PHYS 1500: Introduction to Modern Physics (winter)

Calendar description: The special theory of relativity and early ideas in quantum mechanics are introduced. Topics in relativity include departures from Newtonian theory, Lorentz transformations, space and time dilation, the "Twin Paradox", and relativistic dynamics. Topics in quantum mechanics include the quantum theory of light, the Bohr model of the atom, the wave nature of particles and the Schrödinger equation as applied to one-dimensional problems.

Contents

Overview

This is a first course in modern physics that had been taught as a second-year course until 2007–08. It was brought to first year to relieve the then very heavy second year curriculum, as well as to give in-coming physics majors a taste of relativity and quantum physics as soon as possible. Still, some students will wait until their second year to take this course, and thus one might expect a mix of first- and second-year students here.

Prerequisites

PHYS 1100 University Physics I

PHYS 1500 will benefit from the discussion on Newton's Laws, reference frames, conservation of momentum and energy, collisions, and mechanics in general from PHYS 1100, as well as the problem solving skills achieved there.

MATH 1210 Introductory Calculus I

Students will be introduced to the Schrödinger wave equation, and thus derivatives. By having MATH 1210 as a prerequisite, the instructor can use differential calculus when needed. Since most students will be taking MATH 1211 concurrently, integrals can be used after a month or so into the term.

Dependent courses

PHYS 3300 Classical Mechanics

PHYS 3300 has a short unit on special relativity in which Newton's Laws are recast in Lorentz invariant form using the four-vector representation for momentum and forces. The concept of four-vectors may be too advanced for first-year students (in part, because of their dependence on complex numbers), but it would still be helpful if they were introduced (*e.g.*, collisions) near the end of the relativity unit in PHYS 1500 since PHYS 3300 starts some time (two semesters and two summers) after PHYS 1500 ends.

PHYS 3400 Electrodynamics

PHYS 3400 has a short unit on relativity in which the Lorentz invariance of Maxwell's equations is discussed.

PHYS 3500 Quantum Mechanics I

PHYS 3500 (which starts two semesters and two summers after PHYS 1500 ends) builds on the elementary ideas in quantum mechanics covered in PHYS 1500, namely the Bohr model of the atom and simple 1-D time-independent solutions to the Schrödinger wave equation (*e.g.*, infinite square well where the SWE can be reduced to quadratures). PHYS 3500 can then start with the Schrödinger wave equation and its more complicated applications, most of which (including even the finite square well) are too advanced for first-year students as they involve matching boundary conditions to solutions of second order ODEs.

Student Outcomes

Students completing PHYS 1500 should begin to develop the following skills:

1. be able to abandon intuition (which won't help most students in this course), and rely on the physics and mathematics to reach a solution.
2. think "relativistically", and gain an appreciation that Newton wasn't "wrong"—his ideas just had "limits".
3. gain familiarity with particle/wave duality
4. this course will give students their first exposure to solving a differential equation (time-independent SWE), albeit an integrable one.

Typical problems students completing PHYS 1500 should be able to solve:

1. Using space-time diagrams, give a self-consistent explanation for the "twin paradox".

2. Using the Bohr model of the atom, explain the spectrum of atomic hydrogen.
3. Find the energy levels and allowed wave functions of a particle trapped in an infinite square well.

Curriculum

In parentheses is the approximate number of lectures to spend on each topic.

1. Relativity (8)
   - Galilean and Einstein relativity
   - events and measurements
   - simultaneity, time dilation (Twin Paradox), length contraction
   - Lorentz transformations
   - relativistic momentum and energy (4-vectors); collisions
   - conservation vs. invariance
2. The end of classical physics (2)
   - Faraday
   - cathode rays, J. J. Thomson and the discovery of the electron
   - Millikan and the fundamental unit of charge
   - Rutherford and the discovery of the nucleus
   - emission and absorption of light
   - blackbody radiation (the ultraviolet catastrophe)
3. Quantisation (3)
   - photoelectric effect and photons
   - matter waves and energy quantisation
   - Bohr's model of the atom
   - the hydrogen spectrum
4. Wave functions and uncertainty (2)
   - waves, particles and the double slit experiment
   - wave-particle duality
   - the wave function, normalisation, wave packets
   - the Heisenberg Uncertainty Principle
5. One-dimensional quantum mechanics (5)

- Schrödinger's equation
- particle in a rigid box
- Correspondence Principle
- the infinite potential wells, wave-functions

6. Optional topics (3)
    - nuclear physics
    - particle physics
    - solid state physics

Suggested texts

The text used for this course should be the same as the text used for PHYS 1100 and PHYS 1101 (University Physics I and II). Virtually all first-year calculus-based physics texts have a reasonable unit on modern physics with ample material for a semester-long course, including relativity, simple quantum mechanics, and units on nuclear and solid state physics.

While this was a second year course, the text used was *Modern Physics* by Tipler and Llewellyn (ISBN 07-16743-45-3). It is probably at too high a level for first-year students, but may still be useful for reference and a source of "challenge problems".

Notes to the instructor

1. This course was taught as a second-year course at SMU until the 2006-07 academic year. It was moved to the first year for three reasons:
    i) to give first-year students a taste of those subjects in physics that captures their imagination most, namely relativity and quantum mechanics.
    ii) to make a first course in relativity and quantum mechanics accessible to more students than physics majors.
    iii) to lighten the load on second-year students, who were finding the transition from first to second years too brutal.

    Putting this course to the first year means the level had to be reduced, but it was felt that PHYS 3300 (where four-vectors are first used) and PHYS 3500 (which starts with the finite square well) could cover the topics not appropriate for a first year course.

2. Instructors for the three first-year courses [this, PHYS 1100 (University Physics I), and PHYS 1101 (University Physics II)] are strongly urged to discuss and agree upon a mutually suitable text in time for ordering texts for the fall.