Applied Physics 216
— Electromagnetic Interactions with Matter —
Professor: Donhee Ham

Spring 2017, Harvard University
Wednesday and Friday, 10:30 am – 12:00 pm, Pierce Rm 100F

Teaching Staffs

Professor: Donhee Ham, PhD. Gordon McKay Professor of Applied Physics and EE
— Maxwell-Dworkin 131, 6-9451, donhee@seas.harvard.edu
— http://ham.seas.harvard.edu
— Office hours: TBD

Teaching Fellow: TBD

Course Description

The first half of the course will cover the interaction of quantized atoms with electromagnetic fields, introducing a number of basic concepts such as coherent Rabi transitions vs. rate-equation dynamics, stimulated & spontaneous transitions, and energy & phase relaxations. These will be then used to study a range of applications of atom-field interactions, such as nuclear magnetic resonance, molecular beam and paramagnetic masers, passive and active atomic clocks, dynamic nuclear polarization, pulse sequence techniques to coherently manipulate atomic quantum states, and laser oscillators with applications. We will also touch upon the interaction of quantized atoms with quantized fields, discussing the atom+photon (Jaynes-Cummings) Hamiltonian, dressed states, and cavity quantum electrodynamics. The second half will cover the classical interaction of electromagnetic fields with matter, with special attentions to collective electrodynamics—in particular, magnetohydrodynamics and plasma physics—with applications in astrophysics, space physics, and Bloch electrons in crystalline solids. The detailed list of topics is in the next page.

Prerequisite

Undergraduate-level quantum mechanics and electromagnetism.

Materials

Throughout the semester I will hand out lecture notes as main materials for the course. There is no textbook.

Grading

1. Homework: 100%.

2. Late grading policy: Homework will be handed out in class on Friday, due 10:20am next Friday with a grace period of 10 minutes sharp under through the door of my office (Maxwell-Dworkin Room 131). Late work will be reduced 50% per week. There is **no exception** to this rule, other than University-established emergency cases (a letter from authorized official is required). This late grading policy will be strictly enforced for fairness to all.

3. Cooperation policy: You should work on problems marked with "no collaboration" on your own, without discussing any aspect of them with other students; in other words, you should treat these problems strictly as take-home exam problems. For the rest problems, cooperation is permitted, but you should turn in your own solution — You can discuss these problems with other students taking the course, but final solutions should not be exchanged. You should make it sure that you understand the solution you turn in, and write up the solution in your own words. Basic guideline is not to take undue advantage of any other student.

Topics

Sec. 1. Atom-field interactions.

1. Atoms with electric and magnetic dipolar transitions.

2. Coherent atom-field interaction — Rabi oscillation.

3. Relaxation processes (1) — T_1 and T_2 relaxations; spontaneous decay vs. T_1 relaxation; Einstein theory of thermal noise and equilibrium.

4. Rabi regime vs. rate-equation regime; Bloch-Feynman equation; saturation.

5. Relaxation processes (2) — Homogeneous vs. inhomogeneous broadening.

6. Relaxation processes (3) — Overhauser effect and dynamic nuclear polarization.

7. Applications of coherent atom-field interaction:

- Molecular beam masers.
- Ramsey spectroscopy.
- Active and passive atomic clocks.
- Nuclear magnetic resonance spectroscopy.
- Pulse sequence techniques — coherent manipulation of atomic quantum states.

8. Jaynes-Cummings Hamiltonian; dressed states; cavity QED.

9. Applications of rate-equation regime dynamics in lasers — 1) Laser oscillation; 2) multi-mode lasing & mode locking; 3) spatial and spectral hole burning; and 4) laser stabilization techniques.

Sec. 2. Collective electrodynamics.

1. Introduction to magnetohydrodynamics.

— Hydromagnetic flows; Alfv́en waves; dynamos; magnetosonic waves.

2. Introduction to waves and particle kinetics in cold and warm plasmas.

— Langmuir waves, ion-acoustic waves, Vlasov equation, Landau damping, and particle trapping.

3. Parametric instabilities in plasma.

4. Solitons and shocks in ion-acoustic dynamics in plasma.

5. Korteweg de Vries (KdV) equation and inverse-scattering transform.

6. Plasma dynamics of Bloch electrons in crystalline solids.

7. Connection to quantum liquids.