

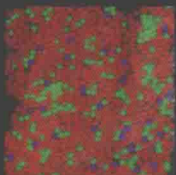
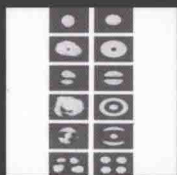
Third Edition

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HANDBOOK OF OPTICS

Volume III

Vision and Vision Optics



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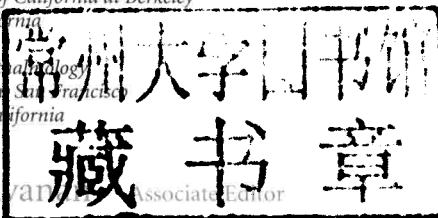
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HANDBOOK OF OPTICS

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COVER ILLUSTRATIONS

A Photograph Taken of a Lady Viewing Her Face Using One of the World's Oldest Ground and Polished Mirrors. The oldest known manufactured mirrors (ground and polished), made of obsidian (volcanic glass) have been found in ancient Anatolia in the ruins of the City of Çatal Hüyük = “mound at a road-fork.” The locations where the mirrors were discovered were dated 6000 to 5900 B.C.E. by Mellaart and his coworkers. That city is located in the South Konya Plane of Modern Turkey. Thus, these mirrors are about 8000 years old (B.P.). The obsidian was transported over a distance of more than one hundred miles to the city for processing. These mirrors can be found at the Museum of Anatolian Civilizations in Ankara. One cannot fail to be impressed by the quality of this image seen by reflectance from this ancient mirror! These mirrors had been buried twice. There is an extended history of processing of obsidian at that site for scrapers, spear, and arrow points and other tools. This very early city contained an estimated 10,000 individuals at that time(!); it was a center for development of modern agriculture, Indo-European languages, various crafts, etc., and had established road connections and trade relations [Enoch, J., *Optom. Vision Sci.* **83**(10):775–781, 2006]. (*This figure is published with permission of Prof. Mellaart, the Director of the Museum of Anatolian Civilizations, the author, and the editor of the Journal.*)

Waveguide Modal Patterns in Vertebrate Eyes (Including Human). This illustration demonstrates the variety of waveguide modal patterns observed in freshly removed retinas obtained from normal human, monkey, and rat retinas [Enoch, J., *J. Opt. Soc. Am.* **53**(1):71–85, 1963]. These modal patterns have been recorded in paracentral retinal receptors. Reverse path illumination was employed. These modes were photographed in near monochromatic light. This figure provides representative modal patterns observed and recorded near terminations of these photoreceptor waveguides. With variation of wavelength, at cutoff (please refer to the “V” parameter), it is possible to witness sharp modal pattern alterations. In this figure, the intent was to show the classes of modal patterns observed in these retinal receptors. (*This figure is reproduced with permission of JOSA and the author.*)

Photoreceptors in the Human Eye. This figure shows the first map ever made of the spatial arrangement of the three cone classes in the human retina. The three colors (red, green, and blue) indicate cones that are sensitive to the long, middle, and short wavelength ranges of the visible spectrum and are classified as L, M, and S cones. The image was recorded from a living human eye using the adaptive optics ophthalmoscope, which was developed by David Williams' lab at the University of Rochester [Liang, J., Williams, D. R., and Miller, D. (1997). Supernormal vision and high-resolution retinal imaging through adaptive optics, *J. Opt. Soc. Am. A* **14**:2884–2892]. This image was first published in the journal *Nature* [Roorda, A., and Williams, D. R. (1999). The arrangement of the three cone classes in the living human eye, *Nature* **397**:520–522]. (*Courtesy of Austin Roorda and David Williams.*)

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EDITORS' PREFACE

The third edition of the *Handbook of Optics* is designed to pull together the dramatic developments in both the basic and applied aspects of the field while retaining the archival, reference book value of a handbook. This means that it is much more extensive than either the first edition, published in 1978, or the second edition, with Volumes I and II appearing in 1995 and Volumes III and IV in 2001. To cover the greatly expanded field of optics, the *Handbook* now appears in five volumes. Over 100 authors or author teams have contributed to this work.

Volume I is devoted to the fundamentals, components, and instruments that make optics possible. Volume II contains chapters on design, fabrication, testing, sources of light, detection, and a new section devoted to radiometry and photometry. Volume III concerns vision optics only and is printed entirely in color. In Volume IV there are chapters on the optical properties of materials, nonlinear, quantum and molecular optics. Volume V has extensive sections on fiber optics and x ray and neutron optics, along with shorter sections on measurements, modulators, and atmospheric optical properties and turbulence. Several pages of color inserts are provided where appropriate to aid the reader. A purchaser of the print version of any volume of the *Handbook* will be able to download a digital version containing all of the material in that volume in PDF format to one computer (see download instructions on bound-in card). The combined index for all five volumes can be downloaded from www.HandbookofOpticsOnline.com.

It is possible by careful selection of what and how to present that the third edition of the *Handbook* could serve as a text for a comprehensive course in optics. In addition, students who take such a course would have the *Handbook* as a career-long reference.

Topics were selected by the editors so that the *Handbook* could be a desktop (bookshelf) general reference for the parts of optics that had matured enough to warrant archival presentation. New chapters were included on topics that had reached this stage since the second edition, and existing chapters from the second edition were updated where necessary to provide this compendium. In selecting subjects to include, we also had to select which subjects to leave out. The criteria we applied were: (1) was it a specific application of optics rather than a core science or technology and (2) was it a subject in which the role of optics was peripheral to the central issue addressed. Thus, such topics as medical optics, laser surgery, and laser materials processing were not included. While applications of optics are mentioned in the chapters there is no space in the *Handbook* to include separate chapters devoted to all of the myriad uses of optics in today's world. If we had, the third edition would be much longer than it is and much of it would soon be outdated. We designed the third edition of the *Handbook of Optics* so that it concentrates on the principles of optics that make applications possible.

Authors were asked to try to achieve the dual purpose of preparing a chapter that was a worthwhile reference for someone working in the field and that could be used as a starting point to become acquainted with that aspect of optics. They did that and we thank them for the outstanding results seen throughout the *Handbook*. We also thank Mr. Taisuke Soda of McGraw-Hill for his help in putting this complex project together and Mr. Alan Tourtlotte and Ms. Susannah Lehman of the Optical Society of America for logistical help that made this effort possible.

We dedicate the third edition of the *Handbook of Optics* to all of the OSA volunteers who, since OSA's founding in 1916, give their time and energy to promoting the generation, application, archiving, and worldwide dissemination of knowledge in optics and photonics.

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PREFACE TO VOLUME III

Volume III of the *Handbook of Optics*, Third Edition, addresses topics relating to vision and the eye which are applicable to, or relate to the study of optics. For reasons we do not understand fully, in recent years, there seems to have been a tendency for the optics and the vision science communities (the latter group was known in earlier times as “physiological optics”) to drift somewhat apart. Physiological optics had become a meaningful component within optics during the latter part of the nineteenth century. As but one example, we urge interested readers to read H. von Helmholtz’s masterful three-volume *Handbook of Physiological Optics* (third edition) which was translated by J. P. C. Southall, of Columbia University, into English by the Optical Society of America in the 1920s.¹ It should also be noted that Allvar Gullstrand received the Nobel Prize in Physiology/Medicine in 1911 for his work on model eyes, which was a direct application of thick lens theory. Gullstrand was not only a professor of ophthalmology at the University of Uppsala, but was also a professor of physiological and physical optics at that institution. He also added five new chapters to the first volume of Helmholtz’s treatise published in 1909. Not only is this a remarkable scientific work, but much of it remains applicable today! The simple fact is that the two groups, optical science and vision science need each other, or, alternatively, are effectively “joined at the hip.” Thus, here, we seek to provide a broad view of vision, vision processes, and discussions of areas where vision science interacts with the ever broadening field of optics.

Obviously, no treatment such as this one can be complete, but we have tried here to present applicable topics in an orderly manner. In the current edition, we have taken a wide-ranging view of vision and its relationship with optics. In particular, in recent years, we have seen a rapid increase of interest in new technologies and applications in the areas of adaptive optics (AO), scanning laser ophthalmoscopy (SLO), and optical coherence tomography (OCT), amongst others. Separately, there has been rapid growth of refractive surgery (LASIK, etc.), use of intraocular lenses (IOLs), and other forms of visual corrections. And, we do not overlook the incredible expansion of information technology, the broad utilization of computer, video, and other forms of displays which have been employed in myriad applications (with associated implications in vision).

We want to call the reader’s attention to the three cover illustrations. Here, of course, our choices were many! We have chosen one for its historical value, it is a photograph taken of a modern young lady viewing herself in an obsidian mirror in bright sunlight. That obsidian mirror, buried twice for extended time periods in its history, is ca. 8000 years old (!), and it is one of a number of the oldest known mirrors. These items are displayed in the Museum of Anatolian Civilizations, located in Ankara, Turkey² and/or at the Konya Museum in Konya which is in the south-central valley of Turkey and is located near to the dig site. This photograph falls into the evolving field of archaeological optics (not treated in this edition).^{3,4} Please consider the quality of the image in that “stone-age” mirror which was manufactured during the mesolithic or epipaleolithic period! A second figure displays a wave-guide modal pattern obtained radiating from a single human or primate photoreceptor in the early 1960s. There is further discussion of this topic in Chap. 8 on biological waveguides. The third figure is of human parafoveal cone photoreceptors taken from the living human eye by Austin Roorda (see Chap. 15). It was obtained using adaptive optics technology. The long (seen in red), middle (seen in green), and short (seen in blue) wavelength absorbing pigments contained in these individual cone photoreceptors are readily defined.

Please note, with the formation of the section on radiometry and photometry in this edition, the chapter addressing such measurements (as they pertain to visual optics), written by Dr. Yoshi Ohno, was relocated to Volume II, Chap. 37. A new, relatively brief, chapter on radiometry and photometry associated with the Stiles-Crawford effect (of the first kind) (Chap. 9) has been added. It was added after the chapter on biological waveguides (Chap. 8). This chapter fitted more logically there (where