Analytical Mechanics with Computational Laboratory

PHYS 312/314 • Spring 2026

Centenary College of Louisiana

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Office	Centenary Square 203B	**Lecture**	TR 9:45–11:00 am, Centenary Square 204
Office Hours	M 1:00–3:00 pm T 11:00 am–2:00 pm W 12:00–2:00 pm	**Lab**	F 1:00–4:00 pm, Centenary Square 204

Course at a Glance

Lecture Course	PHYS 312: Analytical Mechanics
Laboratory Course	PHYS 314: Analytical Mechanics Laboratory
Lecture Text	John R. Taylor, *Classical Mechanics*
Lab Text	Daniel V. Schroeder, *Physics Simulations in Python: A Lab Manual*
Prerequisites	MATH 201, Calculus II; PHYS 105/115, Physics II and Physics II Lab
Corequisites	PHYS 312 and PHYS 314 are designed to be taken together

Course Description

Analytical Mechanics extends introductory dynamics by developing more powerful ways of describing mechanical systems. We will learn how to use constants of motion—not only energy—to simplify and organize our descriptions of physical systems. We will also expand our vocabulary beyond Newtonian dynamics to include Lagrangian and Hamiltonian descriptions of motion. Along the way, we will use vector calculus, non-Cartesian coordinate systems, linear algebra, and differential equations, reviewing the necessary mathematical tools as they arise.

The accompanying laboratory treats computational modeling as a central activity of physics. Students will implement versions of the mechanical models studied in lecture as computer code, test numerical results against analytically solvable cases, and then use simulations to explore systems whose behavior cannot be predicted by pencil-and-paper methods alone.

Together, the lecture and lab ask students to move back and forth between formal models, numerical models, and physical interpretation.

Learning Goals

By the end of PHYS 312/314, students should be able to:

- identify and use constants of motion in mechanical systems;
- formulate equations of motion using Newtonian, Lagrangian, and Hamiltonian methods;
- incorporate constraints, friction, and driving forces into mechanical models;
- analyze oscillatory systems, including damped, driven, and coupled oscillators;

- use coordinate transformations and effective potentials to study central-force motion;
- describe mechanical systems using matrix methods, eigenfrequencies, and normal modes;
- incorporate the basic insights of special relativity into the framework of classical mechanics;
- implement numerical models of mechanical systems in Python;
- test simulations against analytical limits and conserved quantities;
- communicate the assumptions, methods, results, and limitations of a computational project.

Relationship Between Lecture and Lab

The lecture course develops the analytical structure of mechanics: conservation laws, generalized coordinates, variational principles, oscillations, central forces, Hamiltonian mechanics, normal modes, and relativity. The laboratory develops computational tools for investigating the same kinds of systems numerically. Students will learn the basics of Python programming, plotting, animation, numerical integration, model validation, and independent project design.

A central aim of the combined course is to help students see analytical and computational methods as complementary. Analytical solutions provide insight and serve as checks on numerical work; numerical models allow us to investigate systems that are too complicated to solve exactly.

Assessment

PHYS 312: Analytical Mechanics

The lecture grade emphasizes analytical problem-solving, conceptual reflection, examinations, and a final modeling project.

Component	Weight
Homework	35%
Exams	40%
Final Project	20%
Reflection Questions	5%

PHYS 314: Analytical Mechanics Laboratory

The laboratory grade is based on four computational projects. The first project introduces basic programming, plotting, and animation skills; the remaining projects emphasize numerical modeling, physical interpretation, and independent computational work.

Component	Weight
Project 1: Making Shapes	10%
Project 2: Projectiles	30%
Project 3: Pendulum	30%
Project 4: Final Project	30%

Letter Grades

Grade	Percentage Range
A	90–100%
B	80–89%
C	70–79%
D	60–69%
F	below 60%

Detailed Lecture Schedule

This schedule records the specific lecture topics and approximate textbook coverage. The pacing may be adjusted as needed, but the table reflects the intended structure of the course.

Week	Reading (Taylor)	Lecture Topics
1	Ch. 1	Applying Newton's laws in Cartesian coordinate systems; applying Newton's laws in non-Cartesian coordinate systems
2	Ch. 2	Incorporating frictional force models, including air resistance; using complex numbers for magnetic forces
3	Ch. 3	Momentum conservation and the rocket equation; angular momentum and angular momentum conservation
4–5	Ch. 4	Conservative forces, work, and potential energy; central forces and elastic collisions
5–6	Ch. 5	Describing oscillations using different functional forms; damped and driven oscillations
7	Review	Review and midterm examination
8	Ch. 7	Lagrangian mechanics and Lagrange's equations of motion; Hamilton's principle
9	Ch. 13	Hamiltonian mechanics and Hamilton's equations of motion; phase space
10	Ch. 8	Central forces and effective potentials; project work day
11	Ch. 5 + notes	Fourier series and driven oscillations; project work day
12	Ch. 11 + notes	Coupled oscillators in matrix form; normal modes
13	Ch. 15 + notes	Rotations and Galilean relativity; Lorentz transformations and special relativity
14	Review	Review and final examination

Detailed Laboratory Schedule

The laboratory projects are designed to introduce computational mechanics gradually. Students begin with basic Python, plotting, and animation before moving to numerical integration, model validation, nonlinear dynamics, and independent project work.

Project	**Weeks**	**Computational and Physical Focus**
Project 1: Making Shapes	1–3	Introduction to Python; animations using VPython; plotting with NumPy
Project 2: Projectiles	4–6	Numerical integration using Euler's method and the Euler-Richardson method; incorporating drag
Project 3: Pendulum	8–10	Choosing natural units for computation; testing code using conserved quantities; transition to chaos
Project 4: Final Project	11–13	Applying computational models to an independent mechanics project (your choice)

Final Project Suggestions

Students may choose a final project topic in consultation with the instructor. Possible projects include computational, experimental, and theoretical investigations such as:

- extending projectile motion models to include air resistance, spin, launch angle, or environmental effects relevant to sports such as baseball, basketball, or golf;
- analyzing the Wilberforce pendulum as a coupled oscillator that exchanges energy between translational and rotational motion;
- modeling coupled oscillators and normal modes in systems such as springs, pendula, or simplified molecular vibrations;
- simulating orbital motion, including comparisons among circular, elliptical, and perturbed orbits;
- using Fourier analysis to study oscillatory motion, beats, or normal-mode decompositions;
- simulating mirages or ray-bending through a medium whose index of refraction varies with position;
- developing a Monte Carlo random-walk model for diffusion, shielding, or transport processes;
- constructing and analyzing an SIR-style model as an application of differential equations and numerical modeling;
- investigating relativistic rocket motion and the relationship between acceleration, fuel cost, and time dilation;
- designing an original computational or experimental project that applies the methods of analytical mechanics to a physical system of interest.

Course Policies

Academic Honesty and the Honor Code

Lack of knowledge of the academic honesty policy is not a reasonable explanation for a violation. All students at Centenary are bound by the Honor Code. It is not considered cheating in this course to share suggestions on assignments with peers, although the final work must ultimately be one's own. Examinations, quizzes, and individual assignments are expected to be completed according to the instructions given for that assignment.

Students are required to write the following pledge at the end of any examination or assignment:

> *I have neither given nor received unauthorized aid on this examination (paper), nor have I seen anyone else do so.*

If any student has received aid or suspects others of violating the Honor Code, the following clause is to be added to the pledge: "...except as I shall report immediately to the Honor Court." The complete pledge must be written and signed by the student, shall not be abbreviated, and should never be written until the test or paper has been completed for submission. Students are bound by the Honor Code even if they fail to write the pledge on their assignment or examination.

Attendance

Attendance is required. However, students are expected not to jeopardize their own health or anyone else's health to attend class. Students who are sick, suspect they might be sick, have been exposed to someone sick, or are concerned they may have been exposed to someone sick should notify the professor to arrange appropriate accommodations.

Illness-related absences will be excused. There is no penalty for missing class if students proactively communicate with the professor and complete all required work. If a qualified professional deems remaining in classes and fulfilling the necessary requirements impossible, alternatives will be sought in coordination with Student Support Services.

For PHYS 312, more than six unexcused absences will lead to a failing grade in the course. For PHYS 314, more than three unexcused absences will lead to a failing grade in the course.

Disability Accommodations

It is the policy of Centenary College to accommodate students with disabilities, pursuant to federal law, state law, and the College's commitment to equal educational opportunities. Any student with a disability who needs accommodations should inform the instructor at the beginning of the course. Students with disabilities need to contact Disability Services, a division of the Center for Teaching and Learning, located in the Learning Commons on the second floor of Magale Library. Disability Services can be reached by telephone at 318-869-5738.

Diversity Statement

Centenary College of Louisiana values human diversity in all its richly complex and multi-faceted forms, whether expressed through race and ethnicity, culture, political and social views, religious and spiritual beliefs, language and geographic characteristics, gender, gender identities and sexual orientations, learning and physical abilities, age, and social or economic classes.