Second Edition

Introduction to Classical and Modern Optics

Jurgen R. Meyer-Arendt, M.D.

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Preface

THE PURPOSE AND EMPHASIS of this completely revised second edition remain the same: to provide a clear and readable *Introduction to Classical and Modern Optics*. Its level is intermediate, for advanced undergraduates and for a course spanning two semesters or the equivalent.

I have made the text as self-contained as practical, set out the motivation for each step, and avoided shortcuts of the it-can-be-shown-that type. Also, I have used extensive cross-references within the text to make it useful as a reference tool, after formal classwork has ended.

Compared with the first edition, there are numerous major changes. I have adopted the rational, *Cartesian sign convention*. This convention, long used in ophthalmic optics but until recently somewhat slighted in physics, is essential for the concept of *vergence* and is mandatory in any *lens design*. This dual connection identifies the two groups of readers to which this *Introduction to Optics* is addressed in particular: those interested in the *scientific and engineering applications of optics* and those preparing for the *ophthalmic professions*.

Another useful innovation is that virtually every chapter on *geometric optics* opens with the same triplet combination of lenses. Each time, the light progresses a little further, showing the logic in the sequence of topics:

from the propagation of light, to refraction, to aberrations, to the design of complex systems.

Likewise, every chapter on *physical optics* has been rewritten, most extensively the chapters on interference, diffraction, diffraction gratings, radiometry, absorption, and lasers. The theory of the Fabry–Perot interferometer, light scattering, and atomic spectra are derived step by step. Clerk Maxwell's equations and Fresnel's equations, discussed in detail, are now placed together in one chapter. Electron optics has been deleted.

As before, ample space has been allocated to classical topics such as thin lenses, aberrations, lens systems, and polarization. But modern subjects, such as the use of matrix methods in lens design, catadioptric systems, gradient-index lenses, fiber waveguides, integrated optics, multilayer antireflection coatings, Fourier transform spectroscopy, transfer functions, optical data processing, holography, and of course lasers and laser safety, are also presented in reasonable detail. Radiometry and photometry are discussed in the most recently adopted terminology. Relativistic optics, likely to play an important part in celestial navigation, is fun to read, aside from its utilitarian aspect.

As a *prerequisite,* all that is needed is a good background in general physics and a working knowledge of how to use a hand-held calculator (preferably including inverse trigonometric and exponential functions). A concurrent course in calculus is desirable though not essential.

Numerous worked-out *examples,* from penumbras to relativistic reflection, are interspersed throughout the text. *Problems,* ranging from easy to difficult, are found at the end of each chapter, following the *Suggestions for Further Reading*. Most of the examples and problems are new. All have been use-tested and modified where needed. (Answers to the odd-numbered problems are found in the back of the book.) None of the problems is intended as "busy work"; all are realistic and apply to practical situations; some, in fact, were drawn from consulting work I do from time to time. *Lecture demonstrations* are referred to on occasion. A great many *historical footnotes* have been included to reveal the human side of optics' great masters, adding color to the description of their accomplishments. (For the statistical-minded, there are 28 chapters, 368 illustrations, 197 examples, 510 problems, 134 historical footnotes, and 148 Suggestions for Further Reading, not counting the references.)

I have enjoyed writing this new edition. It took hundreds of hours of lecturing. It also took the patience of a great many individuals, questioning, challenging, attentive, and at times not so attentive, for me to discover —often by trial and error—how to get a concept across. How do I best present the idea of principal planes, the use of Cornu's spiral, the Poincaré sphere, the theory of stimulated emission? How do I present the fantastically wide field of optics at a reasonable level and within a reasonable length of time? There is no final answer, just steps of successive improvement.

Acknowledgments

Many of my colleagues have helped, in ways large and small, with the preparation and revision of the manuscript. Much of my appreciation goes to my students. But comments, both laudatory and critical, have come also from readers I have never met. Helpful suggestions were made in particular by R. Barer, Denis R. Holmes, Ernest V. Loewenstein, D. J. Lovell, Robin G. Simpson, and C. Michael Smith. Other help came from librarians Nancy Blase and Laurel Gregory, from physicians Henry B. Garrison and Albert Starr, from Susan R. Palmer and R. Michael McClung who once more checked the typescript, and from Patricia R. Wakeling, Managing Editor of *Applied Optics*. I also wish to thank Doug Humphrey, Kathleen Lafferty, and the editorial and production staff of Prentice-Hall, Inc. Most of all, my thanks and appreciation go to Thomas B. Greenslade, Jr., of Kenyon College, Gambier, Ohio, one of the reviewers of the manuscript. Without his painstaking attention to detail, and his sometimes caustic remarks, my manuscript would never have become the book it now is.

Jurgen R. Meyer-Arendt

Contents

Introduction

I BEGIN THIS INTRODUCTION TO OPTICS by presenting right away a complex practical problem. Look at Figure 0-1. This is a combination of lenses, a lens *system*, containing a positive lens in front (on the left), a negative lens behind it, and another positive lens in the back (on the right). These lenses have certain surface characteristics, they have certain thicknesses, and they are certain distances apart. Probably, they are made out of different types of glass. By choosing these parameters correctly, we can obtain a system of superior performance. In fact, the system shown is the basis for some of the best, and best known, photographic camera lenses.

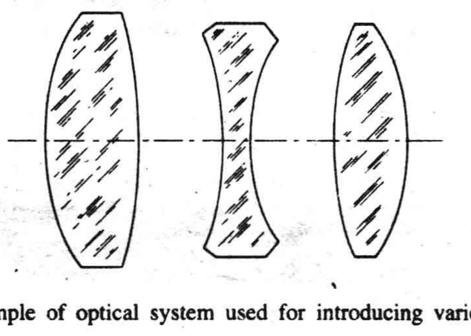

Figure 0-1 Example of optical system used for introducing various aspects of geometric optics.

How does the system work? Why are the lenses of the type shown preferable to other lenses? Why is this system superior to other systems? These are questions that we are not yet ready to answer. We will use this system as an example and a guide to introduce many of the concepts of optics.

More specifically, we will use this model to introduce *geometric optics*. Geometric optics is that part of optics where the wave nature of light can be neglected. *Physical optics* is more inclusive. In fact, image formation can be fully understood only by considering *wave optics* and by considering optical *transformations*. This is a very modern concept, fundamental to optical data processing, pattern recognition, and holography. In *quantum optics* we discuss spectra, absorption, and the ubiquitous laser. *Relativistic optics* points to the future.

Some phenomena in optics are easy to see. Others are very subtle. Tonight, look at a street lamp through the fabric of an open umbrella. You

Figure 0-2 Artist's conception of a star. Stained-glass window in St. John's Church, Herford, Germany, fourteenth centruy.

will see light *fans*, extending in various directions. These are due to *diffraction*.

Or look at a fairly bright star (without the umbrella). You may see faint light fans that seem to come right out of the star. In reality, they do not; the effect is due to your eye. Ordinarily, the pupil of the eye is perfectly round and no such fans are seen. But under certain conditions, the circumference of the pupil has a few straight segments and these cause the fans. And so, in the art of all ages, stars have traditionally been represented as objects with a multitude of points. However, a star with an odd number of points, as shown in Figure 0-2, is wave-optically impossible because the light fans must, by necessity, always occur in pairs.

This brief introduction to some areas of optics may have shown you that optics is a field of science that is lucid, logical, challenging, and beautiful. Most of our appreciation of the outside world—nature, art—comes to us through light. We will now proceed to discuss its many aspects in the way I have outlined.

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