

The Uncertainty Principals: Bohr and Heisenberg from Copenhagen (the city) to *Copenhagen* (the play)

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University of Illinois
Urbana, 27 January 2005

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Two giants shaped 20th century physics



Albert Einstein, 1879-1955

1905 (*Annum Mirabilis*):

Theory of relativity

Photoelectric effect

Brownian motion

1915: General theory of relativity

(1924: Bose-Einstein condensation)

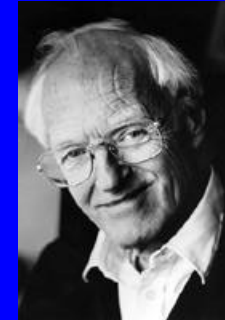
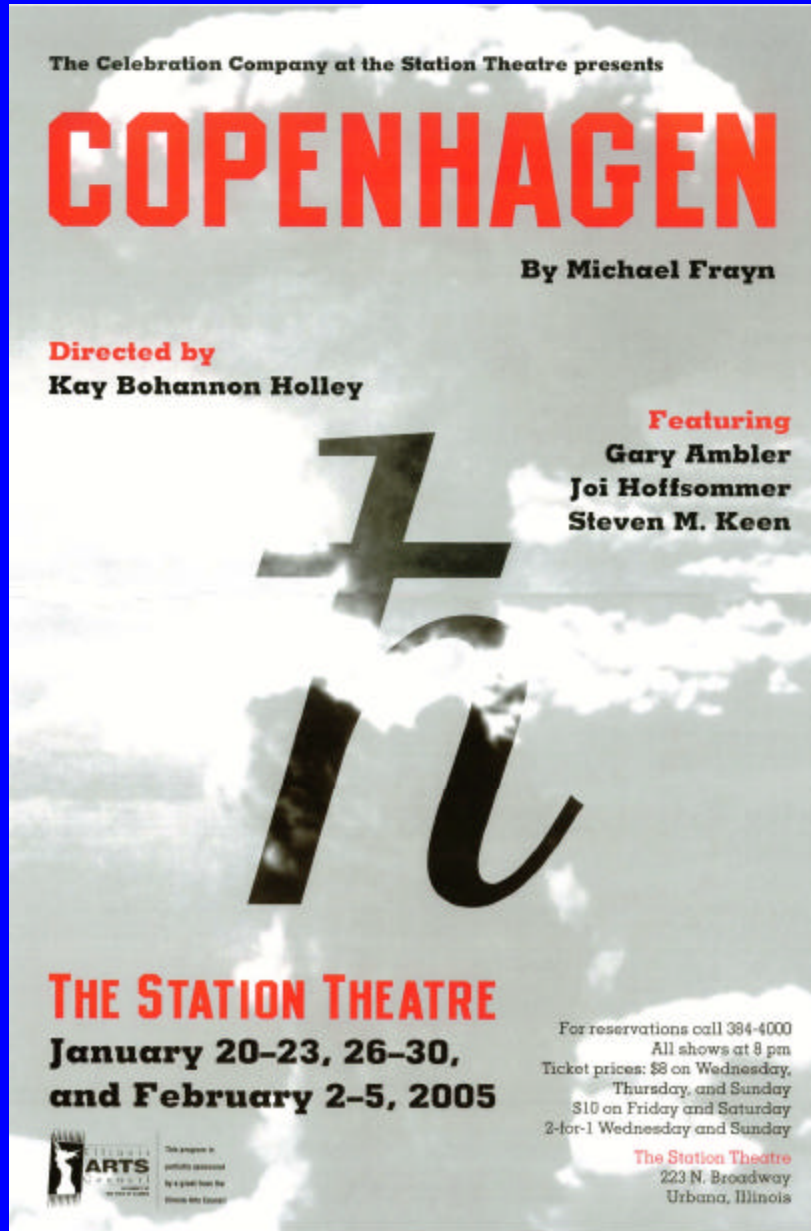


Niels Bohr, 1885-1962

1913: Bohr atom

1920's: Development of the quantum
theory of the microscopic world





Michael Frayn
1998



Steve Keen
as Niels Bohr

Niels Henrik David Bohr, 1885-1962



1896



birthplace in Copenhagen



With mother, Ellen Adler Bohr, 1902



1917

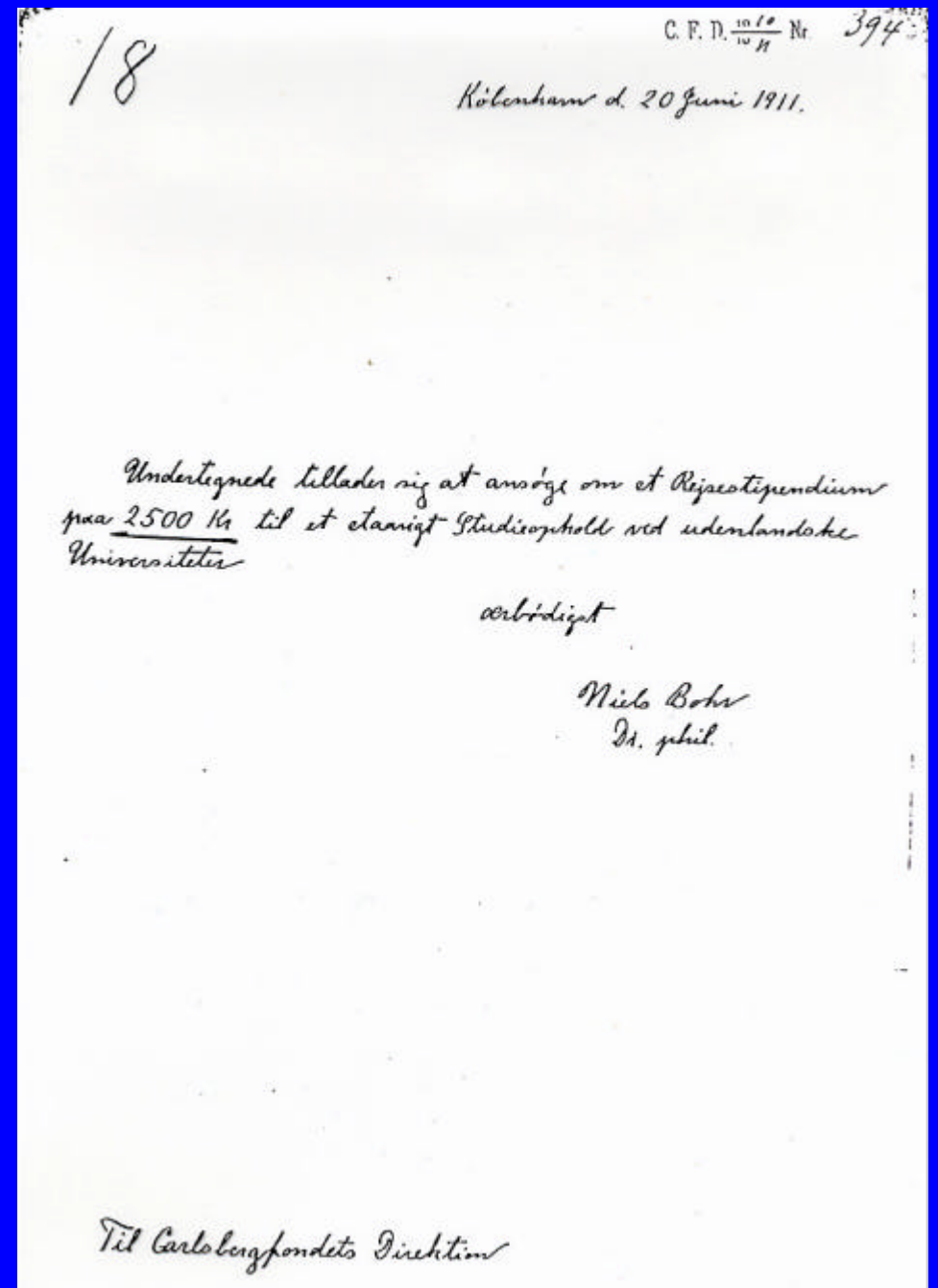
Bohr's grant proposal to the Carlsberg Foundation to work at Cambridge and Manchester

Copenhagen, 20 June 1911

The undersigned permits himself to request a travel stipend of 2500 kroner for a one-year study stay at foreign universities.

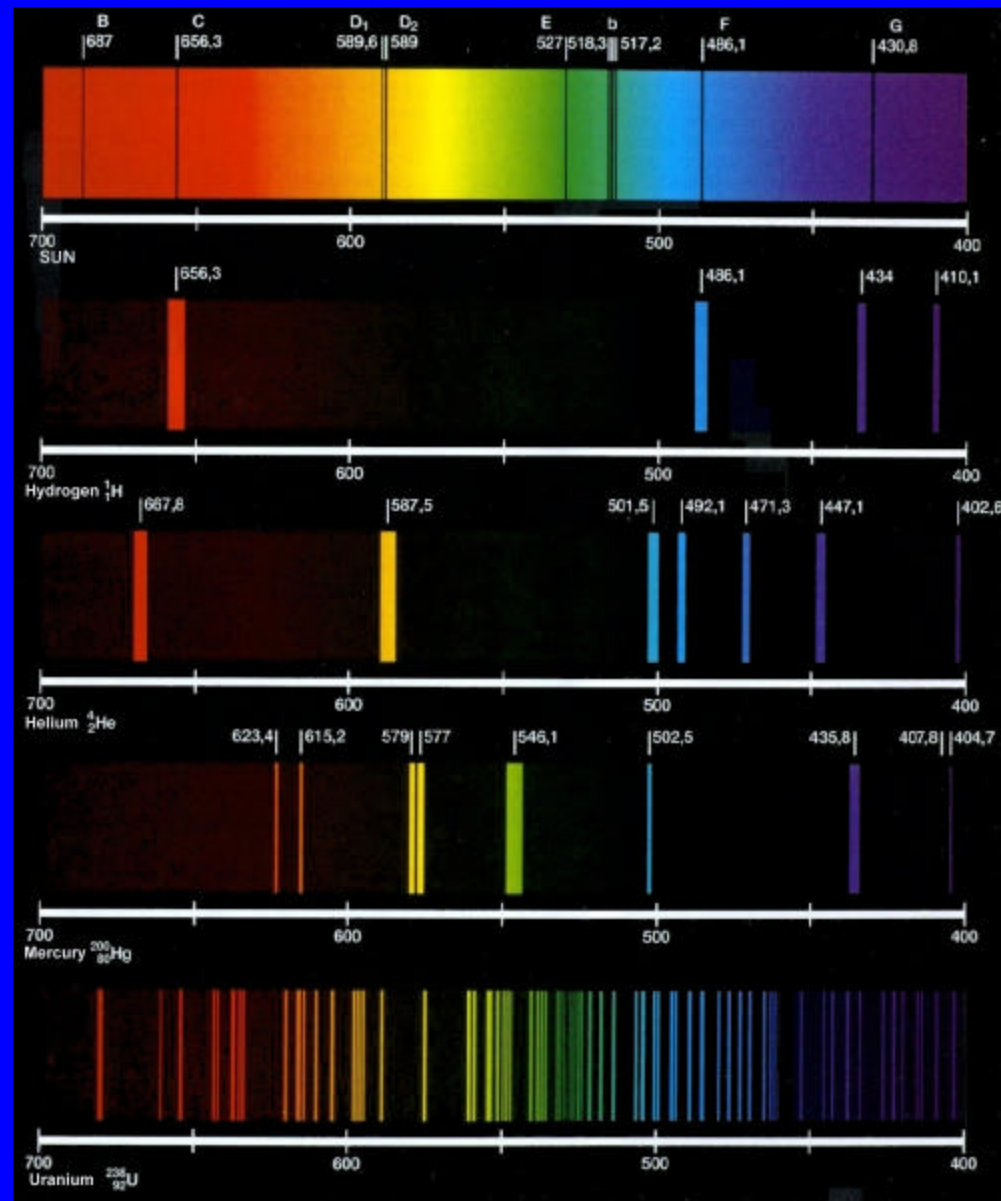
Sincerely,
Niels Bohr
Dr. Phil.

To the Carlsberg Foundation
Directorate



Mystery of atomic spectra

Why do atoms emit light of specific colors only?



Sun

Hydrogen

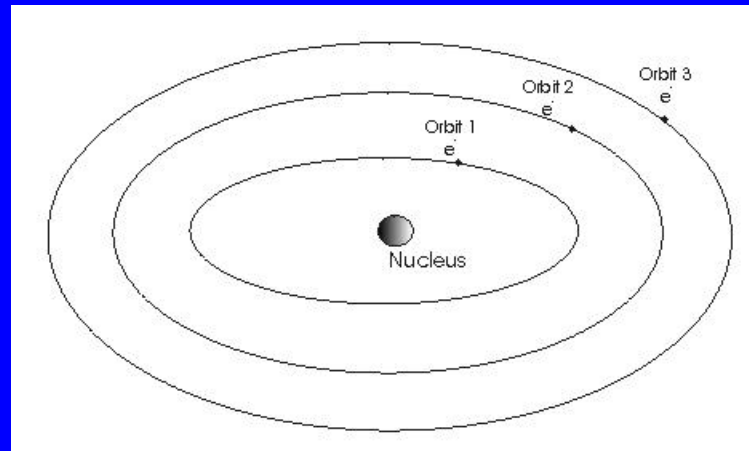
Helium

Mercury

Uranium

Bohr atom, 1913

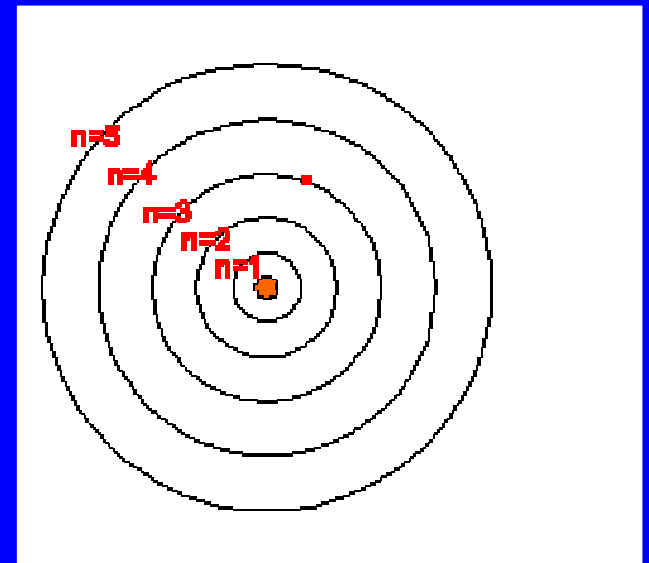
Electron orbits are at only special locations (quantized)



Electron jumps to lower orbit (energy level) losing energy. Energy is given off as light with a frequency (color) proportional to the amount of energy lost:

$$\text{frequency} = (\text{initial energy} - \text{final energy})/h$$

h = Planck's constant



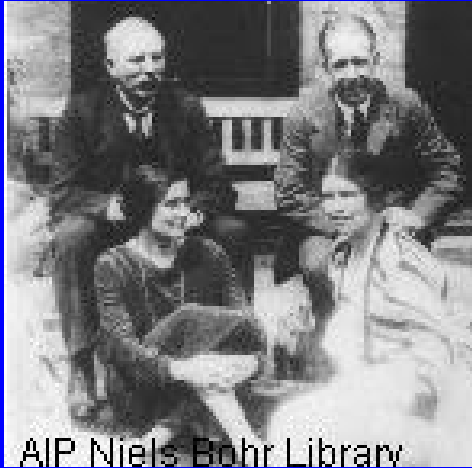
Margrethe (Nordlund) Bohr (1890-1984)

Born in Slagelse, SW of Copenhagen

Married Niels in 1912

Six sons: Christian, Hans, Erik, Aage, Ernest, Harald

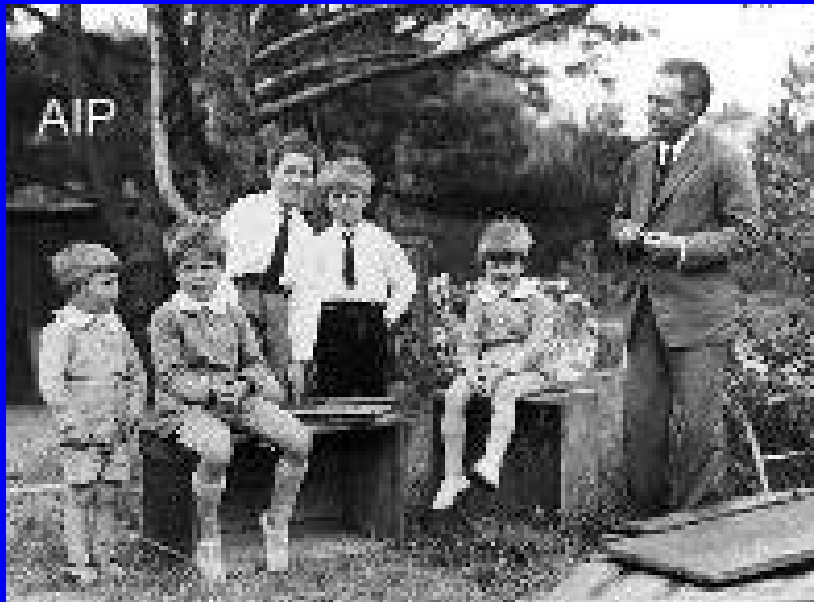




With the Rutherfords



c. 1920



With sons Ernest, Erik, Christian, Hans, and Aage



Aage Bohr, 1922-

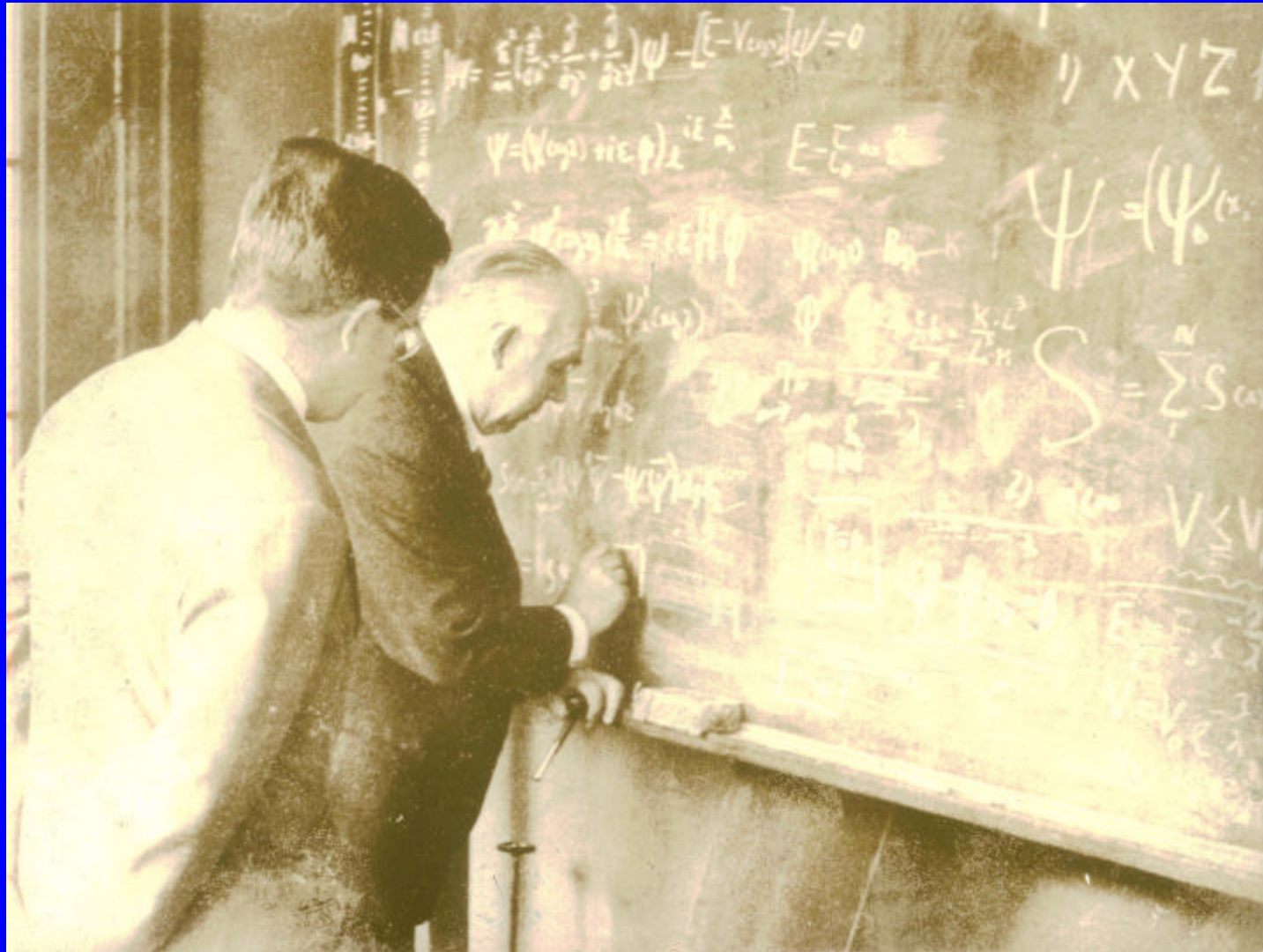
Nobel Prize 1975 with Ben Mottelson



Aage Bohr



Ben Mottelson



Bohr's Institute on Blegdamsvej in Copenhagen

Built in 1921 at the *University Institute for Theoretical Physics*
(*Universitetets Institut for Teoretisk Fysik*)
renamed the *Niels Bohr Institute* in 1965



1920's



Werner Heisenberg, 1901-1976

Works with Bohr in Copenhagen 1924-5 (Rockefeller fellow), 1926-7
Uncertainty principle: March 1927



Werner and older brother
Erwin in Würzburg



Werner and Erwin
with their father
1914

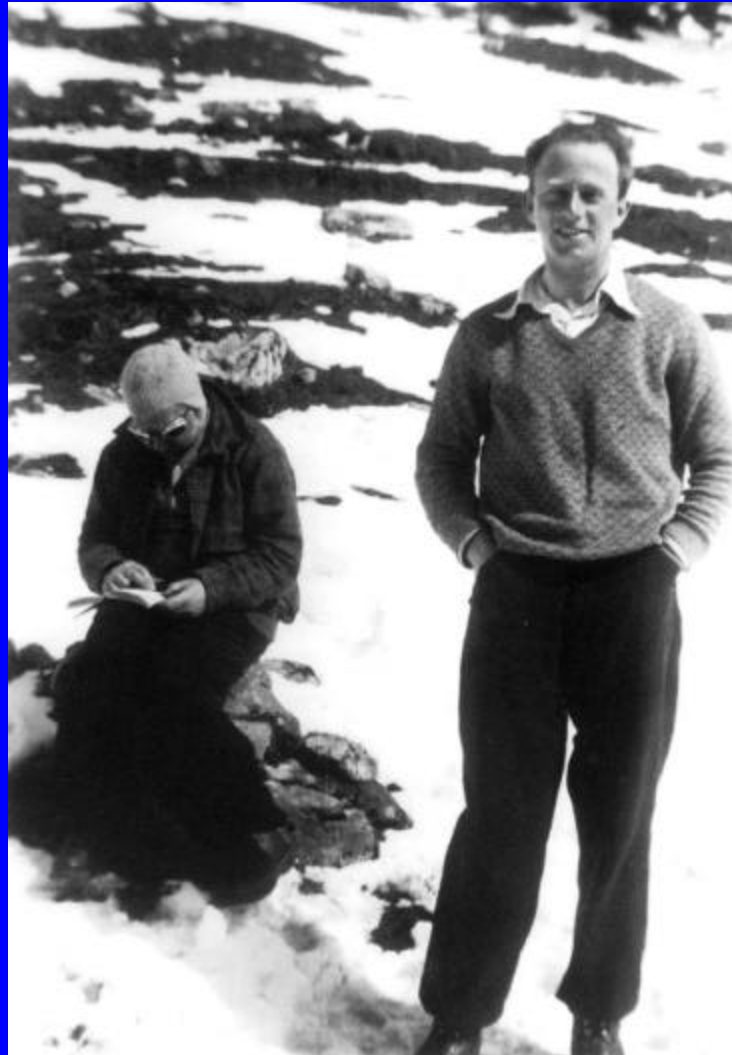


1924

Heisenberg and Bohr



At the Institute, 1923



Skiing in the Tyrol, 1932



With Elisabeth
Heisenberg,
Copenhagen
1937

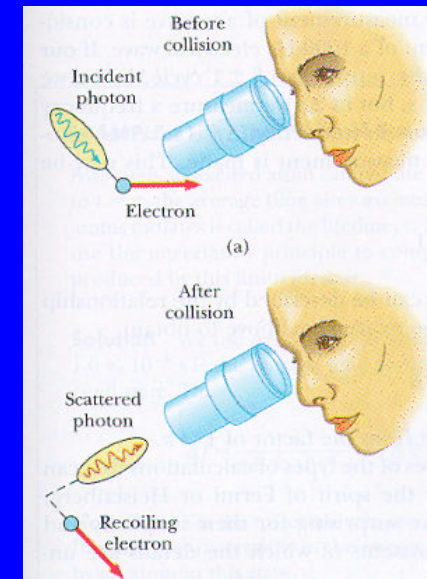
Measuring the microscopic world -- the uncertainty principle

To measure in macroscopic world can use particles of microscopic world, e.g., light beams, which do not disturb system being measured. But in microscopic world can only use same microscopic particles, which being the same size, disturb system.

To measure electron position use light, which gives electron a kick, like using bowling ball to measure position of bowling pins. The shorter the wavelength of light, the more accurate the position, but the greater uncertainty in the electron recoil speed. To measure speed accurately, lose information about electron's position.



$$\Delta x \Delta p > \sim$$

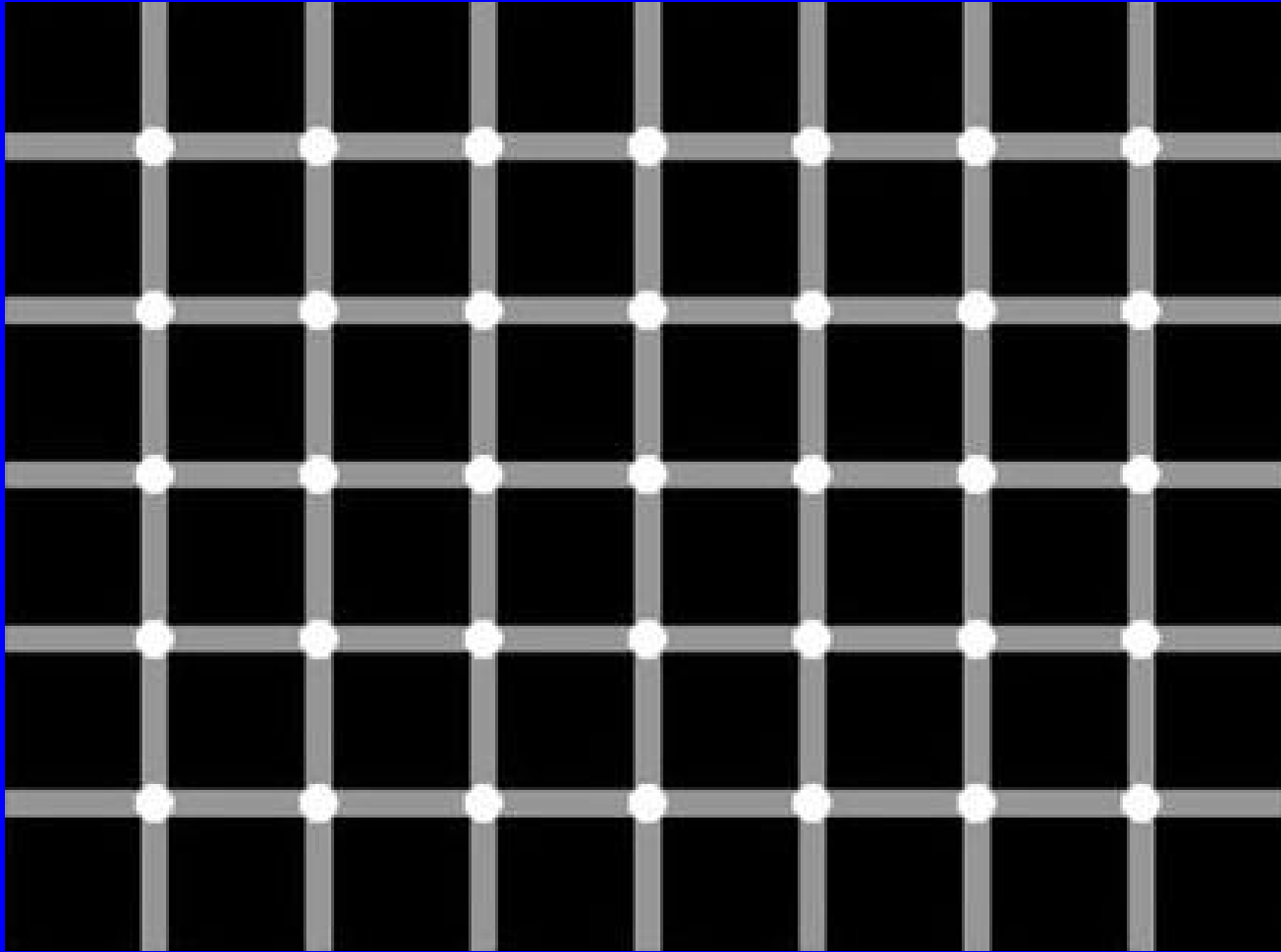


Electron position in atom is uncertain!
“The ‘path’ comes into existence only when we observe it.” Heisenberg, 1927.



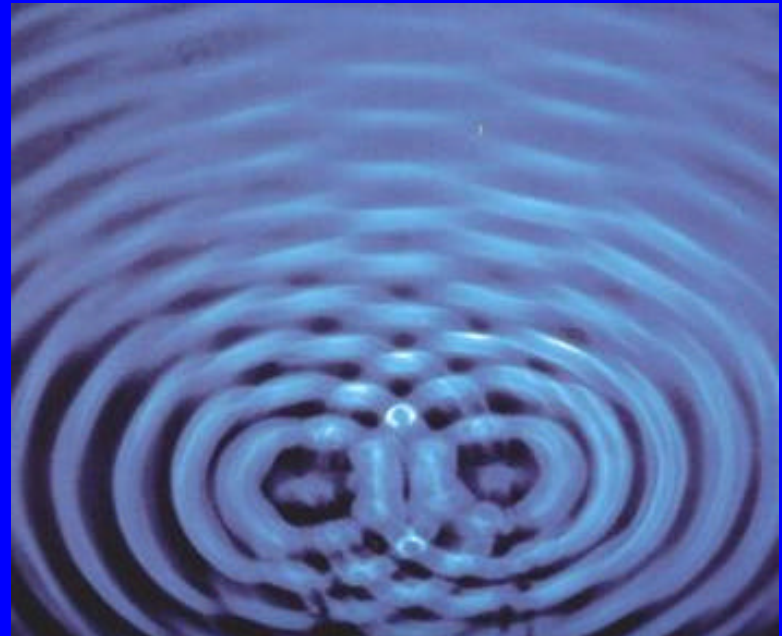
Describe probability of finding electron by a wave.
Wave-particle duality, complementarity

Count the black dots!



Observation can change the state of the system
(not quantum mechanics)

Electrons, atoms, and other microscopic particles can act like waves and interfere, like waves on water:



Wave-particle duality. Bohr's principle of complementarity: need both classical descriptions to have adequate picture of microscopic world.

Waves and Particles on Broadway

The play, "Copenhagen," which centers on the mysterious meeting between two nuclear physicists, interprets and incorporates a number of complex scientific concepts.

SUPERPOSITION

In quantum physics, particles can exist in numerous possible positions and states of energy at once. These possibilities, called a "superposition," are represented by a wave.

POSSIBLE LOCATIONS

A particle has a high chance of being where the amplitude of its wave, often referred to as a cloud of probability, is large.

DEFINITE POSITION

It is only when a particle is actually observed that it settles into a specific state and has a well-defined position.

SUBATOMIC PARTICLE

HEISENBERG'S UNCERTAINTY PRINCIPLE

The position and the momentum of a particle cannot be precisely known at the same time.

POSITION

A particle's position is likely to be where the peaks of its wave are highest.

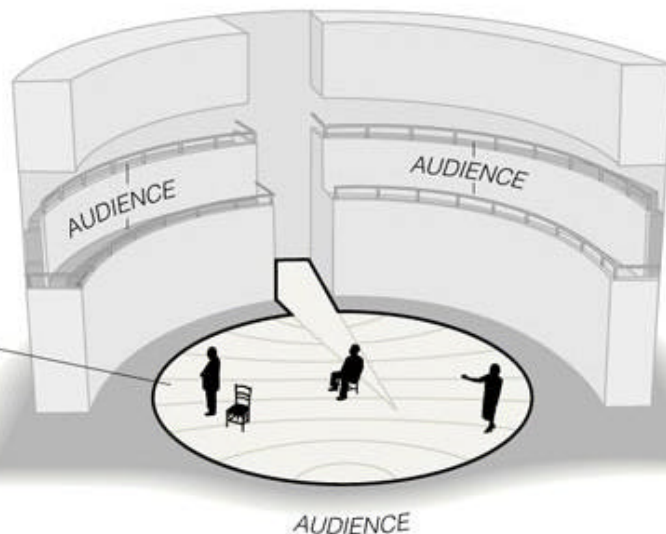
MOMENTUM

However, momentum is most precisely determined when a particle's wave is spread out and smooth.

ADAPTING SCIENCE FOR THE STAGE

The director of the play, Michael Blakemore, says: "The play tests purely scientific principles against human behavior. Does uncertainty apply to human events?"

The stage is an ellipse on which the characters move about as if they were particles in an experiment.



In a dramatic analogue to quantum uncertainty, multiple versions of the crucial meeting between the physicists are staged. Each version is a possibility which is given life as the audience "observes" it.

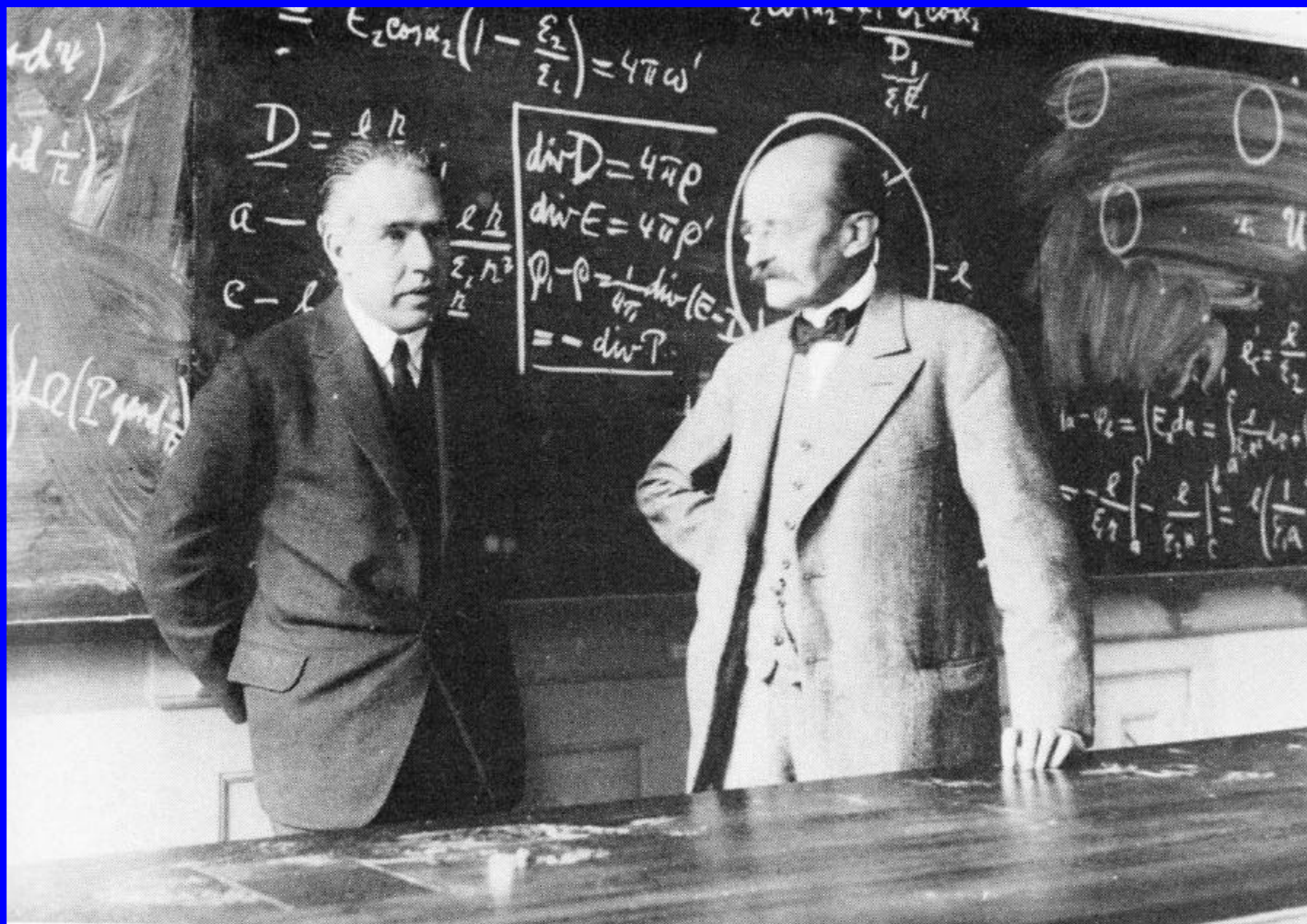
New York Times
21 March 2000



1930 Conference in Auditorium

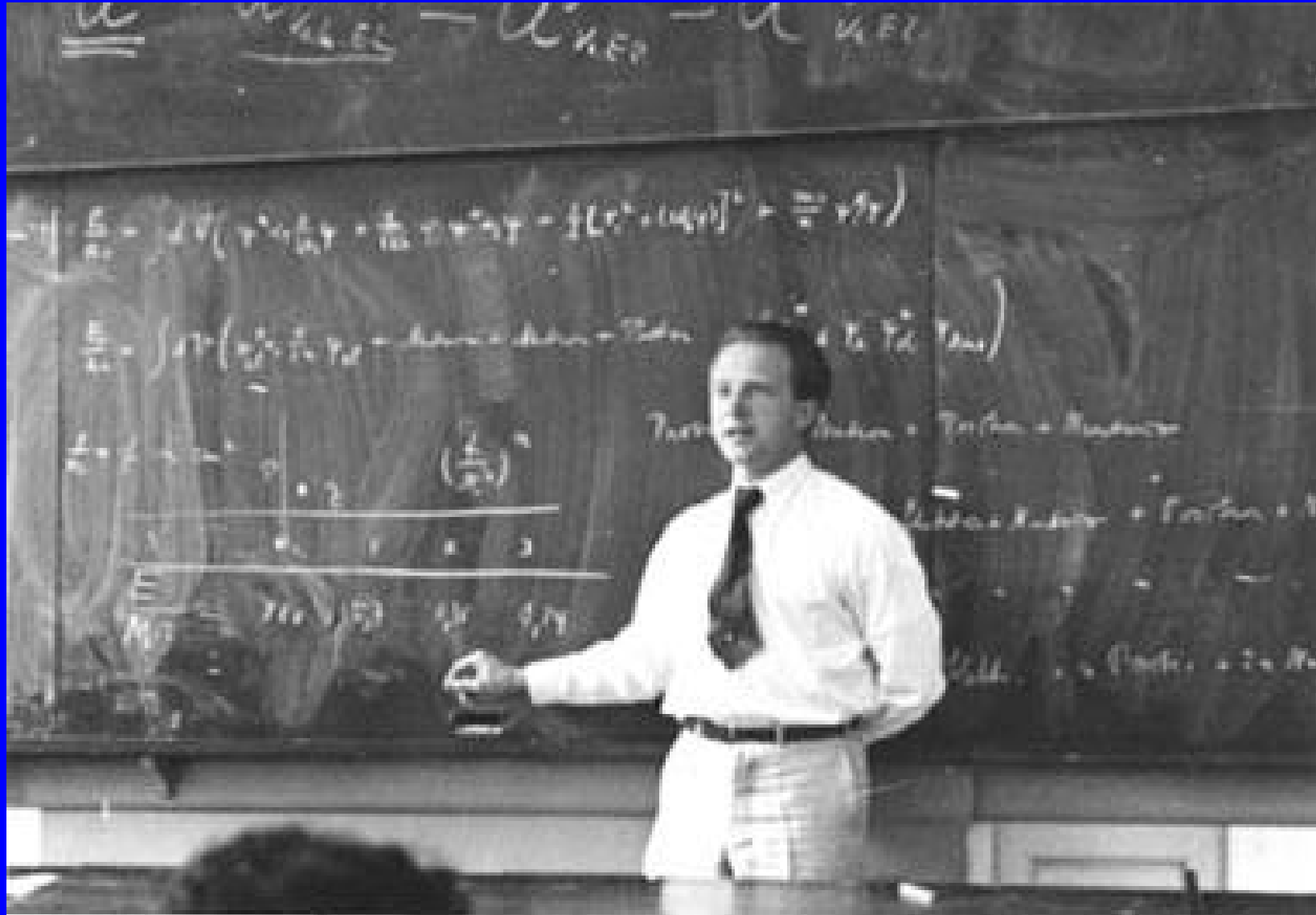


front: Klein, Bohr, Heisenberg, Pauli, Gamow, Landau and Kramers;
second row: Waller, ..., Peierls, ...



Bohr and Planck, Auditorium

Heisenberg in Auditorium, 1936



Copenhagen, 1936

with Pauli



lunch in the canteen

Germany invades Denmark and Norway

9 April 1940



The Bohr-Heisenberg Meeting

German Physical Society Meeting, on astrophysics,
Copenhagen, week of 15 -21 Sept. 1941 at the *German
Cultural Institute*

Heisenberg comes, together with Carl von Weizsäcker



Only Dane to attend is Bengt Strömgren

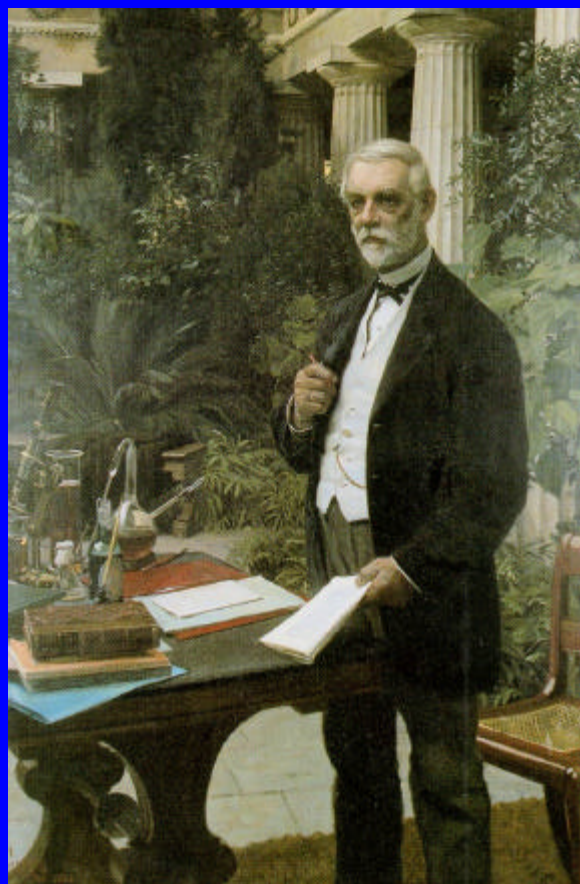


Heisenberg and von Weizsäcker lunch with Bohr and
others in canteen at Institute. Bohr invites Heisenberg
home to dinner at the Carlsberg house, 17 Sept.

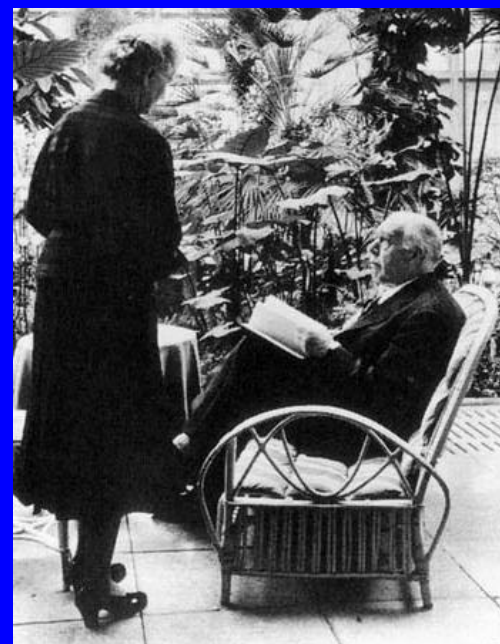


Carlsberg House of Honor (Æresbolig)

Gamle Carlsbergvej



J.C. Jacobsen



Heisenberg to Elisabeth from Copenhagen, Sept. 1941

Kopenhagen, September 1941

Meine liebe El! Du bist so wieder in deiner Stadt,
so wie es verheißt ist und in dem Teil meines Lebens,
mit dem ich von fünfzehn Jahren bis jetzt verbunden ist. Ich
ist "hinter" in dem Prozess meines Lebens, wie immer die Gedanken
von Gedanken kommen, wenn ich mich mit dir verstehe, ganz so
wie ganz leicht und leicht, und alles ist so schön zu
hören, als ich kommen in den Teil meines Lebens. Ich
so unendlich, wenn man plötzlich in den Teil des eigenen
Lebens aufpassen will, wie ich es nun nicht kann.
Aber die Dinge werden so sehr gefallen, in denen ich
in meinem Leben, in der Geschichte meines und ganz
schön, in der Geschichte meines, von dem ich mich
nun die kleine, kleine, fast vollkommen, wie
immer noch schäfer, und ich so sehr, wie ich
den großen Teil, wie ich mich, wie ich mich, wie ich
den die wunderliche Stadt in Bonn.

Ich und meine Familie geht es gut, es ist
so sehr schön geworden, wie ich mich, wie ich mich
werden. Die Dinge, die ich in den letzten Jahren
und in der letzten Zeit, wie ich mich, wie ich mich
von selbst gehen, hat den letzten Teil, wie ich
nicht fertig, das ist die letzte, wie ich
den Teil, die Dinge, wie ich mich, wie ich mich
den Teil, die Dinge, wie ich mich, wie ich mich
den Teil, die Dinge, wie ich mich, wie ich mich

Aber die Dinge, wie ich mich, wie ich mich
den Teil, die Dinge, wie ich mich, wie ich mich
den Teil, die Dinge, wie ich mich, wie ich mich
den Teil, die Dinge, wie ich mich, wie ich mich
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den Teil, die Dinge, wie ich mich, wie ich mich
den Teil, die Dinge, wie ich mich, wie ich mich
den Teil, die Dinge, wie ich mich, wie ich mich

Donnerstag, 19. September 1941

Es ist jetzt so schön, wie ich mich, wie ich mich
den Teil, die Dinge, wie ich mich, wie ich mich
den Teil, die Dinge, wie ich mich, wie ich mich
den Teil, die Dinge, wie ich mich, wie ich mich
den Teil, die Dinge, wie ich mich, wie ich mich
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den Teil, die Dinge, wie ich mich, wie ich mich
den Teil, die Dinge, wie ich mich, wie ich mich



1947

“Bohr and his family are doing fine; he himself has aged a little, his sons are all fully grown now. The conversation quickly turned to the human concerns and unhappy events of these times; ... Later I sat for a long time with Bohr alone; it was after midnight when he accompanied me to the streetcar, together with Hans (Bohr).”

Unsent letters from Bohr to Heisenberg

www.nbi.dk/nba

Bohr drafted, 1957-1961, some 8 letters to Heisenberg, about the meeting in 1941. Bohr was angered by Jungk's book, *Brighter than a Thousand Suns*, telling Heisenberg's revisionist story of his wartime efforts.

Letters were never sent, avoiding hurt to Heisenberg and family.

Dictated to Aage Petersen, Aage Bohr, and Margrethe Bohr.

Letters were to have been released Dec. 2012, the 50th anniversary of Bohr's death. After historians urged the Bohr family (Aage and Ernest), they were released Feb. 2002. The release was also a response to Frayn. (Play, 1998.)

Collection includes as well two drafts of congratulatory letter to Heisenberg on his 60th birthday, and Heisenberg's reply to telegram that was sent instead.

Dear Heisenberg,

Document 1 dictated to Aage Petersen

I have seen a book, “Stærkere end tusind sole” [“Brighter than a thousand suns”] by Robert Jungk, recently published in Danish, and I think that I owe it to you to tell you that **I am greatly amazed to see how much your memory has deceived you in your letter to the author of the book**, excerpts of which are printed in the Danish edition.

Personally, I remember every word of our conversations, which took place on a background of extreme sorrow and tension for us here in Denmark. In particular, it made a strong impression both on Margrethe and me, and on everyone at the Institute that the two of you spoke to, that you and Weizsäcker expressed your definite conviction that Germany would win and that it was therefore quite foolish for us to maintain the hope of a different outcome of the war and to be reticent as regards all German offers of cooperation. I also remember quite clearly our conversation in my room at the Institute, where in vague terms you spoke in a manner that could only give me the firm impression that, **under your leadership, everything was being done in Germany to develop atomic weapons and that you said that there was no need to talk about details since you were completely familiar with them and had spent the past two years working more or less exclusively on such preparations.** I listened to this without speaking since [a] great matter for mankind was at issue in which, despite our personal friendship, we had to be regarded as representatives of two sides engaged in mortal combat. That my silence and gravity, as you write in the

letter, could be taken as an expression of shock at your reports that it was possible to make an atomic bomb is a quite peculiar misunderstanding, which must be due to the great tension in your own mind. From the day three years earlier when I realized that slow neutrons could only cause fission in Uranium 235 and not 238, it was of course obvious to me that a bomb with certain effect could be produced by separating the uraniums. In June 1939 I had even given a public lecture in Birmingham about uranium fission, where I talked about the effects of such a bomb but of course added that the technical preparations would be so large that one did not know how soon they could be overcome. **If anything in my behaviour could be interpreted as shock, it did not derive from such reports but rather from the news, as I had to understand it, that Germany was participating vigorously in a race to be the first with atomic weapons.**

Besides, at the time I knew nothing about how far one had already come in England and America, which I learned only the following year when I was able to go to England after being informed that the German occupation force in Denmark had made preparations for my arrest.

All this is of course just a rendition of what I remember clearly from our conversations, which subsequently were naturally the subject of thorough discussions at the Institute and with other trusted friends in Denmark. It is quite another matter that, at that time and ever since, **I have always had the definite impression that you and Weizsäcker had arranged the symposium at the German Institute, in which I did not take part myself as a matter of principle, and the visit to us in order to assure yourselves that we suffered no harm and to try in every way to help us in our dangerous situation.**

This letter is essentially just between the two of us, but because of the stir the book has already caused in Danish newspapers, I have thought it appropriate to relate the contents of the letter in confidence to the head of the Danish Foreign Office and to Ambassador Duckwitz.

The next day, 18 Sept. 1941, Bohr went to the Danish Army to have them relay Heisenberg's revelation of the German bomb project, via Sweden, to the British. The transmission was unfortunately garbled and lost en route!

Document 7, Bohr to Heisenberg, in Margrethe Bohr's writing

[illegible][illegible]

hvordeu alle dekke eguelligt haugs sammen, det er klart
at de kan blep skilte, endda selv under Krigen. Gang
praktis. mætte tale. For en ukyndig fag, og end med
overbevisninger om nødvendigt og jeg kan bekræfte, at de
mætte til slut ikke kunne hørte hvad de mente, og de sagde
under Krigen fik de det men under et så dristigt arrangement
skide, som det i 1941, kan jeg ikke tænke at de skulle have
glemt hvad arrangementet var, forhindrer de træffel med
Nysgerrighederne de lyde Regeringsmyndigheder og det er på
dele punkt at hele Taleren og andre Regeringers
Påseende sig. Jeg tænker derfor meget, at de ved
at fortælle mig lidt om kan bidrage til opklaringen af
den for os alle så pinlige sag.

Let's assume that the figure is:

Document 7, dictated to Margrethe, plus corrections to Aage Bohr

... I am frequently asked about the background and purpose of the visit by you and Weizsäcker to Copenhagen in 1941. It is very difficult for me to give an answer because, as you know from our conversations in Tisvilde, both shortly after the war and during you and your family's summer stay in Liseleje, [I] got a completely different impression of the visit than the one you have described in Jungk's book. I remember quite definitely the course of these conversations, during which I naturally took a very cautious position, when <without preparation, immediately> you informed me that it was your conviction that the war, if it lasted sufficiently long, would be decided with atomic weapons, and <I did> not sense even the slightest hint that you and your friends were making efforts in another direction. ...

It is obvious that during the course of the war such a wise person as yourself must gradually lose faith in a German victory and end with the conviction of defeat, and I can therefore understand that perhaps at the end you may no longer have recalled what you had thought and what you had said during the first years of the war. But I cannot imagine that, during a meeting so boldly arranged as that in 1941, you should have forgotten what arrangements had been made in this regard with the German government authorities, and it is on that point that all the interest of other governments focuses. I therefore very much hope that, by telling me a little about this, you can contribute to the clarification of what is a most awkward matter for us all.

Heisenberg's response, Dec. 22, 1961, to Bohr's greetings, by telegram, on his 60th birthday

document 4

WERNER HEISENBERG
MÜNCHEN 88
RHEINLANDSTRASSE 1
22.12.61.

Lieber Bohr !

Ich danke herzlichsten Dank für Deinen Glückwunsch und den Aufsatz über die Entstehung der Quantenmechanik, der mich so lebendig an die Jahre hier in Deinem Institut erinnert hat und an all das, was ich von Dir lernen konnte. Wie anders ist die Physik seit dieser Zeit geworden ! Es kommt mir heute merkwürdig vor, fast wieder wie damals in Göttingen an dem Kampf der Meinungen teilzunehmen und die verschiedenen widersprechenden Ansätze auf die Goldwaage zu legen so wie wir es vor 30 Jahren in Kopenhagen getan haben. Die jungen Physiker schauen dabei etwas verwundert zu, weil sie sich nicht vorstellen können, dass man sich damals an die Vorstellung gewöhnt hatte, dass man sich nicht hinreichend viele Physiker an hinreichend verschiedenen Stellen stellen müsste, denn kommt schließlich alles von selbst in Ordnung. Aber dies soll kein elegischer Brief sein, ich habe im Gegenteil die

Diskussionen in Göttingen sehr genossen, und ganz besonders wohl deshalb, weil Du auch wieder dabei warst. Einzigen hatte ich seitdem noch eine besondere Freude : die relative Parität von Σ - und N -Teilchen, über die ich mit Talam und anderen in Aix en Provence und Göttingen verschiedene Meinungen war, ist inzwischen in Kalifornien gemessen worden und kommt ungefähr heraus, so wie es aus den Rechnungen von Tamm u. mir sich ergeben hatte. Ich frage dich doch an, das komplizierte Spielchen der Elementarteilchen zu verstehen.

Ich hoffe, dass es Dir gesundheitlich gut geht und dass Du auch zum Jahreswechsel in den Besuchen der ganzen Familie, Kindern und Enkel, Freude findest.

Mit vielen herzlichsten Wünschen, auch von Heide und den Kindern

Dein Werner

Dear Bohr!

document 4

Please accept my cordial thanks for your congratulations and the article about the genesis of quantum mechanics, which reminded me so vividly of the wonderful time at your Institute and of all that I was able to learn from you. How much physics has changed since those days! It strikes me as almost strange to take part once again, as recently in Brussels, in the battle of opinions and carefully to weigh the various contradictory arguments, just as we did 30 years ago in Copenhagen. The young physicists watch this with some amazement, since they have probably become used to the notion that, in the end, if only sufficiently many physicists are placed at sufficiently big machines, then everything will fall into place in the end. But this letter is not meant to be an elegy; on the contrary, I greatly enjoyed the discussions in Brussels and most particularly because you were there, too. By the way, I have since had yet a special pleasure: the relative parity of the Sigma and Lambda particles, about which I disagreed with Salam and others in Aix en Provence and Brussels, has in the meantime been measured in California, and it turns out to be odd, just as it came out in Dürr's and my calculations. Thus, we now begin to understand the complicated spectrum of elementary particles.

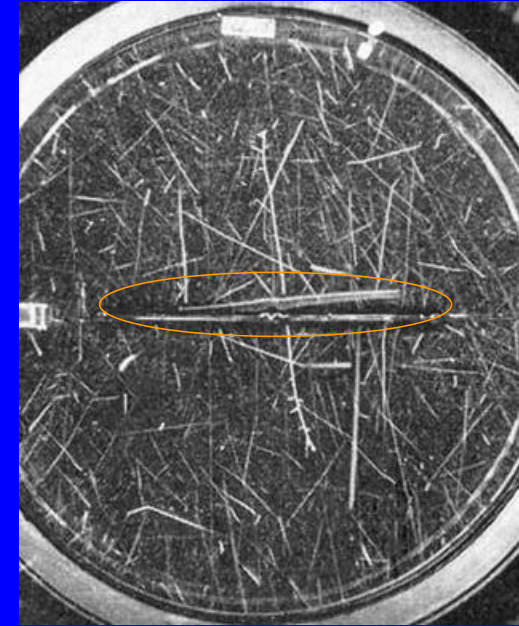
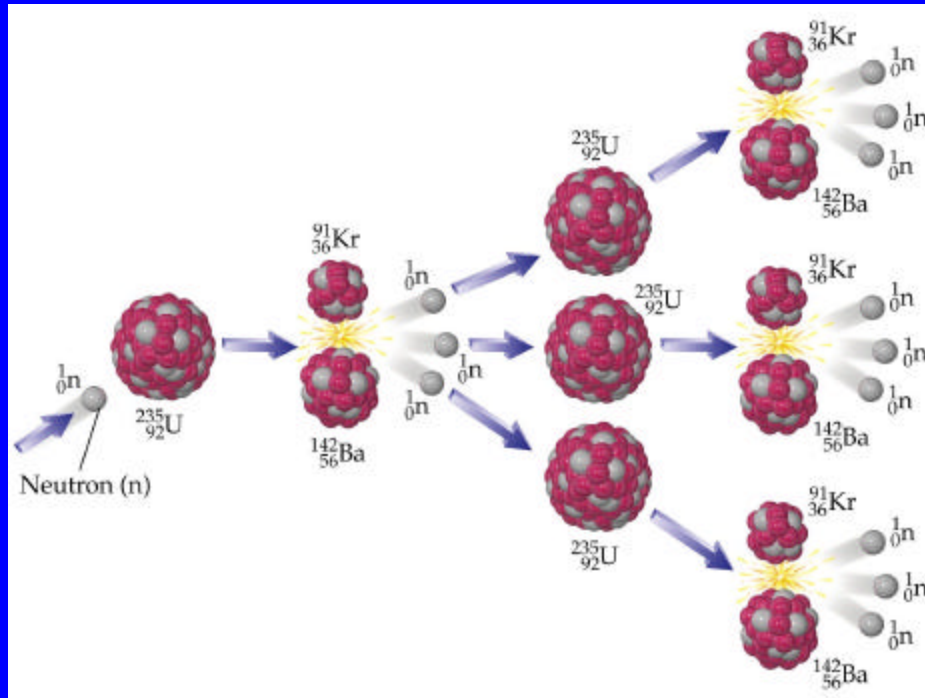
I hope that you are in good health and that at the turn of the year you can enjoy the visits from the entire family, children and grandchildren.

With many cordial greetings, also from Elisabeth and the children

Yours

Werner

Fission of uranium nuclei leads to chain reaction



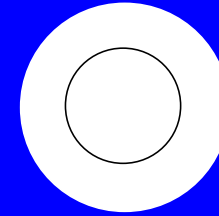
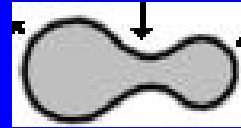
U nucleus in thin foil hit by neutron, splitting into two fragments. Copenhagen 1941

Naturally occurring U-238 fissions only with fast neutrons -- good for reactor but not bomb.

Rare isotope (one part in 140) U-235 fissions with slow neutrons!

Bohr and the atom bomb

1938; Discovery of fission by Lise Meitner and Otto Hahn, told to Otto Frisch.



1939: Bohr announces of discovery of fission in Washington.
Bohr-Wheeler Phys. Rev. paper on fission. U-235 (and Pu-239.).

1940: U.S. bomb program starts (National Research Defense Committee)
Pegram, Beams, Bush, Fermi, Szilard, ...



March: MAUD Committee; calculation of critical mass of U-235 (Peierls, Frisch) .

1943: Bohr asked by Cockcroft, via **microfilm in key**, to work on bomb.
Escape with Aage to Sweden. Brief stay in London.
Trip to U.S.: Washington, Chicago-New Mexico with General Groves

Late 1943-1945: Bohr and Aage in Los Alamos, as part of British *Tube Alloys Project*.
Bohr = Nicholas Baker (“Uncle Nick”), Aage = Jim Baker,
Enrico Fermi = Henry Farmer, Hans Bethe = Howard Battle, ...

Feb. 1945, Oppenheimer asks Bohr to be member of Initiator Committee for Pu bomb.
Niels and Aage tell Fermi that device promises to work.

TO: 'PETER.
From: JARLEN.

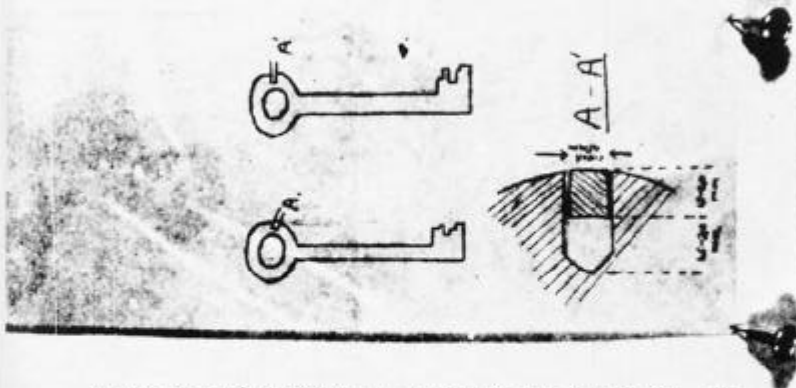
27/2

S. 66

MOST IMPORTANT

We intend sending to JUSTITSRAADEN in the near future a bunch of keys which contain a very important message from the British Government to Professor Niels Bohr. We would be very grateful if you could see that Professor BOHR gets the keys and also if you or someone appointed by you would explain to him how to find the message.

The following diagram shows the position in keys A. and A.1. of the message which has to be extracted. Key A.1. is the one with number 229 on it and Key A. is the long key next to it.



A small hole to a depth of 4 mm. has been bored in the two keys. The holes were plugged up and concealed after the message was inserted. Professor Bohr should gently file the keys at the point indicated until the hole appears. The message can then be syringed or floated out on to a micro-slide. The message is a very very small micro film and is repeated in duplicate in each key. It should be handled very delicately.

I do not myself know the contents of the message except that I do know it is very important. Will you kindly warn JUSTITSRAADEN and tell him to expect the bunch of keys. We will send the keys through to him by separate courier as soon as we know that this sending has reached you and that you have had time to warn Justitsraaden.



I disse nøgler blev mikrofilm med et hemmeligt budskab sendt til Niels Bohr fra England under krigen. Teksten giver en nøjagtig forklaring på, hvordan filmene, der ses som små sorte prikker under glassene til venstre, er anbragt i udboingen

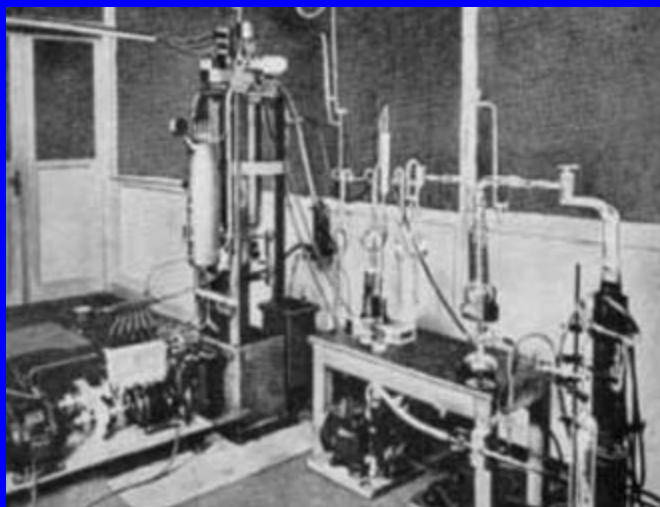
Secret message from Cockcroft in England to Bohr, early 1943, asking him to work on bomb.

Key was buried in garden in Carlsberg during the war, and now hangs on the wall in Aage Bohr's office at the Institute.

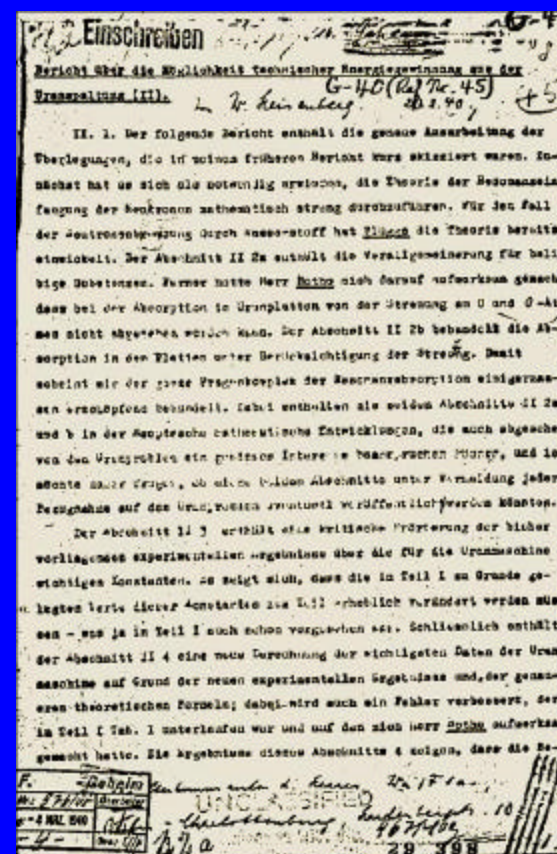
Heisenberg and the German bomb

1939: Sept. 16: German Army Weapons Bureau assembles scientists to begin fission research. Kaiser-Wilhelm Institute for Physics, Berlin-Dahlem (KWI).

Dec. 6: Heisenberg secret report to Army Weapons Bureau (Heereswaffenamt) on nuclear fission weapons. Heads small reactor research group in Leipzig, advised larger group in Berlin.



Model centrifuge for uranium enrichment, Harteck and Groth (Hamburg)



Heisenberg, "On the Possibility of Technical Energy Production from Uranium Splitting. II"

1940 Feb. 29: Report, part 2.

May 3: Germany seizes heavy-water production plant at Norsk Hydro, Vemork, Norway. (Destroyed by Norwegian commando raid in Feb. 1944.)

July 17: von Weizsäcker suggests neptunium, bred in reactor, for fission bomb.

1941: Jan.: W. Bothe and P. Jensen, neutron absorption in graphite: due to boron-10 contamination, graphite cannot be used as a moderator. (Szilard in U.S.!)

Aug.: Houtermans reports possibility of using plutonium in a bomb.

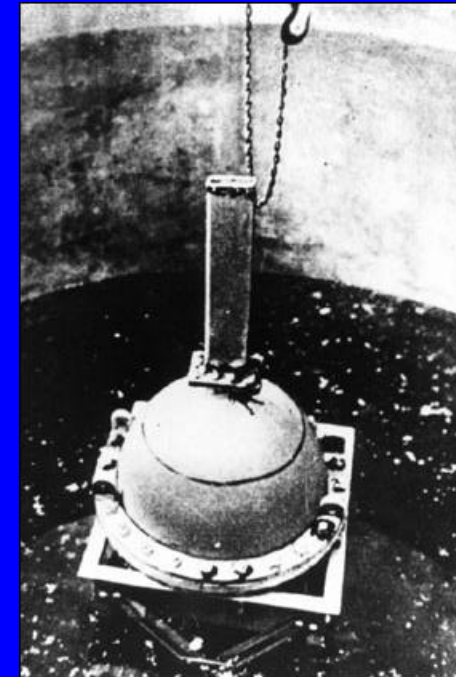
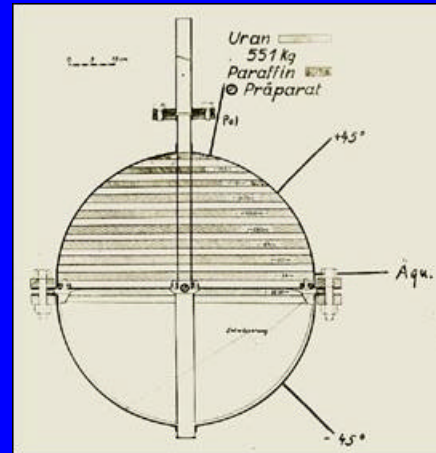
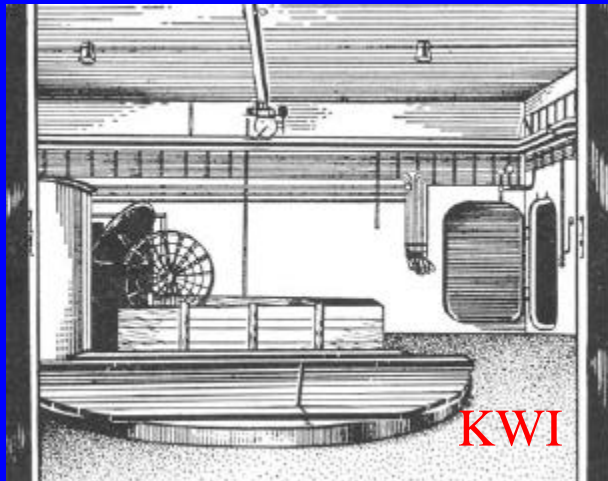
1942: Feb. Army Weapons Bureau withdraws from fission research. Heisenberg, Hahn, and other scientists lecture on nuclear research to the Reich Education Ministry; gain backing for project under the Reich Research Council. H. says that a uranium bomb could be made, and that a reactor would produce new element -- plutonium -- for a bomb. H. to KWI -- publishes on high energy physics.

Heisenberg gives sanctuary to German physicists wanting to avoid combat.



J.H.D. Jensen

Apr 1942.: Heisenberg achieves first neutron multiplication in Leipzig test reactor with alternating layers of uranium and paraffin:



June: Heisenberg reports on fission research to Albert Speer.

July: Heisenberg becomes acting head of KWI, plans construction of reactor with heavy water and uranium. Kurt Diebner begins reactor construction with U in heavy water, positive neutron multiplication the following year.

Dec. 2 Fermi's pile of uranium spheres in graphite bricks, Stagg field, works!

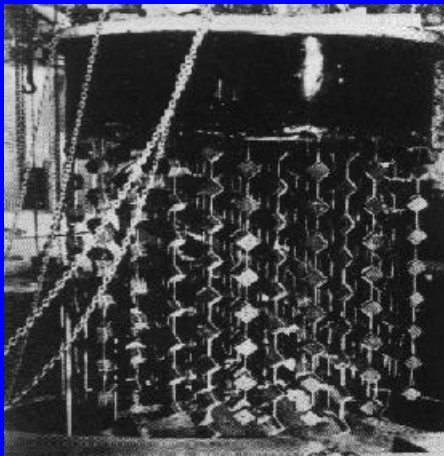
1943: May: Heisenberg, Hahn, and other scientists deliver lectures on fission research to Göring's German Academy of Aerodynamical Research.

Fall: KWI split, moves for safety, to Hechingen and Haigerloch.

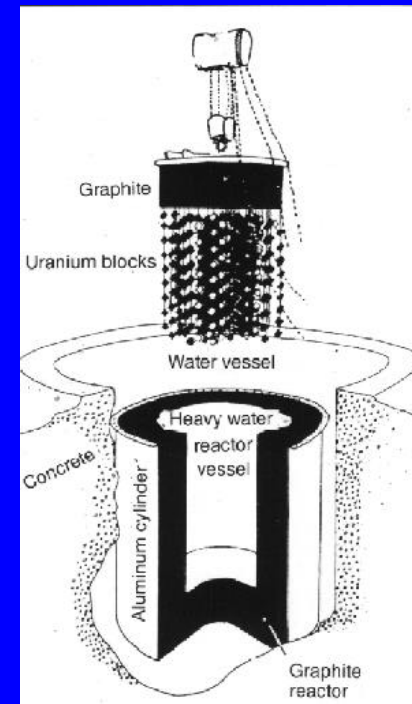
Haigerloch (near Tübingen) reactor project



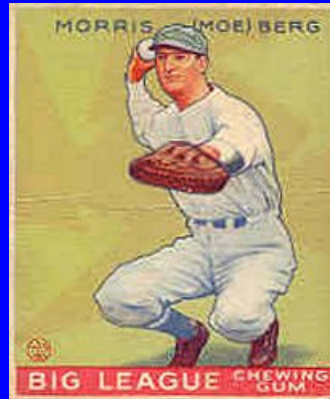
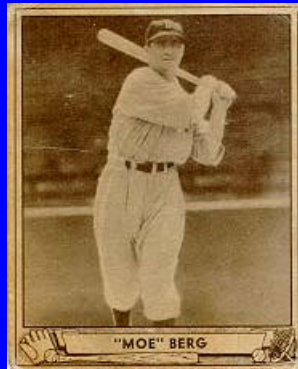
cave under castle-church



model nuclear reactor,
made of 664 uranium cubes



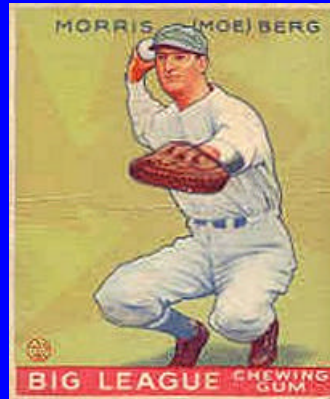
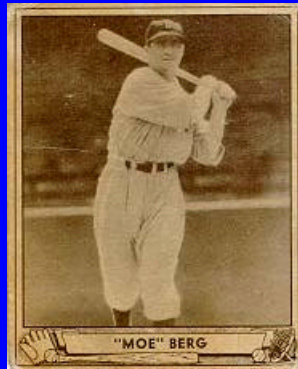
Moe Berg, 1902-1972



1926-1939
White Sox,
Cleveland Indians
Washington Senators
Red Sox



Moe Berg, 1902-1972



1926-1939
White Sox,
Cleveland Indians
Washington Senators
Red Sox

Fluent in German, spoke Japanese, French, Latin.

Spy with *U.S. Office of Strategic Services*.

On All-Star team in Japan, 1934, with Lou Gehrig and Babe Ruth: took movies from hospital roof of Tokyo skyline, used in Doolittle's bombing of Tokyo, 1942.

Plan to shoot Heisenberg, 1944

Heisenberg was to lecture in Zurich at Paul Scherrer's institute in late 1944

Berg trained by Hans Bethe and Vicki Weisskopf to recognize if Heisenberg understood about making bombs. If so he was to shoot him on the spot! Lecture was on S-matrix theory.



Scherrer and Berg in Zurich



Scherrer

“It was crazy what we did then.”
Bethe in Atlanta, 1999

1944: Jan. 1 Gerlach appointed "plenipotentiary" of all Reich Research Council fission research.

Aug: Alsos Mission arrives in Europe.

Nov.: Alsos determines that no bomb exists.

1945: Mar.: Heisenberg team in Haigerloch begins last attempt to achieve a critical reactor.

Apr, May: Alsos captures scientists and equipment in Hechingen and Haigerloch, Diebner and Gerlach in Munich, Heisenberg in Bavaria.

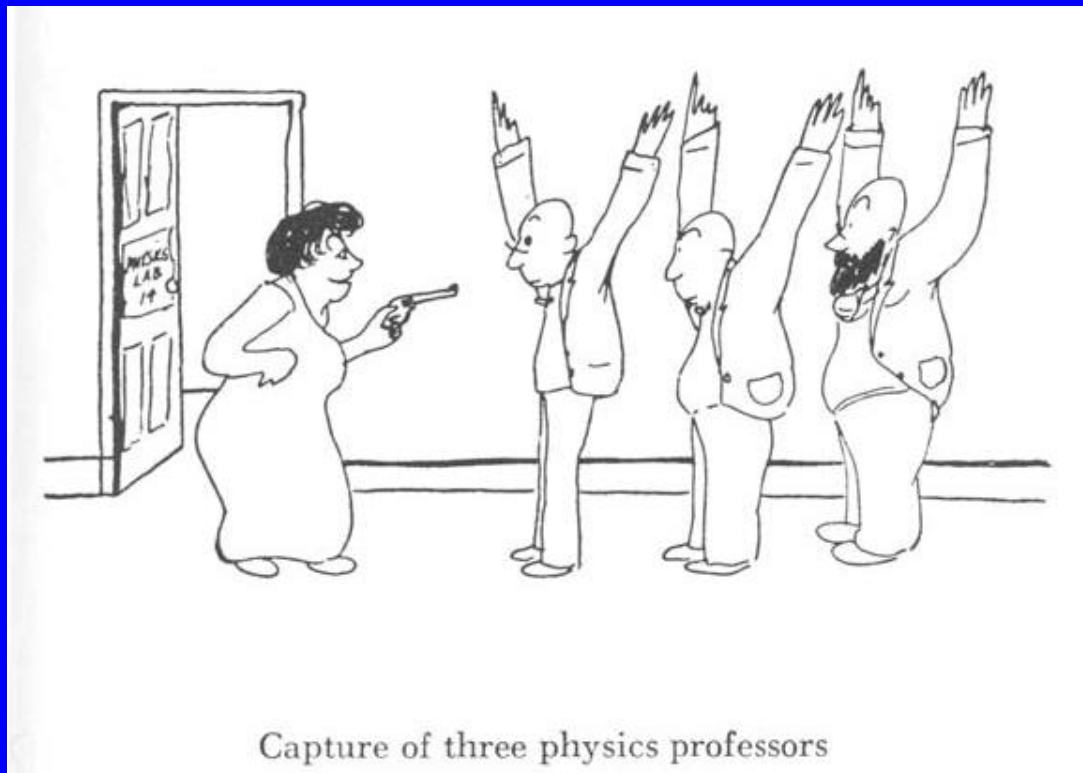
3 July 1945 - 3 Jan. 1946: Ten of the captive German scientists interned at Farm Hall.

6 Aug. 1945: Uranium fission bomb (Little Boy) -- Hiroshima.

9 Aug. 1945: Plutonium fission bomb (Fat Man) -- Nagasaki.

Farm Hall, 1945 (Operation Epsilon)

10 German scientists arrested by Alsos Mission
(Goudsmit). Detained at English country manor
3 July 1945- 3 Jan. 1946.
All conversations secretly taped.



James Thurber
New Yorker, 1934

Walther Gerlach -- administrator of German fission research

Otto Hahn -- co-discover of fission.

Nobel Prize while detained

Werner Heisenberg

Max von Laue -- did not do fission research

Carl von Weizsäcker

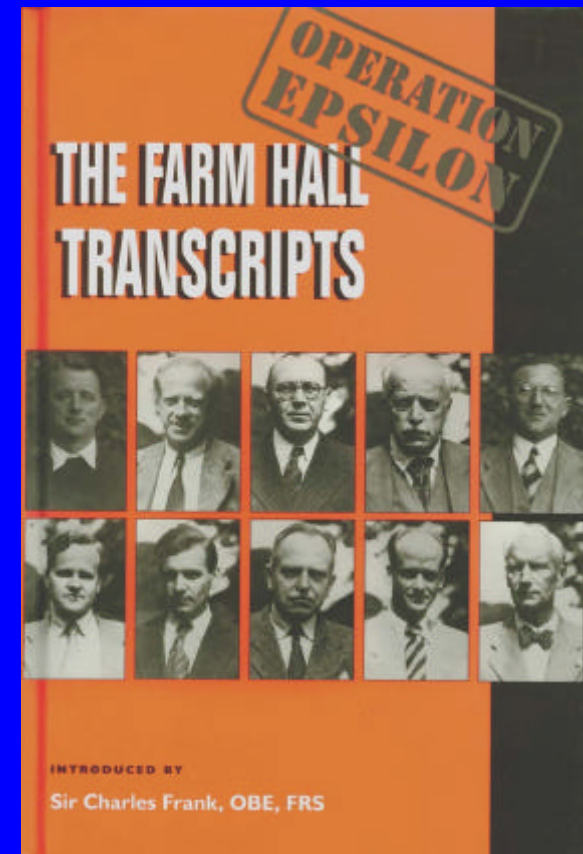
Kurt Diebner -- organizer of German Army fission project, reactor experiments

Erich Bagge -- junior physicist, fission research, isotope separation

Paul Harteck -- isotope separation, reactor design

Horst Korsching -- junior physicist, isotope separation

Karl Wirtz -- head of reactor construction, Kaiser-Wilhelm Institute, Berlin



Moral superiority argument:

“History will record that the Americans and the English made a bomb, and that at the same time the Germans, under the Hitler regime, produced a workable engine [reactor]. In other words, the peaceful development of the uranium engine was made in Germany under the Hitler regime, whereas the Americans and the English developed this ghastly weapon of war.”

“I believe the reason we didn't do it was that all the physicists didn't want to do it, on principle ... If we had all wanted Germany to win the war we would have succeeded.”

von Weizsäcker, Farm Hall

“I don't believe that, but I am thankful we didn't succeed.”

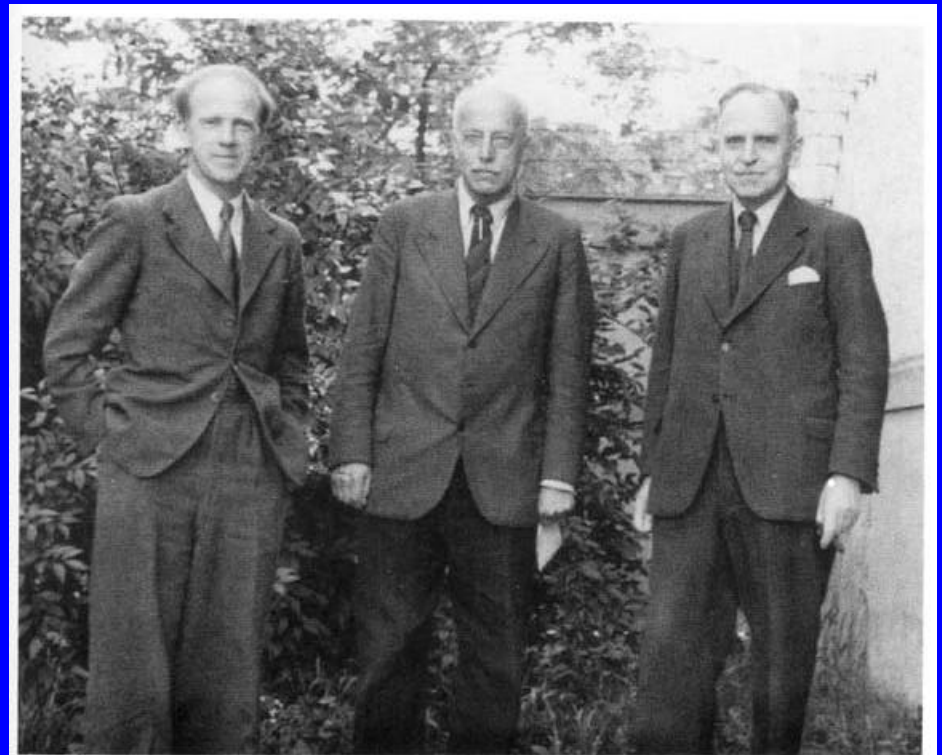
Hahn, Farm Hall

“We had in fact begun in 1939 and continued work until 1941 on the atom bomb and investigated the conditions for its construction.”

von Weizsäcker

“The letter [Bohr, unsent] changed my view ... It seems to me that in 1941 Heisenberg wanted to build a bomb.”

Hans Bethe, Science 15 Feb 02



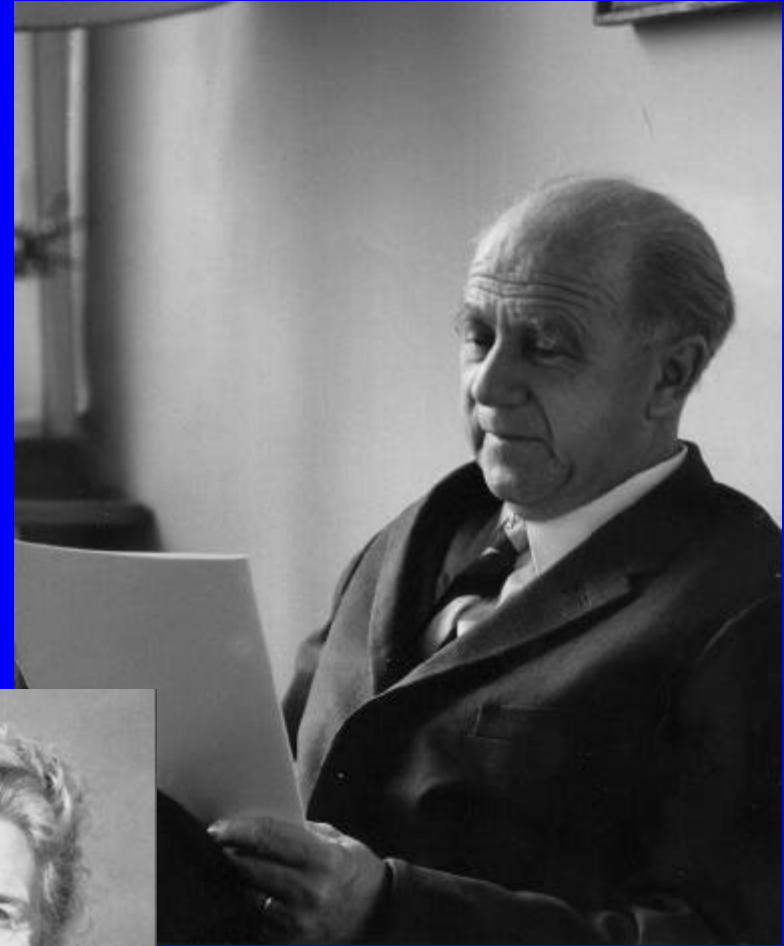
Heisenberg, Otto Hahn, Max von Laue, late 1940s.

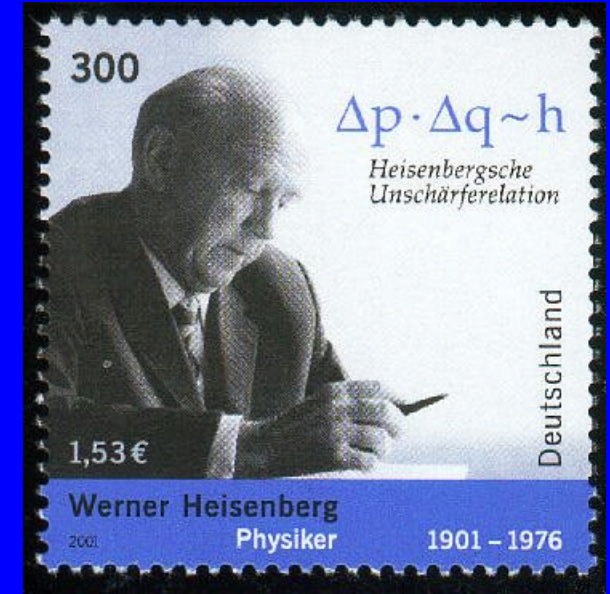
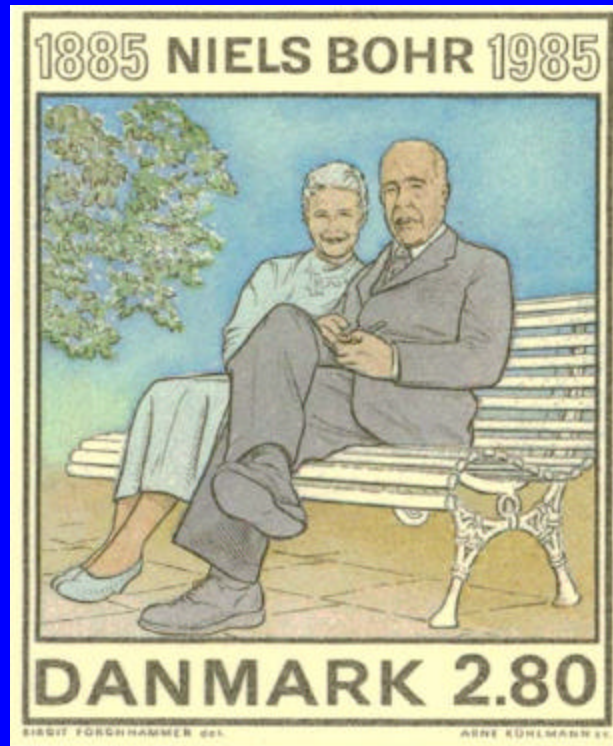
Bohrs and Heisenbergs on vacation in Greece, 1953



Bohr with Heisenbergs

Bohrs with Elisabeth and Heisenberg daughter





“A grandchild must learn to eat”



Grandchildren: in the Winter Garden



under picture of Christian

Why did German bomb project fail?

Failure to calculate critical mass correctly. One ton vs. 10 kg.

Failure to separate isotopes by gaseous diffusion;
invented by Gustav Hertz = 1/4 Jewish.

Moderator: didn't understand need for ultrapure graphite.

Design of reactor: Heisenberg insisted, **for mathematical simplicity**, on sheets of Uranium! Switch to cubes only in 1944.

Low priority by military.

Gradually failing German military and industrial situation.

No evidence of Heisenberg “dragging his feet.”

David Cassidy, APS talk Albuquerque 2002

Bohr letters written nearly two decades after the meeting -- not reliable historic records.

No evidence of Heisenberg “dragging his feet.”

“Heisenberg was working full blast on getting as far as he could on nuclear fission, including a bomb.” Cassidy.

Bohr and Heisenberg were on different planets in 1941.

"For us there remains nothing but to turn to the simple things, ... we should conscientiously fulfill the duties and tasks that life presents to us without asking much about the why or the wherefore ... And then we should wait for what happens ... Reality is transforming itself without our influence." Heisenberg, 1942

BACKGROUND MATERIAL:

A. Pais, *Niels Bohr's Times, in Physics, Philosophy, and Polity*, 1991

D. Cassidy, *Uncertainty: The Life and Science of Werner Heisenberg*, 1992

Bohr letters: www.nbi.dk/nba

Washington symposium:

<http://web.gc.cuny.edu/sciart/copenhagen/symposium.htm>

S. Goudsmit, *Alsos*, 1947

Operation Epsilon, the Farm Hall Transcripts, 1993

J. Bernstein, *Hitler's Uranium Club*, 1995

R. Rhodes, *The Making of the Atomic Bomb*, 1986

L. Hoddeson et al., *Critical Assembly, A Technical History of Los Alamos during the Oppenheimer Years*, 1993

T. Powers, *Heisenberg's War: The Secret History of the German Bomb*, 1993