PHYSIOLOGY OF THE BYE

VOLUME 1

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ARTHUR LINKSZ, M.D., F.A.C.S.

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Optics

ARTHUR LINKSZ, M.D., F.A.C.S.

Manhattan Eye, Ear and Throat Hospital; University Hospital; New York University College of Medicine

Foreword by WALTER B. LANCASTER, M.D.



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Arthur Linksz, M.D., F.A.C.S.

PHYSIOLOGY OF THE EYE

Vol. 1. Optics

Vol. 2. Physiology of Vision

Vol. 3. Biochemistry of the Eye

Foreword

N 1913 I published two papers urging the importance of physiologic optics in the training of the ophthalmologist. Ever since I have been calling attention to the need of instruction in this department so fundamental to ophthalmology. Hence my great pleasure when I learned that Dr. Linksz was writing a book covering this field, and not one volume only but three.

What are some of the requirements that such a work should meet? First of all it must be accurate. Deliver us from textbooks that are not accurate! I was fond of inviting students to "open a certain textbook anywhere at random and I will point out some statement that is false without having to turn a page." I warn you if you think you have found something in this textbook that is false, better investigate carefully, for it is ten to one you are wrong and Linksz is right.

Then it must be clear. Many an erudite volume full of valuable meat is so poorly written that readers are unable to extract the nourishment from it. The first step toward clear writing is clear thinking. In that Dr. Linksz excels. Moreover he has had opportunities to teach beginners and so has learned what methods of presentation are within the capacities of students.

A third requirement is that it shall be interesting to the reader. Many little touches here and there serve to excite and maintain the interest of the beginner for whom the bearings and the significance are pointed out and not merely the principles stated. Interest is contagious, fortunately, hence the intense interest of the author is communicated to the reader.

A fourth feature is that it shall not be too condensed. There is always the temptation to deal with a mathematical subject in the concise way that so many writers with keen mathematical minds fall into. The average reader can not take it in unless it is spread out and presented step by step.

Lastly, since space is limited, I would call attention to only one more feature and that is the illustrations. This is a subject which demands illustrations. Dr. Linksz has realized this and spared no pains to secure an outstanding set of figures, most of them original, skillfully designed and executed in masterly fashion.

Ophthalmologists are to be congratulated that now such a satisfactory work is available and will look eagerly forward to the publication of the second and third volumes.

Walter B. Lancaster, M.D.

Boston, Mass.

Preface

HEN ONE is engaged in teaching, it is hard to escape one certain temptation. Almost all teachers end up writing text books. This author is no exception. He, too, has hoped for years to see in print what seemed to him a successful venture into teaching ocular physiology to future eye specialists. However, without the kind invitation and encouragement of Mr. Henry M. Stratton, President of Grune & Stratton, Inc., this hope would have never realized.

If one has been thinking for a number of years of writing a book, many fancy titles for that book of the future pass through his mind. Attempts to convey knowledge to a greater public have always fascinated me; what I planned was a book that can be understood easily, that is "popular" in form, if not in contents. When I came across some of the masterworks of popular science, as Hogben's "Mathematics for the Million," or Selig Hecht's incomparable "Understanding the Atom," I thought of writing a "Physiologic Optics for the Million" (a publisher's dream!), or a book called "Understanding Physiologic Optics." But how could anyone ever hope to write anything even resembling these great books in appeal and success of presentation? The title "Clinical Physiology of the Eye" would have been too daring. It would have reminded the reader of that American classic, Adler's textbook, which we all hope will come out in a second edition some time. The real title of this book should be: "An Introduction to Duke-Elder's Textbook, Volume I." This book, the greatest ever written by an ophthalmologist, really needs an introduction. In its greatness it is bewildering to the beginner, the uninitiated. It is almost impossible for the future ophthalmologist to start studying his subject using this as a text. What he needs is a general survey, a point of view, an acquaintance with its issues. He needs someone to steady his steps in his first trial, to reassure him that he too will be able to master at least part of what is given in Duke-Elder's text, his Bible for the coming years of his professional career.

The reader should therefore know that this is not a textbook, but an introduction, and an informal one at that. It contains very few data, it is not systematic, and it is extremely repetitious. However, it is this author's belief that basic concepts, especially the strange concepts of visual physiology, can be brought home only by constant repetition. The facts can be found in other books. It would have been useless to add a second-rate textbook to those first-rate books the author himself has had the good fortune to study.

VIII PREFACE

This book is actually a transcript of lectures, retaining the informality of lectures. The author has not even tried to change the first person plural in which he usually formulates his sentences, or the second person in addressing his audience whenever he sees that one or the other listener is falling asleep.

Three volumes are planned. The present volume, "Optics," deals with the *Physics of Light, Geometric Optics* and the *Eye as an Image-Forming Mechanism;* the second volume will deal with the "Physiology of Vision," and the last with the "Biochemistry of the Eye."

A book like this could not come into being without the help, cooperation and encouragement of many. Dr. R. Townley Paton, surgeon director, and Mr. Fred Heffinger, superintendent, of Manhattan Eye, Ear and Throat Hospital in New York, were the first to encourage me to start a course of lectures for the residents of the hospital, of which I am so proud to be a member. Dr. Daniel B. Kirby invited me to the faculty of New York University, College of Medicine, and Dr. Conrad Berens assigned me to take an increasing part in the graduate course of ophthalmology he has been directing so admirably at this college for the past years. The present first volume is actually a transcript of what lectures I gave in this course in the years 1947–1949 on "Physics of Light and Geometric Optics." The third volume, dealing with the "Biochemistry of the Eye and the Autonomous Functions of the Eye," will be an elaboration of a course repeatedly given at Bellevue Hospital and Manhattan Eye, Ear and Throat Hospital in the years since 1945.

My greatest indebtedness belongs to Dr. Walter B. Lancaster of Boston, Massachusetts, my former chief at the Dartmouth Eye Institute in Hanover, New Hampshire, the man to whom I owe more than to anyone in my long career—leader, teacher or friend. His influence upon me as man, physician, surgeon, teacher, was immense and it is he who, from a bewildered stranger, transformed me into an American ophthalmologist. The foreign accent is inevitable, and the reader will find it throughout this book, both in language and in concepts. What could be overcome of it is due to Dr. Lancaster's help. I had the privilege to lecture on "Physiology of Vision" in what is now, I hope, a permanent institution, The Lancaster-Basic-Course in Ophthalmology, in Portland, Maine, from its inception in 1946, and the second volume of this introduction will be a transcript of my Portland lectures.

But the list to whom this author is indebted does not end here. He is neither a physicist, nor a physiologist, nor a psychologist. What he knows of these subjects is second-hand and motivated by the desire to become more intelligent in his own field and to be able to help his younger colleagues to become better eye doctors.

I am especially indebted to Professor Armin v. Tschermak-Seysenegg of Prague University, my first teacher in physiologic optics; to Professor Francis W. Sears of Massachusetts Institute of Technology and his "Principles of Physics"; to Dr. Paul Boeder of Southbridge, Massachusetts, whose magnificent little book "An Introduction to the Mathematics of Ophthalmic Optics" I consulted freely, and to Dr. Sölve Stenström whose outstanding monograph "Untersuchungen

Acknowledgements

Most of the figures are new, drawn to illustrate the concepts as presented in this book. Still, it was unavoidable to use material of other writers—for two reasons. Some like the illustrations of Horrabin (an artist in his own right) for Hogben's "Science for the Citizen," New York, A. A. Knopf, 1938, are of a personal touch which is indelible, even in the new drawings (figs. 2, 22) made by another artist, Mrs. Bergman. Other illustrations are of such standard content that (even if newly drawn and lettered, as most of them were for the present text) they are more or less identical with those found in other books. Fig. 25, the scotopic and photopic luminosity curve, or fig. 23, indicating the relative distribution of wave lengths ("color temperature") are examples of this sort.

The authors and their works to whom this author is indebted for the use of illustrations are:

- Duke-Elder, Textbook of Ophthalmology, Vol. I, 1944, Henry Kimpton, London, from which, with Mr. Henry Kimpton's permission, figs. 16 and 23 were taken.
- Dr. Harry Eggers and the American Medical Association who kindly permitted the use of an illustration (fig. 81 of the present volume) which appeared in the April 1946 issue of the Archives of Ophthalmology.
- Sears, Principles of Physics, 1945, Addison-Wesley Press, Inc., Cambridge, Massachusetts, upon which figs. 5, 6, 7, 14, 20, 21, 24, 25, 26 and 116 are based. The plates for figs. 17, 18 and 19 were furnished by the courtesy of the Addison-Wesley Press.
- Stenström, Variations and Correlations of the Optical Components of the Eye, in Modern Trends in Ophthalmology, Vol. II, Butterworth & Co., Ltd., London, from which, with permission, figs. 132, 133, 134, 135, 136, 137 and Table I were copied.
- Tscherning, Physiologic Optics, Keystone, Philadelphia, 1900, supplied figs. 108, 109, 110 and 111.

PREFACE

Ueber Die Variation und Kovariation Der Optischen Elemente des Menschlichen Auges" was used to a great extent in the preparation of Part III of the present volume. I hope they will not sue me for plagiarism. And then, of course, one hardly has to mention Helmholtz' "Handbook" with the supplements by Gullstrand, and Tscherning's "Physiologic Optics." These books are classics—and, like all the classics, beyond any copyright. I have used them freely and extensively.

But there are many others to be thankful to:

I have to be grateful to my wife for her constant encouragement, her forebearance and her help and advice in designing some of the drawings that accompany this text and to Bergman Associates, of Brooklyn, for their beautiful execution of the drawings, particularly to Mrs. Sylvia Bergman, for many suggestions, her great skill and cooperation.

Especial thanks go to Mrs. Martha Auber-Weiss, assistant in the Department of Aniseikonia of the Manhattan Eye, Ear and Throat Hospital, for typing of the manuscript and reading of the proofs. She participated from the very beginning in the growing of the manuscript and with great endurance took part in its endless revisions into its present shape.

Authors usually dedicate their books. I would have to write many books to have occasion to dedicate a volume each to those who are close to my heart or whom I hold in high esteem. I had planned to dedicate this volume to Dr. Walter B. Lancaster, had it not been for one reason—sad and personal. I want to dedicate it to the memory of my father and my mother who met their death in Camp Auschwitz in the year (should I say, Of Our Western Civilization) 1944. They have no monument, because, most likely, they rest in no grave. Nothing but this page is left to keep their memory alive.

A. L.

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I. Physics of Light

Strange Views—Corpuscular Theory—Wave Theory—The Ether-Wave Fronts—Velocity of Light

TREATISE on physiologic optics properly starts with a discussion of the nature of light.

Long before any consistent theory on its nature could be formulated, observation had taught two important facts about light: (1) that in its origin it is somehow related to heat (the flame of a candle that lights your room can also burn your fingers), and (2) that it travels along straight lines. A cardboard held between a candle and the wall throws a shadow upon the wall, and if one makes a hole in the cardboard he sees a bright spot on the wall surrounded by the shadow. The outlines, both of the shadow and the bright spot, seem to be determined by straight lines one can draw from the candle. Whatever light may be, it seems to travel, according to everyday experience, along such straight lines, being intercepted in its course by objects like the cardboard or the wall. These objects in their turn seem to change its direction, to repel the light.

But this is not the only characteristic of light to reveal itself to even the most casual observer. A candle, when lit, can be seen from almost any direction. Light thus seems to travel from its source in all possible directions. But when intercepted in its course by any object, light does not reach the eye; one cannot see the source of light. However, a spot on the wall becomes illuminated by this source, even if the latter is not seen itself, and this spot in its turn also becomes visible from almost any direction. Thus, an object repels light deriving from the source in all possible directions and behaves like the source of light, at least in this respect and at least as far as the eye or a camera is concerned. We shall see later that in the treatment of trajectories of light in problems of geometric optics it makes no difference whether a so-called point source of light is actually the origin of that light (like a candle or an incandescent filament) from which that light emanates, or whether it is an object point that reflects only the light of some such source, or whether it is finally what we shall call the "image" of that object point. In geometric optics we shall usually start our discussion with so-called points, "object" points, without further specification, and shall consistently forget that the light actually reaching our eyes from objects of our surroundings originates in most instances from the sun in daylight, or from some artificial source at night, and not from the object with which we shall deal as if it were the source of that light. Only in this chapter shall we hold to a clearer definition and examine whatever can be learned in an elementary way about the physical agent itself that emanates from incandescent sources, about the physical agent "light."

4 OPTICS

Nothing seems more obvious than to think of the agent that travels in the way just discussed as *consisting of particles*, *corpuscles*, and to assume that the sensation of light is created by these corpuscles falling upon some sensitive part of the eye.

Strangely enough, even this explanation, apparently so obvious, came up rather late in the history of human thought. Many of the ancient thinkers were obsessed, as Polyak so adequately expresses it, by the belief that vision is accomplished by means of some rays or some emanation emerging from the eyes, with the aid of which outside objects could be "grasped." One has to mention only names like Plato or Euclid to show that even thinkers of great rank were deceived by this obsession. The poet Lucretius had the notion that the eye sees an object as the hand might feel it with a rod. Galen, who lived several centuries later and whose influence on scientific thought lasted all through the Middle Ages, believed in an ill-defined, almost immaterial fluid, a luminous spirit, originating in the brain and filling the optic nerves and the lens (which he thought to be the actual organ of sight), upon which this spirit would confer the property of photoreception. We shall see in another chapter that the great Johannes Müller, the founding father of sense physiology, used, more than 1600 years after Galen, an almost similar concept in his explanation of a "visual substance," which he also stated as originating from the brain. Of course, Müller described this substance (which had, according to him, the specific faculty, or, as he called it, the specific energy of becoming luminous) as pervading the retina instead of the lens. The latter had, as we all know, by Müller's time long been relegated to its minor role of refracting rather than receiving light.

As awkwardly as it was expressed in the romantic phraseology of German philosophers, Müller's concept was the first step toward real understanding of the sensory functions and the beginning of modern sense physiology. We shall analyze it later in due length. He was the first to realize that a definition of light, of luminosity, must incorporate subjective, organismic, as well as physical, elements and that light is not light, is not luminous, unless it is seen. Of course, no one at his time believed any longer that the eye had the power of throwing out invisible tentacles into the outer space to "grasp" the nature of distant objects, and we do not have to discuss the correctness or incorrectness of such a theory. Photography, among other things, has definitely proven that the agent responsible for our sensation of light travels in the opposite direction and although we can not quite rightfully call it light if we do not see it, it no doubt acts independently from the presence of the eye or the perceiving mind.

But it is hard for theories to die a final death! While none of the nineteenth century scientists believed any longer in the existence of such tentacles, the whole concept of something emanating from the eye into outer space was rescued in a rather nonsensical theory of space perception, called the "projection" theory, still contained in many of the textbooks and taught to students all over the world. Later on we shall have to come to grips with this theory.

Returning to the first scientifically sound theory of light, the corpuscular theory, we might state that these particles of which light was assumed to consist

seemed to have the faculty of penetrating certain substances, called "transparent," like glass or water or the cornea of the eye, and seemed to be reflected by other substances, called "opaque." The reflection of these corpuscles by opaque substances occurred, so it seemed, at random, in all possible directions. This is, as already mentioned, the obvious reason why an illuminated object can be seen from many different directions. But soon it was learned that smooth surfaces like that of a mirror would reflect light in some more ordinary fashion, according to some laws of reflection, much like those that govern the path of balls on the billiard table.

Later in our discussion we shall spend some time analyzing the fact that visual objects always appear in certain directions. To be aware of their direction, of their "whereness" in general, is, as one can see, most important to one's proper and successful handling of them and this awareness of direction is obviously related to the very fact that light coming from objects seems to travel in straight lines. The light's direction, as it impings upon the eye, is certainly the most important and usually a sufficient cue for the object's direction. But not always is this the case! Children have to learn that no fairies' castles are standing upside down in lakes and for the dentist to fill a tooth under the direction of his mirror it is indispensable to learn that his object of attention is not in the direction indicated by the light entering his eye. Moreover, an important part of his training is to learn how to coordinate muscular activity with his visual cues. So had we all to learn how to use a mirror while shaving or powdering. But these are exceptions, not the rule. The rule is that light travels in straight lines from objects toward the eye. We see therefore objects in directions determined by the direction of the stimulating light (determined by what shall be called in later lectures: "lines of direction") and stretching out our arms, we usually do find the objects in that direction. If we don't find them there as in the examples just mentioned, our mind is satisfied only if it finds that there is some other object, usually a mirror, interfering with the original direction of light. If no such interfering object can be detected, we infer that whatever caused our visual image was a hallucination or

The word "usually" has been used with purpose several times in the foregoing sentences. Physicists of our time have taught us that all laws of physics are statistical in nature. We cannot expect laws of psychophysiology to do better than that. They express only probabilities, not certainties. Directions of "rays" of light are usually the most outstanding determining factors of visual direction. But sometimes you "see stars" when there are none in the sky. You were hit in the eye and you see stars in directions most certainly determined by some other agent than light since there was no light to cause your sensation. We shall later learn of "false projection," whatever that means, and notice that certain people, under certain conditions, do not stick their fingers in the right direction when they expect to touch the object they see. Still, the odds against us are no higher than one in billions. Whenever we put our feet down we usually do hit the ground. Laws of psychophysiology, or of optics, are no better than statistical. Still, this