A First Course in Laboratory Optics

An optics experiment is the product of intricate planning and imagination, best learned through practice. Bringing forth the creative side of experimental physics through optics, this book introduces its readers to the fundamentals of optical design through eight key experiments. The book includes several topics to support readers preparing to enter industrial or academic research laboratories. Optical sources, model testing and fitting, noise, geometric optics, optical processes such as diffraction, interference, polarization, and optical cavities are just some of the key topics included. Coding tutorials are provided in the book and online to further develop readers' experience with design and experimental analysis. This guide is an invaluable introduction to the creative and explorative world of laboratory optics.

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Preface

The aim of this book is to prepare you for work in a field requiring the use of laboratory optics. Through the experiments, you will build and investigate several of the most important fundamental optical systems. While each experiment is preceded by several pages of theory, this book is not intended to be a comprehensive textbook about optics. There are already many excellent such texts. The idea here is to learn optics by *doing optics* with theory as a backdrop. The theory is presented "purposefully" in order to support the experiments and covers the core elements of each topic, enough for you to really understand what's going on. The idea is that after reading this book and doing the experiments, you'll be able to walk into an industrial or academic research lab and at least know how to get started!

The book has one experiment per chapter (except for the introductory first chapter). Each experiment should take about eight hours to complete. You're given the goals of each experiment and just enough information to get started on each part. After that it's up to you to figure out how to proceed based on the theory and other information you may gather. I've tried hard to avoid giving you "cookbook style" experiments so that you have the opportunity to do your own creative experimental design work. As a result, you'll need to give yourself time to investigate different approaches to a problem. Be careful not to get too deep into an experiment before checking whether your approach is yielding sensible data. Before starting an experiment, make sure you study the relevant chapter(s), do some of the problems and make a preliminary design/plan for each section of the experiment. If you can, visit the lab during the design phase and look at the equipment you'll be using. The experiments are all fairly open-ended. Extending them to include follow-on investigations is always possible and may be expected. A few ideas for follow-on work are included at the end of each experiment but you will need to tailor your investigations to the equipment available/obtainable. In addition to the equipment listed in the experiments, you will need access to an optics bench (either a sizable optical breadboard or an optical table), a set of mirrors and lenses, and a selection of mounting hardware for these and other optical components. Most of the experiments rely on using a computer with Matlab, Python, and so on, for analysis tasks. A small selection of Matlab and Python 3 code for planning and analysis tasks is provided in the appendixes. The Matlab code has also been tested in Octave. While the code can be used verbatim, it's primarily intended as a framework upon which to expand. The Matlab and Python versions of the code are available to download at https://github.com/CambridgeUniversityPress/FirstCourseLaboratoryOptics. Additional support materials are also placed there and errata as they arise.

It's worth mentioning the word "intensity." In much of physics, intensity is synonymous with energy flux density. However, in the subfield of optics known as radiometry,

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"intensity" is sometimes used as a shorthand for "radiant intensity," which has a different meaning. This causes confusion and I try to avoid using the unqualified term "intensity" altogether. I use the term *irradiance* for energy flux density associated with light, that is, "power per unit area perpendicular to the direction of the light's travel." I generally use the letter I for irradiance.

Instructors

I recommend using the book as part of a laboratory-based course in optics with co-requisite lectures. Advanced students will be able to do the labs without formal lectures and the relevant theory sections can be assigned for self-study. In order to reduce the amount of equipment needed for a class, it is helpful to run three or four experiments simultaneously. That way, only two or three setups are required for each experiment. I recommend assigning the relevant theory sections and several exercises as preparation for each experiment. The exercises vary widely in difficulty and some rely on moderate coding ability. Although the number of exercises provided is modest, I hope it is possible to find a mixture that suits the student level and available time.

The text is aimed at upper-level undergraduates and beginning graduate students. The book assumes preparation in vector calculus and at least one physics laboratory course. Some prior programming experience is helpful but an introduction to Matlab and Python is also included in Appendix A. Scientists in other fields embarking on experiments requiring a significant optical component should also find the text useful. By and large, the theory is covered in a survey mode. However, the propagation of laser beams through optics chains is so central to experiments in optics that it is covered more thoroughly. Specialty topics like nonlinear optics, laser cooling, advanced imaging, holography, scattering theory, and so on, are not addressed. The notation and theory development largely follows that of popular optics and laser books, such as *Optics* (Hecht 2017); *Principles of Physical Optics* (Bennett 2008); *Introduction to Modern Optics* (Fowles 1989); *Principles of Lasers* (Svelto 2010); and *Introduction to Optics* (Pedrotti 2007). I've found all of these books to be good supporting texts for the laboratory-based optics class that I teach. As for more advanced texts, I recommend *Lasers* (Siegman 1986); *Photonics: Optical Electronics in Modern Communications* (Yariv 2007); and of course Born and Wolf's *Principles of Optics* (Born and Wolf 2019). There are two other books on laboratory optics I recommend as complementary reading to this text. They are *An Introduction to Practical Laboratory Optics* (James 2014), and *Laboratory Optics: A Practical Guide to Working in an Optics Lab* (Beyersdorf 2014), which is a multimedia book.

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This book was motivated by a decade of teaching laboratory optics to third- and fourth-year undergraduate students. I'm grateful to the students who came through my course and tried hard to get their experiments to work even when the instructions were impossibly

vague. Thanks to them, I have settled on what I hope is "just the right amount" of information to give students who are embarking on an experiment. I owe thanks to the students who pointed out significant manuscript errors and/or gave constructive feedback about the course and/or manuscript content. They include Harsh Menon, Billy Nollet, Aaron and Amy Rose, Marina Koepke, Calley Tinsman, Ashley Elliot, and Brennan Moore. I have surely forgotten some contributions, for which I apologize. Thanks to Professor Darrel Smith, who as the department chair encouraged me to create a serious laboratory optics course for upper-level undergraduates and allowed me a free hand in its design. Thanks to my mother, Anna Garner, for carefully proofreading the manuscript. Special thanks to my wife, Ellie Gretarsson, for testing experiments, reading the manuscript, and giving invaluable feedback at all stages.