Optical Effects in Solids

An overview of the optical effects in solids, this book addresses the physics of materials and their response to electromagnetic radiation. The discussion includes metals, superconductors, semiconductors and insulators. The book begins by introducing the dielectric function into Maxwell's macroscopic equations and finding their plane-wave solution. The physics governing the dielectric function of various materials is then covered, both classically and using basic quantum mechanics. Advanced topics covered include interacting electrons, the anomalous skin effect, anisotropy, magneto-optics, and inhomogeneous materials. Each subject begins with a connection to the basic physics of the particular solid, after which the measurable optical quantities are derived. It allows the reader to connect measurements (reflectance, optical conductivity, and dielectric function) with the underlying physics of solids. Methods of analyzing experimental data are addressed, making this an ideal resource for students and researchers interested in solid-state physics, optics, and materials science.

David B. Tanner is a distinguished professor of physics at the University of Florida. His research focuses on condensed matter physics and on astrophysics. He has previously served as department chair and chair of the Division of Condensed Matter Physics for the American Physical Society (APS). In 2016 he received the APS Frank Isakson Prize for Optical Effects in Solids and, in the same year, shared a Special Breakthrough Prize in Fundamental Physics for the discovery of gravitational waves.

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DAVID B. TANNER
University of Florida

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Preface

This book is a discussion of optical effects in solids, addressing the physics of many types of solids (metals, superconductors, semiconductors, insulators, and others) and their response to electromagnetic radiation. I try to make a connection between what an experimenter can measure or extract from measurements (reflectance, transmittance, optical conductivity, and dielectric function) and the microscopic physics of the solid. Methods of analyzing experimental data are addressed: the optics of thin films and the Kramers–Kronig relations.

I begin with introducing the dielectric function into Maxwell's macroscopic equations and finding their plane-wave solution. Then I discuss (first classically and then using basic quantum mechanics) the dielectric function of various materials. Other topics include interacting electrons, the anomalous skin effect, anisotropy, magneto-optics, and inhomogeneous materials.

I've attempted to write as a relatively complete coverage of the subject, starting with Maxwell's equations for the electromagnetism and with the Schrödinger equation and Newton's laws for the solid-state physics. The level of the presentation is aimed at the first- or second-year experimental graduate student. The electromagnetism assumed is undergraduate (Griffiths or Marion); the level of quantum mechanics is about the same (Griffiths or Peebles). Finally, it is helpful to have gone through solid-state physics (Kittel or Burns).

When I was a postdoc, the book by Frederick Wooten, *Optical Properties of Solids* (1972), appeared in the University Bookstore. I bought a copy and went through it during the next few weeks. It was just what I needed to read at the time: It was clear, it covered topics of interest to me, and it was at a level I could follow. I refer to it still and recommend it to others; I have also used it several times as a text in a course on optical properties for first-year graduate students in physics, materials science, electrical engineering, and chemistry. Unfortunately, the book is long out of print. I've attempted to write at the same level as Wooten and cover many of the topics of his book. (The exception is photoemission, which is a huge subject of its own by now.) I have included a number of things that Wooten did not address, such as phonons, superconductivity, anisotropy, magneto-optics, and inhomogeneous materials.

This book started life as the 2013 lecture notes for a graduate class in the optical properties of solids. This class has been offered to University of Florida graduate students at two- to six-year intervals over more than 25 years. That these started as lectures may be responsible for a certain informality in presentation. I've written in the first person, trying to avoid the royal or inclusive "we" that in much exposition attempts to co-opt the reader or the listener. I think that whenever a person hears "and now we see" or " in the future we must,” a quite proper response is “What do you mean by *we* Kemo Sabe.” First person avoids this response. I have also tried to avoid second-person instructions: “If you look at the figure, you can see . . . ” Well, a person looking at the figure may see what I want her or him to see, but may not. If not, it is my fault for not designing the right figure, not explaining it correctly, or not providing adequate background. In any event, it is better if I say what I see when I look at the figure and not presume more.

All solids may be divided into three classes based on conductivity: metals, semiconductors, and insulators. I use silver, silicon, and sodium chloride as examples of these classes. These materials are useful to persons other than solid-state physicists. The cover of the book shows one example. It shows the bowl of a toddy ladle made in England around 1760. Set into the bowl of the ladle is a silver sixpence that was minted in 1758. The coin was designed during the reign of George II by John Sigismund Tanner, Chief Engraver of the Royal Mint. The sixpence coin was called a “tanner” by the British right up until decimalization. (Six pennies may not seem a lot but the hourly wage at the time was 2–8 pence.)

I’ve had discussion with many persons over many years about the subject of optical effects in solids. I am grateful for all these discussions. A number of these discussions had direct influence on what I wrote here. For such discussions I thank Larry Carr, Jim Garland, Alan Heeger, Claus Jacobsen, Kati Kamarás, Ricardo Lobo, Frank Marsiglio, Dmitri Maslov, Jan Musfeldt, Michael Rice, Danilo Romero, Al Sievers, David Stroud, Lila Tache, Tom Timusk, Axel Zibold, the students who took PHY7097 and made comments and found typos, and the editors at Cambridge University Press for patience and accommodation.