start of the class.

Policy (Others, if applicable)

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