Nanyang Technological University
Division of Physics and Applied Physics

COURSE CONTENT FOR PH7002 for Undergraduates

Academic Year	2022/23	**Semester**	1
Course Coordinator	Asst. Prof. Yong Ee Hou		
Course Code	PH7002 (previously listed as PAP710)		
Course Title	Concepts in Statistical Mechanics		
Pre-requisites	PH3201 Statistical Mechanics I or equivalent and PHY (PPHY) or PHY (APHY) programme and CGPA 4.0 or higher		
No of AUs	4		
Contact Hours	Lectures: 39, Tutorials: 12 (3 hours lecture each week; 1 hour tutorial each week)		
Proposal Date	3rd Feb 2022		

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)

Upon the successful completion of this course, you (as a student) would 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

- *Statistical ensemble*
- *Interacting classical gas (Mayer cluster)*
- *Phase transitions*
- *Ising Model*
- *Landau Theory*
- *Mean Field Theory*
- *Liquid-Gas Phase Transition*
- *Transfer Matrix methods*

- *Series expansions*
- *Markov process, detail balance and Monte Carlo simulations*
- *Scaling hypothesis*
- *Real Space Renormalization Group*

Assessment (includes both continuous and summative assessment)

Component	ILO Tested	Related Programme LO or Graduate Attributes*	Weighting	Team/Individual	Assessment Rubrics
1. *Final Project*	*ALL*	*Communication, Creativity, Character & Competence.*	*50%*	*Individual*	*Appendix 1*
2. *Continuous Assessment 1 (CA1): Problem sets*	*ALL*	*Communication, Creativity, Character & Competence.*	*20%*	*Individual*	*Appendix 2*
3. *CA2: Midterm Test*	*1-4*	*Communication, Creativity, Character & Competence.*	*20%*	*Individual*	*Appendix 3*
4. CA3: In-class participation	ALL	*Competence & Character*	*10%*	*Individual*	*Appendix 4*
Total			100%		

*Align course intended learning outcomes (ILOs) to the 5Cs of an NTU graduate, which are Communication, Character, Civic-mindedness, and Creativity & Competence.

<u>Description of Assessment Components:</u>

Final Project: You will be required to (1) write an essay ("Final Project") and (2) give a ~20 minutes presentation at a date to be arranged near the end of semester. Each component has equal weightage. The course coordinator will give out a list of suggested topics 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).

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 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

Approach	How does this approach support you in achieving the learning outcomes?
Problem solving (tutorial and lecture)	Develop competence and perseverance in solving physics problems
Hands-on group activities (during tutorial)	Develop physical intuition and competence in solving real-life problems. Relate everyday phenomena to physics.
Lecture participation	Develop communication skills and competence in physics. Students are encouraged to discuss their answers with their classmates so that they can learn from one another.

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

Suggested fields for these portions include general policies with regards to students' assignment, punctuality absenteeism, etc.

(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 behavior. The quality of your work as a student relies on adhering to the principles of academic integrity and to the NTU Honor 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

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 **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		-

Appendix 1: Assessment Criteria for Final Project

For the final project, you will be required to (1) write an essay ("Final Project") and (2) give a ∼ 20 minutes presentation at a date to be arranged near the end of semester. Each component is worth 50% each. The course coordinator will give out a list of suggested topics at the start of the semester.

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 PRB (details later). Please submit a Turnitin report together with the term paper; failure to do so will result in a 15% penalty. 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. The paper should be double-columned, not exceeding 8 pages, including main text, figures, and references.

The presentations will take place in-class during week 13 of semester 1. Each presentation should be ~18mins in duration, followed by ~3 minutes of Q&A. The talks must be attended by all PAP 710 students.

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%.

Graduate Attributes

What we want our graduates from Physics and Applied Physics to be able to do:

Upon the successful completion of the PHY, APHY, PHME and PHMS programs, graduates should be able to:

Competency	1	demonstrate a rigorous understanding of the core theories and principles of physics involving (but not limited to) areas such as classical mechanics, electromagnetism, thermal physics and quantum mechanics [PHMS only] demonstrate a rigorous understanding of the core theories and principles of mathematical sciences involving (but not limited to) areas such as analysis, algebra and statistical analysis
	2	read and understand undergraduate level physics content independently;
	3	make educated guesses / estimations of physical quantities in general;
	4	apply fundamental physics knowledge, logical reasoning, mathematical and computational skills to analyse, model and solve problems;
	5	develop theoretical descriptions of physical phenomena with an understanding of the underlying assumptions and limitations;
	6	critically evaluate and distinguish sources of scientific/non-scientific information and to recommend appropriate decisions and choices when needed;
	7	demonstrate the ability to design and conduct experiments in a Physics laboratory, to make measurements, analyse and interpret data to draw valid conclusions.

Creativity	1	propose valid approaches to tackle open-ended problems in unexplored domains;
	2	offer valid alternative perspectives/approaches to a given situation or problem.

Communication	1	

		describe physical phenomena with scientifically sound principles;
	2	communicate (in writing and speaking) scientific and non-scientific ideas effectively to professional scientists and to the general public;
	3	communicate effectively with team members when working in a group.

Character	1	uphold absolute integrity when conducting scientific experiments, reporting and using the scientific results;
	2	readily pick up new skills, particularly technology related ones, to tackle new problems;
	3	contribute as a valued team member when working in a group.

Civic Mindedness	1	put together the skills and knowledge into their work in an effective, responsible and ethical manner for the benefits of society.