Discoveries that changed the world: 1932 – 1942

James Chadwick 1891 – 1974
Lise Meitner 1878 – 1968

I

„The road to the neutron“

Staff and research students at the Cavendish Laboratory, Cambridge, 1923. (Names from left to right. Front row: J. Chadwick, G. Stead, F.W. Aston, Prof. Sir J. J. Thomson, Prof. Sir E. Rutherford, J.A. Crowther, Miss B. Trevelyan, G.I. Taylor, Second row: P. Kapitza, H. de W. Smyth, T. Alty, J.E. Crackston, H. Robinson, L.F. Curtiss, E.S. Bieler, A.G.D. West, P. Mercier. Back row: P.M.S. Blackett, R.E. Clay, H.W.B. Skinner, H.D. Griffith, A.W. Barton, L.F. Bates, J.S. Rogers, K.G. Emeleus.)

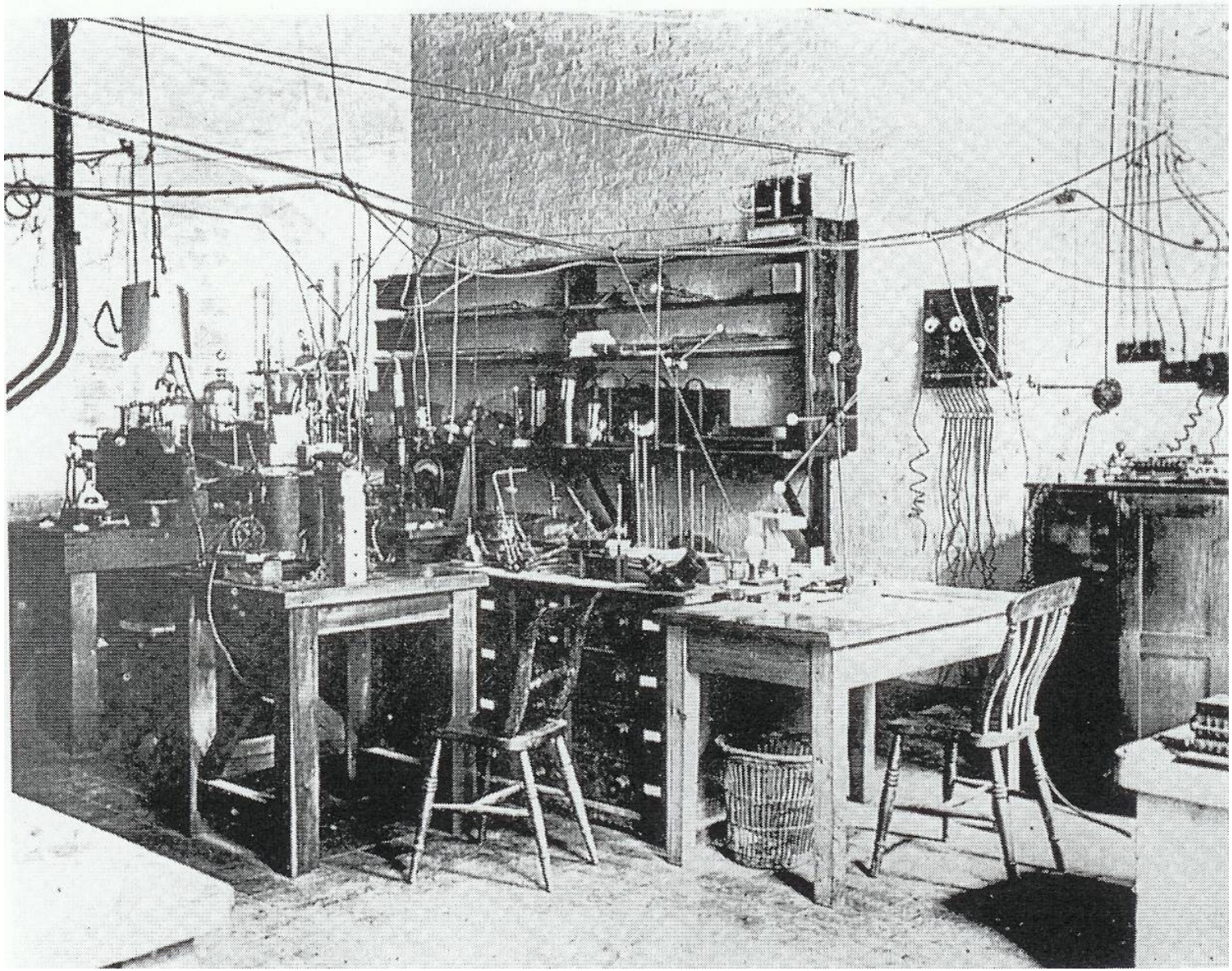
James Chadwick 1891 – 1974

Chadwick arrives at Manchester in 1908, enrolls for physics rather than mathematics and soon meets **Rutherford**, who had returned to UK from McGill in 1907. (Nobel 1908)

Chadwick starts Ph.D. in 1912 with **Geiger** in Berlin, meets **Hahn & Meitner** in 1914, and then in Nov. 1914 is interned outside Berlin until Nov. 1918. Returns with low morale to UK.

In 1919 Rutherford is appointed to Cavendish and takes JC with him. Finishes Ph. D. in 1923 and soon after becomes ER's assistant – a role he plays superbly. In 1925 ER made President of Royal Society, and a Lord in 1931. All this meant that JC essentially *ran* the Cavendish. (FRS – 1932)

Influence of ER on JC was enormous – as it was on many!



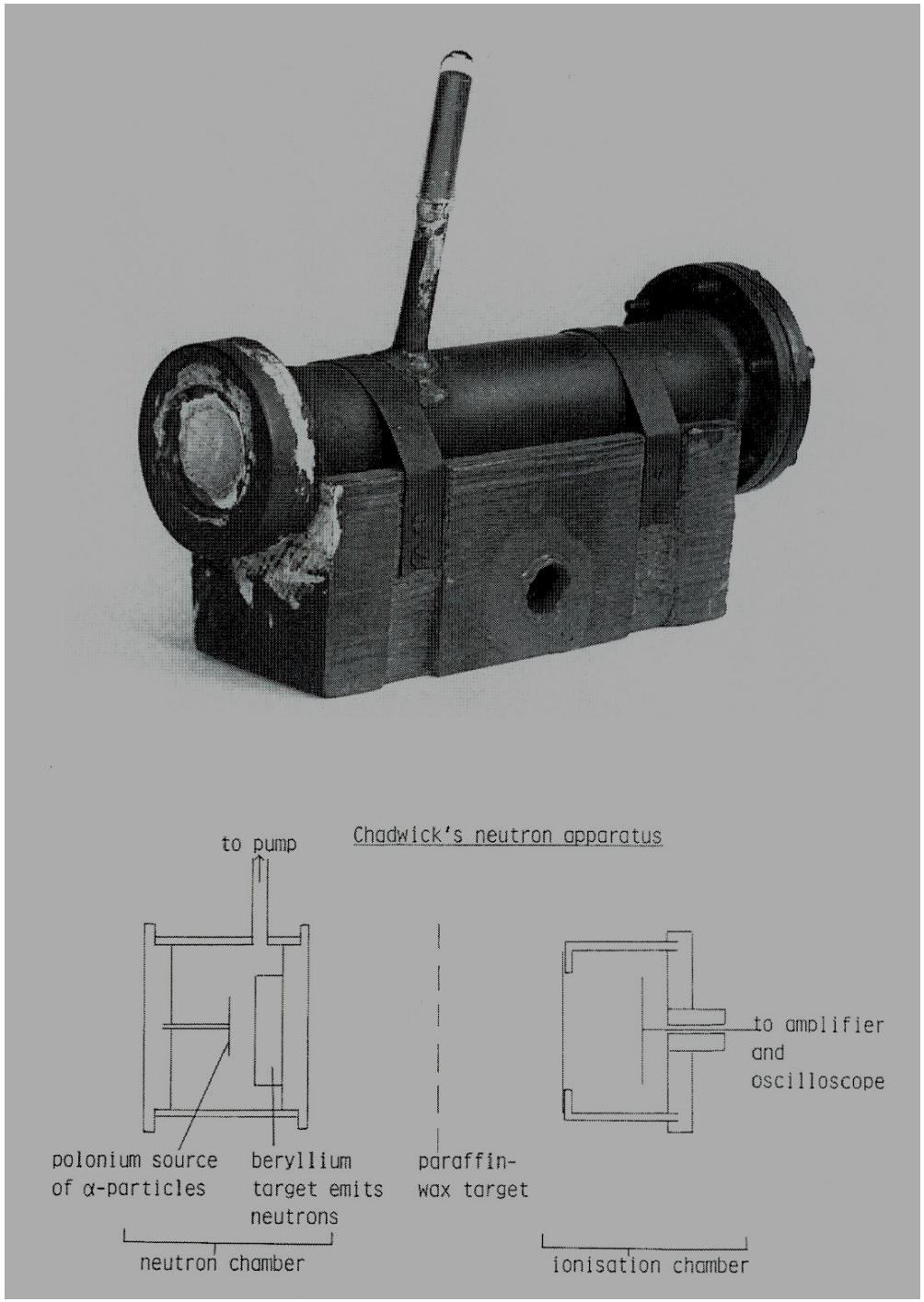
The room which Rutherford and Chadwick used for their scattering experiments in the 1920s. The work was carried out in the dark, often to the accompaniment of Rutherford singing „Onward Christian Soldiers“.

Rutherford had already proposed the neutron in 1920 in his Bakerian Lecture at the Royal Society.
He talked about a **"neutral doublet"** (at that time considered a proton and electron) that could be difficult to detect and be able to move easily through matter.

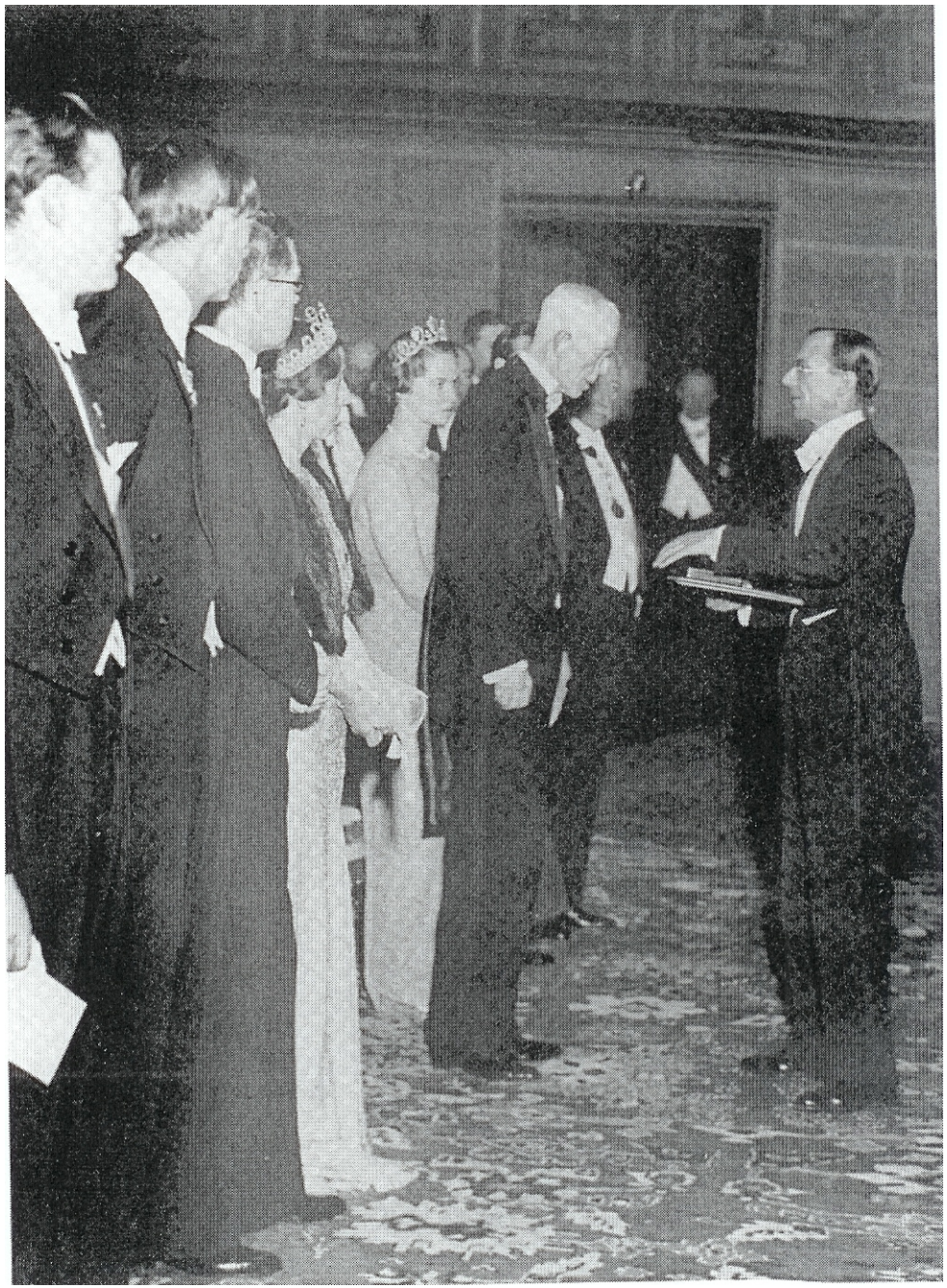
Curie's published (incorrectly) in Jan. 1932 the observation:

$$^{9}Be + {}^{4}He \rightarrow {}^{12}C + {}^{1}n$$

When the radiation was passed through wax the ionisation increased! This increase was due to protons. To make this the Curie's suggested that the emission was of a 55 MeV γ ray, an energy much greater than anything yet seen! **Moreover, the radiation also passed through lead**.



Chadwick's neutron chamber in which α-particles from a polonium source, at the right-hand end, bombarded a beryllium source, at the left-hand end. From there, neutrons emerged to pass through a paraffin wax target, releasing enough protons to register on an oscilloscope. A vacuum pump was attached to the finger-like chimney.



Receiving the **1935** Nobel Price from King Gustav in Stockholm. Moments later Chadwick would drop the cheque!

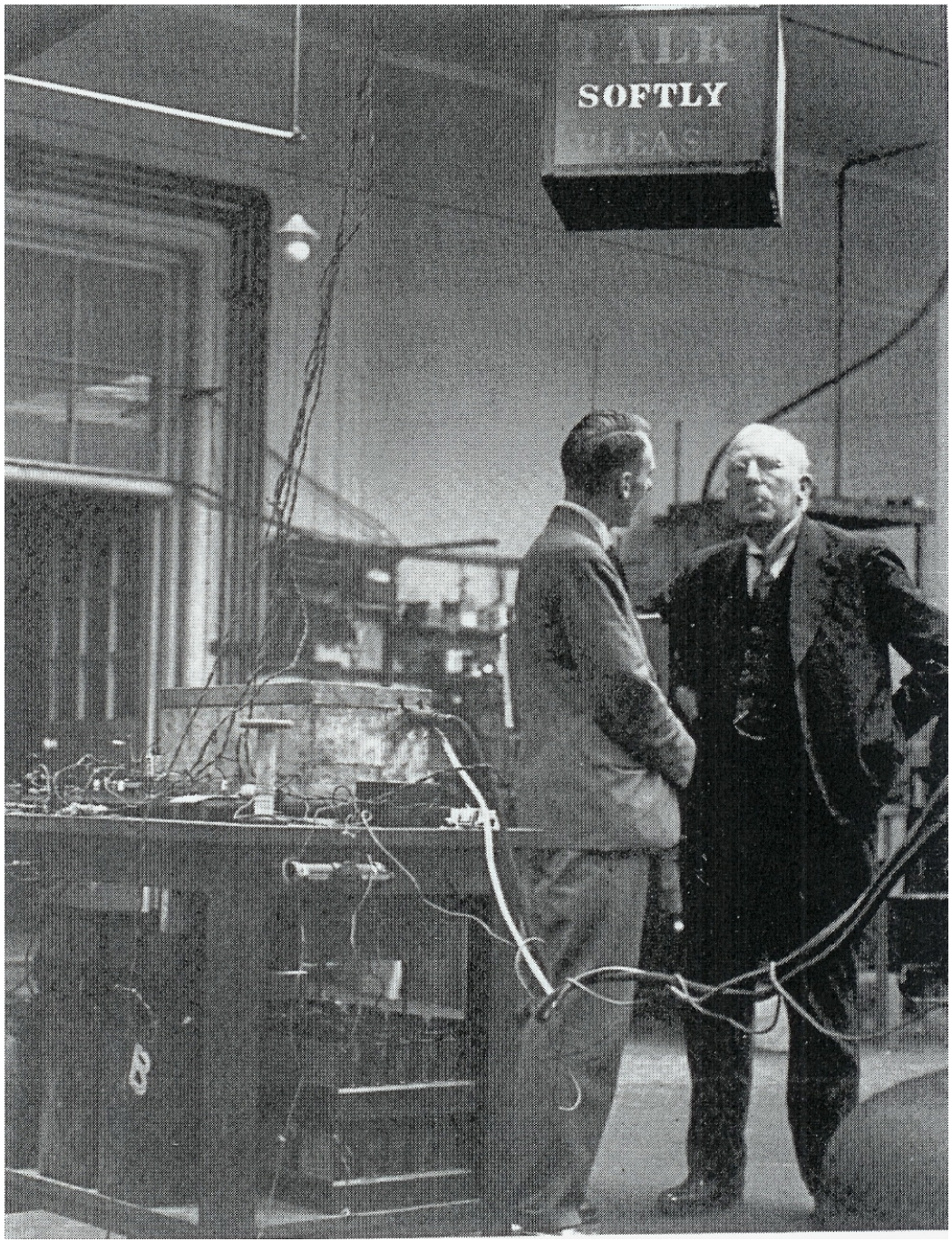
Letter to **Nature** is only 200 words

Secret of his success is that having realised the radiation was neutrons he calculated the mass and found:

n/p = 1.0090

Now recognised as 1.0085

Joliot & Curie are awarded the 1935 Chemistry Nobel for synthesis of new elements



Physics successes in 1932. Chadwick's laboratory with its vibration-sensitive equipment was through the open door. Rutherford is talking to J.A. Ratcliffe.

In April 1932 the Cavendish struck again with the first nuclear disintegration by Cockroft & Walton (Nobel 1951), but nuclear physics then turned more to big accelerators and the Cavendish got left behind. Chadwick moved to Liverpool in 1935 to build a cyclotron. ER died unexpectedly in 1937 at age 66

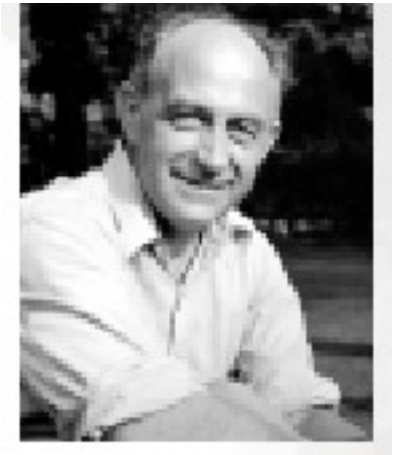
W. L. Bragg becomes new Cavendish Prof. 1938-1953. Watson & Crick (1953)

The Seventh Solvay Council, Brussels, 1933, which was devoted to the atomic nucleus. (Names from left to right. Seated: Schrödinger, Irène Joliot-Curie, Bohr, Joffé, Marie Curie, Richardson, Langevin, Rutherford, De Donder, Maurice de Broglie, Louis de Broglie, Meitner and Chadwick. Standing: Henriot, Perrin, Frédéric Joliot-Curie, Heisenberg, Kramers, Stahel, Fermi, Walton, Dirac, Debye, Mott, Cabrera, Gamow, Bothe, Blackett, Rosenblum, Erra, Bauer, Pauli, Verschaffelt in front of Cosyns, Herzen, Cockcroft, Ellis, Peierls, Piccard, Lawrence and Rosenfeld.)

What important person is missing – **why**?

The neutron was indeed superbly suited to penetrating the “atom” and **Enrico Fermi** [1901–1954] in Rome rapidly became the expert. Fermi’s source of neutrons was radon gas (from a radium source) mixed with Be. This was much more intense than Po-Be sources then in use in other places, but must have been lethal! They proceeded to bombard all elements in the Periodic Table.

They also discovered that slow neutrons were better for possible “transmutations”. By 1938 the situation in Italy had become difficult as Laura Fermi was part Jewish; Fermi receives Nobel 1938 in Stockholm and goes straight to Columbia University, NY.



When Fermi (and also the Joliot-Curie’s in Paris) got to uranium they assumed the transuranium elements were being formed. **No less than 4 new β decay products published in 1935 - quite surprising! Fermi even named them: ausonium and hesperium**

Chapter 2

„The road to fission“

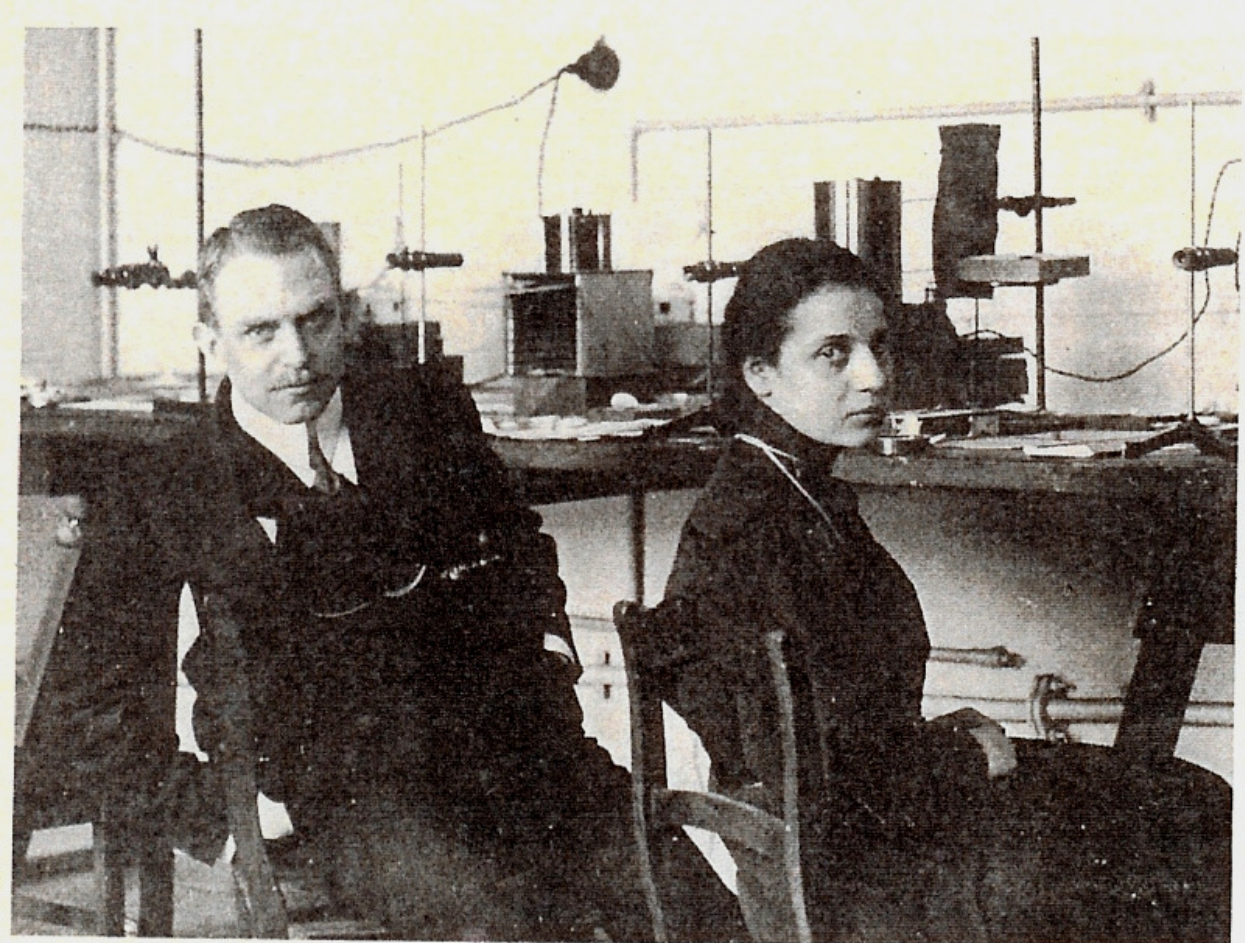
Lise Meitner (1878–1968)

Born in Vienna into close and musical family; despite difficulties manages to take courses privately and graduate.
Inspired by Boltzmann

Arrives in Berlin in 1907 at KWI and has job in radiochemistry with Otto Hahn. Must come in back entrance. Director Fischer thinks women will set fire to their hair in the labs. Moves to Dahlem in 1911 and gets "position" in 1912 (34 yrs).

Grete (or Emma) Planck, Meitner, and Elisabeth Schiemann, about 1913.

Hahn, Meitner, and Emma (or Grete) Planck, about 1910. The Planck sisters were identical twins; usually only one would be in a photograph, no doubt because the other was taking it.



Meitner and Hahn, in their laboratory in Fischer‘s institute, about 1910.

During the war she volunteers for ambulance service and helps with medical x-rays. Falls ill and returns to Berlin. Later helps bring scientific instruments to Ruhleben; Chadwick is a prisoner there.

The small instrument is the simple beta spectrometer first used by Meitner, Hahn, and Otto von Baeyer in 1910. Meitner used the larger instrument for her studies of beta-gamma spectra in the 1920s.

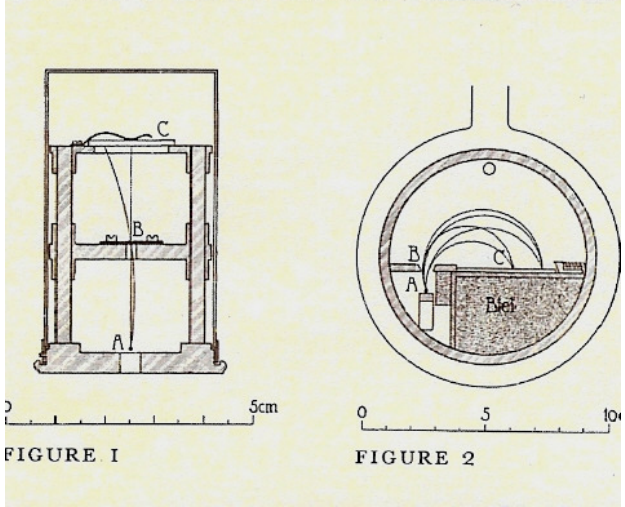
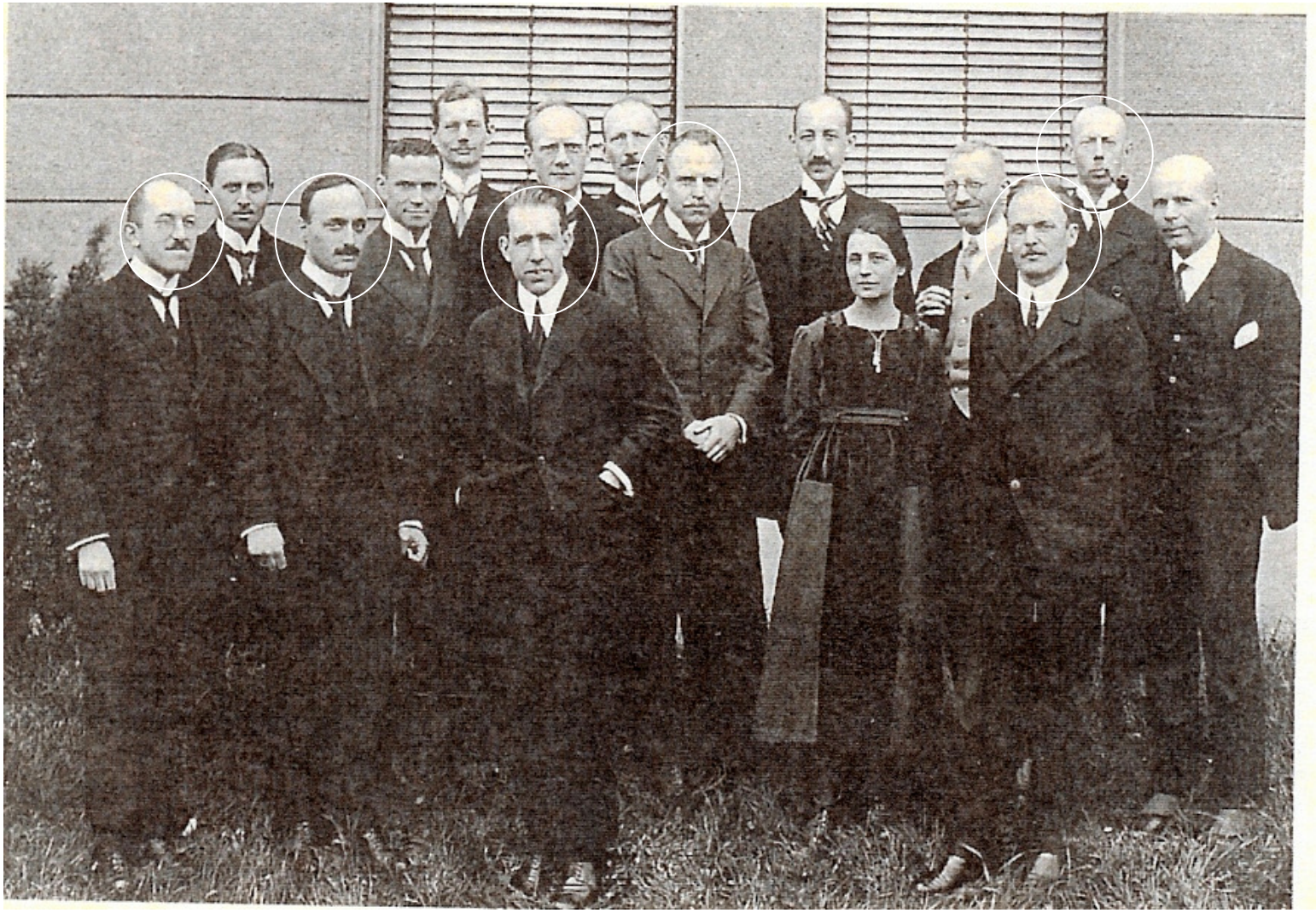


FIGURE 1

FIGURE 2

In the small instrument, figure1, sample **A** emits beta particles (negative electrons) that travel upward through slit **B** and are recorded as a dark line on photographic plate **C**.

In a magnetic field perpendicular to the plane of the diagram, the electrons are deflected into a circular path, the deflection being greater for less energetic electrons. Meitner, Hahn, and von Baeyer observed discrete lines on the photographic plate, evidence of monoenergetic electron groups whose energy they determined from the position of the lines. In the larger instrument, figure 2, the orientation of the photographic plate **C** has been changed to improve the resolution of the electron lines.



Colloquium with Niels Bohr in Berlin, 1920. From left: Otto Stern, Wilhelm Lenz, James Franck, Rudolf Ladenburg, Paul Knipping, Bohr, E. Wagner, Otto von Baeyer, Hahn, George de Hevesy, Meitner, Wilhelm Westphal, Hans Geiger, Gustav Hertz (with pipe), Peter Pringsheim.

Kaiser Wilhelm Institute for Chemistry, about 1930; view from Thielallee. The smaller building at the left is the institute villa, where Meitner lived in an apartment during this period.

Hahn & Meitner isolate Pa in the 1920‘s and specialise on heavier elements. LM is the physicist; OH the chemist. They establish the KWI as a major „player“ in the 1930‘s in studies of nuclear structure.

30–Jan–1933

Hitler becomes Chancellor of Germany.

Immediately problems started with Jews. Because LM was Austrian, she was relatively well protected.
Scientists like Einstein and Schrodinger left; others like Planck & von Laue stayed and tried to protect younger colleagues.

LM had a chance to leave to Bohr's Institute, but could not believe her world would change. In this respect she was completely apolitical.

By 1936 Berlin was working full time on the problem of neutrons and uranium. They made the reactions and then searched the **precipitates**. They did not analyse the filtrates because uranium was in the filtrates and the radioactivity from it was too high (they thought) to see other materials. ***This turned out to be a* huge *mistake!***

$$U + n \rightarrow U\ (10s) \rightarrow \in Re\ (2.2m) \rightarrow \in Os\ (59m) \rightarrow \in Ir\ (66hr)$$
$$[Te_{53}] \rightarrow \in Pt\ (2.5h)\ [I_{53}] \rightarrow \in Au?$$

$$U + n \rightarrow U\ (40s) \rightarrow \in Re\ (16\ m) \rightarrow \in Os\ (5.7h) \rightarrow \in Ir?$$

$$U + n \rightarrow U\ (23m) \rightarrow \in Re?\ [^{93}Np]$$

.

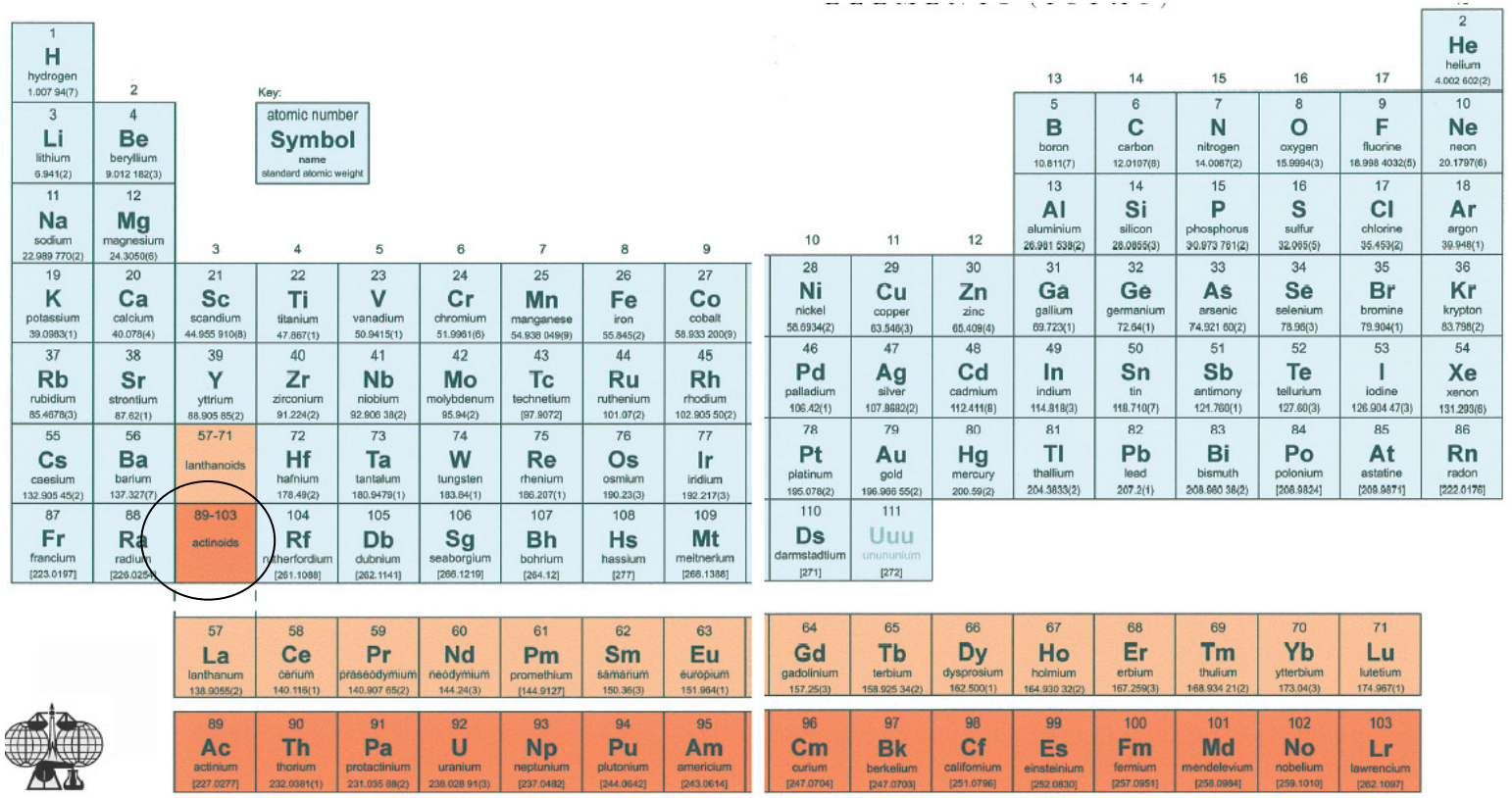
Periodic Table

Period..

Principal quantum levels or shells

Period..

1-7 or (K,L,M …,Q)



Groups 1-8 are organized according to the number of electrons in the outer shell. Number of the group gives the number of (valence) electron

Note that Ba and Ra are in same column!

Although Hahn thought they had the transuranics, as did many, including in Rome, Berkeley, and others, LM did <u>not</u> agree.

The reactions seemed to be formed with both fast and slow neutrons and the chains were far too long given the very small energy of the neutrons.

- In late 1937 the Curie's report a strong **$t_{1/2}$ = 3.5 hr activity** in the filtrate and propose it to be thorium (**Th**). Meitner shows this impossible and the Paris group retract, and then say its **La**. In Berlin they are skeptical and call it "curiosium"!

- But, even by early 1938, Berlin has still **not** looked at the filtrate

Anschluss - 12 - March 1938

LM looses protection of being an Austrian citizen.

There is still a feeling “all will be OK”. She goes away with the von Laue’s at Easter 1938.

Hahn, now Director of KWI, is asked about LM. Becomes very nervous.

By June she has had her passport confiscated.
She leaves to Holland on 15-July in an escape arranged by Coster.
Hahn & Laue help her pack two small suitcases.
Then to Copenhagen, then to Stockholm.

Strassmann returns to 3.5 hr intense β activity reported by the Curies.
He now proposes:

$^{238}U + {}^{1}n \rightarrow \alpha + {}^{235}Th$

$\rightarrow {}^{231}Ra + \alpha$

In Nov. 1938 OH & LM meet in Copenhagen. LM is 60.
She urges OH to check again the chemistry of filtrates.
Back in Berlin they find it is not Ra (Z=88)
but Ba, Z = 56.

They write to LM on 19/12/38; send paper on 24/12, and it is published on 6/1/39

Fritz Strassmann in 1936, age 34.

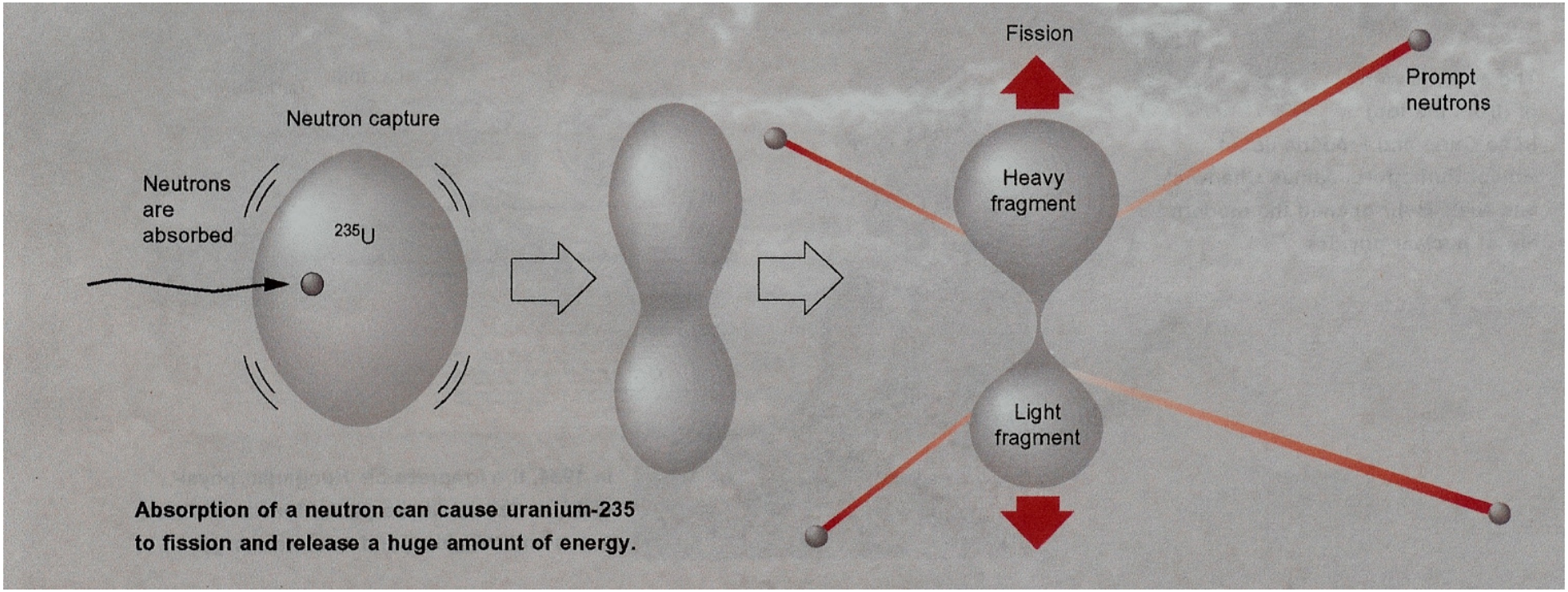
Otto Robert Frisch, age 29, shortly before emigrating from Germany in 1933.

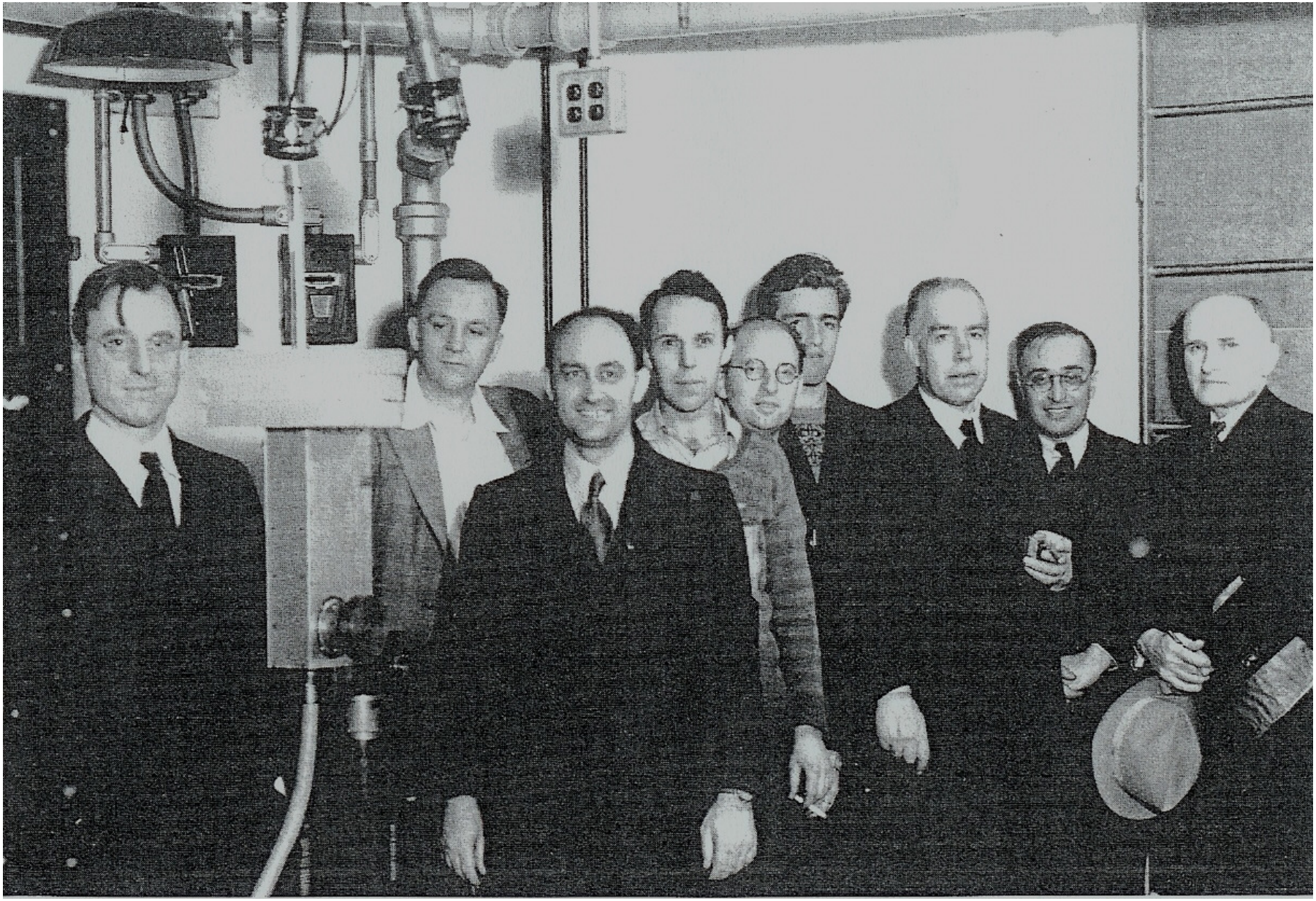
LM has the news and leaves to a friends house in Sweden, where she is joined by her nephew, Otto Frisch, then in Copenhagen. **They take their famous walk in the woods and realise that the U nucleus is unstable and has broken in two via the ideas of the liquid-drop model of Bohr**.

They calculate the charge effect and surface tension, and realise its possible. **They use the $E = mc^2$** to obtain that ~ 0.2 of a proton has disappeared and **200 MeV/fission** released. They predict Kr (Z = 36) should also be there.

Frisch wants to see the fission fragments, which he does. He tells Bohr on 2/1/39. On 6/1/39 Bohr sails to USA; he tells Rosenfeld and forgets to say he must **not** tell anyone. The word is out in Princeton. Frisch submits 2 papers to Nature on 16/1/39, published 11/2/39. “Fission” is borrowed from biology.

$$^{235}U_{92} + {}^{1}n_{0} \rightarrow {}^{144}Ba_{56} + {}^{89}Kr_{36} + 3\ {}^{1}n_{0} + 200\ \text{MeV}$$





Verification of uranium fission at the Carnegie Institution on 28 January 1939

Chapter 3

„The road to the bomb“

The physics of fission in early 1939

- By March 1939, Bohr & Wheeler had understood quantitatively the process, and identified ^{235}U as being the key ingredient. Their paper "The mechanism of nuclear fission", submitted 28/june/39; published Phys. Rev. **56** 426-450 (1939)
- Leo Szilard at U. Chicago is very active and also realises that $^{239}Pu_{94}$ should also be fissionable. ***Questions?***

- How much ^{235}U is needed?
- How could it be separated?
- How many neutrons are produced; is it > 1?
- Are the neutrons prompt or delayed? Prompt could not be controlled.

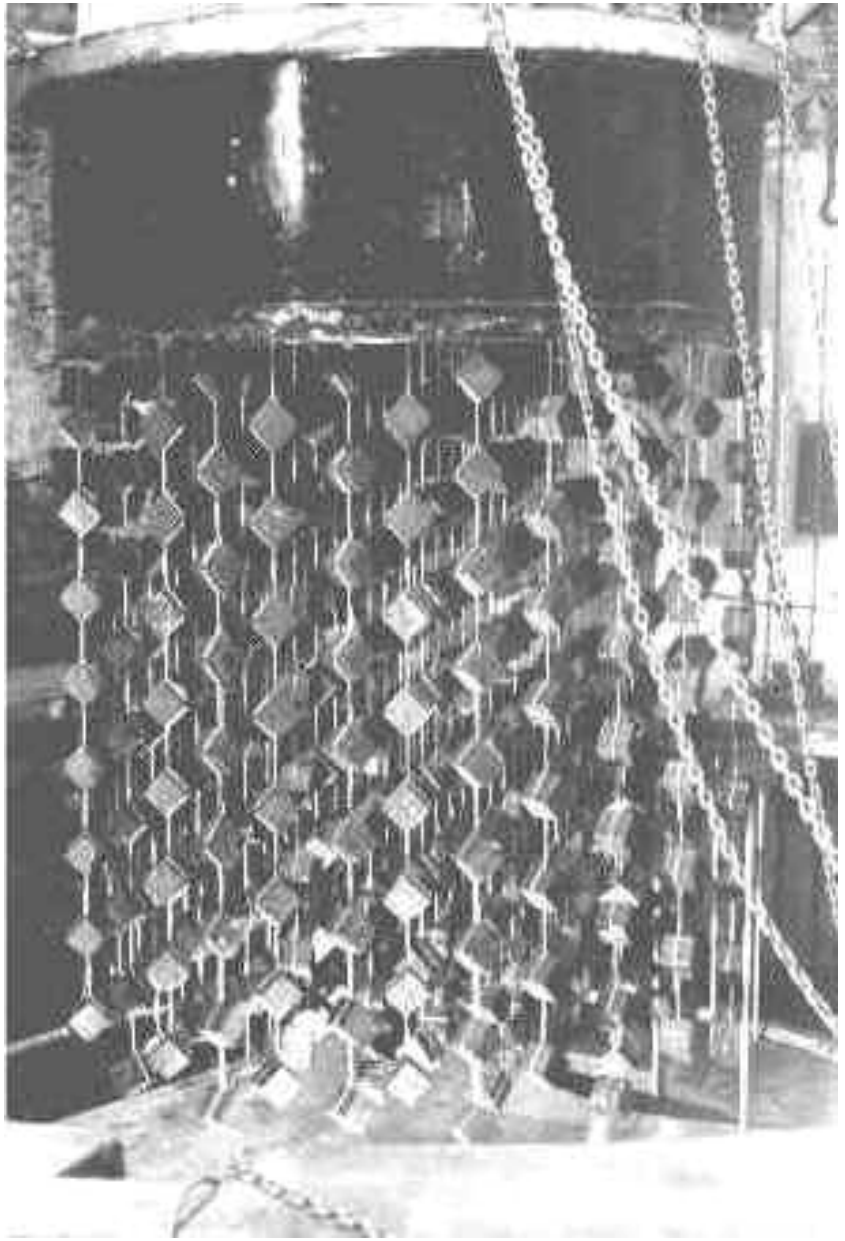
- **1–Aug.–39 Szilard & Teller convince Einstein to write the famous letter to President Roosevelt.**
- **3–Sept.–39: War is declared in Europe. Poland is invaded.**

Progress in the UK: nothing much in USA or Germany

- By early 1940, *Chadwick* (now at Liverpool with his cyclotron) and *G. P. Thomson* (Imperial College, London) were doing experiments on UO_2. At ICL they were unable to sustain any chain reaction and were pessimistic.
- Meanwhile in Birmingham *Otto Frisch* and *Rudolf Peierls* (theorists) studied the matter in detail and proposed methods for enriching U (diffusion using UF_6) and, assuming fast neutron fission, ~ 1 kg of pure ^{235}U might be enough. (We know now the amount is ~ 6 kg) Chadwick & Thompson immediately co-opted Frisch & Peierls and arranged for them to continue working on the project.
- Fast neutron fission cross section first measured in Paris by Joliot et al, and was ~ 2.5 n. After June 1940 they took their D_2O to UK, later to Canada.

- No high priority was assigned in Germany - there were many inter-departmental squabbles. In 1942 *Albert Speer* ended the project. The "Uranium Club" went on, under *Werner Heisenberg's* direction and an effort to make a reactor was made at Haigerloch in the Black Forest with uranium cubes and D_2O.

- Very little initially happened in the USA; the report of the MAUD committee goes to *Briggs* (head of NBS and also the Uranium Committee) in July 1941 but he does nothing. The report states that the critical mass is ~8 kg of ^{235}U. *Ernest Lawrence* (Berkeley) produces first measurable amounts of ^{235}U and starts to galvanise US effort.

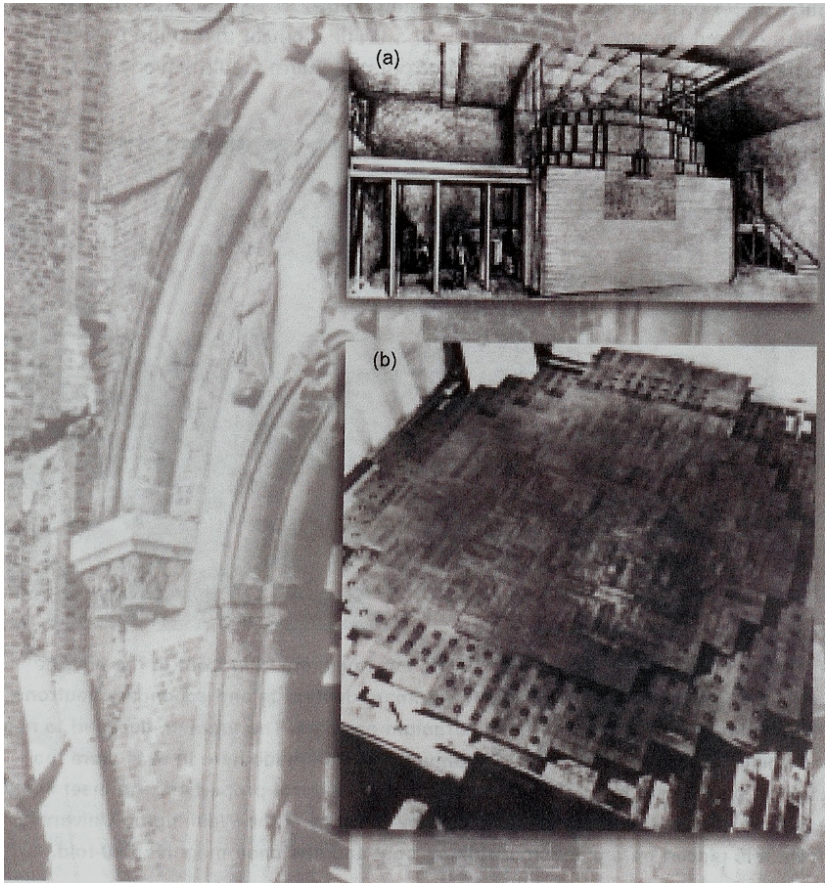


General Leslie Groves and Sir James Chadwick, Washington DC taken in 1944. Groves was put in charge of the Manhatten Project in Sept. 1942.

In November 1941 a delegation from the US visits UK. They are greatly impressed. In early 1942, with the US now at war, a UK delegation goes to the US, but *Chadwick* does not go.

The US now starts to increase the pace of activity, spurred by *Lawrence, Fermi, Conant, Bush, and Compton*. The UK, even *Churchill*, is at first reluctant to join, and this attitude later had negative consequences.

Chadwick goes to Washington in Nov. 1943. He spent all of 1944 at Los Alamos. Saw the Trinity test in July 1945.



CP-1 at the University of Chicago.
2–Dec–1942: 1553 hrs.
349,263 kg graphite; 36,507 kg UO_2, and 5617 kg of U metal (from Ames Lab).

Enrico Fermi - "The Italian Navigator has landed in the New World. The natives are very friendly."
Conversation between *Compton & Conant*. Key other participants were *Leo Szilard & Eugene Wigner*

Chapter 4

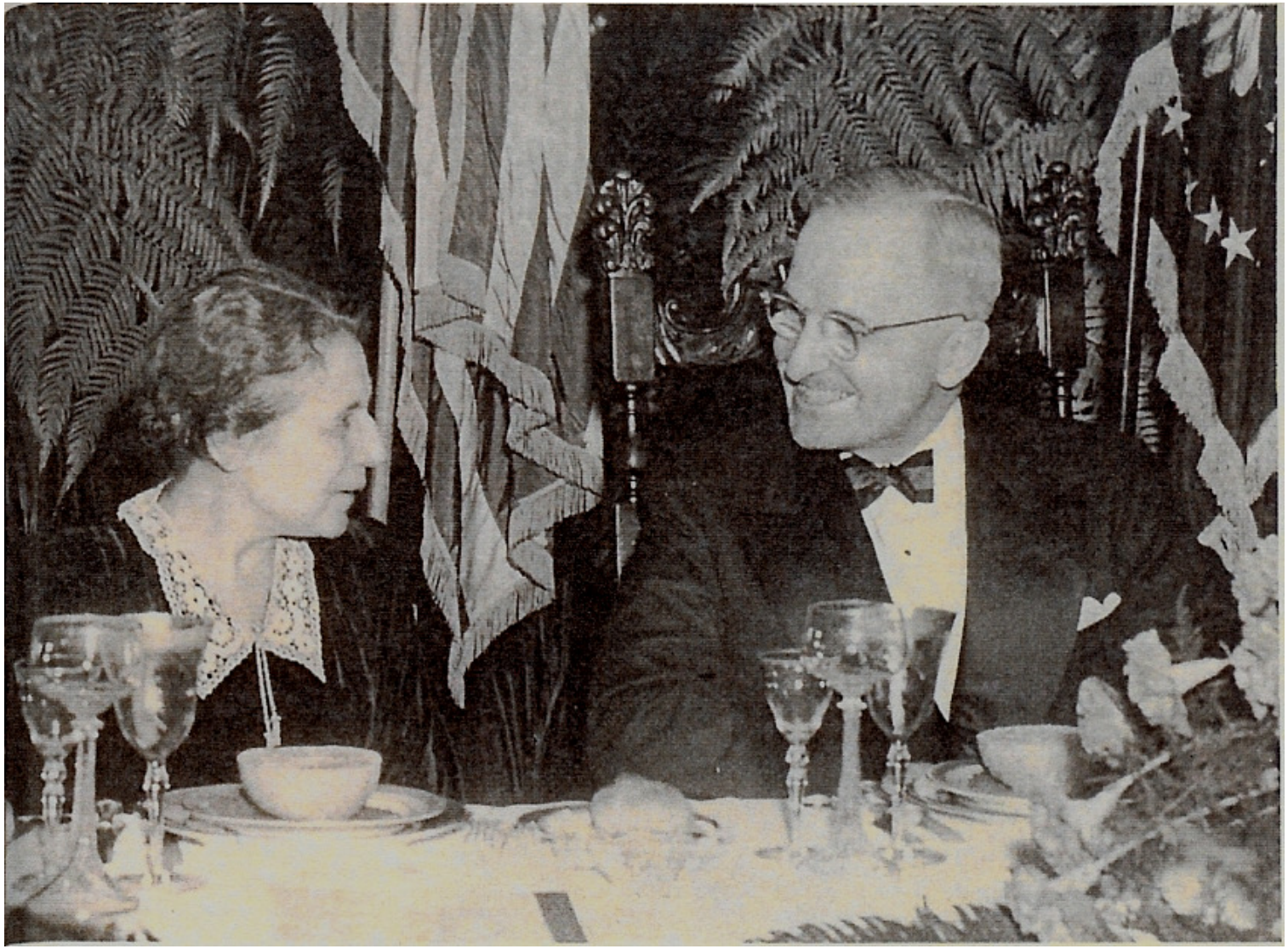
„Aftermath“

Hiroshima: 0815 hrs: 6-August-1945

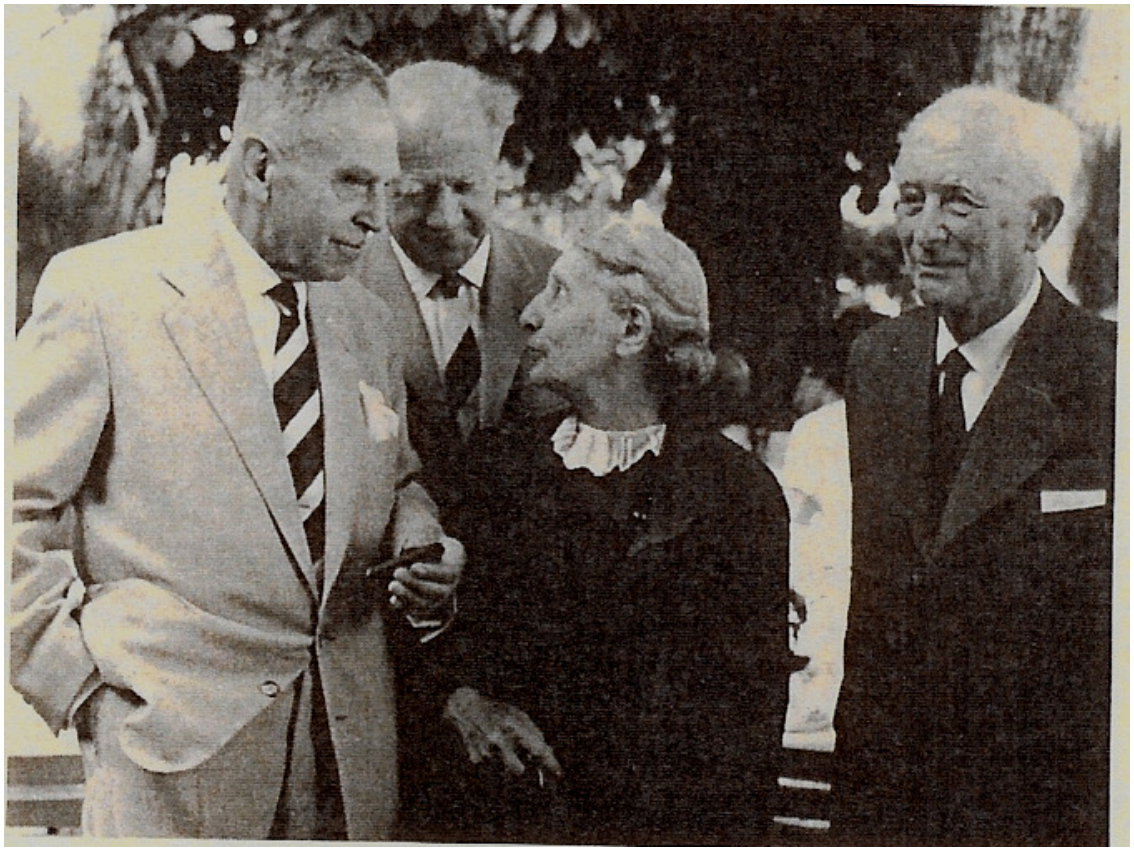
Kaiser Wilhelm Institute for Chemistry and the villa (right) after air raids, February 1944.

16 Nov. 1945 Nobel Committee announces that the 1944 Chemistry Prize will go to Otto Hahn alone. (Physics to I. Rabi). Nominations for LM, OF, & Strassman, but LM almost certainly “blackballed” by Siegbahn, who did not like her.

Otto Hahn (a German “hero”) never really accepted the role that LM had played, nor did he ever acknowledge the difficulties she faced, and this caused a deep gulf between the two. However, Hahn shared the prize money with LM.



Meitner and President Harry S. Truman, 9 February 1946, Washington, D.C. Meitner was honored as **„Woman of the Year“** by the National Women‘s Press Club. She dined with Chadwick on this visit, but they did not agree on the use of nuclear weapons.



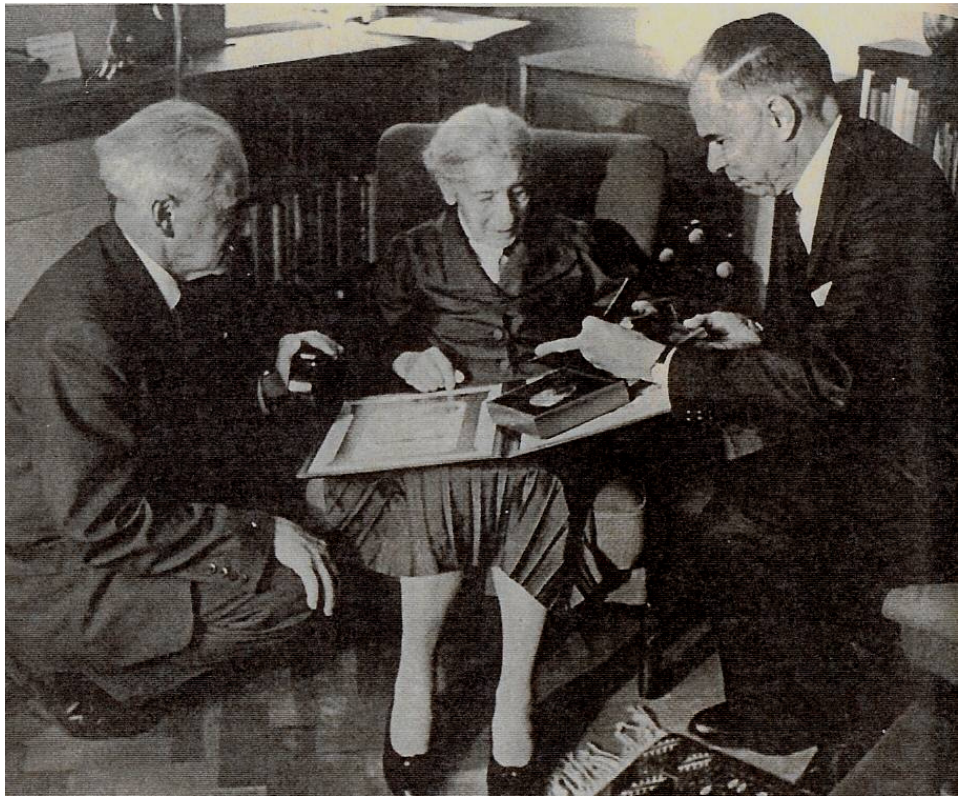
Hahn, *Werner Heisenberg*, *Meitner*, and *Max Born* at the Lindau conference of Nobel Laureates, 1962.

Lise Meitner returned to Germany first in 1947 for the funeral of *Max Planck*. She returned a number of times, but was never completely comfortable. *Strassman* offered her a position in Mainz, and she thought long about it.
She enjoyed Vienna more.
In 1946 she joined the Swedish nuclear programme, where she was much happier. She retired in 1954.

Opening ceremony of Hahn-Meitner Institute in Wannsee, Berlin

- Max von Laue suggested to call the Institute the "Meitner Institute" (as there was already a Hahn Institute) but the fame of Otto Hahn was unavoidable from a historical perspective.
- Opening 14 March 1959 with Willy Brandt and at which Lise M was very happy to attend.

Grand opening of the Hahn-Meitner-Institute for Nuclear Research, Berlin, March 14, 1959
(© Hahn-Meitner-Institute, Berlin)



The 1966 Enrico Fermi Prize, presented to Lise Meitner (& Hahn & Strassman) in October 1966 in Cambridge by Glenn T. Seaborg, chairman of the United States Atomic Energy Commission. Otto Frisch is at Meitner‘s right. (Courtesy Max Perutz)

In 1960 LM moved to Cambridge to be close to Otto Frisch & family.

Lise Meitner 1878 - 1968

- **Lise Meitner** died on 27-Oct-1968, a few days before her 90th birthday.
- She is buried in Hampshire, UK, next to her brother with a simple gravestone reading:
- "Lise Meitner: a physicist who never lost her humanity"

LM with Eva von Bahr-Bergius, Kaiser Wilhelm Institute for Chemistry, about 1920. The women met before World War I, when Eva was a student in Berlin; later, Eva would be Lise's closest friend in Sweden.

James Chadwick 1891–1974

- *Chadwick* returned to Liverpool in 1946. In 1948 is elected as Master of Gonville and Caius College in Cambridge (where he was a student & Fellow). He continues for 10 years, but does not much enjoy squabbles with Fellows.
- Retired to Wales for 10 years, moved back to Cambridge in 1968, and dies at 83 in July 1974.

1925. The photograph which gave Rutherford „a real good laugh“. Peter Kapitza (left), in borrowed top hat, is James Chadwick‘s best man.

Credits

- **Andrew Brown, *The Neutron & the Bomb: A biography of Sir James Chadwick*; Oxford U Press, 1997**
- **Ruth Lewin Sime : *Lise Meitner: A life in Physics* U of C Press, 1996**
- **Patricia Rife: *Lise Meitner and the dawn of the nuclear age.* Birkhäuser, 1999 (published first in German in 1992)**
- **Richard Rhodes: *The making of the atomic bomb* Simon Schuster 1986**
- Per F Dahl, *From Nuclear Transmutation to Nuclear Fission*; 1932–1939, IoP, 2002
- Per F Dahl: *Heavy Water and the wartime race for Nuclear Energy*, IoP, 1999
- *Hitler's Uranium Club*: The Farm Hall tapes edited by J. Bernstein, 1996
- Gregg Harken: *Brotherhood of the Bomb*, Holt & Co. NY 2002

- **Special thanks to Sylvia Schlump at ITU who helped so much with this ppt!**

- **And to you for patiently listening!**