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PREFACE TO THE FIRST EDITION

THE idea of writing this book was a result of frequent enquiries about the possibility of publishing in the English language a book on optics written by one of us* more than twenty-five years ago. A preliminary survey of the literature showed that numerous researches on almost every aspect of optics have been carried out in the intervening years, so that the book no longer gives a comprehensive and balanced picture of the field. In consequence it was felt that a translation was hardly appropriate; instead a substantially new book was prepared, which we are now placing before the reader. In planning this book it soon became apparent that even if only the most important developments which took place since the publication of *Optik* were incorporated, the book would become impracticably large. It was, therefore, deemed necessary to restrict its scope to a narrower field. *Optik* itself did not treat the whole of optics. The optics of moving media, optics of X-rays and γ rays, the theory of spectra and the full connection between optics and atomic physics were not discussed; nor did the old book consider the effects of light on our visual sense organ—the eye. These subjects can be treated more appropriately in connection with other fields such as relativity, quantum mechanics, atomic and nuclear physics, and physiology. In this book not only are these subjects excluded, but also the classical molecular optics which was the subject-matter of almost half of the German book. Thus our discussion is restricted to those optical phenomena which may be treated in terms of MAXWELL's phenomenological theory. This includes all situations in which the atomistic structure of matter plays no decisive part. The connection with atomic physics, quantum mechanics, and physiology is indicated only by short references wherever necessary. The fact that, even after this limitation, the book is much larger than *Optik*, gives some indication about the extent of the researches that have been carried out in classical optics in recent times.

We have aimed at giving, within the framework just outlined, a reasonably complete picture of our present knowledge. We have attempted to present the theory in such a way that practically all the results can be traced back to the basic equations of MAXWELL's electromagnetic theory, from which our whole consideration starts.

In Chapter I the main properties of the electromagnetic field are discussed and the effect of matter on the propagation of the electromagnetic disturbance is described formally, in terms of the usual material constants. A more physical approach to the question of influence of matter is developed in Chapter II: it is shown that in the presence of an external incident field, each volume element of a material medium may be assumed to give rise to a secondary (scattered) wavelet and that the combination of these wavelets leads to the observable, macroscopic field. This approach is of considerable physical significance and its power is illustrated in a later chapter (Chapter XII) in connection with the diffraction of light by ultrasonic waves, first treated in this way by A. B. BHATIA and W. J. NOBLE; Chapter XII was contributed by Prof. BHATIA himself.

A considerable part of Chapter III is devoted to showing how geometrical optics follows from MAXWELL's wave theory as a limiting case of short wavelengths. In addition to discussing the main properties of rays and wave-fronts, the vectorial

* MAX BORN, *Optik* (Berlin, Springer, 1933).

aspects of the problem (propagation of the directions of the field vectors) are also considered. A detailed discussion of the foundations of geometrical optics seemed to us desirable in view of the important developments made in recent years in the related field of microwave optics (optics of short radio waves). These developments were often stimulated by the close analogy between the two fields and have provided new experimental techniques for testing the predictions of the theory. We found it convenient to separate the mathematical apparatus of geometrical optics—the calculus of variations—from the main text; an appendix on this subject (Appendix I) is based in the main part on unpublished lectures given by D. HILBERT at Göttingen University in the early years of this century. The following appendix (Appendix II), contributed by Prof. D. GABOR, shows the close formal analogy that exists between geometrical optics, classical mechanics, and electron optics, when these subjects are presented in the language of the calculus of variations.

We make no apology for basing our treatment of geometrical theory of imaging (Chapter IV) on HAMILTON's classical methods of characteristic functions. Though these methods have found little favour in connection with the design of optical instruments, they represent nevertheless an essential tool for presenting in a unified manner the many diverse aspects of the subject. It is, of course, possible to derive some of the results more simply from *ad hoc* assumptions; but, however valuable such an approach may be for the solution of individual problems, it cannot have more than illustrative value in a book concerned with a systematic development of a theory from a few simple postulates.

The defect of optical images (the influence of aberrations) may be studied either by geometrical optics (appropriate when the aberrations are large), or by diffraction theory (when they are sufficiently small). Since one usually proceeds from quite different starting points in the two methods of treatments, a comparison of results has in the past not always been easy. We have attempted to develop a more unified treatment, based on the concept of the deformation of wave-fronts. In the geometrical analysis of aberrations (Chapter V) we have found it possible and advantageous to follow, after a slight modification of his eikonal, the old method of K. SCHWARZSCHILD. The chapter on diffraction theory of aberrations (Chapter IX) gives an account of the NIJBOER-ZERNIKE theory and also includes an introductory section on the imaging of extended objects, in coherent and in incoherent illumination, based on the techniques of FOURIER transforms.

Chapter VI, contributed by Dr. P. A. WAYMAN, gives a brief description of the main image-forming optical systems. Its purpose is to provide a framework for those parts of the book which deal with the theory of image formation.

Chapter VII is concerned with the elements of the theory of interference and with interferometers. Some of the theoretical sections have their nucleus in the corresponding sections of *Optik*, but the chapter has been completely re-written by Dr. W. L. WILCOCK, who has also considerably broadened its scope.

Chapter VIII is mainly concerned with the FRESNEL-KIRCHHOFF diffraction theory and with some of its applications. In addition to the usual topics, the chapter includes a detailed discussion of the central problem of optical image formation—the analysis of the three-dimensional light distribution near the geometrical focus. An account is also given of a less familiar alternative approach to diffraction, based on the notion of the boundary diffraction wave of T. YOUNG.

The chapters so far referred to are mainly concerned with perfectly monochromatic (and therefore completely coherent) light, produced by point sources. Chapter X deals with the more realistic case of light produced by sources of finite extension and covering a finite frequency range. This is the subject of partial coherence, where considerable progress has been made in recent years. In fact, a systematic theory of interference and diffraction with partially coherent light has now been developed. This chapter also includes an account of the closely related subject of partial polarization, from the standpoint of coherence theory.

Chapter XI deals with rigorous diffraction theory, a field that has witnessed a tremendous development over the period of the last twenty years,* stimulated largely by advances in the ultra-shortwave radio techniques. This chapter was contributed by Dr. P. C. CLEMMOW who also prepared Appendix III, which deals with the mathematical methods of steepest descent and stationary phase.

The last two chapters, Optics of Metals (Chapter XIII) and Optics of Crystals (Chapter XIV) are based largely on the corresponding chapters of *Optik*, but were revised and extended with the help of Prof. A. M. TAYLOR and Dr. A. R. STOKES respectively. These two subjects are perhaps discussed in less detail than might seem appropriate. However, the optics of metals can only be treated adequately with the help of quantum mechanics of electrons, which is outside the scope of this book. In crystal optics the centre of interest has gradually shifted from visible radiation to X-rays, and the progress made in recent years has been of a technical rather than theoretical nature.

Though we have aimed at producing a book which in its methods of presentation and general approach would be similar to *Optik*, it will be evident that the present book is neither a translation of *Optik*, nor entirely a compilation of known data. As regards our own share in its production, the elder co-author (M. B.) has contributed that material from *Optik* which has been used as a basis for some of the chapters in the present treatise, and has taken an active part in the general planning of the book and in numerous discussions concerning disputable points, presentation, etc. Most of the compiling, writing, and checking of the text was done by the younger co-author (E. W.).

Naturally we have tried to use systematic notation throughout the book. But in a book that covers such a wide field, the number of letters in available alphabets is far too limited. We have, therefore, not always been able to use the most elegant notation but we hope that we have succeeded, at least, in avoiding the use in any one section of the same symbol for different quantities.

In general we use vector notation as customary in Great Britain. After much reflection we rejected the use of the nabla operator alone and employed also the customary "div", "grad", and "curl". Also, we did not adopt the modern electro-technical units, as their main advantage lies in connection with purely electromagnetic measurements, and these play a negligible part in our discussions; moreover, we hope, that if ever a second volume (*Molecular and Atomic Optics*) and perhaps a third volume (*Quantum Optics*) is written, the C.G.S. system, as used in Theoretical Physics, will have returned to favour. Although, in this system of units, the magnetic permeability μ of most substances differs inappreciably from unity at optical frequencies, we have retained it in some of the equations. This has the advantage of greater symmetry and makes it possible to derive "dual" results by making use of the symmetry properties of MAXWELL's equations. For time periodic fields we have used. in complex representation, the factor $\exp(-i\omega t)$ throughout.

We have not attempted the task of referring to all the relevant publications. The

* The important review article by C. J. BOUWKAMP, *Rep. Progr. Phys.* (London, Physical Society), **17** (1954), 35, records more than 500 papers published in the period 1940–1954.

references that are given, and which, we hope, include the most important papers, are to help the reader to gain some orientation in the literature; an omission of any particular reference should not be interpreted as due to our lack of regard for its merit.

In conclusion it is a pleasure to thank many friends and colleagues for advice and help. In the first place we wish to record our gratitude to Professor D. GABOR for useful advice and assistance in the early stages of this project, as well as for providing a draft concerning his ingenious method of reconstructed wave-fronts (§ 8.10). We are also greatly indebted to Dr. F. ABELÈS, who prepared a draft, which is the back-bone of § 1.6, on the propagation of electromagnetic waves through stratified media, a field to which he himself has made a substantial contribution. We have also benefited by advice on this subject from Dr. B. H. BILLINGS.

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The main part of the writing was done at the Universities of Edinburgh and Manchester. The last stages were completed whilst one of the authors (E. W.) was a guest at the Institute of Mathematical Sciences, New York University. We are grateful to Professor M. KLINE, Head of its Division of Electromagnetic Research, for his helpful interest and for placing at our disposal some of the technical facilities of the Institute.

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