Nanyang Technological University
Division of Physics and Applied Physics

COURSE CONTENT FOR PH7011 for Undergraduates

Academic Year	2022/23	**Semester**	1
Course Coordinator	Assoc. Prof. Chew Lock Yue		
Course Code	PH7011 (previously listed as PAP721)		
Course Title	Nonlinear Dynamics		
Pre-requisites	PH3502 Chaotic Dynamical Systems or equivalent and PHY (PPHY) or PHY (APHY) programme and CGPA 4.0 or higher		
No of AUs	4 AU		
Contact Hours	Lectures: 39, Tutorial: 12 (3 hr – lecture each week; 1 hr – tutorial each week)		
Proposal Date	February 2022		

Course Aims

This course aims to equip you with the basic concepts of determinism and randomness in the physical world. You will develop a basic understanding of dynamical system theory which is an essential component in physics, engineering, chemistry, biology, and also the social sciences. You will also gain basic computational and analytical skills to solve and understand real-world problems involving chaotic and non-linear systems.

Intended Learning Outcomes (ILO)

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

Mathematical Formalism (MAT) :

1. analyze and solve problems in linear system and linear dynamical system in N-dimensions mathematically and computationally
2. analyze and solve problems in nonlinear system and nonlinear dynamical system in N-dimensions mathematically and computationally
3. formulate first-order differential equations to model the evolution of diverse continuous-time dynamical phenomena and solve the equations mathematically and computationally
4. formulate recurrence equations to model the evolution of diverse discrete-time dynamical phenomena and solve the equations mathematically and computationally
5. perform geometric analysis on the phase portrait of linear and nonlinear dynamical systems.
6. perform mathematical definition and analysis of self-similar and fractal sets

Dynamical System Theory (DYN) :

7. determine the fixed points, limit cycles/periodic orbits, strange and non-strange attractors of the dynamical system under-study analytically and numerically
8. determine the stability properties of the fixed points and limit cycles/periodic orbits of the dynamical system under-study analytically and numerically
9. explain the concept of stable manifold and unstable manifold as geometric structures in phase space that guide the flow of the dynamical trajectories
10. demonstrate mastery in the use of the phase portrait (as a geometric picture of phase space) that contains the set of fixed points, limit cycles, strange attractors, stable and unstable manifolds, as the solution to dynamical system problems
11. analyze dynamical systems that are chaotic, compute its trajectories, and yield the level of chaos by evaluating its Lyapunov exponents numerically or analytically
12. account for the different type of bifurcations that occur in nonlinear dynamical systems

Fractals (FRA) :

13. explain the concepts of countable and uncountable sets
14. identify sets that have fractional dimension
15. construct and analyze fractal sets that are self-similar and non self-similar
16. determine diverse fractal dimensions of fractal sets that are self-similar and non self-similar

Course Content

Introduction
A dynamical view of the world
What is nonlinear dynamics?

Linear Dynamical System
Examples
General formulation

Ingredients of a Dynamical System
Phase space
Evolution equations
Initial conditions

Stability Properties of Linear Dynamical System
Two-dimensional linear dynamical system
N-dimensional linear dynamical system

Phase Portraits from the Stability Properties of Manifolds of Fixed Points in Continuous-Time Nonlinear Dynamical System
Phase portraits
Existence and uniqueness, no-intersection theorem
Stability properties of fixed points in nonlinear dynamical systems
Stable and unstable manifolds

Bifurcations
Saddle-node bifurcation
Transcritical bifurcation
Pitchfork bifurcation
Hopf bifurcation
Global bifurcation of cycles

Lorenz Equations
Linear stability of Poincaŕe orbits via Poincaŕe map
Homoclinic and Heteroclinic orbits
Bifurcations, chaos, and strange attractors

Nonlinear Mapping and their Dynamical Properties
Fixed points and cobwebs
Periodic points
Logistic map
The fully chaotic logistic map at A = 4
Symbolic dynamics and the Bernoulli shift map

Fractals
Countable and uncountable sets
Cantor set
Dimension of self-similar fractals
Box dimension
Hausdorff dimension

Assessment (includes both continuous and summative assessment)

Component	Course LO Tested	Related Programme LO or Graduate Attributes	Weighting	Team / Individual	Assessment Rubrics
1. CA1: Problem Sets	All	Competence (Written) Competency 1, 3, 4, 5	20%	Individual	Point-based marking (not rubric-based)

		Creativity 2			
2. CA2: Project	All	Competence (Presentation) Competency 1, 3, 4, 5, 6, 7 Creativity 1, 2 Communication 1, 2, 3 Character 1, 2, 3	40%	Individual	Rubric-based marking, see Appendix 1
3. CA3: Project	All	Competence (Presentation) Competency 1, 3, 4, 5, 6, 7 Creativity 1, 2 Communication 1, 2, 3 Character 1, 2, 3	40%	Individual	Rubric-based marking, see Appendix 1
Total			100%		

Formative feedback

You will receive formative feedback which will be given through discussion within tutorial lessons.

Feedback will also be provided for each marked problem set, where any particularly problematic areas will be identified in the marked scripts.

Finally, feedback will be given constantly during lectures and tutorials on the common mistakes and level of difficulty of the course materials and applied examples/problems. Past exam questions and examiner's report are also made available for you, and will be discussed near the end of the course.

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
Problem sets (homework)	Apply the theory and mathematical formulation learnt in class to solve problems in nonlinear dynamics in order to develop the understanding, competence, and intuition on the topic, as well as to develop both analytical and computational skills.
Projects (homework, lecture and tutorial)	Sharpen the knowledge in nonlinear dynamics through creatively working on a project in a team of two/three persons. It will also enhance the analytical and computational skills of the students as they work to deliver the requirement of the project. Furthermore, their presentation and communication skills will be developed through project presentation, and answering critical questions from their peers and seniors during the Question and Answer session.

Reading and References

1. Nonlinear dynamics and Chaos, 2nd Edition, Steven Strogatz, (2014). ISBN-13: 978-0738204536; ISBN-10: 0738204536

Course Policies and Student Responsibilities

Absence Due to Medical or Other Reasons

If you are sick and unable to attend your class, you have to:

1. Send an email to the instructor regarding the absence and request for a replacement class
2. Submit the original Medical Certificate* or official letter of excuse to administrator.
3. Attend the assigned replacement class (*subject to availability*)

* 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
Assoc. Prof. Chew Lock Yue	SPMS-PAP-04-04	6316 2968	lockyue@ntu.edu.sg

Planned Weekly Schedule

Week	Topic	Course LO	Readings/ Activities
1	Introduction	MAT1	Lecture
2	Linear Dynamical System and Ingredients of Dynamical System,	MAT1	Lecture, Tutorial
3	Stabilities of Linear Dynamical System	MAT1, MAT3, MAT5, DYN 7-8	Lecture, Tutorial
4	Phase Portraits	MAT 2-3, MAT5, DYN 7-8	Lecture, Tutorial
5	Bifurcations	DYN 12	Lecture, Tutorial
6	Poincaŕe map, Homoclinic and Heteroclinic orbits	DYN 9	Lecture, Tutorial
7	Lorenz equations	MAT 2-3, 5, DYN 9-11	Lecture, Tutorial
8	Lorenz equations	MAT 2-3, 5, DYN 9-11	Lecture, Tutorial
9	Nonlinear Mappings	MAT 2, 4-5, DYN 7-8, 10-11	Lecture, Tutorial
10	Nonlinear Mappings	MAT 2, 4-5, DYN 7-8, 10-11	Lecture, Tutorial
11	Fractals	MAT6, FRA 13-14	Lecture, Tutorial
12	Fractals, Revision	MAT6, FRA 15-16	Lecture, Tutorial
13	Project Presentation	All	Project

Appendix 1: Rubrics for Project

The assessment criteria will be based on a score of 4:

- Excellently demonstrated – 4
- Mostly demonstrated – 3
- Moderately demonstrated – 2
- Somewhat demonstrated – 1
- Never demonstrated – 0

Criteria Description	**Assessment**					**Score**
	Poor (0)	**Somewhat (1)**	**Moderately (2)**	**Good (3)**	**Excellent (4)**	
CREATIVITY AND RESOURCENESS (10%) Ability to make new connections under constraint.	Never Demonstrated	Somewhat Demonstrated	Moderately Demonstrated	Mostly Demonstrated	Excellently Demonstrated	Max 4
KNOWLEDGE (7%) Ability to correctly apply the knowledge in the course.	Never Demonstrated	Somewhat Demonstrated	Moderately Demonstrated	Mostly Demonstrated	Excellently Demonstrated	Max 4
ANALYTICAL SKILL (7%) Ability to conduct rigorous mathematical and numerical analysis as well as perform computational simulation.	Never Demonstrated	Somewhat Demonstrated	Moderately Demonstrated	Mostly Demonstrated	Excellently Demonstrated	Max 4
PREPARATION (8%) Ability to systematically organize the idea, concepts, approach, analysis, results and conclusion in the presentation materials.	Never Demonstrated	Somewhat Demonstrated	Moderately Demonstrated	Mostly Demonstrated	Excellently Demonstrated	Max 4
CLASS PRESENTATION (8%) Ability to communicate clearly and effectively, and to give appropriate response and answers to questions raised on the project	Never Demonstrated	Somewhat Demonstrated	Moderately Demonstrated	Mostly Demonstrated	Excellently Demonstrated	Max 4
					Total	Max 20

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.