Electricity and Magnetism II

PHYS 406

Instructor Info

Prof. Francis-Yan Cyr-Racine

PAIS 3214

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Course Info

Prereq: PHYS 405, some relativity, some analytical mechanics.

Tues & Thurs

12:30-1:45pm

PAIS 1140

Course Website

Office Hours

Tues & Thurs

10-11am

PAIS 3214

TA Info

Kylar Greene

Tuesday 3:30-4pm

Zoom

kygreene@unm.edu

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

This class builds on the foundation established in PHYS 405 to develop the complete theory of electrodynamics. Starting from Maxwell's equations for electrostatics and magnetostatics, we will see how these have to be modified to account for time-varying fields. Equipped with the time-dependent Maxwell's equations, we will be able to discuss the energy, momentum, and angular momentum contained within the electromagnetic field. We will then discuss the very important topic of electromagnetic waves and their propagation both in vacuum and within linear media. We will then argue that scalar and vector potentials are generally easier to handle than fields in electrodynamics, and will use this fact to compute the E&M signatures of moving point charges, including how they radiate energy in the form of electromagnetic waves. We will finally turn our attention to more fundamental aspects of electrodynamics, discussing its relativistic nature and its modern Lagrangian formulation, which reveals the fundamental symmetries underpinning the theory.

About Me

I am a practicing theoretical cosmologist/particle astrophysicist with a keen interest in the physics of the early Universe. My main interest is to use cosmological and astrophysical observations to discover new physics beyond the Standard Model.

Material

Required Text

Griffiths, D. J. *Introduction to Electrodynamics*. 5th Edition. Cambridge University Press. 2024. (ISBN: 978-1009397759). Older editions are fine too.

Useful Reference

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

Grading Scheme

10%	Class Participation (solving problems on the board)
20%	9 Homework Assignments
40%	2 Midterm Exams (20% each)
30%	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 416 problem sessions, and attempt every homework assignments.

What is this class useful for?

The concepts covered in this class underpin most of modern optics and photonics. Electrodynamics is also the gateway to the study of field theory (including its quantum counterpart): many of the concepts developed here are applicable to other field theories, such as those describing the weak and strong forces.

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. Students will be asked often to share their solutions (or their group's solution) with the rest of the class.

Homework Assignment

There will be 9 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. Homework assignments are to be submitted exclusively on CANVAS by 7pm the day they are due. Homework assignments submitted up to 24 hours after they are due will be accepted, but with a 25% penalty (i.e. the maximum grade you can get in this case is 75% of the total points for that homework). Homework submitted after 24 hours will not be graded. 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 416: Problems in Electricity and Magnetism II

This is a very important adjunct to the main lecture class, taking place every Friday from 11 to 11:50am in PAIS 1160. 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 Wednesday 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.

Learning Goals

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

- Understand electromagnetic induction and how it leads to Faraday's law, i.e. that a changing $\mathbf{B}$ field creates an $\mathbf{E}$ field curling around it.
- Explain why the displacement current term in Ampère's law is absolutely necessary for the mathematical consistency of the theory.
- Write down Maxwell's equations for time-dependent fields, and describe their physical content.
- Determine the energy stored in an electromagnetic field configuration.
- Use Poynting's theorem to compute and understand the flow of energy, momentum, and angular momentum in electromagnetic systems.
- Describe the properties of E&M waves propagating in vacuum and how these relate to Maxwell's equations.
- Compute the trajectory of E&M waves within linear media and at interfaces between different material.
- Solve problems related to the absorption and dispersion of E&M waves.
- Solve problems involving wave guides.
- Understand the potential formulation of electromagnetism and its gauge invariance.
- Use the concept of retarded potential to solve problems in electrodynamics.
- Justify the form of the Lagrangian underpinning electrodynamics, and use it to derive Maxwell's equations.
- Describe the fundamental symmetries responsible for the existence of electromagnetism.

Responsible Learning and Academic Honesty

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.

Cheating and plagiarism (academic dishonesty) are often driven by lack of time, desperation, or lack of knowledge about how to identify a source. Communicate with me and ask for help, even at the last minute, rather than risking your academic career by committing academic dishonesty. Academic dishonesty involves presenting material as your own that has been generated on a website, in a publication, by an artificial intelligence algorithm (AI), by another person, or by otherwise breaking the rules of an assignment or exam. It is a Student Code of Conduct violation that can lead to a disciplinary procedure. When you use a resource (such as an AI, article, a friend's work, or a website) in work submitted for this class, document how you used it and distinguish between your original work and the material taken from the resource.

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 Fall 2024 semester. Students are expected to complete a *minimum* of six hours of out-of-class work (or homework, study, assignment completion, and class preparation) each week.

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 Accessibility Resource Center at arcsrvs@unm.edu or by phone at 505-277-3506.

Title IX

The University of New Mexico and its faculty are committed to supporting our students and providing an environment that is free of bias, discrimination, and harassment. The University's programs and activities, including the classroom, should always provide a space of mutual respect, kindness, and support without fear of harassment, violence, or discrimination. Discrimination on the basis of sex includes discrimination on the basis of assigned sex at birth, sex characteristics, pregnancy and pregnancy related conditions, sexual orientation and gender identity. If you have encountered any form of discrimination on the basis of sex, including sexual harassment, sexual assault, stalking, domestic or dating violence, we encourage you to report this to the University. You can access the confidential resources available on campus at the LoboRESPECT Advocacy Center, the Women's Resource Center, and the LGBTQ Resource Center. If you speak with an instructor (including a TA or a GA) regarding an incident connected to discrimination on the basis of sex, they must notify UNM's Title IX Coordinator that you shared an experience relating to Title IX, even if you ask the instructor not to disclose it. The Title IX Coordinator is available to assist you in understanding your options and in connecting you with all possible resources on and off campus. For more information on the campus policy regarding sexual misconduct and reporting, please see this UNM policy and CEEO's website.

If you are pregnant or experiencing a pregnancy-related condition, you may contact UNM's Office of Compliance, Ethics, and Equal Opportunity at ceeo@unm.edu. The CEEO staff will provide you with access to available resources and supportive measures and assist you in understanding your rights.

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.

Tentative Class Schedule

MODULE 1: Electrodynamics and Energy-momentum Conservation

Week 1	Review of electrostatics and magnetostatics	Griffiths Ch. 1-6, 7.1
Week 2	Electromotive Force, Faraday's law	Griffiths Ch. 7.1-7.2
Week 3	Inductance, energy in magnetic field, Maxwell's Equations in electrodynamics	Griffiths Ch. 7.2-7.3
Week 4	Matter effects, boundary conditions, Poynting's theorem and vector, Energy-momentum conservation	Griffiths Ch. 7.3-8.2
Week 5	Angular momentum in E&M fields and review of material covered so far Thursday 09/19: Midterm #1	Griffiths Ch. 8.2-8.3

MODULE 2: Electromagnetic Waves

Week 6	Wave equation, polarization, wave equation for E&B fields, energy and momentum of E&M waves	Griffiths Ch. 9.2
Week 7	E&M waves in matter, linear media, Brewster's angle	Griffiths Ch. 9.3
Week 8	E&M waves in conductors 10/10: No Class (Fall break)	Griffiths Ch. 9.4
Week 9	Absorption and dispersion, group velocity, wave guides	Griffiths Ch. 9.4-9.5
Week 10	Wave guides Thursday 10/24: Midterm #2	Griffiths Ch. 9.5

MODULE 3: Potential, Radiation, and Relativistic Electrodynamics

Week 11	Potential formulation, gauge invariance, retarded potentials	Griffiths Ch. 10.1-10.3
Week 12	Liénard-Wiechert potentials, fields from a moving point charges	Griffiths Ch. 10.3
Week 13	Dipole radiation, Larmor formula	Griffiths Ch. 11.1-11.2
Week 14	Four-vectors, metric, relativistic Lagrangian	Griffiths Ch. 12.2
Week 15	Minkowski force, electromagnetic field strength Thursday 11/28: No Class (Thanksgiving)	Griffiths Ch. 12
Week 16	Symmetries, Maxwell's equations from least action principle	Griffiths Ch. 12
Week 17	Final exam	