Nanyang Technological University
Division of Physics and Applied Physics

Academic Year	2019/20	**Semester**	1
Course Coordinator	Asst. Prof. Timothy Liew		
Course Code	PH2104		
Course Title	Analytical Mechanics		
Pre-requisites	(MH2800 and PH1104) OR (MH1803 and MH2802 and PH1104) OR (CY1601 and CY1602 and CY1308)		
No of AUs	4 AU		
Contact Hours	PH2104 (3 hr – lecture; 1 hr – tutorial)		
Proposal Date	01/2019		

Course Aims

This course aims to equip you with the basic concepts and problem solving skills in Analytical Mechanics. You will develop physical intuition and analytical skills which are important for studying physical systems and solve problems involving mechanical systems. This knowledge and skills lay the foundation for other physics courses such as quantum mechanics and photonics.

Intended Learning Outcomes (ILO)

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

Newtonian Mechanics (NM) :

1. analyse and solve problems involving motion with non-constant acceleration.
2. analyse and solve problems involving oscillatory motions (such as simple harmonic oscillators in the presence of damping and driving force and coupled oscillators).
3. apply conservation of momentum to solve physical problems.
4. determine the properties of a system of particles such as centre of mass, moment of inertia and apply $\Sigma\vec{F}_{ext} = \frac{d\vec{p}}{dt}$ and $\Sigma\vec{\tau}_{ext} = \frac{d\vec{L}}{dt}$.

Non-inertial reference frames and rotating coordinate systems (NIRF) :

5. analyse physics in a rotating frame of reference and discuss the origin of fictitious forces (such as Coriolis force and Centrifugal force).
6. solve various physical problems in rotating frames (such as deflection of an object due to apparent gravity and motion of projectiles in rotating frames).

Lagrangian and Hamiltonian Mechanics (LHM) :

7. identify and solve problems that can be represented as the minimisation of a functional.
8. derive shapes of curves arising in physical problems (such as Brachistochrone and Catenoid) and give examples of where they occur in physics.
9. write and use the Lagrangian to solve problems in classical physics (including systems with multiple objects) in generalized coordinates.
10. derive equations of motion using Euler-Lagrange equations and use them to solve the dynamics of physical systems (including using Lagrange multipliers for constrained motion).
11. discuss the importance of Noether's theorem in explaining the relation between symmetry and conserved quantities.
12. use Hamilton's equations to define the motion of classical physics systems and sketch the phase diagrams of simple systems.
13. use Lagrangian and Hamiltonian mechanics to analyse central force motions (such as deriving the geometric orbital equation and using it to determine shapes of planetary orbits, orbital changes due to impulse and predicting the existence of precession).

Rigid Body Rotation (RBR) :

14. determine the inertia tensor of rigid bodies.
    derive Euler's equations for rotating rigid bodies and solve physical problems (such as precession of symmetric free tops and stability of rotation of asymmetric free tops about an axis.)

Course Content

Newtonian Mechanics (NM)
Equation of Motion with Non-constant Acceleration
Conservation theorems
Simple Harmonic Oscillators
Damped Oscillations
Driven Oscillations
Coupled Oscillators
Centre of Mass
Linear Momentum
Angular Momentum

Non-inertial reference frames and rotating coordinate systems (NIRF)
Rotating Coordinate Systems
Centrifugal and Coriolis Forces
Motion Relative to the Earth

Lagrangian and Hamiltonian Mechanics (LHM)
Euler's Equation
Lagrange's Equations of Motion in Generalized Coordinates
Lagrange's Equations with Undetermined Multipliers
Noether's Theorem
Phase Space Diagram
Hamilton's Equations of Motion
Geometric Orbit Equation
Keplerian Orbits
Precession

Rigid Body Rotation (RBR)
Inertia Tensor
Euler's Equations for Rigid Bodies
Precession of Symmetric Free Tops
Stability of Rigid-Body Rotations

Assessment (includes both continuous and summative assessment)

Component	Course LO Tested	Related Programme LO or Graduate Attributes	Weighting	Team / Individual	Assessment Rubrics
1. Final Examination	All	Competence (1, 2, 3, 4, 5, 6) Communication (1, 2)	50%	Individual	Point-based marking (not rubric-based)
2. CA1: Problem Sets	All	Competence (1, 2, 4, 5, 6) Creativity (1, 2) Communication (1, 2) Character (1, 2)	25%	Individual	Point-based marking (not rubric-based) & Open-ended marking scheme*

3. CA2: Mid-term 1	NM & NIRF	Competence (1, 2, 3, 4, 5, 6) Communication (1, 2)	25%	Individual	Point-based marking (not rubric-based)
Total			100%		

*You would be expected to synthesise the physics concepts learnt in the course to propose scientifically valid approaches to given situations or problems.

Formative feedback

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

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 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 your answers to the Clickers questions so that you can learn from one another.

Reading and References

1. Analytical Mechanics, 7th Edition, G. R. Fowles & G. L. Cassiday. (Brooks Cole). ISBN-13: 978-0534494926
2. Introduction to Classical Mechanics with problems and solutions, David Morin. (Cambridge). ISBN 13: 9780521876223
3. Classical Mechanics, 3rd Edition, Herbert Goldstein, Charles P. Poole Jr. and John L. Safko. (Addison-Wesley). ISBN 13: 9780201657029

Course Policies and Student Responsibilities

Absence Due to Medical or Other Reasons

If you are sick and unable to attend your class / Mid-terms, you have to:

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

* 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
Asst. Prof. Timothy Liew	SPMS-PAP-03-11	6513-7504	tchliew@gmail.com

Planned Weekly Schedule

Week	Topic	Course LO	Readings/ Activities
1	Motion with non-constant acceleration	NM 1	Chapter 1 lecture notes
2	Small oscillations and coupled oscillators	NM 2-4	Chapter 2 lecture notes
3	Non-inertia reference frames and rotating coordinate systems;	NIRF 6	Chapter 3 lecture notes
4	Coriolis and centrifugal forces	NIRF 5	Chapter 4 lecture notes
5	Dynamics of systems of particles	NM and NIRF	Chapter 5 lecture notes
6	Calculus of variations	LHM 7-8	Chapter 6 lecture notes
7	Lagrangian Dynamics	LHM 9	Chapter 6 lecture notes

8	Lagrangian Dynamics	LHM 9-11	Chapter 7 lecture notes
9	Hamiltonian Dynamics	LHM 12	Chapter 7 lecture notes
10	Hamiltonian Dynamics	LHM 12-13	Chapter 8 lecture notes
11	Central Forces and Planetary Motion	LHM 13	Chapter 8 lecture notes
12	Central Forces and Planetary Motion	LHM 13	Chapter 8 lecture notes
13	Rigid Body Rotation	RB 14-15	Chapter 9 lecture notes

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.