

# “ASTONISHING SUCCESSES”; “BITTER DISAPPOINTMENT” FRITZ REICHE’S 1921 QUANTUM THEORY BOOK

## Die Quantentheorie

Ihr Ursprung und ihre Entwicklung

Von

Fritz Reiche

Mit 15 Textfiguren



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**STILL IN PRINT**

Die  
Quantentheorie



Fritz Reiche

The  
Quantum Theory  
(1922)



Fritz Reiche  
H. S. Hatfield

# FRITZ REICHE (1883–1969)



**Fritz Reiche was one of the very few research pupils of Max Planck ... He was a tiny delicate Jew who combined the typical humor of the Berliner with a deep melancholy and pessimism. ... I learned from him a great deal about radiation and quantum theory which he had studied at the source, in personal contact with Planck.**

–Max Born

- Ph.D. with Planck, 1907
- 1908–11: in Breslau, learning experimental physics with Otto Lummer
- 1913: Instructor (*Privatdozent*) at the University of Berlin
- 1915–18: assistant to Planck
- 1919–1920: advisor to Fritz Haber in the Physical Chemistry Institute in Berlin; “little oracle”
- 1921–1933: Professor in Breslau
- 1921: publication of *Die Quantentheorie*
- 1921: popular book, *Aus dem Weltbild der neuen Physik (From the World View of the new Physics)*

# FRITZ REICHE AND QUANTUM THEORY

Reiche's early papers were on aspects of "classical" electromagnetic theory: For example

1911: "On the theory of the diffraction grating" (with Clemens Schaffer)

1916: "On the theory of dispersion in gases and vapors"

In 1917, however, Reiche turned to quantum theory

1917: "On the quantum theory of paramagnetism"

1918: "On the quantization of the asymmetric top"

1918: "On the theory of Roentgen spectra" (with Adolf Smekal)

1919: "On the quantum theory of the rotational heat of hydrogen"

1920: "On the theory of rotational spectra" (half-quanta)

1920: "On helium and parahelium" (with James Franck)

1923: "Absorption, scattering, and dispersion in Bohr's atomic theory" (with Rudolf Ladenburg)

... and so on

# 1913: DIE NATURWISSENSCHAFTEN

## DIE NATURWISSENSCHAFTEN

1. Jahrgang.

3. Januar 1913.

Heft 1.

### Zur Einführung.

Die rasch fortschreitende Spezialisierung auf allen Gebieten der Naturforschung erschwert es dem Einzelnen, sich auch nur auf seinen Nachbargebieten zu orientieren. Geradezu unmöglich wird ihm die Orientierung aber auf den ferner liegenden Gebieten. Andererseits muß sich jedem das geistige Bedürfnis um so fühlbarer machen, den Zusammenhang mit dem Ganzen nicht zu verlieren, je mehr er gezwungen ist, das Feld der eigenen Arbeit einzuengen — ist er doch meistens auf Hilfe von anderen Zweigen der Naturwissenschaft angewiesen. Die Zusammengehörigkeit der gesamten Naturwissenschaften offenbart sich zwar jedes Jahr aufs neue durch Versammlungen wie die Naturforscherversammlung und die British Association, bei denen der Physiker und der Chemiker, der Zoologe und der Botaniker; der Geologe und der Mediziner zusammentreffen, und der Lehrer der Wissenschaft dem Arzte und dem Techniker begegnet. Aber ganz abgesehen davon, daß nur ein kleiner Teil der Gesamtheit der Naturforscher an solchen Veranstaltungen teilnehmen kann und daß ein volles Jahr von der einen zur anderen verfließt, benutzt jeder sie auch dazu, im Gespräche mit näher und ferner stehenden Fachgenossen in Gedankenaustausch zu treten und die Ziele neuer Untersuchung auf dem eigenen Gebiete festzustellen, es bleibt ihm daher nur eine beschränkte Zeit übrig, um sich über die Fortschritte auf den anderen Gebieten zu unterrichten — also auch die allgemeinen Versammlungen lassen hier eine fühlbare Lücke.

Diese Lücke auszufüllen, sind „Die Naturwissenschaften“ bestimmt. Sie wollen jeden auf dem Gebiete der Naturforschung Tätigen über die Fortschritte auf dem Gesamtgebiete der Naturwissenschaften unterrichten. Erreicht wird diese Aufgabe durch *Originalbeiträge* und *Sammelreferate*, durch *Besprechung von Büchern und Zeitschriftenartikeln*, die ein weiter reichendes als nur ein fachspezialistisches Interesse bieten, durch *Berichte über wissenschaftliche Veranstaltungen* (Kongresse, Vorträge, Ausstellungen), durch *Berichte über den Betrieb* an allen Stätten, die der *Lehre und der Forschung* dienen, durch *Berichte über Fragen der Methodik und des Unterrichts* und durch *eine wissenschaftliche Korrespondenz*, die den Meinungsaustausch über schwebende Fragen allgemein naturwissenschaftlichen Interesses anregen soll und die auch die Erlangung einer Auskunft bezweckt, die auf anderen Wegen nur schwer oder gar nicht zu erhalten ist.

Ein solches Programm ist nur dann durchführbar, wenn seine Verwirklichung von allen Naturforschern als ein Bedürfnis empfunden wird. Daran kann aber nach der Zustimmung, die es allenthalben gefunden hat, kein Zweifel bestehen: die Zuschriften auf die Einladung zur Mitarbeit beweisen es, noch mehr aber die tatkräftige Unterstützung, die wir schon jetzt gefunden haben. Wir richten an alle auf naturwissenschaftlichem Gebiete Tätigen die Bitte, an der Durchführung des Programms mitzuwirken, sowohl durch selbständige geeignete Beiträge, durch kurze Mitteilungen aus dem Wissenschaftsbetriebe der Institute, wie durch Zusendung von Separatabzügen solcher Arbeiten, deren Referat auch außerhalb des Kreises der nächsten Fachgenossen auf Interesse rechnen kann. Ganz besonders richten wir die Bitte zur Mitwirkung auch an die auf irgendeinem Gebiete der physikalischen oder der chemischen *Technik* Tätigen, da kaum ein Berufs- und kaum ein Wissenszweig existiert, in dem die angewandten Naturwissenschaften heute nicht eine maßgebende Rolle spielen.

Wir richten unsere Bitte an die Naturforscher aller Länder, unbekümmert um politische Grenzen und hoffen auf die Mitwirkung, *Alle* im Interesse einer Aufgabe, die die *Gesamtheit* der Naturforscher gleichmäßig angeht.

*Die Herausgeber.*

In 1913, Arnold Berliner persuaded Ferdinand Springer to establish a new journal, *Die Naturwissenschaften*, which like *Nature in Britain* and *Science* in the United States, would report on new developments in all of the natural sciences to all scientists.

**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.**

See Michael Stöltzner, Ph.D. dissertation (2003)

# FRITZ REICHE AND *DIE NATURWISSENSCHAFTEN*

Fritz Reiche began writing for *Die Naturwissenschaften* in 1913, its first year, and showed a side of himself notably different from that displayed in his research articles. In December 1913, he began a five-page article on “lattice phenomena” 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.**

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.

# FRITZ REICHE, *DIE NATURWISSENSCHAFTEN*, AND QUANTUM THEORY: 1913

## Die Quantentheorie.

(Dargestellt im Anschluß an den Verhandlungsbericht<sup>1)</sup> des Solvay-Kongresses in Brüssel 1911.)

Von Dr. Fritz Reiche, Berlin.

### § 1.

Griechische Denker haben zuerst mit Klarheit den Gedanken ausgesprochen, daß alle Materie aus kleinen, unteilbaren Teilchen, den Atomen, bestehe. Als die Chemie sich im Laufe des letzten Jahrhunderts zu einer exakten Wissenschaft entwickelte, wurde die Hypothese von der Existenz der Atome (und ihrer Vereinigung zu Molekülen) zum Fundament ihres Baues. Auch in die Physik drang allmählich die Lehre von der molekularen Struktur aller Substanzen ein.

In ein neues, viel verheißendes Entwicklungsstadium trat die Molekulartheorie, als man versuchte, die Methoden der Wahrscheinlichkeitsrechnung und Statistik auf die regellosen Bewegungen von Gasmolekülen anzuwenden, die, einem Mückenschwarm vergleichbar, durcheinander schwirren und miteinander zusammenstoßen. Daß dieser Ver-

In June 1913, Reiche published a nine page, two part article on quantum theory, intended to summarize the 1911 Solvay conference. It was not the first article on quantum theory to appear in *Die Naturwissenschaften*. But it was by far the most comprehensive. Reiche began:

**Greek thinkers were the first to state clearly that all matter consists of small, indivisible particles, atoms.**

He went on to describe 19th century kinetic theory, Brownian motion, electron theory, and black-body radiation; and went on from there to give a thorough description of the experimental evidence for and theoretical scope of quantum theory in 1913, in clear, striking, non-technical language.

Reiche concluded by quoting Marcel Brillouin at the first 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.**

# LESSONS

By 1913,

- Quantum theory was sufficiently established to merit several articles for non-specialist readers in *Die Naturwissenschaften*, including a May article by Max Born on black body theory.
- Although another four years would pass before Reiche began to publish in quantum theory, it is evident that in 1913 he had an encyclopedic knowledge of the subject.
- Finally, Reiche wrote clear, striking prose, and showed that he could present what even by 1913 was a complex, many-faceted subject to scientists at an introductory level.



# BOOK REVIEWS IN *DIE NATURWISSENSCHAFTEN*

Between 1913 and 1936, Reiche published some 20 book reviews in Die Naturwissenschaften, the majority in the teens and early 20s, and many of them on quantum theory: for example

- Arnold Eucken's translation of the proceedings of the 1911 Solvay conference :

**The actual significance, the foundations of this theory are still deeply obscure.**

- Planck's (1908) and Wien's (1913) lectures at Columbia University.
- Proceedings of the Wolfskehl conference in Göttingen (1913)
- Planck's 1920 Nobel Prize lecture:

**Max Planck gives ... an overview of the new wonderland that he opened up twenty years ago.**

- Books by Hermann Sieveking (1914), Siegfried Valentiner (1914, 1919), Arthur March (1919), Ludwik Silberstein (1920), and Rudolf Ladenburg (1921). In his review of Valentiner's two introductory quantum theory books, published in 1914, Reiche says

**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.**

# THE QUANTUM UNDERGROUND

1912–1914

Publication of three books that treated quantum theory, by

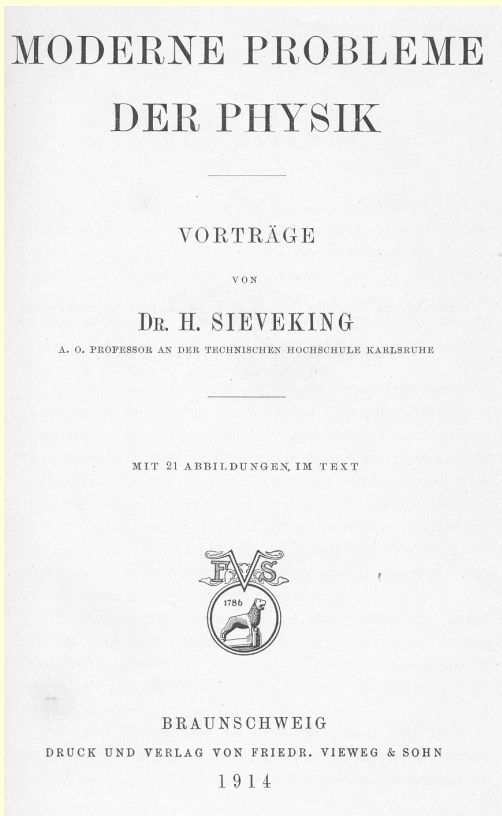
- Hermann Sieveking (1875–1914)
- Siegfried Valentiner (1876–1971)
- Owen Richardson (1879–1959) (not reviewed by Reiche)

All three authors were experimental physicists.

None of the three specialized in quantum theory.

All three gave sophisticated, well informed accounts!

# HERMANN SIEVEKING (1875–1914)



- Ph.D. 1899 (Freiburg)
- ausserordentlicher Professor, Karlsruhe Technical University
- research (divided between experiment, theory) on such topics as radioactivity and electrical discharge in gases, He was also interested in airships, on which he lectured at Karlsruhe in 1913.
- had several articles in *Die Naturwissenschaften*, which published a 1½ page obituary
- book was based on lectures to the local chapter of the Association of German Chemists, in winter 1913, who, he tells us in the introduction, wanted to learn about "**recent achievements in theoretical chemistry and physics.**"

- topics: electron theory, radioactivity, x-rays, relativity, and a final, thirty-page chapter on “Progress in Thermodynamics” — quantum theory

This last chapter had appeared earlier in the Proceedings of the Karlsruhe Natural Sciences Society, dated December 1912, where Sieveking tells us that it had been written even earlier for a prize on the theme “Description of quantum theory,” sponsored by the Eisenlohr Foundation.

# SIEGFRIED VALENTINER (1876–1971)



Die  
**Grundlagen der Quantentheorie**  
in elementarer Darstellung

Von  
**Dr. Siegfried Valentiner**  
Professor der Physik an der Kgl. Bergakademie Clausthal

Mit 8 Abbildungen



DRUCK UND VERLAG VON FRIEDR. VIEWEG & SOHN  
BRAUNSCHWEIG 1914

67 pages

**Anwendungen der Quantenhypothese**  
in der kinetischen Theorie der  
festen Körper und der Gase

In elementarer Darstellung  
von  
**Dr. Siegfried Valentiner**  
Professor der Physik an der Kgl. Bergakademie Clausthal

Mit 4 Abbildungen



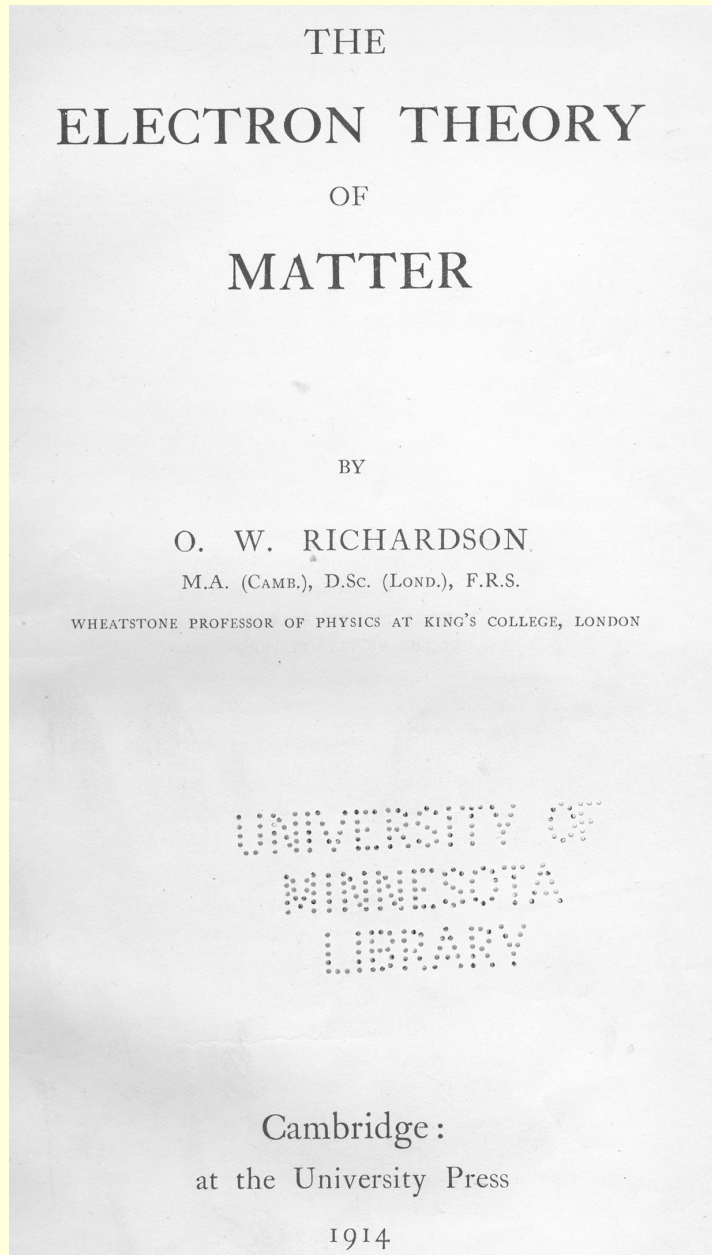
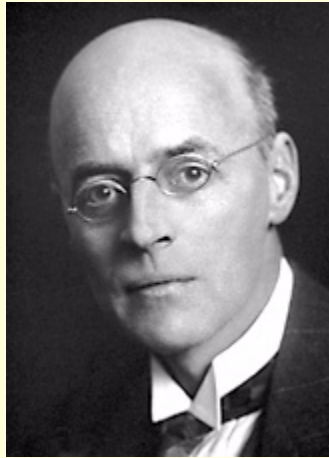
DRUCK UND VERLAG VON FRIEDR. VIEWEG & SOHN  
BRAUNSCHWEIG 1914

72 pages

# SIEGFRIED VALENTINER (1876–1971)

- Ph.D. 1900 (Heidelberg)
  - at PTR in Berlin: 1903 paper comparing optical temperature scales with nitrogen gas thermometers
  - 1906: published textbook on vector analysis (remained in print through 1960s)
  - 1910: Professor at School of Mines [*Bergacademie*], Clausthal
  - several articles in *Die Naturwissenschaften* (1915–1964)
- 
- explicitly intended for beginning students
  - comprehensive coverage: Blackbody radiation, light quanta, Planck's two theories, specific heats of solids, Sommerfeld's theory of non-periodic processes (x-rays, photoelectric effect), rotational specific heats, molecular spectra, prospects for quantizing monatomic gases (Sackur-Tetrode)
  - apparently sold well; plenty of inexpensive copies are currently available on the used book market

# OWEN RICHARDSON (1879–1959)



- written for graduate course at Princeton
- much less systematic treatment compared to Sieveking and Valentiner: blackbody radiation, brief discussion of specific heats of solids
- hoped 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.**
- BUT also gave what is probably the first textbook treatment of Bohr's theory!

See Ole Knudsen, "O. W. Richardson and the Electron Theory of Matter, 1901–1906"

# THE QUANTUM UNDERGROUND

## COMMON THEMES

- All three are skeptical of Einstein's light quantum hypothesis
- All three show a marked preference for Planck's "second theory"
- All three emphasize the importance of the photoelectric effect, and all three promote quantum (albeit not light quantum) explanations
- All three cite Nernst's February 1911 *Zeitschrift für Electrochemie* paper, "**On the theory of specific heats and the lessons of energy quanta for questions in physical chemistry generally.**" Sieveking and Valentiner rely heavily on it.

### By 1912–1913:

- articles/reviews in *Die Naturwissenschaften*
- Karlsruhe prize competition (!)
- books by Sieveking, Valentiner, Richardson

Quantum theory was no longer confined to the experts!

# ***DIE NATURWISSENSCHAFTEN, APRIL 1918***

Volume 6, Number 17 of *Die Naturwissenschaften*, appearing in April 1918, was devoted to a Festschrift celebrating Max Planck's 60th birthday. It included articles by (among others) Arnold Sommerfeld, Wilhelm Wien, Walther Nernst, and Max von Laue.

It also included Reiche's 17 page essay

## **THE QUANTUM THEORY ITS ORIGIN AND DEVELOPMENT**

This essay was the germ of Reiche's book, which appeared three years later in 1921. Like Reiche's 1913 essay:

- The coverage was comprehensive;
- the level was introductory, but intended for scientists; and
- the writing was clear and lively.



# THE QUANTUM THEORY 1921

The book appeared in 1921, published by Springer.

It was immediately translated into English, by Henry L. Brose and Henry S. Hatfield.

- Brose: Australian physicist
- Hatfield: English chemist
- Both were prominent scientific translators; Brose translated Sommerfeld's *Atombau*

Brose and Hatfield may have become acquainted when they were both prisoners in the Ruhleben internment camp near Berlin during World War I.

The book appears to have sold well:

- Inexpensive used copies are still widely available.
- The English translation went through three printings, the last in 1930.

# THE QUANTUM THEORY 1921

1. Very few topics in quantum theory went unmentioned.
  - On unsettled questions (light quantum; Planck's first or second theory), Reiche usually gave a careful summary, but refrained from taking sides.
2. Level was introductory:
  - main text was about 160 pages (125 pages in English translation)
  - about 50 pages of end notes, many of them extending and deepening the treatment in the text
  - historically accurate! Even today, one can get a good picture of quantum theory around 1920 from Reiche's book.
3. As in his *Naturwissenschaften* pieces, Reiche's writing was clear and forceful.

# MORE TO QUANTUM THEORY THAN ATOMIC PHYSICS

Ch. I, II: Black-body radiation: experiments, Stefan Boltzmann and Wien's laws, Planck's path to his radiation formula; equipartition, Rayleigh-Jeans law

Ch. III: Einstein's light quanta: derivation, wave-particle duality, evidence for (including phosphorescence (Stokes' law), fluorescence, photoelectric effect, inverse photoelectric effect.

But also objections from success of wave theory, Planck's "second theory," Planck's and Sommerfeld's action quanta

Ch. IV: Specific heats of solids, including Einstein, Nernst (heat theorem; experiments), Debye, Born and von Kármán; relation to infrared absorption and reflection, thermal expansion, thermal conductivity, electron theory of metals.

Ch. 5, Gas theory: specific heat of hydrogen, infrared molecular absorption spectra, theories of degenerate gases, chemical (or entropy) constant

Ch. 6: Atomic Spectra: Thomson model; Rutherford; 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

Ch. 7: X-ray Spectra

Ch. 8: Molecular models; dispersion; more on molecular spectra

## **EXAMPLE: THE LIGHT QUANTUM**

**This conclusion [Planck's quanta] is a slap in the face to classical electrodynamics....**

**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.**

[several-page, detailed description of Einstein's arguments (including 1909 fluctuation/wave-particle duality) and all of the experimental evidence]

**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....**

[He goes on to outline Planck's "second theory"]

# EXAMPLE: THE LIGHT QUANTUM

Later, in a description of Einstein's 1916 derivation of Planck's radiation law:

**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.**

But in another connection, Reiche says

**[We cannot] decide one of the most fundamental questions of the whole quantum theory, whether, namely, Planck's first or second theory is correct.**

In the end, Reiche leaves the question open.

# **“ASTONISHING SUCCESSES,” “BITTER DISAPPOINTMENT”**

**If we now survey the whole structure, ... we cannot avoid a feeling of admiration ... for the astonishing successes that have sprung from the quantum theory.**

**Nonetheless, no one who studies the quantum theory will be spared bitter disappointment. ... 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.... 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.**

# BOOK REVIEWS

This is an admirable account of the whole field of quantum theory. ... 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.

Anonymous reviewer, *Nature*, February 1922

# BOOK REVIEWS

Prof. Reiche has given an exceptionally lucid exposition of the origin and development of the quantum theory ...

Perhaps the most startling application of the quantum theory is found in the remarkable connection between moving electrons and electromagnetic waves. When light of sufficiently short wave-length is allowed to fall upon a polished metal plate, negative electrons are set free with a velocity  $v$  which depends upon the frequency  $\nu$  of the exciting light. The equation ... applies not only to ordinary light, but also to X-rays... 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. (Bragg, 1921)

H. Stanley Allen, Nature, March 1923

See Roger H. Stuewer, *The Compton Effect*



# WHO READ REICHE'S BOOK? UNDER WHAT CIRCUMSTANCES?



I do have a few data points.

# DATA POINTS

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 ....

Emilio Segré

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.

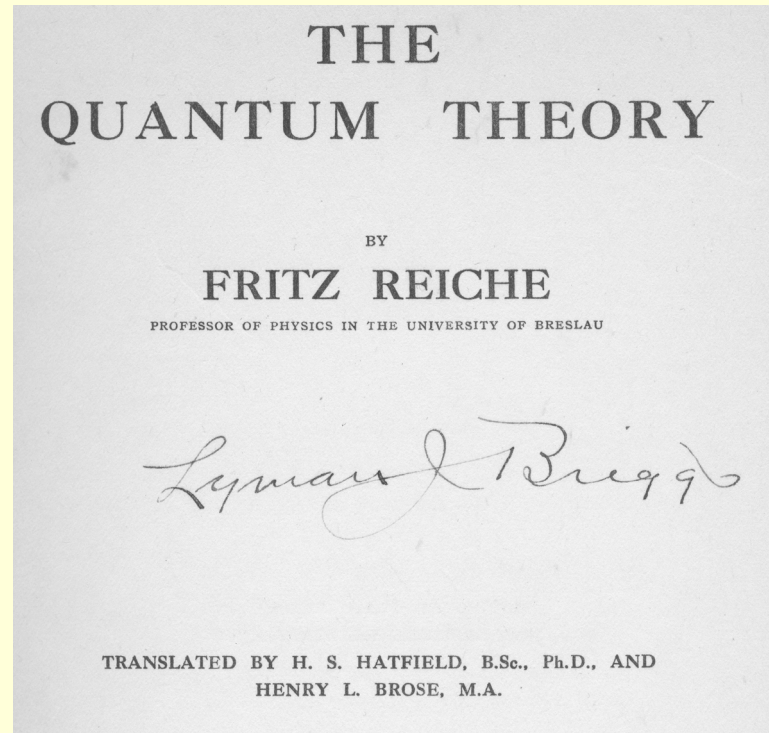
Hideki Yukawa

Perhaps the most interesting of these data points is ...

# LYMAN BRIGGS, *THE QUANTUM THEORY*, AND THE NATURWISSENSCHAFTEN HERITAGE



Lyman James Briggs  
1874–1963



- purchased Reiche's book in January, 1925; later gave to grandson (late 1940s)
- undergraduate degree in agriculture, Michigan Agricultural College [Michigan State], 1893
- Ph.D. in physics, Johns Hopkins, 1903
- Physics Laboratory Division, Department of Agriculture, 1896–1917
- Bureau of Standards, 1917 on; Director, 1933
- chair of Uranium Committee, 1939

# **FRITZ REICHE AS TEACHER**

**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.**

**Benjamin Bederson (2005)**