Handbook for the UNC Charlotte Optics Ph.D. qualifying exam

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Introduction

The Optics Ph.D. qualifying exam is a necessary step in the process of becoming a Ph.D. candidate and being cleared to do work towards one’s Ph.D. degree. It can be the source of much anxiety for those students who anticipate taking it, feelings exacerbated by not knowing exactly what to expect on the exam and how to prepare for it. With this in mind, this guide is intended to explain the qualifying exam process and provide a starting point in preparing for it, including tips on essential topics of study and strategies for successful test-taking.

Structure of the qualifying exam

The purpose of the qualifying exam is to test the student’s knowledge of the material learned in the core classes, and to determine that the student has a sufficiently comprehensive understanding and synthesis of optical concepts to justify his or her pursuit of a doctorate. The core classes are:

- OPTI 8101: Mathematical Methods of Optical Science & Engineering
- OPTI 8102: Principles of Geometrical & Physical Optics
- OPTI 8105: Optical Properties of Materials
- OPTI 8104: Electromagnetic Waves
- OPTI 8211: Introduction to Modern Optics

The qualifying exam takes place in two parts: a 3-hour written exam, followed approximately a week later by an oral exam that will typically take 50 minutes.

The written exam consists of 3 sets of 3 questions each, and the students are required to answer one of the three questions in each set:

- Set A: These are questions related to topics learned in a single core class, though they may bring together multiple ideas from a single class.
- Set B: These are more open-ended questions that require students to synthesize ideas from multiple core classes.
- Set C: These questions are widely open-ended questions that will require students to apply their complete optical knowledge to situations and applications that lie outside of core studies.
An example of each of a question from each set is attached to the end of this document.

In this age where literally everything and anything can be read online or stored on a smartphone or smart calculator, such devices are not allowed to be brought into the exam. However, scientific calculators will be provided for crunching numbers during the test; the TI-30XA is depicted below, and students wishing to familiarize themselves with the device before the exam can borrow one from the qualifying exam committee chairperson.

The oral exam will be scheduled roughly 1 week after the written exam. The oral exam is an opportunity for the committee to follow-up on the students’ answers to the written portion of the exam and to further assess their scientific abilities. Each student will answer questions before the qualifying exam committee for a period of up to 50 minutes; students will be notified of their oral exam times in advance of the day and will be expected to be present at least a half-hour in advance.

The oral exam will typically follow the following pattern of questioning:

- Research questions. The student will be asked to explain their current research project. If the student is not currently working with a research group, they can discuss a research topic that interests them.
- Exam questions. The student will be asked to explain or elaborate upon answers to their written exam questions and potentially on any other questions that were posed on the written exam. (During the week before the oral exam, students are encouraged to research and check their own answers to the written questions!)
- Additional questions. Other optics-based questions may be asked, to further assess the strength of the candidate’s knowledge, that are not based directly on the exam.

**Qualifying exam results**

The qualifying exam committee will meet during the week following the oral exams and evaluate the outcome; students should receive letters in their department mailboxes soon afterwards with the results.
Students who do not pass the exam the first time may be allowed to take it a second time; failure of the qualifying exam a second time results in removal from the Ph.D. program, with no exceptions.

**Studying for the exam**

The qualifying exam is designed to assess the students’ ability to successfully pursue and accomplish Ph.D.-quality research, and requires not only a familiarity of the core class material, but a deeper understanding of the physics involved and an ability to connect concepts from different courses and/or fields of study. All students should treat the exam as a serious challenge and devise a study plan for it in the weeks preceding it.

Any material in the core classes is “fair game” for discussion in the qualifying exam. A list of essential topics for each course, i.e. “the least you need to know”, is presented below as a starting point for study (mostly taken from syllabi/course descriptions, but it is helpful to have it all in one place!):

**OPTI 8101: Mathematical Methods of Optical Science & Engineering**

- Vector calculus
- Matrix methods/linear algebra
- Fourier series
- Complex analysis (including evaluation of definite integrals)
- Fourier transforms

**OPTI 8102: Principles of Geometrical & Physical Optics**

- Ray analysis of common optical elements
- Reflection and refraction at plane and spherical surfaces
- Lensmaker’s equation
- Diffraction
- Interference
- Coherence
- Optics of thin films

**OPTI 8104: Electromagnetic Waves**

- Maxwell’s equations, constitutive relations, and wave equations
- Poynting’s theorem and momentum conservation
- Wave propagation in dielectric, lossy, anisotropic and dispersive media
- Polarization and Jones vectors
- Electromagnetic potentials
- Waves at interfaces
OPTI 8105: Optical Properties of Materials

- Photophysical and photochemical processes in materials
- Linear and nonlinear optical properties of materials
- Optical properties of semiconductors and crystals
- Fluorescence of organic and inorganic materials

OPTI 8211: Introduction to Modern Optics

- Photonic crystals
- Guided-wave optics
- Fiber optics
- Resonator optics
- Electro-optics
- Introduction to nonlinear optics

Some other tips and suggestions for preparing for and taking the qualifying exam are listed below:

- **Study early.** A lot of material is covered in the core courses, and it can take time and multiple readings to really understand and internalize all the information learned. It is suggested that students set up a leisurely schedule to review notes, texts, and homework over the course of several weeks before the exam, probably between two weeks and a month’s time.

- **Read the whole test.** The students will have three hours to write and complete three problems. Doing the math, this amounts to an hour to complete each problem – there is plenty of time! Students are encouraged to read the test in its entirety, all problems in all groups, and spend a few minutes thinking about which problems to answer and how to most clearly answer them before writing.

- **Reexamine problems.** With the amount of time available, many students will have finished writing well in advance of the end of the testing period. These students are encouraged to take advantage of the extra time to reread their answers and revise them for clarity and to fix silly mistakes.

- **A picture is worth a thousand words.** Illustrations help! In almost all problems, drawing a picture of the experimental or physical setup can make it easier for both the student and the graders to understand what is going on.

- **Check your answers for the oral exam.** As noted earlier, students are encouraged to double-check their written exam answers during the week before the oral exam using any material available. The oral exam gives students a great opportunity to correct their own mistakes.

**Sample problems**

The next page provides examples of problems that were used on the Spring 2010 written exam.
A1. Define and describe the main optical properties of materials: absorption, transmission, reflection, scattering, photoluminescence and fluorescence, and stimulated emission. What are the main laws that describe absorption and reflection? How are these optical phenomena related to the electronic band structure of the material? What transmission spectrum do you expect in the visible regime at room temperature for silicon (indirect band gap semiconductor with $E_{g}>...$), gallium arsenide (direct band gap semiconductor with $E_{g}>...$), silica (wide band gap dielectric with $E_{g}>...$), and aluminum. Make qualitative sketches of the transmission spectra which you expect from thin slabs (say 100 micron thick) of these materials.

A3. Describe a fiber-optic sensor to be used somewhere in a kitchen. What parameter will your sensor detect? On what physical principle will your sensor be based? How does it work? Describe the components needed for a complete stand-alone sensor. Your description should include a list of the measurement specifications and an estimate of the sensitivity. What will limit the sensitivity and how might this be improved? Are there practical considerations that will impact the design? Use equations to support your answers wherever you can.

B1. Describe the interference pattern seen from the traditional Young’s double slit experiment. How does the diffraction pattern depend on the slit width, spacing and distance of the observing plane from the two slits? Explain what happens to the diffraction pattern as i) the source bandwidth increases and ii) the source size increases. Use formulae to help clarify your answers whenever you can.

B3. Compare and contrast a microscope and a telescope. Consider things like the basic optical design, image property and quality requirements, and other possible application-specific requirements.

C1. State what information is encoded in a hologram and discuss what conditions/assumptions underly the explanation of how one makes and reconstructs a hologram. Use a mathematical framework to help clarify your answer.

C3. Describe the basic principle of lasers. Examples of the kinds of questions you may want to address are i) Which material (electronic) properties are essential for achieving lasing? ii) Which optical properties are essential for achieving lasing? iii) What is population inversion? iv) What is stimulated emission? v) What are requirements to the system of electronic levels (if any) in order to provide the population inversion? vi) What is the lasing threshold? vii) What defines the spectral separation between the longitudinal modes of the resonator? viii) What is the difference between the solid state and semiconductor laser?