PHYSICS 362D – Electricity and Magnetism

Fall 2021

Lecture: Tu/Th 12-1:15pm, Physics 235

Discussion Session: Th 8-9:15pm, Physics 259 (we may move this around)

Office Hours: Tu 7-9pm on Zoom and Th 3-5pm in Physics 245

TA Office Hours: Wednesday, 2-4pm.

Academic credit: 1 Unit

Course format: Lecture and discussion session

Instructor's information

I am a professor of physics and mathematics at Duke, where I've worked since 1997. I received my B.Sc. (1981) from Tel Aviv University and my Ph.D. (1991) from Harvard University. My research interests center on the geometric structures describing aspects of string theory and quantum field theory.   In recent years I have taught PHY 134 (Introductory Astronomy) and PHY 522 (Special and General Relativity) as well as teaching at DKU.

Office: Physics 245
Email: plesser@cgtp.duke.edu

When not working, I enjoy stargazing and astronomy outreach at the Duke Teaching Observatory, paragliding, rock climbing, birdwatching, hiking, music. and reading.

My preferred form of address is "Ronen," but I will not insist. My preferred pronouns are he/him/his.

The TA for the course is Jhao-Hong Peng, a graduate student in physics. Jhao-Hong will have office hours on Wednesday from 2-4pm.   Contact him at jhaohong.peng@duke.edu to arrange a place to meet him or with any questions you have.

What is this course about?

Electromagnetic interactions underlie physical phenomena at intermediate scales, from atomic physics to optics and material properties. The theoretical formulation embodied in Maxwell's equations of 1873 casts electrodynamics as a relativistically covariant field theory, in which the dynamical degrees of freedom are distributed in space. The equations are most naturally formulated in terms of redundant degrees of freedom (potentials) exhibiting a gauge symmetry. Such theories, often in the context of quantum mechanics, form the basis for the Standard Model of particle physics as well as a primary tool for describing the long-distance properties of condensed matter systems.

The interactions of electromagnetic fields with matter, arising as collective behavior from the interactions of the fundamental charged constituents, produce a remarkable array of phenomena creating the various electric, magnetic, optical, mechanical and thermal properties of matter we encounter.

The equations of classical electrodynamics have been studied extensively for a few centuries. Methods for solving them in various circumstances have become part of the mathematical toolkit of a working physicist, and the properties of these solutions part of the physical intuition we bring to new problems.

All of you have had a class (at least) on electrodynamics. In PHY362, we return to this important field, armed with all the physics and mathematics we can now bring to bear. Our topic is classical electrodynamics, quantum aspects will wait for future classes.

We will start from electrostatics. The force between static charges is given by Coulomb's law together with the superposition principle. We will reformulate this several times, in terms of the electric field and the electrostatic potential. Coulomb's law will be equivalent to a set of linear partial differential equations for these, augmented by some boundary conditions, and we will apply some classic techniques to solving these equations in various physically relevant situations. We will introduce some simple types of bulk matter electric properties -- conductors, insulators, and dielectrics -- and see how their presence modifies the equations and their solutions. This is the content of chapters 2--4 in our textbook.

We will then briefly discuss static magnetic fields and their relation to steady electric currents. This will lead to a new set of linear partial differential equations, and a new type of potential. We will discuss some methods of solving these equations. We will discuss some types of magnetic properties of bulk matter: paramagnetism, diamagnetism, and ferromagnetism, and how they can be incorporated into the equations. This is the content of chapters 5--6 in the textbook.

We then, finally, consider non-static situations in which the fields are time-dependent. We follow a set of theoretical arguments and experimental discoveries (from the 19th century) to find the modifications to the differential equations that apply in the more general case, in vacuum and in matter with simple electromagnetic properties. These are Maxwelll's equations. We will see how to express these in terms of potentials, and discuss the redundancy (gauge invariance) in this description. We will discuss the conservation laws following from the symmetries enjoyed by the equations. This is the content of chapters 7—8 and 10.

Among the solutions of Maxwell's equations, a particularly important set describes nontrivial solutions in regions with no (free) charge or currents, describing electromagnetic radiation. We are all familiar with some of the important properties of these solutions, and we will briefly see how the equations we wrote underlie these properties, relating optics to electrodynamics as promised. This material is in chapters 9 and 11.

As advertised, Maxwell's equations are relativistically covariant. We will end by discussing relativistic aspects of electrodynamics, chapter 12.

We will in some places deviate from the order of topics or the presentation in the text. At this point in your career as a student, learning to integrate different presentations of the same material is a valuable skill to gain.

What background knowledge do I need before taking this course?

Prerequisites for PHY362 are MATH216 (or equivalent, along with its prerequisite MATH212). We will also assume some background in physics, at the level of PHY161/162.   Concepts such as conservation of momentum will be assumed.

In particular, I will assume you are comfortable with the methods of vector analysis. The relevant topics are nicely reviewed in chapter 1 of our textbook (see also Appendix A), and I encourage you to read this before the class begins. If you find any of it difficult or confusing please let me know and we will find a way to review those topics.

What will I learn in this course?

After completing this course, you will be able to

- Formulate Coulomb's law as a set of differential equations for electrostatic fields and for the associated potential
- Apply standard methods to solve problems in electrostatics in the presence of fixed charges or conductors, including: integral form (Gauss), Green's functions, image charges, separation of variables, multipole expansions
- Use macroscopic fields to describe electrostatics in bulk matter
- Formulate the Biot-Savart law (and Loretnz force law) as a set of differential equations for magnetostatic fields and for the associated potential
- Apply standard methods to solve problems in magnetostatics
- Describe the spectrum of magnetic properties of materials and the equations for macroscopic fields in bulk matter
- Describe the experimental and theoretical evidence that leads to the modifications to these equations in the presence of changing fields and their relation to the principle of relativity. Formulate Maxwell's equations in terms of the fields and in terms of the associated potentials, accounting for gauge invariance
- Formulate Maxwell's equations in bulk matter
- Describe some important solutions to Maxwell's equations, including wave solutions
- Demonstrate relativistic invariance of Maxwell's equations and formulate the equations in terms of the field tensor

What will I do in this course?

Lectures will present theoretical material. The emphasis will be on assembling experimental facts, theoretical principles, and mathematical developments into a coherent logical framework.

Weekly homework assignments will challenge students to apply the methods covered that week to solve interesting problems. You should find these challenging, they will not involve repeating procedures you saw in class but, as far as I can, ask you to think about a problem using the ideas we discussed creatively.

The discussion session will be used to fill in mathematical background, review points from lecture, and work sample problems demonstrating the application of concepts from the week's material. Topics for discussion will be determined to a large extent by student input.

Office hours will be used to further pursue questions raised by lecture material or homework problems. Scheduled office hours will be open to any interested student. Students interested in more restricted meetings with me should contact me directly to schedule meetings outside scheduled office hours.

Two midterm exams will help students (and instructor) keep track of how they are doing in the class.

How can I prepare for the class sessions to be successful?

Different students have different needs and strategies for success. You know best what works for you, anything listed here is just a recommendation. Some things that may make the class more enjoyable and productive for all of us include:

- Read assigned material before class, as far ahead as you can. If you find any of the assigned material difficult or confusing, share your questions on the anonymous Sakai forum. Someone may have an answer for you; at the very least I can use this to determine what to focus on.
- If you are not sure you understood something in lecture, you should assume you aren't the only one. As a favor to everyone, **stop me** and ask for a clarification.
- Start working on homework early, the day it is assigned if possible. These assignments take time to figure out. Some of this is time working on them, but some is thinking about them as you do other things. Start early so you can sleep on the tricky problems.
- If an assignment is unclear or you are stuck, use Sakai forum to see if anyone has an idea to get you started – or maybe to get me to fix it.
- Work with friends. Collaboration on homework is **encouraged**. If you learn to work with others on science problems that's important in itself. Talking through a complicated problem can help your thinking. Be sure that after discussing you write your own solution, to make sure you really understand what you are writing.
- Use posted solutions to assignments to see what you did wrong, or what could have been done more easily.
- If you have questions or comments about lecture material, homework, or anything related to the class, there will be time at the beginning of each lecture to bring these up. If you want more immediate response you can post your question or comment to the relevant Sakai forum, where fellow students or instructor can respond.
- You should expect to spend a total of 12-14 hours a week on this class. If you find you are spending more than this consistently, or find that 12-14 hours is not enough to keep up, please **let me know** using one of the communication tools mentioned below. I will try to respond to keep the demands reasonable but need your help to keep tabs on this!

What required texts, materials, and technologies will I need?

Required text: "*Introduction to Electrodynamics*," David J. Griffiths, Cambridge University Press, 2017. This is available electronically here and copies should be available at campus bookstore. Please note, Duke does not have institutional access to the Cambridge Core collection, so we must each purchase a copy of the book, electronic or paper.

If you are having difficulty with textbook and supply costs associated with this course, here are some resources for you:

- Contact the financial aid office (whether or not you are on aid). They have loans and resources for connecting students with programs on campus that might be able to help alleviate these costs.
- DukeLIFE has resources available for students with demonstrated high financial need. To apply for a long-term loan of required course materials, please go here. Please note that program resources are limited.
- Duke Libraries offers textbook rentals through the Top Textbook Program, where you can rent out a textbook for 3 hours at a time.

What optional texts or resources might be helpful?

I may post lecture notes from a previous related course I taught a few years ago.

For further reading beyond the scope of our class on some topics you are invited to consult the standard graduate-level texts. All are available from the campus library:

- "*Classical Electrodynamics*," J.D. Jackson, Wiley, 1998
- "*The Classical Theory of Fields*," L.D. Landau and E.M.Lifshitz, Butterworth-Heinemann, 1980
- "*Electrodynamics of Continuous Media*," L.D. Landau and E.M.Lifshitz, Butterworth-Heinemann, 1984

How will my grade be determined?

Grades will be determined by the **higher** of final exam score or the following weighted average

Homework	40%
Midterms	30%
Final	30%

Note that it is in principle possible to earn a good grade in the course without doing the homework. This is **theoretically** possible but not likely. The best way to learn this challenging material is to work with it, and homework is carefully designed to help you understand things in a deeper way. You are **strongly** encouraged to do the homework

What are the course policies?

Attendance:

- Attendance in class is strongly encouraged but **not** required. I will make every effort to make them useful, but the decision how best to spend your time is yours.
- If you are absent for any reason it is your responsibility to make up material covered in your absence. I will freely assume that everyone is familiar with any topic discussed in class. I will, of course, be happy to help with making material up in any way I can.

Homework Assignments:

- There will be weekly homework assignments, distributed and submitted through gradescope
- Collaboration on homework is **encouraged**. Please note on your assignment the names of anyone with whom you had a conversation that contributed to your solution (whether they are in the class or not). This will have no effect on credit but acknowledging such help is good academic practice
- To be sure you are solving the problem, not writing down someone else's solution, I suggest that after working on an assignment with a group, you go off and write up the solution on your own
- Homework will not be accepted past due date, on which detailed solutions will be posted
- There will be no opportunity to make up missed assignments. Homework not submitted by due date for justified reasons will be dropped from homework average. Homework not submitted in time without a justified reason will receive a grade of **0**.

Exams:

- There will be two midterm exams and a final exam
- The first midterm covers all material on which homework has been assigned by the date of the exam
- The second midterm covers all material on which homework has been assigned by the date of the exam; material covered in first exam will not be emphasized but may be used
- Final exam is cumulative covering all course material
- A midterm exam missed for justified reasons will be dropped from midterm average
- Collaboration on exams is not permitted
- All exams will always be **open book** with full access to notes, texts, etc. Use of laptops for pdf notes or ebook is allowed; searching the internet for solutions to problems is not allowed

Communications:

- The primary tool for communication in this class will be Sakai. Reading assignments, homework solutions, and grades will be distributed through Sakai. You should regularly check the Sakai site.
- Sakai forums will be set up for each week. They will be anonymous so that post authors cannot be identified to encourage open posting. If you want to be known as the author include your name on the post. Sakai forum posts are visible to the entire class so can spark discussions. I will monitor the forums and take part in the discussion if that seems appropriate.
- Homework will be distributed and submitted through gradescope (accessible via Sakai). If you have never used gradescope please familiarize yourself with it.

- For communication not shared with the class, email is the preferred method, you can reach me at plesser@cgtp.duke.edu. Please include PHY362 in the subject line. I will use email if I need to communicate with a particular student, so monitor your email at the address listed in dukehub.
- I will schedule weekly Office Hours in consultation with students. Students are welcome to drop in as they like.
- Students wishing to meet me one (or several) to one are welcome to email me and we will set up a separate time for this.
- You are also welcome to drop by my office anytime. I may not be there, or I may be busy and ask you to return later, but when I can I welcome drop-ins.

Discussion Guidelines:

Civility is an essential ingredient for academic discourse. All communications for this course should be conducted constructively, civilly, and respectfully. Differences in beliefs, opinions, and approaches are to be expected. Please bring any communications you believe to be in violation of this class policy to the attention of your instructor. Active interaction with peers and your instructor is essential to success in this course, paying particular attention to the following:

- Be respectful of others and their opinions, valuing diversity in backgrounds, abilities, and experiences.
- Challenging the ideas held by others is an integral aspect of critical thinking and the academic process. Please word your responses carefully, and recognize that others are expected to challenge your ideas. A positive atmosphere of healthy debate is encouraged.
- Read your online discussion posts carefully before submitting them. Please do not abuse the anonymity of Sakai forum posts.

Academic Integrity:

All students must adhere to the Duke Community Standard (DCS): Duke University is a community dedicated to scholarship, leadership, and service and to the principles of honesty, fairness, and accountability. Citizens of this community commit to reflect upon these principles in all academic and non-academic endeavors, and to protect and promote a culture of integrity.

To uphold the Duke Community Standard:
Students affirm their commitment to uphold the values of the Duke University community by signing a pledge that states:

- I will not lie, cheat, or steal in my academic endeavors;
- I will conduct myself honorably in all my endeavors;
- I will act if the Standard is compromised

Regardless of course delivery format, it is the responsibility of all students to understand and follow Duke policies regarding academic integrity, including doing one's own work, following proper citation of sources, and adhering to guidance around group work projects. Ignoring these requirements is a violation of the Duke Community Standard. If you have any questions about how to follow these requirements, please contact Jeanna McCullers, Director of the Office of Student Conduct.

Academic Accommodations:

The Student Disability Access Office (SDAO) is available to ensure that students are able to engage with their courses and related assignments. Students should be in touch with the Student Disability Access Office to request or update accommodations under these circumstances. I will work with that office to provide you with equal access to course materials and make accommodations for exams and other assessments.

What is the expected course schedule?

This is a tentative schedule, I will update it as the term progresses

Week of	Class topic/unit name	Chapter	Events	Assignments due
8/23	Electric field and potential	2.1-2.4		
8/30	Boundary value problems	2.5-3.3	Drop/Add ends Friday 9/3	
9/6	Methods of Solution	3.4, notes		HW1 9/7
9/13	Electric Fields in Matter	4		HW2 9/14
9/20	Magnetostatics	5	Midterm 1 Thursday 9/23	HW3 9/21
9/27	Magnetic Fields in matter	6	Midsemester grades due 10/1	HW4 9/28
10/4	Electrodynamics	7	No class Tuesday 10/5	HW5 10/7
10/11	Electrodynamics	7		HW6 10/12
10/18	Conservation Laws	8		HW7 10/19
10/25	EM Waves	9	Midterm 2 Thursday 10/28	HW8 10/26
11/1	Potentials and Gauge Invariance	10		HW9 11/2
11/8	Radiation	11		HW10 11/9
11/15	Relativity	12		HW11 11/16

11/22	Relativity	12	No class Thursday 11/25	HW12 11/23
11/29				