PHYS 2301: Analytical Mechanics (winter)

Calendar description: This course continues on some of the ideas introduced in PHYS 2300.1(.2), and introduces the student to a broad range of other areas in classical mechanics. Topics include coupled and 3-D oscillators, non-inertial reference frames, central forces (celestial mechanics), N-body dynamics, rigid bodies, angular momentum and torques, deformation and vibration of beams.

Note: Credit cannot be given to students who already have a credit for PHYS 2305.1(.2), Newtonian Mechanics.

Contents

Overview

This course essentially repeats the topics covered in PHYS 1100, but at a much more sophisticated level. This is the penultimate course in Mechanics, in which everything is still discussed in terms of Newton's laws of motion rather than the Euler-Lagrange formalism reserved for PHYS 3300, Classical Mechanics; the ultimate course in this series.

There is no lab portion to this course.

Prerequisites

MATH 2301 (or 2320) Linear Algebra
MATH 2311 Intermediate Calculus II

Students entering PHYS 2301 are expected to have mastered vector algebra including the dot and cross products, and to have had a good introduction to the algebra of series, Taylor and binomial expansions, partial derivatives, line, surface, and volume integrals, the theorems of Gauss, Green, and Stokes, vector spaces, matrices, determinants, systems of linear equations, Dirac notation, and eigenalgebra. Concurrent to this course, students should be enrolled in MATH 2303 (Differential equations) and soon into the term should be familiar with simple first and second order ODEs with constant coefficients.

PHYS 2300 Vibrations, Waves, and Optics

This course gives an thorough introduction to the wave equation citing many examples of waves in nature. Forced, damped simple harmonic oscillators (spring and LRC circuits) are also covered.

Dependent courses

PHYS 3300 Classical Mechanics

PHYS 3300 begins with the calculus of variations, derives the Euler-Lagrange equations, and then launches into the Lagrangian and Hamiltonian formulations of mechanics. Thus, many of the same ideas and problems taught in PHYS 2301 are revisited in PHYS 3300. Therefore, the instructor of PHYS 3300 relies much more heavily on the enhanced problem-solving skills of a student completing PHYS 2301 than any concepts in physics covered, such as the conservation of energy, momentum, and Newton's laws which were essentially covered in PHYS 1100 (University Physics I) anyway.

Student Outcomes

The overall aim of the Classical Mechanics stream (300) is to develop the student into a solver of dynamic problems, and to build the student's physical intuition into a reliable tool that can be applied to any physical problem.

Students completing PHYS 2301 should have developed the following skills:

1. understand what constitutes a "well-posed" problem;
2. break up a well-posed problem into its mathematical components;
3. understand what constitutes a "system", and how to define it;
4. apply and be aware of simplifications;
5. how and where to apply specific math skills;
6. be able to exploit the symmetry of a problem

Typical problems students completing PHYS 2301 should be able to solve:

1. A billiard ball is struck by a horizontal cue with "top English" (half way between its top and centre). What is its final speed in terms of the initial speed immediately after impact?

2. What are the natural frequencies of vibration of three masses coupled together by two springs confined to move in one dimension?
3. Show that a hurricane must spin counter-clockwise in the northern hemisphere (as viewed from above), and clockwise in the southern hemisphere.
4. How much precession of Mercury's orbit can be accounted for by Jupiter?
5. If a rigid beam is struck by a hammer, how quickly does the wave propagate down the beam?

Curriculum

1. Newtonian mechanics review
   - Free body diagrams
   - constrained motion
2. coupled oscillators
   - normal coordinates/normal modes (eigenvalue/eigenvector approach)
   - normal modes of N coupled objects in 1-D, as $N \to \infty$
3. 3-D oscillators
   - non-linear oscillator (pendulum and elliptical integrals)
   - isochronus problem
   - spherical pendulum
4. non-inertial reference frames
   - centrifugal and Coriolis forces
5. central forces (celestial mechanics)
   - orbits, eccentricity
   - Kepler's laws
6. N-body dynamics
   - scattering
   - collisions in 2-D
7. rigid bodies
   - tensor formulation for moment of inertia
   - deformation, bending
   - vibrating beams

Suggested texts

Analytical Mechanics (6th ed.) by Fowles (ISBN)

- a classic for this subject at this level, used at SMU for some time and still a good choice for the revised curriculum
- no vector calculus required

First half of *Classical Dynamics* by Thornton and Marion (ISBN 0 5344 0896 6)

- 2.5/5 stars (44 reviews) on amazon.com
- second half *may* serve for PHYS 3300
- suitable level for second year, but may be a little too light for third year

Notes to the instructor

1. Students will have a background in matrices (MATH 2301/2320) but not tensors. Indeed, no where else in the curriculum are tensors taught, and thus a short unit on tensor analysis in this course would be both appropriate and needed.
2. The most important outcomes of this course are problem-solving skills and the clever use of symmetry and mathematics to solve problems of classical dynamics. This will be tested most rigorously by problems in the rigid body unit outlined in the curriculum section.
3. Unlike PHYS 2300 (Vibrations, Waves and Optics), there are no labs or math courses with which to coordinate the lectures. However, a discussion with the instructor of PHYS 3600 (Experimental Physics I) to determine what if any labs in classical dynamics will be performed by students next year would allow you to foreshadow these in your lectures, and perhaps use components of these labs as demonstrations.