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X-RAY MICROSCOPY

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BY

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PREFACE

In writing this monograph our intention has been to provide a connected account of the use of X-rays for microscopical investigation, commencing with the physical principles and including some microanalytical applications. Although its possibilities as a supplement to the established optical methods have long been clear, X-ray microscopy has become a practicable research tool only in recent years. A number of technological advances have combined to remove the major difficulties, which indeed largely stem from the properties of short wavelength and high penetration which make the method so attractive. A dioptric system, analogous to the compound light microscope, remains unrealized, but reflexion focusing at near grazing incidence has been thoroughly explored. Its aberrations are now well understood, if not yet more than partially correctable. On the other hand, the difficulties of focusing X-rays have been avoided by means of the two-wavelength procedure, in which a primary image is recorded with X-rays and the final image with visible light, all or part of the magnification being obtained by optical enlargement. The contact method, in which a one-to-one image is first obtained on a fine-grained emulsion, relies upon an optical microscope for the whole of the magnification, whereas in the projection method an image is formed directly at moderate magnification by a point source of X-rays.

These three methods of X-ray microscopy are now finding many practical applications, especially since they allow microanalysis of specific chemical elements to be carried out in a non-destructive manner, on the basis either of differential absorption or of the emission of characteristic line spectra. By the use of television techniques the latter method can be made to give a visible image of the distribution of a particular element in a specimen. These possibilities of microanalysis make the X-ray microscope a valuable complement to optical methods, even though its resolving power is so far no better.

The basic principles and limitations of the different methods have been fully investigated during the past decade, and their fields

of application are now being actively explored. A review of the subject should therefore be timely. Short surveys have appeared in year-books and elsewhere, but no comprehensive treatment has hitherto been published. The Symposium held at Cambridge in 1956, under the auspices of the International Union of Pure and Applied Physics, brought together for the first time the various workers in the subject, and gave the opportunity for an assessment of its state of development and future prospects. The present text owes a great deal to the inspiration of that meeting, as also to the advice and encouragement of many who contributed papers to it; nevertheless, the division of the subject-matter adopted here, and the views expressed on unsettled issues, are those of the authors themselves.

The book falls roughly into three parts: the principles of the main methods of X-ray microscopy (chapters 1–5), the practical details of their use for qualitative microradiography and quantitative microanalysis (chapters 6 and 7, 9–11), and examples of applications in biology, medicine, metallurgy and technology (chapters 12 and 13). In addition, it seemed useful to include some account of the production of X-rays (chapter 8), of microdiffraction procedures (chapter 14) and of certain recent developments of promise for X-ray microscopy (chapter 15). An appendix contains data about the absorption coefficients and the characteristic emission lines of the elements.

In a text covering so wide a field, in much of which the authors have no personal experience, it is only too possible that errors will exist. We shall be grateful to have them brought to our notice, and thanks are tendered in advance for this and for other comments which may help to improve the text of any future edition.

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Our thanks are also due to the following authors, publishers and learned bodies for permission to reproduce Text-figures and Plates from books and journals. Academic Press: Figs. 1.2, 2.1, 2.5, 3.6, 3.8, 6.10, 6.11, 6.12, 6.13, 6.14, 6.17, 7.6, 7.11, 7.13, 8.7, 8.8, 8.12, 9.1, 9.2, 10.3, 10.5, 11.8, 14.4, 14.13, 15.3, 15.4, and Pls. IB, II, III, VA, VIA, XIIB, XIIIA, XIX, XXB, XXIA, XXIB, XXIIIB, XXVA, XXVIIB, XXVIIC. *Acta Orthopaed. Scand.* and Dr K. Holmstrand: Fig. 6.7*b*. *Acta Paediatr. Stockh.* and Dr G. Wallgren: Fig. 8.10. *Acta Radiol., Stockh.*: Figs. 6.3, 6.4, 6.5, 6.6, 6.8. Dr K. W. Andrews: Pls. XIX, XXB. *Appl. Sci. Res.*: Fig. 15.5 and Plate XXXIIA. Prof. A. V. Baez: Fig. 7.13. Dr S. Bellman: Fig. 6.8. *Brit. J. Radiol.*: Pls. VIIIB, XXA, XXIV. *Cancer* and Dr B. Engfeldt: Pl. XVB. *Curr. Sci.*: Fig. 5.7. Dr P. Duncumb: Figs. 7.2, 7.3, 7.4, 7.8, 7.9, 7.10, 8.5, 15.1, 15.2. Dr J. Dyson: Figs. 4.11, 4.15, 4.16. Dr N. A. Dyson: Figs. 6.10, 6.11, 6.12 and Table A. 1. Dr W. Ehrenberg: Fig. 14.1. Prof. A. Engström: Figs. 2.1, 2.5, 6.4, 6.5, 6.13, 9.2, 10.4, 10.5 and Pls. XIIB, XVIA, XVII. *Exp. Cell Res.*: Fig. 10.4. *Fortschr. Phys.* and Dr G. Hildenbrand: Figs. 4.2, 4.3, 4.4, 4.13, 4.14, 4.18, 4.19. Dr A. Franks: Fig. 14.3. General Electric Co., Milwaukee: Pl. IXB. Prof. L. von Hámos: Figs. 5.2, 5.3, 5.4 and Pl. IV. Dr B. L. Henke: Figs. 8.12, 14.2 and Table A. 2. Mr K. Hooper: Pl. XXVIIA. Dr W. Hoppe and Dr H. J. Trurnit: Fig. 5.8. Prof. H. Hydén: Pl. VA. Mr C. K. Jackson: Pls. XVIB, XXIA. *J. Appl. Phys.*: Figs. 10.2, 11.3, 14.2 and Table A. 2. *J. Inst. Metals* and Prof. R. W. K. Honeycombe: Pl. XXVIII. *J. Sci. Instrum.*: Figs. 5.2, 5.3, 5.4, 6.15, 6.16. *J. Ultrastructure Res.*: Pl. XVIA. Prof. P. Kirkpatrick and Dr H. H. Pattee: Figs. 1.2, 4.12, 4.17, 14.4 and Pls. II, III. Dr G.

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