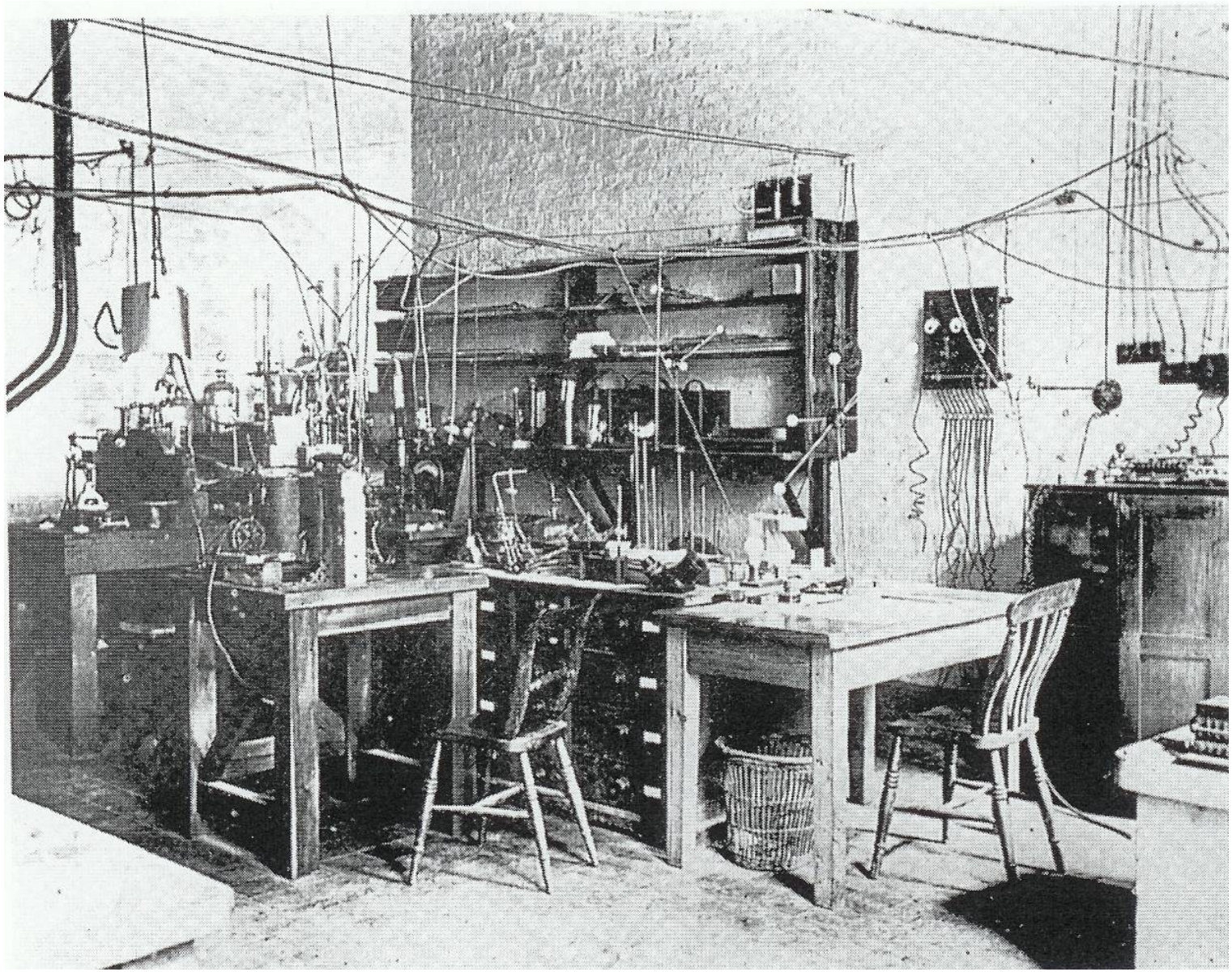
Discoveries that changed the world: 1932 – 1942

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.)



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 move easily through matter.

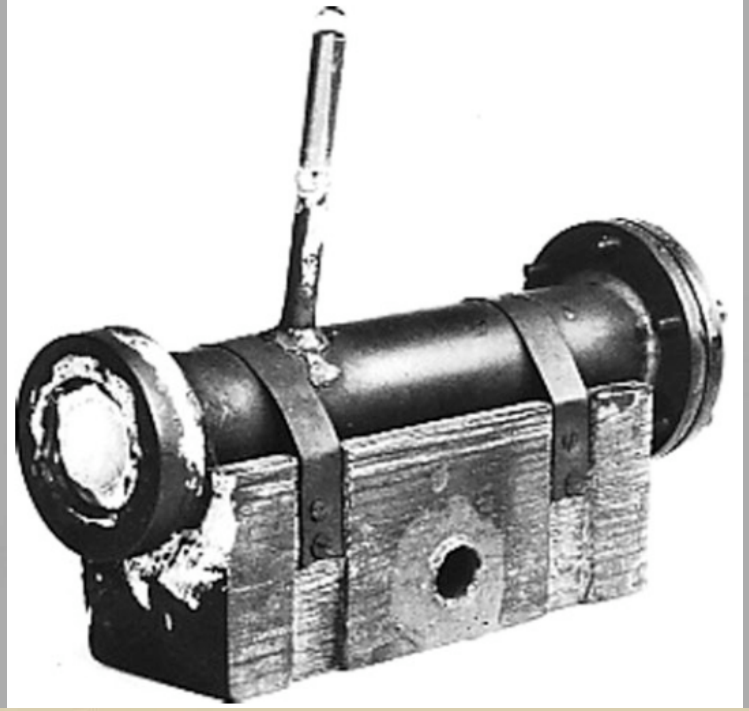
Curie & Joliot published (incorrectly) in Jan. 1932 the observation:

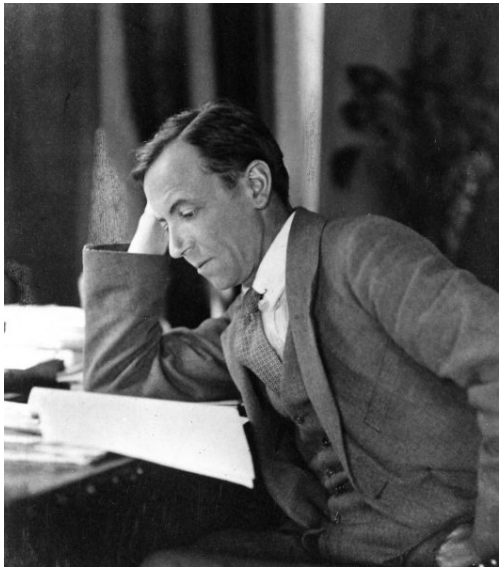
$$^{9}Be + {}^{4}He \rightarrow {}^{12}C + {}^{1}n$$

I. Curie and F. Joliot, C. R. Acad. Sci. Paris **194**, 273 (1932)

When the radiation was passed through wax the ionisation increased! This increase was due to knock-on protons. To explain 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

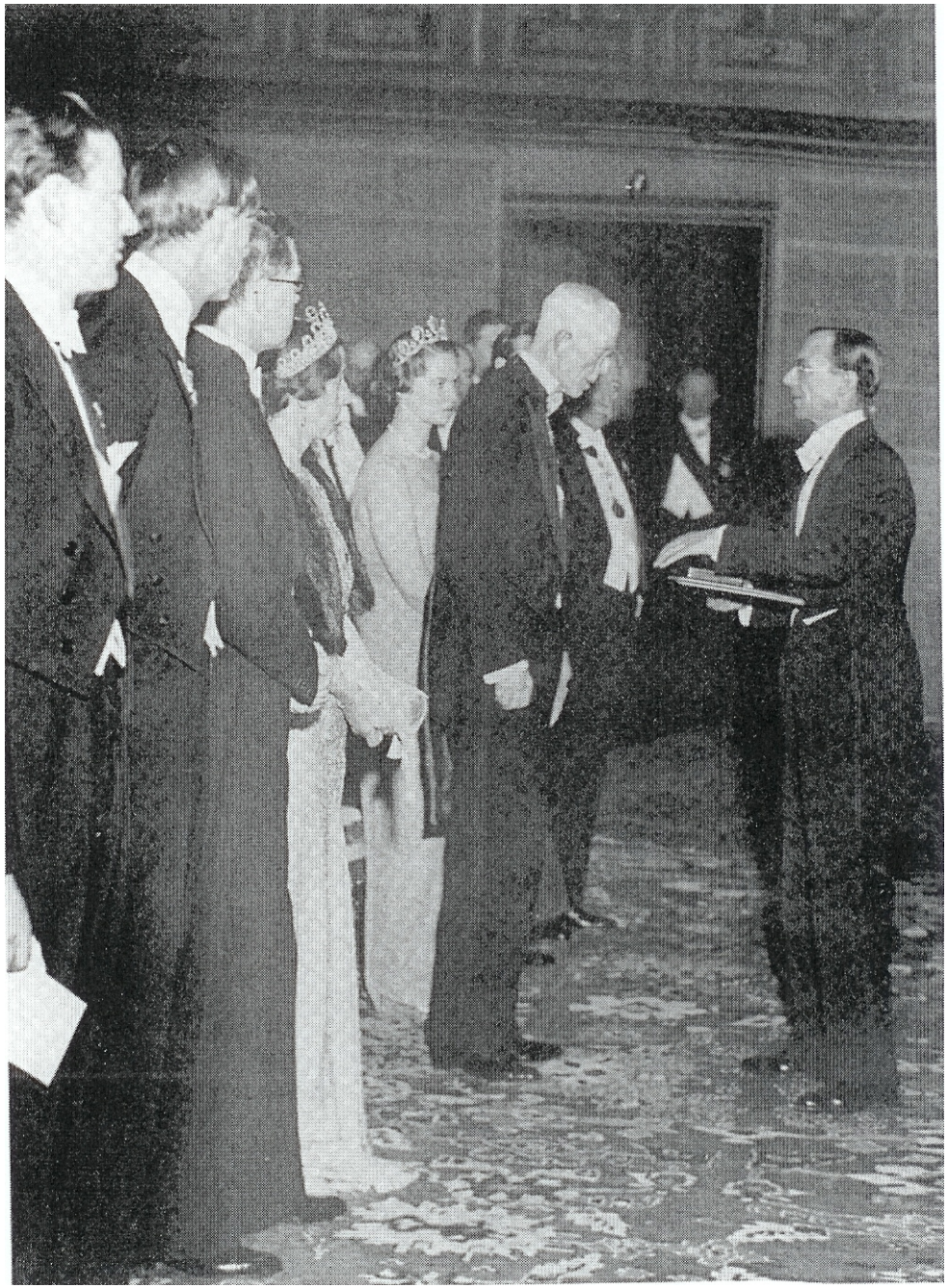
This experiment was first performed in 1930 by Walter Bothe and Herbet Becker at U. of Giessen, Germany





There is some uncertainty where Chadwick got his Po. Perhaps from Madam Curie, who knew Rutherford well?

Another account says that it came from old radon samples, which decay to give Po, at the Baltimore (Maryland) Hospital.



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

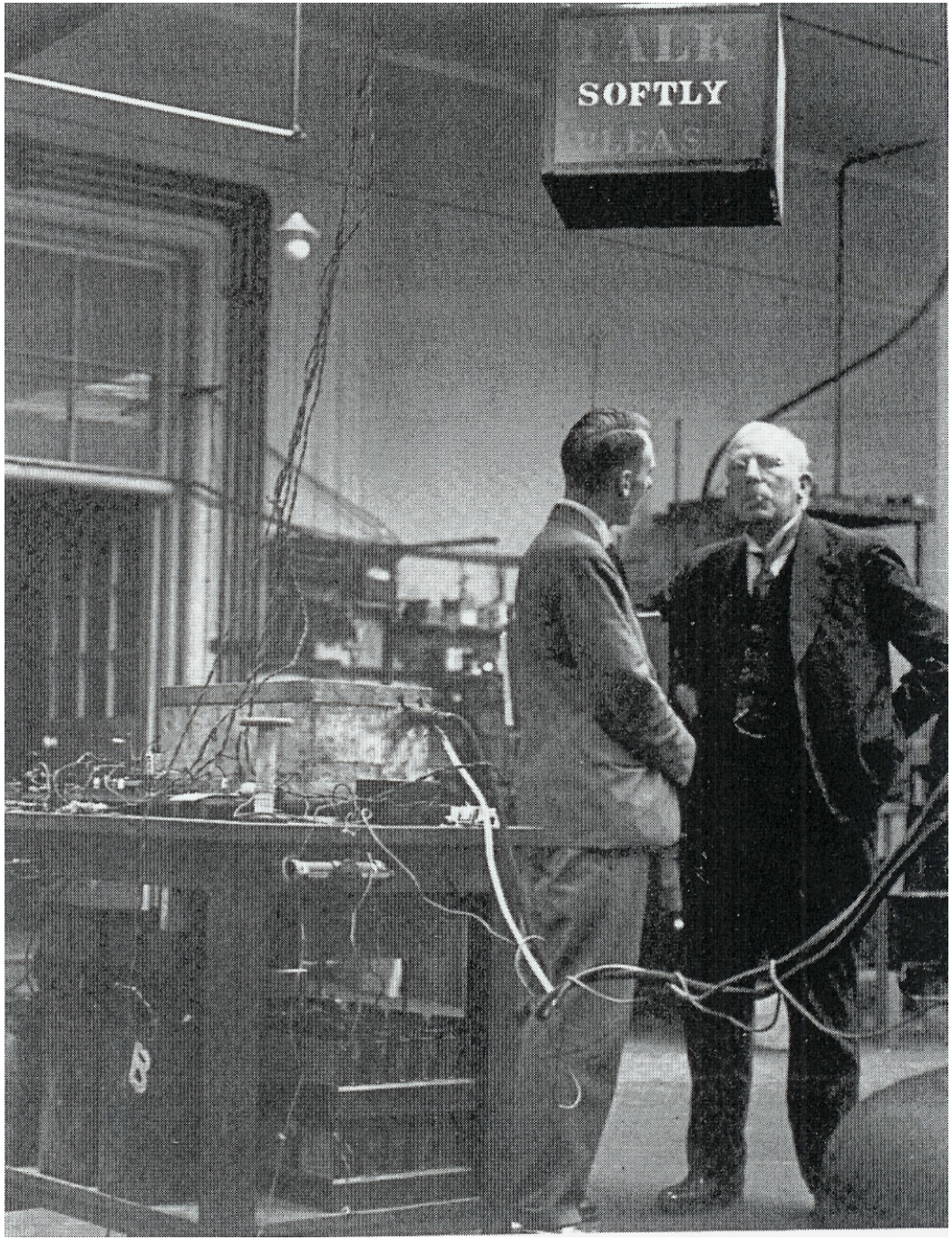
Letter to **Nature** is only 200 words

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. 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 to larger 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)

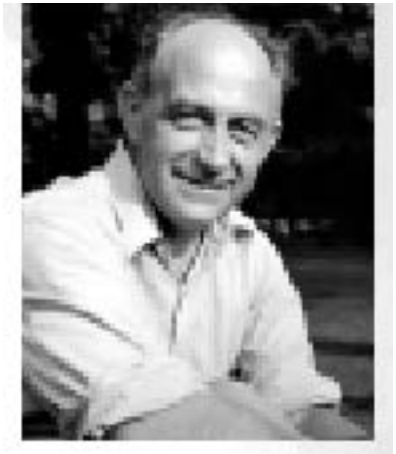
The Seventh Solvay Council, Brussels, October 1933, devoted to the atomic nucleus.

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. **Only 3 women!**

Only **Bohr, Curie, ER known outside science:** 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 Ra source) mixed with *powdered* Be. This was more intense than previous Po-Be sources, but was 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 two of them: ausonium and hesperium**

Chapter 2

„The road to fission“

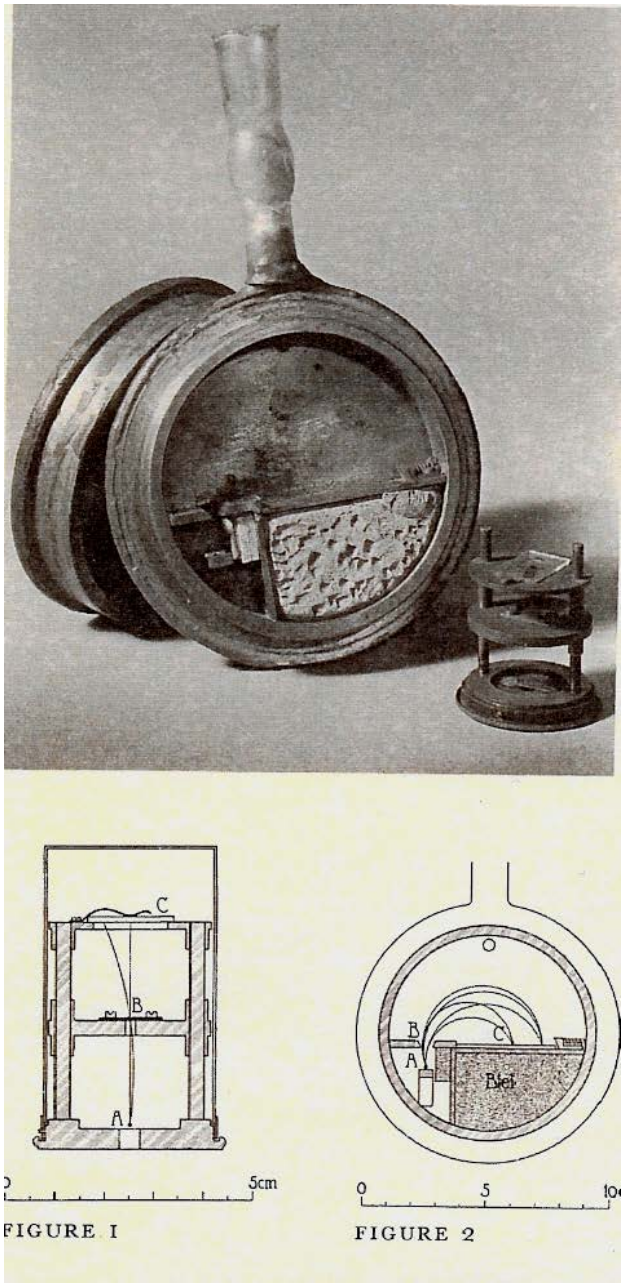
Lise Meitner (1878–1968)

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 finds job in radiochemistry with Otto Hahn. Must come in back entrance.
Director Fischer thinks women will set fire to their hair.
Moves to Dahlem in 1911 and gets "position" in 1912 (34 yrs).

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

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.



LM made many important discoveries. Together with Otto Hahn in 1918-1920 she discovered the element protactinium Pa.

Later, she made important contributions to the experimental evidence surrounding β-decay.

LM & Otto Hahn were nominated for a Chemistry Nobel in the 1930s

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.

30–Jan–1933

Hitler becomes Chancellor of Germany.

Immediately problems started with Jews. Because LM was Austrian, she was 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 mistake!***

$$U + n \rightarrow U\ (10s) \rightarrow \in Re\ (2.2m) \rightarrow \in Os\ (59m)\ [^{134}I_{53}] \rightarrow \in Ir\ (66hr)\ [Te_{53}] \rightarrow \in Pt\ (2.5h)\ [I_{53}] \rightarrow \in Au?$$

$$U + n \rightarrow U\ (40s) \rightarrow \in Re\ (16\ m)\ [^{101}Tc_{43}] \rightarrow \in Os\ (5.7h)\ [^{105}Ru_{44}] \rightarrow \in Ir?$$

$$U + n \rightarrow U\ (23m) \rightarrow \in Re?\ [^{239}U_{92} \rightarrow {}^{239}Np_{93} \rightarrow {}^{239}Pu_{94}]\ \{\beta\ decay\}$$

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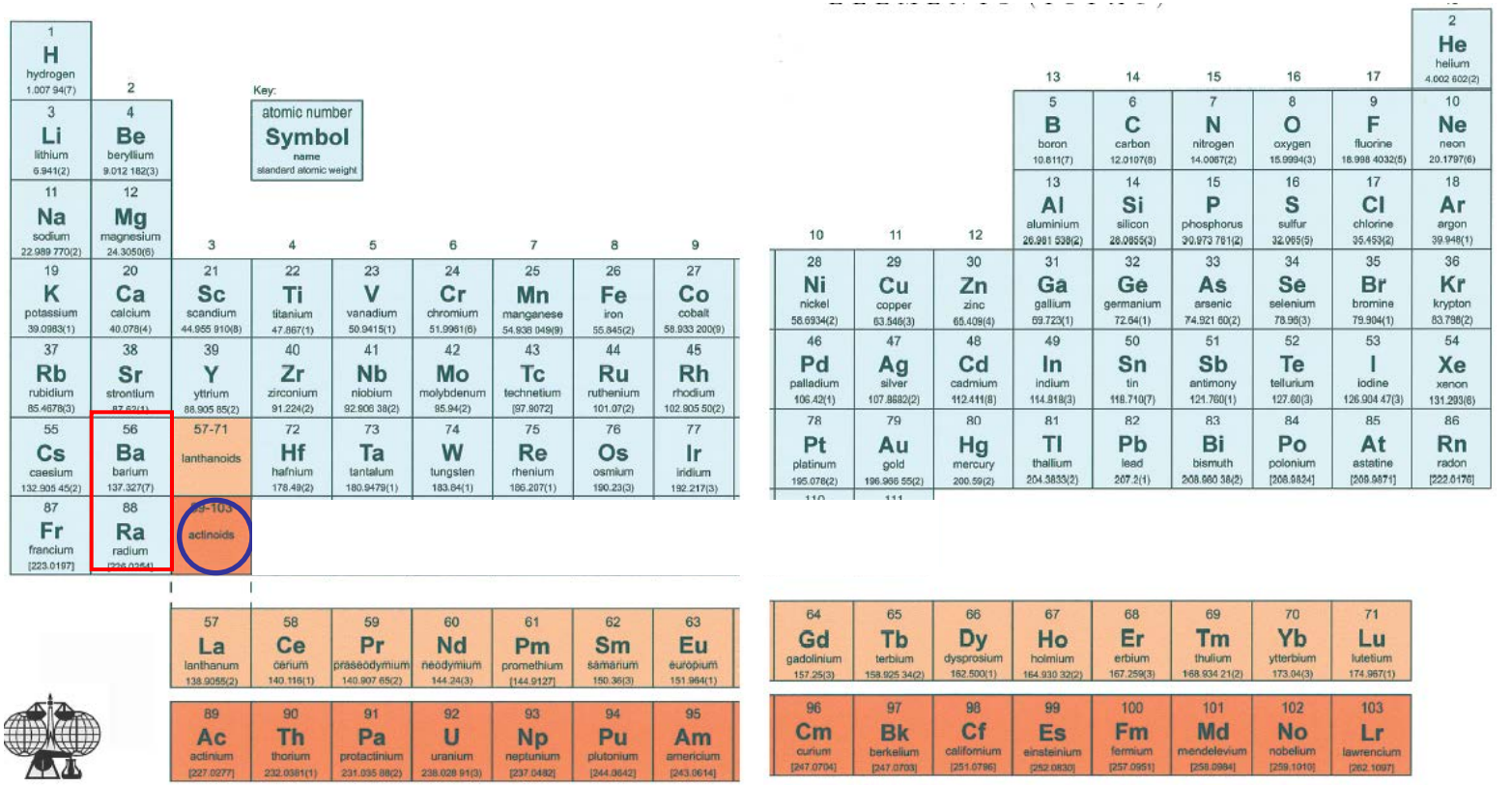
Periodic Table

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 irradiated material (precipitate + **filtrate)** and propose it to be thorium (**Th**). Meitner shows this impossible (and they do not find it in Berlin in the precipitates); the Paris group retract, and then (in 1938) say its **La**. In Berlin they are skeptical and call it "curiosium"! **[$^{92}Y_{39}$]**
- [I. Curie and P. Savitch, J. Phys. Rad. **8**, 385 (1937)]

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

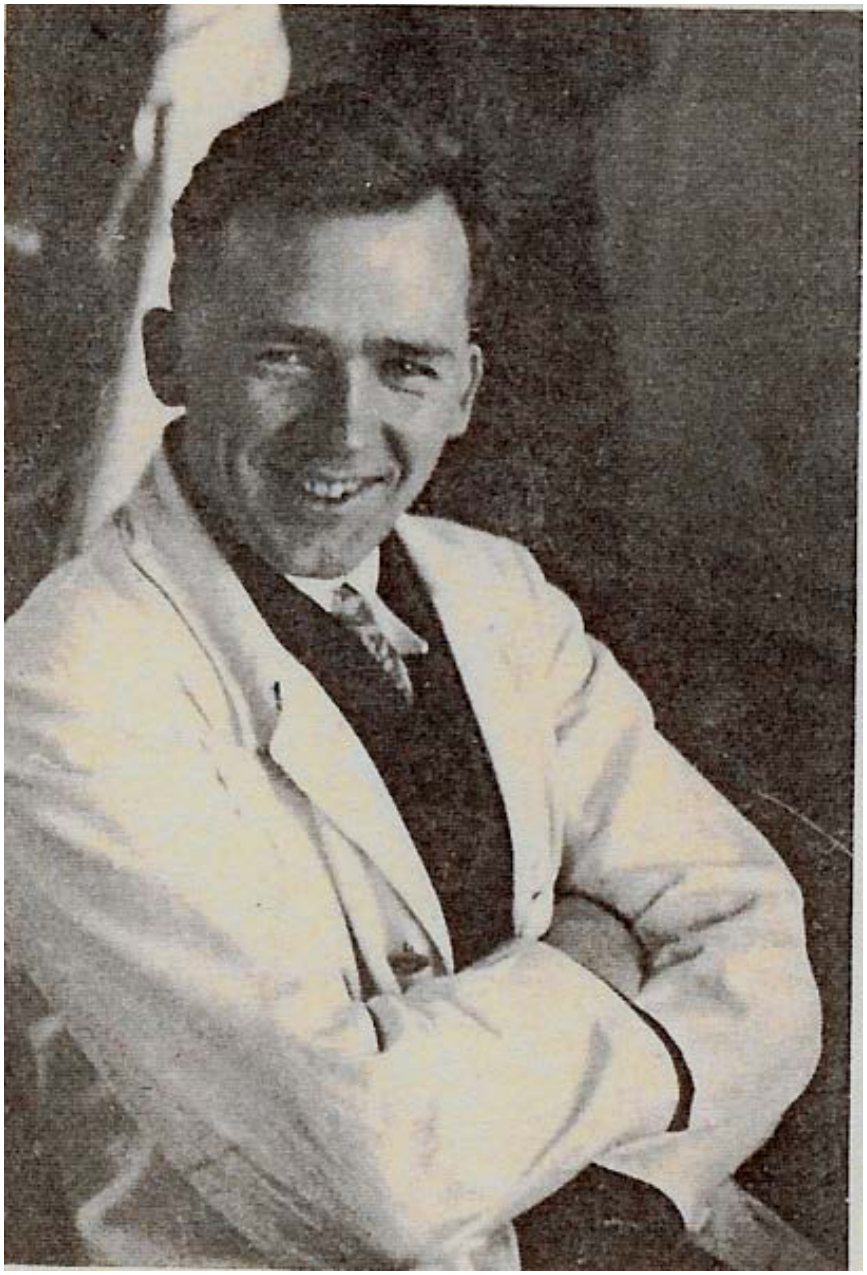
Anschluss - 12 - March 1938

LM loses 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 13-July in an escape arranged by Coster (and Fokker). Hahn & Laue help her pack two small suitcases.
Then to Copenhagen, then to Stockholm with Siegbahn.



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

$^{238}U_{92} + {}^{1}n \rightarrow {}^{235}Th_{90} + \alpha \rightarrow {}^{231}Ra_{88} + \alpha$

In Nov. 1938 OH & LM meet in Copenhagen. LM is 60.

She (and Bohr) urge Hahn 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.

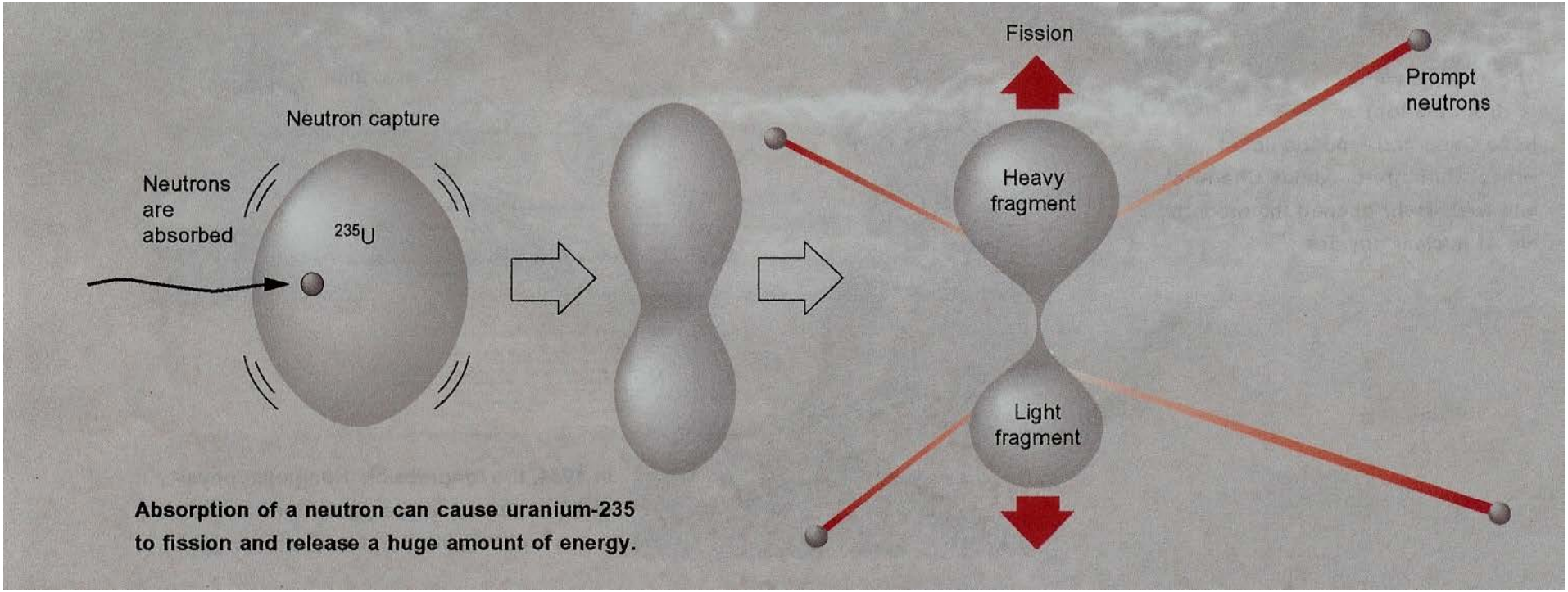
Otto Robert Frisch, age 29, shortly before emigrating from Germany in 1933.

LM has the news and leaves to a friends house in Kungälv, 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 Gamow & Bohr**.

They calculate the charge effect and surface tension, and realise it's 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.

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



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 realises that $^{239}An_{94}$ 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, Wigner & 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.

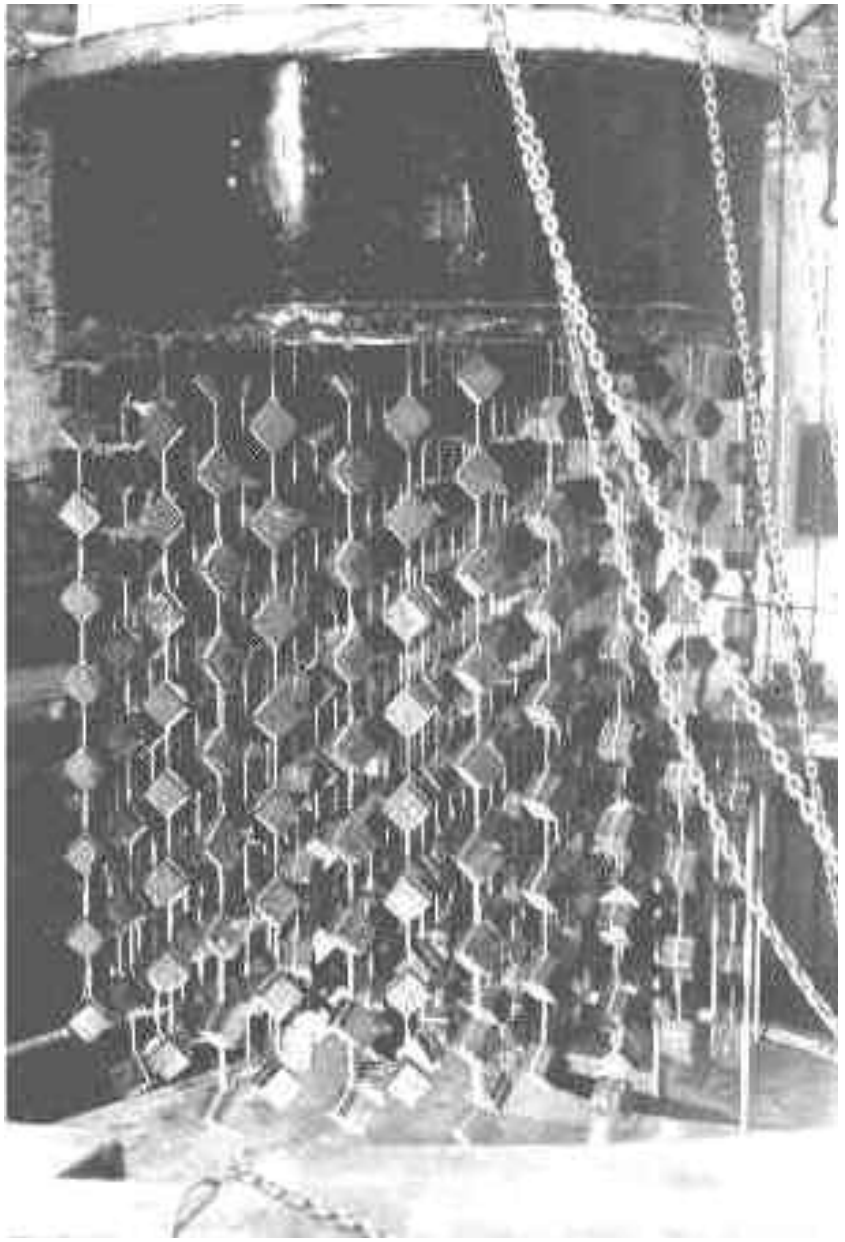
Meanwhile in Birmingham *Otto* ***Frisch*** and *Rudolf* ***Peierls*** (a theorist) studied the matter in detail and proposed (March 1940) methods for enriching U (diffusion using UF_6) and, assuming fast neutron fission, ~ 1 kg of pure ^{235}U might be enough. (Hiroshima bomb used 60 kg.)

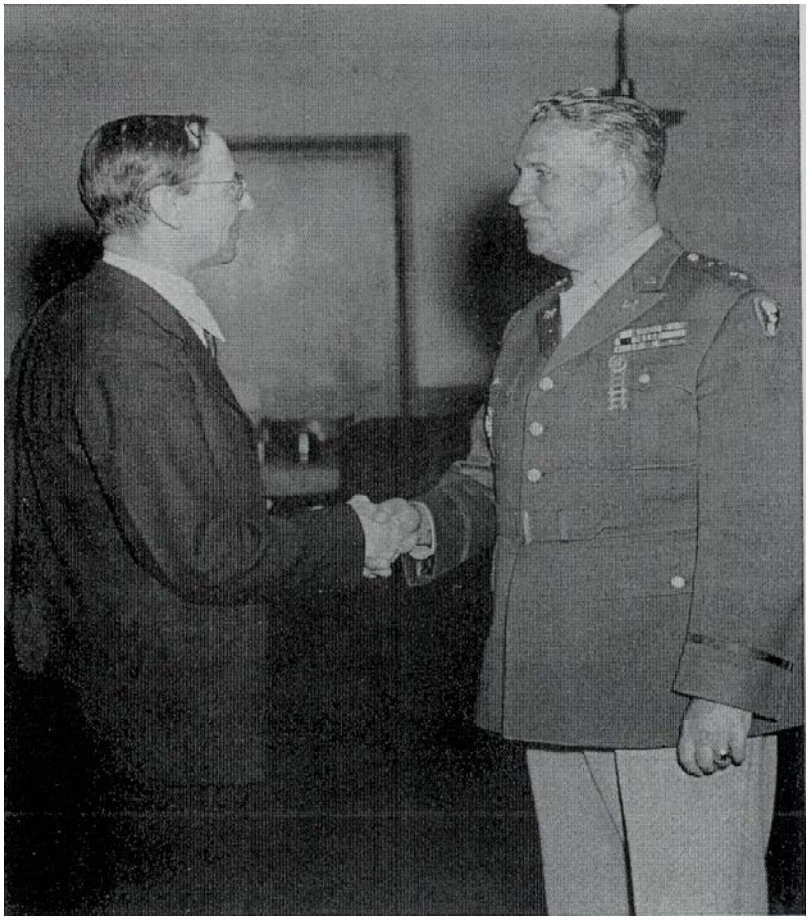
Chadwick & Thompson immediately co-opted Frisch & Peierls.

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 late 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, near Tübingen, 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) 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 galvanize US effort.



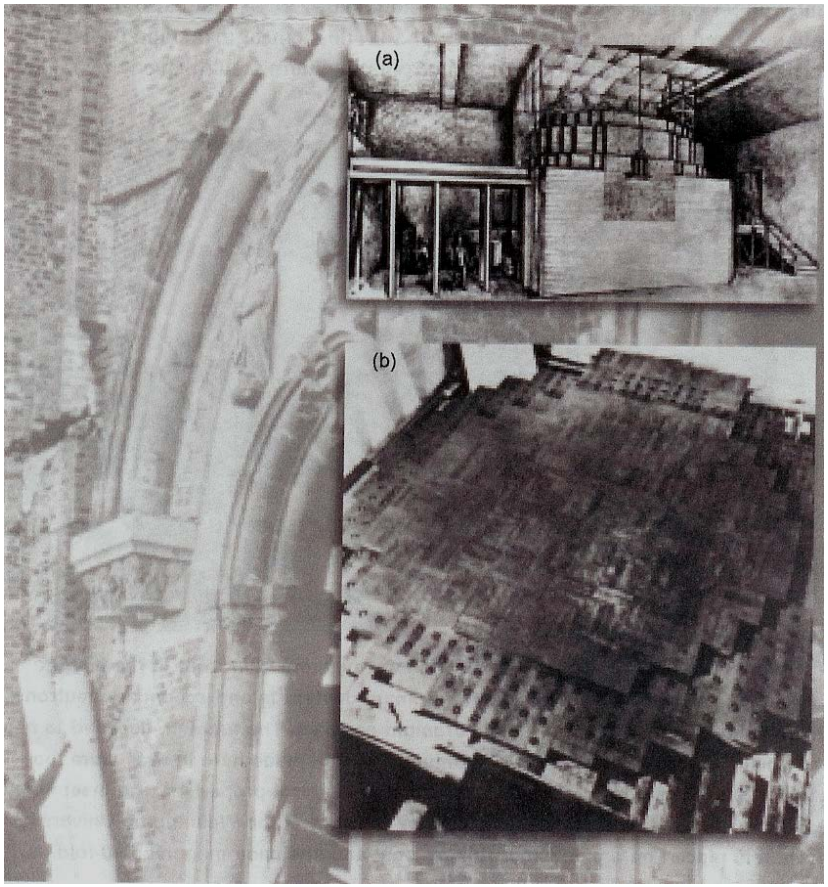


General Leslie Groves and Sir James Chadwick, Washington DC taken in 1944. Groves was put in charge of the Manhatten Project in Sept. 1942.

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***.

Chadwick goes to Washington in Nov. 1943 as Head of British delegation.
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

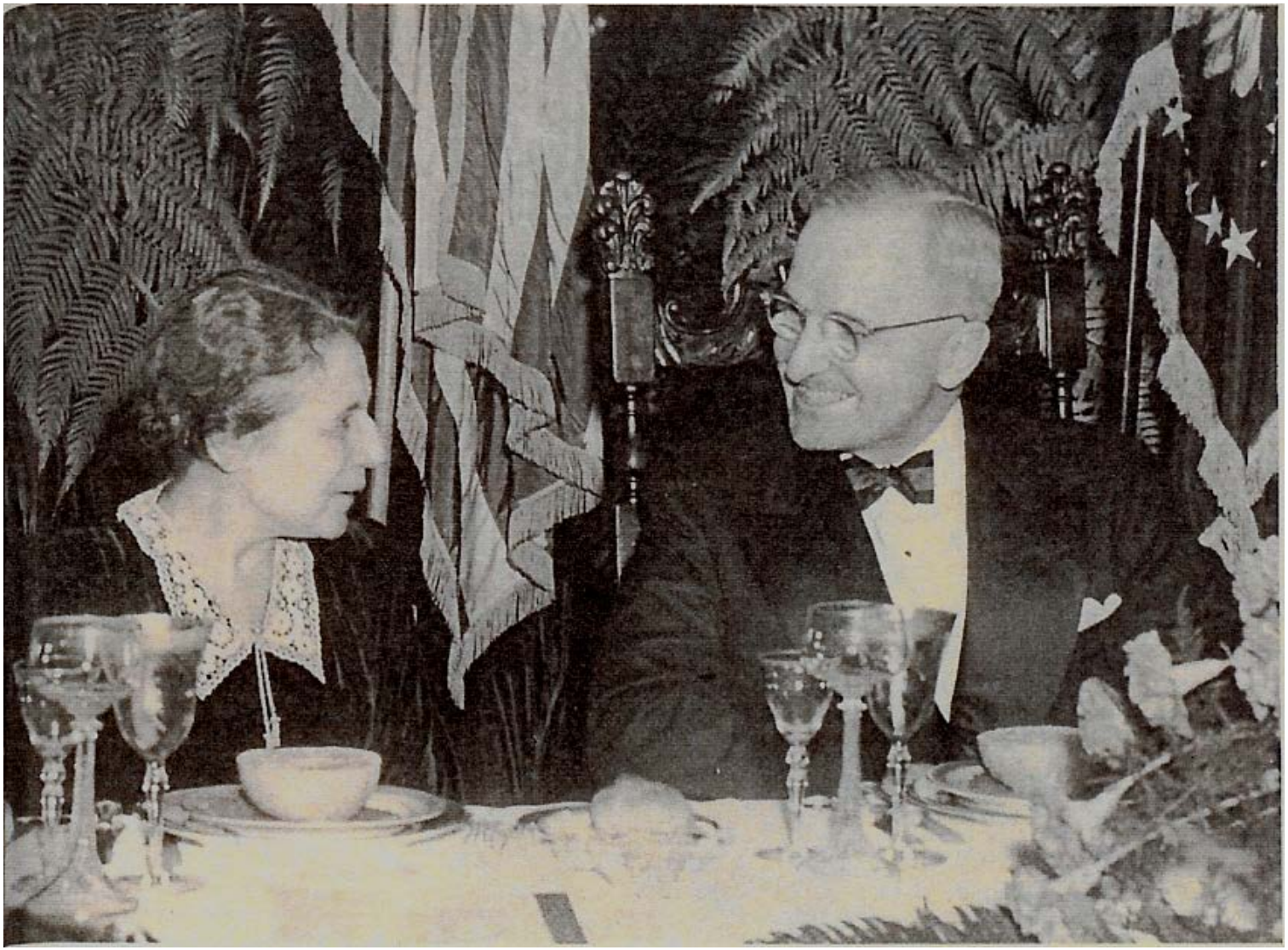
Kaiser Wilhelm Institute for Chemistry and the villa (right) after air raids, February 1944.

Meitner is isolated in Stockholm, unaware of progress in the US.

She is horrified when bomb is used.

16 Nov. 1945 Nobel Committee announces that the 1944 Chemistry Prize will go to Otto **Hahn** alone. (Physics to I. Rabi). Many subsequent nominations of **LM** and **Frisch**, but unsuccessful. **Strassmann**?

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 & FS.

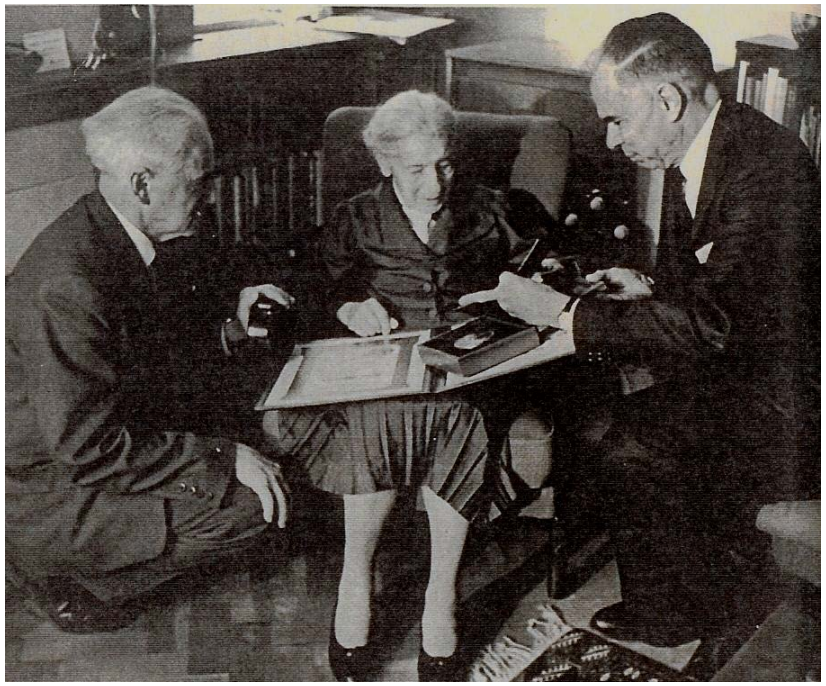


Meitner and President Harry S. Truman, 9 February 1946, Washington, D.C. Meitner was honored as **„Woman of the Year“** by the National Women‘s Press Club. She dined with Chadwick on this visit, but they did not agree on the use of nuclear weapons.

Opening ceremony of Hahn-Meitner Institute in Wannsee, Berlin

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 (Mayor of Berlin). Lise M was very happy to attend.



The 1966 **Enrico Fermi Prize**, presented to Lise **Meitner** (& **Hahn** & **Strassmann**) 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)

Memorial at Mainz listing all ***four*** discoverers. Unveiled in 2002; 100th anniversary of Strassmann’s birth

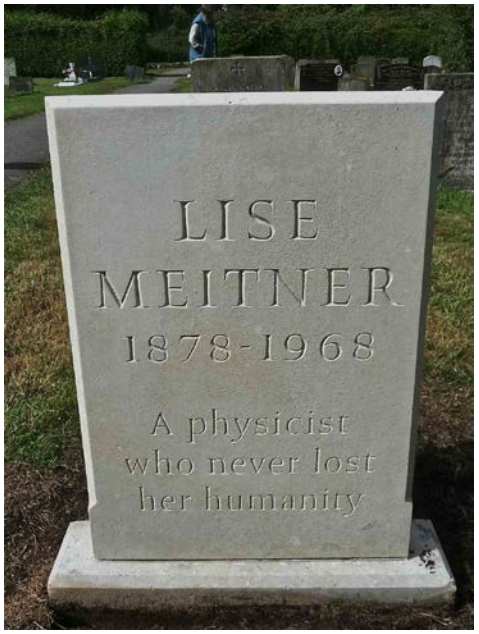
In 1960 LM moved to Cambridge to be close to Otto Frisch & family.

Lise Meitner 1878 - 1968

Statue at HZB, Berlin. Photo by Uschi Steigenberger

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

A photo from about 1910



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 continued for 10 years, but did 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
- Philip Ball: *Serving the Reich*. Bodley Head, 2013
- ***Hitler's Uranium Club*: The Farm Hall tapes edited by J. Bernstein, 1996**
- Graham Farmelo: *Churchill's Bomb*. Faber & Faber, 2013
- Gregg Harken: *Brotherhood of the Bomb*, Holt & Co. NY 2002
- Klaus Hoffmann: *Otto Hahn: Achievement & Responsibility*, Springer 1993
- Michael Schüring: *Minervas verstossene Kinder*. Wallstein Verlag 2006

- **Special thanks to Sylvia Schlump at ITU who helped so much with this ppt and Hildegard Feid for help with German documents!**

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

Discoveries
Some examples

Serendipity	Predictable
Superconductivity (1914)	BCS (1957)
Fission (1938)	Neutron (1932)
High T_c cuprates (1986)	A theory to describe them?
Something else??	Higgs boson?

Discoveries need tools

If Roentgen's x-rays (1901) was serendipity, then were von Laue's (1914) and Bragg's (1915) experiments predictable?

What about Perutz & Kendrew (1962) Crick & Watson (1962) and the solution of the DNA structure?

These surely fall under the development of tools for research

And in our own field we have Shull & Brockhouse (1994) as well as Prizes to Louis Néel (1970) Paul Flory (1974) and Pierre-Gilles de Gennes (1991)

Discoveries

Discoveries will continue to change the world – that is the nature of science

Neutron was expected. Fission was pure serendipity.
What is needed to open possibilities for these discoveries?

- **Intelligent people! A full knowledge of the field.**

New tools for doing research – the ESS

Otto 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. ***Strassmann*** offered her a position in Mainz, and she thought long about it but declined.

In 1946 she joined the Swedish nuclear programme, where she was much happier. She retired in 1954.