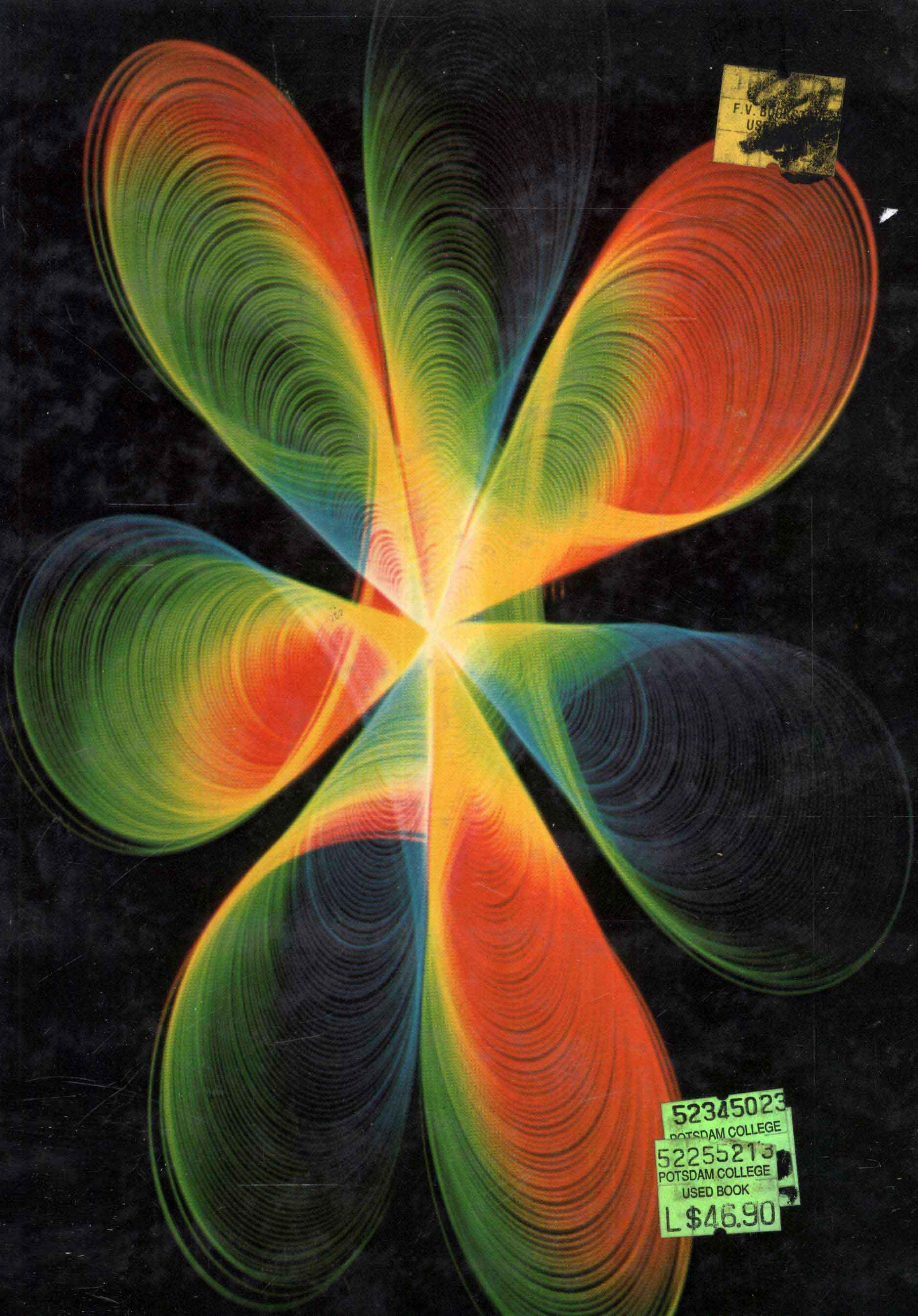

Introduction to Light

The Physics of Light, Vision, and Color

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To Mary Lou

Preface

This book is designed as a text for a one-semester, nonmathematical optics course at the freshman or sophomore level of college. It has grown out of lecture notes for just such a course that I have taught at Florissant Valley Community College for the past eleven years. Although it was written with art majors in mind, it should be suitable for any nonscience majors: Students in my course who have successfully mastered this material include fine art, commercial art, graphics, fashion merchandising, theater, photography, and liberal arts majors.

Because of the intended audience a great deal of effort has gone into presenting reasoning without recourse to the mathematics that would ordinarily accompany such a physical science. There are only about a half dozen equations used in the body of the text, and those are all linear with at most four variables. Additional mathematical details are included in appendices.

The choice of topics covered has also been influenced by the intended audience. There is less material on optical instruments and physical optics than one would expect in a standard optics text, but more on lasers, holography, meteorological optics, and the psychology of vision. The geometrical optics chapter does have what some might consider an inordinate amount of material on the optics of conic sections, but the purpose is to prepare the reader for Tung H. Jeong's clever treatment of holography in terms of hyperbolic reflectors.

It is not necessary in a one-semester course to cover every chapter nor is it necessary to take them in order. The first four chapters form a basis for any of the others, which are largely independent of each other. For example, I have often taught the chapters in the order 1, 2, 3, 4, 8, 9, 10, 11, 6, 7, covering Chapter 5 at the end only if there is time. Certainly other teachers will have other preferences. Furthermore, the subheadings within chapters are designed to allow teachers to "fine tune" the text to their courses by omitting or adding specific topics.

I would like to take this opportunity to acknowledge the invaluable assistance of Jerry Thompkins of the Florissant Valley Physics Department, who helped with the photography, and the photographic and graphics units of Instructional Resources at the college, each of which lent a hand at critical times. Also I am indebted to the reviewers of the original manuscript for Prentice-Hall: Professor Donald D. Ballegeer, University of Wisconsin, Eau Claire, Wisconsin; Professor Joseph L. Aubel, University of South Florida, Tampa, Florida; and Professor Stanley H. Christensen, Kent State University, Kent, Ohio, whose suggested revisions were always good, if sometimes beyond the modest abilities of the author. In addition I must express my gratitude to two fine typists, Delores Orr and Jane Layton. Last, but not least, I would like to thank the many students who have wrestled with this material in my course; their struggle to understand has been the major inspiration for this work.

Gary Waldman

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Part I

What Is Light?

Chapter 1

Early Ideas of Light

Since vision is the primary sense of human beings, we may be certain that people have wondered and speculated about light for many thousands of years, since long before there was any method of writing down those thoughts. Most early civilizations worshipped a sun god in some form, but in about 1370 B.C. Pharoah Akhenaton of Egypt introduced worship of a modified version of such a divinity that included the rays of sunlight. He saw the light from the sun as life-giving and had it clearly depicted that way in the Amarna style of Egyptian art.[1] In the Judeo-Christian tradition, the first chapter of the Bible depicts God's first act of creation as producing light. "And God said, Let there be light: and there was light."[2] The book of Genesis was probably not written down in its present form until 700 B.C. or later, but the tradition may go back much further.[3] By this date we are approaching the time of Greek civilization and with the Greeks, the first attempts at rational, nonreligious explanations of nature.

The Greek philosopher whose ideas about nature were most influential was Aristotle (384 B.C. to 322 B.C.) One reason that his ideas were accepted over such a long time was because he offered a complete and unified picture of the world. His theories of light, although they may seem strange to us today, were just a part of that overall picture. For Aristotle, the key to the nature of light was in transparent bodies, such a body being defined as anything "owing its visibility to the colour of something

[1] Cyril Aldred, *Akhenateu and Nefertiti* (New York: The Viking Press, 1973), pp. 12–20.

[2] The Holy Bible, *Authorized (King James) Version,* (Nashville: The National Publishing Co., 1972), p. 1.

[3] F. M. Cornford, "Pattern of Ionian Cosmogony," in *Theories of the Universe,* ed. Milton K. Munitz (New York: The Free Press, 1957), p. 29.

else; of this character are air, water and many solid bodies." He considered such things transparent because they contain a substance "also found in the eternal body which constitutes the uppermost shell of the physical Cosmos." Light, then is the activity of this almost divine substance. He did not think of light as a substance or even as moving but rather as the "presence of fire or something resembling fire in what is transparent."[4]

There the matter stood for over a thousand years. For although there may have been gains in the techniques of using light, there was no substantial advance in understanding the nature of light until that great flowering of inquiry in Europe known as the Renaissance shattered Aristotle's scheme of the universe. In the later sixteenth and early seventeenth century men such as Nicolaus Copernicus (1473–1543), Johannes Kepler (1571–1630), and Galileo Galilei (1564–1642) completely dismantled Aristotelian concepts in astronomy and mechanics and laid the foundations of modern science. One man of this period whose views are of particular interest to our study of theories of light was the French philosopher, René Descartes (1596–1650). Descartes, like Aristotle 2000 years earlier, tried to establish a unified world system that would explain all natural events. According to Descartes, all of space was filled with globules of a material which he called the "ether" that could transmit forces. A luminous body such as the sun caused a vortex or whirlpool in the ether. The outward centrifugal pressure from the vortex, transmitted through the globules pressing on one another, was light. In this theory, light had infinite speed: it was transmitted instantaneously. Of course, this hypothetical material called the ether was undetectable except insofar as it transmitted light and other forces such as gravity. Especially interesting was Descartes's view of colors as arising from rotation of the globules of the ether, with the most rapidly spinning particles giving rise to red sensations, the slowest giving blue, and particles with intermediate speeds giving orange, yellow, and green.[5] In the final analysis, Descartes's grand intellectual design proved far too ambitious an effort to be supported by the experimental evidence that was then available or obtainable. Furthermore he largely ignored the new emphasis on mathematical explanations in science due to Kepler and Galileo. Still, two of his ideas about light were to reappear in more successful theories: the first was the idea of light as a disturbance transmitted through the ether, and the second was the association of the different colors of the spectrum with different periodic motions of some kind.

QUESTIONS

1. What similarity can you detect between Akhenaton's and Aristotle's conceptions of light?

[4]Richard McKeon, ed., *Introduction to Aristotle* (New York: Random House, Inc., 1947), pp. 188–190.

[5]Sir Edmund Whittaker, *A History of the Theories of Aether and Electricity, Volume I: The Classical Theories* (New York: Harper & Row, Publishers, Inc., 1960), pp. 5–9.

2. What scientist is given primary credit for originating the idea of the ether?
3. In Descartes's theory what sort of motions are connected with color?
4. Compare the period of acceptance of Aristotle's "incorrect" theories with the period of acceptance of more modern theories of light dating from about 1800.

Chapter 2

The Classical Theories