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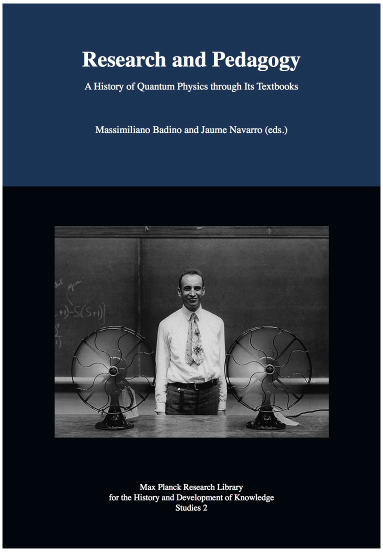
Clayton A. Gearhart:

Fritz Reiche's 1921 Quantum Theory Textbook



In: Massimiliano Badino and Jaume Navarro (eds.): *Research and Pedagogy : A History of Quantum Physics through Its Textbooks*
Online version at http://edition-open-access.de/studies/2/

ISBN 9783844258714
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Printed and distributed by:
Neopubli GmbH, Berlin
http://www.epubli.de/shop/buch/30988

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at http://dnb.d-nb.de

Chapter 5
Fritz Reiche's 1921 Quantum Theory Textbook

Clayton A. Gearhart

5.1 Introduction

Who reads textbooks? Students, of course. But also their professors and other professionals, including both specialists, who need to keep up with the latest developments, and others who want to maintain a comprehensive picture of their discipline. Not least, textbooks can be a treasure trove for historians: Textbooks give us a snapshot of the state of a discipline in a particular time and place, and from a particular point of view.[1]

Here I will examine Fritz Reiche's 1921 quantum theory textbook (Reiche 1921a).[2] At its publication, barely 20 years had passed since Max Planck had introduced his finite "energy elements" to explain black-body radiation and, in the process, inaugurated quantum theory. Yet, as Reiche's book and its antecedents show, quantum theory had been reaching out beyond the realm of specialists for nearly a decade, both to students and to physicists and physical chemists who wanted to know something of this new theory.

Fritz Reiche was born in 1883 and earned his Ph.D. in 1907, as one of Planck's comparatively small number of research students.[3] He spent the years from 1908 to 1911 in Breslau, working with Otto Lummer in a vain attempt to gain proficiency in experimental physics. There he met Max Born, who was in Breslau for the same reason. Judging from their later recollections, the two vied in producing spectacular floods, explosions, and other catastrophes of the experimental life, leading one to conclude that Lummer was not only an eminent experimentalist, but an eminently patient one. Born recalled learning a great deal about relativity and quantum theory from Reiche (Born 1978, 124).[4]

In 1913, Reiche was back in Berlin and, with Planck's support, qualified as a *Privatdozent* (instructor) at the University of Berlin. He was an assistant to Planck from 1915

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[1] The word "textbook" encompasses a multitude of sins. Here I am including under that rubric books written for a professional audience. Since quantum theory was an advanced topic early in the twentieth century, the distinction between books intended specifically for students, and ones aimed at a more general professional audience, was at best hazy.

[2] Remarkably, as of this writing (September 2010), Reiche's book is still in print, in both the German original and the English translation. An electronic copy of the German edition may be found on Google books. The quotations used here draw on the English translation, but often revise it. Other translations in this chapter are my own.

[3] For more comprehensive biographical sketches of Reiche, see (Bederson 2005; Wehefritz 2002). The latter includes a bibliography of Reiche's publications.

[4] See also Thomas S. Kuhn and George E. Uhlenbeck, interview with Fritz Reiche, March and April 1962, Archive for History of Quantum Physics (AHQP). See esp. session 2, pp. 1–2. This episode reminds us that in spite of exceptions like Planck and Einstein, it was still uncommon for physicists to restrict themselves exclusively to theory. It was therefore sensible for both Reiche and Born to seek some background in experimental work. Nevertheless, as their careers demonstrate, their lack of an experimental background was not an insuperable obstacle. See, for example, (Jungnickel and McCormmach 1986).

to 1918, where his duties included correcting students' solutions to the problems Planck assigned, and answering their questions.[5] From 1919 to 1920, he was an advisor to Fritz Haber's Physical Chemistry Institute in Berlin, where, as he later recalled, he became known as the "little oracle"—in contrast to the "big oracle," Albert Einstein.[6] In 1921, the same year in which his book appeared, he was appointed Professor of Physics at the University of Breslau, where he would remain until 1933, when the Nazis forced him out. Reiche's research papers through 1916 were primarily on aspects of electromagnetic theory, including work on diffraction gratings and dispersion theory. But in 1917 his interests turned to quantum theory, and during the late teens and twenties, he published a series of influential and widely cited papers on such topics as dispersion (with Rudolf Ladenburg), molecular spectra, the spectrum of helium (with James Franck), and the specific heat of hydrogen (Gearhart 2010; Duncan and Janssen 2007; Wehefritz 2002).

5.2 Fritz Reiche and *Die Naturwissenschaften*

The story of Reiche's textbook begins in 1913, when Arnold Berliner persuaded Ferdinand Springer to establish a new journal, *Die Naturwissenschaften* (The Natural Sciences), which, like *Nature* in Britain and *Science* in the United States, would report on new developments in all of the natural sciences for all scientists. As Berliner and his co-editor Curt Thesing put it in an editorial in the very first issue,

> The rapidly progressing specialization in all branches of research in the natural sciences [*Naturforschung*] makes it difficult for the individual to become informed about even neighboring domains. It is almost impossible for him to become acquainted with more distant ones [...]. "*Die Naturwissenschaften*" is determined to fill this gap.

As his friend Max Born wrote in a 1942 obituary, Berliner

> insisted that every article in *Die Naturwissenschaften* should be written in such a way that his "simple mind" could understand it. How few of the contributions proved up to the high standard which he set, and how lively was the ensuing correspondence. (Born 1942, 285); quoted in (Stöltzner 2003, 172)

Another friend, Paul Peter Ewald, added that

> Berliner addressed himself mainly to the then young generation of men of science. Much of the success of the journal was due to Berliner's vivid personality, his close contact with the majority of young physicists and mathematicians and his initiative in formulating the subject of articles he wanted written for his journal. Thus *Die Naturwissenschaften* became a mirror reflecting the development of science during 1913–30. (Ewald 1942, 284); quoted in (Stöltzner 2003, 171)

[5] See Reiche's description in his AHQP interview (footnote 4), session 1 (30 March 1962), p. 2, and session 2 (4 April 1962), p. 8.
[6] Letter from Reiche to Kuhn, 17 July 1962, in the interview file (footnote 4).

Reiche began writing for *Die Naturwissenschaften* in the first (1913) volume. He may well have come to Berliner's attention via Max Born, who had met Berliner in Breslau about a decade earlier, though by all accounts, Berliner had an extraordinarily wide circle of acquaintances (Born 1978, 79).[7] From the outset, Reiche showed a gift for direct, striking prose, and an ability to present complex material clearly and simply. In December 1913, he opened a five-page article on "lattice phenomena"—a topic related to his early research—by saying,

> If someone, standing at the window of an evening, looked through a fogged or frost-covered window pane by the light of a street lantern, he would see the light surrounded by colored rings, in which he would easily recognize the colors of the rainbow. (Reiche 1913b, 1193)

By stages, he drew his readers into a careful, detailed, but non-technical discussion of wave motion, diffraction, and interference that ended with a description of Max von Laue's work on X-ray diffraction in crystals.

This piece was not Reiche's first contribution. Six months earlier, in June 1913, Reiche published a nine-page, two-part article on quantum theory, intended to summarize the deliberations of the 1911 Solvay conference.[8] It was not the first article on quantum theory to appear in *Die Naturwissenschaften*; that honor fell to Reiche's friend Max Born (Born 1913). But Reiche's piece was by far the most comprehensive. It began by noting that "Greek thinkers were the first to state clearly that all matter consists of small, indivisible particles, atoms." Reiche then reviewed nineteenth-century kinetic theory, Brownian motion, electron theory, and black-body radiation, and went on to give a thorough description of the experimental evidence for and theoretical scope of quantum theory as of 1913, in clear, striking language. He concluded by quoting Marcel Brillouin, from the closing discussion of the Solvay conference:

> It has become necessary to introduce a discontinuity into our physical ideas, an element that can change only in jumps, whose existence we had not suspected until a few years ago. (Reiche 1913a, 572)

With this article, Reiche showed his ability to present at an introductory level what even in 1913 was a complex, many-faceted subject. And although another four years would pass before he began to publish his own research on quantum theory, it is evident that by 1913 he already had an encyclopedic knowledge of the subject. More generally, we see that quantum theory was sufficiently established to merit several articles for non-specialist readers in *Die Naturwissenschaften*.

5.3 Interlude: The Quantum Underground

Between 1913 and 1936, Reiche published some twenty book reviews in *Die Naturwissenschaften*, the majority during the teens and early twenties, and many of them on quantum

[7] For more on Berliner and *Die Naturwissenschaften*, see (Stöltzner 2003).

[8] This conference, named for its sponsor, the Belgian industrialist Ernst Solvay, and organized by the physical chemist Walther Nernst, explored the implications of the new quantum theory and served to introduce it to a wider scientific audience. See for example (Kormos Barkan 1999, chap. 11).

theory. Most of these reviews are unsurprising. For example, he reviewed Arnold Eucken's 1914 German translation of the proceedings of the 1911 Solvay conference, both Planck's and Wilhelm Wien's lectures at Columbia University, and Planck's 1920 Nobel Prize lecture, in which Reiche tells us, "Max Planck gives [...] an overview of the wonderland that he opened up twenty years ago."[9]

But in 1914 and 1915, Reiche also reviewed two books by Siegfried Valentiner and a third by Hermann Sieveking (Reiche 1914; 1915) that throw an unexpected light on early quantum theory, as does a fourth book, which Reiche did not review, by the British physicist Owen W. Richardson. All three authors were physicists. None was deeply involved in quantum theory. And yet, by 1914, all three had written sophisticated and detailed accounts of quantum theory for students and professional audiences. Before continuing with the story of Reiche's book, let us see what these earlier books can tell us about early quantum theory.

Hermann Sieveking was born in 1875, in Hamburg, and earned his Ph.D. in Freiburg in 1899. He was appointed *außerordentlicher Professor* ("extraordinary professor"—often translated, not altogether accurately, as associate professor) at Karlsruhe Technical University (*Technische Hochschule*) in 1910. He died suddenly in 1914; a long obituary appeared in the same issue of *Die Naturwissenschaften* as the last of his several contributions to that journal (Jensen 1914; see also Weinmeister 1926). His research involved such topics as radioactivity, and electrical discharge in gases, and was divided, judging from the obituary, between theoretical and experimental work. He was also interested in airships, on which he lectured at Karlsruhe in 1913.

Sieveking's 1914 book, *Contemporary Problems in Physics*, grew out of a series of lectures that he gave in Mannheim to the local chapter of the Association of German Chemists, who, he tells us in the introduction, wanted to learn about "recent achievements in theoretical chemistry and physics." The book included chapters on electron theory, radioactivity, X-rays, relativity, and a final, thirty-page chapter on "Progress in Thermodynamics"—in fact, quantum theory (Sieveking 1914).

That final chapter had even earlier roots. It had appeared late in 1912, in the *Proceedings* of the Karlsruhe Natural Scientific Society, with the more descriptive title "On the Radiation Law, the Action Quantum, and Nernst's Theorem." Remarkably, a note at the end of this article stated that, even earlier, the article had been prepared to compete for a prize offered by the Eisenlohr foundation (*Eisenlohrstiftung*), on the topic "Explanation [*Darlegung*] of Energy Quanta" (Sieveking and Viefhaus 1911, 134).[10] Karlsruhe was by no means the end of the earth; after all, Heinrich Hertz had done his experiments detecting electromagnetic waves and thus confirming Maxwell's laws there. And Fritz Haber spent the formative years of his career there, leaving in 1911 to become the director of the newly formed Kaiser Wilhelm Institute for Physical Chemistry in Berlin (Stoltzenberg 1994, esp. chaps. 4 and 5). But neither was it a center of activity on quantum theory. Nevertheless, quantum theory had achieved sufficient notoriety to merit a local foundation prize, and subsequent inclusion in a series of lectures to a group of chemists.

Siegfried Valentiner was born in 1876, and earned his Ph.D. in Heidelberg in 1900. He spent several years in Berlin as both an instructor (*Privatdozent*) at the University and a

[9] *Die Naturwissenschaften* 2 (1914), 662–663; 4 (1916), 650; 9 (1921), 18.

[10] The Eisenlohr foundation may be related to Wilhem Eisenlohr, who taught at the Karlsruhe *Technische Hochschule* in the mid-nineteenth century; see (Jungnickel and McCormmach 1986, vol. 2, 85). I have been unable to learn anything more about this prize or the foundation.

staff member of the Physikalisch Technische Reichsanstalt.[11] There he published one paper comparing optical temperature scales using a nitrogen gas thermometer at high temperatures, an example of the practical side of the PTR's work on black-body radiation (Holborn and Valentiner 1907).[12] It is likely enough that he first became acquainted with quantum theory during his years in Berlin. In 1910 he was appointed Professor of Physics at the School of Mines (*Bergakademie*) at Clausthal, where he spent the rest of his career.[13] The bulk of his published research lay in experimental physics and does not seem related to quantum theory. He wrote other textbooks, most notably a book on vector analysis (Valentiner 1907) that remained in print through the 1960s. He died in 1971.[14]

In 1914, Valentiner published two quantum theory textbooks, *Elementary Foundations of Quantum Theory* and *Applications of Quantum Theory in the Kinetic Theory of Solid Bodies and Gases*. More than any of the books discussed in this essay, Valentiner's were clearly intended for students. Valentiner stated in his introduction to the first book that he hoped it would be useful for young physicists and called attention to its elementary mathematical level. His first chapter gave a long historical introduction that carefully stated (but did not prove) the equipartition theorem, and went on to describe, carefully but qualitatively, the implications of quantum theory for such topics as black-body radiation, the specific heats of solids and gases, and Sommerfeld's theory of non-periodic processes. His readers were thus prepared for the more detailed treatment that followed in both books. The two books—in total, about 140 pages—gave a solid and reasonably complete description of the state of quantum theory in 1914.

In that same year, the British physicist Owen W. Richardson published a fourth book in this genre. Entitled *The Electron Theory of Matter* and extending to over 600 pages, it was based on his graduate course at Princeton University. Richardson was an experimentalist who won the Nobel Prize in 1928 for his work on thermionic emission, the emission of electrons from hot bodies. His book is the subject of an excellent essay by Ole Knudsen (2001). Suffice it to say here that although Richardson's research interests were peripheral to quantum theory, he nevertheless found such topics as Planck's radiation law and the photoelectric effect useful for his work, and devoted considerable space to them (Richardson 1914).[15] In his preface, for example, he expressed the hope that "the difficulties which beset the electron theory of metallic conduction [...] may be overcome by the application of the ideas underlying Planck's theory of radiation." He even included a brief summary of Bohr's 1913 theory of the hydrogen spectrum—hot off the press in 1914. As far as I know, it represents the first textbook reference to Bohr's theory. Richardson gave a considerably expanded treatment of Bohr's theory in the second (1916) edition.

There are a few themes common to all four of these books:

[11] The PTR, as it is often called, was founded in 1887, and might best be described as a national laboratory concerned with integrating pure science with the technological needs of industry. As such, it served as a model for the National Physical Laboratory in England and the National Bureau of Standards (now the National Institute of Standards and Technology) in the United States, both founded a little over a decade later. See (Cahan 1989).

[12] See also (Cahan 1989). Much of the experimental work on black-body radiation that contributed to Planck's discovery of his radiation law late in 1900 was done at the PTR.

[13] Valentiner served on several occasions as rector at Clausthal during the 1920s and 1930s. This history of the *Bergakademie* in these years does not seem to have been studied in great detail; but see (Müller 2005; 2007).

[14] See (Weinmeister 1926) and later editions of Poggendorff.

[15] Richardson had touched on Planck's radiation law as early as 1911 in an essay in the *Proceedings of the American Philosophical Society* (Richardson 1911). Moreover, Richardson and one of his students at Princeton, Karl T. Compton, conducted experiments on the photoelectric effect; see (Stuewer 1975, 63–64).

1. All three authors were skeptical of Einstein's light quantum hypothesis.
2. All three showed a marked preference for Planck's "second theory," in which oscillators absorbed energy continuously but emitted energy quanta.
3. All three emphasized the photoelectric effect and promoted quantum (albeit not light quantum) explanations. Historians often (and correctly) criticize modern textbooks for emphasizing the photoelectric effect, sometimes at the expense of the more fundamental aspects of Einstein's light quantum hypothesis. Nevertheless, this tradition goes back to the early days of quantum theory textbooks!
4. All three made use of a February 1911 paper by Walther Nernst, published in the *Zeitschrift für Elektrochemie*. This paper presented, in a form suitable for chemists, Einstein's quantum theory of the specific heats of solids and Nernst's extensive low-temperature measurements supporting that theory. Nernst had also pointed out the discrepancies between the equipartition theorem and the measured specific heats of gases, and argued that there too, quantum theory offered a way out. Nernst's paper was widely cited, and seems to have played an important role in acquainting physicists and physical chemists with the new quantum theory. Both Sieveking and Valentiner relied heavily on it. Valentiner, in fact, was lead astray by this paper; he did not notice an error in Nernst's treatment of the rotational specific heat of diatomic gases—an error that Einstein corrected at the Solvay conference late in 1911 (Nernst 1911).[16]

When Nernst began to promote what became the 1911 Solvay conference, Max Planck was concerned that there was not yet sufficient interest in quantum theory to justify such a meeting (Kormos Barkan 1999, chap. 11).[17] These books, together with the articles and reviews in *Die Naturwissenschaften* by Reiche, Born, and others suggest that on the contrary, by 1912 or so, quantum theory was arousing considerable interest outside the realm of specialists.

5.4 Reiche's Textbook and the State of Quantum Theory in 1921

Volume 6, Number 17 of *Die Naturwissenschaften* appeared in April 1918, just as Germany was launching the offensive on the Western Front that it hoped would bring victory in the Great War (Keegan 1998, chap. 10). The issue was devoted to a *Festschrift* celebrating Max Planck's sixtieth birthday, and included articles by such luminaries as Arnold Sommerfeld, Wilhelm Wien, Walther Nernst, and Max von Laue. It also included Reiche's seventeen-page essay, "The Quantum Theory: Its Origin and Development" (Reiche 1918). Like its 1913 predecessor, it was comprehensive in its coverage. This essay became the germ of his 1921 book. The book itself appeared in 1921, and was quickly followed by an English translation (Reiche 1921a). The translators were Henry L. Brose, an Australian physicist, and Henry S. Hatfield, an English chemist. Both were prominent scientific translators; Brose, for example, translated the third edition of Sommerfeld's *Atombau*. Brose and Hatfield may have become

[16]For a discussion, see (Gearhart 2010).
[17]Valentiner and Richardson mentioned the Solvay conference in their books. Sieveking did not, either in his book or his earlier article; he did, however, cite the well known paper of Henri Poincaré that appeared in the aftermath of that conference; see for example (Prentis 1995).

acquainted while both were prisoners in the Ruhleben civilian internment camp near Berlin during the Great War (Stibbe 2008).[18]

The book appears to have sold well. Inexpensive copies are still widely available on the used book market. The English edition may have been especially popular; it went through three printings, the second two in 1924 and 1930. For the 1930 edition, Brose and a colleague, John E. Keyston, contributed a "brief outline of the developments since 1922," as they put it in an introductory note.

As in his earlier *Naturwissenschaften* pieces, Reiche's prose was clear and forceful; I give a few examples later. The level remained introductory. The book is, on the whole, historically accurate; even today, one can get from it a good picture—from Reiche's point of view, to be sure—of the state of quantum theory around 1920.

Reiche's 1914 review of Siegfried Valentiner's books shows that, even then, he was thinking about how to present quantum theory to non-specialists:

> As happy as we are to welcome such an introduction, it nevertheless appears to me difficult to find the correct boundary between a strong mathematical line of argument on the one hand, and arguments that are, as much as possible, mathematics-free and still persuasive on the other. It is a well known difficulty with which all popular accounts must struggle. (Reiche 1915)

By 1921 Reiche had found a solution to this dilemma. His main text was about 160 pages (125 pages in the English translation), but included an additional 25 pages of endnotes, many of them extending and deepening the treatment in the text. Readers seeking only an introduction could confine themselves to the text. Advanced readers would find more detailed and mathematical discussions, as well as citations to the research literature, in the notes.[19]

Reiche's coverage was comprehensive, as one can see from the following chapter outline. Very few topics in quantum theory went unmentioned, and on unsettled questions, Reiche usually gave a careful summary but refrained from taking sides. Note especially the emphasis given in Chapter V to molecular topics—the specific heat of hydrogen and infrared absorption spectra—which, in fact, had provided some of the earliest experimental support for quantum theory (Gearhart 2010). Reiche's treatment reminds us that the scope of quantum theory extended far beyond black-body radiation, the specific heats of solids, and atomic spectra:

- Chapters I, II: Black-body radiation, including experiments; the Stefan-Boltzmann law; Wien's law; Planck's path to his radiation formula; equipartition and the Rayleigh-Jeans law.
- Chapter III: Einstein's light quanta, including derivation; fluctuations and the wave-particle duality; evidence in favor (including phosphorescence [Stokes's law], fluorescence, photoelectric effect, inverse photoelectric effect). But also objections from

[18] See also http://ruhleben.tripod.com/index.html, accessed 31 July 2012. Brose achieved the remarkable distinction of being interned twice: in Germany during the Great War, and in Australia during World War II. See (Jenkin 1993).

[19] Reiche took a different tack in a little-known and considerably shorter (just under 50 pages) book, *From the Worldview of the New Physics*, (Reiche 1921b). This book, intended for a popular audience, included numerous drawings, but no equations and no bibliography or notes. It must have been among the earliest popular accounts of quantum theory.

the success of the wave theory; Planck's "second theory;" Planck's and Sommerfeld's early preference for action quanta over energy quanta.[20]

- Chapter IV: Specific heats of solids, including Einstein's 1907 theory; Nernst's heat theorem and specific heat experiments; the theories of Debye and of Born and von Kármán; relation to infrared absorption and reflection, thermal expansion, thermal conductivity; electron theory of metals.
- Chapter V: Gas theory, including the rotational specific heat of hydrogen; infrared molecular absorption spectra; theories of degenerate gases; chemical (or entropy) constant.
- Chapter VI: Atomic spectra, including the Thomson model; Rutherford scattering and planetary model; the Bohr model; Planck's and Sommerfeld's theories for several degrees of freedom; Sommerfeld's relativistic fine structure; Stark effect; Zeeman effect; selection rules; correspondence principle; intensities; helium atom.
- Chapter VII: Quantum theory of Röntgen spectra (X-rays).
- Chapter VIII: Molecular models; dispersion; further discussion of molecular spectra.

Reiche's treatment of Einstein's light quantum allows considerable insight into his treatment of controversial and unsettled questions, and shows off his striking and insightful prose as well. He set the stage in his discussion of Planck's derivation of black-body radiation, when he said that "this conclusion [Planck's quanta] is a slap in the face to classical electrodynamics" (Reiche 1921a, chap. III, § 1).[21] He went on to say, by way of introducing Einstein's light quanta,

> Here at the entry door to the new land yawns a gulf, which either […] must be bridged by a compromise, or else can be ruthlessly widened by a break with tradition. Einstein felt compelled to take the latter radical step. He proposed the hypothesis that the energy quanta not only played a role in the interaction between radiation and matter […] but that radiation also […] had a quantum structure. (Reiche 1921a, chap. III, § 2)

There followed a several-page, detailed description of Einstein's arguments, including his 1909 proposal of the wave-particle duality based on energy and moment fluctuations, as well as a careful summary of the experimental evidence. And later on, in a discussion of Einstein's 1916 derivation of Planck's radiation law (often referred to today as the A and B coefficients derivation), he added,

> Einstein […] was led to the remarkable conclusion that the radiation of Bohr atoms cannot take place in spherical waves, […] but that the process of emission must have a particular direction, like a shot from a cannon. One cannot fail to recognize that the picture of a quantum structure of radiation is thereby brought within easy reach. (Reiche 1921a, chap. VI, § 11)

So far, it sounds as if Reiche were a strong proponent of light quanta. But immediately, he proceeded to give the opposing view:

[20] Planck's constant h has units of "action"—the product of (generalized) momenta and coordinates. Planck's and Sommerfeld's treatments of action were different, but both involved less emphasis on quantized energies.
[21] This striking phrase, first introduced in (Reiche 1913a), did not survive in the English translation.

> With all these successes that the light quantum hypothesis can offer, one must still keep clearly in mind that this radical idea […] can be brought into agreement with classical theory only with difficulty. But since interference and diffraction phenomena […] are best reproduced by the wave theory, and the light quantum leads to almost insuperable difficulties, it is understandable that only a few researchers could bring themselves to sanction so drastic a change […]. M. Planck defended (and defends to this day) this cautious and conservative standpoint, in which he located the significance of the quantum in matter—or at the least, in the interaction between matter and radiation. (Reiche 1921a, chap. III, § 6)

Reiche went on to describe Planck's "second theory." Beginning in 1911, Planck set off in a new direction, motivated by a 1910 calculation of Hendrik Antoon Lorentz (1910), who showed that, especially at short wavelengths, it would take implausibly long times for one of Planck's "resonators" to absorb one energy element from the electromagnetic field. The result was Planck's "second quantum theory," in which he largely abandoned his energy elements. Instead, he assumed that resonators absorb energy continuously but emit quanta of size $h\nu$ when they cross the boundaries of finite cells of size h in the two-dimensional phase space that he had first introduced in his 1906 *Lectures*[22] (Planck 1906, § 150); see also (Kuhn 1978; Gearhart 2002). Planck's second theory was thus an alternative to Einstein's light quanta hypothesis, and it is evident that Reiche took it seriously. At one point in his book, for example, during a discussion of the sharp absorption lines in molecular spectra, he observed that the experimental evidence did not allow one to "decide one of the most fundamental questions of the whole quantum theory, whether, namely, Planck's first or second theory is correct" (Reiche 1921a, chap. V, § 2).

In the end, Reiche left the question open, and in his brief conclusion to the book, pointed to the provisional and downright murky character of the new quantum theory:

> If we now survey the whole structure, as it stands before us, from its foundations to the highest story, we cannot avoid a feeling of admiration: admiration for the few who clear-sightedly recognized the necessity for the new doctrine and fought against tradition, thus laying the foundation for the astonishing successes that have sprung from the quantum theory in so short a time.
>
> Nonetheless, no one who studies the quantum theory will be spared bitter disappointment. For we must admit that, in spite of a comprehensive formulation of quantum rules, we have not come one step nearer to understanding the heart of the matter […].
>
> The decision has not yet been made, as to whether, as Planck's first theory requires, only quantum-allowed states exist […], or whether, according to Planck's second version, intermediate states are also possible. We are still completely in the dark about the details of the absorption and emission process, and do not in the least understand why the energy quanta ejected explosively as radiation should form themselves into the trains of waves which we observe

[22] Both the first edition (1906) in the original German and a translation of the second edition (1913) are reprinted in *The Theory of Heat Radiation* (Planck 1988). By 1913, Planck's theory had changed substantially; the 1913 translation cannot be used as a guide to the 1906 edition.

> far away from the atom. Is radiation really propagated in the manner claimed by classical wave theory, or does it also have a quantum character?
>
> Over all these problems there hovers at the present time a mysterious obscurity. (Reiche 1921a, chap. IX)

5.5 Reviews

Reiche's book was widely and positively reviewed. The British journal *Nature* reviewed both the German edition and the English translation (Anonymous 1922; Allen 1923).[23] The first of these reviews, which observed that the book "is an admirable account of the whole field of quantum theory," went on to take a jab at the Germans:

> the literature is very predominantly German, and it is customary in Germany to permit the publication of much more speculative ideas than is usual in other countries. The great merit of the present book is that it brings together all the threads of the argument and criticizes them, so that a just view can be obtained of the whole theory.

The anonymous reviewer went on to suggest that, if anything, Reiche had been too even handed:[24]

> There is little to criticize in such a fair account of the whole theory, but we may venture to say that the author is perhaps inclined to favor Planck's second hypothesis rather more than would the general consensus of present opinion. [… N]either of Planck's hypotheses has yet been made to cover the facts in a really convincing manner.

In the second review (Allen 1923, 280), the spectroscopist H. Stanley Allen sympathized with Reiche's reluctance to take sides in the matter of light quanta, writing that "the extraordinary problem […] has been well put by Sir William Bragg:"

> In many ways, the transference of energy suggests the return to Newton's corpuscular theory. But the wave theory is too firmly established to be displaced from the ground that it occupies. We are obliged to use each theory as occasion demands, and to wait for further knowledge as to how it may be possible that both should be true at the same time.[25] (Bragg 1921, 374)

Bragg famously observed at about the same time that "On Mondays, Wednesdays, and Fridays we use the wave theory; on Tuesdays, Thursdays, and Saturdays we think […] of flying energy quanta or corpuscles" (Bragg 1922, 158). It is often said, with considerable

[23] Note that these favorable British reviews appeared during the early 1920s, when British and German scientists were often at loggerheads in the aftermath of the Great War.

[24] See (Kuhn 1978, chap. X). Indeed, Planck's "second theory" did slowly fall out of favor during the late teens and early 1920s.

[25] In a section not quoted by Stanley, Bragg added, "Toleration of opinions is a recognized virtue. The curiosity of the present situation is that opposite opinions have to be held and used by the same individual in the faith that some day their combined truth may be made plain." Bragg was writing in the context of his experimental and theoretical efforts to understand X-rays; see (Stuewer 1971; 1975; Wheaton 1983).

truth, that many physicists unambiguously rejected Einstein's light quanta for many years, and that only a handful supported their existence. But the reactions summarized here suggest that others—Reiche included—were content merely to withhold judgment and await further developments.[26]

The *Mathematical Gazette* noted the introductory character of the book, saying that "Several experimental physicists have found it to be very instructive" (Piaggio 1923). The *Bulletin of the American Mathematical Society* added:

> The author disclaims any intention of writing a systematic textbook, yet he has produced as systematic a text as exists on the subject, and a very readable one. [...] The book should not be used as a substitute for Planck's *Heat Radiation* or Sommerfeld's magnificent *Atombau und Spektrallinien*, but as an introduction [...] with which one may physically orient oneself before taking up more complex discussions.[27] (Phillips 1922)

The American physicist Earle Hesse Kennard, who would himself become a prominent textbook author, was more restrained, noting, in 1924, that

> this little book contains a systematic and compact review of the quantum theory [...]. Errors of fact or translation are scarce [...]. In the absence of a preface one cannot be sure for what class of readers the book was intended by the author. It is quite unsuited for use by a class and would hardly do even as a first introduction for a more experienced reader. It will, however, serve admirably as a good index to the quantum theory as it existed four or five years ago. (Kennard 1924)

Not even historians of science were left out. George Sarton himself, one of the founders of the History of Science Society, reviewed the book for *Isis*, the Society's journal, and observed presciently that

> Reiche's book will be very useful not simply to the student of physics, but also to the historian of modern science [...].
>
> The theory of quanta is still full of mystery; suggestive and useful as it is, one can but feel that we have not yet reached the bottom of it. (Sarton 1921)

5.6 Who Read Reiche's Book?

So Reiche's book was favorably reviewed. In all likelihood it sold well. It surely became widely known. But who bought it, and how was it used? It is not so difficult to discover where quantum theory was being taught, and often, who was teaching it.[28] But what textbooks were used in these courses? Or were textbooks used at all? Most early quantum

[26] Richardson (1914, 507–508), took a similar point of view, even though he was skeptical of Einstein's light quanta; see (Knudsen 2001, 244–245).
[27] Phillips was a mathematician at the MIT. Like several other reviews of Reiche's book, this one appeared in a mathematics journal.
[28] See for example (Sopka 1988, 91–95 and 175–193), for the United States.

theory courses were for advanced students, whose instructors often relied on their own lecture notes.[29] Of course, students could and undoubtedly did seek out whatever supplementary material they could lay their hands on. But I have found it difficult to uncover more than anecdotal evidence. For example, the Italian physicist Emilio Segrè remarked in his autobiography that:

> Besides what was taught at school, I studied some physics books [...] on my own. I still have Glazebrook's *Light*, Maxwell's *Theory of Heat*, and above all Reiche's *Die Quantentheorie*, which greatly impressed me [...]. Usually I read these books at school during boring classes. (Segrè 1993, 33)

Similarly, the Japanese theorist Hideki Yukawa tells us:

> My interest in physics gradually deepened, and I became dissatisfied with the physics I learned in school [...]. One day I found a book entitled *Quantum Theory*, written by the German physicist Fritz Reiche and translated into English, and I bought it. With my knowledge of only high school physics, it was hard to understand [...].
>
> Still, I could feel that theoretical physics was in a state of confusion, with discrepancies to be seen everywhere [...].
>
> Never, in my life, have I received greater stimulation or greater encouragement from a single book than I did from that one. (Yukawa 1982, 145–147)

A third example suggests another audience for Reiche's book. One of my own copies of the English translation has the name Lyman J. Briggs inscribed on the flyleaf, with the date 6 June 1925. Briggs is perhaps best known as the head of the 1939 "Uranium Committee," which was charged to look into the prospects for nuclear weapons (Rhodes 1986, 314–317). In 1939 Briggs was the Director of the National Bureau of Standards (now the National Institute of Standards and Technology). His undergraduate degree (in agriculture) was from Michigan Agricultural College (now Michigan State University) in 1893 and his Ph.D. in physics from Johns Hopkins in 1906. From 1896 until 1917, he was in the Physics Laboratory Division of the Department of Agriculture. In 1917 he transferred to the Bureau of Standards and became Director in 1933.

Briggs, whose research interests did not include quantum theory, nevertheless bought his copy in 1925, at the age of 50. Judging from another flyleaf inscription, it appears that he thought enough of it to give his copy to his grandson, Peter Briggs Myers, when the latter was working on a Ph.D. in physics in the late 1940s. Briggs was surely not alone in wanting to keep up with new developments in physics outside his own research interests; Reiche's book would have been ideal for this purpose.[30]

A final example comes from Benjamin Bederson, formerly the Editor-in-Chief of the American Physical Society, who gives the only reminiscence I have found of Reiche as a teacher of physics. Reiche came to the United States in 1941. As a Jew, he had been

[29] See for example the lecture notes of Peter Debye at Göttingen (circa 1914) and Edwin C. Kemble at Harvard (early 1920s), AHQP, reels 24, 55–57. See also the chapter by Midwinter and Janssen in this volume.

[30] For more on Briggs, including lists of publications, see (Myers and Levelt Sengers 1999; Landa and Nimmo 2003).

dismissed from his Breslau Professorship in 1933, and must have been among the last to escape Nazi Germany. He spent much of his remaining career at New York University. Bederson recalled that,

> In 1949 I was completing course work for a Ph.D. degree at New York University (NYU) but needed one additional course in statistical mechanics as a degree requirement. The course was given by a diminutive professor with a slight German accent whose name was Fritz Reiche. This course turned out to be the most memorable one I was ever to take at NYU […]. The clarity, the seeming simplicity of the concepts […] succeeded in transmitting to the listener the impression that he or she was able to follow deeply and with brilliant clarity the true essence of statistical mechanics […].
>
> When reading Reiche's book I discovered, not to my surprise, that it had precisely the same flavor that I recalled from Reiche's lectures at NYU […]. It remains one of the most accessible, and substantive textbooks I have ever read. (Bederson 2005, 453 and 458)

Reiche remained a teacher throughout his life. His papers are on file at the American Institute of Physics, Niels Bohr Library, in College Park, Maryland. There I came across a handwritten manuscript of a modern physics text that seems to date from the mid-1930s (judging from the material on nuclear physics), when Reiche was back in Berlin after being dismissed from his professorship in Breslau. It is a sad document to read. Reiche must have known that it could never have been published in Germany. It serves to remind us, as we study the exciting days of early quantum theory, that our actors were players on a wider stage. It is a side of this history that we do well to keep in mind.

Abbreviations and Archives

AHQP	Archive for History of Quantum Physics. American Philosophical Society, Philadelphia

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