

OPTICS

The Science of Vision



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Translator's Preface



Figure 22 is reproduced from Polyak's *The Retina* (University of Chicago Press) by kind permission of Mrs. Stephen Polyak. Figures 26 and 27 are reproduced from H. K. Hartline's article on "The Nerve Messages in the Fibers of the Visual Pathway," which appeared in the *Journal of the Optical Society of America*, 1940, 30, 242, 244.

It is a pleasure to acknowledge my debt to two friends who volunteered to read the translation in typescript. Robert I. Wolff, Professor of Physics at the City College of New York, proposed a considerable number of improvements in the translation, which has benefited from his profound knowledge of physics, optics, and astronomy as well as from his love for precision in terminology. Lloyd Motz, Associate Professor of Astronomy at Columbia University, was likewise kind enough to offer some valuable suggestions. To both these men I desire to express my heartfelt thanks, at the same time absolving them of whatever imperfections remain.

E. R.

Bibliographical Note



Were I to recall the names and writings of all who have made some contribution to the studies utilized in this book, I should have to present an interminable list, so huge is the number of those who have dealt with this vast and important subject. I have therefore dispensed with the compilation of such a list.

V. R.

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OPTICS

The Science of Vision

CHAPTER I

The Definition of Optics



1. As I sit down to write this book, about four decades have passed since I first heard about optics. Forty years ago I learned that there was light, consisting of rays capable of being reflected and refracted; that there were mirrors, prisms, and lenses able to produce images; that there were optical instruments; and that there was a sense organ called the eye. Certain interference fringes also were mentioned, and likewise a sequence of colors known as the *spectrum*. In the classrooms of the secondary school I thus formed an initial concept of optics: it was a chapter of physics.

A few years later at the university I had a second encounter with optics, again in the course on physics. There the ideas that had been outlined in secondary school were confirmed and perfected. The geometrical reasoning was refined and completed in that magnificent construction, the Gaussian homography. Light waves were studied in close connection with color, and their wonderful capacity to explain the phenomena of interference, diffraction, and polarization was demonstrated. The conception of the spectrum was broadened to include the ultraviolet and infrared regions. The electromagnetic nature of light waves was expounded. Knowledge of how the most important optical instruments worked was imparted. Everything was presented as beautiful, finished, orderly.

But then there was talk about a split. *Geometrical Optics*, which discussed rectilinear rays, was not in agreement with wave phenomena. It was, therefore, considered a provisional optics, useful and practical, but to be disregarded when an approach to the essence of the phenomena was desired. For then it was necessary to

enter into *Physical Optics*, which succeeded in accounting so well for the experimental data by means of the wave mechanism.

Inexperienced and timid young minds, impressed by the splendid results achieved by their predecessors and overawed by the authority of their professors, could not suspect the dangerous significance and profound importance of this split. In these minds the firm conviction grew, even without any such explicit assertion by the instructors, that by now in optics everything was known.

When I finished my program at the university, fate decreed that I should dedicate myself completely to the study of optics, in an environment of research in physics, where a special department devoted to optics for technical purposes was deemed essential. I then found out that there was also a *Technical Optics*; that there was an industry of *optical glass*; and that there was an *Engineering Optics*, busy with *optical calculations* for prescribing optical systems, and concerned likewise with designing the instruments in which these systems were to be placed.

I discovered that in addition there was a *Physiological Optics*, which undertook to examine the functioning of the eye regarded as an organ of the human body.

2. The further I advanced in the field, the vaguer my ideas became about the meaning of the term "optics." At first I had the feeling that optics, a very ancient and fully developed discipline, had as it were fallen apart, like a great empire that had dismembered itself by ceding a portion of its territory to each of its neighboring states, which had then proceeded to convert these areas into provinces of their own.

Since the possibility presented itself of creating an institution devoted exclusively to optics, I conceived the ambitious project of reuniting the empire. But as I deepened my knowledge of the subject, the problem seemed ever more indefinite. Optics was intermingled with so many different sciences that it appeared extremely hard to determine by a reasonable criterion where to put the border of the new empire. Indeed I ran the risk of incorporating in it units that were clearly alien to it or of leaving outside its frontiers districts that were unquestionably optical—the sort of difficulty that

occurs quite frequently in drawing the political boundaries of nations.

This, however, was not a crucial question. What mattered was to work either theoretically or experimentally in such a way as to make real contributions to our knowledge; it was of little importance whether or not they came within the logical limits of the field bearing the name "optics."

3. The uncertainty about the meaning of this term, however, was a sign that something was wrong. Meanwhile in physics the famous controversy between the quantum theory and the wave theory became acute. Although its repercussions on the content of "optics" were only moderate, from the classificatory point of view it nevertheless led to the proof that *Physical Optics* could no longer be identified with *Wave Optics*. The latter became, after the indisputable establishment of the quantum concept, a new kind of *Geometrical Optics*. Just as classical *Geometrical Optics* had substituted a network of straight lines for the actual radiation, so now a system of wave motions was introduced. Thus when a treatment of the familiar phenomena of interference, diffraction, and polarization by the wave mechanism was desired, *Wave Optics* was invoked. But the task of seeking to ascertain the nature of the radiations had to be left to *Physical Optics*.

This clarification showed itself to be increasingly more accurate and sensible as research progressed. The meaning of the word "optics," however, suffered a new blow. For geometrical and wave optics, now deprived of a secure physical basis and reduced to the status of provisional studies of schematic models, like the ray and the wave, acquired the value of chapters of mathematics, from whose conclusions the necessary correspondence to experience could not be demanded, because it was admitted from the start that this correspondence did not exist. And if these two were "chapters of mathematics," they lost their standing as branches of optics, since the universal intention was to give this science the character of a chapter of physics.

Even more serious was the effect of the clarification on physical optics, so called. If optics was to be a chapter of physics, its essence should have been contained in physical optics. Instead, the latter

lost all significance and ended up by disappearing altogether. For at heart its subject matter should have been the investigation of the nature and properties of the radiation. But this imposing task is a general theme of physics, because it concerns not only the visible but also the invisible radiations, whether these be electromagnetic waves, microwaves, infrared, ultraviolet, X rays or γ rays. The fact that a very small group of all these radiations is capable of affecting the eye forms a minor detail, utterly insufficient to justify the label of optics for so vast and important a class of studies. Its proper name is *radiation physics*.

4. The more I sought to delimit the meaning of the term "optics" and to define its content, the more they both escaped me. What was commonly considered most characteristic of optics as a chapter of physics slipped away into two purely mathematical constructions, to wit, geometrical optics and wave optics; and in the part that should have retained the essence of physical optics, general physics was found, and "optics" lost all its significance.

In the meantime, however, I had gone into the branches regarded as technical offshoots, which have as their aim to put the rules of optical science into practice.

One of the divisions of this technology is *optical calculation*. Anyone who examines it finds therein a variety of mathematical procedures, both algebraic and trigonometric, based on the laws of reflection and refraction. By means of these procedures the attempt is made to determine the curvatures, thicknesses, and diameters of lenses in order to find the proper combination. Anybody who concerns himself with optical calculation engages in an exclusively mathematical task, which is completed when he has compiled the "prescription" of the calculated optical system. This is, therefore, clearly a question of applied mathematics. It would be futile, however, to look there for anything distinctively optical. True, the point of departure is two postulates, namely, the laws of reflection and of refraction. But these two laws, it should be noted, are not peculiar to optics since all radiations and all wave motions, material included, obey them. The conclusion was inescapable that "optical calculation" was essentially a chapter of applied mathematics,

wherein the only optical feature was the purpose for which the work was done.

The same inference had to be drawn when I went on to examine the technique of optical works, so called. I found first of all an industry that produced "optical glass" as a special and indispensable raw material for making lenses and prisms. But the manufacture of optical glass does not differ fundamentally from that of ordinary glass, except in the care that must be taken to ensure its homogeneity, and in the types or combinations of mixed powders, from whose fusion glass results. The technology of optical glass, therefore, is a glass technology, particularly refined, in view of the end for which its product is destined. But in itself it does not have any specific traits of its own, optically speaking.

This raw material, that is, the glass so produced, is *worked* by means of abrasives in order to give to the individual pieces the shape of plates, lenses, and prisms. This operation too does not have any specific traits of its own, optically speaking. It is a question of giving a geometrically determined form, generally plane or spherical, to the surfaces and then of polishing them. The same thing is done in many other processes and techniques, whether of wood, metal, stone, or glass. Therefore the working of glass to make lenses and prisms deserves the designation of optics only because the product is used for an optical aim.

Hence in the so-called optical technology, from calculation to raw material to finished product, I found no justification for the label other than in the intent. The calculating, glass-making, abrasion, and polishing are done as they are done elsewhere, with this difference, that when those calculations, glasses, and operations are to serve a purpose of another nature, they are not called optical; and they are called optical if the objects produced are to serve optical purposes.

5. I then proposed to define these "optical purposes." What seemed the most immediate and obvious purpose in common parlance was the production of "optical instruments." Again I asked myself what characteristics led to the classification of an instrument as optical, and I did not find even one. In short, I had to give up the idea that to consider an instrument as optical was "purpose"

enough to regard one of the aforementioned operations of calculation or fabrication as optical.

To sum it all up, my investigation had thus far led me to the following observation. In ordinary speech there was talk about a certain optics, which was supposed to be a chapter of physics; but as such it disappeared in a very vast and much more general treatise, losing all its own specific traits. On the other hand, in that presumed chapter of physics, studies developed that as usual were distinctively mathematical. Or, to cross over into technology, manipulations were carried out that pertained to mathematics or mechanics or glass-making, but had nothing optical about them except their purpose. In none of all this was anything found that was intrinsically optical.

I had thus attained an advanced degree of perplexity, because the conclusion was almost inescapable that a true optics *did not exist*, at least in that mathematico-physico-technical sphere in which I had looked for it with such great eagerness.

6. Then I bethought me that the world of physiologists, biologists, and pathologists also is interested in optics. In fact we speak of *Physiological Optics* and *Ophthalmology*. Essentially, these disciplines study the functioning of the normal eye, the causes of abnormalities, and the diseases of the eye and their cure. It would obviously be more appropriate to say "physiology of the eye" rather than "physiological optics," just as we say, not "pathological optics," but "pathology of the eye."

Whatever its name, this entire branch of study is in fact carried forward in an atmosphere completely different from that described above, with criteria and methods unrelated to the mathematical, mechanical, and glass-making procedures, whose place in optics was discussed in § 4. Moreover, the persons who pursue this new class of studies differ in training and mentality from those in the scientifico-technical group mentioned above. Between the two groups there are sporadic contacts and tenuous relations. The students of physiological optics barely take into account that in what they are accustomed to call "physical optics" (namely, the optics considered by everybody to be a chapter of physics) there is "light" consisting of rays or waves, and there are laws of reflection and