The Establishment of Quantum Physics in Göttingen

Arne Schirrmacher

Humboldt-Universität zu Berlin

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Fachverband Geschichte der Physik

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Can a whole town be a historic site of physics?

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In what sense

Can a whole town be a historic site of physics?

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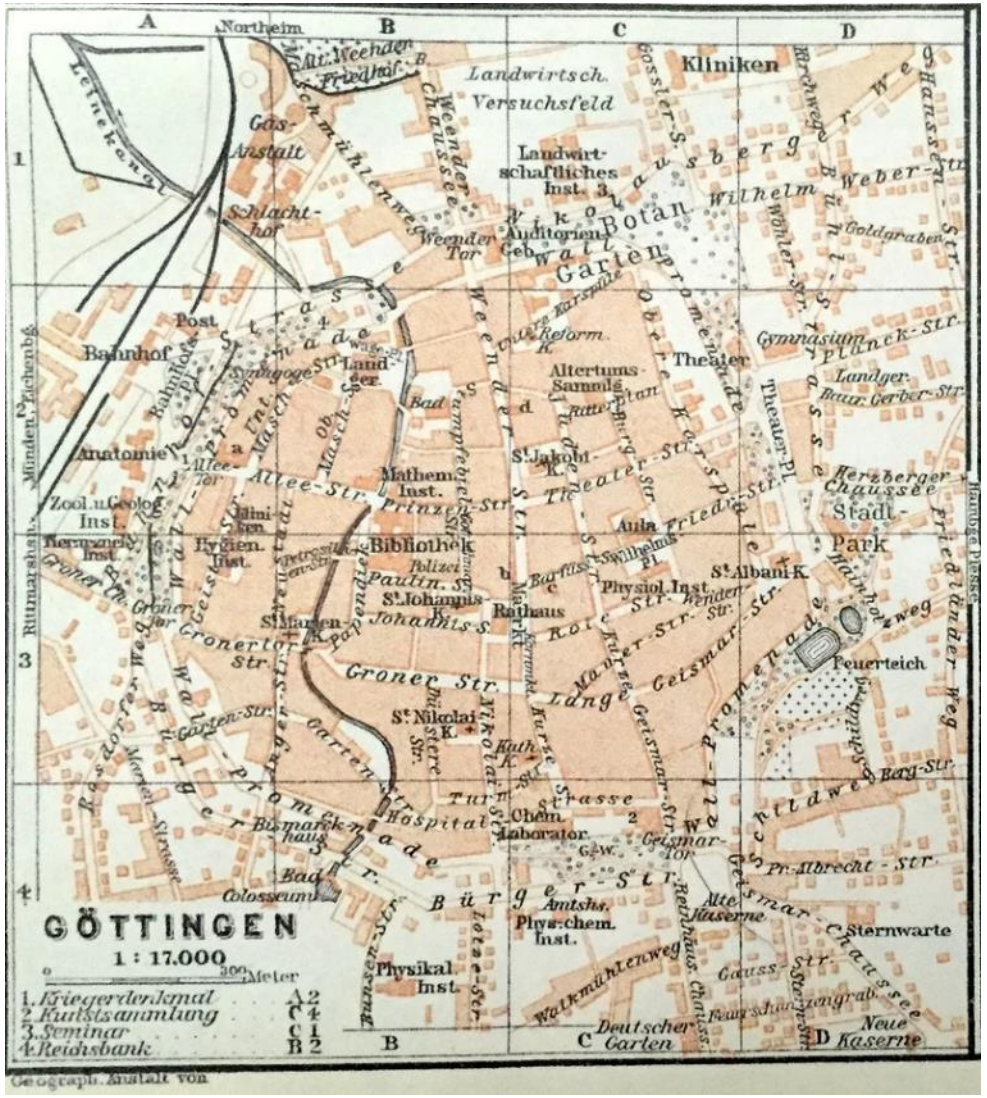
European Physical Society – EPS Historic Site

The City of Göttingen

In 1925, the foundations of quantum mechanics were laid in Göttingen by Max Born, Werner Heisenberg and Pascual Jordan. This new theory fundamentally changed our understanding of nature. Quantum Mechanics was rapidly developed and applied, with further ground-breaking contributions from Maria Goeppert-Mayer, Friedrich Hund, Lucy Mensing, John von Neumann, Robert Oppenheimer, Wolfgang Pauli, Viktor Weisskopf, and Eugene Wigner, who all worked in this city. Göttingen quickly became a leading centre for modern physics, building on the excellence of world-leading mathematicians, notably Richard Courant, David Hilbert, Felix Klein, Emmy Noether, and Hermann Weyl. Atomic and molecular spectroscopy experiments performed by James Franck and Hertha Sponer confirmed the theoretical work and spurred the success of quantum mechanics.



Göttingen 1925, Baedeker Norddeutschland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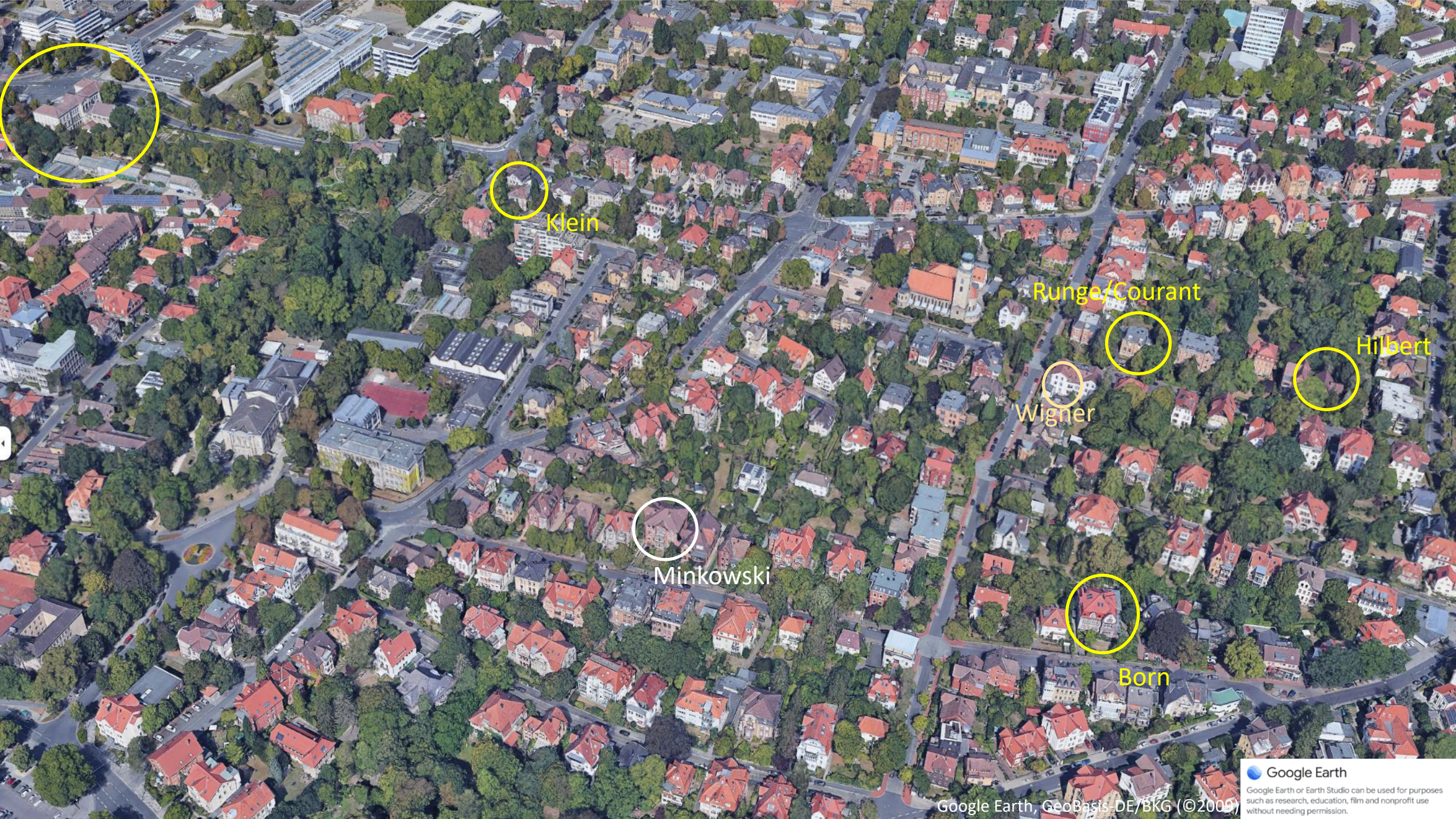
Klein
Runge/Courant
Hilbert
Wigner
Minkowski
Born
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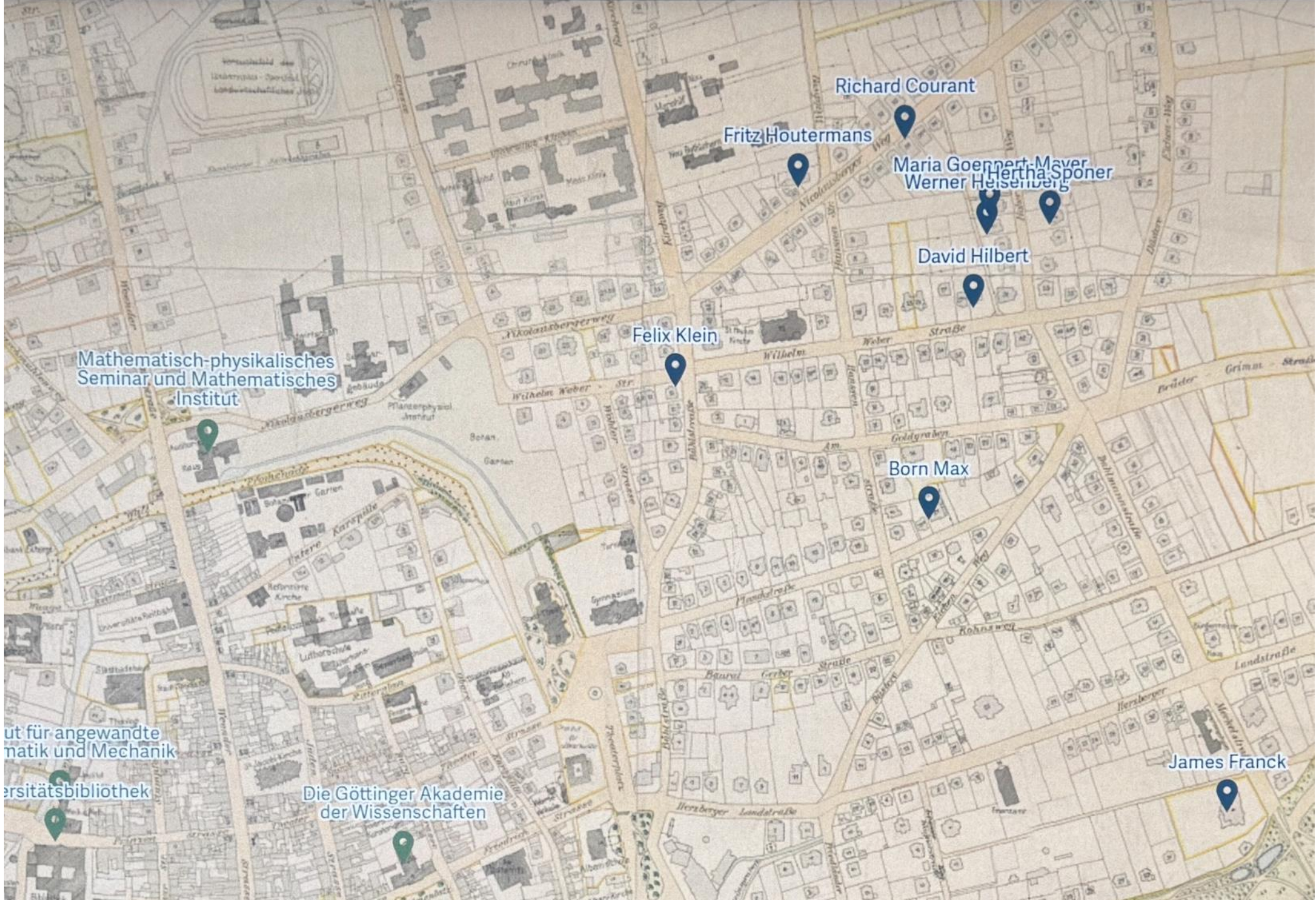
1925


Richard Courant
Fritz Houtermans
Maria Goeppert-Mayer
Hertha Sponer
Werner Heisenberg
David Hilbert
Felix Klein
Mathematisch-physikalisches Seminar und Mathematisches Institut
Born Max
James Franck
Die Göttinger Akademie der Wissenschaften


FORUM WISSEN
WAS ZUM QUANT?!
Die Ausstellung zum Quantenjahr in Göttingen
27.03. – 05.10.2025

What kind of scientific place was Göttingen 100 years ago?

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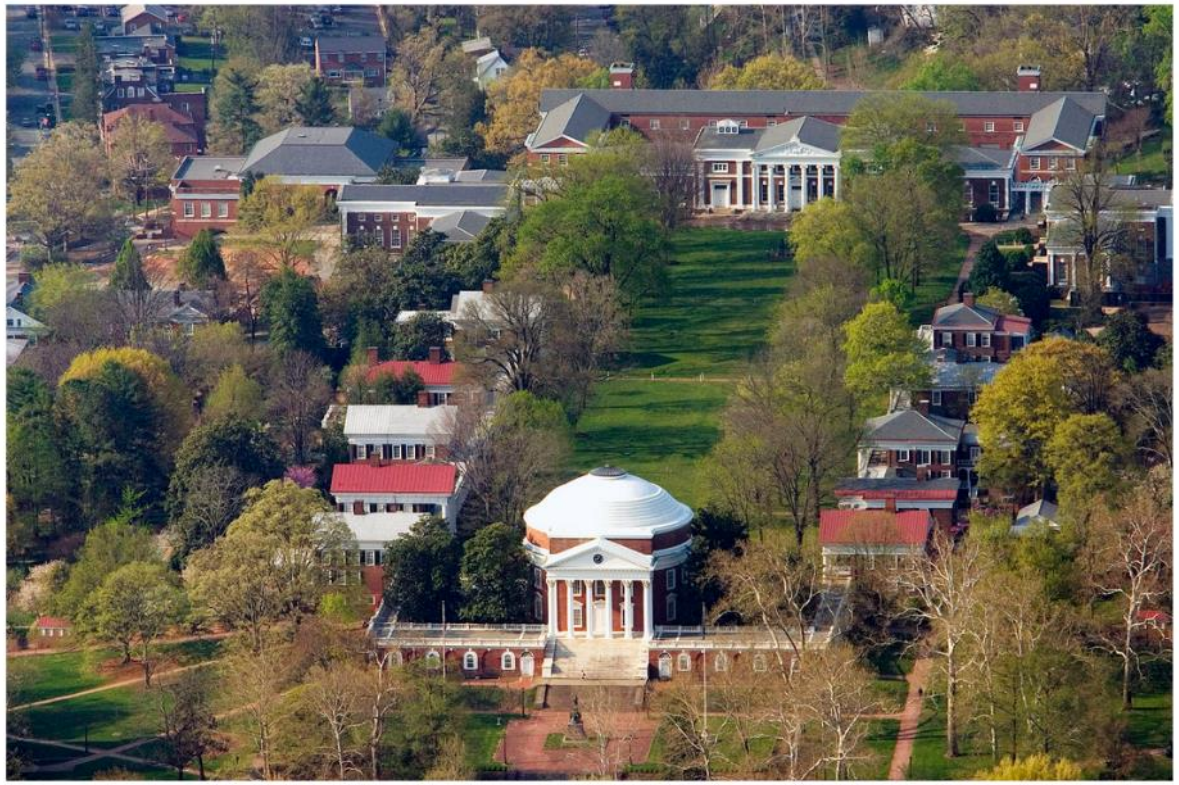
Oxford University

Map of the central and eastern part of the city of Oxford from David Loggan, *Oxonia Illustrata* (1675).

Academical Village, 1819

THOMAS JEFFERSON'S ACADEMICAL VILLAGE, UNIVERSITY OF VIRGINIA



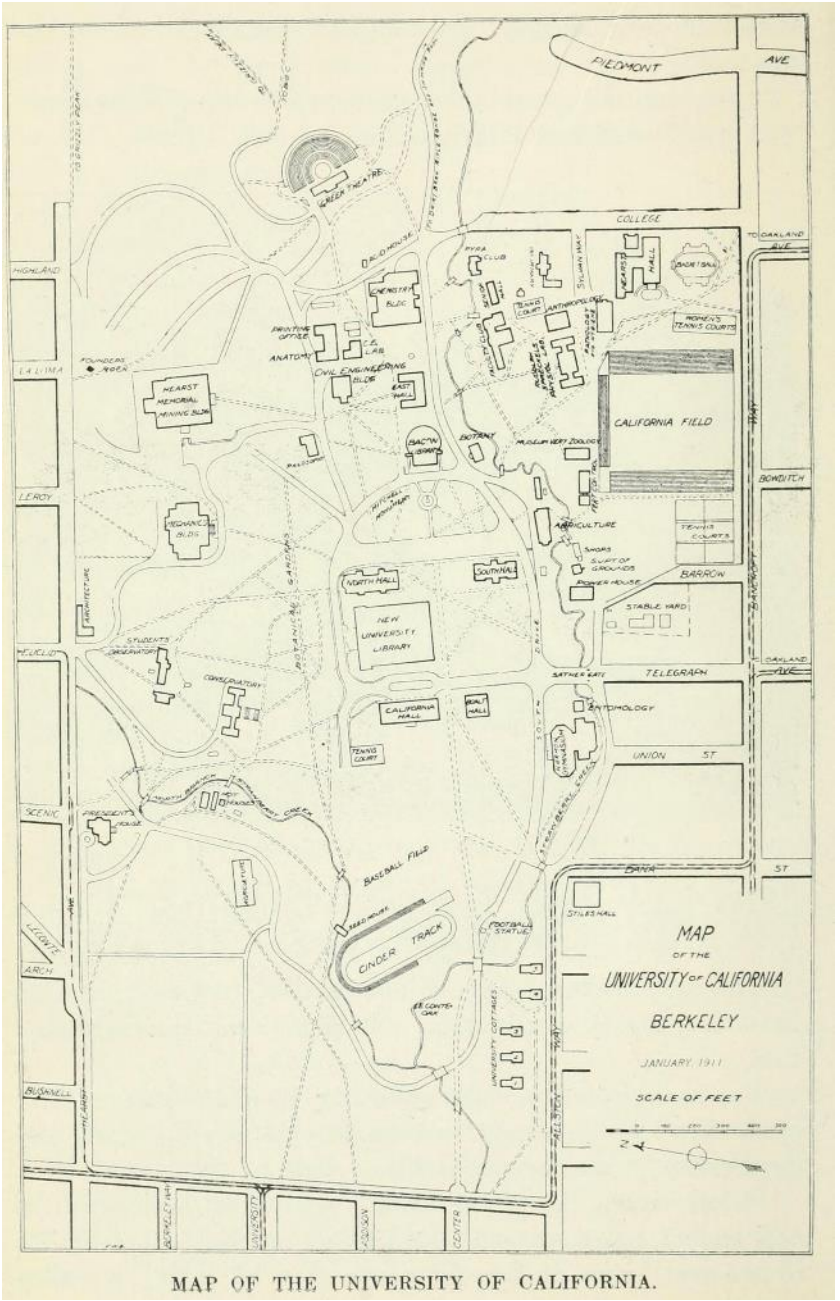
City: Charlottesville

Date: 1819

Architect: Thomas Jefferson

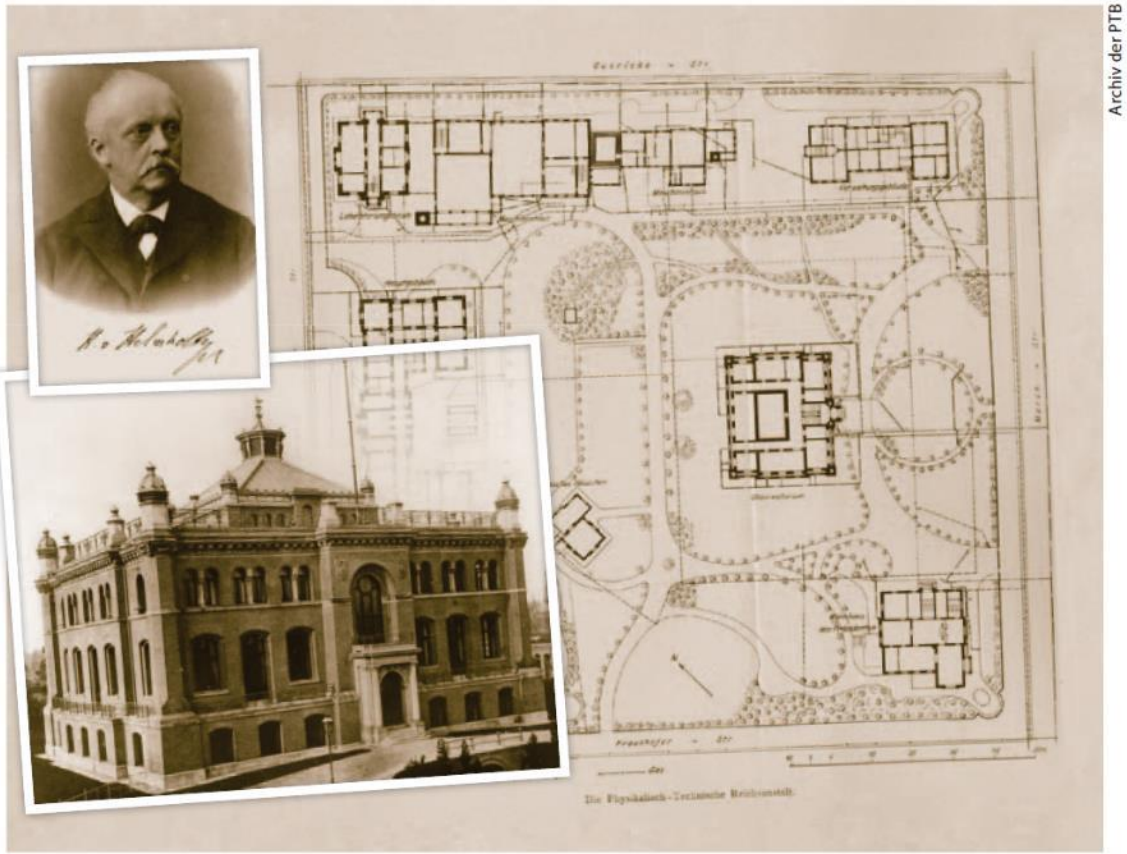
Berkeley (1868)

Plan 1914



MAP OF THE UNIVERSITY OF CALIFORNIA.

Physikalisch-Technische Reichsanstalt, Berlin



Archiv der PTB

Bohr Institute (1921)

European Physical Society – EPS Historic Site

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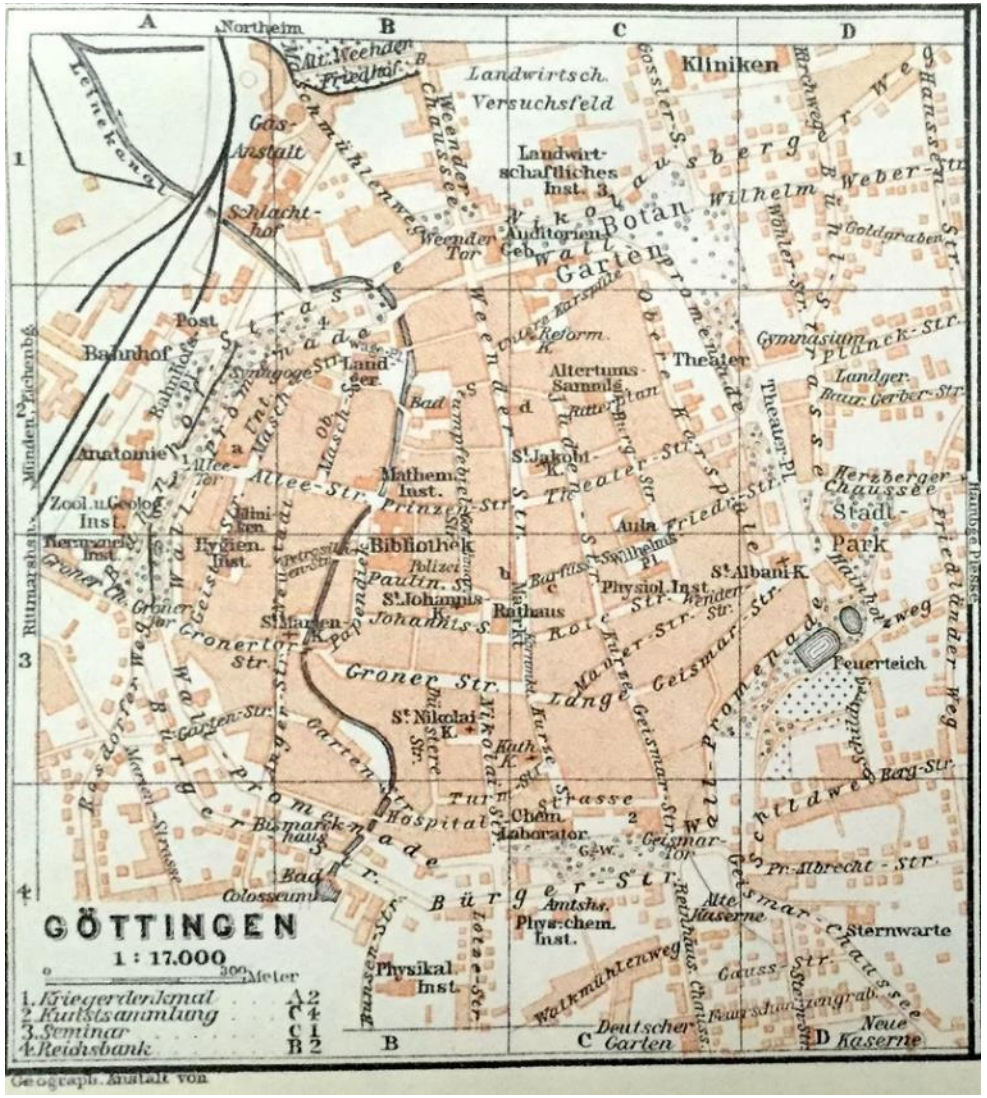

Göttingen 1925, Baedeker Norddeutschland

Quantum Physics in Göttingen in the early 20th century

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Göttingen Contributions to Quantum Physics up to 1920

combination principle – Ritz

black-body radiation – Abraham

quantum discontinuity – Ehrenfest

(heat theorem – Nernst)

(Stark effect – Stark/Voigt)

black-body radiation – Born/Ladenburg
specific heats – Born/von Kármán
Eötvös' law – Born/Courant

(atomic constitution of matter – Born/Landé/Madelung)

photos of Bohr atom rings? – Debye/Scherrer

Göttingen Contributions to Quantum Physics up to 1920 – **No coherent picture!**

combination principle – Ritz

black-body radiation – Abraham

quantum discontinuity – Ehrenfest

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The Hilbert Picture (perspective)

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The Hilbert Picture

on science and method

Private Notebooks, between 1905 and 1910

I protest against the objection that physics were not developed enough to be axiomatized. Any science is at any time not only ripe enough but requires with necessity axiomatization, understood in the correct sense.

Ich protestire gegen den Einwand, die Physik sei noch nicht weit genug zur Axiomatisierung. Jede Wissenschaft ist zu jeder Zeit nicht nur reif genug, sondern erfordert mit Notwendigkeit die Axiomatisierung, diese im richtigen Sinne verstanden

"Axiomatisches Denken" (Mathematische Annalen, 1917)

I believe: Everything that can be object of scientific thought at all becomes object of the axiomatic method and hence of mathematics as soon as it is ripe for forming a theory. By progressing to deeper and deeper layers of axioms in the above described sense, we gain also deeper and deeper insight in the nature of scientific thought itself and realize the unity of our knowledge more and more. **Under the sign of the axiomatic method mathematics appears to be called upon having the leading role in science.**

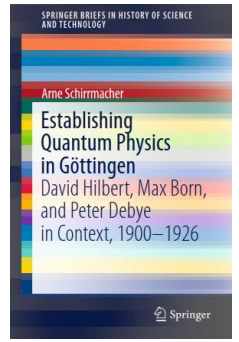
Ich glaube: Alles, was Gegenstand des wissenschaftlichen Denkens überhaupt sein kann, verfällt, sobald es zur Bildung einer Theorie reif ist, der axiomatischen Methode und damit mittelbar der Mathematik. Durch Vordringen zu immer tieferliegender Schichten von Axiomen im vorhin dargelegten Sinne gewinnen wir auch in das Wesen des wissenschaftlichen Denkens selbst immer tiefere Einblicke und werden uns der Einheit unseres Wissens immer mehr bewußt. In dem Zeichen der axiomatischen Methode erscheint die Mathematik berufen zu einer führenden Rolle in der Wissenschaft überhaupt.

Math. Ann. **78**, 405–415 (1917)

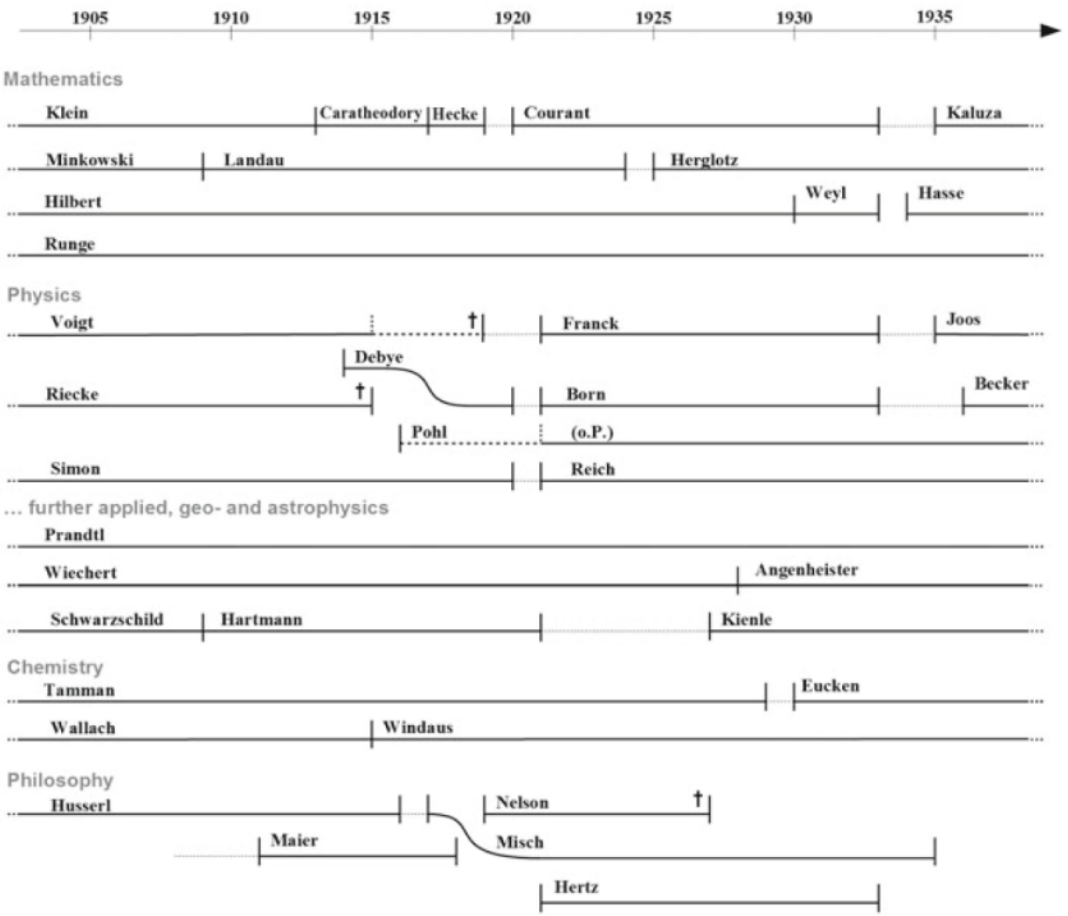
The Hilbert Picture
personal resources

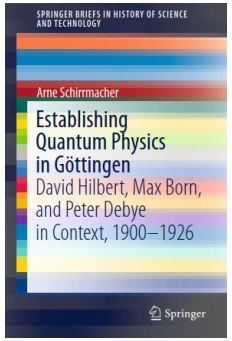
Table 3.1 Hilbert's assistants and their pay 1904–1930, compiled from various sources

	Mathematics assistants	Pay/yr.	Physics assistants	Pay/yr.
(SS 04, WS 04)[a] from SS 05	Born Privatassistent	—		
WS 05 SS 06, WS 06	Hellinger	900[b]		
(WS 06)	Ewald	?		
SS 07, WS 07 SS 08, WS 08	Haar	900		
SS 09, WS 09 SS 10, WS 10	Courant (1910: Dr.)	900		
WS 10	Behrens	1200		
SS 11, WS 11	Hecke (Dr.)	1200		
SS 12, WS 12	Hecke (PD)	1200	Ewald (Dr.)	800[c]
SS 13, WS13	Hecke (PD) as 1st assist. (Baule)	1200	Landé as 2nd assist.	800
SS 14, WS 14	Hecke (PD) as 2nd assist.	1200	Landé (Dr.) as 1st assist.	1200
SS 15, WS 15 SS 16 (part)	Krafft (PD)	1200		
SS 16 (part) WS 16, SS 17	Bär (Dr.?)	1200		
WS 17 SS 18, WS 18	Bernays (Dr.)	1200		
SS 19, ZS 19 WS 19	Bernays (PD)	1200	Baule (Dr.) SS, Sponer (ZS, WS)	1200
SS 20, WS 20	Bernays (PD)	2400[d]	Kratzer (Dr.)	3000[d]
SS 21, WS 21	Bernays (PD)	10,000	E. Hückel (Dr.)	8400
SS 22 ... 1927	Bernays (a. pl. Prof.)	(16,000)	Nordheim (1923: Dr.)	(16,000)
After 1927	Bernays, Schmidt, Gentzen		Wigner	



The Hilbert Picture: New Professorships





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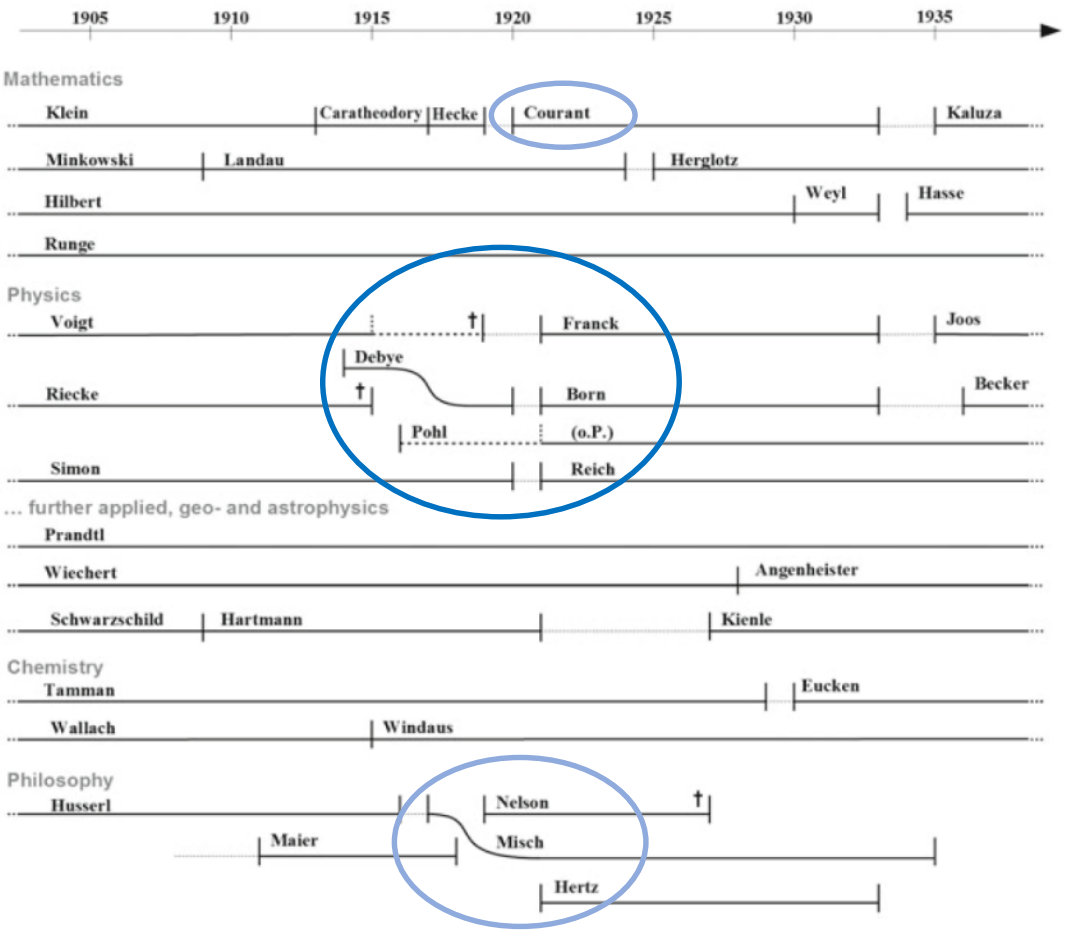
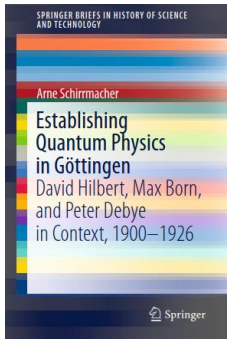


Hilbert (autobiographical sketch, 1932)

... I have never taken an interest in administrative matters.

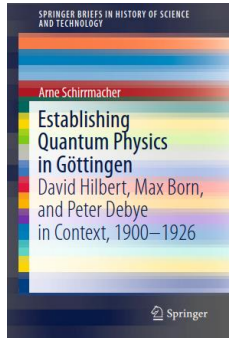
But when it came to important decisions, especially appointments, the creation of new positions and the like, I always took an active part.



The Hilbert Picture: spending/diverting money – e.g. Wolfkehl Fund

Table 3.5 Overview of the spending of Wolfskehl funds and means for *Gastprofessur*

Date	Speaker/grants for	Comments
22–29 April 1909	Poincaré	Six talks on integral equations and relativity, 2500 M.
1909	Wieferich	Mathematician in Münster, 1000 M. for papers on Fermat problem
24–29 October 1910	Lorentz	Lorentz-Woche, talks "On the developments of our conceptions of ether," discusses Planck's radiation formula
June 1911	[Michelson]	Lectures by exchange professor [German American professor exchange], no Wolfskehl money spent
1911	Zermelo	5000 M. for his works on set theory and as a grant to allow his recover from illness
July 1912	Sommerfeld	1000 M. for lectures on quantum theory in Hilbert's class (Laue's discovery was presented in *Physikalische Gesellschaft*)
21–26 April 1913	Planck, Nernst, Debye, Lorentz, Sommerfeld, von Smoluchowski (Einstein declined)	Congress, "Gaswoche" on "the kinetic theory of matter and electricity" 4800 M. spent (800 M. each)
Spring 1914	[Lorentz planned as model *Gastprofessor*]	Requested 5000 M; not granted by the ministry
Summer term 1914	Haar	Guest professor for theoretical astronomy (lectures on cosmogony); 2000 M. paid by Wolfskehl funds
Summer term 1914	Debye	Guest professor for theoretical physics; 1000 M. paid by Wolfskehl funds and 1000 M. support from the ministry
Winter 1914/15 until summer 1916	Debye	To raise professorial salary above usual state limit 2000 M. from Wolfskehl fund and 2000 from Voigt annually
Spring 1915	[talks planned]	Lecture series cancelled due to war
In summer 1915	Pohl E. Meyer	Job talks by experimental physicists for Riecke position
June 1915	Born Sommerfeld Einstein	Talk in Math. Ges. on crystal structure, 7 June talk in Math. Ges. on modern physics, 15 June six talks, one in Math. Ges. on gravitation, 29 June
Spring 1916	Smoluchowski	Lectures in mathematical physics
4–6 June 1917	Mie	Three talks on Einstein's theory of gravitation and matter, had been planned for 1916
25–29 June 1917	Hecke	Lectures on mathematics
11 December 1917	Born	Talk on liquid crystals in *Math. Ges.*
[1918]	[Ehrenfest invited]	Refused to come
14–17 May 1918	Planck	lectures on the current state of quantum physics
16–19 December 1918	Driesch	Talks on "organic causality"
1919	Bachmann	Paul Bachmann for book "Das Fermatproblem" 1500 M.
1920		?
1921		No Wolfskehl funds spent
1922	Bohr	Invited for 1921, money for *Gastprofessur* requested
[1922]	[Russell invited]	Money for *Gastprofessur* requested



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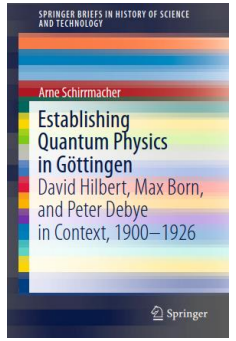


The Hilbert Picture:

on science an method (axiomatic thinking)

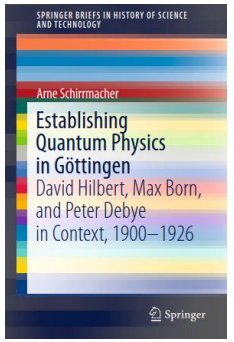
personal resources

new professorships

spending/diverting money – e.g. Wolfskehl Fund

introducing a curriculum in of quantum theory – first with Debye, then with Born and Franck

…



The Hilbert Picture: the *Göttingen Spirit*?

Autobiographical sketch 1932

But it was by no means easy for my wife and me to immediately feel at home in the somewhat chilly atmosphere in Göttingen at the time. We were often looked at with a shake of the head when we ignored the strict differences in rank and socialised casually with Privatdozenten and even students.

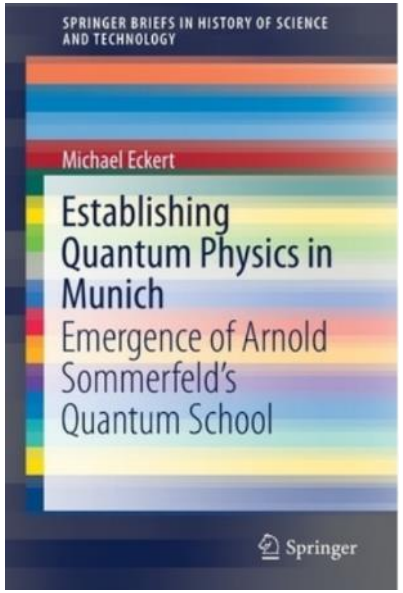
In conversations after lectures, on walks and bike rides, in the garden, at social gatherings and generally at any opportunity that presented itself, such discussions were often continued with students or colleagues.

‘The Spirit of Göttingen’

‘The Copenhagen Spirit’

‘Sommerfeld’s Quantum School’

…



FOREDRAG

The Copenhagen Spirit: A History of the Niels Bohr Institute

“Copenhagen”—few city names evoke stronger associations among physicists. Niels Bohr’s Institute for Theoretical Physics opened its doors in 1921. It became a key context for the genesis and further elaboration of quantum mechanics. The city of Copenhagen also lent the most prominent interpretation of the theory its name. After Bohr’s 1922 Nobel Prize, physicists from all over the world flocked to the Institute. They were attracted by a unique confluence of factors that Werner Heisenberg in 1930 dubbed the “Copenhagen spirit.” In my talk, I will present a short history of twentieth-century physics in Copenhagen, discuss the reasons for the Institute’s successes both before and after World War II, and elaborate on the secrets of the “Copenhagen spirit.

Foredraget afholdes på engelsk / The lecture will be in English.

Efter foredraget uddeles H.C. Ørsted Medaljen til en inspirerende grundskolelærer.

‘The Spirit of Göttingen’

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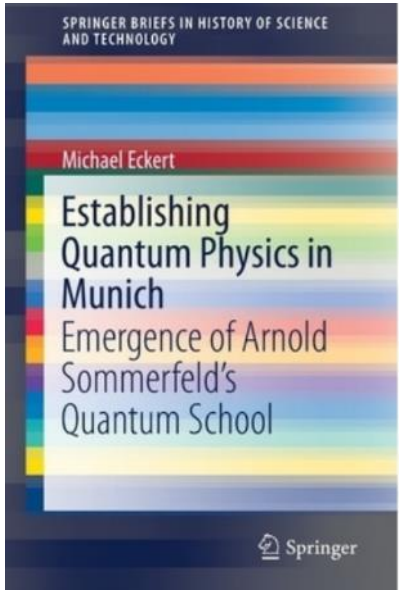

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NB: Good science needs good and long-term ‘infrastructures’!

This was created in Göttingen in the 1910s and 1920s for the collaboration of mathematics, experimental and theoretical physics.

The Heisenberg Picture

The Heisenberg Picture – Heisenberg in Göttingen's Quantum History

June 1922
attends 'Bohr festival'

Oct 1922 – May 1923
studies in Göttingen with Born (while Sommerfeld in US)

(PhD Munich)

Oct 1923 – Sept 1924
(privately funded) assistant to Born, habilitation

Sept 1924 – Oct 1925
IEB/Rockefeller Fnd Fellow in Bohr's Institute

8. – 18. June 1925 Helgoland
then short visit to Göttingen until c. mid July
Umdeutung paper (only observable quantities)

Oct 1925 – April 1926
Privatdozent at Göttingen, substitute for Born (US)
Born/Heisenberg/Jordan: Zur Quantenmechanik II

May 1926 –
lector and assistant to Bohr
Heisenberg: uncertainty principle

Oct 1927 –
Professor in Leipzig

Was Heisenberg a Göttinger?

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Oct 1927 –
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1922/23
Hilbert lecture: mathematical methods of quantum theory

June 1924
Born: Über Quantenmechanik

11. June 1925
Born/Jordan (only observable quantities)

Sept 1925
Born/Jordan: Zur Quantenmachanik

June 1926
Born: statistical interpretation

1926/1927
Hilbert/Nordheim/von Neumann: mathematical foundations

The Postdoc Picture

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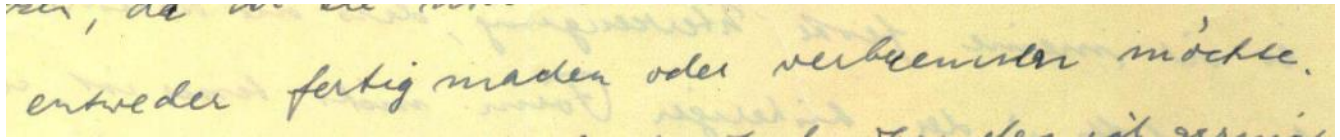
The Postdoc Picture: superstar Heisenberg with some grains of salt

Heisenberg to his parents, 29 Nov. 1923

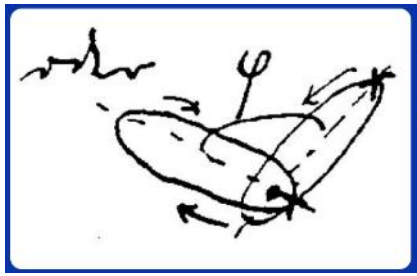
"[A]s long as I am here in Gött[ingen] I must do what Born wishes, just as in Munich I had to do what S[ommerfeld] wished"
(and in Copenhagen…)

Heisenberg to Pauli, 9 July 1925, on Umdeutung manuscript

"I believe that [my work] contains real physics, at least in the critical, i.e. negative part. … as I would like to either finish it or burn it in the last days of my stay here [in Göttingen]. … but perhaps people who are more capable can make something reasonable out of it."



Quantum History Wall **quantum–history.de**



October 1922
A Succesfull Model, Which Bohr Didn't Like

Prof. Bohr zu herzlichem Danke verpflichtet.

1927
Don't Mess With Bohr

The Postdoc Picture: superstar Heisenberg with some grains of salt

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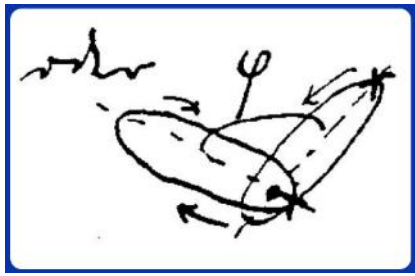
> "I believe that [my work] contains real physics, at least in the critical, i.e. negative part. … as I would like to either finish it or burn it in the last days of my stay here [in Göttingen]. … but perhaps people who are more capable can make something reasonable out of it."

Alexei Kojevnikov:

> "It requires some effort, psychologically, to think about [Heisenberg and Pauli] as vulnerable and insecure students, without permanent positions and funding ... But once we make this effort of historical empathy, we are better able to understand and reinterpret some of their important moves, choices, and ideas for the radical reconceptualization of quantum theory during the 1920s."

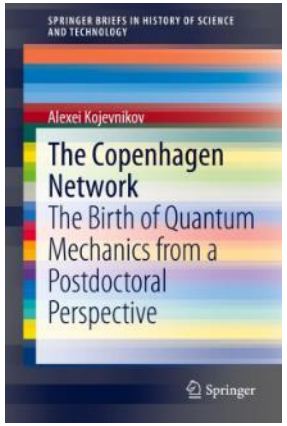
Quantum History Wall **quantum–history.de**

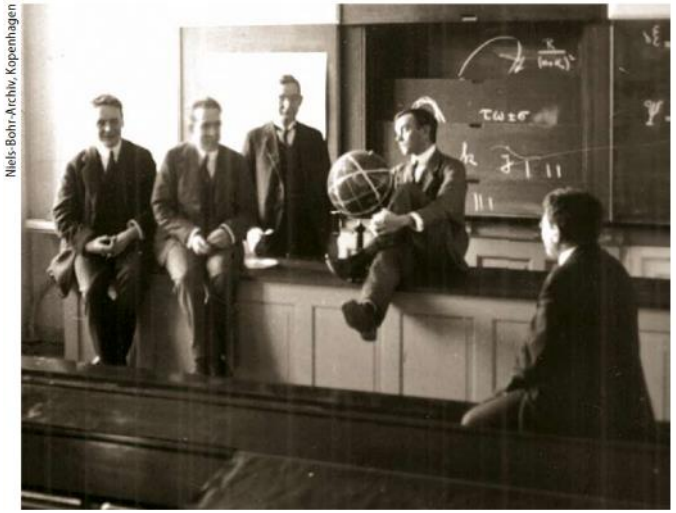


October 1922
A Succesfull Model, Which Bohr Didn't Like

Prof. Bohr zu herzlichem Danke verpflichtet.

1927
Don't Mess With Bohr





The Born Picture

The Born Picture

in Göttingen
Student (with Hilbert, Minkowski, Runge, Voigt…)
PhD 1906 (Klein => Runge) & Habilitation
1909-1914 Privatdozent

(War, Berlin)

Frankfurt
turns to experimenting with molecular beams (with Stern, SGE)

1920/21 call to Göttingen, gets Franck included
key organiser of new institutes, curriculum and research fields

1921 start of Borns quantum project
no need to wait for Bohr 1922
1922 Pauli, from Sommerfeld
1923 Heisenberg

June 1924
Born: Über Quantenmechanik

MATRIX MECHANICS

June 1926
Born: statistical interpretation

1926/1927
Hilbert/Nordheim/von Neumann: mathematical foundations

Oct 1925 – April 1926
Born in the USA

1926-1933 flocks of Postdocs from US and all over the world
Oppenheimer, Weisskopf, Wigner, Teller, …

1933 forced migration

The Born Picture

The multiple avenues to quantum mechanics

Atomic and Molecular Beams — experimental grounding

- in Frankfurt determination of mean free length of silver atoms
- Born had students experimenting with molecular beams as late as 1925, keeping institute mechanics busy

Many-electron quantum theory

- started in Frankfurt
- with Emmerich Brody initially on crystal structure
- perturbation theory, celestial mechanics
- later with Pauli and Heisenberg on this lines
- preparatory efforts to see where old quantum theory fails

Ramsauer effect

- Born heard Raumsauer at 1920 Naturforscherverssammlung
- 1921 presentation at Jena
- Franck: „a paper by Ramsauer that I an not able to believe, though I cannot show any mistake in his experiment…“
- Born: „the simply crazy claim by Ramsauer“
  => Hertha Sponer experiments, Friedrich Hund theory
- Finally: Born and Jordan (1925)

Collision processes

- quantum theory must also describe aperiodic phenomna
- especially collisions
- difference calculus

Born to Einstein 15 July 1925

Chiefly, however, I am interested in the also quite mysterious difference calculus that is behind the quantum theory of atomic structure. With Jordan, I am systematically examining—though with limited mental effort—every imaginable correspondence relationship between classical, multiply periodic systems and quantum atoms. [...] This is preliminary work for an investigation into the processes at atomic collisions (quenching of fluorescence, sensitized fluorescence à la Franck, etc.); [...] (Born and Einstein 1969, 118f.)

Combine Born + Postdoc + Gender Picture

‘Girls’ Physics’ in Göttingen

Hertha Sponer

- PhD with Peter Debye in 1920 at age 23
- James Franck's assistant the following year
- Rockefeller Fellow at in 1925.
- Göttingen associate professor of physics in 1932

Lucy Mensing

- worked closely with Wolfgang Pauli on her PhD in Hamburg
- prize for dissertation made possible:
- postdoc in Göttingen in 1926 at the age of 25

Bertha Swirles

- did her doctorate in Cambridge
- came a 24-year-old doctoral student to Göttingen
- visited Heisenberg in Leipzig in 1927/28

Maria Goeppert

- PhD in 1930 at age 23 with Max Born
- applied quantum mechanics to two-photon processes
- married Joe Edward Mayer

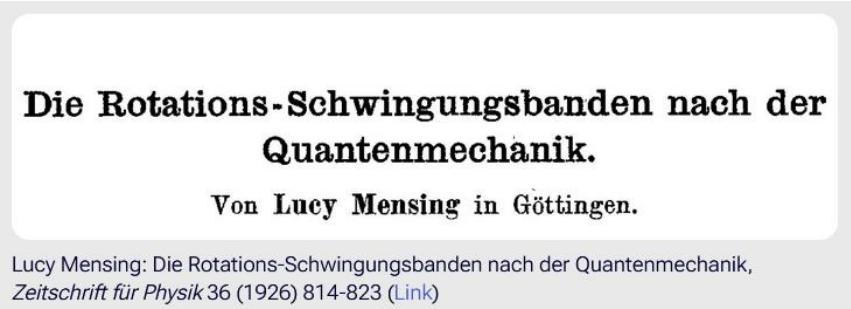
Emmy Noether

- first and foremost a mathematician
- Noether theorem important for quantum mechanics

Grete Herrmann

- PhD with Emmy Noether in 1925 at the age of 24
- assistant to the Göttingen philosopher Leonard Nelson
- work on foundations of quantum mechanics

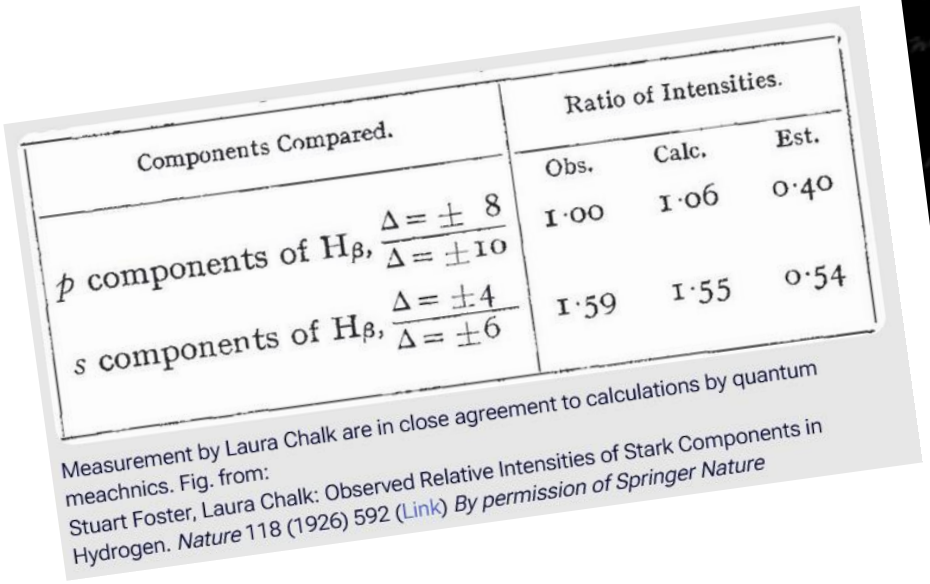
Women in the History of Quantum Physics



Die Rotations-Schwingungsbanden nach der Quantenmechanik.

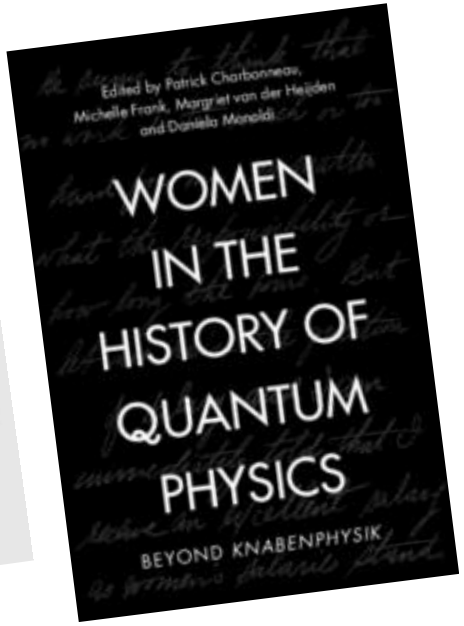
Von **Lucy Mensing** in Göttingen.

Lucy Mensing: Die Rotations-Schwingungsbanden nach der Quantenmechanik, *Zeitschrift für Physik* 36 (1926) 814-823 (Link)

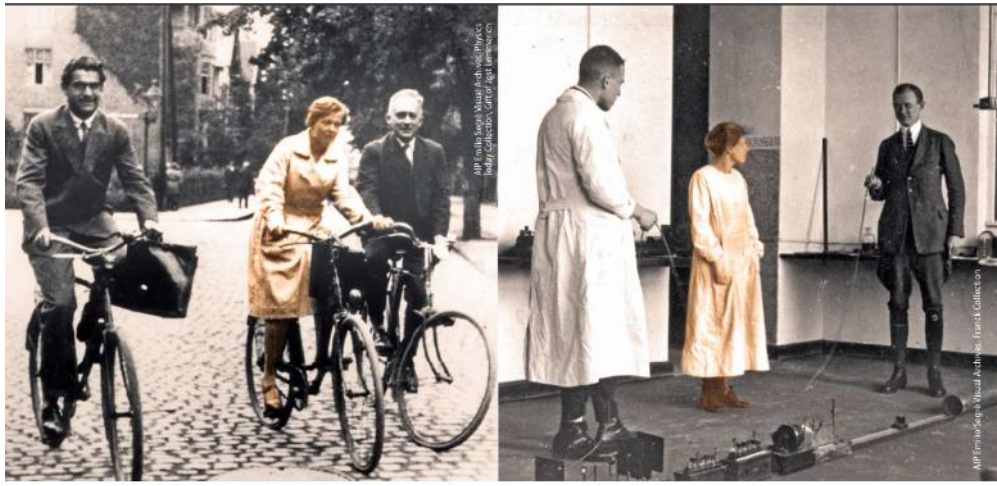


Components Compared.	Ratio of Intensities.		
	Obs.	Calc.	Est.
p components of Hβ, $\frac{\Delta = \pm 8}{\Delta = \pm 10}$	1·00	1·06	0·40
s components of Hβ, $\frac{\Delta = \pm 4}{\Delta = \pm 6}$	1·59	1·55	0·54

Measurement by Laura Chalk are in close agreement to calculations by quantum meachnics. Fig. from:
Stuart Foster, Laura Chalk: Observed Relative Intensities of Stark Components in Hydrogen. *Nature* 118 (1926) 592 (Link) *By permission of Springer Nature*



Physik Journal



Die Quantenphysikerinnen

Eine Artikelserie porträtiert Physikerinnen, deren Beiträge zur Quantenphysik bislang kaum gewürdigt wurden.

A historic site of physics, indeed

- not a Göttingen School
- rather not simply a Göttingen Spirit
- a scientific town, where scientific and private spaces where in superposition
- an organised rich infrastructure of manifold resources

The Establishment of Quantum Physics in Göttingen

Arne Schirrmacher

Humboldt-Universität zu Berlin

DPG
Fachverband Geschichte der Physik

HUMBOLDT-UNIVERSITÄT ZU BERLIN