Optical Physics
Fourth Edition

This fourth edition of a well-established textbook takes students from fundamental ideas to the most modern developments in optics. Illustrated with 400 figures, it contains numerous practical examples, many from student laboratory experiments and lecture demonstrations. Aimed at undergraduate and advanced courses on modern optics, it is ideal for scientists and engineers.

The book covers the principles of geometrical and physical optics, leading into quantum optics, using mainly Fourier transforms and linear algebra. Chapters are supplemented with advanced topics and up-to-date applications, exposing readers to key research themes, including negative refractive index, surface plasmon resonance, phase retrieval in crystal diffraction and the Hubble telescope, photonic crystals, super-resolved imaging in biology, electromagnetically induced transparency, slow light and superluminal propagation, entangled photons and solar energy collectors. Solutions to the problems, simulation programs, key figures and further discussions of several topics are available at www.cambridge.org/Lipson.

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Fourth Edition

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Additional resources for this publication at www.cambridge.org/Lipson

Dedicated to the memory of our parents and grandparents,
Jane Lipson (1910–2009) and Henry Lipson (1910–1991)

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Preface to the fourth edition

We use optics overwhelmingly in our everyday life: in art and sciences, in modern communications and medical technology, to name just a few fields. This is because 90% of the information we receive is visual. The main purpose of this book is to communicate our enthusiasm for optics, as a subject both practical and aesthetic, and standing on a solid theoretical basis.

We were very pleased to be invited by the publishers to update *Optical Physics* for a fourth edition. The first edition appeared in 1969, a decade after the construction of the first lasers, which created a renaissance in optics that is still continuing. That edition was strongly influenced by the work of Henry Lipson (1910–1991), based on the analogy between X-ray crystallography and optical Fraunhofer diffraction in the Fourier transform relationship realized by Max von Laue in the 1930s. The text was illustrated with many photographs taken with the optical diffractometers that Henry and his colleagues built as 'analogue computers' for solving crystallographic problems. Henry wrote much of the first and second editions, and was involved in planning the third edition, but did not live to see its publication. In the later editions, we have continued the tradition of illustrating the principles of physical optics with photographs taken in the laboratory, both by ourselves and by our students, and hope that readers will be encouraged to carry out and further develop these experiments themselves.

We have made every effort to bring this edition up to date, both in terms of its layout and its scientific content. We have introduced several new features. First, starting with Chapter 2, each chapter has a short introduction defining the material that will be covered, with maybe a pictorial example of a significant application, as well as a summary of the main points at the end. In addition there are boxes that describe topics and examples related to the text. Furthermore, we have taken advantage of the margins to include some peripheral notes related to the text, and short remarks to direct the reader to related topics.

For several decades we have used this text for two courses. The first one is a basic second-year course on geometrical and physical optics, given to students who already have an elementary knowledge of electromagnetic theory and an introduction to calculus and linear algebra, which are generally taught in the first year of an undergraduate degree. This first course includes much of Chapters 3 (Geometrical optics), 4 (Fourier theory), 7 (Scalar-wave and Fresnel diffraction), 8 (Fraunhofer diffraction), 11 (Coherence) and 12 (Imaging), with parts of 9 (Interferometry) and 14 (Quantum optics and lasers).

A second advanced course has been built out of Chapters 6 (Crystal optics), 9 (Interferometry), 10 (Optical fibres and multilayers), 13 (Dispersion) and 14 (Quantum optics and lasers), with the more advanced parts of Chapters 8, 11 and 12 and research references. We have included in all the chapters short and not too technical descriptions of many recent developments in the field, either in the boxes or the more extended 'Advanced topic' sections, and hope that lecturers will use these to enliven their presentations and show that optics is a very broad and living subject. The remaining chapters, 1 (History), 2 (Wave propagation), 4 (Fourier theory) and 5 (Electromagnetic waves) contain introductory material, which may or may not have been covered in the prerequisite courses, together with examples of up-to-date applications such as gravitational lensing, spiral waves and negative refractive index materials. To assist lecturers, we shall make many of the figures in the book available on-line in an associated website (www.cambridge.org/Lipson).

We are not mathematicians, and have not indulged in elegant or rigorous mathematics unless they are necessary to underpin physical understanding. On the other hand, we have tried to avoid purely qualitative approaches. The main mathematical tools used are Fourier analysis and linear algebra. It is often claimed that Fraunhofer diffraction and wave propagation are the best ways to learn Fourier methods, and for this reason we devote a full chapter (4) to Fourier methods, including the important concepts of convolution and correlation.

In our efforts to bring the book up to date we have necessarily had to remove some older topics from the previous editions, so as to keep the length similar to the previous edition. Some of these topics will be transferred to the website together with other topics that there was no room to include. The website will also include solutions to the 190 problems at the ends of the chapters, and details of some of the computer programs used in topics such as diffraction, wave propagation and phase retrieval.

We are indebted to our colleagues, students and families for considerable help they have given us in many ways. In particular, David Tannhauser, who was co-author of the third edition, left an indelible mark on the book. Among those who have helped us with discussions of various topics during the preparation of this and the previous editions are: John Baldwin, Eberhart Bodenshatz, Sam Braunstein, Netta Cohen, Arnon Dar, Gary Eden, Michael Elbaum, Yoel Fink, Ofer Firstenberg, Baruch Fischer, Stephen Harris, Rainer Heintzmann, Shahar Hirschfeld, Antoine Labeyrie, Peter Nisenson, Meir Orenstein, Kopel Rabinovitch, Erez Ribak, Amiram Ron, Vassilios Sarafis, David Sayre, Mordechai Segev, Israel Senitzky, John Shakeshaft, Joshua Smith, Michael Woolfson and Eric Yeatman. All these people have our sincere thanks. We are also grateful to Carni Lipson for preparing many of the figures, and to the students who carried out the experiments illustrating many of the topics and are mentioned individually in the figure captions.

We must also thank the many researchers who have given us permission to use some of their most up-to-date research results as illustrations of advanced

topics, and are mentioned in the text. In addition we thank the following publishers and organizations for permission to use copyrighted material:

American Association for the Advancement of Science: Figs. 13.16, 13.17;
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We are also grateful to John Fowler and Sophie Bulbrook of Cambridge University Press for assistance and advice about the structure and planning of the book.

S.G.L. is indebted to the Materials Science and Engineering Department of the Massachusetts Institute of Technology for hospitality during 2008–9, where much of the work of revision of the book was carried out.

We hope that you will enjoy reading the text as much as we have enjoyed writing it!

Ariel Lipson, Tel Aviv
Stephen G. Lipson, Haifa

Preface from the original edition

There are two sorts of textbooks. On the one hand, there are works of reference to which students can turn for the clarification of some obscure point or for the intimate details of some important experiment. On the other hand, there are explanatory books which deal mainly with principles and which help in the understanding of the first type.

We have tried to produce a textbook of the second sort. It deals essentially with the principles of optics, but wherever possible we have emphasized the relevance of these principles to other branches of physics – hence the rather unusual title. We have omitted descriptions of many of the classical experiments in optics – such as Foucault's determination of the velocity of light – because they are now dealt with excellently in most school textbooks. In addition, we have tried not to duplicate approaches, and since we think that the graphical approach to Fraunhofer interference and diffraction problems is entirely covered by the complex-wave approach, we have not introduced the former.

For these reasons, it will be seen that the book will not serve as an introductory textbook, but we hope that it will be useful to university students at all levels. The earlier chapters are reasonably elementary, and it is hoped that by the time those chapters which involve a knowledge of vector calculus and complex-number theory are reached, the student will have acquired the necessary mathematics.

The use of Fourier series is emphasized; in particular, the Fourier transform – which plays such an important part in so many branches of physics – is treated in considerable detail. In addition, we have given some prominence – both theoretical and experimental – to the operation of convolution, with which we think that every physicist should be conversant.

We would like to thank the considerable number of people who have helped to put this book into shape. Professor C. A. Taylor and Professor A. B. Pippard had considerable influence upon its final shape – perhaps more than they realize. Dr I. G. Edmunds and Mr T. Ashworth have read through the complete text, and it is thanks to them that the inconsistencies are not more numerous than they are. (We cannot believe that they are zero!) Dr G. L. Squires and Mr T. Blaney have given us some helpful advice about particular parts of the book. Mr F. Kirkman and his assistants – Mr A. Pennington and Mr R. McQuade – have shown exemplary patience in producing some of our more exacting photographic illustrations, and in providing beautifully finished

prints for the press. Mr L. Spero gave us considerable help in putting the finishing touches to our manuscript.

And finally we should like to thank the three ladies who produced the final manuscript for the press – Miss M. Allen, Mrs E. Midgley and Mrs K. Beanland. They have shown extreme forbearance in tolerating our last-minute changes, and their ready help has done much to lighten our work.

S. G. L.
H. L.