Physics 4: Introductory Physics
Electromagnetism and Light

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1. Welcome to Physics 4: Electromagnetism and Light

Welcome to Physics 4! What is your goal in life? If it is to become an engineer or to pursue a career in science, this is a key class for you. Understanding electromagnetism and light is critical to so many technologies and scientific phenomena that it is almost impossible to overstate the importance of this subject. From cell-phones to medical imaging, from energy generation to rainbows, from information storage to the Global Positioning System, the applications are endless.

The unification of two seemingly different forces, the electric force and the magnetic force, is one of the great achievements in science. This unification is expressed in the four Maxwell's equations, which we will develop this quarter. From these equations, we will predict the existence and properties of light, including its speed.

2. How to succeed in Physics 4

Physics 4 will be a challenging course, but I am confident that the importance of this subject is well worth the effort. Please remember that the course builds on a foundation that includes many of the topics that were covered in Ph 1-3. If you have not learned that material reasonably well, Ph 4 will be extremely difficult.

My goal is to prepare people heading towards an engineering or science career and help them to achieve their ambitions. I will act as your guide to the world of electromagnetic phenomena. This is an intrinsically hard subject. I'm not going to water it down—because I want you to have a solid foundation for acquiring the knowledge you need to compete and succeed.

I have a second goal: to change the way you look at the world. The discoveries and tools of physics are not only extremely practical, they can alter your picture of physical reality, or at least enable you to appreciate it at a much deeper level.

If you take yourself and your own goals for the future seriously, this will be a good class for you. To succeed in learning this subject, here is what you need to do:

1. Attend all of the lectures and carefully read all the chapters. As you read the text, I recommend taking your own notes and carrying out parallel calculations, rather than underlining and marking up the book. Ask yourself: "What questions are these results the answers to?"
2. Do all the physics problems on the homework. Carefully write out your solutions on paper *before* entering your answers into MasteringPhysics. (See also *Richman's method for solving physics problems* below.)
3. Stay engaged and active in class. We will be using clickers to help create an interactive environment. Ask questions in class or during office hours when you are confused. This is crucial! (Note: I will not be able to answer lengthy questions by e-mail.) If you fall behind, do not stop coming to class. Remember: 75% of success in life is showing up and paying attention.

3. Approximate Schedule for Physics 4 in Winter 2011

Class	Date	Topics	Chapters and Reading
1	Tues, Jan 4	Review of vector cross product Field concepts, dipole field patterns; magnetic force on a charged particle;	27.1-27.2
2	Thurs, Jan 6	Properties of B-field lines; flux of B-field; motion of charged particles in B field; forces on current-carrying wire in B-field	27.3-27.6
3	Tues, Jan 11	Magnetic torques on current loops; Hall effect; B-fields produced by moving charged particles	27.7-27.9, 28.1
4	Thurs, Jan 13	Examples; B-field produced by moving charge; B-field of long, straight wire; force between two parallel wires.	28.2-28.4
5	Tues, Jan 18	B-fields of moving charge vs. currents; circular current loop; electromagnets vs. permanent magnets; Ampere's Law and "circulation"; magnetic materials	28.5-28.8
6	Thurs, Jan 20	Electromagnetic induction; Faraday's Law (2 forms) and Lenz's Law	29.1-29.2
7	Tues, Jan 25	Faraday's Law: many examples; inductance	29.3-29.5
8	Thurs, Jan 27	Eddy currents; inductors vs. capacitors; Maxwell's fix of Ampere's Law; displacement current; superconductivity	29.6-29.8
9	Tues, Feb 1	Summary of Maxwell's equations; review of wave propagation; electromagnetic waves	32.1-32.3
10	Thurs, Feb 3	Electromagnetic waves: examples; propagation in matter; energy and momentum in EM waves; the EM spectrum	32.4-32.6
11	**Tues, Feb 8**	**MIDTERM**	**Chapters 27, 28, 29**
12	Thurs, Feb 10	Nature and propagation of light: concepts; reflection, refraction, dispersion	33.1-33.2
13	Tues, Feb 15	Refraction; total internal reflection; concepts of imaging (real and virtual images); disperson (prism, rainbows); polarization and Malus's Law	33.3-33.7
14	Thurs, Feb 17	Reflection at a spherical surface; paraxial approximation; sign rules and	34.1-34.3

		conventions; refraction at a spherical surface; imaging capabilities of mirrors	
15	Tues, Feb 22	Thin lenses; lensmaker's equation; comparison of mirrors and lenses; the eye and optical instruments	34.4-34.9
16	Thurs, Feb 24	Wave superposition effects: interference of light; double-slit experiment	35.1-35.3
17	Tues, Mar 1	Interference; effect in thin films; interferometric instruments	35.4-35.5
18	Thurs, Mar 3	Diffraction; single-slit diffraction	36.1-36.3
19	Tues, Mar 8	Multiple slit diffraction & interference; X-ray diffraction	36.4-36.6
20	Thurs, Mar 10	Review	All
FINAL	**Thurs, Mar 18**	***FINAL EXAM*** 4:00—7:00 PM	**Covers textbook, HW, lectures, demonstrations**

4. Grades, homework, tests, and all that stuff

- Homework (online) will be assigned on Tuesday morning and is due on the following Tuesday, using the Mastering Physics online system. Late HW will not be accepted.
- Lectures: Tues, Thurs from 3:30—4:45 AM in Broida 1610.
- Lab Sections—see Schedule of Classes
- Professor Richman's office hours: to be announced; students are strongly encouraged to come!
- E-mail: I will do my best to answer e-mail, but I get so much that it can be extremely difficult to answer quickly. FOR ALL YOUR MESSAGES. PLEASE MAKE THE SUBJECT: PHYSICS 4 (not Ph 4, or Phy 4, …). This will really help me a lot!
- Grading policy:
  1. Homework: 15%
  2. Midterm: 20%
  3. Final exam: 65%
- Textbook: *University Physics, by H.D. Young and R.A. Freedman, 12th Edition*
- Final Exam Date: see schedule below.
- You will use the Mastering Physics online system (http://www.masteringphysics.com) to submit your answers to homework problems. You should be familiar with this system from Physics 3. The Course ID to use when registering on MasteringPhysics is MPRICHMAN64358.
- Laboratory sections: you must register separately for Physics 4L and buy a lab manual from the bookstore. Grades from Physics 4L are determined separately from those for Physics 4. The lab (Physics 4L) is treated almost as a separate course, with independent grading and policies. Please consult your lab T.A. for information.
- **Cheating in any form is not acceptable and will result in severe consequences. If you have any questions about this, please come and talk to me**.

Richman's tried and true recipe for solving physics problems

Physics is a lot more fun when it isn't just a bunch of formulas with abstract symbols. And anyway, as engineers, you need to understand the formulas at a deeper level, otherwise you won't know whether they are applicable to the problem you are trying to solve. When you are working a physics problem, try the following procedure:

1. **Write down all of the information you are given**, taking care to include units for all quantities. For any quantity that is just given numerically, **introduce a symbol**, such as *m, q*, or *d*. This is essential, because later you need to solve equations in terms of symbols and you need to have a clear mapping between the symbols and the numerical quantities. Feel free to include subcripts to make you symbols more useful or meaningful.
2. **Convert all quantities to an appropriate unit system (usually SI).**
3. **Whenever possible, draw a picture to describe the situation.** In your picture, label objects or distances with the information from step 1. In many cases, you will need to introduce an *xyz* coordinate system into your drawing. You may then need to re-express some of the given vector quantities in terms of this coordinate system.
4. **You should only have to read the problem <u>once or twice</u> to transcribe the information onto your own paper. If you are reading the problem multiple times something is wrong!**
5. **Write down the question or the quantity you are asked to determine.** I like to put down something like E=? to identify the desired quantity.
6. **Think about what is going on in the physical situation.** What kind of behavior is involved? What do you think is actually happening or will happen? Can you describe it in words? It might help to look at your picture and think about how the desired quantity is related to what you see.
7. **Write down the <u>fundamental equations</u> that you think must govern the situation.** Identify which quantities in the equations are directly given. Analyze any special conditions you are given to see if they help in evaluating the formulas. Students often have trouble here: they don't recognize that the auxiliary information in some way provides the needed quantities.
8. **In general, it is better not to substitute numerical information into the formulas until after you have solved (abstractly) for the desired quantity.**
9. **Check your formula for reasonableness.** If you substitute very large or very small values for each quantity, do the results make sense?
10. **After solving for the quantity of interest, substitute the numerical values.**
11. **Think about your result—does it make sense?** Are the units correct? If your work is written neatly, it will be much easier for you to find your mistakes!

You might think this list is too much. It isn't. It's exactly what you need to do. This process will save you time in the end. If you are building a bridge, designing a new cell phone, creating new diagnostic instrumentation for a hospital, or inventing a new process, you will be committing resources of your company. Carefulness and correct results will be rewarded (and vice versa). Good luck!

List of Objectives for this Class

The schedule at the end of this syllabus gives you a lecture-by-lecture plan of the material we will cover in this course. Below I list some of the main concepts you will need to master. I don't list every one here, just the main ideas.

1. The effect of magnetic fields on charged particles and on objects containing charged particles. In other words, if a magnetic field is present, what is the response of a system to this field? The response of magnetic dipoles is extremely important, because (as far as we know) there are no magnetic monopoles, so dipoles are the simplest system we can treat (C27).
2. How to produce static (constant in time) magnetic fields. In physics, we use the term "sources" to indicate something that can produce a certain type of field. Interestingly, the sources of magnetic fields come in two characteristic types: (1) electric charges in motion (either individually or as currents) and (2) electric charges that are spinning. Most elementary particles, such as electrons and protons, have an intrinsic, quantum-mechanical spin, so they generate magnetic fields automatically (C28). This explains how we can have substances like iron, which generate magnetic fields without an obvious source of electric current.
3. How a time-changing magnetic field produces an electric field. How a time-changing electric field produces a magnetic field. (These are called induced fields.) Synthesis of these and other results into Maxwell's equations (C29).
4. How energy is stored in magnetic fields and how we characterize this using the quantity of inductance (C30).
5. Analysis of circuits with R, L, and C circuit elements (C30, C31). These topics will be covered almost entirely in the lab. It will be helpful for you to familiarize yourself with the material in these chapters before doing the related labs. Many engineering students are already familiar with this material.
6. How propagating and standing electromagnetic waves arise from the interplay of time-varying electric and magnetic fields. Properties of electromagnetic waves (C32).
7. Phenomena involving light: reflection, refraction, dispersion, polarization, other wave effects (C33).
8. Geometric optics and optical instruments. Practical applications (C34).
9. Interference effects arising from the linear superposition of electromagnetic waves (C35). Diffraction (C36) is also a superposition effect closely related to interference.

A Perspective on Electromagnetism

Maxwell's equations came about through the efforts of many people, and after much experimentation, but the full set of equations was finally synthesized by Maxwell around the time of the U.S. Civil War. The famous physicist Richard Feynman wrote (*Feynman Lectures on Physics*, Vol. II, p. 1-11) that when historians 10,000 years from now look back at the events of the 1800s, the Civil War will pale in significance compared with the discovery of Maxwell's equations. It is certainly true that our ability to control and exploit the electromagnetic field has had profound implications for human history. Consider just a few examples: the electric light bulb, radio communications, radar, the television, medical imaging with X-rays and nuclear magnetic resonance, electronic circuits, fiber optics, lasers, the computer, magnetic and optical storage disks, and the cell phone. Each of these and countless other innovations affect our daily lives.

One of the most intriguing and useful aspects of electromagnetism is the existence of electromagnetic waves. In such waves, the electric and magnetic fields interact with each other in a way that sustains and propagates the wave. We will be able to infer the existence of such waves from Maxwell's equations. Although visible light is just a narrow sliver of the electromagnetic spectrum, it is a very important sliver to us! Each of us owns two extremely powerful visible-light optical systems: our eyes. But other parts of the spectrum, from gamma rays and X-rays to infrared light, microwaves, and radio waves also play a huge role in science and technology.

Maxwell's equations underlie all classical phenomena involving electric and magnetic forces. The term *classical* is often used in physics to mean that we are not including quantum phenomena. We will, however, discuss some of the limitations of Maxwell's equations so that you understand their range of applicability. In particular, if you investigate the behavior of electromagnetic fields at very low intensities, you would discover that electromagnetic energy cannot be manipulated in arbitrary amounts. The excitations of the electromagnetic field occur in discrete quanta, called photons.

For many, many processes of interest, we do not notice this "graininess" of the electromagnetic field, but for other processes it is absolutely crucial. If you want to continue with physics and go on to study quantum phenomena involving electromagnetism, you will certainly need to know Maxwell's equations to serve as the starting point.

One interesting feature of Maxwell's equations is that they are fully compatible with Einstein's special theory of relativity. In Einstein's theory, the speed of light is a constant, as long as the light is propagating in vacuum. At first this might seem obvious, but it is quite surprising, even shocking, when you realize that regardless of the velocity of the observer, the speed of light is the same. Even if you "chase" the light coming from a flashlight, the speed of the wave with respect to you does not change! This conclusion, which is fully supported by experiment, means that space and time are inextricably linked.

Another aspect of Maxwell's equations is that if one reference frame is moving with respect to another, the observers in these two frames see different electric and magnetic fields. One person's electric field is another person's magnetic field! We will touch on this point briefly, but you will need to take an upper-division class on electromagnetism to fully explore this phenomenon.

Advice for Physics 4

Electromagnetism is a difficult subject, with many abstract concepts and some complicated mathematics. Here are some specific suggestions on how to do well in Ph 4:

1. As for nearly all physics classes**, the single most important thing is to do the problem sets as well and as carefully as you can**. It is amazing how many mistakes can be avoided and how much time can be saved by simply writing neatly! You will often need to "debug" your homework solutions, much as you would debug a computer program. Well organized and carefully written solutions will be much easier for you to debug than a sloppy mess. They will also help you study for the quizzes and the final!

2. Special comment about MasteringPhysics. The online MasteringPhysics system is reasonably good, but it can have its frustrations. **Print out the MP assignment and work on it away from the computer, writing out complete solutions before attempting enter your answer.** If you come to me in my office for help on a homework problem, the first thing I will do is ask to see your work.

3. You should review your old problem sets from time to time to check that you have assimilated the material.

4. **Prepare ahead for the lectures**. Read the chapter before I present the material in lecture. Why? The book is available to you all the time. The lecture happens only once. To get the most out of it, you should already have some familiarity with the material.

5. **Remember things**. Many physics students are disinclined to remember important results, thinking that these can always be derived or looked up whenever necessary. However, if you remember things, it will greatly facilitate both learning new material and solving problems: the amount of “new” material will seem less, because you will be more familiar with the old material used in the derivations.

6. Given the difficulty of the subject, it is important to work especially hard to keep up. In studying my lectures or the text, you will generally need to go over the material several times. **Reading the text or your notes is not enough. You have to actively carry through the derivations and analyses on your own.** Some students simply try to read the same thing over and over again, and then discover that they aren’t learning any more by doing so. A better approach is to read through the material once or twice and then **try to derive the results on your own**, referring to the text only if you are stuck. If you don’t understand a particular aspect of the analysis, note this down and continue. Then, bring your list of questions to class, discussion section, or office hours.

7. **Be an active listener and a participant in lectures.** It is essential to make the best use of your time in lecture. This means really paying attention, taking good notes, and

asking good questions. But don't just be a note-taker! Questions from students are usually incredibly helpful to everyone—professor and other students—by helping the professor to clarify confusing points and to make sure that the most important information does not get lost in the details. Often, the best students are the ones who ask questions, since others feel that they do not know enough to ask one. I strongly encourage you to ask questions even if they are not perfectly formulated!

8. **You are encouraged to find other books on electromagnetism**—there is a vast number—to find alternative presentations, examples, and problems. The *Feynman Lecture on Physics* are great. Don't let the class set the boundary for your learning. There is no boundary!

Advice for ALL of LIFE

Many of the skills and habits that will increase your success as a student are exactly the same ones that will help you to be successful as an engineer.

Always *show up, pay full attention* and be as *disciplined* as possible. In the university, *showing up* means coming to every class, just as engineers must always *show up* to work on time and to meetings in their companies.

In the real world, you will be expected to absorb and to use information rapidly. Learning *to pay full attention* in class is very good practice. Why do students sometimes come to class and not listen? I don't know.

Engineers need to deliver results in the real world on schedule and on budget. Companies require their engineers to deliver products, designs, and ideas. Engineers are expected to perform at a very high level in their companies---or else the company will find someone else to do the job. In a company, you would not dare to hand in sloppy work. Develop a professional style and professional habits ***now***.

Learn to plan and to develop strong organizational skills. They will not only help you now, they will be essential in your future jobs. Use self-discipline in implementing your plans. CAREFUL PLANNING WORKS if you stick to your plans.

Now is the time to invest in your own future. The world is a very competitive place. Prepare for it by setting high goals and high standards for yourself.