

Foreword

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1 Introduction

Optics in the twenty-first century is a vibrant part of modern physics, with stunning developments in fundamental science (imaging, correlations, and coherence, and so much more), as well as underpinning our technological world, including providing high bit rate optical communications, and precision laser engineering. But, 75 years ago, optics as a major field of research had been regarded by many as a backwater. One of the leaders of my own department at Imperial College London had described it as “all pins and mirrors” and pushed to have it dropped from the undergraduate syllabus. How wrong he was and how fashions have changed: the field was by then poised for explosive development, starting with the realisation, very much pioneered by Emil Wolf, that the study of correlations in light fields unlocked new insights. Understanding partial coherence, the extension to higher-order correlations with the work of Hanbury Brown and Twiss, and then of course the realisation of the laser transformed our views of the optical world. And the magnificent monograph by Max Born and Emil Wolf was at the fore in this revolution. With the publication of B&W, at last we had a magisterial account of the fundamental principles and their application. What an achievement! It has become a major sourcebook used throughout the world.

2 Physical Optics Prior to the Appearance of Born and Wolf

In the early twentieth century, authoritative books on optics, developing the basic phenomena in a systematic fashion, were not plentiful, especially ones building up the theoretical basis from proper electromagnetic foundations. It was, it seems, hard to locate sound and rigorous analytic treatments of diffraction theory, let alone high-level discussions of image formation.

Born’s own monograph *Optik* was published by Springer Verlag in 1933, just as he was forced to leave Germany by the Nazis. *Optik* itself eventually formed the seed for what became Born and Wolf, and was wrongly thought at the time by Born to have had very limited sales. Springer’s scientific advisor in the 1930’s was Paul Rosbaud, an influential figure in pre-war German science, in contact with all the important figures in German physics and much valued by Born. He was later to be revealed as a highly valued British Intelligence agent throughout the Nazi years as described by Kramish (1986) and will appear again in this account of how Born and Wolf came about.

3 Max Born

Max Born, one of the greatest figures in twentieth-century science, is best known for his pioneering work in the creation of quantum mechanics in the 1920s in Goettingen, for which he was awarded the Nobel Prize much later and after an inexplicable delay where the citation read for “fundamental research in Quantum Mechanics, especially in the statistical interpretation of the wave function.” Born had led an extraordinarily talented group of theoretical physicists, including Werner Heisenberg and Pascual Jordan, in the 1920s, who had pioneered the development of quantum mechanics, developing the matrix mechanics approach, commutation relations, and much more that underpins our understanding of the microscopic world. Indeed, Hedwig and Max Born’s tombstone in the Goettingen Stadtfriedhof carries the famous p, q quantum commutation relation, one that Born himself considered to be his main single contribution to science, according to his son Gustav (Born 2002).

But Born was truly a polymath, active in an extraordinary range of physics, including continuum mechanics, solid state physics, and of course optics. Max Delbrück, Siegfried Flügge, Friedrich Hund, Pascual Jordan, Maria Goeppert-Mayer, Lothar Wolfgang Nordheim, Robert Oppenheimer, and Victor Weisskopf all received their Ph.D. degrees under Born at Goettingen, and his assistants included Enrico Fermi, Werner Heisenberg, Gerhard Herzberg, Friedrich Hund, Pascual Jordan, Wolfgang Pauli, Léon Rosenfeld, Edward Teller, Walter Heitler, and Eugene Wigner. The catastrophic rise of the Nazis at the start of the 1930s destroyed this wonderful centre: expulsions and a mass exodus dispersed this incredible talent around the world, and Born’s *Optik* appeared as a kind of last act from this Goettingen world.

Max Born, for some years after 1933, led a peripatetic life in Cambridge and elsewhere, before finally setting in Edinburgh as Tait Professor of Natural Philosophy, where his group members included Kellerman, Fuchs, Schlapp, Nisbet, and others. His Edinburgh “Natural Philosophers” – really the theoretical physics group – were housed in High School Yard on Drummond Street, a rather dingy back street behind Thin’s University Bookshop, with a small lecture room and a large room to house the entire group. Born would progress round each of his group – and especially his students – every morning, asking what progress had been made since the day before. I vividly remember Wolf explaining to me the tensions this progression induced in the young researchers!

Born had been a prolific textbook author, on relativity, atomic physics, optics, and crystal lattice dynamics, demonstrating his enormous breadth of interests and his encyclopaedic knowledge. He retired from his chair in 1952 and he and his wife returned to Germany in 1954, and he continued with active writing for many years. He finally, and very belatedly, received his Nobel Prize in 1954 for his fundamental work in quantum mechanics. Max Born died at age 87 in hospital in Goettingen on January 5, 1970.

Born’s very precise mathematical approach to fundamental physical phenomena must have stemmed in part from his early academic career in Goettingen as the assistant to David Hilbert, the doyen of mathematics at the turn of the twentieth century. Born and Wolf beautifully displays this approach: elegant, deep, and precise. Kemmer and Schlapp (1971), in their Royal Society Biographical Memoir of Born, captured this precisely: “Born’s approach here, as in most of his other work, was to face his problem in all its complexity, to devise a mathematical formulation of appropriate generality and then to descend to the simpler, more tractable (and usually physically most interesting) cases as clearly defined specialisations and approximations to the general formalisms.”

4 Emil Wolf

Wolf, the father of optical coherence theory, dominated optics for more than half a century. He was born in Prague in 1922 to Jewish parents and at age 16, following the 1939 German invasion of Czechoslovakia, became a refugee, initially in Paris, and then, after a perilous escape from Paris, arrived in England after the fall of France in 1940. He completed high school in England and studied at the University of Bristol for his B.Sc. in Mathematics and Physics (1945) and stayed on for his Ph.D. with E. H. Linfoot, with a dissertation entitled “A Contribution to the Theory of Aspheric Optical Systems.”

About the time of Wolf’s Bristol thesis completion, his advisor E. H. Linfoot moved to the Cambridge University Observatory, taking Wolf with him as his assistant for the next two years. During this time, Wolf participated in the regular meetings then held at Imperial College of the small UK optics community, and cemented his strong links with Dennis Gabor, G. P. Thomson, and others.

Between January 1951 and 1954, Wolf worked at the University of Edinburgh with Max Born, writing B&W. According to Wolf (2005), Born wrote to Appleton, the then Principal of Edinburgh, saying that he felt the decision about appointing his assistant should not be made by Born alone as he “would like to appoint a Wolf after a Fox” (a previous holder of his assistantship was the atom spy Klaus Fuchs – “fox” in German)! After Born’s retirement, Wolf led a peripatetic career for a while. After a period on the Faculty of the University of Manchester, notably forming his close and highly successful collaboration on partial coherence with Brian Thompson (later to be Dean in Rochester), Wolf moved to the United States in 1959 to take a position at the University of Rochester where he supervised many Ph.D. students who went on to highly successful careers. He eventually became a naturalised US citizen and became the Wilson Professor of Optical Physics at the University of Rochester. My own stay in the group of Joseph Eberly at the University of Rochester (with an office along the corridor from Emil) in the early 1970s was enlivened by our daily group lunches at the University Faculty Club, where new developments in optics were vigorously dissected, and Emil showed his extraordinary grasp of the whole swathe of optical science. In 1978 he became President of the Optical Society of America, his spiritual home, and attended without fail the OSA Annual Meetings, always making a point of meeting up with student members to learn about the latest developments in optics.

5 Postwar Situation and Translation Plans for *Optik*

Paul Rosbaud, whom we met in an earlier section, was thanked in the preface of the first edition of B&W for having been closely associated with the project in its early days. Rosbaud had been involved in the earlier Born monograph *Optik* as a former editor for Springer, and was by then interested in translating German texts into English. Rosbaud after the war had moved to England, where he helped set up a publishing company, Butterworth-Springer, with a distinguished Scientific Advisory Board that included Alfred Egerton, Charles Galton Darwin (Born’s predecessor as Tait Professor of Natural Philosophy in Edinburgh), Edward Salisbury, and Alexander Fleming. When the Butterworth Company decided to pull out of the English/German liaison, Robert Maxwell (like Wolf, a Czech wartime refugee) acquired 75 percent of the shares of the company, while 25 percent rested with Rosbaud. The company name was changed

to Pergamon Press; the partners, with their considerable language skills, cooperated in establishing new academic journals until 1956, when, after an inevitable disagreement, Rosbaud left.

Maxwell from then on dominated Pergamon, with unhappy implications described below. Maxwell himself was ejected from the board of Pergamon in October 1969. An inquiry by the UK Government Department of Trade and Industry reported in mid-1971: “We regret having to conclude that, notwithstanding Mr Maxwell’s acknowledged abilities and energy, he is not in our opinion a person who can be relied on to exercise proper stewardship of a publicly quoted company.” Nevertheless, Maxwell reacquired Pergamon in 1974, although it was sold to Elsevier in 1991 after Maxwell’s strange drowning from his yacht in the Atlantic led to the collapse of his very extensive publishing group.

6 The Move from an Update of *Optik* to a New Book

As Born’s plans for a translation and updating of *Optik* were developing, he became aware of a curious involvement of the US Government in the rights for the book. The US had spent considerable sums in acquiring access to German scientific publications before the war. Then, during the war, they had reproduced many foreign journals and books under the aegis of the “Office of Alien Property Custodian,” which allowed US publishers with licences to print without royalty payments to authors or original publishers. Born, of course, had been a British citizen since before the war, yet was caught up in all this and had made no progress in restoring his rights to *Optik*, despite many appeals to the authorities. Indeed, according to Nancy Thorndike Greenspan, Born’s biographer (Greenspan 2005), Thomas H. Creighton of the Office of Alien Property insisted the rights were vested in the US under the Trading with the Enemy Act, that he would need to apply to the US Government for a licence if he wanted to use portions of *Optik* in the new book - and, what’s more, had to pay 2 percent royalties on the new book as they owned the copyright! The US Government finally relented, presumably realising that Born was far from ever being an enemy alien and had for many years been a citizen of an allied country! They returned to Born his copyright and, belatedly, the royalties on what he discovered were an unexpected 1,000 sales. As we will see, this should have alerted Born to be wary in future about reliable sales figures and royalties.

7 Update and Co-authorship

The (quite sparse in those pre-laser days) scientists working in optics in the 1940s and 1950s would gather regularly at Imperial College London for meetings of what had been called the “Optical Society of London,” and then became the Optical Group of the Physical Society, now the Institute of Physics. Regular attendees included Born, Dennis Gabor, Harold Hopkins, E. H. Linfoot, and, of course, Emil Wolf. Later attendees included Leonard Mandel, who became Wolf’s closest collaborator over many years. The early plans envisaged Born contributing material from *Optik*, with new sections contributed by proposed co-authors Dennis Gabor and Harold Hopkins. The initial plan was to complete the book by late 1951, before Born’s retirement from the Tait chair, although of course the writing took eight years in the end. Hopkins withdrew from the

project early in 1950, and in October 1950 Gabor, encouraged by Born, wrote to Linfoot and Wolf asking if they could take Hopkins' place (Wolf 2005). Eventually, Born, Gabor, and Wolf agreed to author the new book. Wolf moved from Cambridge at the end of January 1951 to focus on the book. But then Gabor, like Hopkins earlier, decided he really did not have the time to devote to the writing as a full author but agreed he would contribute a section on electron optics. So, at that point, we see the emergence of the Born and Wolf collaboration.

The book was intended from the outset to have sections on various specialist topics contributed by others (Wolf himself was initially drawn into the project to write one on the diffraction theory of aberrations!). Distinguished contributors included Clemmow on rigorous diffraction theory (and the appendix on steepest descent and stationary phase), Wilcock on interferometers, Wayman on image-forming optics, Bhatia on ultrasonic diffraction, Gabor on the link between geometrical optics and classical mechanics – especially for electron optics – and so on. An appendix on the calculus of variations is based on unpublished lectures by David Hilbert, Born's early mentor in Goettingen, providing a link going back a century by then to one of the greatest mathematicians in the world.

Most of the writing was done in Edinburgh and Manchester, and finally completed when Wolf was a guest at the Institute of Mathematical Sciences at New York University. Born was always able to write quickly, and according to Wolf was often none too pleased with the slow progress made overall on the Principles of Optics project. The delays in part stemmed from the new developments in optical coherence developed principally by Wolf. By 1957, Wolf received a letter from Born asking why the book was still unfinished. Wolf replied that it was essentially completed, except for the chapter on partial coherence. According to Wolf (2005), Born wrote back to ask “who apart from you is interested in partial coherence. Leave that chapter out and send the rest of the manuscript to the printers.” Fortunately, he resisted, and within a couple of years the laser revolution was upon us and optical coherence became centre stage in the subject.

One of the features of the book from the outset was the careful discussion of optical correlations, both of amplitudes and of intensities. The early Manchester experiments carried out by Brian Thompson on the effects of partial coherence on two-beam interference were included to illustrate the importance of first-order coherence. The dramatic discovery of intensity correlations by Hanbury Brown and Twiss also appeared at this time and featured in the book.

8 The First Born and Wolf

The first edition appeared in January 1959, by which time Max Born had retired from his chair in Edinburgh to live in Bad Pyrmont in Germany. Emil Wolf was then working in Manchester University. This first edition of Born and Wolf was very well received for its unique comprehensiveness and depth: to quote Kemmer and Schlapp (1971), “it presents a systematic treatment based on electromagnetic theory of all optical phenomena that can be described in terms of a continuous distribution of matter.”

Born and Wolf appeared at an extremely opportune time: just before the realisation of the laser, where its spatial and temporal coherence and ability to transform image science and information technology. Suddenly, everyone needed the insights that Born and Wolf provided. Gabor himself stated that Born and Wolf was the first systematic account

of holography in an authoritative text. Serendipity played its role too: for example, as lasers were used to explore nonlinear optics, it was necessary to understand the spatial distribution of intensity and phase of focused laser beams, and there in B&W already was a beautiful discussion of the very isophotes the pioneers needed to understand phase matching.

9 The Reception of Born and Wolf

Born and Wolf was very warmly received from the outset. University teachers quarried it for insights in their courses, researchers used it as a source of rigorous reliable information in optical science, and the resultant excellent sales reflected the real value the world community placed on this treasure.

10 Updates

Updates and new editions appeared on a regular basis as new developments were carefully incorporated by Wolf. The authors had considerable difficulties for some years with Pergamon Press over royalties, with discrepancies over sales figures and the emergence of perhaps previously unknown editions; this led to complex legal arbitration, described in the biography by Greenspan and in detail by Max Born's son, Professor Gustav Born, in an article written shortly after Maxwell's death, entitled "Pilfering from the Professors" in the UK magazine *The Oldie*, edited then by Richard Ingrams. The British satirical magazine *Private Eye*, also edited by Ingrams, had previously lampooned Maxwell as the "bouncing Czech," a nickname originally coined by Prime Minister Harold Wilson when Maxwell had been Labour MP for Buckingham. The happy transition to Cambridge University Press for this edition of B&W (and the previous two editions) put an end to what can only be described as a sorry story of the collisions of two worlds, one of academia and what had sadly been revealed as one of a predatory publisher. What a contrast this revealed between two Czech refugees from Nazi tyranny with such different characters – Emil Wolf being one, and Robert Maxwell the other, entangled over Born and Wolf! The first five revised editions were published by Pergamon Press (1959–1975). Cambridge University Press took over the publishing of the monograph in 1980 with a seventh expanded edition published in 1999. I still treasure my own Pergamon and Cambridge editions complete with a handwritten greeting from Emil.

Plans were already expressed in the preface of the first edition of B&W for a volume II on Molecular and Atomic Optics, and volume III on Quantum Optics (one of the earliest uses of this term, to my knowledge). Rather touchingly, the authors expressed the hope that the CGS system of units would have returned to favour by the time these volumes might appear. Readers of the famous 1995 monograph *Optical Coherence and Quantum Optics* by Leonard Mandel and Emil Wolf, representing in itself – in a sense – this long-awaited "volume 3," will have noted a partial fulfillment of this hope!

11 Lasting Value, Scholarship, and Reliable Knowledge

Here one continues to find in this masterpiece of lucid authoritative writing the most complete account of modern classical optical physics. Born and Wolf remains one of

the most influential science books of the past 75 years. Here you will find the most precise accounts of the Kirchhoff theory of diffraction, the theory of image formation and aberrations, of partial coherence, and the like. You will find here the principles of diffraction tomography, of scattering by inhomogeneous media – I could go on, of course! Its impact can be measured by the many editions and reprints it has gone through: a book that has a treasured place on the shelves of anyone working seriously in optics.

Acknowledgements

In writing this preface to the anniversary edition, I have drawn on many years of discussions with Emil Wolf and his colleagues, and with Max Born's son G. V. R. Born (Gus), as well as from the many publications of and about Born and Wolf – but especially from a lifetime of consulting this magnificent book!

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