Electricity and Magnetism I

PHYS 405 (Spring 2023)

Instructor Info

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Course Info

Prereq: A good foundation in classical mechanics and vector calculus; PHYS 366

Mon & Wed

8:30-9:45am

PAIS 1140

Course Website

Office Hours

Tue & Wed

1-2pm

PAIS 3214

TA Info

Loc Ngo

Office hour: Friday 10-11am

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Why Electromagnetism?

While electric and magnetic phenomena have been known to mankind for millennia, the theory of electricity and magnetism was put on rigorous mathematical footing only in the 1800s. The work of Maxwell and others showed that electric and magnetic phenomena are two sides of the same coin, hence providing the first example that apparently distinct forces could be unified into a single theory. This breakthrough had a huge impact on the evolution of physics and continue to shape how we think about fundamental interactions in our world. Together with gravity, electromagnetism is the most important force shaping our everyday life. From the colors we see, the textures we feel and the bio-chemical reactions going on inside our bodies, to the precise electronic circuits powering our phones and computers, electromagnetic forces play a huge role in making the world around us works. As such, a good understanding of classical electromagnetism is key to explore a plethora of other phenomena, including more complex forces such as the weak and strong nuclear force. Many of the concepts introduced in this class can be applied to other physical contexts, making this course a central pillar of a physicist academic career.

Overview

The goal of this class is to introduce the subject of classical electromagnetism at the advanced undergraduate level. Classical electromagnetism (EM) is fundamentally a local theory of vector fields and its proper treatment requires methods of vector analysis and differential equations. We will briefly review these mathematical concepts as we encounter them throughout this course. In this class, we will entirely focus on static (time-independent) fields interacting with charges at rest or in steady motion. In this case, the electric and magnetic fields decouple from one another so they can be treated independently. Such independent treatment of electrostatics and magnetostatics is the central content of this class. A sizable fraction of this class will be spent computing the electric field and potential created by a static distribution of charges. We will also discuss how the electric field behaves within conductors and insulators. The second part of the class will be spent computing magnetic field resulting from static currents, including how the magnetic field behaves in the presence of insulating matter. Time-dependent electric and magnetic fields created by moving charges and nonsteady currents will be covered in the next Electricity and Magnetism course, PHYS 406.

About Me

I am a practicing theoretical cosmologist/astrophysicist with a keen interest about dark matter and the physics of the early Universe.

Material

Required Text

Griffiths, D. J. *Introduction to Electrodynamics*. 4th Edition. Cambridge University Press. 2017. (ISBN: 978-1108420419)

Useful Reference

Purcell, E. M. and Morin, D. J. *Electricity and Magnetism*. 3rd Edition. Cambridge University Press. 2013. (ISBN: 978-1107014022)

Grading Scheme

10%	Attendance/Class participation
25%	Homework Assignments
40%	2 Midterm Exams (20% each)
25%	Final Exam

FAQs

? What are the most important things I need to do to succeed in this class?

! It's quite simple: Come to every class, register and attend the PHYS 415 problem sessions, and attempt every homework assignments.

? Is this a "hard" class?

! This may be the most mathematically advanced class you have taken so far. Getting the right answers will require that you rigorously follow the rules of vector calculus. But understanding the physical picture beyond the math is even more important (and it can often save you a lot of algebra!).

? My vector calculus is rusty. What should I do?

! Take a deep breath. Relax. You probably already master more vector calculus than you can remember. In any case, we'll start the course with a brief review. Remember, this is a physics class, not a math class.

? Will we cover how magnets work?

! Absolutely! We will see how tiny currents at the atomic levels can lead to macroscopic magnetic field, such as those of fridge magnets.

Class Format

The class will consist of a mix of lecturing and active problem solving by the students in small groups. It is very important that you attend every class, and 10% of the final grade is tied to class attendance and active participation in class activities. Students will be asked to share their solutions (or their group's solution) with the rest of the class.

Homework Assignment

There will be 9 to 11 homework assignments spread out over the course of the semester. They will be due every 7-10 days. They will be posted on the course webpage. Homeworks are to be submitted at my office on the due date. *Late Homework assignments will be accepted but with a 25% penalty for each day past the deadline.* So a homework handed-in within 24 hrs of the deadline will carry a 25% penalty, one handed-in within 48 hrs will carry a 50% penalty, as so on. *Let me know if you are planning on submitting your homework late such that I can delay the posting of the solutions.* Once the solutions are posted, assignments will no longer be accepted. It is very important that you attempt every assignment as they will help you make sure you are staying on top of the class material.

While I strongly encourage you to discuss the homework assignments with your classmates, the work you hand in must be entirely yours.

PHYS 415: Problems in Electricity and Magnetism I

This is a very important adjunct to the main lecture class, taking place every Wednesday from 4 to 4:50pm in PAIS 1140. It will provide you additional practice with solving problems beyond the homework assignments and self study. Furthermore, the class will also give you a valuable opportunity to bring to my attention your difficulties with any concepts covered in the lecture class so I can address them in a group setting. The problem sheets would be posted on the course webpage on the Tuesday before the problem class. The corresponding solutions will be posted after the problem class. You will receive credit for the problems class as long as you register and show up for more than 10 sessions. Even if you don't register for the class, I encourage you to attend anyway, just to get the extra practice.

Student Learning Outcomes

Upon successful completion of this course, students will be able to . . .

- Compute the electric field and electric potential for simple static charge distributions and boundary conditions.
- Compute the energy contained in a given electric field configuration.
- Explain the behavior of the electric field and potential in the presence of a conductor.
- Compute charges induced on a conductor when the latter is placed in an external electric field.
- Explain the behavior of the electric field and potential in the presence of a dielectric.
- Compute the bound and surface charges induced in a dielectric material when placed in an external electric field.
- Compute the electric potential a large distance away from an arbitrary charge distribution using the multipole expansion.
- Compute the magnetic field and vector potential for a steady current.
- Explain the behavior of the magnetic field and vector potential in the presence of matter.
- Explain the difference between a diamagnet, a paramagnet, and a ferromagnet.
- Compute the bound and surface currents induced in an object placed in an external magnetic field.
- Write down and explain the physical meaning of Maxwell's equations for electrostatics and magnetostatics.

Tentative Class Schedule

MODULE 1: Review of Vector Calculus

Week 1	Vectors, vector products, Einstein summation convention, multivariate functions, gradient operator and its fundamental theorem, divergence of vector fields, divergence theorem	Griffiths Ch. 1.1-1.3
Week 2	Curl of vector fields, Stoke's theorem, second derivatives, spherical and cylindrical coordinates, Dirac delta function, Helmholtz decomposition	Griffiths Ch. 1.2-1.6

MODULE 2: Electric field

Week 3	Electric charge, Coulomb law, electric field, field lines, Gauss's law	Griffiths Ch. 2.1-2.2
Week 4	Electric potential, work done to move charges, energy of charge distribution	Griffiths Ch. 2.3-2.4
Week 5	Electrostatic energy, Conductors, induced charges, capacitors	Griffiths Ch. 2.4-2.5
Week 6	Overflow and Review of material covered so far 02/22: Midterm #1	
Week 7	Laplace's equation for the electric potential, uniqueness theorem, method of images, Direct solutions to Laplace's equation in cartesian coordinates	Griffiths Ch. 3.1-3.3
Week 8	Direct solutions to Laplace's equation in spherical and cylindrical coordinates	Griffiths Ch. 3.3
Week 9	Spring Break	
Week 10	The multiple expansion for the electric potential, electric dipole, force and torque on dipole	Griffiths Chs. 3.4, 4.1
Week 11	Dielectrics, polarization, electric field inside a dielectric, bound charges, electric displacement field, Boundary conditions	Griffiths Ch. 4.1-4.3
Week 12	Linear dielectrics, energy in dielectric systems	Griffiths Ch. 4.4
Week 13	Review of chapters 3 and 4 04/12: Midterm #2	

MODULE 3: Magnetic field

Week 14	Origin of magnetism, the Lorentz force, Biot-Savart law, Magnetic field from steady currents, the curl and divergence of the magnetic field, Ampère's law, vector potential	Griffiths Ch. 5.1-5.4
Week 15	Multiple expansion of the vector potential, magnetic dipole, diamagnets and paramagnets, magnetization, bound currents	Griffiths Chs. 5.5, 6.1-6.2
Week 16	Magnetic field in matter, the H field, magnetic susceptibility and permeability, ferromagnetism	Griffiths Ch. 6.3-6.4

Week 17	Final exam

Academic Integrity

Each student is expected to maintain the highest standards of honesty and integrity in academic and professional matters. The University reserves the right to take disciplinary action, up to and including dismissal, against any student who is found guilty of academic dishonesty or otherwise fails to meet the standards. Any student judged to have engaged in academic dishonesty in course work may receive a reduced or failing grade for the work in question and/or for the course. Academic dishonesty includes, but is not limited to, dishonesty in quizzes, tests, or assignments; claiming credit for work not done or done by others; hindering the academic work of other students; misrepresenting academic or professional qualifications within or without the University; and nondisclosure or misrepresentation in filling out applications or other University records.

Credit-hour statement

This is a three credit-hour course. Class meets for two 75-minute sessions of direct instruction for fifteen weeks during the Spring 2023 semester. Please plan for a minimum of six hours of out-of-class work (or homework, study, assignment completion, and class preparation) each week.

Diversity and Inclusion Statements

I consider this classroom to be a place where you will be treated with respect, and I welcome individuals of all ages, backgrounds, beliefs, ethnicities, genders, gender identities, gender expressions, national origins, religious affiliations, sexual orientations, ability - and other visible and non-visible differences. All members of this class are expected to contribute to a respectful, welcoming and inclusive environment for every other member of the class.

Citizenship and/or Immigration Status: All students are welcome in this class regardless of citizenship, residency, or immigration status. Your professor will respect your privacy if you choose to disclose your status. UNM as an institution has made a core commitment to the success of all our students, including members of our undocumented community. The Administration's welcome is found on our website.

Our classroom and our university should always be spaces of mutual respect, kindness, and support, without fear of discrimination, harassment, or violence. Should you ever need assistance or have concerns about incidents that violate this principle, please access the resources available to you on campus, especially the LoboRESPECT Advocacy Center and the support services listed on its website. Please note that, because UNM faculty, TAs, and GAs are considered "responsible employees" by the Department of Education, any disclosure of gender discrimination (including sexual harassment, sexual misconduct, and sexual violence) made to a faculty member, TA, or GA must be reported by that faculty member, TA, or GA to the university's Title IX coordinator at the Office of Compliance, Ethics, and Equal Opportunity. For more information on the campus policy regarding sexual misconduct, please see this link.

Accommodations for Students with Disabilities

UNM is committed to providing equitable access to learning opportunities for students with documented disabilities. As your instructor, it is my objective to facilitate an inclusive classroom setting, in which students have full access and opportunity to participate. To engage in a confidential conversation about the process for requesting reasonable accommodations for this class and/or program, please contact Accessibility Resource Center at arcsrvs@unm.edu or by phone at 505-277-3506. Support: Contact me at fycr@unm.edu or at my office hours, and also contact the Accessibility Resource Center.

COVID-19 Health and Awareness

UNM is a mask friendly, but not a mask required, community. To be registered or employed at UNM, Students, faculty, and staff must all meet UNM's Administrative Mandate on Required COVID-19 vaccination. If you are experiencing COVID-19 symptoms, please do not come to class. If you have a positive COVID-19 test, please stay home for five days and isolate yourself from others, per the Centers for Disease Control (CDC) guidelines. If you do need to stay home, please communicate with me at fycr@unm.edu; I can work with you to provide alternatives for course participation and completion. UNM faculty and staff know that these are challenging times. Please let us know that you need support so that we can connect you to the right resources and please be aware that UNM will publish information on websites and email about any changes to our public health status and community response.