Physics 217: Electricity and Magnetism I

Fall 2002

This semester we will explore electrostatics and magnetostatics – the consequences of the laws discovered empirically by Coulomb, Gauss, Ampère and Faraday – to a point just short of writing down and using the complete version of the Maxwell equations. Along the way, we will also learn and practice the higher-level applied math involved in complicated electromagnetic problems, such as the solution of linear partial-differential equations in boundary-value problems.

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Textbooks: David J. Griffiths, *Introduction to electrodynamics*, third edition (1999), and Edward M. Purcell, *Electricity and magnetism: Berkeley physics course v.2*, second edition (1985). Both of these books are on two-hour reserve in the Physics-Optics-Astronomy library.

World Wide Web site: www.pas.rochester.edu/~dmw/phy217/. In these pages one will find complete lecture presentations, a calendar of class meetings and office hours, homework-problem solutions, exam solutions, practice examinations, study aids, links to other useful Web sites, and even a copy of this document.

Lectures: In B&L 405, 9:00-9:50 AM, Mondays, Wednesdays and Fridays, conducted by Dan. All students are expected to attend all of the lectures. Complete electronic copies of each lecture presentation can be found on our Web site, about a week before the lecture is given, and can be downloaded and printed in a format that's handy for taking additional lecture notes.

Recitations: In B&L 405, 3:25-4:40 PM on Fridays, conducted by Drew. All students are expected to attend all of the recitations. These classes will usually operate as workshops, in which the students will work in small teams (3-4 students each) to set up and/or solve practice problems similar to those on the homework and exams. They are scheduled strategically on Friday afternoons; in our experience, most students do most of the work on their problem sets over the weekend.

E-mail list server: phy217@mail.rochester.edu. Messages sent to this address will be re-sent to everybody in the class. Obviously this provides a good way to make general announcements. We also encourage use of the list server to ask questions about readings, lectures, homework problems and the like; the rest of the class will probably also be interested in your questions and the answers you'll receive. (We will answer e-mail questions privately, too.)

Homework: Twelve problem sets, usually assigned during the lecture on Wednesday and due during class the following Wednesday. Each problem set counts equally toward the final grade. Normally, detailed solutions to the problem sets will be posted directly following the lecture they are due, which will make it difficult to accept late homework.

About two-thirds of every homework assignment will be designated as *solo* problems, and the rest as *team* problems. For the solo problems, students are expected to work independently, but the team problems are to be worked out by groups of 3-4 students working together. Each student is meant to submit solutions of all of the problems, but of course the solutions of the team problems would be essentially identical to those of the other team members. The problems chosen for the team homework usually will be the most difficult ones in the assignment. At least at first, the teams will be those formed rather arbitrarily during the first recitation. We will take care to rotate the membership of the teams as the semester progresses. Drew will be the official arbiter of homework-team membership.

Examinations: One midterm exam, covering most of electrostatics, will be given on 18 October 2002 during the time and in the place normally scheduled for recitation. A final examination, covering the whole course, but with emphasis on the latter parts, will be given on 21 December 2002, 4-7 PM. Detailed solutions will be posted at the conclusion of each exam. If you miss an exam due to illness or emergency, a makeup exam may be scheduled by appointment. ***All makeups will be oral examination***s, lasting as long as the exams they replace, and will be administered and graded by Dan.

To each exam you are allowed to bring only a writing instrument, a calculator, and one letter-size sheet on which *you* have written as many notes, formulas, and physical constants as you like. No computers, or graphing calculators into which text and graphics may be downloaded, are allowed.

The best way to study for the examinations is to do the homework problems, to work out the sample exams that are available (with solutions) in our World Wide Web pages, and to make a good cheat sheet to bring to the exam.

Grades: Based 36% on the homework and 64% on the examinations. The midterm is worth 26%, and the final exam 38%, of the final grade, with each problem set counting for 3%. In terms of the percentage of the maximum possible score, the grading scale will be as follows:

Percentage score	≥ 85	≥ 80	≥ 75	≥ 70	≥ 65	≥ 60	≥ 55	≥ 50	≥ 40	< 40
Final grade	A	A-	B+	B	B-	C+	C	C-	D	E

Last time Dan taught this course, in Fall 1990 (!), the 27 students who took it received an average percentage score of 69.9, for a B. (We round up to integers before assigning the final grade.)

Academic honesty disclaimer: For our purposes, *cheating* consists of submission of solo-homework or exam solutions that are not one's own work, or submission of such work under someone else's name. According to University rules, any detected act of cheating that is not the result of a simple misunderstanding must be handed over to the Board on Academic Honesty for investigation.

Help: Our office hours are posted on the Calendar page of the PHY 217 Web site. We can also be found most afternoons in or near our offices or labs, right down the hall from the classroom. Please come and talk to us whenever you want. Or email us, privately or through the list server. We will be happy enough to deal with specific questions about the course, homework or exams, but would be even more interested in talking to those who find the course confusing enough that they're not even sure what to ask.

Course outline

Most of the material we will cover is found in the principal textbook, *Introduction to Electrodynamics* (third edition, 1999), by D.J. Griffiths. The relevant volume from the Berkeley Physics Course provides supplementary material: *Electricity and Magnetism* (second edition, 1985), by E.M. Purcell. The lecture notes follow these books fairly closely in content; reading assignments corresponding to each lecture are given in the following.

Vector Fields

The mathematical apparatus that we will use in our discussion of electromagnetism is introduced here: vector fields, potentials, and the integral and differential relationships governing them. It is assumed that you are familiar with vector algebra and vector calculus in Cartesian coordinates.

Lecture 1 – 4 September 2002
Reading: Griffiths, pp. 10-12.
Vector and tensor transformations; pseudo-vectors. Brief review of vector identities. Homework problem set 1 assigned.
Lecture 2 – 6 September 2002
Reading: Griffiths, pp. 13-24; Purcell, pp. 46-48, 56-64, 68-79.
Vector derivatives: gradient, divergence, curl. Product rules, second derivatives.

Lecture 3 – 9 September 2002
Reading: Griffiths, pp. 24-38.
Integral theorems: gradient, Gauss's, Stokes's, Green's.
Lecture 4 – 11 September 2002
Reading: Griffiths, pp. 38-45.
Polar coordinates: volume, area and length differentials; gradient, divergence and curl in polar coordinates; coordinate transformations. Homework 1 due; homework 2 assigned.
Lecture 5 – 13 September 2002
Reading: Griffiths, pp. 45-54; Appendix B.
Dirac delta function. Helmholtz theorem; scalar and vector potentials.

Introduction to Electrostatics

Starting with the fundamental definition of the electric field obtained from Coulomb's law for electrostatic forces, we develop the theory of electrostatics, by straightforward application of vector field theory.

Lecture 6 – 16 September 2002
Reading: Griffiths, pp. 58-69 Coulomb's Law, units. $\boldsymbol{E}$ as a vector field. $\boldsymbol{E}$ from point charges; superposition. Example of calculation of field from Coulomb's law. Lines of $\boldsymbol{E}$.
Lecture 7 – 18 September 2002
Reading: Griffiths, pp. 69-74; Purcell, pp. 22-31.
Flux of $\boldsymbol{E}$, divergence of $\boldsymbol{E}$ and Gauss' Law. Examples of field calculations using Coulomb's and Gauss' laws. Homework 2 due; homework 3 assigned.
Lecture 8 – 20 September 2002
Reading: Griffiths, pp. 76-77.
More Gauss' Law examples. Curl of $\boldsymbol{E}$ (= 0 in electrostatics).

Lecture 9 – 23 September 2002
Reading: Griffiths, pp. 77-86; Purcell, 42-46, 48-56.
Electric (scalar) potential V, $\boldsymbol{E} = -\nabla V$, *etc.* Arbitrariness of reference potential. Superposition. Poisson's and Laplace's equation. Example calculations of potential.
Lecture 10 – 25 September 2002
Reading: Griffiths, pp. 87-93; Purcell, pp. 64-67.
Boundary conditions; summary of calculation paths: Purcell's triangle. Homework 3 due; homework 4 assigned.
Lecture 11 – 27 September 2002
Reading: Griffiths, pp. 93-96; Purcell, pp. 31-33.
Work and energy; relation to $\boldsymbol{F}$ and V; nonsuperposition. Examples.

Lecture 12 – 30 September 2002
Reading: Griffiths, pp. 96-103.
Conductors in electrostatics. Induced charge, force between charges and conductors. Examples.

Lecture 13 – 2 October 2002
Reading: Griffiths, pp. 103-106.

Capacitors. Examples of parallel plates, concentric spheres, one sphere. $Q = CV$, $W = CV^2/2$. Homework 4 due; homework 5 assigned.

Boundary-Value Problems in Electrostatics

The best approach to a large class of problems in electrostatics involves solution of the linear, second-order differential equations in the electrostatic potential *V*, Laplace's equation and Poisson's equation, subject to certain boundary conditions. The general properties of solutions to these equations, and a couple of useful solution techniques, are discussed in the following lectures.

Lecture 14 – 4 October 2002
Reading: Griffiths, pp. 110-120.
Calculation of *V* from Laplace's equation: introduction to boundary value problems in physics. Example to show how it works, first.

Lecture 15 – 9 October 2002
Reading: Griffiths, pp. 110-120 (again).
Properties of solutions to Laplace's equation. Averages, lack of local extrema, uniqueness of solutions. Instability of electrostatic mechanical equilibrium. Homework 5 due; homework 6 assigned.
Lecture 16 – 11 October 2002
Reading: Griffiths, pp. 121-126.
Calculation of *V* by method of images. Induced charge on conductors; example of point charge and conducting sphere.

Lecture 17 – 14 October 2002
Reading: Griffiths, pp. 127-136.
Solution of Laplace's equation by separation of variables. Example of semi-infinite slot: harmonic solutions, Fourier coefficients.
Lecture 18 – 16 October 2002
Reading: Griffiths, pp. 137-144.
Solution of Laplace's equation by separation of variables, in spherical coordinates; Legendre polynomials. Example of conducting sphere in uniform applied electric field. Homework 6 due.
Lecture 19 – 18 October 2002
Reading: Griffiths, pp. 127-144 (again).
Complete boundary-value examples.
Exam #1 --- 18 October 2002, 3:25-4:40 PM
Midterm examination on all material covered to date.

Electrostatic Fields in Matter

A third method of solution of Poisson's equation – that of expansion in electric multipole moments – is used as a bridge to the theory of the electrostatic field and potential in dielectric matter.

Lecture 20 – 20 October 2002
Reading: Griffiths, pp. 146-154.
Multipole expansions of the potential; potential and field from an electric dipole.
Lecture 21 – 23 October 2002
Reading: Griffiths, pp. 160-166.
Polarizability; induced dipoles; torque on electric dipole in uniform electric field. Polarization vector field. Homework 7 assigned.
Lecture 22 – 25 October 2002
Reading: Griffiths, pp. 166-179.
Bound charge. Electric fields from polarized media. The electric displacement vector field.

Lecture 23 – 28 October 2002
Reading: Griffiths, pp. 179-193.
Dielectrics and electric susceptibility. Some calculations of ***E*** and *V* for linear dielectrics.
Lecture 24 – 30 October 2002
Reading: Griffiths, pp. 193-196.
Forces and energy in dielectrics; capacitor oil-pump example. Homework 7 due; homework 8 assigned.

Magnetostatics

Starting from the empirical Lorentz force law and Biot-Savart field law, we develop the theory of magnetic fields from steady currents in much the same way we just developed electrostatics.

Lecture 25 – 1 November 2002
Reading: Griffiths, pp. 202-214.
Begin magnetostatics: Lorentz force law; cyclotron motion; force on a steady current. Current density, continuity equation.

Lecture 26 – 4 November 2002
Reading: Griffiths, pp. 215-220.
Magnetic fields from Biot-Savart Law: force between two currents; field from a circular loop.

Lecture 27 – 6 November 2002
Reading: Griffiths, pp. 221-224.
Divergence and curl of ***B***, derivation of Ampere's Law. Homework 8 due; homework 9 assigned.
Lecture 28 – 8 November 2002
Reading: Griffiths, pp. 225-232.
Calculation of ***B*** from Ampere's Law: solenoid, toroid.

Lecture 29 – 11 November 2002
Reading: Griffiths, pp. 232-238.
Comparison of magnetostatics and electrostatics. Vector potential ***A***. Example of calculation of ***A*** , then ***B***, from spinning, charged spherical shell.
Lecture 30 – 13 November 2002
Reading: Griffiths, pp. 240-242.
Boundary conditions; summary of calculation paths, using Purcell's other triangle. Homework 9 due; homework 10 assigned.

Magnetic Materials

Of the three forms magnetism takes in matter, we will discuss two: paramagnetism, which is the analog of linear electrostatic polarization, and diamagnetism, which can be treated semiclassically even though it is a quantum-mechanical phenomenon.

Lecture 31 – 15 November 2002
Reading: Griffiths, pp. 242-246.
Magnetic multipoles; calculation of magnetic dipole moment from current loop; torque on the loop; comparison between electric and magnetic dipoles.

Lecture 32 – 18 November 2002
Reading: Griffiths, pp. 255-274.
Magnetization vector field ***M***; bound currents; magnetic vector field ***H***. Dia- and paramagnetism. Boundary conditions.
Lecture 33 – 20 November 2002
Reading: Griffiths, pp. 274-277.
Calculation of ***B*** and ***H*** in linear media. Magnetic susceptibility and permeability. [Leave out ferromagnetism. pp. 278-282] Homework 10 due; homework 11 assigned.
Lecture 34 – 22 November 2002
Reading: Griffiths, pp. 285-290.
Begin electrodynamics. Ohm's law, simple treatment of collisions, resistance. Examples.

Lecture 35 – 25 November 2002
Reading: Griffiths, pp. 292-304.
EMF and magnetic flux; some examples; Faraday's Law.
Lecture 36 – 27 November 2002
Reading: Griffiths, pp. 305-309.
Examples of use of Faraday's Law; magnetoquasistatics. Homework 11 due.

Lecture 37 – 2 December 2002
Reading: Griffiths, pp. 310-320.
Inductance, transformers. Energy in magnetic fields.

Circuits

As a prelude to writing down Maxwell's equations and using them to deal with time-dependent fields and electromagnetic radiation, we will develop certain useful concepts in the lower-dimensional environment of electrical circuits.

Lecture 38 – 4 December 2002
Reading: Purcell, pp. 148-159.
Kirchhoff's rules, resistor networks. Homework 12 assigned.
Lecture 39 – 6 December 2002
Reading: Purcell, pp. 159-161, 282-286.
Time-dependent currents: *RC* and *RL* circuits.

Lecture 40 – 9 December 2002
Reading: Purcell, pp. 298-310.
AC circuits; series *LRC* circuit, resonance, *Q*.
Lecture 41 – 11 December 2002
Reading: Purcell, pp. 310-318.
AC networks; impedance and admittance.
Homework 12 due.

Final exam – 21 December 2002, 4-7 PM

Reading list

These days, there are quite a few good junior-level E&M books, which you may find helpful to consult when you want a different explanation or example related to a concept you find troublesome. Many other books, at levels both higher and lower, will also serve as useful references. Here are the books that will be on reserve in the Physics, Optics and Astronomy Library. The titles of required textbooks appear in ***bold italics***. They include most of my favorite E&M books; I have added brief descriptions of each to give an idea of what they're best at, and to encourage you to read them.

1. D.J. Griffiths, *Introduction to Electrodynamics* (third edition, 1999). This is the principal required textbook for the course. It is extremely well-written and easy to read, with good problems and lots of examples, and reaches a level of mathematical elegance that was rare in the textbooks used when I was an undergrad. This makes it especially good as preparation for a graduate E&M course that uses the book by Jackson (see below), except for its use of MKS units throughout instead of CGS. It lacks discussions of circuits and a couple of topics in radiation which I would not like to omit, which will be filled in by use of the other required textbook and lectures.

2,3. G.L. Pollack and D.R. Stump, *Electromagnetism* (2002); R.K. Wangsness, *Electromagnetic Fields* (second edition, 1986). Very similar in approach, content and style to Griffiths' book; these books should be your next recourse. They are also very well written and have good examples. They also use MKS units.

4. M.H. Nayfeh and M.K. Brussel, *Electricity and Magnetism* (1985). Their discussions of the principles are very brief and dry, compared to those in Griffiths, but they include a very large number of examples on every topic, including many not found in those other books. Also uses MKS units.

5. M.A. Heald and J.B. Marion, *Classical Electromagnetic Radiation* (third edition, 1995). A nice book which seems a little too heavy on electromagnetic radiation and too light on electrostatics and magnetostatics to use as a textbook for PHY 217, but will be a useful reference here and especially in PHY 218. It is also the only good junior-level textbook that uses CGS units.

6. J.D. Jackson, *Classical Electrodynamics* (second edition, 1975; third edition, 1999). You will become intimately familiar with this book if you go to graduate school in physics. It's the classic, definitive text for E&M, very well-written and reflecting a profound understanding of the subject. The relevant parts are sometimes helpful for you juniors, especially since you don't have to worry about solving the diabolically clever and extremely difficult problems at the ends of the chapters. CGS unit are used throughout the second edition, which is still widely preferred to the third edition; the appendix in either edition that tells you all you need to know about unit conversions is better than similar discussions in the other books.

7. E.M. Purcell, ***Electricity and Magnetism*** (second edition, 1985). Also known as Volume 2 of the Berkeley Physics Course, this book will serve as a supplementary text through most of Physics 217 and through the treatment of relativity in Physics 218. It will be the principal source of information on DC and AC circuits. Although it was originally intended as a freshman-level text, it has rarely performed that function, but it is used quite frequently in junior E&M because it is eminently readable, and has all of the physics of the more mathematically-advanced texts, presented succinctly and beautifully. The author was a very distinguished physicist; he won the Nobel Prize (1952) for his role in the development of nuclear magnetic resonance studies of atomic and molecular structure, and also has the co-discovery of interstellar neutral atomic hydrogen to his credit.

8. R.P. Feynman, R.B. Leighton, and M. Sands, *The Feynman Lectures On Physics*, volumes 1 and 2 (1963). You are probably already familiar with these lectures by one of the most famous and brilliant

scientists in history (Nobel Prize in Physics, 1965, for the invention of much of quantum electrodynamics). They are full of terrific insights into electrodynamics, as well as all other basic branches of physics, and are worth reading at every stage of your physics education.