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Book Review

Polarized Light, 3rd edn, by Dennis H. Goldstein, CRC Press, 2010, 808 pp., ISBN 978-1-43983-040-6, US $199.95.

1. Summary

Polarized Light 1st edition was produced in the 1990s by Edward Collett as a 581 pages manual which was largely a compilation of Collett's own papers. It was written with a great deal of dedication and care and with an overarching theme of how to use Stokes parameters and Mueller matrices to describe physical phenomena. The book was imbued with historical context, often these historical snippets were repeated throughout the text. Collett took the approach of repeating a common analysis method throughout many of the chapters, which served to reinforce the usefulness of Mueller matrix manipulations when describing polarized light. Collett's text could well be described as a masterpiece – it was a seminal text, the most detailed and yet approachable book on polarized light produced in the 1990s.

In the early 2000s Dennis Goldstein was given the task of updating the Collett book. Goldstein is an extremely experienced engineer who has made a career of developing polarizing spectrometers. He is a well-respected figure in the SPIE community, and has edited several *Proceedings of the SPIE* for *Polarized Light* conferences. To his credit, Goldstein took on the task of updating a fantastic text, and when he produced the 2nd edition of *Polarized Light*, he largely kept the 25 chapters of the Collett 1st edition intact, while reorganising the order of the chapters and adding 4 chapters of his own.

Perhaps dissatisfied with the slightly disjointed nature of the 2nd edition, Goldstein took another bite at updating the classic Collett text in 2011. The result is a extremely handsome hardcover book with a striking cover showing an interference pattern under crossed polarizers, colour inserts in the middle of the book, with every figure re-drawn and the book freshly typeset. Goldstein drew on experienced colleagues to write two new chapters, and re-wrote the introduction and added a short chapter himself. New equation numbers for every equation.

It must be noted that a large number of typographical errors that have crept into the third edition. Because all the equations in the book were renumbered, there are a large number (this author counted 24 typographical errors) including a section in pages 682, 683 and 686 were the editor must have gone to sleep because equations (33.17)–(33.24) all have denominators missing, which is unfortunate from the reader's point of view.

2. Evolution of the book

Table 1 shows the evolution of *Polarized Light* from edition 1 to 3. The table shows which chapters were in the first edition and how they were carried into editions 2 and 3.

3. Changes in the third 2011 edition

For the reader of this review who wishes to simply be informed what changes have occurred from edition 2 to 3, we discuss these changes in depth in the following paragraphs.

Dennis Goldstein wrote in the preface to the 3rd edition that the changes were "intended to inspire the reader to study polarized light". He achieved this by making three alterations to the beginning of the book:

(1) Collett's 5-pages 'Historical note' before chapter 1 was re-written to become a introductory section called 'Polarized light: A history' (also 5 pages long) in the third edition. Goldstein's re-write gives much insight into the different approaches of Goldstein and Collett. Collett's focus is on the science and the line of discoveries by scientists. This is the first time in the book where he tells the story of the "re-discovery of the Stokes Vectors", and the focus remains on scientific discoveries rather than personalities. Goldstein, however, takes an approach that your correspondent has seen in many engineering texts. He splits each paragraph into one scientist or engineer and gives their birth and death dates and

Table 1
Evolution of Collett and Goldstein's book *Polarized Light* across 3 editions

Edition 1, 1993	Edition 2, 2003	Edition 3, 2011
Author: Edward Collett	Author: Dennis Goldstein	Author: Dennis Goldstein
Publisher: Marcel Dekker	Publisher: Marcel Dekker	Publisher: CRC Press
25 chapters, 581 pages	29 chapters, 653 pages	34 chapters, 770 pages
1 appendix:	Added 3 appendices:	Added 1 appendix:
'Vector representation of the optical field – application to optical activity'	'Jones and Stokes vectors'	'Conventions in polarimetry'
	'Jones and Mueller matrices'	Updated 2 page bibliography
	'Relationships between the Jones and Mueller matrix elements'	
	Added a 2 page bibliography	
Part I – The classical optical field	**Part I – The classical optical field**	**Part I – Introduction to *Polarized Light***
1. Introduction	1. Introduction	1. Introduction
2. The wave equation in classical optics	2. The wave equation in classical optics	2. Polarization in the natural environment
3. The Polarization ellipse	3. The polarization ellipse	3. Wave equation in classical optics
4. The Stokes polarization parameters	4. The Stokes polarization parameters	4. The polarization ellipse
5. The Mueller matrices for polarizing components	5. The Mueller matrices for polarizing components	5. The Stokes polarization parameters
6. Methods of measuring the Stokes polarization parameters	6. Methods of measuring the Stokes polarization parameters	6. The Mueller matrices for polarizing components
7. The measurement of the characteristics of polarizing elements	7. The measurement of the characteristics of polarizing elements	7. Fresnel equations: Derivation and Mueller matrix formulation (was Chapter 8)
8. Mueller matrices for reflection and transmission	8. Mueller matrices for reflection and transmission	*8. The mathematics of the Mueller matrix*
9. The Mueller matrices for dielectric plates	*9. The mathematics of the Mueller matrix*	9. The Mueller matrices for dielectric plates
10. The Jones Mueller calculus	10. The Mueller matrices for dielectric plates	10. The Jones matrix formalism
11. The Poincare sphere	11. The Jones matrix calculus	11. The Poincare sphere
12. The interference laws of Fresnel and Arago	12. The Poincare sphere	12. Fresnel–Arago interference laws
	13. The interference laws of Fresnel and Arago	
Part II – The classical and quantum theory of radiation by accelerating charges	**Part II – The classical and quantum theory of radiation by accelerating charges**	**Part II – Polarimetry**
13. Introduction	14. Introduction	13. Introduction (added half page)
14. Maxwell's equations for the electromagnetic field	15. Maxwell's equations for the electromagnetic field	14. Methods of measuring the Stokes polarization parameters
15. The classical radiation field	16. The classical radiation field	15. The measurement of the characteristics of polarizing elements
16. Radiation emitting by accelerating charges	17. Radiation emitting by accelerating charges	*16. Stokes polarimetry*
17. The radiation of an accelerating charge in the electromagnetic field	18. The radiation of an accelerating charge in the electromagnetic field	*17. Mueller matrix polarimetry*
18. The classical Zeeman effect	19. The classical Zeeman effect	18. Techniques in imaging polarimetry
19. Further applications of the classical radiation theory	20. Further applications of the classical radiation theory	19. Channeled Polarimetry for snapshot measurements
20. The Stokes parameters and Mueller matrices for optical and Faraday rotation	21. The Stokes parameters and Mueller matrices for optical and Faraday rotation	
21. The Stokes parameters for quantum systems	22. The Stokes parameters for quantum systems	

Table 1

(Continued)

Edition 1, 1993	Edition 2, 2003	Edition 3, 2011
Part III – Applications	**Part III – Applications**	**Part III – Applications**
22. Introduction	23. Introduction	20. Introduction
23. Crystal optics	24. Crystal optics	21. Crystal optics
24. Optics of metals	25. Optics of metals	22. Optics of metals
25. Ellipsometry	*26. Polarization optical elements*	*23. Polarization optical elements*
	27. Stokes polarimetry	24. Ellipsometry
	28. Mueller matrix polarimetry	25. Form birefringence and meanderline retarders
	29. Ellipsometry	
		Part IV – The classical and quantum theory of radiation by accelerating charges
		26. Introduction
		27. Maxwell's equations for the electromagnetic field
		28. The classical radiation field
		29. Radiation emitting by accelerating charges
		30. The radiation of an accelerating charge in the electromagnetic field
		31. The classical Zeeman effect
		32. Further applications of the classical radiation theory
		33. The Stokes parameters and Mueller matrices for optical and Faraday rotation
		34. The Stokes parameters for quantum systems

their contributions to the field of polarized light. There is no doubt he covers more researchers in this manner, and he even adds a section on the Rumford Medal. The approach may come off as a little dry, however, and it lacks the enthusiasm of Collett's original Historical Note. In addition, Collett's Historical Note was designed to outlay the approach the author was taking to the subject throughout the book, and laying at the center the importance of the Stokes vectors.

(2) Collett's 2 pages Introduction (which is mainly historical and overlaps with the 'Historical note') is re-focused by Goldstein on applications – several large figures are added and Goldstein does indeed succeed in his goal of piquing the interest of the undecided reader with examples of polarization phenomena.

(3) A new chapter is added and forms Chapter 2 of the book entitled 'Polarization in the natural environment'. The chapter is 19 pages long and briefly introduces Rayleigh scattering in the sky, rainbows, glories and polarization of scarab beetles, squid, shrimp and discusses the sensitivity of animals to polarized light. This chapter is quite interesting and very well illustrated. Goldstein's efforts to entice and inspire the reader are therefore well taken in at least two of three changes to the introduction of the book.

Other changes elsewhere in the 3rd edition include:

(1) Insertion of an appendix, 'Conventions in *Polarized Light*' which covers differences between texts on representation of optical indices.
(2) An invited chapter on Imaging Polarimetry (23 pages review by Scott Tyo, David Chenault, Joseph Shaw).
(3) An invited chapter on Chaneled Polarimetry (33 pages review by Michael Kudenov).
(4) A small (4 pages) chapter on Form Birefringence and Meanderlines.

The review of Imaging Polarimetry is well written, if somewhat introductory, look at how imaging polarimeters work from an engineering perspective. It boasts a comprehensive bibliography and is very similar in style to review papers from SPIE Proceedings by the contributing authors. The review of Channeled Polarimetry is dense with equations that unfortunately are unsupported by the rest of the text and is written for engineers who are interested in the engineering specifications achievable by channeled polarimetry, which is a huge contrast to the rest of the book, and completely out of keeping with the Collett approach. It's inclusion here is a mystery and it should probably be skipped unless the reader is about to build a channeled polarimeter. It may be that Goldstein views channeled polarimetry an emerging and important method for future polarization specialists to become familiar with, however it would have benefited from further editing to bring it within the purview of the Collett text. The chapter on Form Birefringence and Meanderlines is also a mysterious addition to the text and at only 4 pages (1.5 of those being filled with large figures), it is perhaps most akin to an SPIE Proceedings abstract.

4. Outline of the book and pedagogical approach

This section of the review is intended for the reader who has not read a previous edition of *Polarized Light* at is interested to know what they will learn if they read the book cover to cover (like your correspondent!).

We follow the chapter organization of the 3rd edition – the interested reader can use Table 1 to translate the organization of chapters for earlier editions.

Since we have mentioned the re-worked introductory Chapters 1 and 2, we take up our outline at Chapter 3, 'Wave equation in classical optics'. In the opinion of this author, Collett got the book off to a somewhat shaky start with its somewhat ham-fisted discussion of solving the wave equation using plane waves and Fourier transforms, however it doesn't take long before he hits his stride at the end with a discussion of polarized reflection and transmission of waves at an interface. In Chapter 4, in a brisk 10 pages, 'The polarization ellipse', Collett covers the basics of the polarization ellipse.

It is Chapter 5 where Collett's love for the Stokes parameters begins to shine through, with an exceptional discussion of the history of the parameters and how they are used to represent light in various states. The reader is treated to a cogent and patient discussion of the relevant properties and equations of the Stokes parameters. The chapter ends with links to the coherency matrix and Pauli matrices, which are a bit of an afterthought. Chapter 6 builds on this established platform by introducing Mueller matrices and painstakingly develops the matrices for a polarizer, retarder, rotator and depolarizer.

Chapter 7 (renamed in the 3rd edition) is possibly the heart of the whole book. The start is somewhat shaky, with an exceptionally brief introduction to Maxwell's equations, added by Goldstein in the 2nd edition (Collett's approach was to delay the introduction of Maxwell's equations, though I think Goldstein was right to introduce them at this point because of the use he immediately makes of them). Goldstein then demonstrates a very effective derivation of the Fresnel's equations with polarization included and equations (7.37) and (7.41) (Fresnel reflection for TE and TM radiation at an interface) are given – these are then used throughout the rest of the book. Reflected and Transmitted Mueller matrices for dielectrics are also given here, and are also used throughout the book. In a further foreshadowing of future parts of the book, Collett develops the cases of Mueller matrices for normal and 45° incident light. Most of the chapter was originally based on 1971 and 1987 papers by Collett on linkages between Mueller matrices and Fresnel equations.

Chapter 8, 'Mathematics of the Mueller matrix', was added by Goldstein in the 2nd edition and the contrast with Collett's approach can be detected – linear analysis is used extensively in this chapter and is only minimal in the rest of the book. The Lu–Chipman decomposition is introduced, but it would have been great to see it used elsewhere in the book.

Chapter 9 is another masterful Collett chapter – this time discussing Mueller matrices of light reflected and transmitted from dieletric plates, including multiple scattering. Chapters 7–9 leave the reader feeling confident they could apply these techniques in their everyday practice.

Chapter 10 deals with the Jones Matrix approach to polarized light. Chapter 11 discusses how the Poincare sphere can be used to handle complex light transmission paths. Chapter 12 is a little unusual – again following a 1971 *Am. J. Phys.* paper by Collett, this time on the use of Stokes parameters to describe the Fresnel–Arago interference laws. This author is not convinced this chapter adds substantially to the book's narrative.

Chapter 13 is a short introduction to part II, 'Polarimetry', and Chapter 14 is an excellent Collett chapter on how to measure the Mueller Matrix of an arbitrary target using a retarder and linear polarizer, using several different approaches. Chapter 15 continues with this discussion, but focuses on how to measure the characteristics of three polarizing elements: a polarizer, retarder and rotator.

Chapter 16 is a Goldstein chapter that discusses engineering methods for measuring the Stokes state of light using various engineering approaches (rotating element, oscillating element, phase modulation and division of amplitude). It serves as a very interesting introduction to these methods, and is possibly the best Goldstein chapter. Chapter 17 is a Goldstein chapter that leads on from Chapter 16, this time discussing to the measurement of the Mueller matrix of arbitrary targets using differing engineering approaches (rotating element and phase modulation approaches). Spectropolarimetry and scatterometers are mentioned at the end of the chapter.

Chapters 18 and 19 are discussed thoroughly earlier in this review.

Part III, 'Applications', starts with Chapter 20, a short introduction, then goes to an excellent Collett chapter (21) that introduces birefringence and crystal optics in a reassuring manner. Chapter 22 follows on in this manner with Optics of Metals, devoting 20 pages of the 30 pages chapter to how measure the optical constants of metals using polarimetry.

Chapter 23, 'Polarization optical elements', is another Goldstein engineering chapter that first appeared in the 2nd edition. The text discusses how polarizers, rotators, retarders and depolarizers are made – it is a very useful introduction to the topic.

Chapter 24, 'Ellipsometry', is a long Collett chapter – 37 pages, discussing the manner in which ellipsometry measurements are made and developing the fundamental equation of classical ellipsometry, and how to solve it. It is an important addition to the book.

Chapter 25 is on meanderline retarders and is discussed earlier in this review.

Part IV, 'Classical and quantum theory of radiation by accelerating charges', is a fascinating section of the book that stands on the results introduced in the previous sections. The chapters were designed by Collett to tie together and Goldstein has kept them together in the 2nd and 3rd edition. The eight chapters lead the reader through a dizzying array of applications of the Stokes parameters to physical optics.

Chapter 26 is a 1-page introduction and Chapter 27 is the long-awaited discussion of Maxwell's Equations (in just 5 pages). Chapter 28 takes an interesting approach to the mathematical boundaries of the text – rather than deal with the vector calculus required to develop them, the transverse field components (E-phi and E-theta) for an accelerating charge in cylindrical coordinates (equations (28.12) and (28.13), called 'transverse equations' from now on) are simply stated without proof. These two equations are used in the remainder of the book to develop the Stokes Parameters for a range of situations of interest. Chapter 29 uses the transverse equations to deal with the radiation classically emitted by an accelerating charge (linearly oriented, randomly oriented and charges rotating in a circle and ellipse). Chapter 30 uses the transverse equations to deal with motion of an electron in a constant electric and then magnetic and then crossed electric–magnetic fields, and then derives their Stokes parameters.

Chapter 31 is an exciting diversion into the world of the Zeeman effect and its historical importance in the acceptance of the transverse wave nature of light. It is partly based on a 1968 Collett *Am. J. Phys.* paper, and again uses the transverse EM equations to derive the Stokes Parameters for Zeeman split emission lines.

Under the heading of 'Further applications of classical radiation theory', Chapter 32 discusses relativistic beaming and polarization, synchrotron and Cerenkov effect of wave self-interference. The chapter ends with an excellent section on Thompson and Rayleigh scattering and is capped by a brilliant summary on page 678.

From your correspondent's point of view, Chapter 32 is the brilliant climax of the Collett text. The final two chapters offer a discussion of Optical Activity and Faraday rotation (Chapter 33) which somehow doesn't quite fit into the rest of the book, and the final chapter (34) is an all-too-brief mention that Stokes parameters can also be used in quantum optics, and offers the reader interested in taking up the topic quantum polarization an introductory bibliography.

5. Who will this book appeal to and why?

Who will this book appeal to? The preface to the 3rd edition states that the target is "scientists and engineers working in a variety of fields" and states that this "can be used as a textbook for advance undergraduates or graduate students who have had calculus and linear algebra . . .". It is the broad and historically oriented approach of Collett and Goldstein that makes such a wide readership possible. Certainly this author would heartily recommend that any individual scientist or engineer working in the field of polarimetry should own a copy of this book.

Whether an owner of the second or first edition of the book should expend a large amount of money buying the third edition of the book will depend on whether they are part of the polarization community who will find the chapters on 'Imaging polarimetry and channeled polarimetry' (Chapters 18 and 19) of interest. They should also have some experience in polarimetry to appreciate Chapter 19 fully.

6. Conclusion

Edward Collett repeats at least three times in the book the "story of the Stokes parameters and their rediscovery". This is a compelling scientific story, whereby George Stokes published his famous vectors that were immensely successful in describing polarized light in a manner that the French genius Fresnel had been unable to develop (perhaps had he lived longer we would be talking of 'Fresnel's vectors'). Stokes' discovery was forgotten by himself and the English-speaking world until they were uncovered by Subrahmanyan Chandrasekhar in his treatise 'Radiative transfer'.

Collett takes the approach of using the Stokes vectors to describe light in several different settings. In this book, he succeeds in delivery a patient explanation of how Stokes parameters can be used by the practicing scientist and engineer.

Dennis Goldstein has added some valuable material to the original Collett book, primarily on engineering approaches to the construction of polarimeters. *Polarized Light* remains a landmark text, and a must for the collection of the polarized light practioner.

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