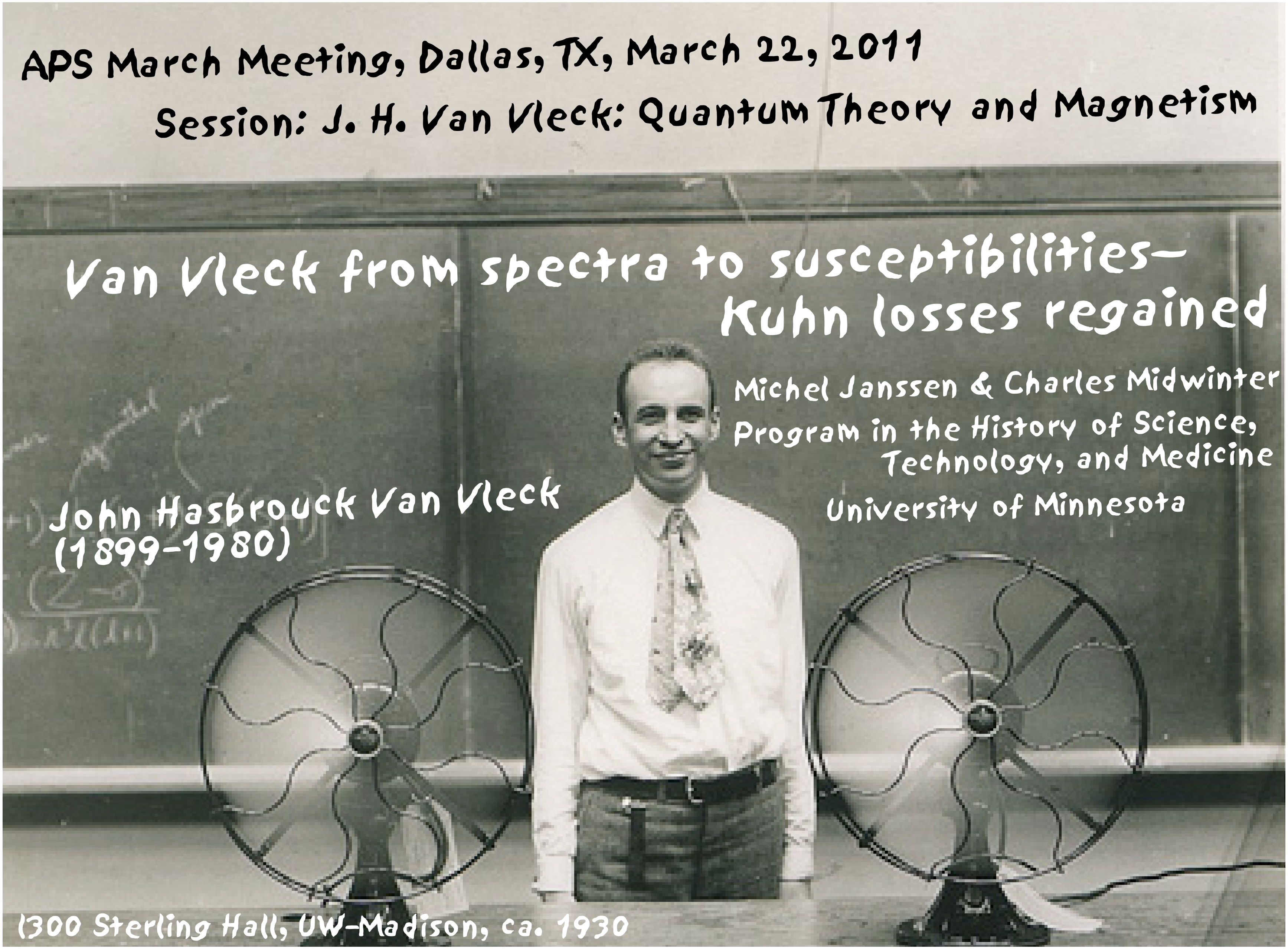

APS March Meeting, Dallas, TX, March 22, 2011
Session: J. H. Van Vleck: Quantum Theory and Magnetism
Van Vleck from spectra to susceptibilities—
Kuhn losses regained
Michel Janssen & Charles Midwinter
Program in the History of Science,
Technology, and Medicine
University of Minnesota
John Hasbrouck Van Vleck
(1899-1980)
1300 Sterling Hall, UW-Madison, ca. 1930

John H. Van Vleck (1899–1980) from *Quantum Principles and Line Spectra* (Minnesota, 1926) to *The Theory of Electric and Magnetic Susceptibilities* (Wisconsin, 1932)

BULLETIN
OF THE
NATIONAL RESEARCH COUNCIL

Vol. 10. Part 4. March, 1926 Number 54

QUANTUM PRINCIPLES AND LINE SPECTRA

BY

J. H. VAN VLECK

Assistant Professor of Physics, University of Minnesota

This monograph is part of the report of the National Research Council Committee on Ionization Potentials and Related Subjects. The committee consists of the following members: Paul D. Foote, U. S. Bureau of Standards, *Chairman*; K. T. Compton, Princeton University; Saul Dushman, General Electric Company; F. L. Mohler, U. S. Bureau of Standards; H. N. Russell, Princeton University and Mt. Wilson Observatory; S. E. Sheppard, Eastman Kodak Company; J. H. Van Vleck, University of Minnesota.

THE
THEORY
OF
ELECTRIC AND MAGNETIC
SUSCEPTIBILITIES

BY

J. H. VAN VLECK

PROFESSOR OF THEORETICAL PHYSICS IN
THE UNIVERSITY OF WISCONSIN

OXFORD UNIVERSITY PRESS

Kuhn losses regained: results from classical theory of susceptibilities that were lost in the old quantum theory were recovered in the new quantum mechanics.

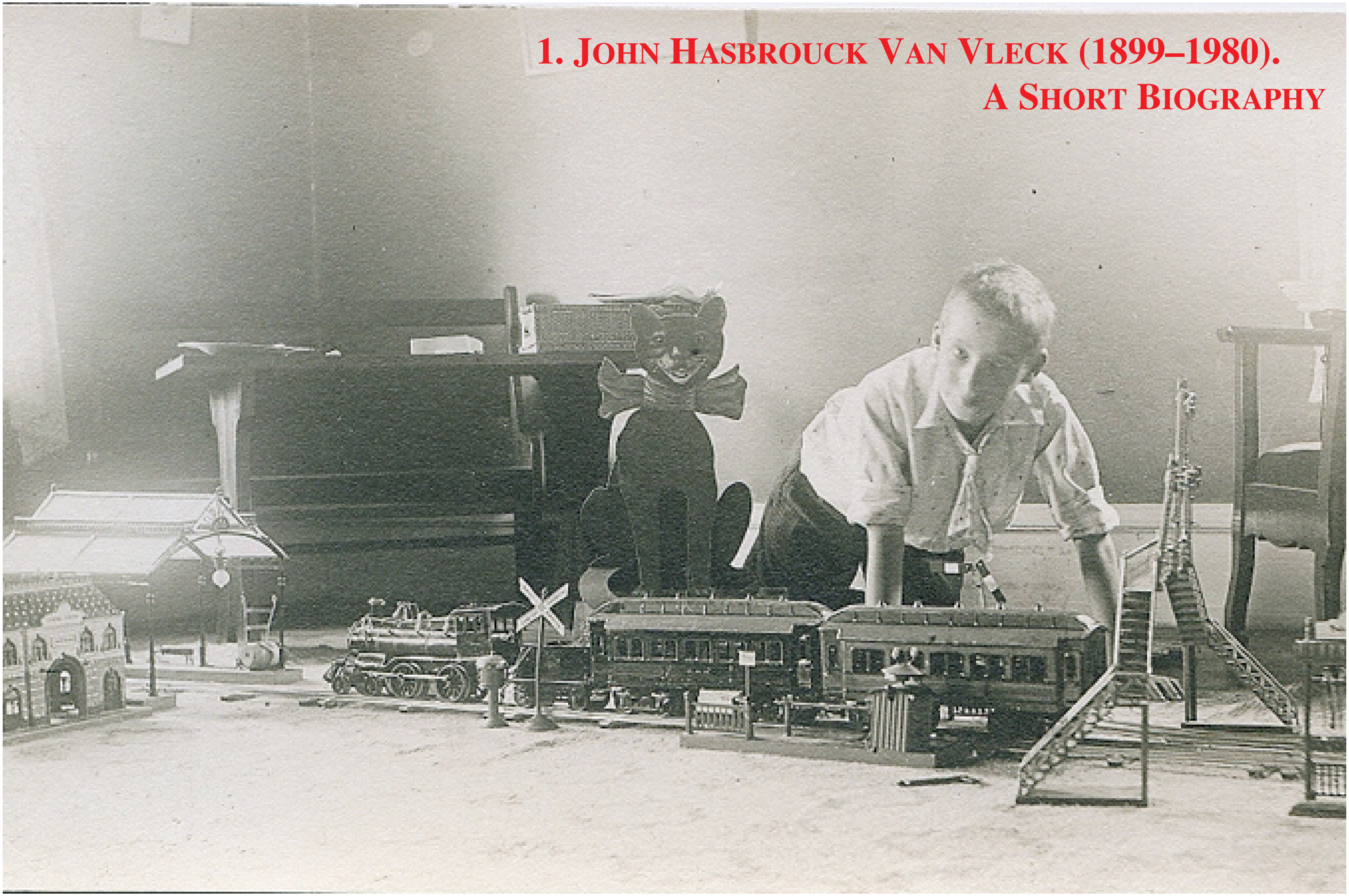
Outline of my talk

1. Biography of Van Vleck.
2. Quantum theory in US in 1920s.
3. *Quantum Principles and Line Spectra* (1926).
4. *The Theory of Electric and Magnetic Susceptibilities* (1932).

Main sources:

- Fred Fellows, *J. H. Van Vleck: The Early Life and Work of a Mathematical Physicist*. Ph.D. Thesis, University of Minnesota, 1985 (Advisor: Roger H. Stuewer).
- Tony Duncan and Michel Janssen, "On the Verge of *Umdeutung* in Minnesota: Van Vleck and the Correspondence Principle." *Archive for History of Exact Sciences* (2007).
- Materials donated by John Comstock, nephew of John and Abigail Van Vleck, to University of Wisconsin—Madison. See Van Vleck Exhibit– Physics Library, UW-Madison (organized by Jean Buehlman)

1. John Hasbrouck Van Vleck (1899–1980). A Short Biography



- 1899. Born in Middletown, Connecticut (10th generation American), son of **Edward Burr Van Vleck (1863–1943)**, professor of mathematics at the University of Wisconsin–Madison, 1906–1929.

- 1916–1919. Undergraduate Madison (summer school Minnesota [1917, 1918], Chicago [1919, 1920]).

- 1920–1922 Graduate Studies Harvard.

  Ph.D. Advisor: **Edwin C. Kemble (1889–1984)**. Thesis: “The normal helium atom and its relation to the quantum theory.” Published in *Philosophical Magazine* in 1922.

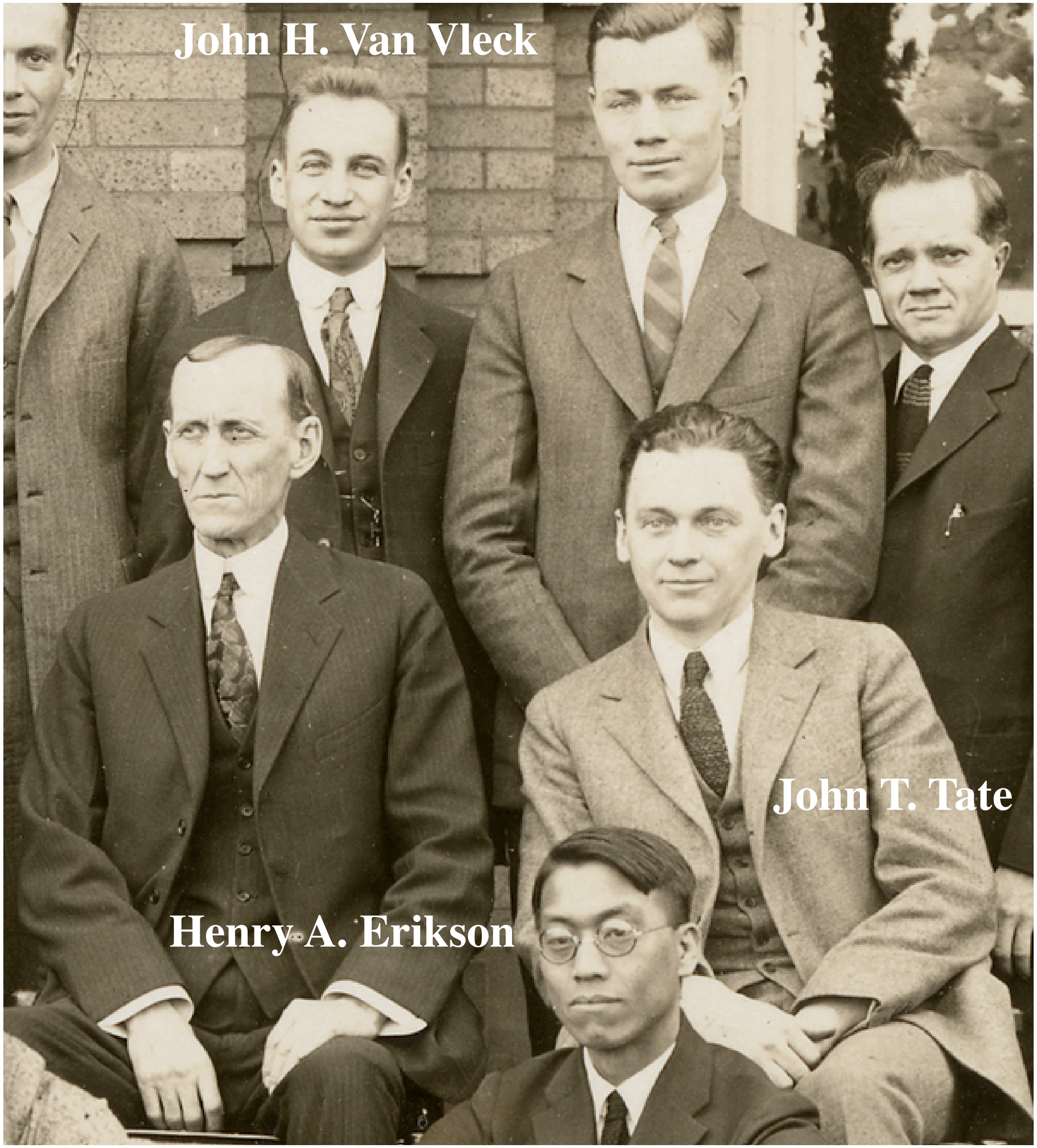
- 1922–1923 Instructor Harvard.

- **1923–1928 Minnesota.**

Van Vleck in Minnesota, 1924–1925.

Van Vleck in Minnesota, 1924–1925.

Van Vleck in Minnesota, 1924–1925.



Van Vleck biography (cont'd).

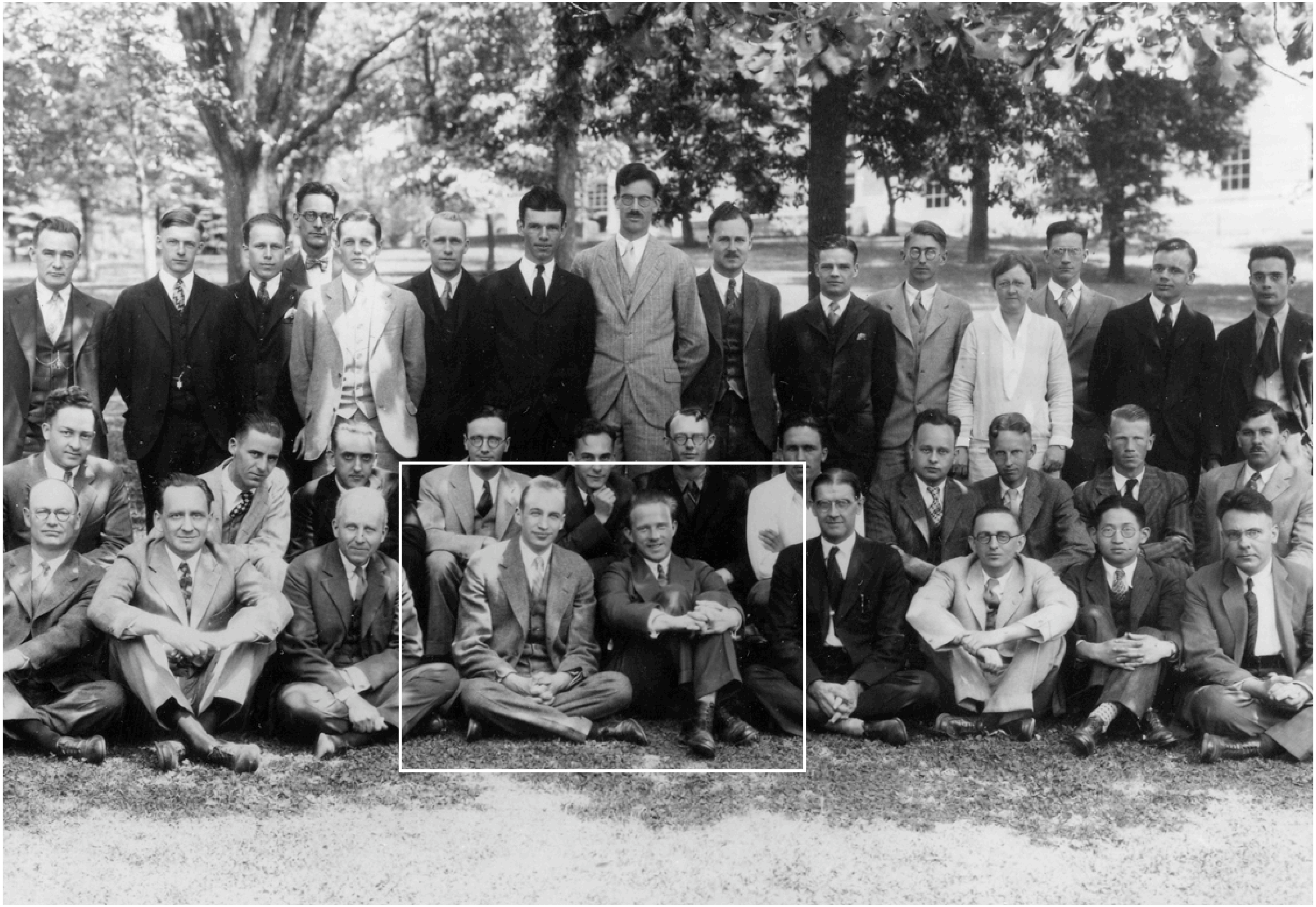
- 1923–1928 Minnesota;
  - 1926: Associate Professor;
  - 1927: Full Professor.
- 1924. Two-part paper in *Physical Review* on a correspondence principle for absorption (Part III, co-authored with David L. Huber, appeared in 1977)
- **1926 *Quantum Principles and Line Spectra.***
- 1927 Marries **Abigail June Pearson (1900–1989)**.

Van Vleck biography (cont'd).

- 1923–1928 Minnesota.
- **1928–1934 Wisconsin–Madison.**
- 1927–1928 Three-part paper"On Dielectric Constants and Magnetic Susceptibilities in the new Quantum Mechanics."
- **1932 *The Theory of Electric and Magnetic Susceptibilities*.** Van known as the "father of modern magnetism."
- 1934 The Call from Harvard.

Van Vleck in Madison, 1929.

Van Vleck in Madison, 1929, with …



Van Vleck in Madison, 1929, with Werner Heisenberg (1901–1976).

Badgers & Gophers: Chun Lin (WI), Roger Stuewer (MN), Van Vleck (Harvard).

1976 DECEMBER/1977 JANUARY

alumni news

PUBLISHED BY THE UNIVERSITY OF MINNESOTA ALUMNI ASSOCIATION

• And much, much more. . .

"On, Minnesota" gave Wisconsin its popular fight song

following joint communication by three physicists on a topic connected with the history of college music is the result. It has been submitted in slightly different versions to the alumni magazines of both Minnesota and Wisconsin, since there is probably much less overlap in their readership than in the history of their songs.

had done so with the idea of entering it for a prize in a song contest being conducted by the University of Minnesota — but was talked into making it "On, Wisconsin" by Carl Beck who had previously attended the University of Wisconsin for two years, and was then living in the same rooming house as Purdy was in Chicago.

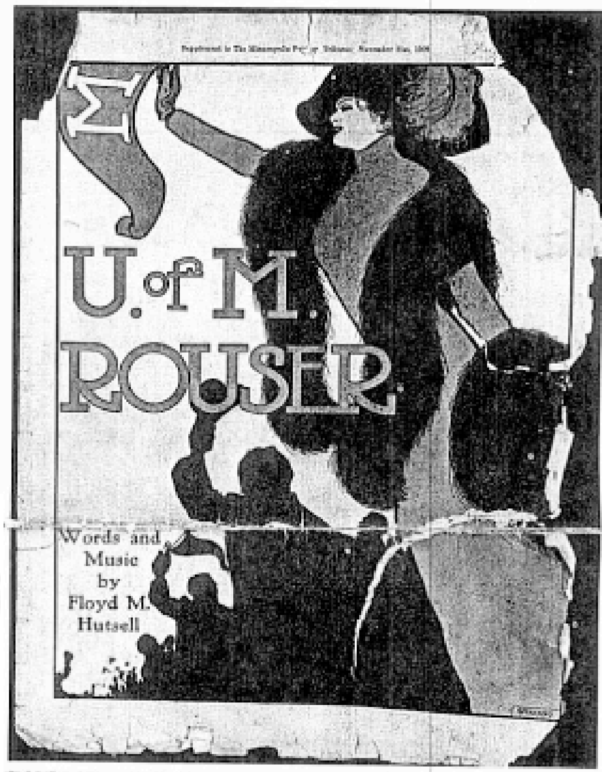
The receipt of th
kindled in the recip
about which he ha
time. First, what v
University of Min
chance "The Rous
to Thee . . .")? S
boy, a Wisconsin
1909, he wondered
sin" hadn't won a
interest in the song
nesota is the result
Madison, having
Band (1916-18) a
member of the facul
different times.

He therefore wro
friends on the facult
consin, respectively
Some surprising fac

Early Daily articles detail University of Minnesota song contest

One of us (RHS) searched the Minnesota *Daily* for 1909, and it turns out that indeed it was the "Rouser" that won the $100 Minnesota prize. The University of Minnesota contest had developed increasing momentum as time progressed. Originally, the prize was to be only $5 contributed by the *Daily*, but the stipend was gradually upped to $100 (in gold!) because of a $5 contribution from an alumnus, $50 from a Minneapolis newspaper (*The Tribune*) and $40 from Horace Lowry, Class of 1900. Thus, contrary to statements made from time to time in Madison newspapers, it was not sponsored by a Saint Paul or Minneapolis music store.

There were almost a hundred entries in the



FLORIZEL MODE '36MSW, Natick, Massachusetts, sent along this time-worn copy of one of the first copies of the "Minnesota Rouser" when her husband Walter '42BBA traveled to the Twin Cities to attend a board meeting of the Minnesota Alumni Association this fall. This was the song that won the $100 prize in a 1909 University contest that sought an appropriate and rousing tune with words that would inspire the Minnesota athletic teams to victory.

Van Vleck's "almost juvenile interest in the songs of Wisconsin and Minnesota is the result of his having grown up in Madison, having played in the Wisconsin band, and later having been a member of the faculties of both institutions."

Van Vleck on horseback (1933).

Van Vleck biography (cont'd).

- **1934–1969 Harvard.**

  1942–1945 Radio Research Laboratory (jamming enemy radar);

  1945–1949 Chair, Physics Department;

  1951–1957 Dean of Engineering and Applied Physics;

  1951–1969 Hollis Chair of Mathematics and Natural Philosophy [successor of Percy W. Bridgman (1882–1961)];

  1952–1953 President of the *American Physical Society*.

1967 (Van 68). National Medal of Science from President Lyndon B. Johnson.

1977 (Van 78) Nobel Prize with **Sir Nevill Francis Mott (1905–1996)** and former graduate student **Philip W. Anderson (b. 1923)**, "for their fundamental theoretical investigations of the electronic structure of magnetic and disordered systems."

2. Quantum theory in the US in the early 1920s.

In 1910s, US respectable in experimental quantum physics, backwater in quantum theory. Changed in early 1920s.

- **Education.** Graduate courses in quantum theory start to get offered.
- **Fellowships** from, among others, the *National Research Council* (*NRC*) and the *International Education Board* (*IEB*) [both paid for by the *Rockefeller Foundation*] make it possible for recent Ph.D.'s to study with leading quantum theorists in Europe.
- **Jobs.** Young American quantum theorists get offered faculty positions with provisions ensuring that they can spend most of their time on research and graduate teaching
- **Journals.** American physics journals become internationally important.

First cohort of American quantum theorists (Ph.D. right *before* 1925/26 quantum breakthrough): Harold C. Urey (1893–1981), Robert S. Mulliken (1896–1987), Frank C. Hoyt (1989–1977), John H. Van Vleck (1899–1980), Gregory Breit (1899–1981), John C. Slater (1900–1976), David M. Dennison (1900–1976).

Second cohort of American quantum theorists (Ph.D. right *after* 1925/26 quantum breakthrough): Isidor I. Rabi (1898–1988), Edward U. Condon (1902–1974), J. Robert Oppenheimer (1904–1967).

A somewhat closer look at Slater and Van Vleck.

Quantum theory in the US in the early 1920s.

Edwin C. Kemble (1889–1984)

- **Education.** Van Vleck and Slater both started graduate school at Harvard in 1920 (Van Vleck in February, Slater in September). They take quantum theory with Kemble.

  Van Vleck (autobiographical note published with his Nobel lecture, 1977): Kemble "was the one person in America at that time qualified to direct purely theoretical research in quantum atomic physics."

Quantum theory in the US in the early 1920s.

- Upon graduation, Slater got a Sheldon **fellowship** from Harvard to go to Copenhagen to study with Bohr and Kramers, Van Vleck stayed on as an instructor at Harvard for a year.

John C. Slater (1900–1976)

Hendrik A. (Hans) Kramers (1894–1952)

Quantum theory in the US in the early 1920s.

- **Jobs.** In fall 1923, Minnesota hired two young quantum theorists, Van Vleck and Breit.

Van Vleck (autobiographical note, 1977): "I was fortunate in being offered an assistant professorship … with purely graduate courses to teach. This was an unusual move … recent Ph.D.'s were traditionally handicapped by heavy loads of undergraduate teaching which left little time to think about research"

Gregory Breit (1899–1981)

Quantum theory in the US in the early 1920s.

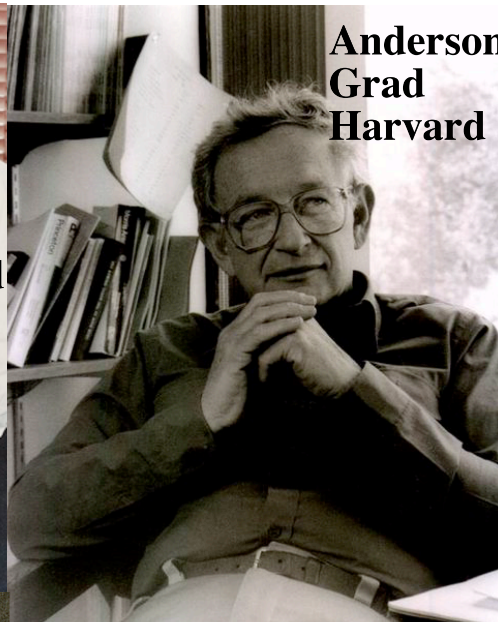
- **Journals.** **John Torrence Tate, Sr. (1889–1950)**, senior colleague of Van Vleck at Minnesota, turned lack-luster *Physical Review* into the prestigious journal it is today (editor of *Phys Rev*, 1926–1950; first editor of *Reviews of Modern Physics*, 1929–1950).

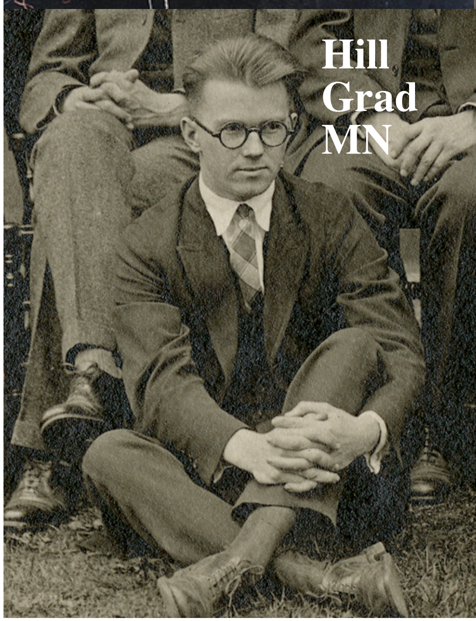
I. I. Rabi: "[T]he University of Göttingen … ordered all twelve monthly issues at once to save postage." & "in Hamburg … the librarian uncrated the issues only once a year."

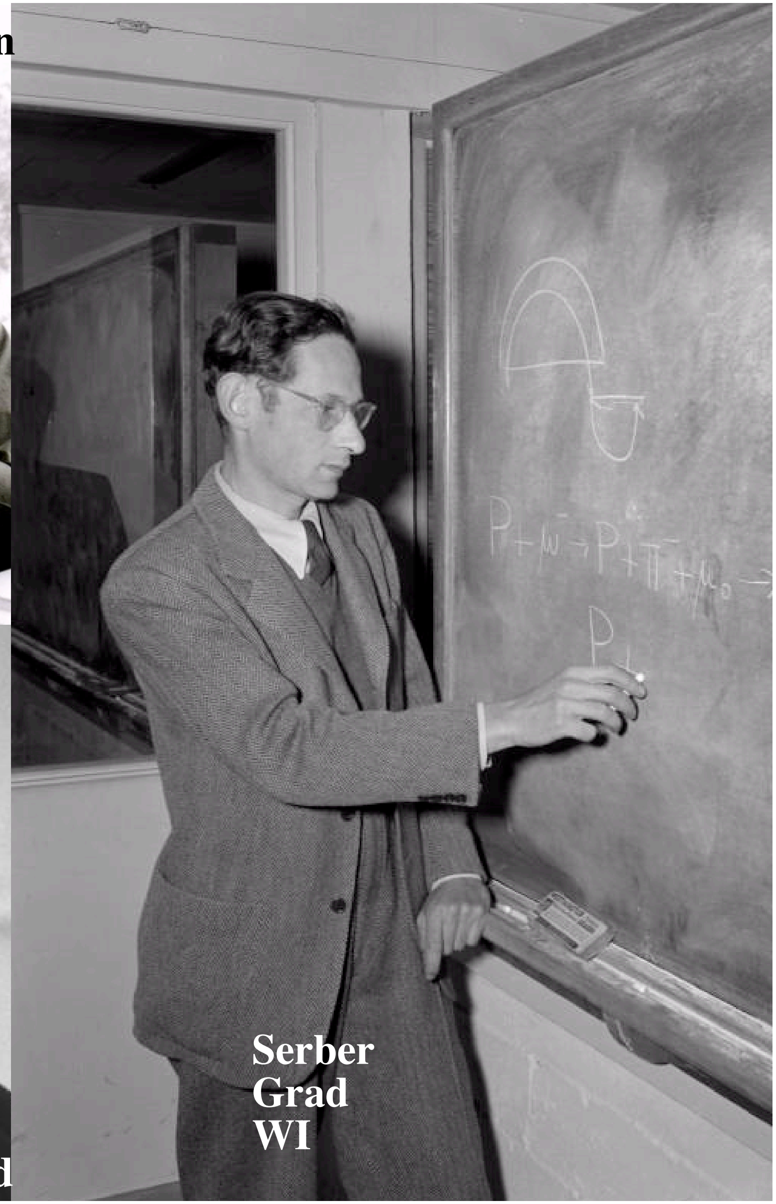
Van Vleck: "The *Physical Review* was only so-so, especially in theory, and in 1922 I was greatly pleased that my … thesis was accepted … by the *Philosophical Magazine* … By 1930 or so, the relative standings of *The Physical Review* and *Philosophical Magazine* were interchanged.

Some of Van Vleck's students

Some of Van Vleck’s students



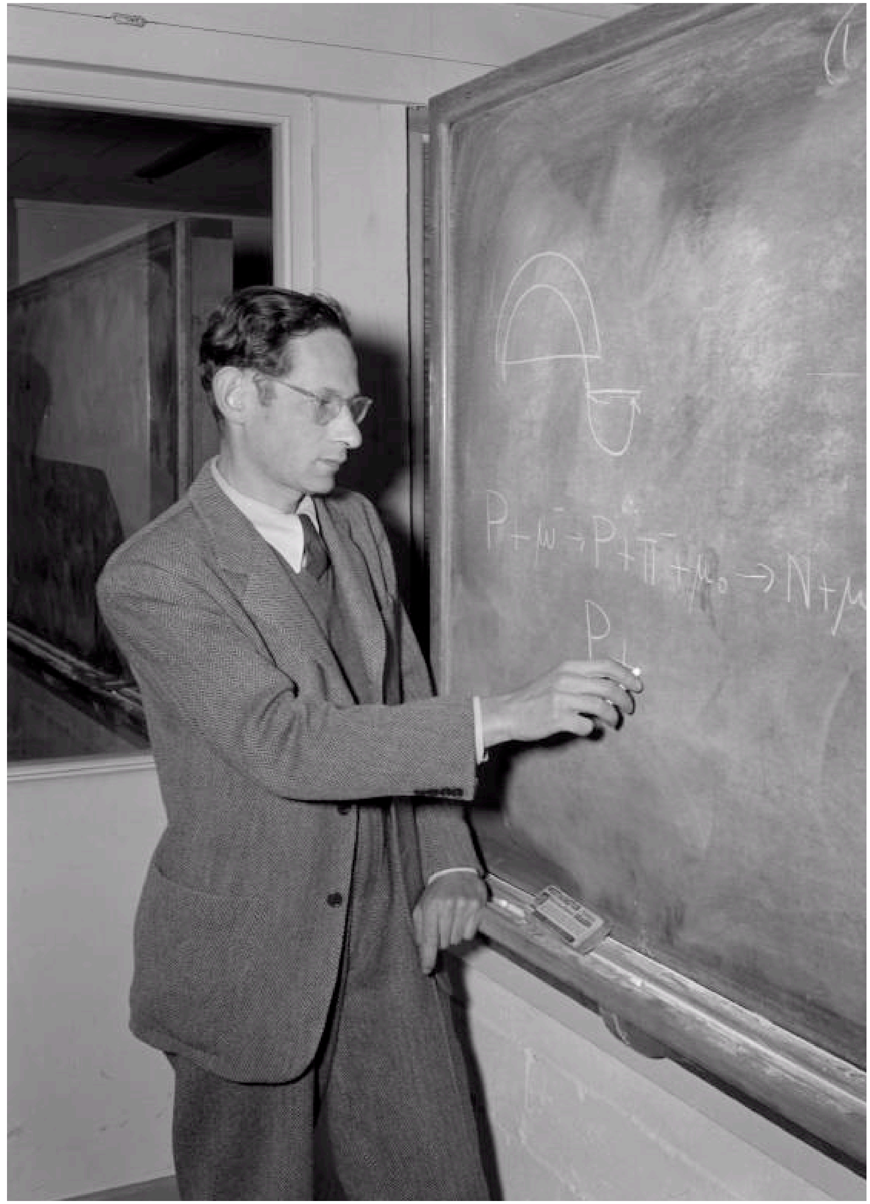




Robert Serber (1909–1997), Ph.D. Madison. 1934.

"John Van Vleck was my professor at Wisconsin. The first year I was there he gave a course in quantum mechanics. Noone wanted to take a degree that year … there weren't any jobs. The next year Van had the same bunch of students, so he gave us advanced quantum mechanics, The year after that he gave us advanced quantum mechanics II."

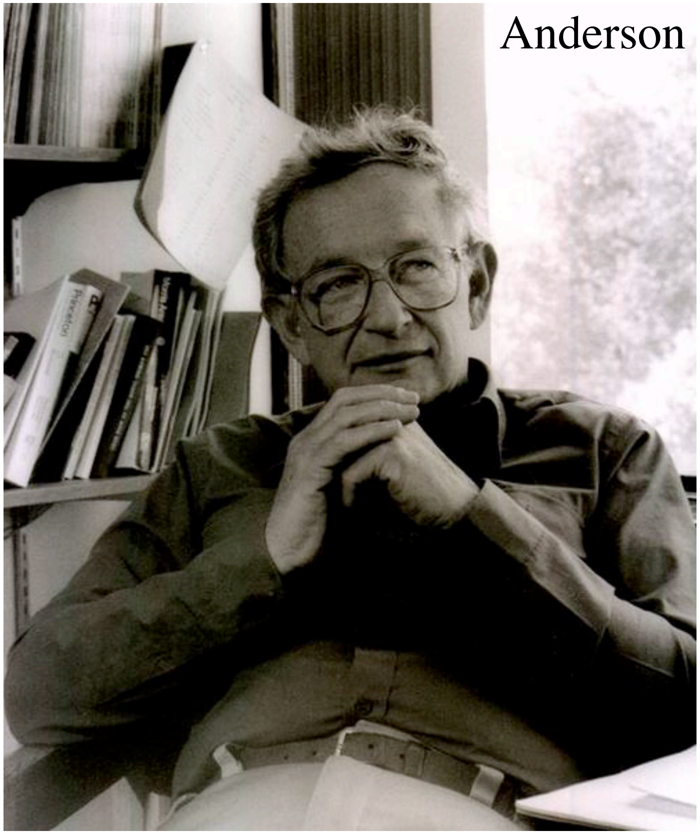
—Preface, *The Los Alamos Primer* (1992).



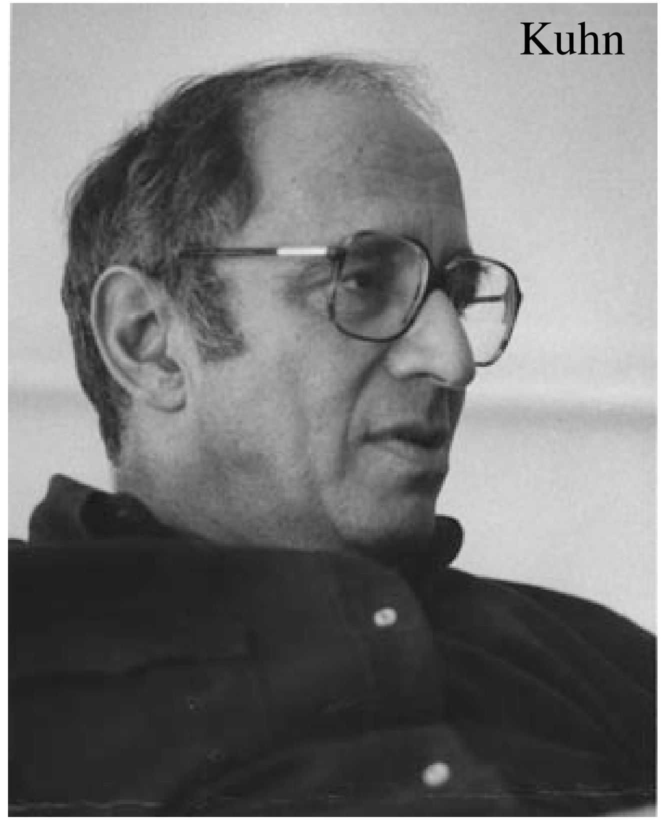
Some student notes of Van Vleck's early quantum courses have been preserved:

- Minnesota, 1927–1928 (Robert B. Whitney) [Photocopy Roger Stuewer];
- Wisconsin, 1930–1931 (Ralph P. Winch) [Niels Bohr Library & Archives, AIP].

Philip W. Anderson (b. 1923) & Thomas S. Kuhn (1922–1996), Ph.D. 1949 Harvard.



“The decision to work with him was one of the wiser choices of my life.”



“By the time I decided on a thesis topic, I was quite certain that I was not going to take a career in physics … Otherwise I would have shot for a chance to work with Julian Schwinger.”

3. *Quantum Principles and Line Spectra* (Minnesota 1926)

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Recall: "I was … offered an assistant professorship … with purely graduate courses to teach … recent Ph.D.'s were traditionally handicapped by heavy loads of undergraduate teaching which left little time to think about research"

In fact, most of Van Vleck's time during this period went into *fixating* the correspondence-principle techniques of his 1924 research in his 1926 NRC *Bulletin* and not into *advancing* that research …

Because of the quantum revolution of 1925–1926, the *Bulletin* "in a sense was obsolete by the time it was off the press" (Van Vleck 1971).

Correspondence principle

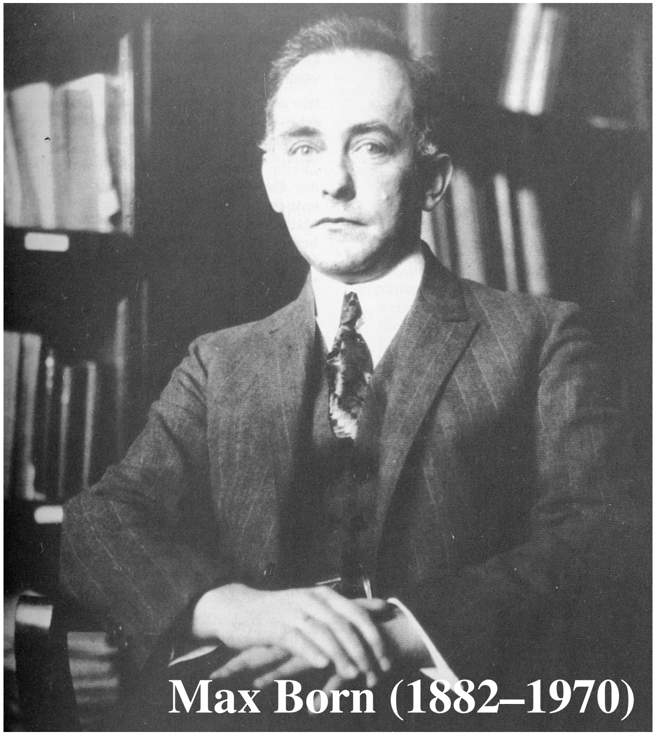
Embryonic version (1913): Make radical departure from classical theory more palatable (especially the severing of the link between orbital frequency and radiation frequency).

Sophisticated version (1920s): Translation scheme for generating quantum formulas out of classical formulas.

Classical formula (in action-angle variables)	$\rightarrow$	**Quantum formula** (for high quantum numbers N)
orbital frequencies ν_N	$\rightarrow$	radiation frequencies $\nu_{(N+1)\rightarrow N}$;
amplitudes squared a_N^2	$\rightarrow$	transition probabilities $A_{(N+1)\rightarrow N}$;
derivatives $\left.\dfrac{\partial F}{\partial J}\right\vert_{J=Nh}$	$\rightarrow$	difference quotients $\dfrac{F((N+1)h) - F(Nh)}{h}$.

Construction guarantees that quantum formula merges with classical formula for high quantum numbers N. Leap of faith: quantum formula holds for all quantum numbers (example: Kramers dispersion formula).

Correspondence principle. Sophisticated version (1920s): Translation scheme for generating quantum formulas out of classical formulas.



- Central to 1924 research papers of both Van Vleck and Born (testy correspondence between them).
- Approach expanded into books by both Van Vleck and Born (*Atommechanik*, 1924).
- Van Vleck more accessible than Born.
- Next step missed by both Van Vleck and Born: use this translation scheme for the basic laws of classical mechanics rather than for individual formulas (Heisenberg's *Umdeutung*).

Van Vleck: "I did not have sufficient insight for this" (AHQP interview, 1963);

Born: "discussions with my collaborators Heisenberg, Jordan, and Hund which attended the writing of this book have prepared the way for the critical step which we owe to Heisenberg" (preface to 1927 English translation of *Atommechanik*).

Limitations and provisional character of the old quantum theory.

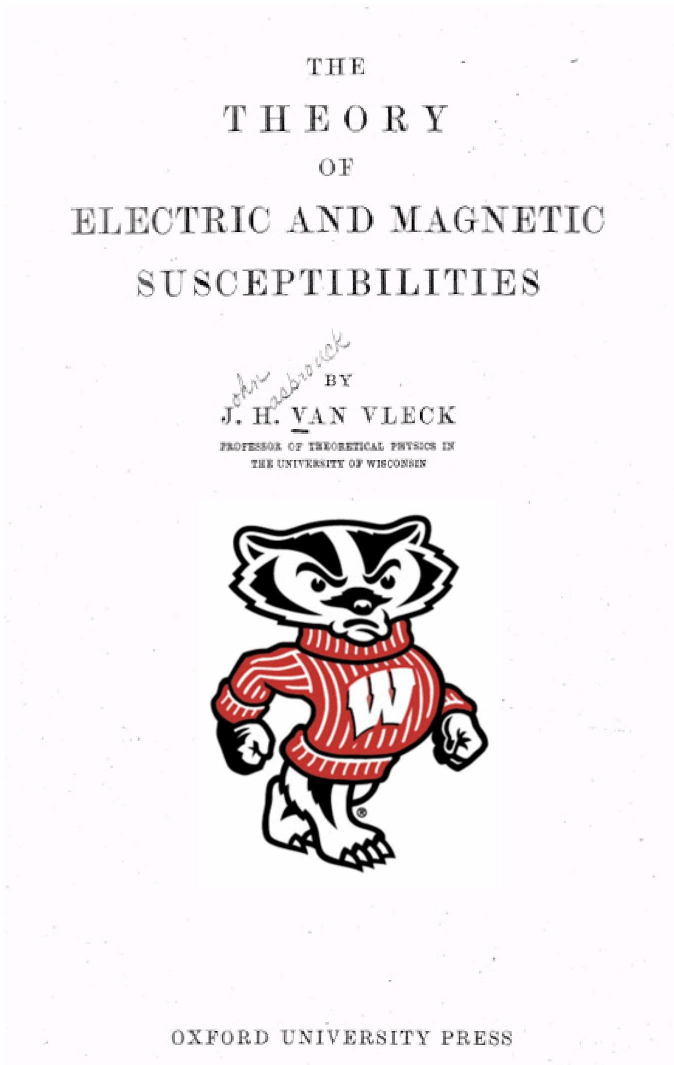
- **Already clear to Born before 1925–1926 breakthrough.** Preface of *Atommechanik*: "ascertain the limit within which the present principles of atomic and quantum theory are valid and … explore the ways by which we may hope to proceed … to make this programme clear … I have called the present book "Vol. I" … The second volume may… remain for many years unwritten. In the meantime let its virtual existence serve to make clear the aim and spirit of this work."

  Vol. II: Born and Jordan. *Elementare Quantenmechanik*. Berlin: Springer, 1930.

  From Pauli's review: "the second volume in a series in which goal and purpose of the n^{th} volume is a lways made clear through the virtual existence of the $(n+1)^{\mathrm{th}}$ volume … *Die Ausstattung des Buches hinsichtlich Druck und Papier ist vortrefflich*"

- **Not fully clear to Van Vleck until after 1925–1926 breakthrough.** 1928 article in *Chemical Reviews*:"[O]ne cannot use a meter stick to measure the diameter of an atom, or an alarm clock to record when an electron is at the perihelion of its orbit. Consequently we must not be surprised … that models cannot be constructed with the same kind of mechanics as Henry Ford uses in designing an automobile."

4 *The Theory of Electric and Magnetic Susceptibilities* (Wisconsin 1932).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Unlike the 1926 NRC *Bulletin*, this 1932 book:

- not just fixated but advanced earlier research (the 1927–28 trilogy on susceptibilities)
- was not dead on arrival but helped spawn solid-state physics

Philip W. Anderson (biographical memoir 1987):

“It was an enormously influential book and set a standard and a style for American solid-state physics that greatly influenced its development during decades to come—for the better.”

“It is marked—perhaps even slightly marred, as a modern text for physicists poorly trained in classical mechanics—by careful discussion of the ways in which quantum mechanics, the old quantum theory, and classical physics differ”

From spectra to susceptibilities: Kuhn losses regained

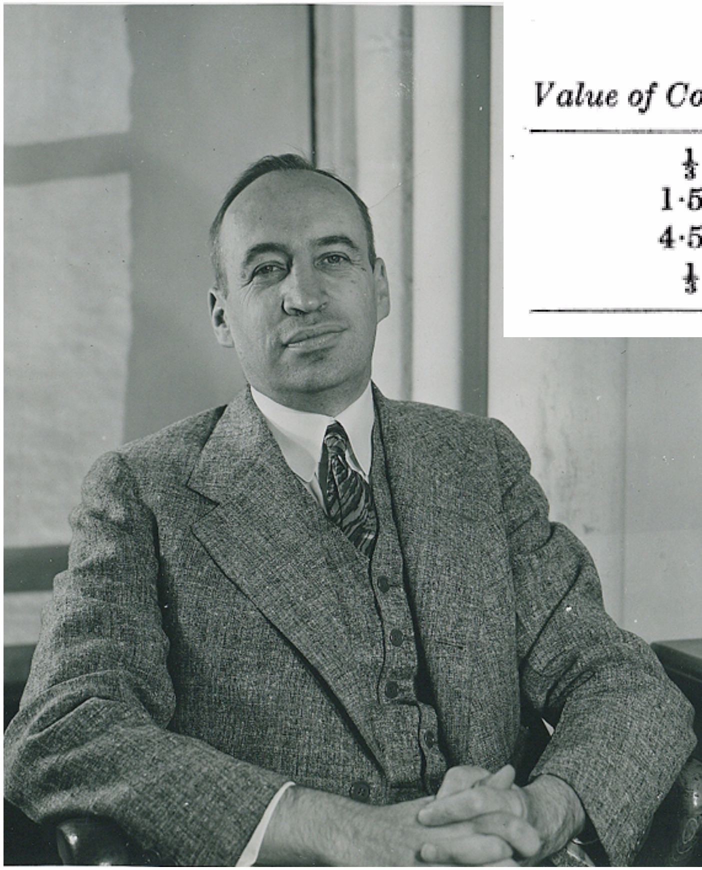
The Theory of Electric and Magnetic Susceptibilities (Wisconsin 1932)

Preface: "The new quantum mechanics is perhaps most noted for its triumphs in the field of spectroscopy, but its less heralded successes in the theory of electric and magnetic susceptibilities must be regarded as one of its great achievements. At the same time the accomplishments of classical mechanics in this field must not be overlooked [hence: topic of Chs. I–IV] … the new quantum mechanics has restored the validity of many classical theorems violated in the old quantum theory."

Ch. V, Susceptibilities in the old quantum theory contrasted with the new: "[I]t may seem like unburying the dead to devote a chapter to the old quantum theory … However, there is perhaps no better field than that of electric and magnetic susceptibilities to illustrate the inadequacies of the old quantum theory and how they have been removed by the new mechanics."

From spectra to susceptibilities: Kuhn losses regained

Value of Constant C.	*Form and Year of Theory.*	*Corresponding Value of Electrical Moment μ of HCl Molecule.*
$\frac{1}{3}$	Classical, 1912	$1{\cdot}034 \times 10^{-18}$ e.s.u.
1·54	Whole quanta, 1921	$0{\cdot}481 \times 10^{-18}$
4·57	Half quanta, 1925	$0{\cdot}332 \times 10^{-18}$
$\frac{1}{3}$	New mechanics, 1926	$1{\cdot}034 \times 10^{-18}$



"It is seen that this new dynamics restores the factor $\frac{1}{3}$ characteristic of the classical Langevin formula. After quite a history, the computed electrical moment of the HCl molecule thus reverts to its original value. In general, the susceptibilities obtained with the new quantum mechanics are more closely akin to those of the classical theory than are those obtained with the old quantum theory."

Van Vleck first published the table above in a 1928 article on quantum mechanics in Chemical Reviews; a version of it can still be found in his 1977 Nobel lecture.

Conclusion: Do Van Vleck's two books bear out Kuhn's claims about Kuhn losses and the role of textbooks in scientific revolutions?

Kuhn on textbooks in *Structure of Scientific Revolutions*: "[Textbooks] **[a]** address themselves to an already articulated body of problems, data, and theory, most often to the particular set of paradigms [in Kuhn's later terminology: *exemplars*] to which the scientific community is committed at the time they are written …**[b]** being pedagogic vehicles for the perpetuation of normal science … [they] have to be rewritten in the aftermath of each scientific revolution, and, **[c]** once rewritten, they inevitably disguise not only the role but the very existence of the revolutions that produced them … [thereby] truncating the scientist's sense of his discipline's history."

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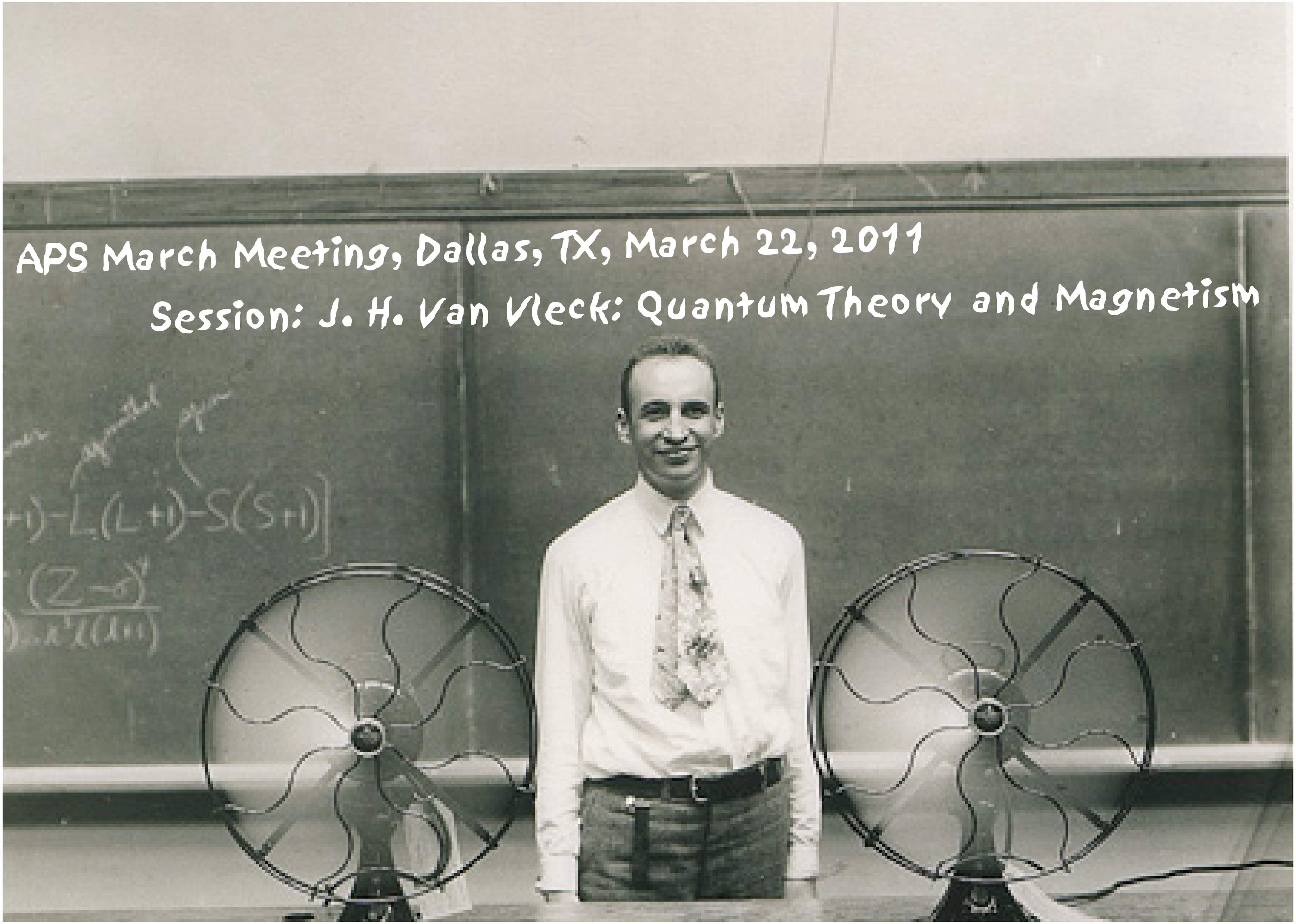
Van Vleck's books bear out (a) and (b) but not (c): they equipped readers with the tools they needed to start contributing to the research tradition that these books grew out of *without* the distortion and suppression of the prehistory of their subject matter that Kuhn claimed are unavoidable.

Corollary: While Kuhn losses may be swept under the rug, *regained* Kuhn losses can be put to good use to promote a new theory.

Van Vleck from spectra to susceptibilities (1926–1932)

Final observation: Van Vleck's two books nicely illustrate that Kuhn exaggerated the discontinuity in scientific revolutions.

The quantum perturbation techniques used in the 1932 book to deal with susceptibilities (see Ch. VI, Quantum-Mechanical Foundations) grew naturally out of the classical perturbation techniques (borrowed from celestial mechanics) used in the 1926 NRC *Bulletin* to deal with spectra.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