December 29, 2014

Applied Physics – M.Sc. exam guidelines

The Applied Physics department ascribes a great deal of importance to the M.Sc. degree and to the final Master exam. The department seeks to educate and guide excellent M.Sc. graduates, who have completed high-level research as described in their thesis, and acquired a full, broad knowledge and understanding of the applied physics curriculum. Such training is designed to place the department's graduates in leading positions, both in industry and in academia.

In order to provide a clear, unified structure to the final master exam, the following guidelines are presented:

1. The exam will be conducted orally, in the presence of the thesis advisor and two additional faculty members.
2. The duration of the exam will not exceed 2 hours.
3. Students are requested not to provide refreshments.
4. The exam will include a (nominally) 20 minute presentation of the research (accompanied by related questions by the examiners), followed by a general questions sessions.
5. The general questions will be based on the provided list of questions (see below). The examiners will use this list as a framework for questions, but will not be limited to it.
6. In order to slightly ease the stressful exam event, the student will be notified 2 hours in advance of 2 questions which will be raised during the exam (chosen randomly). Note that these questions can be elaborated on, and additional questions may be asked as well.

Exam questions

General:

1. How does a charged particle move in magnetic and electric fields, in the classical and in the quantum regimes? What approximation is made in the classical limit, and what are the energy levels and the phase acquired by the particle in the quantum limit?
2. Describe the similarities and differences between spontaneous and stimulated emissions. How would you explain spontaneous emission of a single photon into vacuum?
3. How would the energy levels and behavior of a material will change as its dimensions are reduced (2D, 1D, 0D)?
4. Describe methods for solving problems that do not have an analytical solution. What are the advantages and disadvantages of the different methods?
5. What classical and quantum effects occur as a particle traverses a potential barrier?
6. Describe scattering processes in the classical and in the quantum world, and relevant approaches for calculating these processes in the two limits.
7. Describe the different scattering processes of electromagnetic radiation from matter that you know. What determines which scattering process dominates?
8. What types of interferometers are you familiar with, and what are their applications? How does an interferometer work? If there is no energy transfer to a specific port of an interferometer, where does the energy go to and what is the underlying mechanism? Plot the output of a white-light Michelson interferometer as a function of its arm length.
9. What is a spectrum of a signal, and what are the techniques for measuring it? What will determine the measurement resolution?
10. Describe various types of noise one encounters in a measurement. What are the noise sources, and how can their effect be suppressed?
11. How does a lock-in amplifier work? What are the advantages of a lock-in amplifier compared to other types of amplifier?
12. What is the origin of the exponential term in the thermal Boltzmann distribution?
13. What is plasma? What is the plasma frequency? Describe Drude's model. How is conductance affected by a magnetic field?
14. How would you measure the angular size of a distant star? Describe a relevant experimental setup.
15. Explain the operating principle of a PN junction. Describe the current and charge flow in forward and reverse bias and the relevant IV curve. How does the junction react to illumination with photons? What are the working conditions for creating a detector from the PN junction and for creating a solar cell?
16. What is Fermi's Golden Rule? What is the dipole approximation? What are forbidden lines and how can they be measured?
17. A Helium balloon is attached to the floor of a train car, and a weight is attached to its ceiling. The train is accelerating with an acceleration a. Draw the train car, balloon and weight in these conditions. How is this related to solid-state phenomena?
18. What is irreversible dynamics? Where is it encountered? How is this described in the context of quantum mechanics?

19. Identify the difference between classical and quantum behavior in non-interacting systems?
20. What are classical and quantum correlations?
21. What is the diffraction limit? Given a single point emitter, how well can one determine its center?
22. How do fermions and bosons differ? Give an example of a fundamental natural law which is directly derived from the nature of fermions.
23. Explain the difference between micro-canonical, canonical and grand-canonical ensembles.
24. What is the difference between equilibrium and steady-state (quasi-equilibrium) from a statistical mechanics point of view?
25. A small amount of water of mass m = 50 g in a container at temperature T = 273 K is places inside a vacuum chamber which evacuated rapidly. As a result, part of the water freezes and becomes ice and the rest becomes vapor. What amount of water initially transforms into ice? The latent heat of fusion (ice/water) qi = 80 cal/g, and the latent heat of vaporization (water/vapor) qv = 540 cal/g.
26. How does a mass spectrometer work, and what are its uses?
27. What would be a method to obtain the vibrational spectrum of e.g. O2? What is the basis of this choice? Describe the components and instrumental method used to accomplish this.
28. If one has a very large polymer molecule made of carbon and hydrogen and the same molecule made of carbon and deuterium which will have the larger dimension.
29. In a solid, what is the absorption spectrum (from zero energy to infinity)? Discuss the relevant degrees of freedom.
30. Describe the basic electronic energy structure in a solid. What are Bloch oscillations, and how does electronic transport emerge?
31. What kind of optical effects do you know that couple to mechanical forces?

Micro-electronics:

1. Describe the structure and operation of FET/npn transistors.
2. Explain the operating principle of MOS transistors.
3. What are the limitations in device miniaturization? In the process of scaling down the device dimensions (Moore's law), how is the conflict between the need to move to shorter wavelengths in the lithography process and the resulting reduction in focal depth resolved?
4. Describe design principles for ultrafast devices.
5. Describe the operating principle of a phased array. What defines directivity and angular width?
6. Describe various types of microwave antennas. How does a horn antenna work? How can it create polarized radiation?
7. Describe the design principles of transmission lines. Define impedance matching, relevant S-parameters, etc. What determines the losses and the frequency response?
8. What are the scaling laws for dense transistors arrays on chip, and what is the main loss mechanism?
9. What is the difference between MOS and CMOS?

10. Describe the operating principles and differences between CCD and CMOS image sensors.
11. Describe the fabrication processes of Si-based integrated circuits.
12. Compare between the various semiconductor electronic materials: Si, GaAs, InP.
13. Describe ways to increase the electron and hole mobilities in Si for high-speed devices.

Opto-electronics:

1. Describe devices for electro-optic modulation of light and their principle of operation.
2. What are the symmetry requirements for electro-optic crystals? What other physical phenomena have similar/related symmetry requirements? What is the requirement of a material non-linearity in order to obtain a DC field out of a light beam?
3. Describe the physics behind the semiconductor LED and laser.
4. Describe the phenomena of Bragg diffraction and its applications.
5. Describe the operating principle of wave plates, and their uses in optical systems.
6. What are the differences in imaging with coherent and incoherent light?
7. Spatial Fourier transform: optical arrangements, scaling rules, and uses.
8. Describe different techniques for light detection, their operating principles, and operating wavelength regimes.
9. What are optical waveguides? Describe their main properties.
10. Describe in detail the operation of a certain realization of a laser.
11. What is the spectral width of a short-pulse laser and what does it depend on? What is the role of optical non-linearity in a short-pulse laser? Describe different non-linear mechanisms used in short-pulse lasers.
12. Describe ways to characterize the output of lasers (CW/pulsed).
13. Describe surface plasmons, their propagation, and their loss mechanism. How are they excited?