Lise Meitner and O. R. Frisch (1969), *Disintegration of Uranium by Neutrons: a New Type of Nuclear Reaction*, Nature, 224, Nov. 1

The article can be found at https://www.nature.com/articles/224466a0 This version is a reprint in Nature in 1969 but looks cool – all references to page and column in the questions refer to this version. An easier to read version can be found here http://www.ymambrini.com/My_World/Physics_files/Meitner%20Frisch.pdf

The paper is presented alongside another. We're going to be reading ***below the horizontal line*** on ***both pages***. So this paper is less than a page long. It's going to be worth having a periodic table available to view whilst looking through this paper.

This paper stems from Fermi and collaborators work where they bombarded each known atom at the time with neutrons and made a note of what happened (you can see that paper here if you're interested: https://royalsocietypublishing.org/doi/pdf/10.1098/rspa.1934.0168). For most of the atoms that Fermi and friends looked at their description of their results is just a couple of lines. Uranium, though, requires half a page and a note to say that it'll get its own paper. At the time, the experimental result was very difficult to understand. Lise Meitner, a physicist, worked in a team of experimental chemists to understand this problem for a long time. Her role was the explain the results that the chemists found. Here, she presents her solution. At the end of the article, we'll look at the events surrounding this work and, ultimately, why Lise Meitner never received a Nobel Prize which she thoroughly deserved.

As always, take a skim-read through the paper first and come up with a few **SKIM-READ QUESTIONS** that you'll need to research to ensure you understand as much as possible when we read it through again in detail, answering the questions below as we go. This week, you're going to be coming up with the **SKIM-READ QUESTIONS** yourself and submitting them along with your summaries.

(P1, C1) Why do certain atoms emit radiation?	
(P1, C1) Radioactive substances are those that emit alpha, beta, gamma radiation or neutrons from their nuclei. Discuss what each of these types of radiation is and any of their properties.	
(P1, C1) Why do we say that radiation is a random process?	

(P1, C1) What is the atomic number and mass number for the most common form of uranium? How many protons and neutrons must it have?	

When they say that ‘four radioactive substances were produced’, this isn’t from a single uranium nucleus decaying. The sample of uranium that was bombarded with neutrons contained billions of atoms. The different nuclei could decay in different ways, leading to seemingly four different products that were radioactive (and possibly more that weren’t radioactive).

(P1, C1) How might the experimentalists have detected that there were radioactive substances produced?	
(P1, C1) What is a nuclear isomer?	

At this point in history, scientists were expecting that, when bombarded with neutrons, a nucleus would do one of two things:

- nothing
- absorb the neutron (and possibly even more than one) and then go through a series of decays (alpha, beta, gamma, neutron emission) until we got to something stable.

(P1, C1) “It was always assumed that these radioactive bodies had atomic numbers near that of the element bombarded”. Given the two bullet points above, why is this?	
(P1, C1) “only particles with one or two charges were known to be emitted” - what are they referring to here?	
(P1, C1) ‘eka-osmium’ is now called Plutonium. Looking at the periodic table, why would osmium and ruthenium be	

expected to have similar properties?	
(P1, C1) If something is "isotopic with radium", then it is an isotope of radium. What does this mean?	
(P1, C1) If bombardment of uranium (Z=92) lead to something "chemically similar to barium" (Z=54), what two reasons would lead them to initially conclude it was an isotope of radium (Z=88)?	
(P1, C1&C2) Why were Hahn and Strassman "*forced*" into a conclusion that they probably weren't happy with?	

(P1, C2) Meitner and Frisch draw an analogy to a liquid drop. Concentrating simple on a liquid, what keeps a droplet together?	
(P1, C2) What similarities do Meitner and Frisch draw between the uranium nucleus and a 'liquid drop'?	
(P1, C2) What do you think the authors mean by "stability of form"?	
(P1, C2) Given that we're discussing nuclear radiation and the behaviour of nuclei, why is it perhaps not surprising that the size of the smaller pieces of uranium may be dictated "partly on chance"?	
(P1, C2) Why will the two nuclei that are formed	

when uranium splits repel one another?	
(P1, C2) What is the definition of fission? And hence what is the definition of nuclear fission?	

Remember that the article continues below the horizontal line on the second page.

(P2, C1) What do they mean when they say "After division, the high neutron/proton ratio of uranium will tend to readjust itself by beta decay to the lower value suitable for lighter elements."	
(P2, C1) Look at the periodic table and explain why krypton "might decay through rubidium, strontium and yttrium to zirconium"	

In the paragraph that begins "It is possible, and seems to us rather probable", Meitner and Frisch are explaining the previous puzzling experimental evidence through this new lens of nuclear fission. Fermi and friends had previously detected radioactive nuclei with short half-lives as some of the products of the uranium reaction. Rather than having to ascribe these values to new, heavy elements, they are better understood as half-lives of much lighter elements (that were already known) but simply weren't expected to be seen.

The final few paragraphs involved Meitner and Frisch giving their opinions on other confusing experimental results: explaining the neutron bombardment of thorium through a fission paradigm and shining some light onto the isotopes of uranium produced.

It is true of all papers that it's important to understand the work in the context of the time. It's certainly true of this paper and something we're going to do by reading what amounts to a small biography of this particular bit of research.

To do:

1. Read the following paper:

   Ruth Lewin Sime (1989), *Lise Meitner and the Discovery of Fission*, Reflections on Nuclear Fission at Its Half-Century, Journal of Chemical Education, **66**, 5.

   https://pubs.acs.org/doi/pdf/10.1021/ed066p373

2. Within this paper, find ***up to five key quotes*** that helped you to better understand the original paper by Lise Meitner and Otto Frisch.

SUMMARY QUESTIONS (submit these, along with your SKIM-READ questions and answers to thomas.millichamp@warwick.ac.uk)

What is nuclear fission?

Describe, in as clear a way as possible, what the troubling results were surrounding the neutron bombardment of uranium, and explain why they were troubling prior to the 'nuclear fission' explanation.

How did the second paper *(Lise Meitner and the Discovery of Fission)* help you to better understand Meitner and Frisch's original paper?

What did you learn from the second paper *(Lise Meitner and the Discovery of Fission)* about the relationship between science and society?

FURTHER INFORMATION

This interactive, 3D model shows the radioactive nuclei on an N-Z graph (mass number vs atomic number). Find uranium and track what the "improbable series of beta decays" would have to have been to achieve barium.

https://people.physics.anu.edu.au/~ecs103/chart3d/

Nuclear fission is now routinely used for electricity generation, this interactive model shows such a reactor and explains what every single part does

https://www.nuclearinst.com/Nuclear-Reactor-Simulator

This article looks at the invention of the nuclear bomb, using the ideas of nuclear fission

https://www.newscientist.com/term/invention-nuclear-bomb/

This short editorial by Robert Oppenheimer discusses another relationship between nuclear physics and society in the creation of the atomic bomb

https://www.nature.com/articles/nphys3287.pdf