Physics under Hitler

8.225 / STS.042, Physics in the 20th Century
Professor David Kaiser, 19 October 2020
1. *deutsche Physik* Revisited

2. Nuclear Fission*

3. Heisenberg and the “Uranium Machine”

* See *Lecture Notes* on “Energy released from nuclear fission”
Beginning as early as spring 1920, political opportunists took advantage of Albert Einstein’s new fame to stage “anti-relativity” rallies. The public faces of the movement included German physicist Nobel laureates Johannes Stark and Philipp Lenard.

The rhetoric of the deutsche Physik movement was that of the “tatmensch”: the “man of action.” Newton, Galileo, and Faraday had all been “Aryan,” according to Lenard; he argued that they partook of the same leadership spirit as Hitler.

Though the group began on the fringes, they quickly gained powerful adherents, especially once the Nazis achieved power in January 1933. Then advocates of deutsche Physik took charge of the German Education Ministry, with authority over all professorial appointments in the universities.
By spring 1933, the Nazis had begun to implement new “civil service” laws, which barred non-Aryans from holding government positions (including university faculty). This triggered a large exodus of scholars out of Germany.

About 100 physicists and mathematicians emigrated to the UK and US: Albert Einstein to the Institute for Advanced Study in Princeton; Erwin Schrödinger to Oxford and then Dublin; Emmy Noether to Bryn Mawr; Max Born to Cambridge and then Edinburgh; Hans Bethe to Cornell; James Franck to Chicago; Felix Bloch to Stanford; Viki Weisskopf to Rochester and then MIT, ...

These were not easy transitions: the US was deep into the Great Depression, so there were many US scholars looking for university positions. Plus, entrenched anti-Semitism within US universities further hindered placements (e.g., J. Robert Oppenheimer at Berkeley in 1929). Dartmouth: a refugee faculty candidate “shouldn’t seem too Jewish.”
Within Germany, Nazi officials criticized non-Jewish physicists who seemed to demonstrate insufficient loyalty to the regime, e.g., by continuing to teach “Jewish physics” (such as relativity).

In 1937, they blocked Werner Heisenberg from becoming the successor to Arnold Sommerfeld as Ordinarius professor in Munich. They organized a press campaign against Heisenberg, labeling him a “white Jew” and attacking him in the Gestapo press. The attacks only subsided after Heisenberg’s mother interceded directly with a close family friend: the mother of Heinrich Himmler, chief of the paramilitary Schutzstaffel (SS).

The power of the deutsche Physik movement declined soon after that. Physics was no longer associated for the regime only with philosophy or ideology. New variable: power. By the late 1930s, the Nazis began to think that physicists could be useful to the Reich. What had changed? Nuclear physics.
Questions?
The Neutron

Throughout the late 1920s and early 1930s, several research groups working on radioactivity suspected there might exist a second kind of particle within atomic nuclei: an electrically neutral particle with mass close to the mass of the proton. Irène and Frédéric Joliot-Curie in Paris were especially active in this area. (They shared the 1935 Nobel Prize in chemistry for their studies of “artificial” or induced radioactivity.)

In January 1932, British physicist James Chadwick (former student of Ernest Rutherford) followed up on one of their suggestions and conducted a new experiment:

\[ \alpha_2^4 + \text{Be}_4^9 \rightarrow \text{C}_{6}^{12} + n_0^1 \]

Chadwick inferred the mass of the new particle (the “neutron”) from the recoil velocity of protons scattered from (hydrogen-rich) paraffin wax. (Chadwick received the 1935 Nobel Prize in Physics for this work.)
Right away, Enrico Fermi and his group in Rome began bombarding each element of the periodic table with neutrons, to induce radioactive reactions. They got all the way to uranium — the heaviest naturally occurring element in the periodic table — and found significant reaction rates, especially when Fermi placed a block of paraffin between the neutron source and the uranium target. They assumed they were measuring

\[ \text{U}^{238}_{\text{92}} + n^1_0 \rightarrow \text{U}^{239}_{\text{92}} \rightarrow \text{Np}^{239}_{\text{93}} \]

“Neptunium”: the first transuranic element, just as the planet Neptune is the next planet in our Solar System beyond Uranus.

And these are Rome police officers checking our paperwork while we were working on a documentary film about Fermi and the neutrino this past January …

These are the original materials that Fermi and his group used for these experiments, now in a new Fermi museum in Rome!
“Transuranic Elements”

Fermi receiving the Nobel Prize, December 1938
Benito Mussolini, Italian dictator

Until recently it was generally admitted that the atoms existing were chemically distinct and that they were not chemically related. This view was shared by most chemists, and it was generally accepted that the atoms were in some way different from one another. The discovery of the transuranic elements, however, has shown that this view is incorrect. The transuranic elements are chemically identical with the atoms of the periodic table, and they are all chemically identical with each other.

The discovery of the transuranic elements has been made possible by the use of the transuranic elements as a source of energy. The transuranic elements are produced by the fission of the uranium-235 nucleus, and they are used as a source of energy in nuclear reactors. The transuranic elements are also used as a source of energy in nuclear fusion reactors.

The discovery of the transuranic elements has opened up a new field of research in the field of nuclear chemistry. The transuranic elements are being used to study the effects of nuclear reactions on the properties of the atoms.

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Revisiting Transuranics

Other groups actively worked on nuclear transformations associated with neutron capture, including a team in Berlin: nuclear chemists Otto Hahn and Fritz Strassmann together with nuclear physicist Lise Meitner.

Meitner, from a Jewish family in Austria, was only allowed to attend formal school until age 14. After reforms, she rushed through the standard high school curriculum, via self-study, in a few months and passed the entrance exam to study physics at the University of Vienna. She was among the first women to earn a PhD in physics anywhere. After her degree (1905), she began to collaborate with Hahn in Berlin—in the basement, since women were not yet allowed in the main Institute.

After the Anschluss in March 1938, when Nazi Germany took over Austria, Meitner became subject to the Nazi employment laws, and lost her job.
Hahn and Strassmann’s experimental arrangement, 1938 (reconstructed in the Deutsches Museum, Munich)

Image is in the public domain.

While Meitner fled Germany and sought shelter in Scandinavia, Hahn and Strassmann continued their neutron-bombardment experiments. They re-did Fermi’s famous experiment multiple times—just as Fermi was receiving his Nobel Prize for that work—and concluded that *neither* Fermi nor they had produced transuranic elements. Instead:

\[
U_{92} + n \rightarrow Ba_{56} + Kr_{36}
\]

“As chemists, we must actually say the new particles do not behave like radium but, in fact, like barium; as nuclear physicists, we cannot make this conclusion, which is in conflict with all experience in nuclear physics.”

Hahn and Strassmann, “On the splitting of Uranium nuclei by slow neutrons,” Dec. 1938
Nuclear Fission

In December 1938, Meitner received an update from Hahn about the latest experiments, indicating the presence of barium. While skiing with her nephew, theoretical physicist Otto Robert Frisch, near Stockholm, they worked out a physical model for nuclear fission.

Slow neutrons were key, because of quantum theory. The neutron’s de Broglie wavelength becomes large for slow velocities:

$$\lambda = \frac{h}{mv}$$

$n$ wavelength: comparable in size to the entire U nucleus. Can set the nucleus wobbling like a liquid drop.
Nuclear Fission

\[
E_{\text{nuc}} \sim \frac{(qe)^2}{R_{\text{nuc}}}, \quad q \sim 100, \quad R_{\text{nuc}} \sim 10^{-12} \text{ cm}
\]

\[
E_{\text{chem}} \sim \frac{(qe)^2}{R_{\text{atom}}}, \quad q \sim 1, \quad R_{\text{atom}} \sim 10^{-8} \text{ cm}
\]

\[
\frac{E_{\text{nuc}}}{E_{\text{chem}}} \sim 10^8!
\]

After splitting, each piece carries about \( E_{\text{piece}} \sim \frac{1}{3} E_{\text{whole}} \). That leaves

\[
E_{\text{whole}} - 2E_{\text{piece}} \sim \frac{1}{3} E_{\text{nuc}}
\]

to be released as “raw” energy, every time a uranium nucleus splits. And \( E_{\text{nuc}} \sim 10^8 E_{\text{chem}} \).

That estimate — based on simple Coulomb repulsion between the two smaller nuclei — matched an independent estimate, based on binding energy:

\[
m_U = (m_{\text{Ba}} + m_{\text{Kr}}) + \Delta m \quad \Rightarrow \quad E_{\text{release}} \sim \Delta m \ c^2 \sim \frac{1}{3} E_{\text{nuc}}
\]

* See Lecture Notes on “Energy released from nuclear fission”

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Frisch returned to Niels Bohr’s Institute in Copenhagen and told Bohr all about his and Meitner’s ideas about fission. He swore Bohr to secrecy, so he and Meitner could check their work and perform some follow-up tests.

Bohr sailed to the US in January 1939 to spend a semester at Princeton. He was met at the docks in New York City by Enrico Fermi and Samuel Goudsmit, and told them immediately all about Meitner’s and Frisch’s work — then he told Eugene Wigner, Albert Einstein, and John Wheeler (Bohr’s former postdoc) in Princeton. Within days, several laboratories up and down the East Coast had verified fission. (Easy to do once one knows to conduct tests for barium among the reaction products.)

Together with Wheeler, Bohr worked out a more detailed, quantitative analysis of nuclear fission, drawing on Meitner’s work to identify the most fissionable uranium isotope to be U\(^{235}\). Their article was published the same day that Nazi troops invaded Poland, triggering the start of the Second World War.
Nuclear Fission

*Everyone* in physics knew immediately that nuclear fission could lead to *bombs*. *And* they knew that the *Germans* must know this, too!

Fission had been identified in a Berlin laboratory. Although many researchers had fled Nazi Germany, it remained the world’s center for nuclear physics at the time: *Werner Heisenberg, Otto Hahn, Hans Geiger, Walther Bothe, Max Planck, Max von Laue, Carl Friedrich von Weizsäcker*, and more.

*At exactly the same time*, the Second World War erupted:

March 12, 1938: Nazi *Anschluss* of Austria.
December 1938: Hahn and Strassmann identify barium among reaction products; Meitner and Frisch work out nuclear fission
January 1939: Bohr arrives in NYC, tells others about fission
March 15, 1939: Nazis occupy Czechoslovakia.
September 1, 1939: Nazis invade Poland.
September 3-10, 1939: UK, France, Australia, New Zealand, and Canada declare war against Germany.
September 17, 1939: Soviets invade Poland.

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Nuclear Fission

April 1939: German Reich Ministry of Education holds secret meeting on military applications of nuclear fission, bans uranium exports.

April 1939: Japanese government begins secret nuclear-weapons project ("Project Ni"); underfunded, not seen as high priority for current war.

Fall 1939: UK considers fission weapons, ramps up larger effort early in 1940 after Frisch-Perierls memo (Frisch having emigrated to the UK). They underestimated amount of U\textsuperscript{235} required by ~20.

Fall 1939: Igor Kurchatov informs Soviet government about military applications of nuclear fission. As in Japan, the project is given a low priority at first, and then further slowed after the German invasion in 1941.
Questions?
Heisenberg and the “Uranium Machine”

By September 1939, the German Army Ordnance Office assumed control of the Kaiser Wilhelm Institut für Physik in Berlin-Dahlem, to coordinate research on nuclear fission. Werner Heisenberg became an early member of the Uranverein (“Uranium club”) and advised the military multiple times about possibilities for both weapons and (civilian) power-generation from nuclear fission (bombs and reactors). In summer 1942, he was placed in charge of the nuclear effort.

Heisenberg was also sent on diplomatic missions throughout neutral countries and (soon) German-occupied territories, including Denmark. To some of his colleagues, he often sounded explicitly nationalistic: not pro-Nazi, but proudly German and (at times) even suggesting that Germany should rule all of Europe, given its traditions of culture and learning.

His visit to Bohr in Copenhagen in 1941 was part of those scientific-diplomacy missions. They were afraid that Bohr’s house might be bugged by the Nazis, so they took long strolls in the gardens. What did they (and Margrethe Bohr) really talk about?
Heisenberg and the “Uranium Machine”

*Heisenberg* advised the German military authorities that nuclear *bombs* were possible, though probably not during the present war — because, with the early success of the *Blitzkrieg*, everyone expected that Germany would win the war by 1941 or 1942. But the authorities still saw *future* promise of nuclear weapons, so they continued to fund Heisenberg’s effort and also seized the Belgian Congo and mined uranium.

*Walther Bothe* estimated that carbon / graphite moderators (to slow neutrons and increase fission rates) would need to be *very* pure so as not to absorb too many neutrons, so the German team turned to *heavy water* as a moderator instead. (Allied commando mission to blow up heavy-water plant in Norway, Feb 1942 ...) Also, *Heisenberg* overestimated how much enriched U^{235} would be needed for a critical mass (opposite to Frisch-Peierls error!).

As the war dragged on, the bomb project was given lower priority, because the *Reich* needed to direct resources to short-term military priorities.
Heisenberg and the “Uranium Machine”

Samuel Goudsmit had emigrated to the US in the late 1920s; his family later perished in Auschwitz. He led the Allied reconnaissance missions inside Germany to learn about the Nazi nuclear effort and “collect” (kidnap) German nuclear scientists.

As early as 1942, American baseball player Moe Berg was sent to listen to Heisenberg lecture in Switzerland, armed with a pistol. If it sounded like the Germans were getting close to a working weapon, Berg was to kill Heisenberg! He was convinced they were not very close.

During spring 1945 the Alsos mission captured 10 German nuclear scientists and took them to Farm Hall, near Cambridge, UK (Operation Epsilon). The house was bugged; their conversations were constantly audiotaped, transcribed, and translated. The transcripts were sealed for (nearly) 50 years, first released in 1992.
Heisenberg and the “Uranium Machine”

Farm Hall transcript of August 6, 1945 (reactions to news about bombing of Hiroshima):

*First reaction* (to paraphrase):

“I didn’t lose the race, because they didn’t really make a nuclear weapon.”

*Second reaction* (to paraphrase):

“I didn’t lose the race, because I didn’t want to make a nuclear weapon.”

Otto Hahn: “If the Americans have a uranium bomb, then you’re all second-raters. Poor old Heisenberg.”

Heisenberg: “Did they use the word uranium [in the BBC report] in connection with this atomic bomb?”

All: “No.”

Heisenberg: “Then it’s got nothing to do with atoms. ... All I can suggest is some dilettante in America who knows very little about it has bluffed [the reporters] in saying, ‘If you drop this it has the equivalent of 20,000 tons of high explosive’ and in reality it doesn’t work at all.”

Hahn: “At any rate, Heisenberg you’re just second-raters. ... They are fifty years further advanced than we.”

Heisenberg: “I am willing to believe that it is a high pressure bomb and I don’t believe it has anything to do with uranium but that it is a chemical thing.”

(About 10 minutes later:) Carl Friedrich von Weizsäcker: “I believe the reason we didn’t do it was because all the physicists didn’t want to do it, on principle. If we had wanted Germany to win the war we would have succeeded.”

(A few minutes later:) Heisenberg: “I would say that I was absolutely convinced of the possibility of our making a uranium engine [reactor] but I never thought that we would make a bomb and at the bottom of my heart I was really glad it was to be an engine [reactor] and not a bomb. I must admit that.”
Heisenberg and the “Uranium Machine”

As early as 1946 (upon his return to Germany), Heisenberg gave several descriptions of the wartime German nuclear effort. He emphasized the group’s interest in reactors for civilian energy production. Yet Heisenberg himself had emphasized in reports to the German Army Ordnance office as early as 1941-42 that reactors could produce plutonium, which could be used for bombs.

In 1956, Austrian journalist Robert Jungk published Brigher than a Thousand Suns, in which he argued that Heisenberg had purposely, actively resisted Hitler by dragging his feet on nuclear weapons — suggesting that Heisenberg was a stronger moral figure than the Allied scientists who had worked on the Manhattan Project.

Heisenberg and the “Uranium Machine”

In private correspondence, Heisenberg consistently distanced himself from the “active resistance” interpretation.

Heisenberg to Jungk, November 1956: “You speak here towards the end of the second paragraph about active resistance to Hitler, and I believe — pardon my frankness — that this passage is determined by a total misunderstanding of a totalitarian dictatorship. [...] I would not want this remark to be misunderstood as saying that I myself engaged in resistance to Hitler.”

Heisenberg to other correspondents, 1957: For “material and technical reasons in 1941-42,” the German nuclear scientists did not have to decide whether to build a bomb. German victory seemed assured, so complicated new weapons were not given priority.

“Jungk’s book is written carefully and with the best of intentions; nonetheless, I am still always somewhat afraid about these popular representations, since they can never exactly represent the very complicated circumstances and psychological situations of wartime.”