FUNDAMENTALS OF OPTICS

An Introductory Course

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Translated from the Spanish by
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SPIE.

This book is dedicated to my wife, Janneth, and my children,
Ana Catalina, María Isabel, and Daniel.

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Translator's Preface

This translation was made from the first edition of the book *Fundamentos de Óptica*, in Spanish, written by Professor Yobani Mejía-Barbosa and published in 2021 by the Universidad Nacional de Colombia (UNAL). While the English translation retains the originality of Mejía-Barbosa's writing and the technical content remains unchanged, a literal translation was not always possible due to the inability of English to capture some of the intricate nuances of the Spanish language and the ways in which Spanish allows for the expression of some sentences in a simplified manner with the use of syntactic and contextual twists. In such cases, the English translation opts for alternative ways of expressing the same ideas without losing their original meaning. The translator has worked along with the author (Prof. Mejía-Barbosa), SPIE editors, and volunteer reviewers to ensure that the final translation of this book is fluent and adopts the standard technical terminology (in English) currently used by the optics community.

This translation has also benefited from the fact that, coincidentally, the translator of this book (me) was introduced to the field of optics with the material presented through the pages of this book, taught directly by Prof. Mejía-Barbosa, when this book did not even exist in its Spanish version. That was in 2005, when I was a student in the Physics Department of UNAL at Bogotá and decided to take an elective course called Fundamentos de Óptica. I fell in love with optics through that course and have since decided to pursue a career in the field, specifically in applied optics. If I had to say today which lectures, from all the classes I have taken so far, have had the greatest influence on my professional life, they would be the ones from the Fundamentals of Optics course taught by Prof. Mejía-Barbosa at UNAL, which are included in this book. In addition to representing an important turn in my career toward applied sciences, taking me away from a strongly theoretical emphasis that dominates the UNAL physics program, Fundamentos de Óptica equipped me with a basic understanding of optics that I needed in order to pursue graduate studies at the College of Optics and Photonics of the University of Central Florida and then earn a Ph.D. in Optical Science and Engineering from the University of North Carolina at Charlotte (UNCC).

Optics is a field that is filled with a wide range of multidisciplinary career opportunities. By attending the meetings sponsored by SPIE, the international society for optics and photonics, one can realize how high the current demand in the job market is for optical engineers and how much people with knowledge of optical science are appreciated. For me, learning optics has fueled my career and led to my employment at world-renowned optical companies, at Nikon from 2015 to 2019, and most recently, since 2019, at ZEISS. The field of applied optics has enriched my life in a way that I could never have predicted when I was younger. The Fundamentals of Optics course that I took at UNAL laid the foundation. I am forever grateful. This is the main reason why I volunteered to translate *Fundamentos de Óptica* from Spanish to English. I would like to see Prof. Mejía-Barbosa's book reach wider audiences and help many students from around the world, not just from Spanish-speaking countries, with the study of optics.

This book presents a simple but elegant introduction to classical optics that focuses primarily on establishing fundamental concepts that students exposed to the field of optics for the first time need to learn. With examples demonstrating the use of optics in a wide range of practical applications, it reflects the pedagogical approach used by Prof. Mejía-Barbosa to teach his Fundamentals of Optics course at UNAL. This book will prove useful for college students, and even graduate students, of physics, optical science, optical engineering, and any other related science or engineering discipline that deals with optics at some level.

I would like to express my gratitude to Prof. Mejía-Barbosa, UNAL, and SPIE for giving me the opportunity to translate this book. In addition, I would like to express my appreciation to Prof. Glenn D. Boreman of the University of North Carolina at Charlotte and editors (Alexandra MacWade and Patrick Franzen) of SPIE who provided valuable feedback on previous versions of this translation, thus contributing to its improvement.

Herminso Villarraga-Gómez
Ann Arbor, Michigan, USA
October 3, 2022

Author's Preface

This book presents lectures on classical optics, based on the Fundamentals of Optics course that I have been teaching for 12 years in the Physics Department of the Universidad Nacional de Colombia (UNAL) at Bogotá. At first, I occasionally taught these lectures as an elective course* in the Physics undergraduate program. Beginning in the fall of 2009 through the fall of 2017, I taught the same lectures each semester as an optative regular course** of four hours per week in a 16-week semester format. The content of the course was based on my own research experience in the field of applied optics, which was enriched at the Centro de Investigaciones en Óptica, México, where I pursued my Ph.D. in Optics (1998–2001). This book comprises four chapters: Geometrical Optics, Polarization, Interference, and Diffraction, each consisting of several sections. Each section corresponds to a lecture of two hours. The book includes 30 sections and six appendices.

I have written this book to provide students of physics, optics, and engineering with a basic understanding of the main topics related to geometrical and physical optics. For further reading on classical optics, students may consult other well-known textbooks such as *Fundamentals of Optics, Fourth Edition*, by Jenkins and White (McGraw-Hill Education, 2001), *Optics, Fifth Edition*, by Hecht (Pearson, 2016), and *Principles of Optics, Sixth Edition*, by Born and Wolf (Pergamon Press, 1980).

I would like to thank UNAL for granting me a sabbatical year (February 2018 to February 2019), during which I was able to write this book.

Yobani Mejía-Barbosa
Bogotá, D. C., Colombia
March 2021

*A course that is not specifically designated as part of a degree requirement, but rather offered by a professor for students who want to take it.

**A course that is included in a curriculum but noncompulsory. Students select such a course from a limited set of specialized subjects.

Introduction

In the current state of the art, optics can be defined as a science that studies the nature of light (visible range of the electromagnetic spectrum), its propagation, and its interaction with matter. The origins of optics are closely related to studies of vision and the propagation of light. Alhazen (965–1040) compared the image formation in the human eye with the image formation in a camera obscura (a closed box with a small hole in one of its walls), which he himself built for the first time. The camera obscura also makes it possible to observe the rectilinear propagation of light (light rays). Centuries ago, in his treatise on optics, Euclid (325–265 BCE) presented a geometrical description of light propagation. Following one of Euclid's postulates (a straight line segment can be drawn joining any two points), to go from one point to another in a homogeneous medium, light follows the straight line that connects these points; i.e., light follows the shortest geometrical path. This is a preliminary version of Fermat's principle of the propagation of light, which can be used to derive the laws of reflection and refraction of light. In the seventeenth century, Huygens proposed a new description for the propagation of light, a preliminary version of the wave theory of light. Huygens concluded that light slows down as it enters denser media and explained reflection and refraction with his wave theory. In the following century, Fresnel added wave interference to Huygens' theory, and with this, he explained diffraction phenomena. Currently, both the geometrical (in terms of rays) and wave-like behaviors are accepted models for describing the propagation of light. Whereas the ray version is better suited for the design of optical instruments, the wave version is more appropriate for the study of image quality.[*]

[*]A look at the origins of optics up to the nineteenth century can be found in Olivier Darrigol's book, *A History of Optics from Greek Antiquity to the Nineteenth Century* (Oxford University Press, 2012).