PHYS 2400: Electricity and Magnetism (winter)

Calendar description: This course gives a comprehensive introduction to one the self-consistent mathematical theory for electric and magnet fields which was developed during the latter half of the 19$^{\text{th}}$ century. Topics include electric field and potential, Gauss' law, capacitance, elementary circuit analysis, Ampère's law, the Law of Biot and Savart, magnetisation of matter, Faraday's law of inductance, and Maxwell's equations in integral and differential form.

Classes 3 hrs. and lab 3 hrs. per week; 1 semester.

Contents

Overview

The lab portion of this course is described separately at PHYS 2400L. The instructors of the lab portion enjoy some autonomy in how the lab is conducted, but it is the instructor of the lecture portion of the course, hereafter the "lecturer", who is responsible for the overall course, assigns final grades to the students, and is judged by student evaluations. Therefore, the lab instructor needs to consult with the lecturer in how the lab is conducted, and where there is disagreement the view of the lecturer shall prevail.

Prerequisites

PHYS 1101 University Physics II

The last half of PHYS 1101 is dedicated to electricity and magnetism, where students see and use the Laws of Gauss, Ampère and Faraday (all in integral form) to solve problems with a high degree of symmetry. Much of the curriculum of PHYS 2400 may seem to be a review of all the concepts covered in PHYS 1101, but the mathematical sophistication and expectation in the kind of problems to be solved is significantly higher.

MATH 2301 Linear Algebra for Engineers
MATH 2311 Intermediate Calculus II

These courses provides the necessary background in vector calculus (including the theorems of Gauss and Stokes), line and surface integration, partial differentiation, and the solutions of systems of equations.

Dependent courses

ASTR 4600 High-Energy Astrophysics

ASTR 4600 depends on PHYS 2400 for its introduction to Maxwell's equations, so that the wave equation of electromagnetic radiation may be developed.

PHYS 3400 Electrodynamics

If taught as recommended, PHYS 2400 is based on the first half of Griffiths' text *Introduction to Electrodynamics*, while PHYS 3400 is based on the second half. Thus, PHYS 3400 is very much a follow-on course to this, and will depend a great deal on the instructor of PHYS 2400 covering the prescribed material, as well as the concepts and problem solving skills developed in this course.

PHYS 3600 Experimental Physics I

PHYS 3600 depends, in part, upon the material in the lab portion of this course (PHYS 2400L), but not directly on the lecture portion.

PHYS 4370 Philosophy of Physics

This course, part of the Philosophy/Physics double major and honours programmes, is co-taught by faculty in the Department of Astronomy and Physics and the Department of Philosophy. It is a discussion-oriented course that depends on PHYS 2400 and PHYS 3500 (Quantum Mechanics I) for an overall level of knowledge in physics so that discussion may be based on sound physical principles. The problem-solving and lab skills gained in PHYS 2400 are less germane.

Student Outcomes

Students completing PHYS 2400 should begin to develop the following skills:

1. analyse elementary circuits
2. learn to deal with non-intuitive physical phenomena
3. This is the student's first real course based on "applied math". Thus, the student should strive to:

- solidify math skills and learn to solve vector differential equations and use line and surface integrals in the context of real physical problems
- learn to prepare a complete and concise mathematical solution
- draw out a physical understanding and explanation from a mathematical solution

Curriculum

The suggested curriculum is based on chapters 2–7 of *Introduction to Electrodynamics* by David Griffiths, the preferred text for this course. See the section *Suggested texts* for more discussion.

1. Electrostatics
   - electric field, and Coulomb's Law
   - field lines, flux, and Gauss' Law
   - electric potential and capacitance
   - work done in moving/assembling charges
   - conductors and induced charges
2. Elementary circuit analysis
   - resistors, capacitors, and inductors
   - LR, RC, CL circuits
   - oscilloscopes and hysteresis
   - LRC circuits and the damped forced harmonic oscillator; resonance
3. The equations of Laplace and Poisson
   - 1, 2, and 3 dimensions
   - boundary conditions and uniqueness theorems
   - method of images
   - separation of variables
   - multipole expansion
4. Electric fields in matter
   - dielectrics
   - dipoles, torques
   - polarisation
   - electric displacement, and Gauss' Law in a dielectric
   - susceptibility, permittivity, and dielectric constants

- energy/forces in/on a dielectric

5. Magnetostatics
   - magnetic field, and the Lorentz force
   - Law of Biot and Savart
   - Ampère's Law
   - solenoids, and inductance
   - magnetic vector potential
6. Magnetic fields in matter
   - dia/para/ferromagnetism
   - magnetic dipoles, torques
   - Ampère's Law and magnetisation
   - magnetic susceptibility and permeability
7. Electrodynamics
   - *emf* and Ohm's law
   - electromagnetic induction and Faraday's Law
   - energy in magnetic fields
   - inductance
   - Maxwell's equations (integral and differential forms)

Suggested texts

For the most part, the curriculum committee gives names of texts merely as suggestions. However, in this stream the committee strongly urges the instructor to use *Introduction to Electrodynamics* by Griffiths, which can serve both this course and its follow-on, PHYS 3400 (Electrodynamics). Students and instructors universally praise both of Griffiths' texts (this, and *Introduction to Quantum Mechanics*) as the most enjoyable and comprehensible treatment of both subjects; there simply is no equal. Other texts are offered as possible supplements for problems and examples, and alternative approaches.

Chapters 2–7 of *Introduction to Electrodynamics*, by David Griffiths, (ISBN 0-13-805326-X).

- universally praised by students and instructors as the best text on the market for a two-semester upper-year course in electrodynamics.
- second half of the text ideal for PHYS 3400.
- covers all the topics required, except circuits

- includes many problems of varying degrees of difficulty, with many worked examples

Schaum's Outline of Electric Circuits (ISBN 0-07-139307-2)

- an excellent, cheap, and comprehensive supplement to Griffiths for circuit analysis, which can be used by both the lecture and lab portions of this course.

Additional reference texts for problems and alternate approaches:

Principles of Electricity and Magnetism by Pugh and Pugh (ISBN 0-201-06014-0)

- a possible alternative to Griffiths, as it covers both electrostatics and electrodynamics.
- includes engineering applications (wave guides, *etc.*)

Basic Electromagnetic Theory by Paris and Hurd (ISBN 07-048470-8)

- mostly an engineering text
- not much in electrodynamics (thus not particularly suited for PHYS 3400, yet written more at the third year level.

Electric and Magnetic Fields by Charles Oatley (ISBN 0-521-29076-7)

- mostly a sophomore level text

Notes to the instructor

1. While the topics in the course echo many of those in PHYS 1101, the level of problems and the depth of discussion is much greater.
2. Coordination with the instructor in PHYS 3400 (Electrodynamics) is important so that PHYS 3400 can pick up right where PHYS 2400 leaves off, and so that topics students may have had trouble with in PHYS 2400 can be reviewed in PHYS 3400. This is particularly important if, for some reason, both instructors are not using the same text.
3. Together, this course and PHYS 3400 (Electrodynamics) are intended to provide a thorough coverage of electrodynamics at the undergraduate level (*e.g.*, covering all of Griffith's text *Introduction to Electrodynamics*), and should prepare a student for a graduate course based on J. D. Jackson's text *Classical Electrodynamics*.
4. The instructor should meet with the instructor of PHYS 2400L (the lab portion of this course) before classes begin to discuss how the labs and lectures will couple. Frequent meetings throughout the term to retain cohesion is strongly encouraged. For example, circuits and circuit elements need to be discussed early in the course to provide the necessary background for the first labs.

5. Portion of course grade assigned to the lab portion should be between 20% and 30%.

6. It has been departmental policy that students repeating this course may be be exempt from repeating the lab portion *if*:

    - the grade attained in the lab portion in the previous attempt of the course was a C− or better;

    - the grade attained in the lab from the previous attempt of the course is used as the lab grade for the current attempt.