MILITARY HISTORY

The development of the atomic bombs 1911 to 1945 – Part 1

Hiroshima 6 August 1945

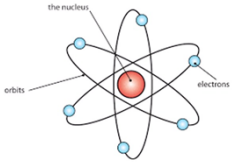
Nagasaki 9 August 1945

What are atoms?

- Chemists had discovered that chemicals always react together in fixed proportions
- They had also identified basic building blocks (**elements**) that reacted to make chemical compounds
- This suggested that if you kept reducing the amount of an element you should/would/must eventually end up with a single **atom** of that substance
- But no one knew what an atom was or what one looked like or if they really existed
- But, if they did, they would be very, very small
- This was the state of knowledge up to the start of the 20th Century

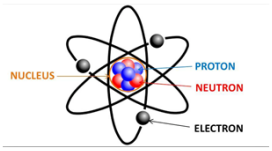
What we know now about the atom

- In 1911, the modern picture of the atom emerged
- The atom comprises a tiny **positively** charged **nucleus** surrounded by a "cloud" of **negatively** charged **electrons**
- *Like charges repel, opposite charges attract*
- The electrons are attracted to the nucleus but keep orbiting around the nucleus, just like the planets orbiting the sun
- The atom is 10,000 times bigger than the nucleus
- If the nucleus was a golf ball, the electrons would be a kilometre away
- So most of the atom is just empty space!



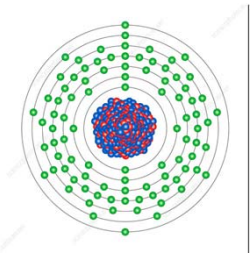
More about the atom

- The electrons control the chemical reactions
- The nucleus comprises **positively** charged **protons** and a *similar or larger* number of **neutrons** packed into the really tiny volume
- The neutrons are just like protons except they don't have any charge
- **The number of protons in the nucleus determines what element it is (atomic number)**
- For example, **hydrogen** has 1 proton, carbon has 6, oxygen has 8, iron has 26, lead has 82, **uranium** has 92 and **plutonium** has 94
- **The total number of protons and neutrons is the atomic weight of the atom**



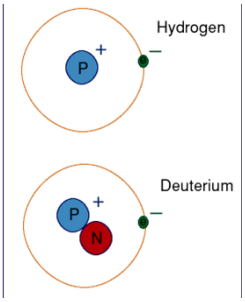
But this can't work!

- Protons should push each other away and blow the nucleus apart
- The electrons should give off radiation and collapse into the nucleus
- As for neutrons, their role was very unclear
- And there were different types of **radioactivity** that seemed to be coming out of the nucleus
- But atoms don't fly apart or collapse
- A new theory of Physics was needed



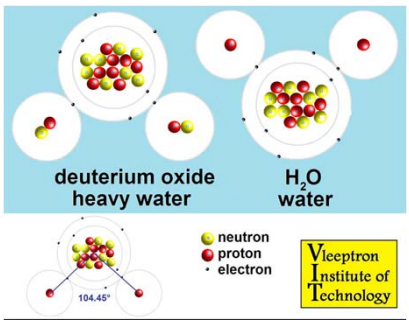
Isotopes

- There are different forms of the same element - known as **isotopes**
- The number of protons remains the same but the number of neutrons varies
- Same atomic number, different atomic weight
- Hydrogen has 1 proton in its nucleus while **deuterium** has a proton and a neutron
- So deuterium is still hydrogen because it has one proton and one electron but it is twice as heavy



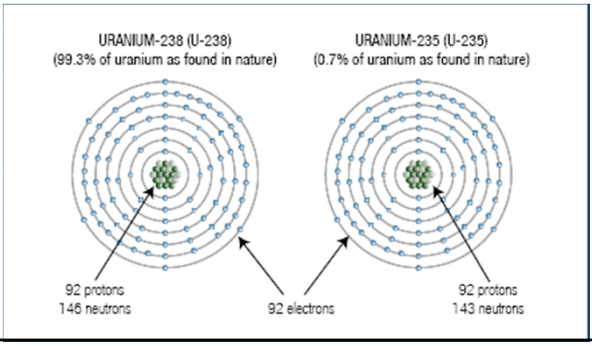
Heavy water

- Water is formed when 2 atoms of hydrogen combine with one atom of oxygen – H_2O
- **Heavy water** is formed when 2 atoms of deuterium combine with one atom of oxygen – D_2O
- It is about 11% heavier than normal water
- It occurs about 1 part in 6,400 in normal water



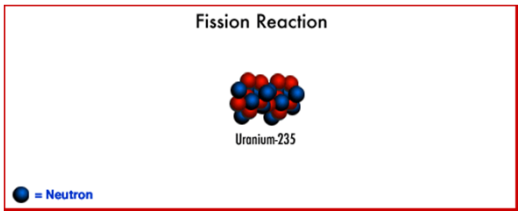
Uranium and plutonium

- Other relevant isotopes are uranium: **U-235** with 92 protons and 143 neutrons and **U-238** with 92 protons and 146 neutrons
- And plutonium - it has 3 relevant isotopes, each with 94 protons: **Pu-239**, **Pu-240** and **Pu-241**
- Uranium and plutonium are very relevant to this story since they are what the bombs were made from



Splitting the atom – the fission reaction

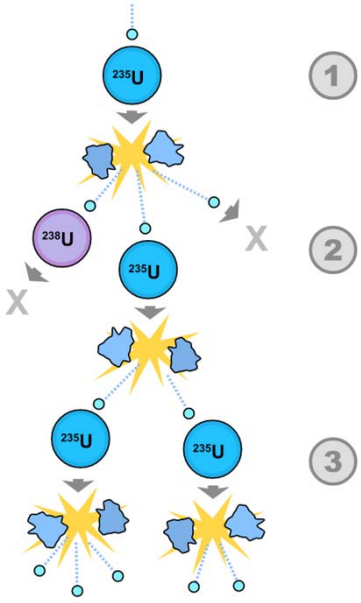
- For U-235, the large nucleus is tightly bound together but it is borderline unstable
- If a stray neutron is captured by the nucleus, the nucleus starts to deform and then wobble back and forth until it splits into 2 smaller parts
- The total energy required to hold the 2 smaller nuclei together is less than the energy required to hold the big nucleus together so there is a **release of energy**
- Also the ratio of neutrons to protons is smaller in the smaller atoms so there are **surplus neutrons** released



Chain reaction and critical mass

- If those surplus neutrons hit other atoms causing them to split this process can repeat and multiply very quickly releasing huge amounts of energy
- This is a **chain reaction**
- If the lump of uranium is small then most of the neutrons will escape before they hit another nucleus
- If the U-235 atoms are too far apart then the neutrons will also escape without hitting another nucleus
- This leads to the important concept of **critical mass**
- A chain reaction cannot be sustained if the lump of uranium is not big enough or dense enough
- The natural level of U-235 is tiny (0.7%), so uranium needs to be **enriched** to 80% U-235 to achieve critical mass

Fission chain reaction



Slow neutrons

- If the neutrons are too fast they don't get captured by the U-235 nucleus
- Slowing the neutrons down makes it more likely that they will be captured
- A good material for slowing neutrons down is heavy water
- Heavy water doesn't really have any other uses
- So when a country is buying up supplies of heavy water, it is a bit of a give away ...
- Another good material is **graphite** but ...
- To work as a moderator, graphite has to be very pure
- And, if it's exposed to air, it burns (*see Chernobyl disaster*)

Plutonium

- Plutonium occurs naturally but only in tiny quantities
- It was only discovered in 1941
- But plutonium can be created by bombarding U-238 with slow neutrons
- Pu-239 and Pu-241 are **fissile** materials as is Pu-240 but the latter is highly unstable which can lead to premature fission
- This is far from ideal for bomb manufacture, storage, transport etc
- A different approach is required to produce critical mass only when you need it

NO MORE PHYSICS!

Pre-WWII Germany - Deutsche Physik

- German Physics was a pseudo-scientific movement that arose out of WWI
- It started with a bit of name-calling between German and British physicists
- After the war, led by Nobel Prize winners Philip Lenard and Johannes Stark, it started to get nasty when Lenard developed the idea of Jewish Physics
- This was targeted at Einstein and his Theory of Relativity
- It quickly broadened from there to include other Jewish physicists and the new atomic physics
- In 1933 the Nazis came to power and sacked all the Jews from universities, forcing many of the targets to emigrate
- Lenard and Stark then started attacking the "White Jews" – Germans who used or taught Jewish Physics
- This put a handicap on doing research or teaching in Germany since Jewish Physics was really just modern Physics

Law for the Restoration of the Professional Civil Service

- The law had been introduced shortly after Hitler was elected in 1933 but it came into full effect in 1934
- All Jewish civil servants, including university employees, were immediately sacked
- 1,145 university teachers, in all fields, were driven from their posts, about 14% of the total
- Out of 26 German nuclear physicists cited in the literature before 1933, 50% emigrated
- 11 physicists and 4 chemists who had won or would win the Nobel Prize emigrated
- This was a serious brain drain from Germany

Impact on Germany's future opponents

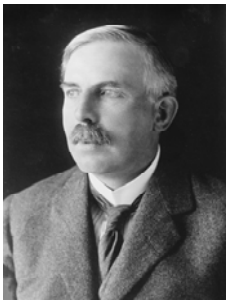
- Importantly, it greatly increased the talent pool elsewhere
- The Rockefeller Foundation created a fund to help support refugee academics in Europe and in the USA
- In Britain, the Academic Assistance Council organised the placement of scientists around various universities
- The Emergency Committee in Aid of Displaced German Scholars played a similar role In the USA
- Regional universities in both countries were now able to attract some of the leading physicists including Nobel Prize winners
- Many of these scientists were committed to seeing Germany defeated and they would provide a highly motivated workforce for the Manhattan Project

The big beasts

- Some physicists make broad contributions to Physics that are even more important than their own discoveries
- They provide leadership, new projects and training for students and young researchers as well as mentoring
- For this story, I have chosen four that made crucial scientific discoveries but had an even greater impact in relation to the development of modern Physics - and the atomic bombs
- Each was awarded a Nobel Prize as were many researchers from their labs

Ernest Rutherford

- b. 1871 Nelson, New Zealand d. 1937
- Postgraduate studies at the Cavendish Laboratory at Cambridge (UK)
- Researcher at McGill University (Canada), Professor at Manchester (UK)
- 1908 he had been awarded the Nobel Prize for Chemistry for his work on radioactivity
- 1919 he returned to the Cavendish Laboratory as Director



Ernest Rutherford (2)

- 1911 he discovered the structure of the atom
- His team fired tiny positively charged alpha particles (discovered by Rutherford in 1899) at a thin gold foil
- Most passed through straight through but a tiny number came straight back
- "*It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you.*"
- From that he worked out that the nucleus must be tiny and positively charged
- He later proved that the nucleus contained protons
- He also predicted the existence of neutrons, which were later discovered in 1932 by James Chadwick, one of his collaborators
- But Chadwick had trouble getting them to do anything

Ernest Rutherford (3)

- 4 collaborators won Nobel Prizes, and 2 of these, James Chadwick and John Cockroft worked on the Manhattan Project
- An Australian, Mark Oliphant, also worked with Rutherford and would play a crucial role in the Allied bomb program
- On the other hand, there was Hans Geiger, who became famous for the Geiger counter he invented to do the radioactivity measurements for the early experiments
- He worked on the German bomb program

Niels Bohr

- b. 1885 Copenhagen, Denmark d. 1962
- Jewish through his mother
- Nobel Prize for Physics in 1922
- After visiting Rutherford in 1911 he developed a new model of the hydrogen atom that kick-started the search for new theories to explain all these strange results
- Scientists from everywhere would visit him to discuss their work and receive advice and guidance
- After the German invasion he was allowed to continue his work in Copehagen but late in 1943, fearing arrest, he escaped to Sweden
- He was flown to UK and then to the US where he became a father figure to many of the scientists (including his son) working on the Manhattan Project

Max Born

- b. 1882 Breslau, German Empire d. 1970
- Of Jewish descent
- Nobel Prize for Physics 1954
- Professor at Göttingen University from 1921 to 1933 during which time it was the leading centre for Theoretical Physics in Europe and hence the world
- After 1933, he went to Edinburgh University, via Cambridge
- Some of his students and assistants and colleagues from Göttingen played major roles in the development of nuclear weapons, although Born himself did not

Students, assistants and colleagues of Max Born at Göttingen involved in development of nuclear weapons

Manhattan Project	German nuclear program
Robert Oppenheimer Enrico Fermi (Nobel Prize) Wolfgang Pauli (Nobel Prize) Edward Teller Eugene Wigner (Nobel Prize) Maria Goeppert-Mayer (Nobel Prize) Victor Weisskopf John von Neumann James Franck	Werner Heisenberg (Nobel Prize) Siegfried Flügge

Ernest O Lawrence

- b. 1901 South Dakota d. 1958
- 1930 Professor University of California Berkeley
- 1939 Nobel Prize for Physics
- He invented the cyclotron, the first circular particle accelerator, 10 cm in diameter
- All modern accelerators, including the Large Hadron Collider, are based on his design
- He was an excellent hustler for funding to build ever bigger machines
- His influence and connections in the US were to prove very valuable
- He was a close friend of Robert Oppenheimer at Berkeley

Splitting the atom

- A lot of Physics from this period (1911-1939) can be summarised as follows:

1. Fire some radiation at some atoms
2. See if anything unexpected happens
3. If it does, see if you can work out what it was
4. Then try and come up with an explanation of why
5. Or find a friend who can help with that
6. If all that goes well ...
7. Start planning your trip to Sweden to collect your Nobel Prize

The Importance of neutrons

- **Enrico Fermi** had spent time with Born and with Bohr and made many important contributions to Physics
- In 1934 he found that, if you slowed neutrons down, you could make ordinary atoms extra radioactive
- He was the first person to split the atom but didn't realise it until much later when it was too late to claim credit
- When he picked up in his Nobel Prize in 1938, he decided not to return to Rome as his wife was Jewish and the Fascists were going the same way as the Nazis
- He was welcomed in the USA and would play a significant role in the Manhattan Project
- He would work closely with **Leo Szilard**, a Hungarian physicist and engineer who had first thought of the chain reaction

Hahn & Strassman, Meitner & Frisch

- In Berlin, at the Kaiser Wilhelm Institute, **Lise Meitner** was having some difficulties after 1933
- She was Austrian, female and Jewish - as well as being a brilliant physicist
- She could not hold a government-paid position but the Institute still had money to pay her to continue her long collaboration with **Otto Hahn** who was an excellent chemist
- But there were some rabid Nazis in the Institute who were unhappy at her continued presence
- After the Anschluss, Meitner became a German citizen by default and she was now in danger
- She managed to escape to Holland and then found her way to Sweden

Hahn & Strassman, Meitner & Frisch (2)

- Meitner kept up correspondence with Hahn, continuing to give him advice on how to conduct the experiments of firing neutrons at uranium
- In December 1938 Hahn wrote to Meitner describing his results he had obtained with his student **Fritz Strassman**
- He believed he had split the uranium atom because he had found Barium, about half the the atomic weight of uranium, but could not explain the mechanism
- Meitner's nephew, **Otto Frisch**, who was working with Bohr in Copenhagen, had come to visit her just after she had received Hahn's letter
- By the end of the day, they had worked out an explanation of how nuclear "**fission**" came about and calculated how much energy would be released - quite a lot in fact - along with the surplus neutrons

Hahn & Strassman, Meitner & Frisch (3)

- In January 1939, Hahn and Strassmann published their paper and Meitner and Frisch published their paper
- Hahn received the Nobel Prize for Chemistry in 1944, Meitner received nothing - until much later
- Back in Copenhagen, Frisch told Bohr who quickly worked out that it was U-235 that had split and not the more abundant U-238
- A whole new field of research had suddenly been opened up and making a bomb, or at least the fear of someone else making a bomb, was very much on the agenda among scientists
- Bohr was the keynote speaker at a conference on Theoretical Physics in Washington in January and his announcement caused a sensation
- In Germany they already knew about it

German bomb program

- In considering the German program, we need to distinguish between what actually happened, what the Allied scientists feared was happening, and the post-war justifications by the participants
- It began informally in April 1939 with the formation of the Uranverein or Uranium Club
- On 1 Sept 1939 it came under the direction of the HWA (Army Ordnance Office)
- They had a head start on the Allies, with access to uranium from Czechoslovakia and would soon have access to heavy water from Norway
- At its peak, there were about 70 scientists working on the program, but progress was slow and they concluded that a workable bomb was still some years away
- Fortunately, they missed some important insights that would have enabled them to progress much faster

German bomb program (2)

- By December 1941, with Germany's resources being fully stretched and with a desire/need for short term benefits from weapons programs, the program was wound back and by July 1942 the Army handed control back to the RFR (Reich Research Council)
- The irony is that the German program was winding back just as the Manhattan Project was getting under way motivated by the Allied scientists' fears about what the German program might have achieved with their head start
- The German scientists later claimed that they had abandoned the idea of developing a bomb and were concentrating on developing the Uranmaschine (nuclear reactor) for producing electricity
- However, a nuclear reactor to produce electricity from uranium fuel looks a lot like a reactor to produce plutonium for a bomb

German bomb program (3)

- Heavy water occurs naturally in water in one part per 6,400
- The Norsk Hydro plant in Norway used hydroelectricity to produce fertilizer
- It had been discovered that the process led to an increase in the concentration of heavy water in the output water to about 1 part in 48
- So they moved into heavy water production in 1935, becoming the only plant in Europe to do so
- Production was significantly ramped up from mid 1941 for shipping to Germany
- This made a German nuclear reactor to produce plutonium a real risk for the Allies
- In late 1942, the British decided to take out the Norsk Hydro plant to disrupt the German program

Werner Heisenberg

- b. 1901 Bavaria, d. 1976
- Werner Heisenberg was a brilliant young researcher at Göttingen who, in 1925, with advice from Niels Bohr and Max Born, developed a new theory of physics (now known as Quantum Mechanics) that provided explanations for all the weird and wonderful discoveries that had been made since 1900
- This theory has been expanded and improved but modern physics still depends on it
- In 1932, he was awarded the Nobel Prize for Physics
- By late 1942, he was effectively running the German program
- He was the one that the Allied scientists feared the most because of his brilliance

Werner Heisenberg (2)

- With no Jewish physicists left in Germany after 1933, Heisenberg had become the most high profile target of the German Physics movement because of his associations with Einstein, Born, Bohr and other Jewish physicists and the fact that he understood and taught “Jewish Physics” to students
- The SS newspapers ran articles attacking him as a "White Jew" and he was summoned for interrogation in Berlin
- He had believed he was untouchable but this was clearly not the case
- In desperation, his mother contacted her old friend, Frau Himmler, to ask, as one mother to another, if she would ask her well-known son to intervene
- Shortly afterwards, Heisenberg received a personal letter *“from the Office of the Director of the SS”*

Werner Heisenberg (3)

- *"Very esteemed Herr Professor Heisenberg," the letter began. "Only today can I answer your letter of July 1, 1937 in which you direct yourself to me because of Dr. Stark's article…*
- *Because you were recommended to me by my family, I have had your case investigated with special care and precision.*
- *I am glad that I can now inform you that I do not approve of the attack, ... and that I have taken measures against any further attack against you. ...*
- *With friendly greetings, yours, H. Himmler.*
- *P.S. I consider it best, however, if, in the future, you make a distinction for your audience between the results of scientific research and the personal and political attitude of the scientists involved."*
- On the same day he sent a letter to SS-Gruppenführer Rienhard Heydrich, saying that Germany could not afford to lose or silence Heisenberg as he would be useful for teaching a generation of scientists

Werner Heisenberg (4)

- As a loyal German, Heisenberg had been quite willing to participate in the German nuclear program although he later argued otherwise
- He was highly capable but he missed some key breakthroughs
- What might have been possible if he had not missed these, became very clear after the end of the war
- After VE-Day, 10 senior German scientists, who had been incarcerated in Britain (Operation Epsilon), after being captured as part of Mission Alsos, were recorded on hidden microphones
- When they heard that the bombs had been dropped on Japan they could not believe it at first
- But within a week Heisenberg announced to the others that he had reworked his calculations and had come up with an estimate of 20 kg as the required critical mass rather than several tonnes as he had previously concluded

Key failings of the German bomb program

- Sacking the Jewish scientists
- The effect the Jewish Physics movement had on the remaining scientists
- Competition within Germany for resources particularly manpower
- The growing need for short term weapons solutions
- Lack of diversity in the scientists - mostly physicists and chemists
- *On the other side, some of the Jewish physicists had trained as engineers and brought crucially valuable skills to the Manhattan Project*
- Distributed research teams and strong egos led to competition rather than collaboration
- Heisenberg was no different in that he gave directions to his subordinates and did not accept questioning from them or criticism while trying to solve all the problems himself because he was smarter than they were

End of Part 1