Electricity and Magnetism

Spring 2013 | Physics 341 | PEngel 319

Instructor:

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Informal Office Hours: 7:30 A.M. – 5:30 P.M.

Text:

- *Foundations of Electromagnetic Theory*
  by Reitz, Milford, & Christy
  Chapters 1–13, 16–17
- `http://www.physics.csbsju.edu/341/`

Grading:

Your grade will be determined by averaging six scores: total homework score, three exam scores, and the final exam score (which is double-counted). Assigned homework is due at the beginning of the next class period. Late homework is generally not accepted. I encourage you to work together on homework and to seek help/hints from me. The exams will consist of a few (∼5) problems. You may use a "formula sheet" to assist you on the exam. The formula sheet should be limited to formulas and definitions—no worked examples. Approximate exam dates are: February 7 (Thursday), March 13 (Wednesday), and April 18 (Thursday), but I can easily be swayed to move exam dates. The final exam will be comprehensive and have a structure similar to the other exams. The final exam is scheduled for May 9 (Thursday) at 10:30 A.M..

Questions:

There is no such thing as a dumb question. Questions asked during lecture do not "interrupt" the lecture, rather they indicate your interests or misunderstandings. I'd much rather clear up a misunderstanding or further develop a topic of interest than continue a dull lecture.

Remember: you are almost never alone in your interests, your misunderstandings, or your problems. Please help your classmates by asking any question vaguely related to physics. If you don't want to ask your question during class, that's fine too: I can be found almost any time in my office (PEngel 111) or the nearby electronics labs. Drop in any time!

Topics:

This course covers the physics of electric and magnetic fields. Electricity and magnetism (hereafter E&M) is one of the great successes of 19^{th} century physics. While the 1700s were spent digesting Newton's magnificent discoveries of mechanics and the gravitational force law, the 1800s were spent understanding how to fit E&M into Newton's picture. (Additionally the 1800s produced an understanding of thermodynamics.) Post-1900 there were two important revolutions in physics: relativity and quantum mechanics. E&M actually has close ties to both. Surprisingly, the theory Maxwell wrote down in the 1860s to explain E&M was already relativistic (folks then just didn't know what that was) and, as a *field* theory, it has close ties to quantum mechanics. (In mechanics you studied how the coordinates of a particle change in time: $x(t)$; in a field theory we study how some quantity (e.g., voltage) changes with location and time: $V(\vec{\mathbf{r}}, t)$.) In addition Maxwell's E&M demonstrates some defining traits of physics: mathematical simplicity (a very slippery idea: I don't mean easy and you know you've spent three years in math courses learning this "simple" mathematics) and increasing unity (i.e., Maxwell's E&M is not a theory of magnetism placed next to a theory of electricity; instead the two are all part of the same single thing). Whoa! "Electricity and magnetism are really part of the same thing" . . . You should be wondering what could justify the statement that two more or less imaginary things—electric and magnetic fields—are part of the *same thing*. Unfortunately, since this is only an "introduction" you will see little of this justification unless you ask for it. Although we will talk about changing electric and magnetic fields (e.g., in light waves), most of this book and this course deals with static (i.e., unchanging in time) fields. We will be mostly concerned with the *source* of E&M fields, but we will spend some time describing how matter responds to those fields.

Many topics should be familiar to you from 200: charge, current, voltage, $\vec{E}$, $\vec{B}$, the Lorentz force ($\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$), Gauss' law (surface integral of $\vec{E}$ tells you the enclosed charge), no magnetic monopoles (surface integral of $\vec{B}$ is zero), Ampere's law (line integral around a loop tells you the current flowing through the loop), Faraday's law of induction (changing magnetic fields cause electric fields), and Maxwell's equations. If these topics seem unfamiliar, you should page through your 200 book.

Much of the mathematics we'll be using should be familiar to you from Multivariable Calculus: $\text{grad}(\phi) = \vec{\nabla}\phi$, $\text{div}(\vec{A}) = \vec{\nabla} \cdot \vec{A}$, $\text{curl}(\vec{A}) = \vec{\nabla} \times \vec{A}$, line integrals, path independence, surface integrals, Green's theorem, Gauss' theorem, and Stokes' theorem. If these topics seem unfamiliar, you should tell me ASAP, so I can yell at your 305 instructor and modify this course.

Note: I have used above the "blackboard" notation for vectors: an arrow over the letter as in $\vec{E}$. Recognize that in print (e.g., in our textbook) vectors are commonly denoted using boldface[1] as in **E**.

This is a course in *mathematical* physics. Much of the class will be devoted to reconsidering Maxwell's laws using the mathematical language you've just learned in Multivariable Calculus. Some mathematical aesthetics will be present in the course; you are responsible, for example, for understanding the proofs and the details of mathematical manipulation. It is always proper for you (or me!) to ask a "details" question, like how do you get from Eq. (4–6) to Eq. (4–8). In fact, I now assign you to ask such a question before the next exam! (Please remind me to check off your completion of this assignment when you ask your question.) When the book says "it can be shown that…", I really do expect you to get out pencil and paper and work it out, and, if you can't show it, to ask me for help.

E&M is a terrifyingly beautiful subject. This may get lost in the next few months as we sog through the details ("the Devil is in the details"). As we sog, think first of J. C. Maxwell, who did all this work without any idea of a vector—so what is one vector equation for us was three separate equations for him, and think second of the end result which explains all E&M phenomena with (A) Maxwell's four vector equations, or (B) the "simpler" relativistic form: $F^{\mu\nu}_{,\nu} = \mu_0 J^\mu$ and $G^{\mu\nu}_{,\nu} = 0$, or (C) the statement that E&M is the simplest possible gauge force. So the wealth of phenomena can be reduced (explained?) by a few words. Einstein asked the ultimate question: can *all* phenomena be reduced to nothing, i.e., is light the way it is because it can be no other. Einstein phrased his question: "What I am really interested in is whether God could have made the world in a different way".

[1] Oliver Heaviside invented this notation for vectors. Heaviside, along with the American Josiah Willard Gibbs, are generally credited with creating modern vector analysis from the more elaborate and abstract algebras of Hamilton and Grassmann.

References:

Foundations of Electromagnetic Theory by Reitz, Milford & Christy (QC670)

Introduction to Electrodynamics by David Griffiths (QC680.G74)

Classical Electricity and Magnetism by Barger & Olsson (QC760)

Classical Electricity and Magnetism by Panofsky & Phillips (QC5181)

Introduction to Electromagnetic Fields and Waves by Bohn (QC670)

The Electromagnetic Field by Shadowitz (QC665)

Electromagnetic Fields, Energy, and Waves by Magid (QC670)

Electricity and Magnetism (Berkeley) by Edward Purcell (QC522)

Classical Electrodynamics by Jackson (QC631) — graduate text