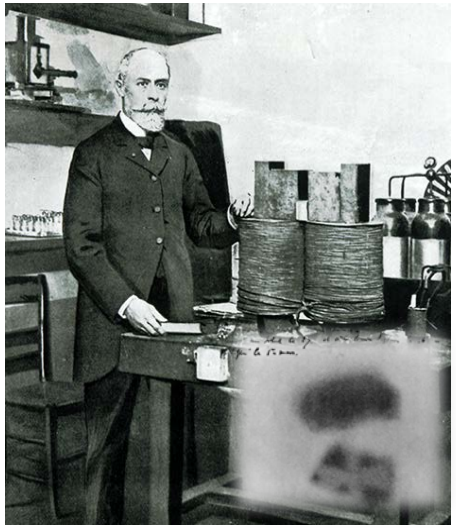
Radioactivity

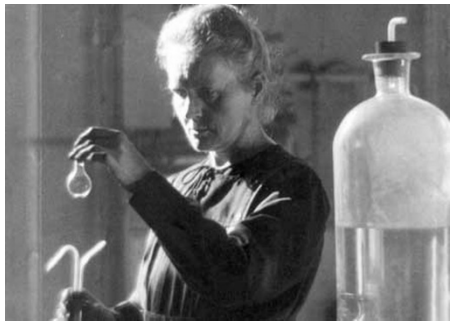
Lecture 3

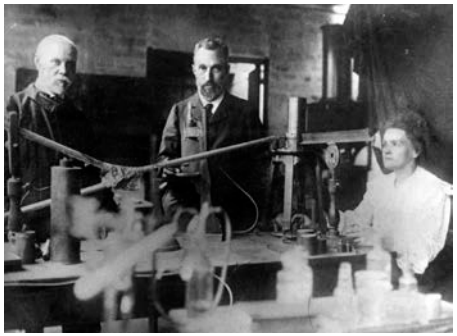
The Discovery of Radioactivity
Science and Applications

First Indications of new Phenomena

- Henri Becquerel discovered 1896 that **Uranium** blackens a photographic film or silver-photo emulsion. He concluded that there must be a kind of unknown light. In this he was stimulated by the discovery of x-rays a decade before.
- Marie and Pierre Curie looked for other materials that may emit this new kind of light. They found **Pitchblende**. They discovered a time dependence of the emitted radiation and a change of nature of radiation that they saw as indication for new elements, **Radium** and **Polonium**, which they extracted by chemical methods.
- They developed new experimental methods to detect radiation, they coined the term **Radioactivity** and introduced a unit for the intensity "*Curie*", which represents the number of emitted radiation events by 1 g of Radium. It corresponds to $3.7 \cdot 10^{10}$ events/s, but says nothing about the origin or nature of the radiation.







Observations

- Radioactivity produces heat (decay heat)
- Radioactivity can emanate as gas (Radon)
- Radioactivity darkens chemical emulsions
- Radioactivity generates fluorescence
- Radioactivity generates thermoluminescence
- Radioactivity causes chemical reactions
- Radioactivity causes burns and other physiological changes
- Radioactivity can kill (bacteria, mice)
- Radioactivity is temperature independent

Discovery Conclusions

Curies expectation and explanation of chemical conversion

Quelle: Deutsche Fotothek

Four times higher activity than Uran, suspicion was there must be something else, a different element?

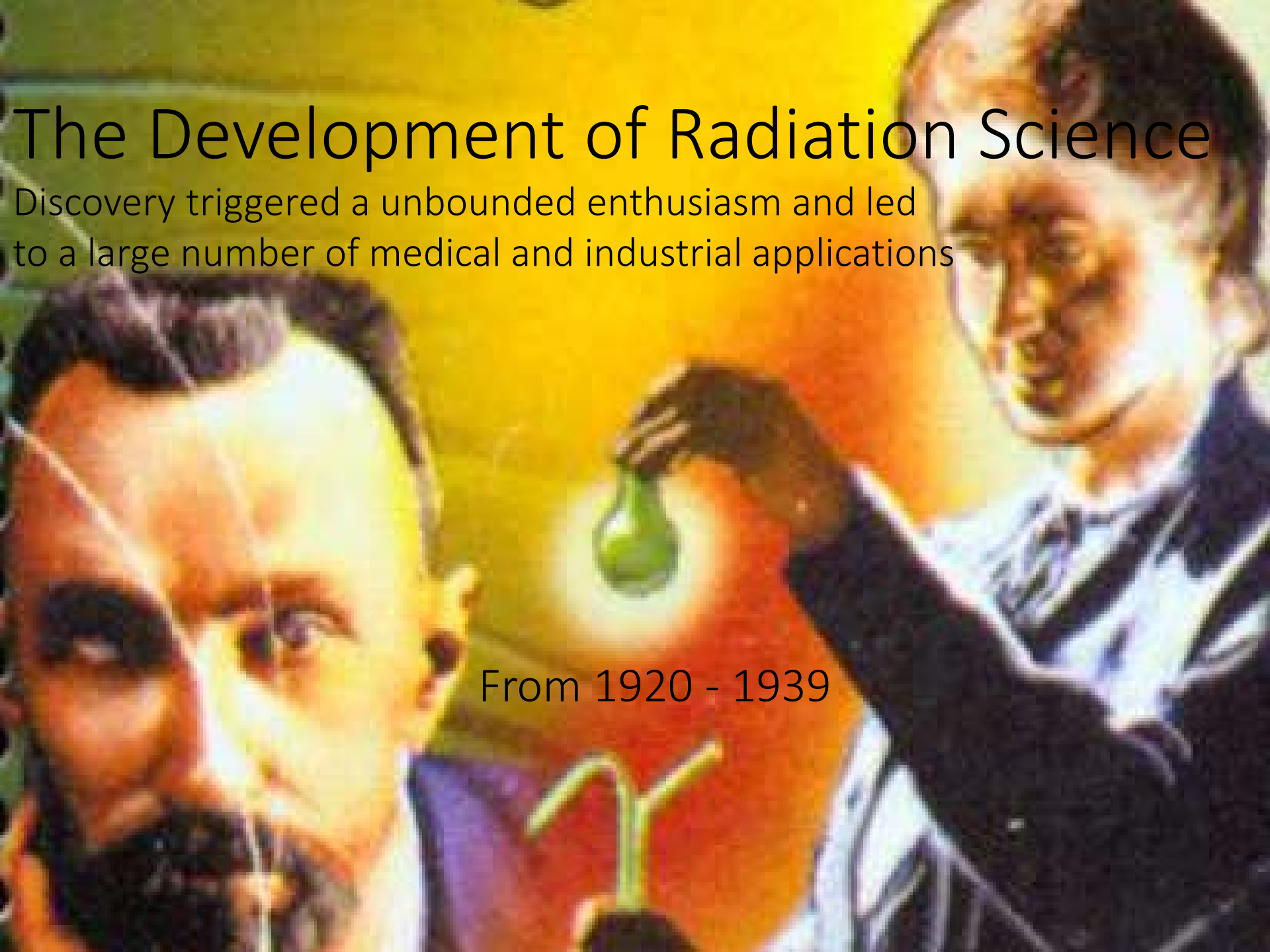
The Curies analyzed and converted several tons of left-over material from silver and uranium mining containing Pitchblende a highly radioactive uranium mineral, primarily uranium oxide. It was a tedious chemical effort to extract Radium and Polonium as decay products from the Uranium in the material. During that process they were exposed to enormous amounts of radiation, still observed on their notes, working and living quarters, even in the kitchen.

Consequences of Radiation

- Pierre Curie was very interested in possible application of the new phenomenon.
- This was motivated by the enormous success of the discovery of X-rays a decade earlier by Wilhelm Konrad Röntgen a few years (1895) earlier, which had instantaneously translated into a medical success story.
- Pierre Curie was the first who performed medical self experiments with the new materials by exposing his arm to Radium.
- He died in 1906 in an accident, but most likely caused indirectly by radiation sickness. Marie Curie died in 1934 on leukemia. In their joint experiments they received more than 10% of the entire radiation dose released in the course of the Chernobyl accident in 1986

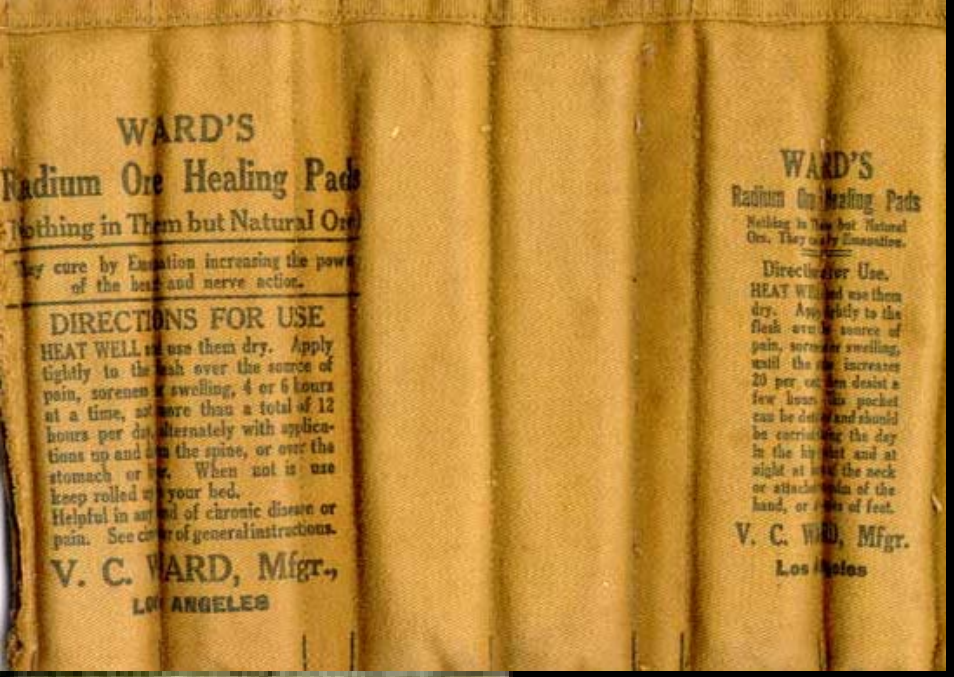
The Development of Radiation Science

Discovery triggered a unbounded enthusiasm and led to a large number of medical and industrial applications



From 1920 - 1939

Applications for Radioactivity



Applications

Popular products included radioactive tooth paste for cleaner teeth and better digestion, face cream to lighten the skin; radioactive hair tonic, suppositories, and radium-laced chocolate bars marketed in Germany as a "rejuvenator." In the U.S, hundreds of thousands of people began drinking bottled water laced with radium, as a general elixir known popularly as "liquid sunshine." As recently as 1952 LIFE magazine wrote about the beneficial effects of inhaling radioactive radon gas in deep mines. As late as 1953, a company in Denver was promoting a radium-based contraceptive jelly. Albert Geyser made a fortune in 1920 selling x-ray machines as hair removal systems. ”X-Ray treatment is save, harmless and effective, and in this he was brilliantly successful. The Tricho System of Treatment is the result. This dries up the hair roots in a manner similar to that of gradually getting bald, instead of attempting their sudden and violent destruction.”

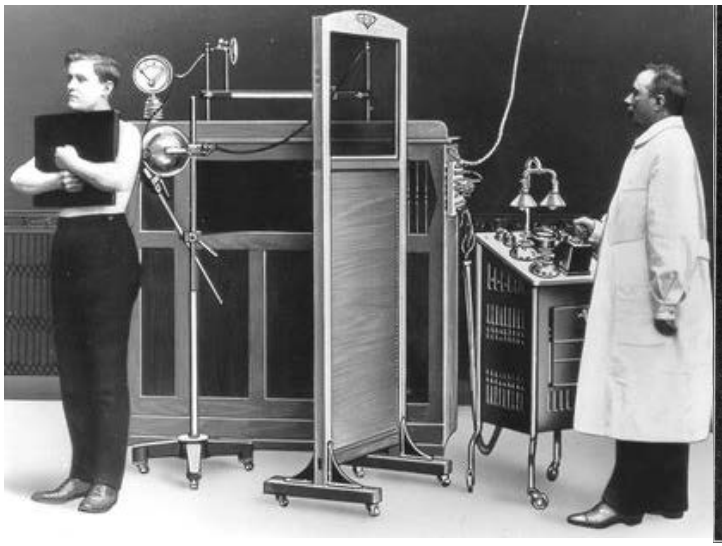
Radon Spas

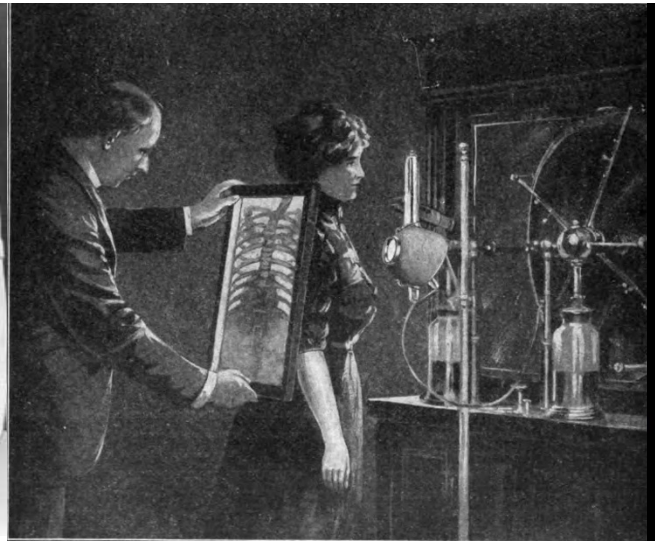
Radon bath and therapy in St. Joachimsthal in Bohemia, now Czech Republic

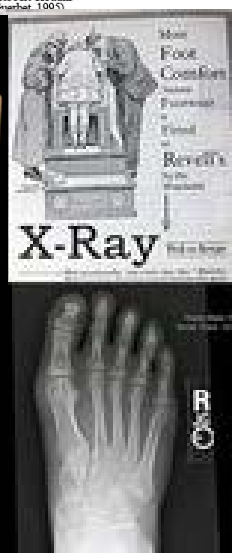
Medical Science

- X-rays offered opportunity for new diagnostics
- Radioactivity offered opportunity for treatment.
- Big business in radiation

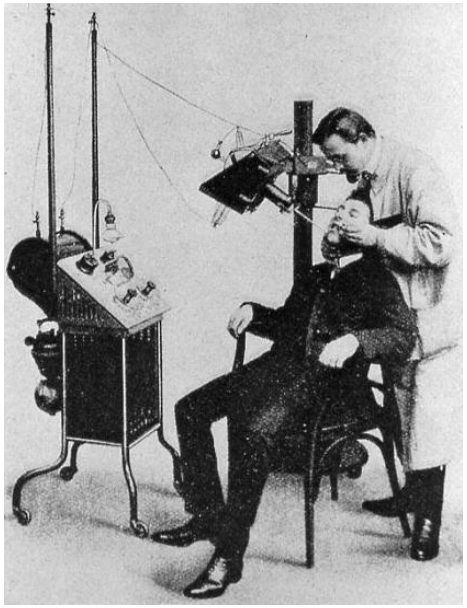
Affiche de spectacle au Théâtre Robert-Houdin
(source : revue *Contrastes* de Guerbet, 1995)







Radiation induced skin damage



Caused by the interaction of energetic decay products with the molecular structure of skin tissue, breaking up molecular bindings, initiating new chemical reactions of aggressive radicals (OH^-), which can damage further the chemical composition of skin tissue. The slow death of Thomas Edison's assistant Clarence Dally in 1900 on cancer after excessive experimentation with X-ray tubes, caused Edison to abandon all experimentation with x-rays. In 1903, when asked about the event Edison replied, "Don't talk to me about X-rays, I am afraid of them".

Radiation Diagnostics

Scientific accomplishments:

George de Hevesy was an independently wealthy Hungarian who worked in England and Germany, later Danmark and Sweden. He began the use of radioactive isotopes in studying the metabolic processes of plants and animals, by tracing chemicals in the body by replacing part of stable isotopes with small quantities of the radioactive isotopes. In 1923, Hevesy published the first study on the use of the naturally radioactive ^{212}Pb as radioactive tracer to follow the absorption and translocation in the roots, stems and leaves of bean plants.

The first tracer study:

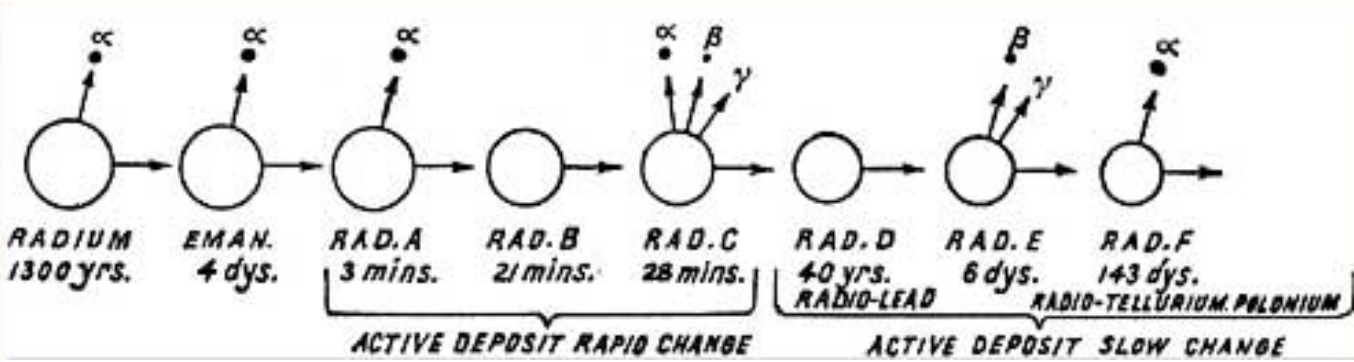
At Manchester, Hevesy was suspicious about his landlady serving recycled food refusing to serve freshly prepared meat more than once a week. Hevesy secretly spiked the leftovers on his plate with radioactive material. A few days later, the electroscope he smuggled into the dining room revealed the presence of the tracer - radioactive hash!

The first radiotracer investigation had successfully followed leftover meat from the Sunday meal to the kitchen meat grinder, into the hash pot, and back onto the dining room table. To this day, it is doubtful if a successful radiotracer study has provided greater personal satisfaction!

Hevesy laid the groundwork for many of the radioactive tracer and diagnostic techniques that radiation medicine relies on today.

Explanation of natural radioactivity

Radioactivity comes in three forms α, β, γ

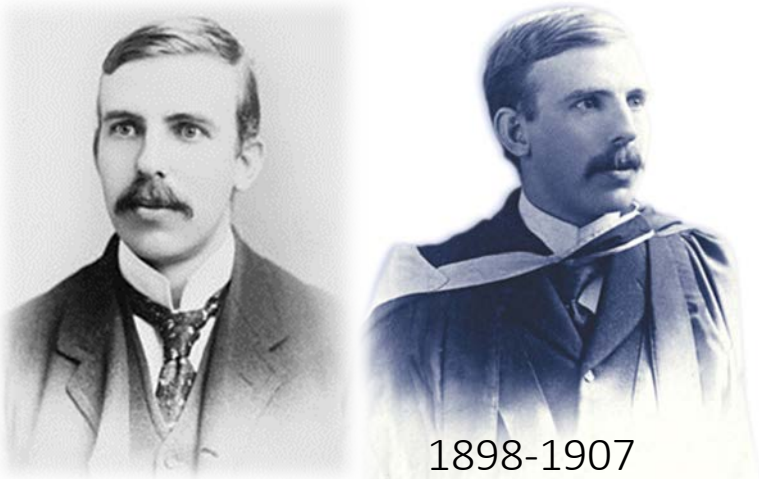


Nobel Prize 1908

Ernest Rutherford's

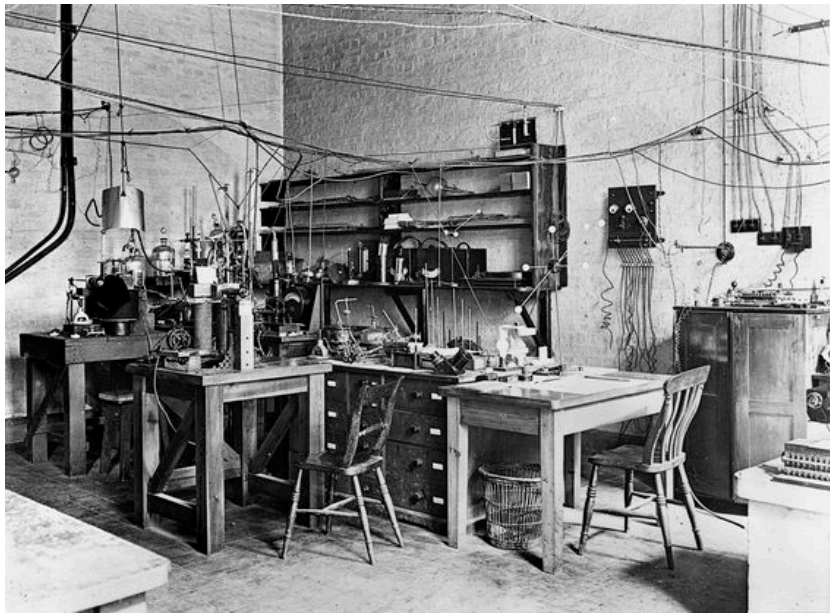
picture of transmutation. A radium atom emits an alpha particle, turning into “Emanation” (in fact the gas radon). This atom in turn emits a particle to become “Radium A” (now known to be a form of polonium). The chain eventually ends with stable lead. *Philosophical Transactions of the Royal Society of London,* 1905.

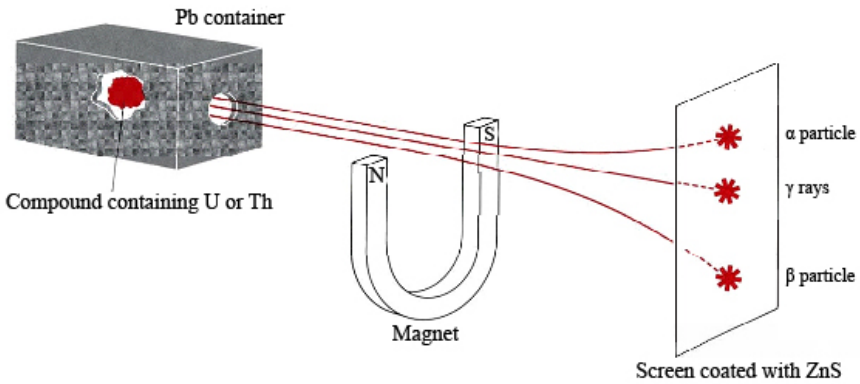
Rutherford and Radioactivity

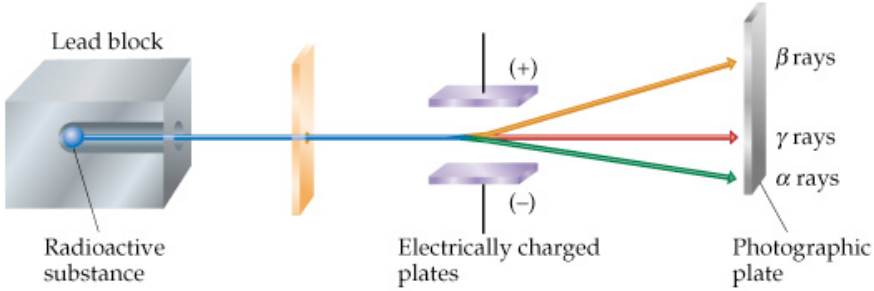


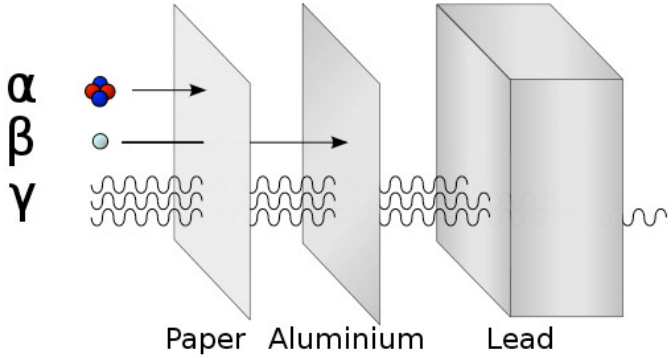
1898-1907

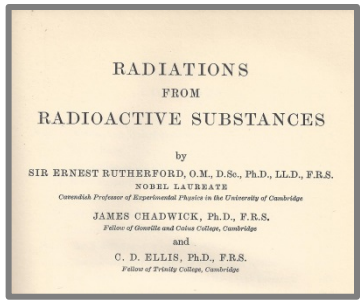
Rutherford at McGill University, Montreal











RADIATIONS
FROM
RADIOACTIVE SUBSTANCES

by

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Cavendish Professor of Experimental Physics in the University of Cambridge

JAMES CHADWICK, Ph.D., F.R.S.
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Fellow of Trinity College, Cambridge

Deducing the decay patterns

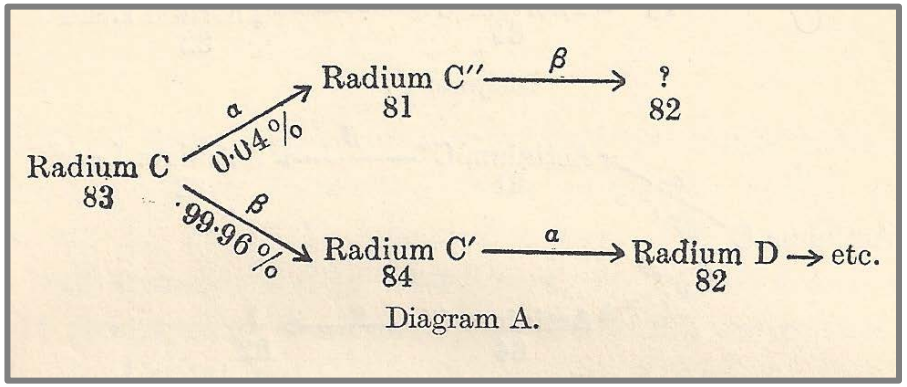


Diagram A.

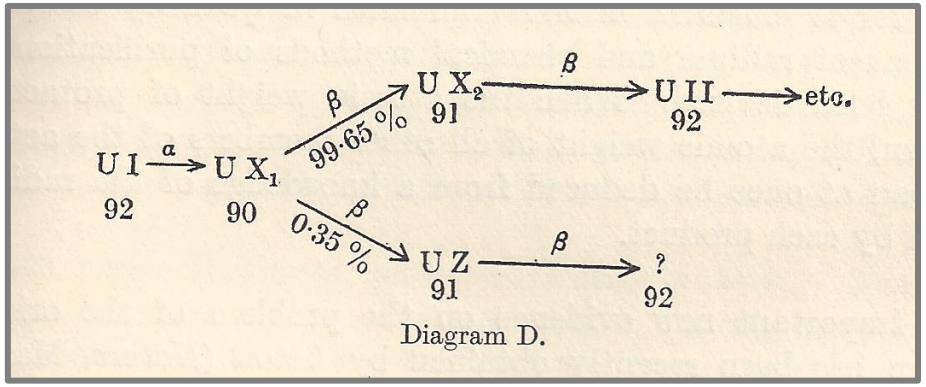


Diagram D.

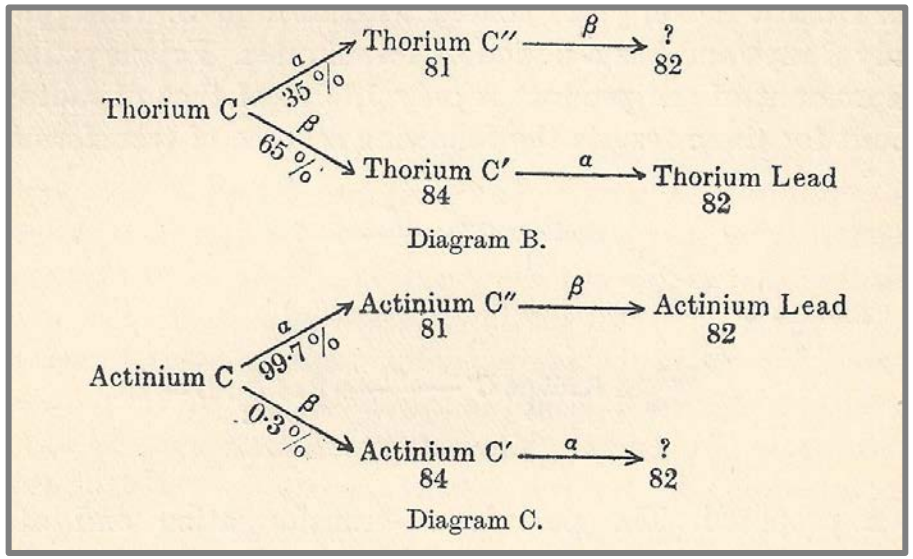
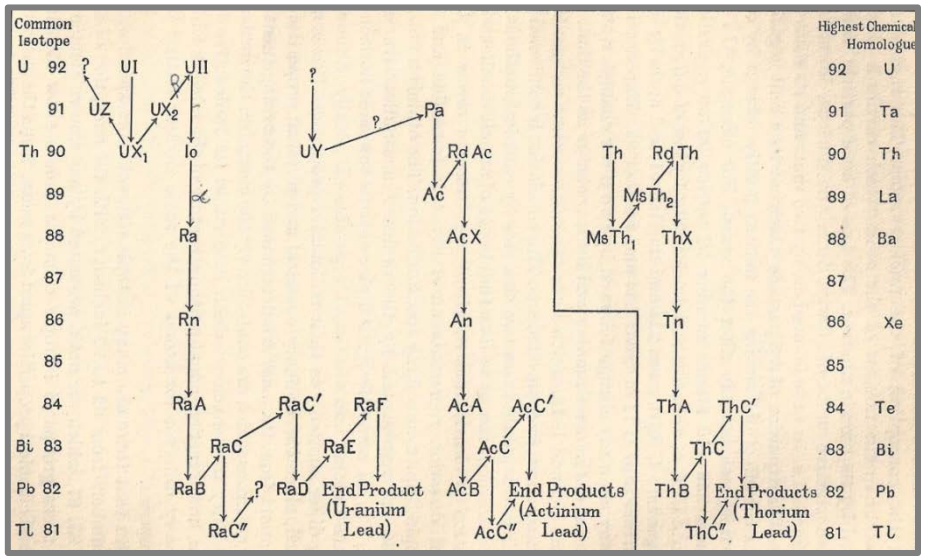
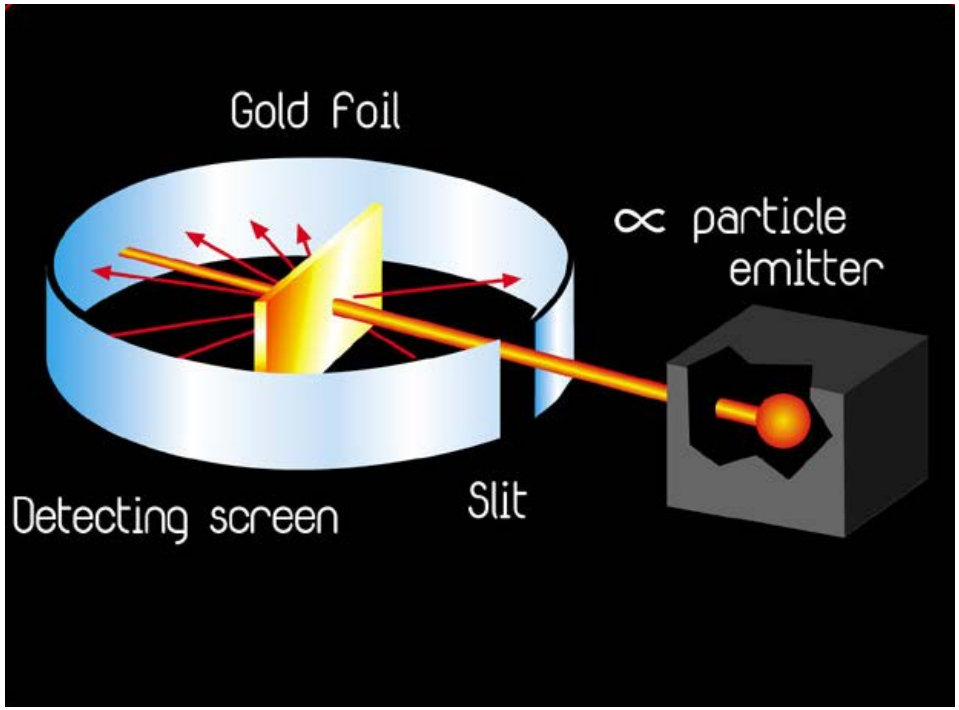


Diagram B.

Diagram C.

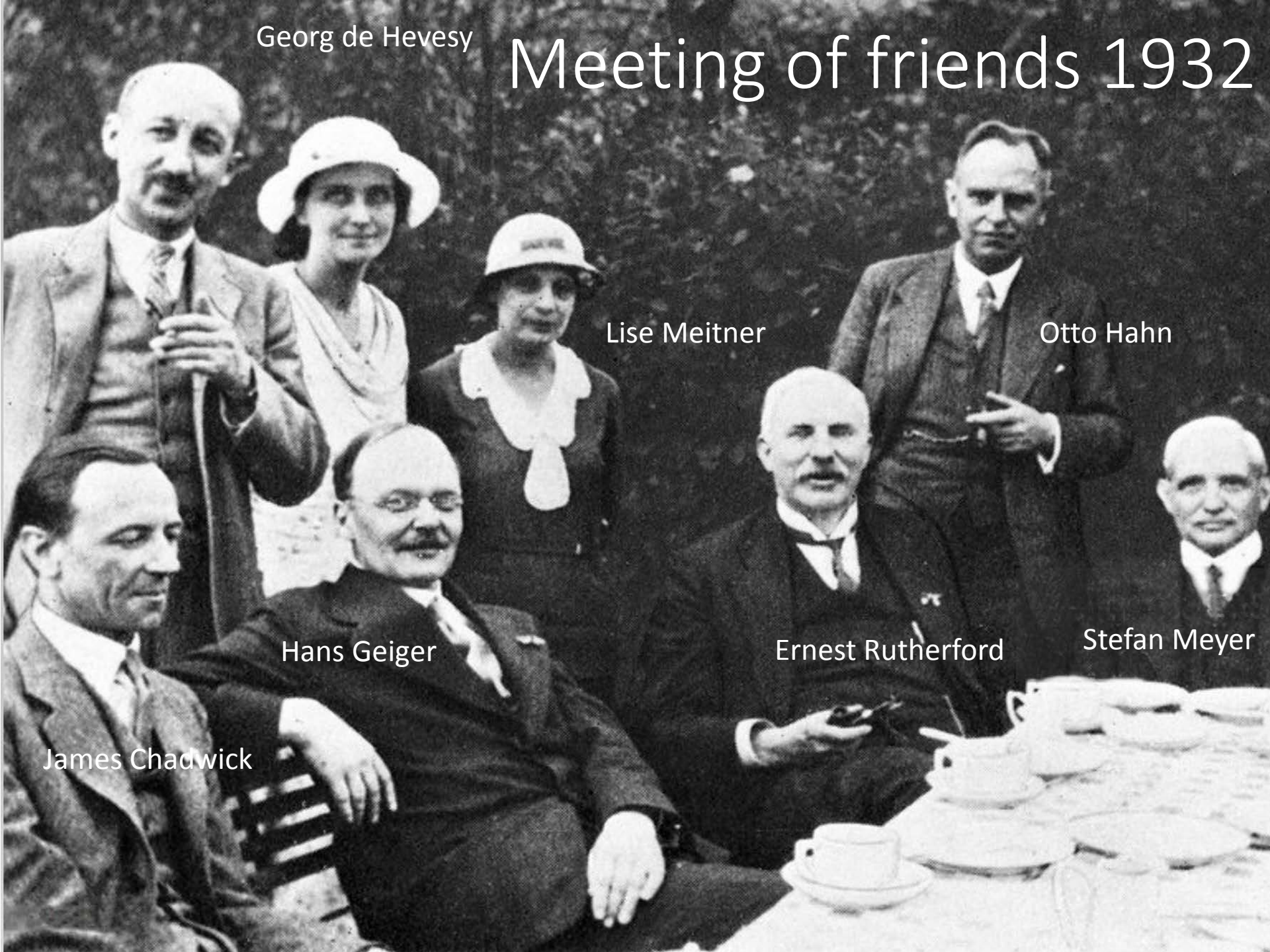


Rutherford's scattering experiment and the nature of the atom



The scattering probability (cross section) depends on charge, energy and scattering angle: $\frac{d\sigma}{d\Omega} = \left(\frac{Z_1 Z_2 e^2}{4E}\right)^2 \sin^{-4}\frac{\theta}{2}$ indicating that the scatter has a much smaller size than anticipated.

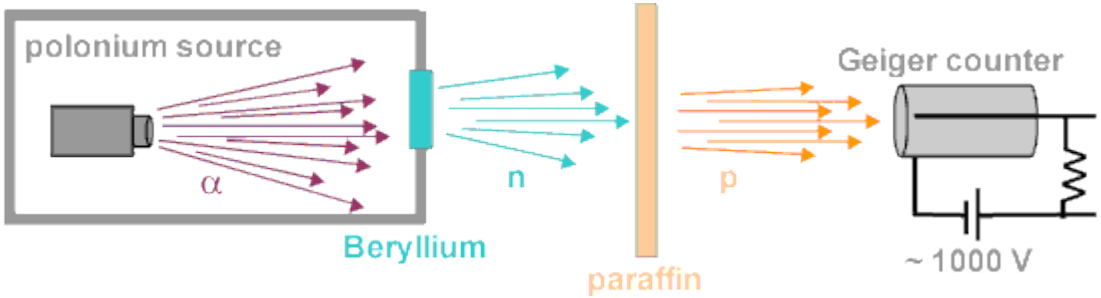
Meeting of friends 1932

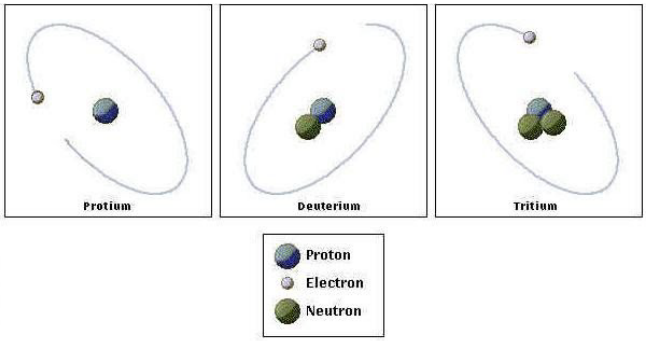


Neutrons as critical ingredients

Atomic number was always smaller than the mass number of nucleus, there must be more mass somewhere. Rutherford suggested a neutral particle within the nucleus might provide the missing mass.

James Chadwick – student of Hans Geiger in Germany and Ernest Rutherford in Cambridge designed the experiment in 1932 bombarding Beryllium with alpha particles from radioactive Polonium. This generated neutrons, which in turn were converted by paraffin to protons and counted with a Geiger counter (supplied by Geiger). Nobel prize 1935!





The first isotopes

Notation for Nuclei

Rutherford's explanation of the nucleus

Neutron

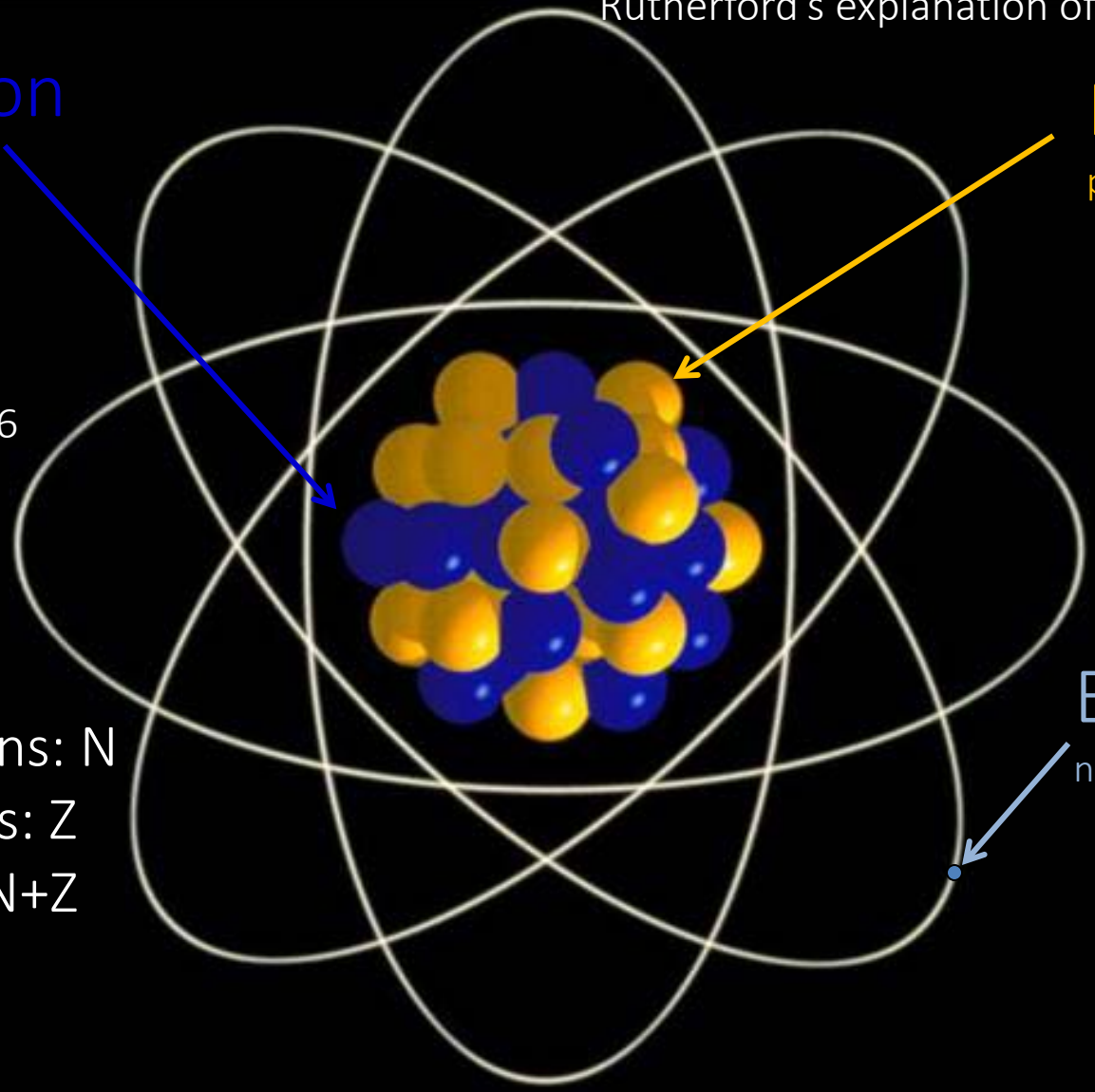
no charge

Proton

positive charge

$^{A}_{Z}\text{Element}_{N}$

$^{12}_{6}C_{6}$, $^{208}_{82}Pb_{126}$



Electron

negative charge

Number of neutrons: N

Number of protons: Z

Mass number: A=N+Z

Isotopes and Nuclide charts

Nucleus with Z protons (p) and N neutrons (n) with a total mass number *A=Z+N*

Hydrogen: 1 p, 0,1 n $^{1}_{1}H_{0}$ $^{2}_{1}D_{1}$

Helium: 2 p, 1,2 n $^{3}_{2}He_{1}$ $^{4}_{2}He_{2}$

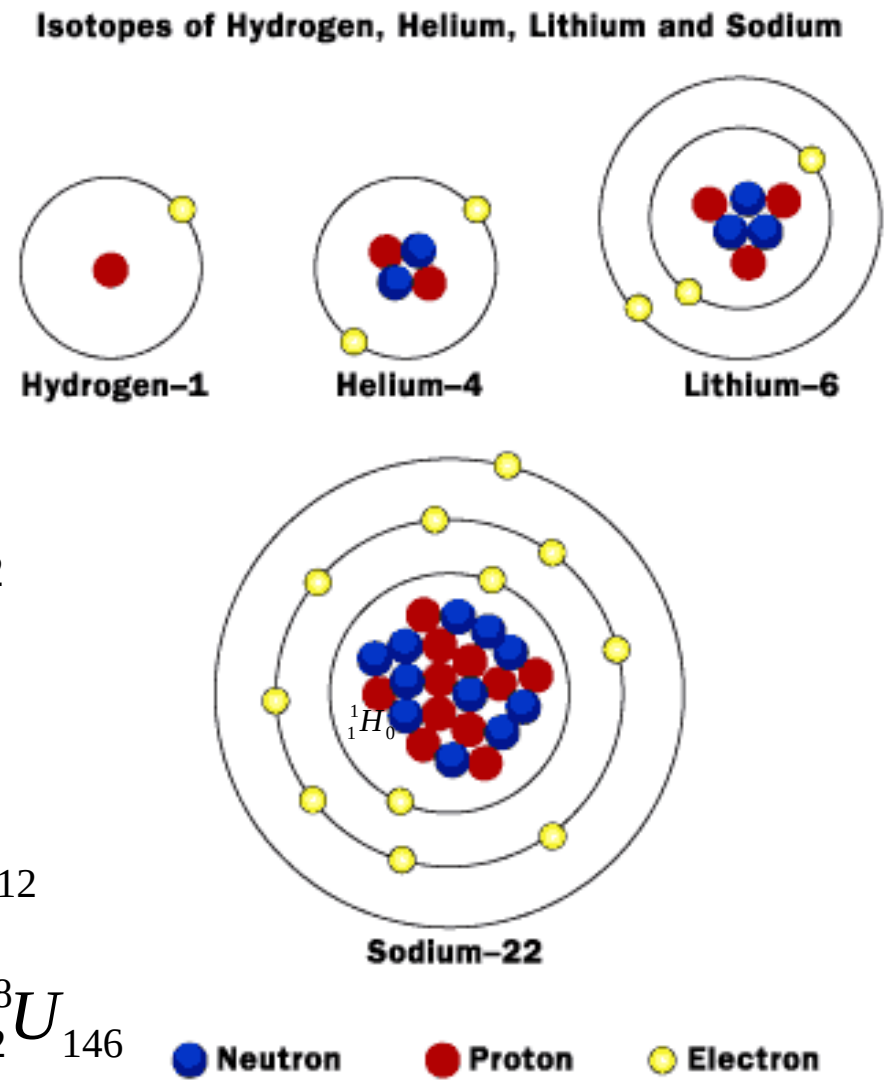
Lithium: 3 p, 3,4 n $^{6}_{3}Li_{3}$ $^{7}_{3}Li_{4}$

Carbon: 6 p, 6,7 n $^{12}_{6}C_{6}$ $^{13}_{6}C_{7}$

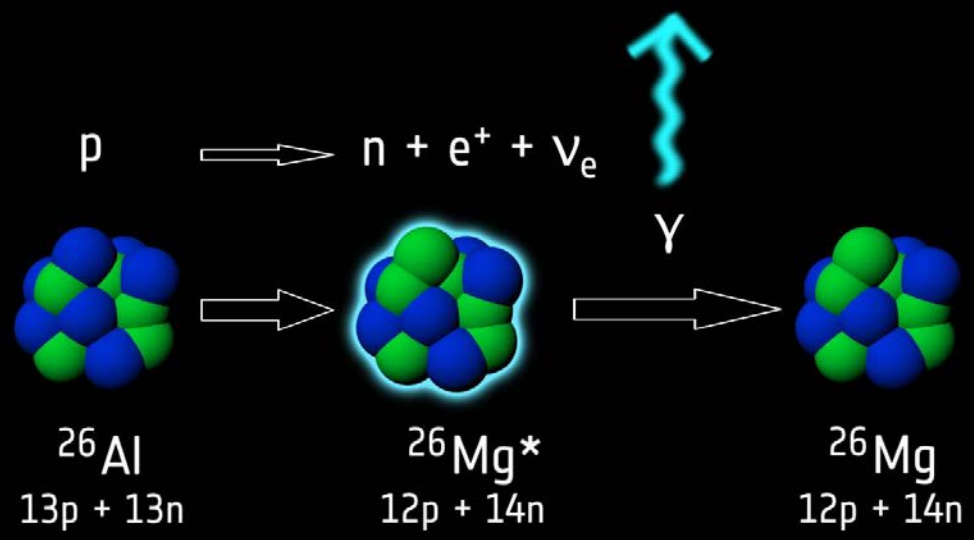
Sodium: 11 p, 11,12 n $^{22}_{11}Na_{11}$ $^{23}_{11}Na_{12}$

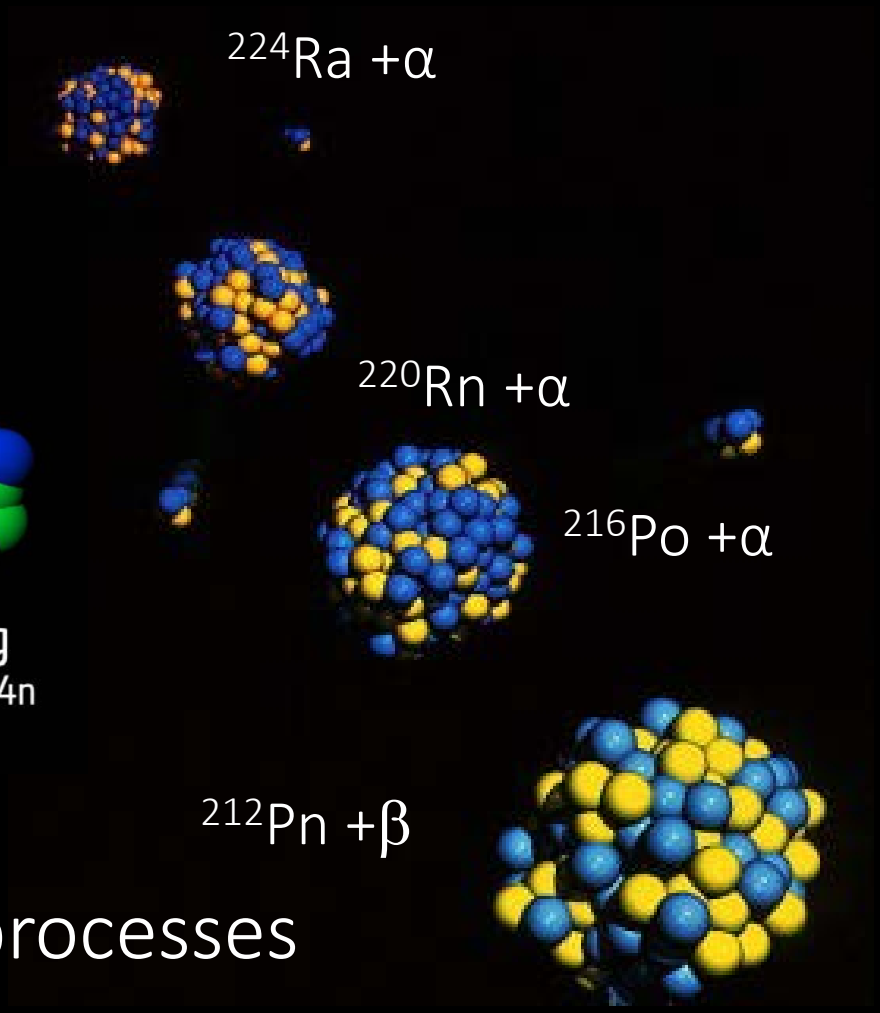
...

Uranium: 92 p, 143,146 n $^{235}_{92}U_{143}$ $^{238}_{92}U_{146}$



Radioactivity is associated with Nuclear Transmutation





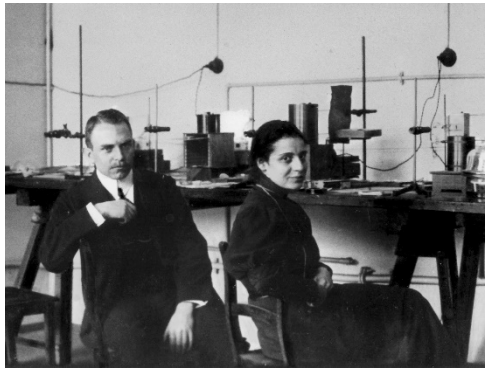
Naturally occurring decay processes

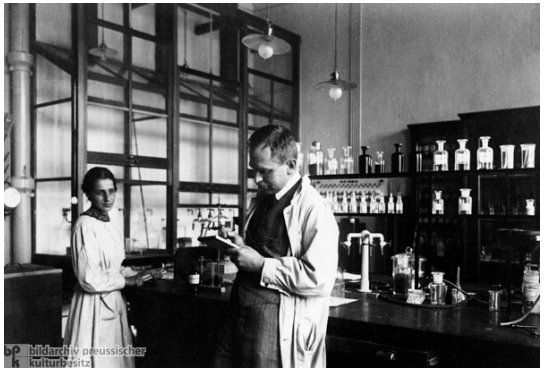
Nuclear Reactions and artificial Radioactivity

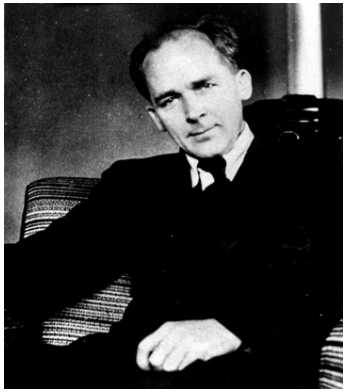
- 1932 James Chadwick discovered the neutron, by a nuclear reaction.
- 1934 Irene and Frederic Joliot Curie produced artificial (anthropogenic) radioactivity by other nuclear reactions.

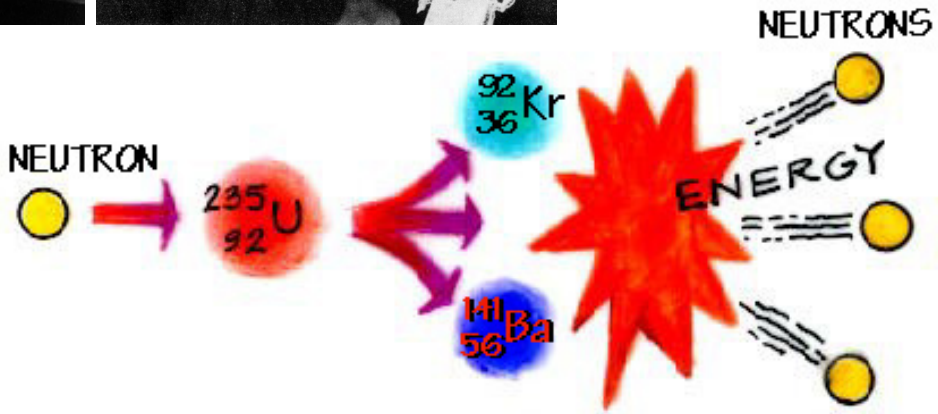
The Joliot-Curies were bombarding aluminum with α particles from radioactive sources. Afterwards they discovered phosphorus in the sample. They started with aluminum-27 (13 protons plus 14 neutrons) and ended with phosphorus-30 (15 protons plus 15 neutrons). But natural phosphorus is made up of one atom variety only, phosphorus-31 (15 protons plus 16 neutrons). Phosphorus-30, therefore, was an artificial isotope, one that did not occur in nature since it was radioactive, with a half-life of only 14 days. Its radioactivity was the source of the continuing particle radiation the Joliot-Curies had observed. The Joliot-Curies had produced the first case of *artificial radioactivity*. Since 1934 over a thousand isotopes not occurring in nature have been formed, and every one of them is radioactive.

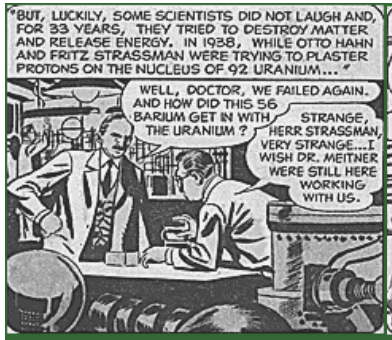
Nuclear Fission

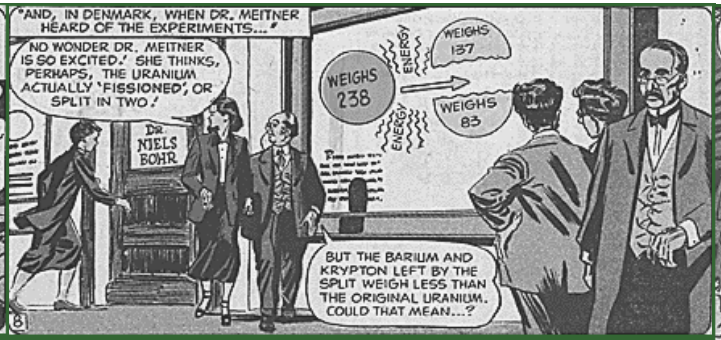


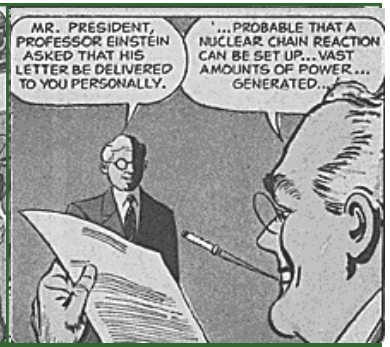




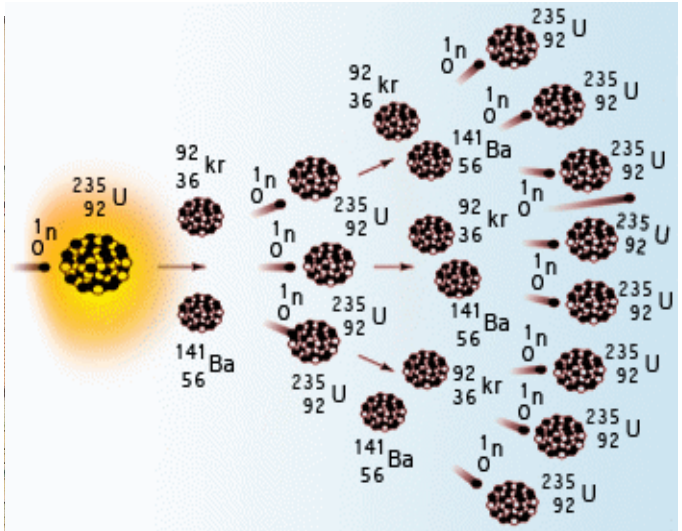




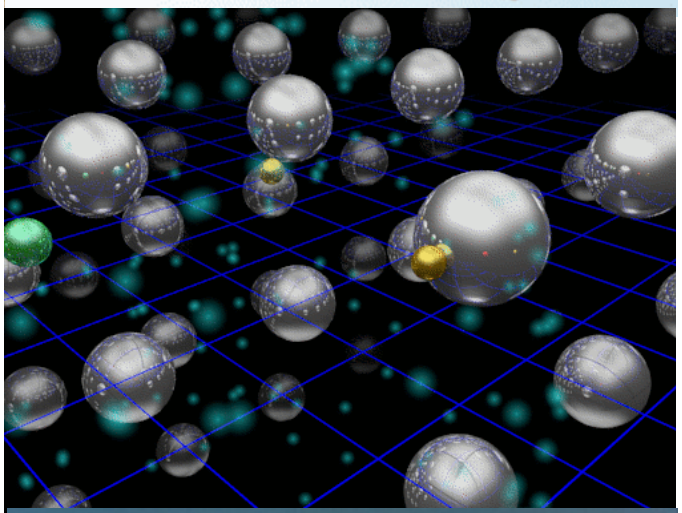


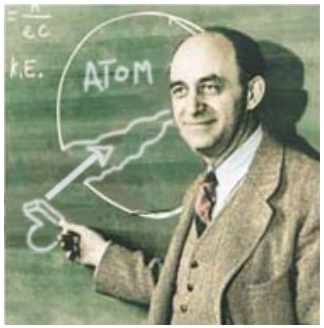


Chain Reactions



Slow neutrons are more likely to be captured by ^{235}U and induce fission!





The first nuclear reactor developed by Enrico Fermi in Chicago in 1942.