PHY 303/573 – Analytical Mechanics

Fall 2024

General Course Information

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Prerequisites: PHY 251 and PHY 277 or permission of department; MAT 303 or MAT 305 or AMS 361 or MAT 308. 3 credits.

Overview

Analytical Mechanics is the generic name given to a number of theoretical approaches to Classical Mechanics in which *vectorial* quantities of motion take a less prominent place than in Newton's original approach. While Newton's formulation of Classical Mechanics proved tremendously successful and became in many ways the defining paradigm of our scientific age, its direct generalization potential turned out, from a historical perspective, to be rather limited. In contrast, the methods of Analytical Mechanics — the Lagrangian and the Hamiltonian formalisms, the Hamilton-Jacobi theory, the principle of least action, the idea of phase space, and the beautiful and deep relation between symmetries and conservation laws expressed by Noether's theorem — led to powerful and far-ranging generalizations. In some form or another their essential principles sit now at the heart of modern theoretical physics and play a central role in such varied fields as relativistic mechanics, general relativity, quantum mechanics, statistical mechanics, classical and quantum field theory. Our aim in this course will be to retrace this conceptual shift and walk the bridge between the Newtonian mind frame and the modern "analytical" one.

A more concrete goal of the course is for you to learn to solve classical mechanical problems using the methods and concepts of Analytical Mechanics. The mathematical level of the course should be considered as advanced, in accordance with the listed prerequisites. In particular, **you will be expected to have a solid working command of algebra and multivariate calculus.** For a successful outcome, you should anticipate to spend a substantial amount of time every week preparing for the course and working on the homework assignments.

Instructor: *Radu Ionaş*

- Email: radu.ionas@stonybrook.edu. Reserved for personal issues; I prefer to answer questions about the material covered in class and the homework as much as possible during office hours, and not via email. When inquiring about homework-related issues please c.c. our graduate TA into your correspondence.
- Office hours: TBA

Graduate TA: *Tymothy Mangan*

- Email: tymothy.mangan@stonybrook.edu
- Office hours: TBA

Lectures

TuTh 8:00 – 9:20 am, Frey Hall 301. The lectures will be live-streamed online and recorded (subject to possibility). Lecture notes/slides will be posted at regular intervals (and usually ahead of being discussed in class) in the Course Documents module in Brightspace.

Textbook and Other Resources

The suggested (as in "not mandatory, only recommended") textbook for the course is

- D. Morin — *Introduction to Classical Mechanics with Problems and Solutions*, 2009 (1st ed.)

This book contains a large collection of rather nice worked-out problems, preceded by succinct discussions of the relevant theory. We will not follow it very closely — but nonetheless, it is quite a useful and greatly recommended read due to its emphasis on applications and problem-solving.

Many other books exist, covering a wide range of difficulty levels, pedagogical approaches and mathematical tastes. Observations have shown that a common side effect of studying Analytical Mechanics consists in developing strong contrary opinions about these books. To avoid this dreadful condition I encourage you to browse, in preparation for the course, through the further references listed below, and set aside those which you deem best suited for your learning style and needs.

The canonical references in the field are considered to be

- L. D. Landau, E. M. Lifshitz — *Mechanics*, 1960 (the first volume in a magisterial ten-volume *Course of Theoretical Physics*)
- H. Goldstein — *Classical Mechanics*, 1951 (with the latest, extended 3rd edition from 2005 including also C. P. Poole and J. L. Safko as co-authors).

These books discuss theory in a much greater depth than Morin's book. Other widely-used references include

- G. R. Fowles, G. L. Cassiday — *Analytical Mechanics*, 2005 (7th ed.)
- J. R. Taylor — *Classical Mechanics*, 2005
- L. N. Hand, J. D. Finch — *Analytical Mechanics*, 1998 (1st ed.)
- J. B. Marion, S. T. Thornton — *Classical Dynamics of Particles and Systems*, 2004 (5th ed.)

Among the freely available resources which you might find useful to consult are

- Professor Konstantin Likharev's book on *Classical Mechanics* (2013), part of his *Essential Graduate Physics* series (Stony Brook).
- Professor Derek Teaney's lecture notes for the corresponding graduate-level course (Stony Brook).
- D. Tong — *Lecture Notes on Classical Dynamics* (University of Cambridge, UK).
- S. Golwala — *Lecture Notes on Classical Mechanics* (Caltech).
- D. Arovas — *Lecture Notes on Classical Mechanics* (U. of California at San Diego).
- J. C. Baez, D. K. Wise — *Lectures on Classical Mechanics* (U. of California at Riverside).

A mathematically advanced reference, for those interested in a deeper, geometric understanding of the foundations of Classical Mechanics, is

- V. I. Arnol'd — *Mathematical Methods of Classical Mechanics*, 1989 (2nd ed.)

Finally, Analytical Mechanics is a standard component of the so-called "comprehensive" exams given at the beginning of graduate school and meant to test students' comprehension of core physics areas. Here you can find a collection of past such exams, with solutions, given over the years by the Physics & Astronomy Department at Stony Brook.

Homework

Homework will be assigned weekly on (usually) Thursdays, and will be due on the morning of the *second* Tuesday after that, at 8:00 am. It will consist of several problems, some of which are going to be quite challenging; you should expect to spend several days studying the relevant theory and working on them. As part of your homework you will be expected to learn to use a mathematical symbolic software system (I myself will be using Maple). To submit the homework, upload a digital copy in the Assignments section in Brightspace. **The submission deadlines will be strict. No extensions can be given as the solutions will be published shortly thereafter, and no make-up assignments are available.** In exchange, to accommodate for unforeseen events, the lowest homework score will be dropped from the final grade calculation. Discussing the homework with your colleagues is not only allowed but in fact strongly encouraged; your submissions must however be entirely your own work. For full credit, show the details of the derivations, not just the end results.

Exams

There will be one midterm and one final exam. These are scheduled as follows:

Midterm exam	Oct. 17, 8:00 – 9:20 am (during regular lecture hours)
Final exam	Dec. 19, 8:00 – 10:45 am

All students must take the exams on the dates scheduled, so please plan accordingly. Only exceptionally serious and documented reasons for missing an exam will be considered.

Grades

Your course score will be calculated based on the following percentage weights:

Midterm exam	30%
Final exam	45%
Homework	25%

There will be no possibility of earning extra credit at any time during the semester. Letter grades for the course will be assigned on a curve, which I reserve the right to choose as I see fit in accordance with the difficulty of the exams.

Course Outline

The following is a tentative list of some of the topics that I plan to discuss throughout the semester:

- Various mathematical reviews

- Mechanics in non-inertial reference frames
- Lagrangian mechanics
- Linear oscillators
- The principle of least action and variational calculus
- Lagrange multipliers
- Symmetries and Noether's theorem
- Central potentials and Kepler's problem
- The Hamiltonian formalism
- Dynamics of rigid bodies

Standard University Policy

A. Student Accessibility Support Center Statement: If you have a physical, psychological, medical, or learning disability that may impact your course work, please contact the Student Accessibility Support Center, 128 ECC Building, (631) 632-6748, or at sasc@stonybrook.edu. They will determine with you what accommodations are necessary and appropriate. All information and documentation is confidential.

B. Academic Integrity Statement: Each student must pursue his or her academic goals honestly and be personally accountable for all submitted work. Representing another person's work as your own is always wrong. Faculty is required to report any suspected instances of academic dishonesty to the Academic Judiciary. Faculty in the Health Sciences Center (School of Health Technology & Management, Nursing, Social Welfare, Dental Medicine) and School of Medicine are required to follow their school-specific procedures. For more comprehensive information on academic integrity, including categories of academic dishonesty please refer to the Academic Judiciary website.

C. Critical Incident Management: Stony Brook University expects students to respect the rights, privileges, and property of other people. Faculty are required to report to the Office of Student Conduct and Community Standards any disruptive behavior that interrupts their ability to teach, compromises the safety of the learning environment, or inhibits students' ability to learn.

D. Religious Holidays: This course will operate in compliance with the University's policy regarding religious holidays, set forth here. In particular, you should notify the instructor in advance, but definitely before the final date of the 'add/drop' period, of your intention to be out for religious observance.

Further information about most academic matters can be found in the Undergraduate Bulletin, the Undergraduate Class Schedule, and the Faculty-Employee Handbook.