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

11am-12:15pm

PAIS 1140

Course Website

Office Hours

Tues & Thurs

3-4pm

PAIS 3214/Zoom

TA Info

Loc Ngo

Monday 1-2pm

PAIS 3414

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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

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*. 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%	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

This will be face-to-face class held at the regular times outlined above. If the COVID situation gets out of hand, we might have to go back to being online for some time. Let's hope this doesn't happen.

In terms of the actual format for the class itself, it 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 10-12 days. They will be posted on the course webpage. Homeworks are to be submitted directly to me during class on the due date. 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 Thursdays from 1 to 1:50pm 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 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 related 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.
- Compute the radiation emitted by accelerating charges in the dipole limit, including bremsstrahlung and synchrotron radiation.
- 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.

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 Fall 2021 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.

Diversity and Inclusivity Statement

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

In accordance with University Policy 2310 and the Americans with Disabilities Act (ADA), academic accommodations may be made for any student who notifies the instructor of the need for an accommodation. It is imperative that you take the initiative to bring such needs to the instructor's attention, as I am not legally permitted to inquire. Students who may require assistance in emergency evacuations should contact the instructor as to the most appropriate procedures to follow. Contact Accessibility Resource Center at (505) 277-3506 for additional information.

If you need an accommodation based on how course requirement interact with the impact of a disability, you should contact me to arrange an appointment as soon as possible. At the appointment we can discuss the course format and requirements, anticipate the need for adjustments and explore potential accommodations. I rely on the Accessibility Resource Center for assistance in developing strategies and verifying accommodation needs. If you have not previously contacted them I encourage you to do so.

UNM Administrative Mandate on Required Vaccinations

All students, staff, and instructors are required by UNM Administrative Mandate on Required Vaccinations to be fully vaccinated for COVID-19 as soon as possible, but no later than September 30, 2021, and must provide proof of vaccination or of a UNM validated limited exemption or exemption no later than September 30, 2021 to the UNM vaccination verification site. Students seeking medical exemption from the vaccination policy must submit a request to the UNM verification site for review by the UNM Accessibility Resource Center. Students seeking religious exemption from the vaccination policy must submit a request for reasonable accommodation to the UNM verification site for review by the Compliance, Ethics, and Equal Opportunity Office. For further information on the requirement and on limited exemptions and exemptions, see the UNM Administrative Mandate on Required Vaccinations.

UNM Requirement on Masking in Indoor Spaces

All students, staff, and instructors are required to wear face masks in indoor classes, labs, studios and meetings on UNM campuses, see masking requirement. Students who do not wear a mask indoors on UNM campuses can expect to be asked to leave the classroom and to be dropped from a class if failure to wear a mask occurs more than once in that class. Students and employees who do not wear a mask in classrooms and other indoor public spaces on UNM campuses are subject to disciplinary actions. UNM will periodically evaluate and update the mask policy relative to public health conditions.

Acceptable masks and mask wearing in class: A two-layer mask that covers the nose and mouth and that is cleaned regularly is acceptable, as are disposable medical masks, KN95, KF94, FFP1 and FFP2 masks. A face shield is not sufficient protection. It is vital that you wear your mask correctly, covering your nose and mouth. Removing your mask for an extended period to eat or drink in class violates the university mask requirement and endangers others.

Consequences of not wearing a mask properly: If you don't wear a mask, or if you do not wear a mask properly by covering your nose and mouth, you will be asked to leave class. If you fail to wear a mask properly on more than one occasion, you can expect to be dropped from the class. If you insist on remaining in the classroom while not wearing a mask, class will be dismissed for the day to protect others and you will be dropped from the class immediately.

Communication on change in modality

The President and Provost of UNM may direct that classes move to remote delivery at any time to preserve the health and safety of the students, instructor and community. Please check your email regularly for updates about our class and please check bringbackthepack.unm.edu regularly for general UNM updates about COVID-19 and the health of our community.

Tentative Class Schedule

MODULE 1: Electrodynamics and Energy-momentum Conservation

Week 1	Review of electrostatics, electromotive Force, Faraday's law	Griffiths Ch. 7.1
Week 2	Inductance, energy in magnetic field, Maxwell's Equations in electrodynamics	Griffiths Ch. 7.2-7.3
Week 3	Matter effects, boundary conditions	Griffiths Ch. 7.3
Week 4	Poynting's theorem and vector, Energy-momentum conservation	Griffiths Ch. 8.1-8.2
Week 5	Angular momentum in E&M fields and review of material covered so far Thursday 09/23: Midterm #1	Griffiths Ch. 8.3

MODULE 2: Electromagnetic Waves

Week 6	Wave equation, polarization, wave equation for E&B fields, monochromatic plane waves	Griffiths Ch. 9.1-9.2
Week 7	Energy and momentum of E&M waves, E&M waves in matter, linear media	Griffiths Ch. 9.2-9.3
Week 8	Reflection and transmission, refraction, Snell's law 10/14: No Class (Fall break)	Griffiths Ch. 9.3
Week 9	Absorption and dispersion, group velocity, wave guides	Griffiths Ch. 9.4-9.5
Week 10	Wave guides Thursday 10/28: Midterm #2	Griffiths Ch. 9.5

MODULE 3: Potential, Radiation, and Relativistic Electrodynamics

Week 11	Potential formulation, gauge invariance, retarded potentials	Griffiths Ch. 10.1-10.2
Week 12	Liénard-Wiechert potentials, fields from a moving point charges	Griffiths Ch. 10.3
Week 13	Dipole radiation, Larmor formula, bremsstrahlung	Griffiths Ch. 11.1-11.2
Week 14	Synchrotron radiation, radiation damping Thursday 11/25: No Class (Thanksgiving)	Griffiths Ch. 11.2
Week 15	Review of relativity, spacetime intervals, Lorentz boosts, relativistic dynamics, Lagrangian formulation of electrodynamics	Griffiths Chs. 12.1-12.2
Week 16	Symmetries, field strength tensor, Minkowski force, Maxwell's equations from least action principle	Griffiths Ch. 12.3
Week 17	Final exam	