APPHY 217

Harvard College/Graduate School of Arts and Sciences: 121975

Term: 2024 Fall / Full Term

Course Instructor(s): Lene Hau

Location: Maxwell Dworkin G125 (SEAS)

Meeting Time: Tuesday 10:30 AM - 11:45 AM; Thursday 10:30 AM - 11:45 AM

Exam Group: FAS10_D

Course Description:
Foundational concepts of E&M, optics, imaging, and interaction of electromagnetic fields with matter. Topics include electromagnetic wave propagation, optical properties of materials from a microscopic viewpoint, propagation of electromagnetic fields in inhomogeneous media: Ray optics and effective forces on optical rays and ray bending. Fourier Optics and advanced imaging based on full E-M wave theory. The lens as a Fourier transformer, Fourier synthesis and phase contrast imaging. Light matter interactions in the semiclassical limit and quantization of the electromagnetic radiation field. We will illustrate the material with applications in AMO physics and in biological as well as astrophysical imaging. The class has two weekly lectures and, in parallel, a series of workshops with a project-based approach that will illustrate and support the material covered in the lectures and motivate the homework problems.

Notes: AP 217 is also offered as Physics 217. Students may not take both for credit.

Recommended Preparation and Student Background: Elements of electromagnetism, for example an undergraduate course in electromagnetism such as Physics 153 or similar.

The lectures are Tuesdays and Thursdays 10:30-11:45 am in Mawell-Dworkin G125. It should be noted that attendance at lectures is required.

The workshops/sections will be every second week on Tuesdays 5-6 pm in Pierce Hall 209. The next workshop is September 24. The workshops will introduce you to Python and to Computational E&M that you will need as background for the homework sets.

Professor **Lene Vestergaard Hau** (hau@fas.harvard.edu) will be teaching this class and will hold **Office Hour Thursdays at 2-3 pm in Lyman 229**.

Yifan Wang (ywang6@g.harvard.edu) and **Kerolos Yousef** are the TFs for the class and will hold **Office Hour Fridays 2-3 pm in Pierce 306.** Yifan will hold an additional weekly office hour via zoom Monday 2-3pm. If you cannot make our regular in person OH, you can join: (https://harvard.zoom.us/j/5740244579)

More Detailed Info:

AP 217 teaches **foundational concepts of E&M, optics, imaging, and interaction of electromagnetic fields with matter.** While the main parts are based on classical electromagnetic fields, the class also has a module on **quantization of the E-M fields**.

This will be covered in the two weekly **lectures. T**here will also be a series of **workshops** with a project-based approach that will illustrate and support the material covered in the lectures and motivate the homework problems.

In the workshops and the office hours, the students will have a chance to get help with Problem Sets and to discuss the lecture material.

Problem Sets will be be handed out every second Friday starting Friday September 13. They will be due on the Monday 10 days later. So the first problem set is due Monday September 23 at 11:59 pm.

Project and Presentation: The students will pair up in teams of two, and after discussions with the instructors, each team picks a project that they will do a literature research on. They will make a presentation to the rest of the class on the topic. **The team has 25 minutes for the presentation plus 5 minutes for Q&A.** The students will explicitly reference material taught in the class to analyze and interpret selected, published papers. Work on this project will teach the students to think critically and analytically about research papers that can be papers of historic significance as well as newer papers of interest.

Final Paper: The project will also form the basis for the final paper for the class with one paper of roughly 10 pages per team (text should be font 11, single spaced; the count of 10 pages is text beyond references and figures). The individual student teams will meet with Lene Hau to discuss their graded final paper in detail.

Deadline for deciding on team members and project: Aim for October 16 - **absolute deadline is November 1.** Remember to consult with and get approval from Lene Hau.

Assessment:

The three components:

Problem Sets

Project work and Presentation

Final paper on the project

will form the basis for assessment of student performance in the class. The three components will have weights 40 %, 30 %, and 30 %, respectively, for the final class grade.

Participation in the class is also important, and it can change the class grade by half a grade up or down.

Material covered in the lectures:

<u>Electromagnetic waves</u>:

We start with Maxwell's equations and study propagation of electromagnetic plane waves in homogeneous media.

We discuss the macroscopic versus the microscopic Maxwell equations, and derive the Fresnel equations for refraction and reflection at interfaces.

We study energy transport, energy density, and dissipation of electromagnetic waves.

<u>Optical properties of materials</u>:

We discuss the physics behind the dielectric function and refractive index in both dilute and dense dielectric media.

We separately treat conduction electrons in metals and discuss their contribution to the susceptibility of a material and discuss plasmons as a collective electron effect.

<u>Propagation of electromagnetic fields in inhomogeneous media</u>:

Ray optics/geometrical optics and Eikonal approximation. We derive the effective force on propagating optical rays and ray bending in inhomogeneous media.

<u>Full wave theory of light and advanced imaging with examples in biology and astrophysics</u>:

We will discuss Fourier Optics and Imaging in detail with full E-M wave theory.

We will derive the conditions for a lens to act as a perfect Fourier transformer.

We will discuss Fourier synthesis and phase contrast imaging, and Fresnel and Fraunhofer diffraction.

<u>Light matter interactions in the semiclassical limit</u>

We will discuss Rabi oscillations and stimulated emission of radiation.

<u>Quantization of the electromagnetic radiation field</u>

Photons and spontaneous emission.

Quantum electrodynamics and dressed-state polaritons: Entangled states of light and matter.

Possible team projects:

You are encouraged to propose a topic you have encountered that you would like to learn more about and use the class material to explore.

Here are **a few examples** of possible topics:

Adaptive Optics: How it works - and applications in astronomy for black hole and exoplanet imaging, or in life sciences for deep tissue and brain imaging.

Fluorescent green protein – and blue, cyan, yellow,… - and its properties and applications

FRET (Foerster resonance energy transfer): Protein dynamics – conformational dynamics of proteins with nanometer resolution, including single molecule dynamics.

Metamaterials: Flat lenses and applications

Optical tweezers: Trap and study single cells or biomolecules

Optogenetics for studies of neuronal networks underlying behavior

Super-resolution imaging – including the latest progress that allows for time-dependent, dynamical studies

Two-photon and three-photon microscopy for brain imaging

Polaritons and vibrational polaritons – entangled states of light and molecules in a cavity. Applications for the control of energy levels of molecules and the energy landscape for chemical reactions, opening up new chemical reaction paths. Could be important in applications for making the important chemical industry more sustainable with lower CO_2 emissions.

Cryo-EM for structure determination of soft matter and biomolecules.