PY 405 — Electromagnetic Fields and Waves Syllabus–2019.v2 (September 11, 2019)

Professor Kenneth Lane

Physics 405 is the first semester of the upper-level course on electricity and magnetism. PY 355 (Methods of Theoretical Physics) is the prerequisite for this course, along with the corresponding math background courses. Of course, it is assumed that you have passed the prerequisites for PY 355. If you do not meet these requirements, you **must** consult with Professor Lane before permission to take this course can be granted.

The general plan of PY 405 is as follows: We will start in Purcell, E&M, and cover most of the material through Chapter 9 (skipping Chap. 8). The discussion on solving Laplace's equation will be augmented with material from Griffiths' book. The main reason for using Purcell is to teach you that magnetism is a *relativistic* phenomenon. That is the way Purcell introduces magnetism and it is the right way to understand the appearance of magnetic fields: they *always* arise as a consequence of *moving* electric charges. We will preface that discussion with an introduction/review to special relativity, sufficient to deal with the material in Purcell's chapters 5–7. (I will teach you all the relativity you need to know. Also, a good reference for it is to be found in "Mechanics", Volume 1 in the Berkeley physics series.) In Purcell, we will learn how electric and magnetic fields transform into each other when viewed from different inertial frames, thereby establishing the fundamental kinship of electric and magnetic fields. We will also develop Maxwell's equations (in differential form) for the electric and magnetic fields. From these, we will be able to take a first look at electromagnetic fields and EM waves.

Throughout this course, I will use cgs units (which I will remind you of in the first lecture). My reason for this is that, in cgs units, electric and magnetic fields $\boldsymbol{E}$ and $\boldsymbol{B}$ have the *same units* — and this also emphasizes their close connection. Dimensional analysis is greatly facilitated because there are no constants ϵ_0 and μ_0 with obscure meanings to carry around. The only fundamental constants are the electric charge $e \cong 4.80 \times 10^{-10}$ esu of a proton and the speed of light $c \cong 3.00 \times 10^{10}$ cm/sec.

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Class: Monday, Wednesday and Friday, 2:30–3:20 PM in PSY (Psychology building) B51.

Discussion: Thursday, 3:35–4:25 PM, also in PSY B51. The first discussion section will be on September 15. Our TF, **TBD**, will generally be running the discussion sections.

Office hours: Monday and Wednesday, 4:00–5:00 PM. *Note:* You can usually see me at other times by sending an e-mail or calling to make an appointment. Take advantage of this! *Announcements will be made by e-mail. Please check your e-mail daily!*

Teaching Fellow (TF) and Homework Graders: Our TF is David Long; David was the TF for this course last year and did an excellent job. David will also serve as one of our homework graders. His coordinates are: email–dmlong@bu.edu (this email address is David's preferred means of contact), office–SCI 249, BU phone number–ext. 8-0378. David's office hours will be Tuesday and Friday, 10:00–11:00, in SCI 121 (starting this Friday, September 6. Our other homework grader is Victoria Kovalchuk. Her email address is vic3@bu.edu and her office in SCI 226. Victoria and David will grade alternate homework sets, with Victoria

starting with HW Set 1. As stated in the course outline below, homework is generally due in class one week after it is assigned. If you are a little late (same day as due), you may put your homework in the PY405 box that has been set up on the 1st floor of SCI. Homework turned in past the due date will be penalized by an amount determined by how late it is. For questions about homework, you may ask me or the TF & grader (David), our other grader (Victoria), or the LA (Sal Pace; see below). If you have a question about grading of homework, please see the relevant grader first. If that does not resolve the question, see me. It is always a good idea to call or e-mail to make an appointment with David or Victoria.

Learning Assistant (LA) Our LA is Sal Pace. Sal is available for questions about the notes/book and homework. His office hours are Wednesday 3:30–4:30 and Thursday 4:30–5:30 in SCI 122. Sal's email address is space20@bu.edu. He can be reached by phone at 717-949-9262. Take advantage of the opportunity of having Sal as LA. He's a very good young physicist, as I know from having taught him a semester of undergraduate quantum mechanics.

Attendance and Participation: Your attendance in class and discussion section and participation in class discussions are **strongly** recommended!

Principal Text:
Electricity and Magnetism—Berkeley Physics Course, Vol. 2, by Edward M. Purcell.

Supplemental Texts: (on reserve in the Science Library):

Notes by me will supplement the texts.
Introduction to Electrodynamics, by David J. Griffiths
Mechanics—Berkeley Physics Course, Vol. 1 by Charles Kittel, et al. This is a useful resource on special relativity.
Classical Electromagnetic Radiation, by Mark A. Heald and Jerry B. Marion.
Feynman Lectures on Physics, Vol. II, by R. P. Feynman, R. B. Leighton and M. Sands;

Course Grade: Your course grade will be based on homework (25%) two midterm exams, discussed below, (total 50%), and the final exam (25%). Homework assignments and their due dates appear in the course outline below. *You are encouraged to work together on homework, but your submitted homework solutions must be your own.*
N.B.: Because our class periods are only 50 minutes long, it is difficult to give decent midterm exams, ones that really test your knowledge in such a short time. My current thinking is that there will be three take-home exams, each covering about a third of the course. Each exam will have two or three problems and will be distributed in class on a Friday and due in class the following Monday. **There will be no collaboration allowed on exams. You will be allowed to use Purcell's book and my notes, but no other sources. The Honor System will be strictly enforced.** I will discuss this with you during the first week of class and, hopefully, we will devise a plan. The final exam date will be announced soon.
Again: collaboration on exams is **NEVER** allowed. There will be **NO** make-up exams without an adequate doctor's (or other) official/acceptable excuse.

You are expected to be familiar with and adhere to the BU Academic Code of Conduct (posted at `https://www.bu.edu/academics/policies/academic-conduct-code/`). In par-

ticular, cheating on exams or other coursework will not be tolerated; suspected cases will be dealt with in accordance with BU Academic Conduct procedures.

The last day to drop classes (without a "W" grade) or to change from credit to audit is 5 weeks from the start of the semester, Monday, October 7. The last day to withdraw (with a "W" grade) is Friday, November 8. See https://www.bu.edu/reg/calendars/semester/.

Format of the lectures: The topics of the lectures are listed below. They follow Purcell's book *and* my notes (and, to some extent, Griffiths' book). **I strongly recommend that you read the relevant material, at least superficially, BEFORE I lecture on it.** That way, you will have a much better understanding of my lectures, and you will be able to ask timely questions. Following my lecture, you can go back and re-read the text and work problems to solidify your understanding.
THIS IS BY FAR THE BEST ADVICE I CAN GIVE YOU FOR SUCCEEDING IN THIS COURSE!

COURSE & LECTURE OUTLINE[1]

Note: In the reading assignments, P=Purcell and G=Griffiths. P1 means Purcell, Chapter 1, etc. In the homework assignments, P1-5 means Purcell, Chapter 1, problem 5; etc. The schedule below was designed for 90-minute lectures. So each of the items below comprises approximately 1.550-minute lectures. Remember to consult this syllabus for lecture topics, homework assignments and exam dates.

1. Organization of PY405; the syllabus; cgs units vs. SI units.

2. P1:**Electrostatics:** Coulomb's law; electrostatic potential energy; electric field, $\boldsymbol{E}$; the importance of superposition; and the importance of dimensional analysis — whose use in E&M is made easy by cgs units!

   Homework set 1, due in class 9/13: P1–2,4,5,9,10,15,19,21,26,30. (A word to the wise: this first set is long, so don't wait to the last minute to start it!)

3. P1: Gauss's law in integral form and its application to calculating $\boldsymbol{E}$ for simple geometries, i.e., *symmetrical* distributions of charge.

4. P1: The force on a layer of electric charge; the energy and energy density) associated with the electric field (with dimensional analysis).

   Homework Set 2, due in class 9/20: P2–1,2,7,10.

5. P2: Line integral of $\boldsymbol{E}$; electric potential, ϕ; the gradient; $\boldsymbol{E}(\boldsymbol{r}) = -\nabla\phi(\boldsymbol{r})$ for *electrostatic* $\boldsymbol{E}-$fields.

[1] Subject to change.

6. P2: Equipotentials and examples of ϕ and $\boldsymbol{E}$.

   Homework set 3, due in class 9/27: P2–14,16,17,19,25,29.

7. P2: Divergence of a vector field; Gauss's divergence *theorem*; Gauss's *law* in differential form and its meaning; the Laplacian, and Poisson's and Laplace's equations, and the average-value theorem.

8. P2: Curl of a vector field; $\nabla \times \boldsymbol{E} = 0$ as the defining equation of electrostatics! Stokes' theorem.

9. P3 & G3: Applications of electrostatics; $\boldsymbol{E}$-fields around conductors; equipotentials; Boundary conditions and boundary-value problems; uniqueness theorem for the solution to Laplace's equation.

   Homework set 4, due in class 10/4: P3–1,3,5,7,8,21.

10. P3 & G3: Simple electrostatic systems; method of images with examples;

11. P3 & G3: Solutions to Laplace's equation using Fourier series and Legendre polynomials. Multipole expansions of ϕ and $\boldsymbol{E}$.
    So long, electrostatics!

    Take-home Exam 1, distributed October 11 and due in class Tuesday, October 15 (October 14 is a holiday). The exam covers Purcell chapters 1–3.

12. P4: Electric currents; current densities; the continuity equation; steady currents.

    Homework set 5, due in class 10/18: pdf to be distributed.

13. Lane notes: Relativity. Einstein's postulates; Lorentz transformations.

14. Lane notes: Lorentz transformations with examples.

    Homework set 6, due in class 10/25: pdf to be distributed.

16. P5: Fields of moving charges: Lorentz force; Lorentz invariance of (total) electric charge;

17. P5: Electric fields in different inertial frames; field of a point charge moving with constant velocity; field of a charge that starts and stops.

18. P5: Force on a moving charge; the interaction between moving charges (in different inertial frames) $\Longrightarrow$ Magnetic fields arise from moving charges!

    Homework set 7, due in class 11/1: TBD

19. P6: Magnetic field: Definition and properties; Ampère's law; $\nabla \times \boldsymbol{B}$ and $\nabla \cdot \boldsymbol{B}$; $\boldsymbol{B} = \nabla \times \boldsymbol{A}$; vector potential $\boldsymbol{A}$ and its Poisson eqn.

20. P6: Biot-Savart law; calculating $\boldsymbol{B}$-fields; change of $\boldsymbol{B}$ at a sheet of current.

    Homework set 8, due in class 11/8: TBD

21. P6: Lorentz transformation of $\boldsymbol{E}$ and $\boldsymbol{B}$-fields; Lorentz force law and applications.

    Take-home Exam 2, distributed November 15 and due in class November 18. The exam covers Purcell chapters 4-6, and will use relativity (as do Purcell's text and my notes).

22. P7: Electromagnetic induction: Faraday's discovery; motion of conductors through magnetic fields.

23.

    November 27–December 1 Thanksgiving break, no class.

    Homework set 9, due in class 12/7: TBD

24. P7 and P9, Sections 1-4: Faraday's Law of induction; the displacement current.

25. P9: Maxwell's equations; EM waves and their velocity *in vacuo*.

    Homework set 10, due at my office Friday, December 13, by 3:00 pm: TBD

26. EM waves *in vacuo*. continued.

    Final exam: to be announced.