



NE290D: Special Topics in Nuclear History, Politics, and Futures

20th Century Physics Part 2

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Introduction

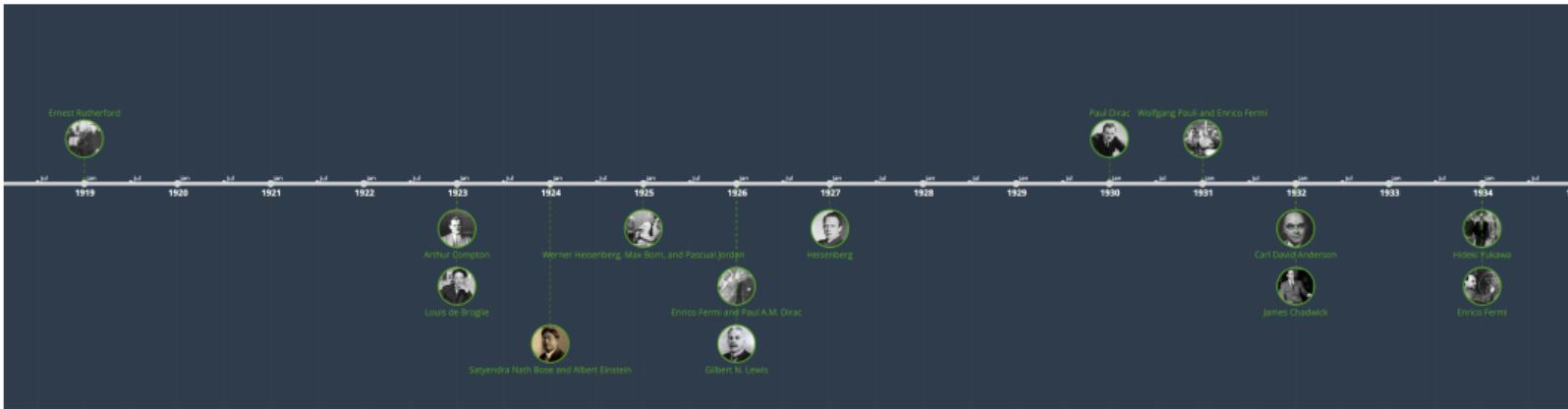
Agenda

1. Setting the Stage
1890-1899
2. A Play In 3 Parts
1900-1910
3. Atomic Physics
1910-1930
4. Relativity
1910-1930
5. Quantum Mechanics
1910-1930

W2L4 Learning Outcomes

1. Recall the major historical milestones in early 20th century physics and describe the experiments that led to them.
2. Organize the events on a timeline.
3. Draw connections between the developments in atomic physics, relativity, and quantum mechanics and explain how their roots in nuclear physics.
4. Weigh the importance of events and help design specific aspects of the Gather.Town project that would contribute to immersive learning environment for undergraduates.

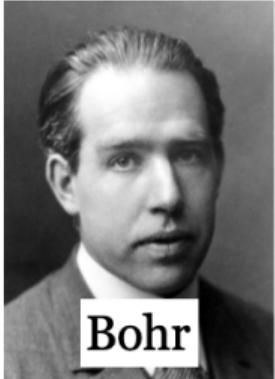
Timeline



Players



Players



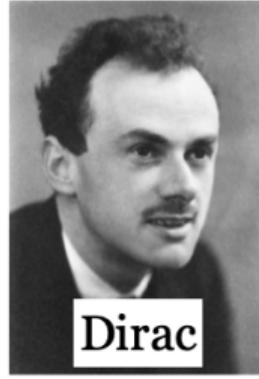
Bohr



Pauli



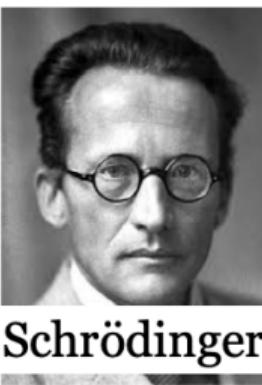
Heisenberg



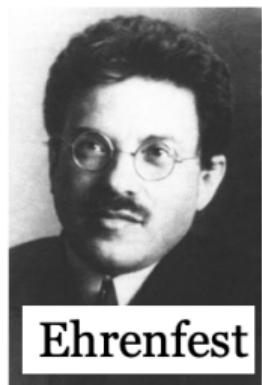
Dirac



Born



Schrödinger



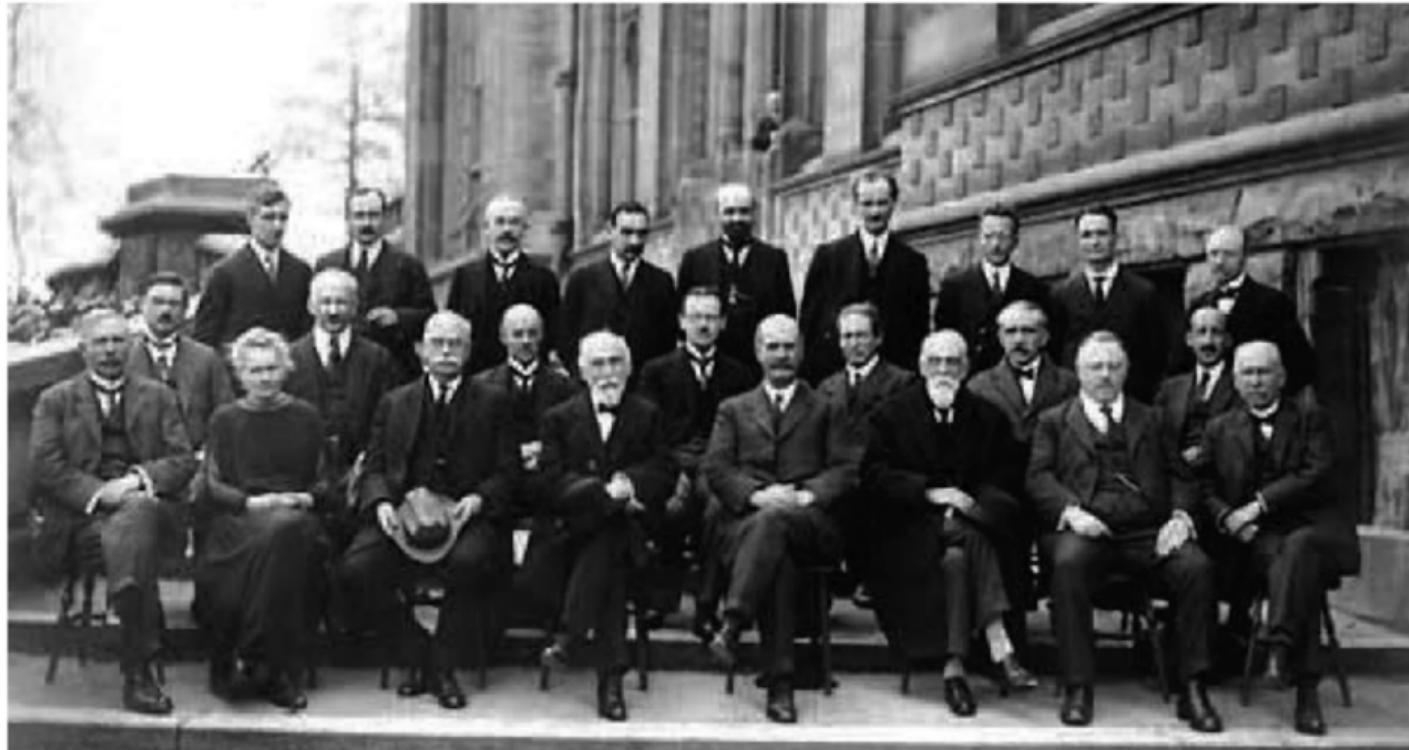
Ehrenfest



Fermi

1920-1930: A Play In 3 Parts

1924 Solvay Conference on “Electric conductivity of metals and related problems”



1920-1930: A Play In 3 Parts

QM in 1925: Heisenberg's Matrix Mechanics

- ▶ Heisenberg gets hay fever, takes a trip to Heligoland.
- ▶ He climbs and reads Goethe's *West–östlicher Divan* (*West–Eastern Diwan*). He also tries to relate theory and experiments from the newest spectral line data.
- ▶ "It was about three o' clock at night when the final result of the calculation lay before me. At first I was deeply shaken. I was so excited that I could not think of sleep. So I left the house and awaited the sunrise on the top of a rock."



¹ Heisenberg, Werner. *Der Teil und das Ganze: Gespräche im Umkreis der Atomphysik*. Piper verlag, 2013.

1920-1930: A Play In 3 Parts

QM in 1925: Heisenberg's Matrix Mechanics

- ▶ Heisenberg returns and consults Pauli
- ▶ “Everything is still vague and unclear to me, but it seems as if the electrons will no more move on orbits.”



¹ A Brief History of Quantum Structures and IQSA. <https://www.vub.be/CLEA/IQSA/history.html>

² W. Heisenberg, Über quantentheoretische Umdeutung kinematischer und mechanischer Beziehungen, Zeitschrift für Physik, 33, 879-893, 1925 (received July 29, 1925). [English translation in: B. L. van der Waerden, editor, Sources of Quantum Mechanics (Dover Publications, 1968) ISBN 0-486-61881-1 (English title: Quantum-Theoretical Re-interpretation of Kinematic and Mechanical Relations).]

³ M. Born and P. Jordan, Zur Quantenmechanik, Zeitschrift für Physik, 34, 858-888, 1925 (received September 27, 1925). [English translation in: B. L. van der Waerden, editor, Sources of Quantum Mechanics (Dover Publications, 1968) ISBN 0-486-61881-1 (English title: On Quantum Mechanics).]

⁴ M. Born, W. Heisenberg, and P. Jordan, Zur Quantenmechanik II, Zeitschrift für Physik, 35, 557-615, 1926 (received November 16, 1925). [English translation in: B. L. van der Waerden, editor, Sources of Quantum Mechanics (Dover Publications, 1968) ISBN 0-486-61881-1 (English title: On Quantum Mechanics II).]

1920-1930: A Play In 3 Parts

QM in 1926: Schrödinger's Equation

- ▶ Linear partial differential equation that governs the wave function of a quantum-mechanical system

$$i\hbar \frac{\partial}{\partial t} \Psi(\mathbf{r}, t) = \hat{H}\Psi(\mathbf{r}, t)$$

- ▶ Debye challenges "Schrödinger, you are not working right now on very important problems anyway. Why don't you tell us some time about that thesis of de Broglie, which seems to have attracted some attention."



¹ Schrödinger, Erwin. "Quantisierung als eigenwertproblem; von erwin schrödinger." Ann Physik 79.79 (1926): 361-377.

² Bloch, Felix. "Heisenberg and the early days of quantum mechanics." Physics Today 29.12 (1976): 23-27.



1920-1930: A Play In 3 Parts

Heisenberg What, with all the Schrödinger nonsense?

Bohr Nonsense? Come, come. Schrödinger's wave formulation?

Margrethe Yes, suddenly everyone's turned their backs on your wonderful new matrix mechanics.

Heisenberg No one can understand it.

Margrethe And they *can* understand Schrödinger's wave mechanics.

Heisenberg Because they'd learnt it in school! We're going backwards to classical physics! And when I'm a little cautious about accepting it ...

Bohr A little cautious? Not to criticise, but ...

Margrethe ... You described it as repulsive!

Heisenberg I said the physical implications were repulsive. Schrödinger said my mathematics were repulsive.

Bohr I seem to recall you used the word ... well, I won't repeat it in mixed company.

Heisenberg In private. But by that time people had gone crazy.

Margrethe They thought you were simply jealous.

¹Frayn, Michael. Copenhagen. Bloomsbury Publishing, 2017.



1920-1930: A Play In 3 Parts

Heisenberg And you fell on him like a madman. You meet him at the station—of course—and you pitch into him before he's even got his bags off the train. Then you go on at him from first thing in the morning until last thing at night.

Bohr I go on? He goes on!

Heisenberg Because you won't make the least concession!

Bohr Nor will he!

Heisenberg You made him ill! He had to retire to bed to get away from you!

Bohr He had a slight feverish cold.

Heisenberg Margrethe had to nurse him!

Margrethe I dosed him with tea and cake to keep his strength up.

Heisenberg Yes, while you pursued him even into the sickroom! Sat on his bed and hammered away at him!

Bohr Perfectly politely.

¹Frayn, Michael. Copenhagen. Bloomsbury Publishing, 2017.

1920-1930: A Play In 3 Parts

QM in 1927: Heisenberg's Uncertainty Principle

- ▶ states that the more precisely the position of some particle is determined, the less precisely its momentum can be predicted from initial conditions, and vice versa

$$\sigma_x \sigma_p \geq \frac{\hbar}{2}$$

Quantum Mechanics as Philosophy

- ▶ When we speak of the picture of nature in the exact science of our age, we do not mean a picture of nature so much as a picture of our relationships with nature. ...Science no longer confronts nature as an objective observer, but sees itself as an actor in this interplay between man [sic] and nature. The scientific method of analysing, explaining and classifying has become conscious of its limitations, which arise out of the fact that by its intervention science alters and refashions the object of investigation. In other words, method and object can no longer be separate

¹Heisenberg, Werner. "Über den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik." Original Scientific Papers Wissenschaftliche Originalarbeiten. Springer, Berlin, Heidelberg, 1985. 478-504.

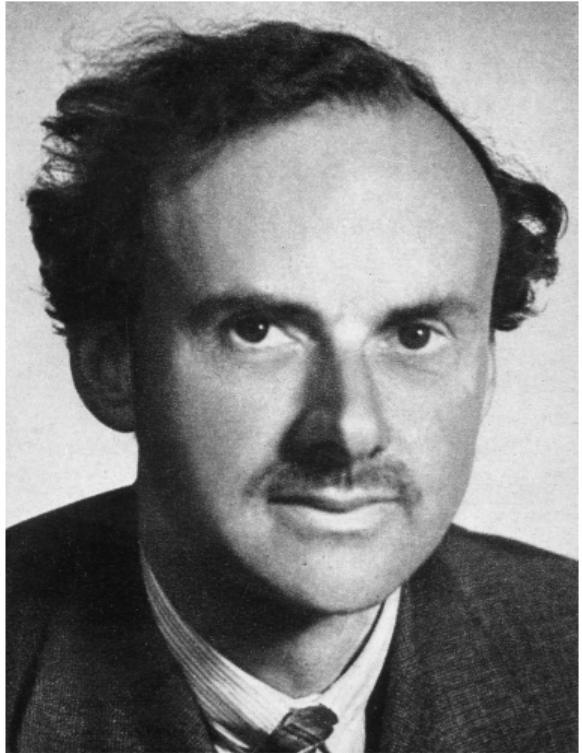
²Heisenberg, Werner, and Arnold J. Pomerans. "The physicist's conception of nature." (1958).

1920-1930: A Play In 3 Parts

QM in 1927: Dirac's Equation

- ▶ Synthesizes relativity with QM with a relativistic wave equation

$$\left(\beta mc^2 + c \sum_{n=1}^3 \alpha p_n \right) \psi(x, t) = i\hbar \frac{\partial}{\partial t} \psi(x, t)$$



¹ Dirac, Paul Adrien Maurice. "The quantum theory of the electron." Proceedings of the Royal Society of London. Series A, Containing Papers of a Mathematical and Physical Character 117.778 (1928): 610-624.

1920-1930: A Play In 3 Parts

1927 Solvay Conference on “Electrons and photons”



1920-1930: A Play In 3 Parts

On Religion

- ▶ *Einstein (Jewish) and Planck (Lutheran) discussing religion*
- ▶ Dirac: I cannot understand why we idle discussing religion. If we are honest – and as scientists honesty is our precise duty – we cannot help but admit that any religion is a pack of false statements, deprived of any real foundation. The very idea of God is a product of human imagination. I do not recognize any religious myth, at least because they contradict one another.
- ▶ Heisenberg: *silence*
- ▶ Pauli: Well, our friend Dirac, too, has a religion, and its guiding principle is "God does not exist and Dirac is His prophet."



¹Heisenberg, Werner. "Physics and beyond: encounters and conversations." (1971).

1930-1939: A Play In 3 Parts

1930 Solvay Conference on "Magnetism"



1930-1939: A Play In 3 Parts

Pauli's Neutrino, Chadwick's Neutron, and Fermi's Theory



Faust in Copenhagen



¹ Blegdamsvej Faust. <https://cds.cern.ch/record/96459/files/CERN-ARCH-PMC-08-484.pdf>



Faust in Copenhagen

WHOM THE CHARACTERS REPRESENT

(Note: the Master of Ceremonies is played by Max Delbrück, German physicist)

ARCHANGEL EDDINGTON	A. Eddington, British astronomer
ARCHANGEL JEANS	J. Jeans, British astronomer
ARCHANGEL MILNE	E. A. Milne, British astronomer
MEPHISTOPHELES	W. Pauli, German physicist
THE LORD	Niels Bohr, Danish physicist
THE HEAVENLY HOSTS	"Extras"
FAUST	P. Ehrenfest, Dutch physicist
GRETCHEN	The Neutrino
OPPIE	R. Oppenheimer, American physicist
A TALL MAN	R. C. Tolman, American physicist

MILLIKAN-ARIEL	R. A. Millikan, American physicist
LANDAU (DAU)	L. Landau, Russian physicist
GAMOW	G. Gamow, Russian physicist
SLATER	J. C. Slater, American physicist
DIRAC	P. A. M. Dirac, British physicist
DARWIN	C. Darwin, British physicist
POWLER	R. H. Fowler, British physicist
FOUR GRAY WOMEN	The Gauge Invariant, Fine Structure Constant, Neg- ative Energy, Singularity
FRIENDLY PHOTOGRAPHER	A friendly photographer
WAGNER	J. Chadwick, British physicist
MYSTICAL CHORUS	Everybody who can sing

¹ Gamow, George. Thirty years that shook physics: The story of quantum theory. Courier Corporation, 1985.

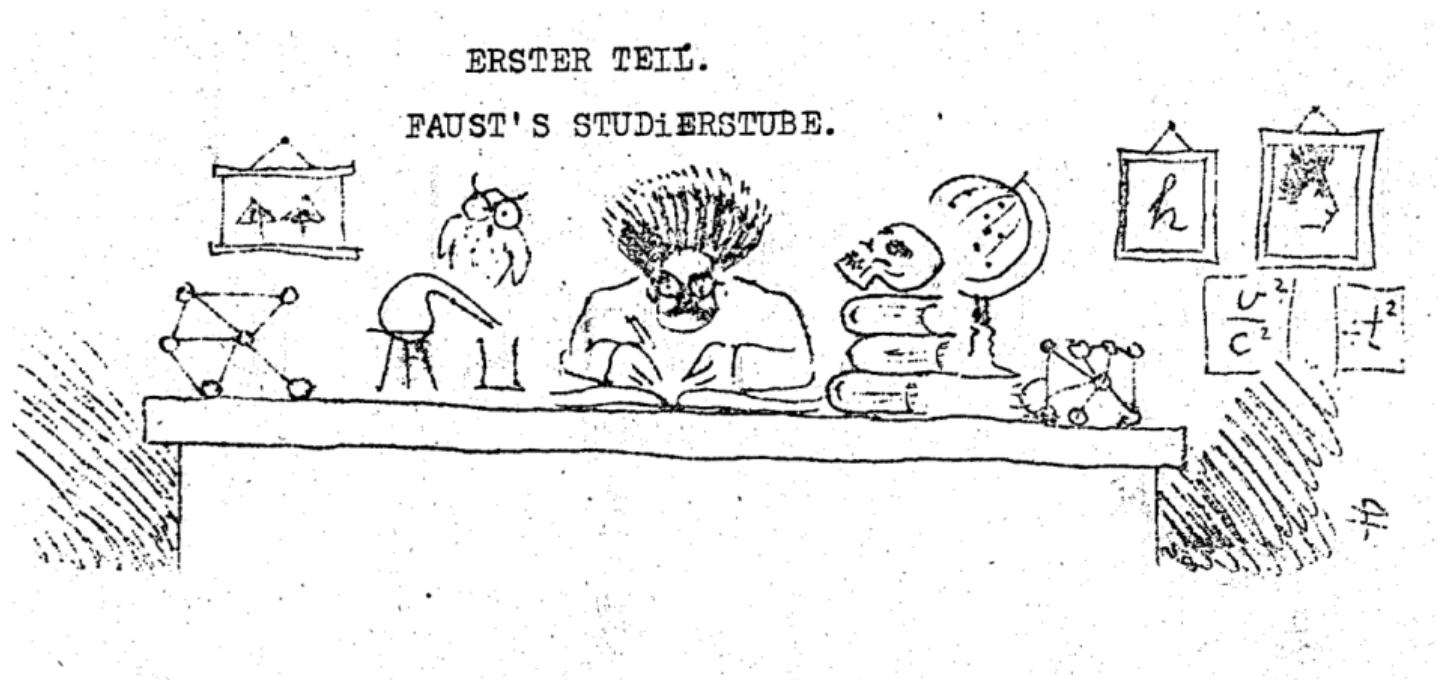
Faust in Copenhagen

Mephistopheles (springt hervor):



¹ Blegdamsvej Faust. <https://cds.cern.ch/record/96459/files/CERN-ARCH-PMC-08-484.pdf>

Faust in Copenhagen



¹Blegdamsvej Faust. <https://cds.cern.ch/record/96459/files/CERN-ARCH-PMC-08-484.pdf>

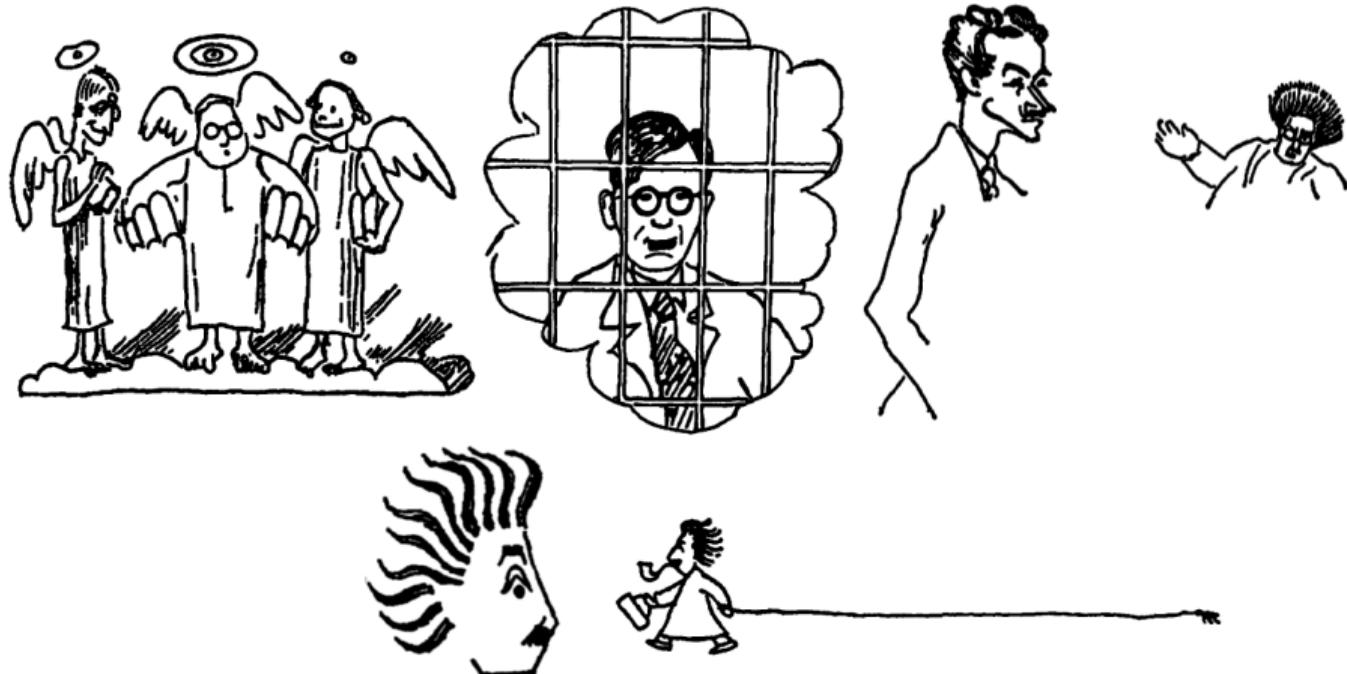
Faust in Copenhagen



Gretchen tritt auf und singt:

¹ Blegdamsvej Faust. <https://cds.cern.ch/record/96459/files/CERN-ARCH-PMC-08-484.pdf>

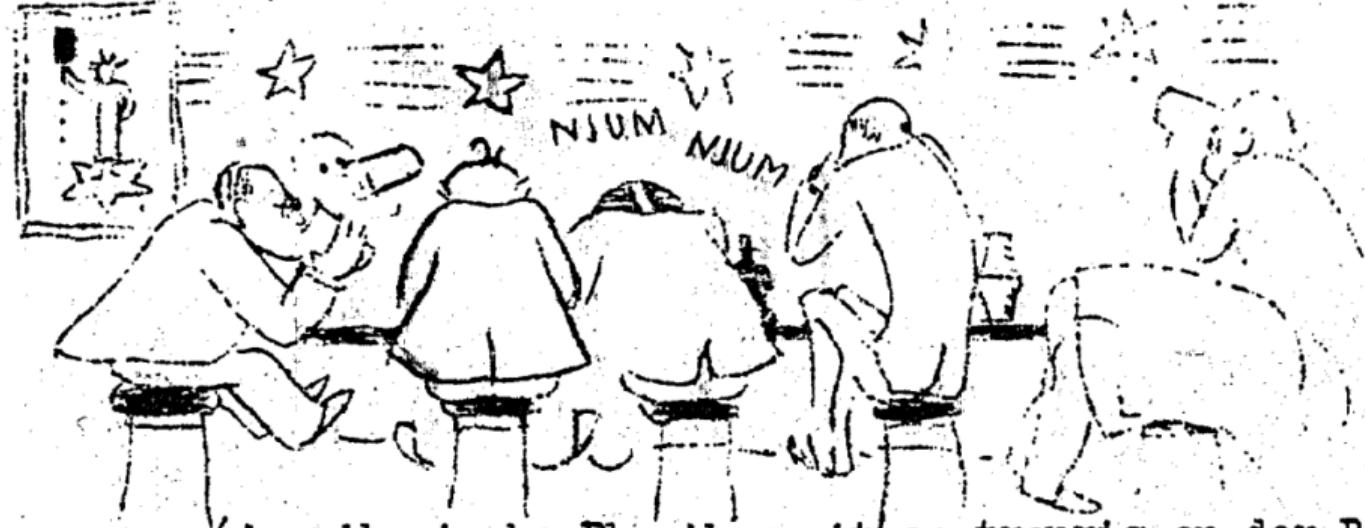
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¹ Blegdamsvej Faust. <https://cds.cern.ch/record/96459/files/CERN-ARCH-PMC-08-484.pdf>

Faust in Copenhagen

(sonst Auerbachs Keller genannt)



(Amerikanische Physiker sitzen traurig an der Bar)

¹Blegdamsvej Faust. <https://cds.cern.ch/record/96459/files/CERN-ARCH-PMC-08-484.pdf>

Faust in Copenhagen

(DIRAC comes forward, followed by FOUR GRAY WOMEN)



THE FIRST

The *Gauge Invariant* is my name.

THE SECOND

I'm of *Fine Structure Constant* fame.⁸⁷

THE THIRD

Negative Energy—that's me.⁸⁸

THE FOURTH

(to THE THIRD)

Just watch your grammar, Number Three!

(to the others)

Sisters, into the reckoning
You cannot and you may not spring.
But in the end there I shall be,
For I am *Singularity*.⁸⁹

¹ Blegdamsvej Faust. <https://cds.cern.ch/record/96459/files/CERN-ARCH-PMC-08-484.pdf>

Faust in Copenhagen

WAGNER⁴¹

(appears, as the personification of the ideal experimentalist, balancing a black ball on his finger, and says, with pride)



The Neutron has come to be.
Loaded with Mass is he.
Of Charge, forever free.
Pauli, do you agree?



MEPHISTO

That which experiment has found—
Though theory had no part in—
Is always reckoned more than sound
To put your mind and heart in.
Good luck, you heavyweight Ersatz—⁴²
We welcome you with pleasure!
But passion ever spins our plots,
And Gretchen is my treasure!

MYSTICAL CHORUS

Now a reality,
Once but a vision.
What classicality,
Grace and precision!
Hailed with cordiality,
Honored in song,
Eternal Neutrality
Pulls us along!



¹ Blegdamsvej Faust. <https://cds.cern.ch/record/96459/files/CERN-ARCH-PMC-08-484.pdf>

The Idea

- ▶ Struggle of the new knowledge for its acceptance by the scientific community.
- ▶ It is the eternal struggle against the prejudices, which hamper progress rather than foster it.

¹Pantidos, Panagiotis, Kalliopi Spathi, and Evangelos Vitoratos. "The use of drama in science education: The case of "Blegdamsvej Faust"." Science Education 10.1 (2001): 107-117.

Faust in Copenhagen

The Source of Inspiration – According to Pantidos

- ▶ The science itself is identical to Faust's character, meaning that there is a continuous struggle between the old and the new.
- ▶ Goethe (1749-1832) had studied physics and was the first one who had the opinion that science looks like Faust, that is, there is a struggle between the bad and the good embodied in the scientific ideas with the intention to capture the human soul.

Or...

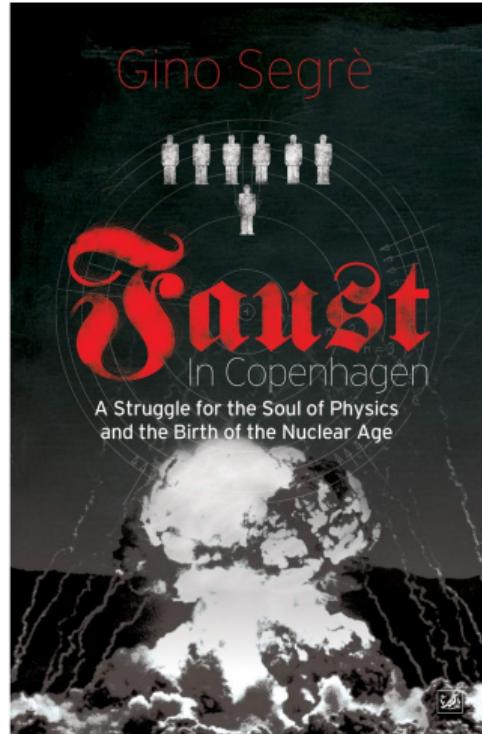
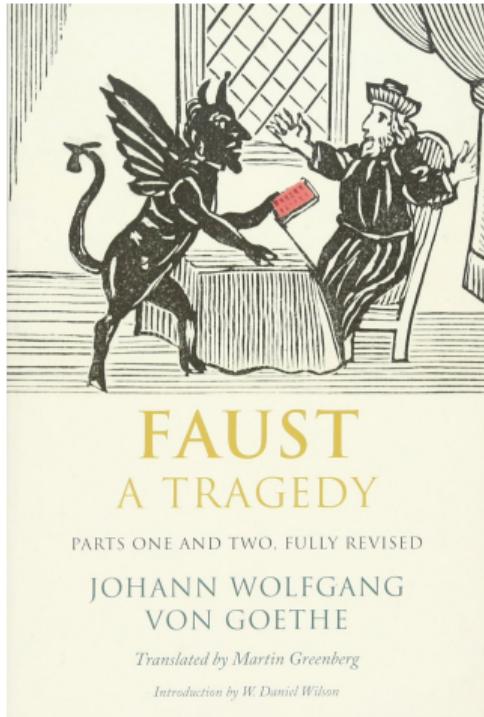
- ▶ I think Delbrück was just having fun.
- ▶ ““The skit, meant as comic relief from the intensity of the week’s discussions, remains a fascinating portrayal of the world of physics seen through the eyes of its very young practitioners.”

¹Pantidos, Panagiotis, Kalliopi Spathi, and Evangelos Vitoratos. "The use of drama in science education: The case of "Blegdamsvej Faust". " *Science Education* 10.1 (2001): 107-117.

¹Segrè, Gino. *Faust in Copenhagen: A struggle for the soul of physics*. Penguin, 2007.

Faust in Copenhagen

Some Issues With the Tale...





Discussion

Tentative Project Ideas

1. Modernize *Blegdamsvej Faust* with a new cast solving a current problem
2. Adopt a different work of literature with either a cast and problem from history or using current affairs



1930-1939: A Play In 3 Parts

1933 Solvay Conference on "Structure properties of the atomic nucleus"

INSTITUT INTERNATIONAL DE PHYSIQUE SOLVAY

SEPTIÈME CONSEIL DE PHYSIQUE -- BRUXELLES. 22-29 OCTOBRE 1933

