Academic Year	2020/21	**Semester**	1
Course Coordinator	Assoc. Prof. Massimo Pica Ciamarra, Asst. Prof. Bing Sui Lu		
Course Code	PH2103		
Course Title	Thermal Physics		
Pre-requisites	PH1104 and MH2800 OR MH1803 and MH2802 and PH1104 OR CY1308 and CY1601 and CY1602 OR MH1101 and MH1200		
No of AUs	4 AU		
Contact Hours	Lecture: 39 hours (3 hours per week); Tutorial: 12 hours (1 hour per week)		
Proposal Date	16 March 2020		
Course Aims			

The course aims to equip you with the basic concepts in Thermal Physics. You will develop physical intuition and analytical skills which are important for studying physical systems and solve problems involving temperature, heat and energy. These knowledge and skills are at the basis of subsequent higher-level courses and are critical in the engineering profession.

Intended Learning Outcomes (ILO)

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

1. perform units conversion, dimensional analysis of formulas and make simple estimates of physical quantities related to thermal physics in daily life;
2. solve problems and explain daily phenomena involving change in temperature, energy, solid/liquid/gas transformations, heat flow.
3. explain the working principles of thermometers (such as liquid in gas, constant volume thermometer) and how thermometric properties and fixed points are used in the calibration of the various temperature scales (including Celsius and Kelvin scale).
4. se definition of thermal equilibrium to solve problems involving heat exchanges between two or more bodies and changing of phase
5. solve problems involving the change of phase of a substance, heat exchange, and latent heat.
6. identify the different heat transfer mechanisms at work in different daily context.
7. apply the ideal gas law and the kinetic theory of gases to analyze a given system of gas.
8. apply the van der Waals equation to analyze the behavior or real gases.
9. use PV diagrams to describe thermodynamic transformations.
10. apply the first law of thermodynamics to analyze the heat exchange, change in internal energy, work done and thermal efficiency of a given heat engine.
11. solve problems involving the heating and cooling of gases, distinguishing the constant volume and the constant pressure behavior.
12. use the second law of thermodynamics to explain why some processes occur spontaneously, while others do not; and its implications on the maximum efficiency of thermal cycles.
13. evaluate the entropy change associated to a thermodynamic transformation
14. estimate the entropy starting from the concept of microstates and of macrostates, for simple model systems.
15. evaluate the entropy dependence on the volume and on the energy of a system
16. use the second law of thermodynamic, and the concept of entropy, to define temperature, pressure and chemical potential.
17. solve thermodynamic problems of systems interacting with reservoir
18. approximate large numbers of microstates in Boltzmann’s entropy formula using Stirling’s approximation
19. calculate the entropy of an ideal gas using microstates, and use it to derive the ideal gas law
20. correctly apply different types of free energy (e.g., Helmholtz, enthalpy) to systems with different types of mechanical constraints
21. use the concept of Boltzmann factor and partition function to calculate the distribution of speeds of gas particles
22. derive the Stefan-Boltzmann law using microstates of radiation and use it to estimate the temperature of black bodies

Course Content

Basic Principles
Units
Mass, Weight and Density
Atoms, microscopic structures and states of matter
Pressure, Temperature, Energy
Entropy

Thermal Physics
Temperature and Thermometer
Thermodynamic equilibrium
Heat transport: conduction, radiation, and convection
Thermal Expansion
Equation of state
Perfect gases and absolute zero
Ideal Gases
Kinetic Theory of Gases
Real Gases

Thermodynamics
First Law of Thermodynamics
Heat capacities
Phase changes and latent heat
Zeroth Law of Thermodynamics
Work, heat and internal energy
Adiabatic, reversible and irreversible changes
Second law of Thermodynamics
Macrostate and microstates
Entropy
Heat engines, efficiency, and Carnot cycles.
The third law of thermodynamics

Statistical Mechanics
Probability and multiplicity; large numbers and central limit theorem
Boltzmann's microscopic definition of Entropy
Microscopic definition of temperature
Paramagnetism
Einstein solid
Entropy of an ideal gas
Mechanical equilibrium and pressure
Diffusive equilibrium and chemical potential
Concept of free energies (Helmholtz, enthalpy, etc)
Thermodynamic identities
Boltzmann distribution
Partition function
Maxwell distribution of velocities
Blackbody radiation
Stefan-Boltzmann law

Assessment (includes both continuous and summative assessment)

Component	Course ILO Tested	Related Programme LO or Graduate Attributes	Weighting	Team / Individual	Assessment Rubrics

1. Final Examination	All	Competence (2,3), (Written) Communication (1)	50%	Individual	Point-based marking (not rubric-based)
2. CA1: Assignments (every two weeks)	All	Competence (2,3) (Written), Creativity (1) Communication (1)	15%	Individual	Point-based marking (not rubric-based)
3. CA2: Mid-term Test	1-13	Competence (2,3) (Written) Communication (1) (Written)	30%	Individual	Point-based marking (not rubric-based)
4. CA3: Quiz	All	Competence (2,3) (Written) Creativity (1)	5%	Individual	Learning Catalytics
Total			100%		

Formative feedback

Formative feedback is given through discussion within tutorial lessons as well as interactive computer-based hints.

Formative feedback is given through the in-class discussion of the assignments. Feedback is always provided for student's response to each question.

Feedback is also given after the midterm on the common mistakes and level of difficulty of the problems. Past exam questions and examiner's report are made available for students.

Learning and Teaching approach

Approach	**How does this approach support students 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.
Peer Instruction (during lecture)	Develop communication skills and competence in physics. You are encouraged to discuss about your answers so that they can learn from one another.

Reading and References

1. H. D. Young and R. A. Freedman, Sears and Zemansky's University Physics with Modern Physics, 14th Edition (Pearson, 2016), ISBN 978-1292100319
2. S. J. Blundell and K. M. Blundell, Concepts in Thermal Physics, 2nd Edition (Oxford, 2010), ISBN 978-0199562107
3. D. V. Schroeder, An Introduction to Thermal Physics (Addison Wesley Longman, 2000), ISBN 978-0201380279

Course Policies and Student Responsibilities

Absence Due to Medical or Other Reasons

If you are sick and unable to attend your mid-term, you have to:

1. Send an email to the instructor regarding the absence.
2. Submit the original Medical Certificate* or official letter of excuse to administrator.

* The medical certificate mentioned above should be issued in Singapore by a medical practitioner registered with the Singapore Medical Association.

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
Massimo Pica Ciamarra	SPMS PAP 03-14	65922542	massimo@ntu.edu.sg
Bing Sui Lu	SPMS PAP 05-01A		bslu@ntu.edu.sg

Planned Weekly Schedule

Week	Topic	Course ILO	Readings/ Activities
1	Thermodynamic equilibrium; thermal expansion; thermometers; temperature scales; perfect gases and absolute zero;	1-4, 9, 10	In-class Learning Catalytics; experiment: temperature of melting ice; YF 17
2	Mechanical equivalent of heat; heat capacities, specific heat capacity, molar heat capacity. Latent heat; Heat transport – conduction, radiation, and convection as transport mechanisms;	5-7	In-class Learning Catalytics; experiment: Newton's law of cooling; YF 17
3	Equation of state; ideal gas; kinetic theory; pressure; mean free path;	8	In-class Learning Catalytics; YF 18
4	Heat capacities and equipartition principle; heat flux and heat diffusion equation; thermal conductivity of the ideal gas	11	In-class Learning Catalytics; YF 17, YF 18, Schroeder 1.7
5	Equations of state; phase diagrams; PV diagrams	11-13	Mid-term exam; YF 18
6	The first law of thermodynamics – work, heat, and internal energy; adiabatic, reversible and irreversible changes;	14	In-class Learning Catalytics; YF 19
7	Heat capacities of an ideal gas; Adiabatic proceses	15	In-class Learning Catalytics; YF 19
8	Heat engines and Carnot cycle, refrigerators, efficiency, Clausius' theorem and second law of thermodynamics	10, 16, 17	YF 20 In-class Learning Catalytics; Schroeder 2.4, 2.5, 2.6, 3.1
9	Multiplicity; large numbers and central limit theorem; Stirling's approximation; Boltzmann's Entropy Formula; Microscopic definition of temperature	16, 18	
10	Paramagnetism; Einstein solid; Entropy of an ideal gas	19	In-class Learning Catalytics; Schroeder 2.1, 2.2, 2.6, 3.3
11	Thermodynamic potentials and Maxwell relations; Boltzmann factor and partition function	20	In-class Learning Catalytics; Schroeder 5.1, 5.2, 6.1-6.3
12	Maxwell distribution of velocities; Statistical mechanics of a diatomic gas	21	In-class Learning Catalytics; Schroeder 6.2, 6.4
13	Statistical mechanics of photons and phonons; revision lecture	22	In-class Learning Catalytics; Schroeder 7.4, 7.5

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 and PHMA 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 [PHMA 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.