PHYSICAL OPTICS

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BY

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INTRODUCTION

The preparation of the present edition of *Physical Optics* has been governed by the generally expressed opinion that the most appreciated feature of the book is the large amount of space devoted to the experimental side of the subject, and the inclusion of somewhat lengthy descriptions of the experimental technique employed in the investigations with which the author has been more or less associated.

Since the last revision (1911) the theory of optical phenomena has developed to such an extent that nearly one half of the old edition has become obsolete. This has necessitated the rewriting of many of the old chapters and the inclusion of several new ones. The earlier chapters show little change as judged by the Table of Contents, yet some new material has been added, such as a revised list of light filters, Michelson's newer experiments on light velocity, Hubble's photographs showing the enormous velocities of the extra-gallactic nebulae and a number of other matters of minor importance.

The introduction of a new Chapter on the Origin of Spectra has seemed necessary, as the subjects of Magneto- and Electro-Optics, Resonance Radiation and Fluorescence, which certainly belong to physical optics, cannot be treated without an elementary knowledge of the present theories of the radiation of light by matter. The scope of the other Chapters is indicated in the Table of Contents. The Chapters on Relativity and the Nature of White Light have been omitted entirely, and a Chapter on the Raman Effect introduced. A good deal of new material will be found in the Chapters on Diffraction and Interference. The newer refractometers and interference spectroscopes are described in considerable detail, ten pages being devoted to the Lummer Gehrcke plate and the technique employed in its use. The Chapters on the Theory of Dispersion, Magneto- and Electro-Optics have been practically rewritten, and three new Chapters on Resonance Radiation and Fluorescence of Atoms and Molecules, and of Liquids and Solids replace the old Chapter on Transformation of Absorbed Radiations which dealt for the most part with phenomena for which no satisfactory theory had been developed at the time.

Nine new full page plates (two in color) and over one hundred and fifty new illustrations have been prepared; ninety of the old ones having been discarded. Of the 827 pages of the new edition (an increase of 132 pages), only 332 have been taken from the old edition, 495 pages being new material.

In the work of revision I have attempted to give, in as many instances as possible, a physical picture of the processes usually described by equations. In this effort I have been greatly assisted by my colleagues, Professors Herzfeld and Dieke, with whom I have spent many hours in conference over the interpretation of the equations employed in the theories of scattering, refraction, dispersion, magneto- and electro-optics, thermal radiation and the Raman effect. Any small success achieved along these lines is very largely due to their patient coöperation.

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CHAPTER I

THE NATURE AND RECTILINEAR PROPAGATION OF LIGHT

The Nature of Light: Older Theories. — The foundations of our present knowledge respecting the nature of light were laid during the latter part of the 17th century, although the modern wave-theory did not take definite form until over a century later. The important discoveries which may be said to mark the beginning of the science of optics may be summed up in a few words.

In 1666 Sir Isaac Newton effected the prismatic decomposition of white light into its component colors, and proved that no further color change resulted from subsequent refractions. He moreover recombined the spectrum colors, and formed from them white light. This was a great step in advance in one way, for it had been thought previously that color was produced by refraction, manufactured by the prism so to speak, whereas Newton showed that the colors were originally present in the white light, the function of the prism being merely to separate them or sort them out, which it accomplished in virtue of its power of deviating rays of different colors through different angles. The present theory, however, is that white light is constituted of irregular pulses, the wave-trains giving rise to colors being manufactured within the prism, by its action on the pulses.

The importance of Newton's discovery is not to be underestimated on this account, and his conception of the nature of white light will be held throughout the greater part of this book, for it represents perfectly all of the experimental facts with which we are acquainted, and the treatments of nearly all of the optical phenomena which we are to study are greatly simplified by its use.

Newton elaborated what is known as the corpuscular theory of light, and clung to it tenaciously to the last, the weight of his opinion retarding in no small degree the development of the wave-theory, which was first clearly expressed in 1678. On the corpuscular theory light was regarded as a flight of material particles emitted by the source, the sensation of sight being produced by their mechanical action upon the retina. The rectilinear propagation followed at once from the second law of motion, whereas the early supporters of the wave-theory were unable to account for it, as every known form of wave-motion bent freely around the edges of obstacles.

Reflection and refraction he explained as due to forces of repulsion and attraction exerted at the surface of the medium, the corpuscle being supposed to arrive at the surface in different "phases" in some of which it was repelled or reflected by the surface, in others attracted or refracted. He had studied carefully the colors of thin films and had established the relation between the color of the reflected light and the thickness of the film. The intensity of the transmitted light is a minimum, — he stated — if the corpuscles that have traversed the front surface of the film, having reached that surface in a phase of "easy transmission" have passed to the opposite phase the moment they arrive at the back surface. The results of his experiments with thin films, if handled from the point of view of the wave-theory, would have established its validity beyond any doubt, but he clung tenaciously to the idea of corpuscles.

As to the "phases" Newton expressed himself as follows: "Nothing more is requisite for putting the Rays of Light into Fits of easy Reflection and easy Transmission than that they be small Bodies, which, by their attractive Powers or some other Force, stir up *Vibrations* in what they act upon, which Vibrations being swifter than the Rays, overtake successively, and agitate them so as by turns to increase and decrease their Velocities and thereby put them into those Fits."

We thus see that Newton had a dim notion of a *dual* nature of light, Corpuscles and Waves (vibrations in a medium) acting together. This is interesting in view of the most recent theory of light corpuscles or "light quanta" (sometimes called "photons") which travel along paths marked out by a wave-field. This matter will be more fully discussed when we come to the quantum theory of radiation.

In the early part of the 19th century the final blow was given to the corpuscular theory by the experiments of Foucault, which showed that the velocity of light in water was less than in air, as required by the wave-theory whereas the theory of Newton required a higher velocity.

In 1676 it was demonstrated by Römer, a Danish astronomer, that light required a finite time for its propagation, travelling across space with a velocity which he estimated at 192,000 miles per second. Now the impact of corpuscles moving at such a speed