

A brief history of nuclear physics: from the discovery of the nucleus to element 118.

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Goals

- Some history...
- Some news....

Outline

- *From Radioactivity to the Discovery of the Proton* : Radioactivity & Nuclear Dimensions
- *From the Discovery of the Proton to today* : Nuclear Mass, Stability & Interaction

Some good tools

- National Nuclear Data Center (NNDC)

<http://www.nndc.bnl.gov>

The screenshot shows the NNDC website with a blue header. The header includes the NNDC logo, the text "National Nuclear Data Center", the Brookhaven National Laboratory logo, and a "Site Index" search bar. The main content area is divided into two columns. The left column features a "Chart of Nuclides" and several tool buttons: NSR, XUNDL, ENSDF, NuDat, Databases, MIRD, Sigma, CSISRS, ENDF, Networks, CSEWG, USNDP, Atlas of n Resonances, Empire, Nuclear Wallet Cards, Tools and Publications, and Nuclear Data Sheets. The right column displays the "ND2013 Proceedings" section, featuring a cover image of "Nuclear Data Sheets" and text stating "First Volume (118) for ND2013 is available!", "We moved! Click on this text for map.", "EXFOR 20,000 Milestone", and "Atomic Mass Evaluations Available". Below the main content is a navigation bar with tabs: Main, Structure & Decay, Reactions, Bibliography, Networks & Links, Publications, and Meetings. The "Main" tab is selected, showing a grid of links to various tools and databases, including AMDC, Covariances, ENDF, NMMSS & DoE NMIRD, NucRates, XUNDL, Atlas of Neutron Resonances, CSEWG, ENSDF, NSR, NuDat, CapGam, CSISRS alias EXFOR, IRDF, Nuclear Data Sheets, USNDP, Chart of Nuclides, Empire, MIRD, Nuclear Wallet Cards, and USNDP/CSEWG GForge.

NNDC National Nuclear Data Center **BROOKHAVEN NATIONAL LABORATORY** Site Index -

ND2013 Proceedings

Nuclear Data Sheets

First Volume (118) for ND2013 is available!

We moved! Click on this text for map.

EXFOR 20,000 Milestone

Atomic Mass Evaluations Available

Main | Structure & Decay | Reactions | Bibliography | Networks & Links | Publications | Meetings

AMDC Atomic Mass Data Center, [Q-value Calculator](#)

Covariances of Neutron Reactions

ENDF Evaluated Nuclear (reaction) Data File, [Sigma](#)

NMMSS & DoE NMIRD Safeguards & inventory decay data standards

NucRates MACS & Astro-physical reaction rates

XUNDL Experimental Un-evaluated Nuclear Data List

Atlas of Neutron Resonances Parameters & thermal values

CSEWG Cross Section Evaluation Working Group

ENSDF Evaluated Nuclear Structure Data File

NSR Nuclear Science References

NuDat Nuclear structure & decay Data

CapGam Thermal Neutron Capture γ -rays

CSISRS alias EXFOR Nuclear reaction experimental data

IRDF International Reactor Dosimetry File

Nuclear Data Sheets Nuclear structure & decay data journal, [Special Issues on reaction data](#)

USNDP U.S. Nuclear Data Program

Chart of Nuclides Basic properties of atomic nuclei

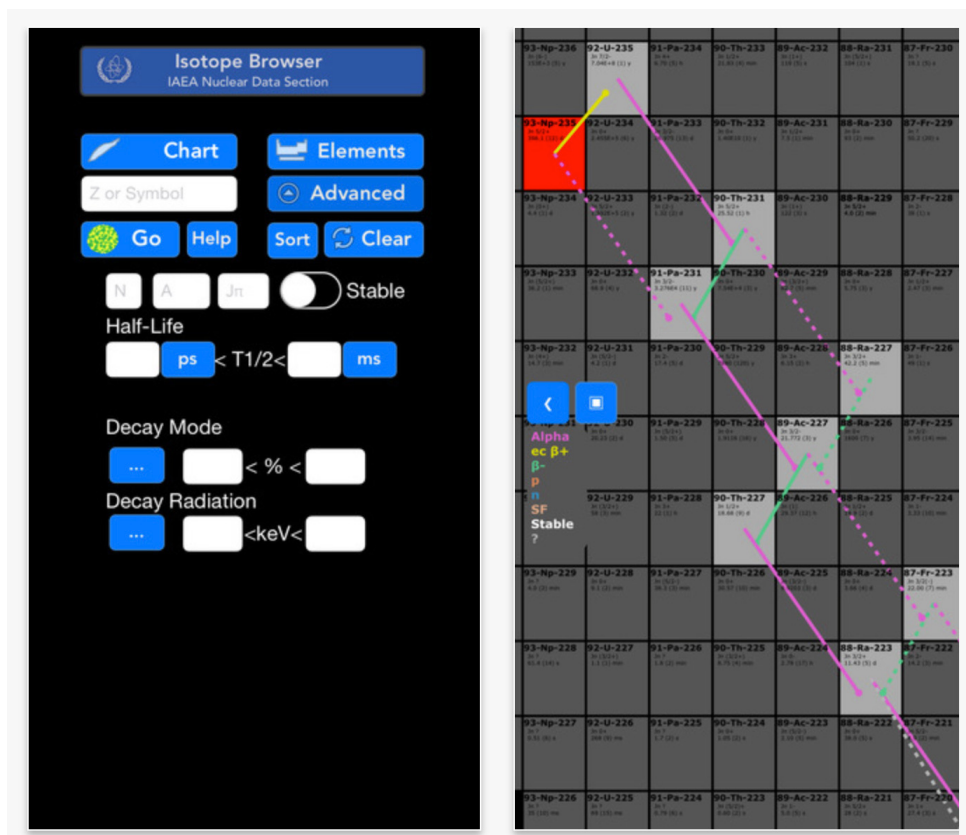
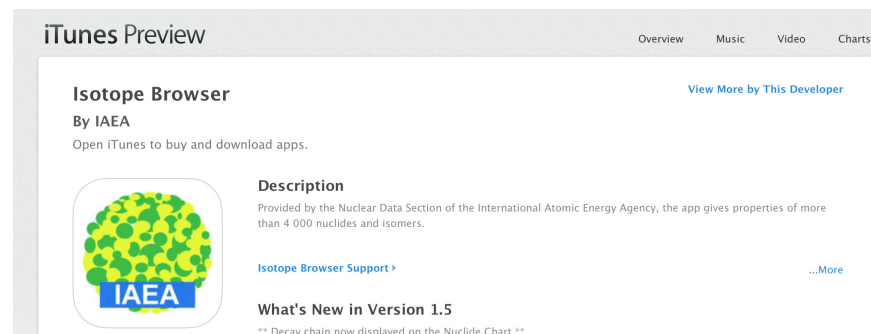
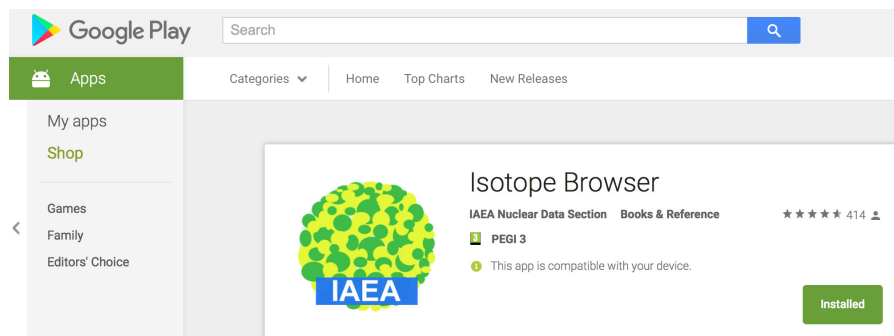
Empire Nuclear reaction model code system, [Reference paper](#)

MIRD Medical Internal Radiation Dose

Nuclear Wallet Cards Ground & isomeric states properties, [Homeland Security version](#)

USNDP/CSEWG GForge Collaboration Server

Some good applications



48 Nuclides found with:
element = 54 order by Z, N

Z	N	T _{1/2}	Spin	Decay Mode	Intensity
54	13	2 ms	(7/2+)	α	100%
54	14	93 (3) ms	0+	α	64.35%
54	15	0.74 (20) s		α	8+8.5%
54	16	2.7 (8) s		α	0.0080%
54	17	2.74 (8) s	(5/2+)	α	≈ 0.011%
54	18	10.0 (4) s	0+	ec β+	100%
54	19	18 (4) s	(5/2+)	α	0.0003 1%
54	20	59 (2) s	0+	ec β+	100%
54	21	61 (2) s	5/2(+)	ec β+	100%
54	22	3.8 (9) min	0+	ec β+	100%
54	23	5.8 (3) min	(5/2+)	ec β+	100%
54	24	40 (1) min	0+	ec β+	100%
54	25	40.1 (20) min	5/2(+)	ec β+	100%

54-Xe-135 Xenon
Uncertainty applies to the least significant digit(s)
Z 54 N 81 Jn 3/2+
Half-life 9.14 (2) h

Decay
β- 100 %
Qα -3630.67 (415) keV
Qβ 1165.048 (4071) keV
Qec -2627.807 (6812) keV
Sn 6363.78 (423) keV
Sp 9646.63 (690) keV
Electric Moment +0.214 (7) barn
Magnetic Moment +0.9032 (7) barn
Binding/A 8398.503 (31) keV
Mass 134.907228 (4455) AMU

Decay Radiations
From β- decay

Energy [keV]	Intensity %
β-	310.2 (16) 96 (4)
	173.3 (15) 3.11 (14)
	248.1 (16) 0.59 (3)
	26.9 (11) 0.123 (6)
	50.0 (12) 0.075 (5)
γ	249.794 (15) 90 (3)
	608.185 (15) 2.90 (13)
	407.99 (2) 0.358 (17)
	158.197 (18) 0.289 (14)
	358.39 (3) 0.221 (11)
X	30.9728 (3) 2.64 (13)
	30.6251 (3) 1.43 (7)

Some good reads...

The screenshot shows the Nobelprize.org website. The header includes the logo, navigation links (Home, Nobel Prizes and Laureates, Nomination, Ceremonies, Alfred Nobel, Educational, Events), and a search bar. The main content area is titled 'The Nobel Prize in Physics 1922' and 'Niels Bohr'. It features a portrait of Bohr, a 'Share this' section with social media icons, and a 'Niels Bohr - Facts' section. The facts section includes his birth and death dates, his affiliation at the time of the award (Copenhagen University), and his prize motivation: "for his services in the investigation of the structure of atoms and of the radiation emanating from them". The field is listed as 'theoretical nuclear physics'. On the left, there is a sidebar with 'Nobel Prizes and Laureates' and a dropdown menu for 'Physics Prizes' set to '1922'. Below this, there are links for 'About the Nobel Prize in Physics 1922' and 'Niels Bohr', with sub-links for 'Facts', 'Biographical', 'Nobel Lecture', 'Banquet Speech', 'Documentary', 'Photo Gallery', and 'Other Resources'. On the right, there are promotional banners for 'The Age to Come', '2014 Nobel Prize Announcements', and '2013 Nobel Laureates'.

Nobelprize.org
The Official Web Site of the Nobel Prize

Video Podcast About Us Search

Home Nobel Prizes and Laureates Nomination Ceremonies Alfred Nobel Educational Events

Nobel Prizes and Laureates

Physics Prizes < 1922 >

► About the Nobel Prize in Physics 1922

▼ Niels Bohr

- Facts
- Biographical
- Nobel Lecture
- Banquet Speech
- Documentary
- Photo Gallery
- Other Resources

All Nobel Prizes in Physics
All Nobel Prizes in 1922

The Nobel Prize in Physics 1922
Niels Bohr

Share this: 32

Niels Bohr - Facts

Niels Henrik David Bohr

Born: 7 October 1885, Copenhagen, Denmark

Died: 18 November 1962, Copenhagen, Denmark

Affiliation at the time of the award:
Copenhagen University, Copenhagen, Denmark

Prize motivation: "for his services in the investigation of the structure of atoms and of the radiation emanating from them"

Field: theoretical nuclear physics

The Age to Come
New scientific and cultural perspectives on ageing
Nobel Week Dialogue

2014 Nobel Prize Announcements

2013 Nobel Laureates
© The Nobel Foundation. Photo: Lovisa Engblom.

- ❖ K. Krane, Introductory Nuclear Physics
- ❖ R. Casten, Nuclear Structure from a Simple Perspective
- ❖ A. Bohr & B. Mottelson, Nuclear Structure Vol. I & II

Part 1 – Introduction, Radioactivity & Nuclear Dimensions

The nucleus

Z protons, N neutrons

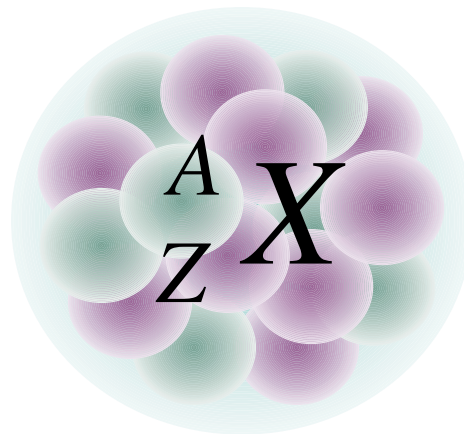
Mass number $A = Z + N$

Atomic number Z

Mass of the nucleus accounts for more than 99% of the mass of the atom

Charge of the nucleus $+Ze$ ($e = 1.6 \cdot 10^{-19}$ C)

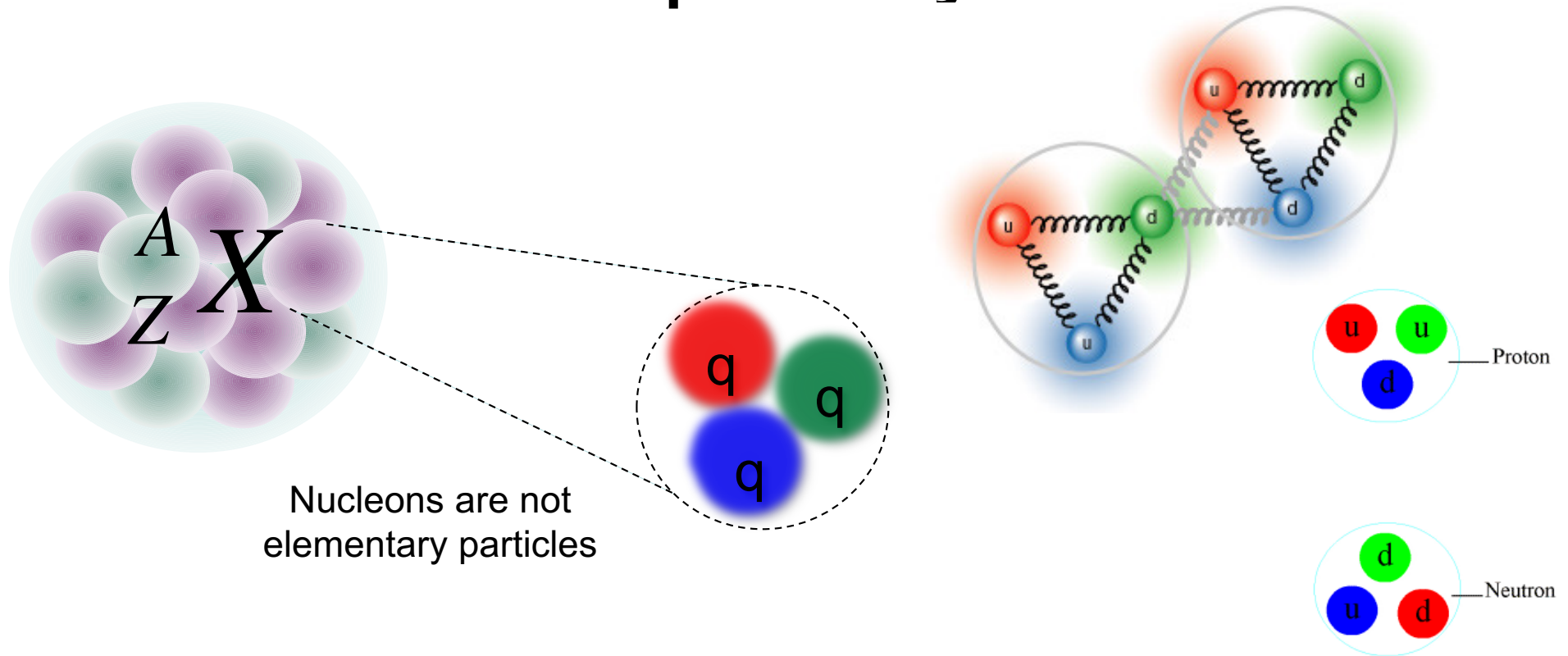
Nucleons are **fermions**: spin $1/2$, Pauli's exclusion principle



A interacting nucleons

3 forces: weak, electromagnetic & strong

A complex system



Understand and predict the organisation of nucleons inside the nucleus and the resulting nuclear properties

=

Challenge of nuclear physics

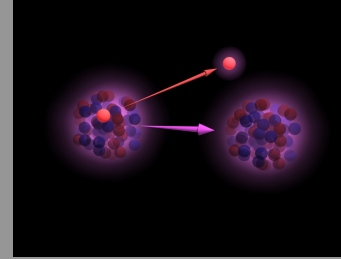
Nuclear chart

3430 nuclei (2026)
118 elements

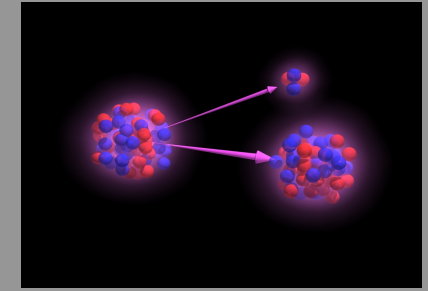
Isotones ($N=cst$)
Isobars ($A=cst$)
Isotopes ($Z=cst$)

Proton radioactivity

nucleus $\rightarrow$ proton + (nucleus - 1 proton)

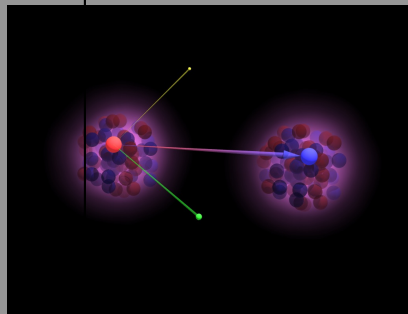


alpha emission of ^4He

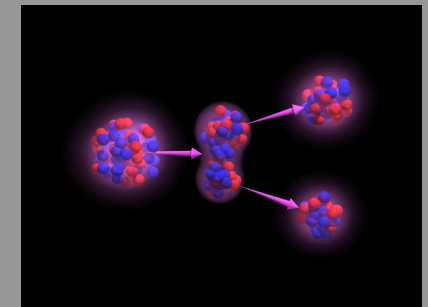


beta +

proton $\rightarrow$ neutron
 $+ e^+ + \nu_e$

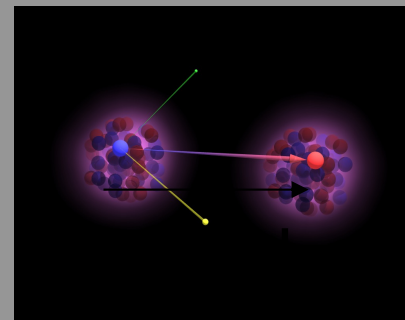


fission



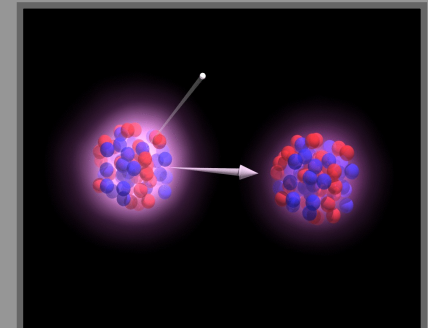
beta -

neutron $\rightarrow$ proton
 $+ e^- + \bar{\nu}_e$



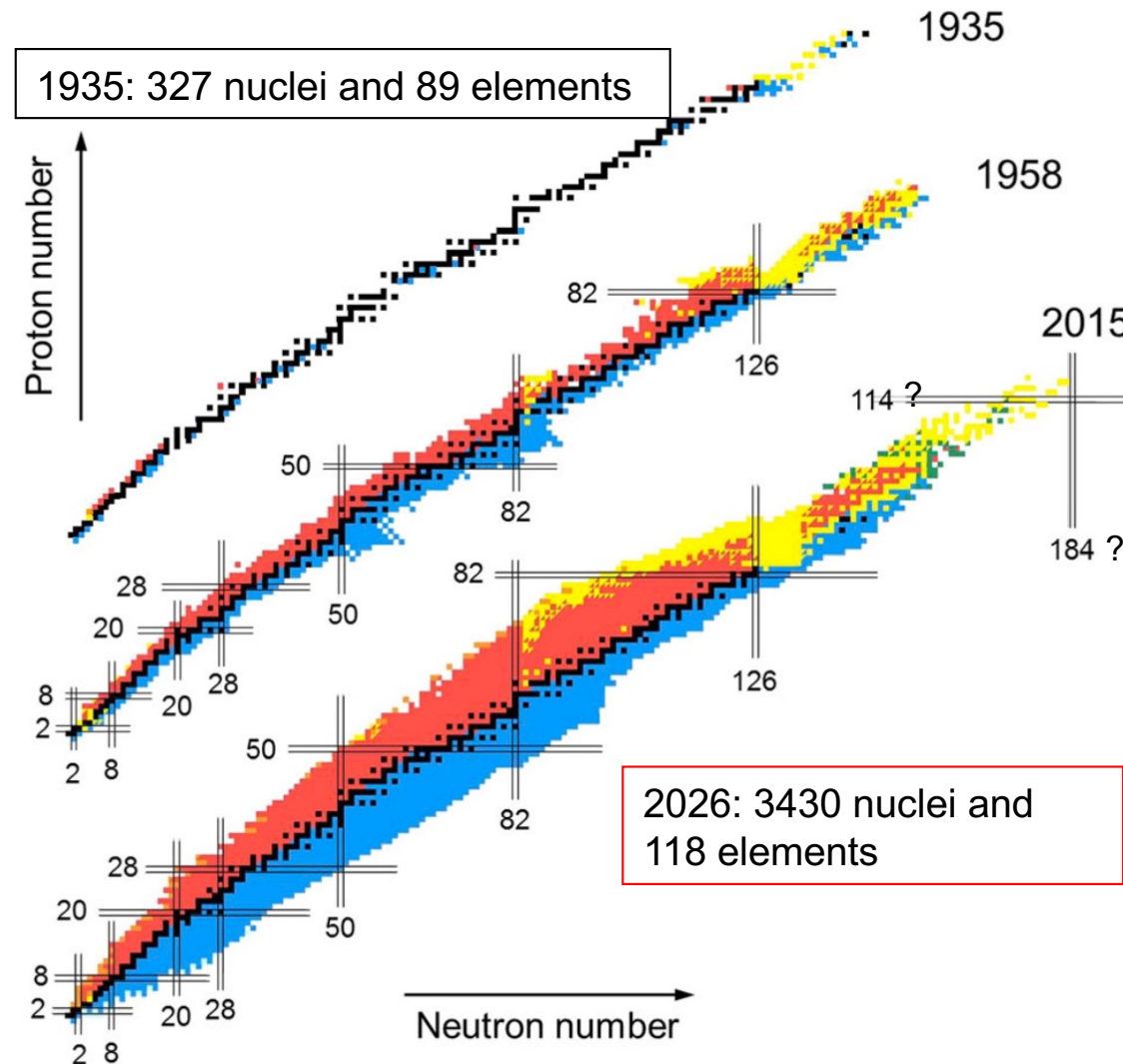
Gamma

nuclear relaxation
 $+ \text{photon } \gamma$



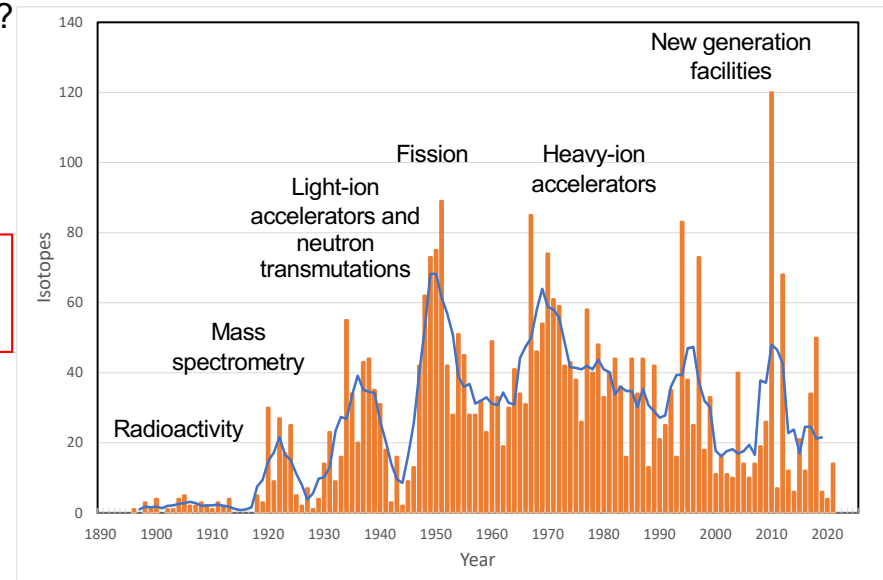
Evolution of the nuclear landscape

Adamian, G.G., Antonenko, N.V., Diaz-Torres, A. et al., Eur. Phys. J. A (2020) 56:47,
<http://creativecommons.org/licenses/by/4.0/>.



Rank	Country	# of Isotopes
1	USA	1345
2	Germany	569
3	United Kingdom	300
4	Japan	294
5	Russia	255
6	France	215
7	Switzerland	122
8	Canada	67
9	Sweden	60
10	Finland	49
11	China	42
12	Netherlands	36
13	Belgium	17
14	Argentina	13
15	Denmark	12

<https://frib.msu.edu/public/nuclides>

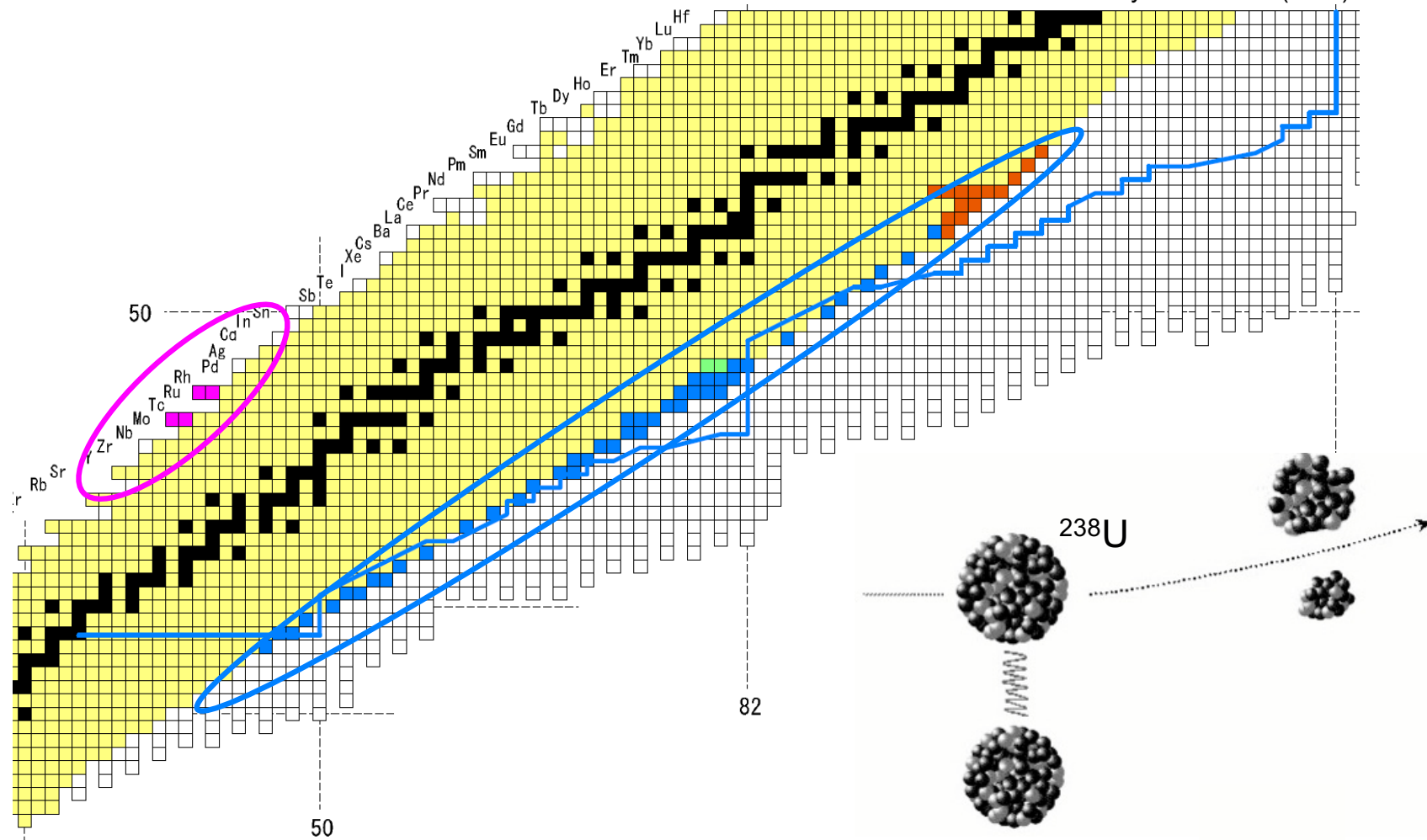


M. Thoennessen, private comm.

Discovery of New isotopes

T. Ohnishi et al. , J. Phys. Soc. Jpn. 79 (2010) 073201

D. Kameda et al.: Phys. Rev. C 86 (2012) 054319



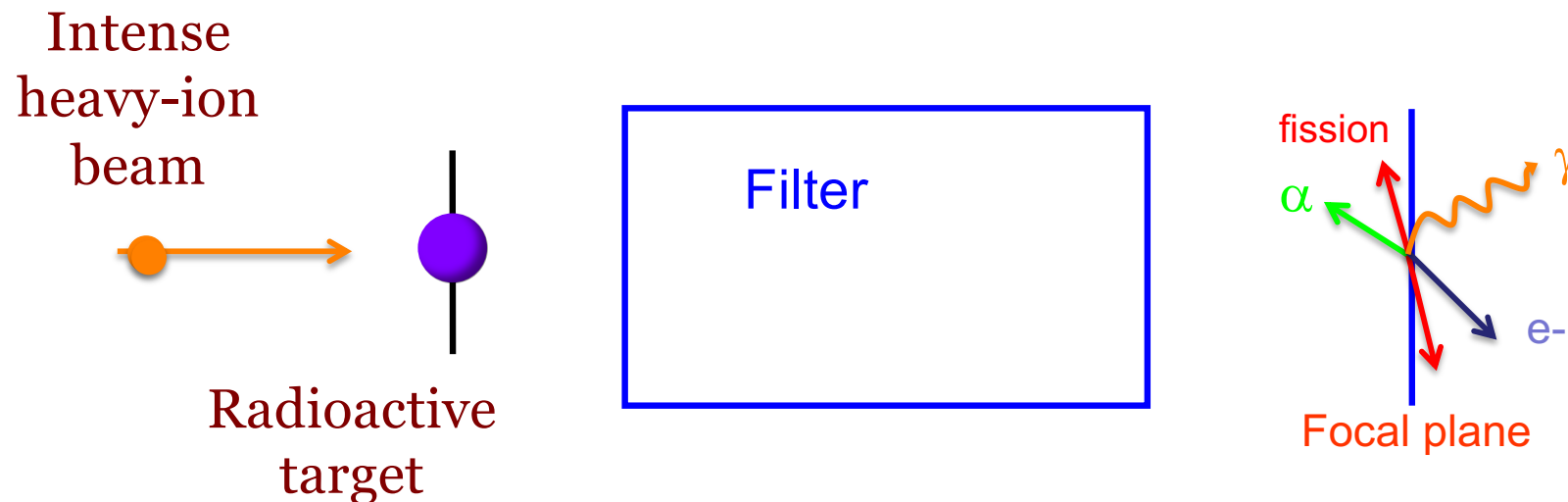
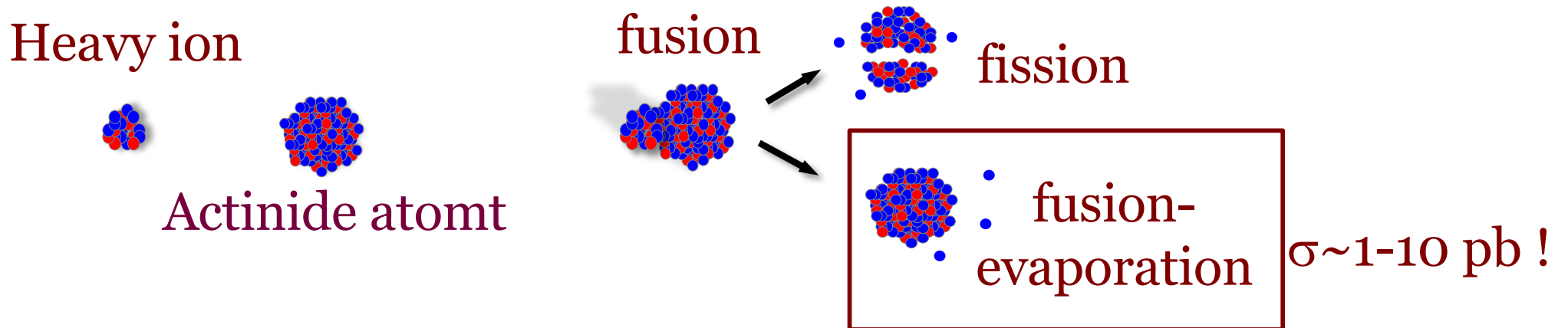
2007, 2008, 2011 (^{238}U): 61 new isotopes

2014-2022 (^{238}U): 91 new isotopes

2011 (^{124}Xe): 4 new isotopes

2016-2021 (^{124}Xe): 10 new isotopes

Synthesis of New Elements

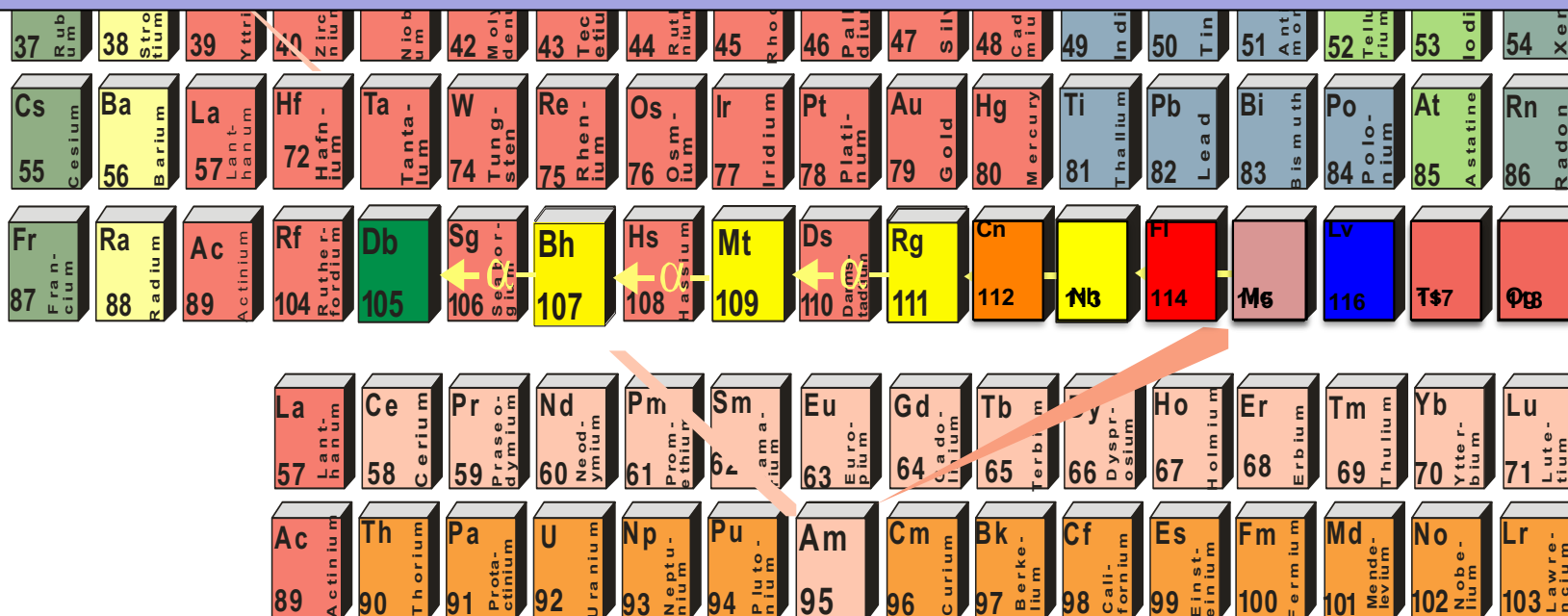


Super Heavy Elements



28/11/2016: IUPAC approves the names of the 4 new elements !

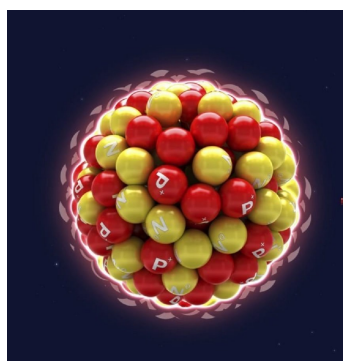
30/12/2015: IUPAC announces that the 7th période of the periodic table is complete!



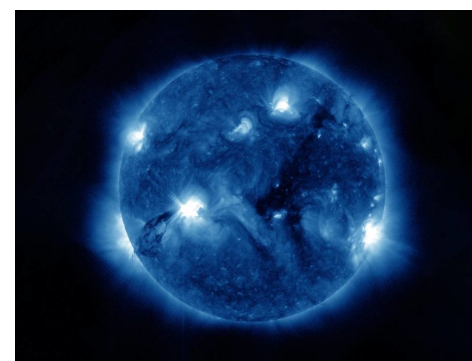
New state of nuclear matter (?)



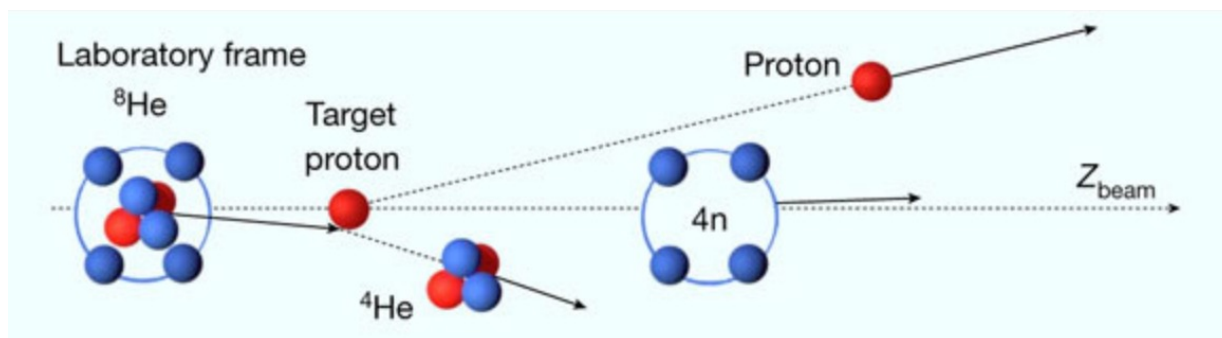
n unstable



n stable/unstable

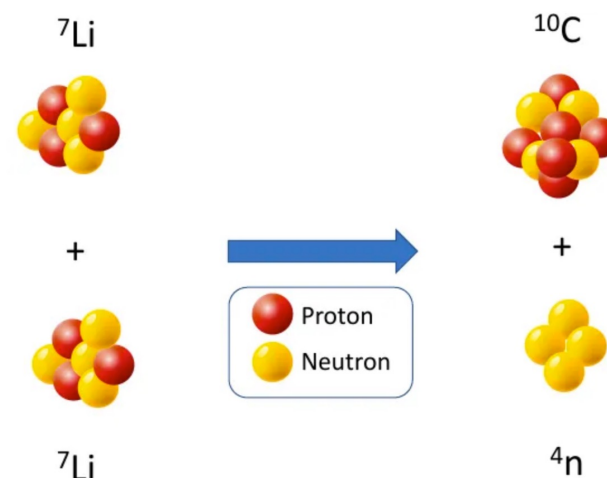


n stable



Observation of a correlated 4-neutron system,
 $T_{1/2} = (3.8 \pm 0.8) \times 10^{-22} \text{ s}$

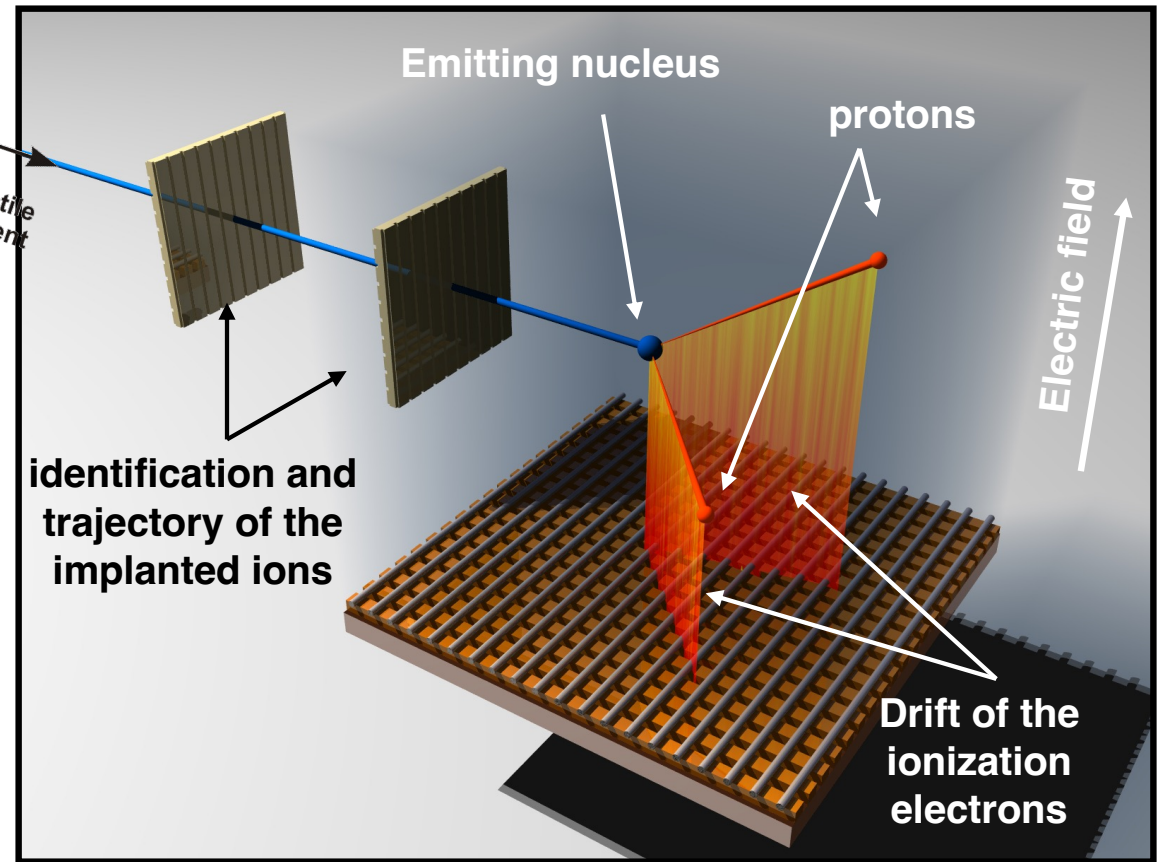
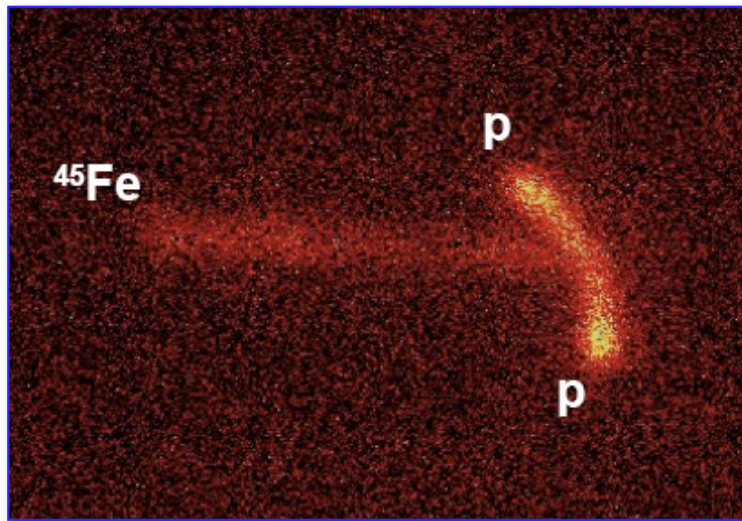
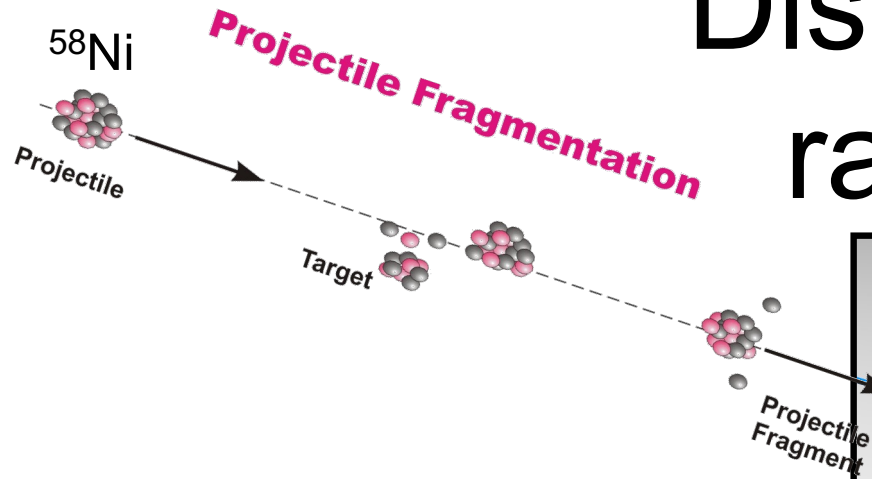
M. Duer et al., Nature 606, 678 (2022)



Observation of a bound 4-neutron system, $T_{1/2} \sim T_{1/2}(n)$

T. Faestermann et al., Phys. Lett. B 824, 136799 (2022)

Discovery of new radioactivities



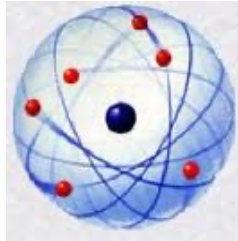
J. Giovinazzo et al., Phys. Rev. Lett. 89, 102501 (2002)
M. Pfützner et al., Eur. Phys. J. A14, 279 (2002)

4 other cases observed since: ^{54}Zn , ^{48}Ni , ^{19}Mg , ^{67}Kr

115 years ago.....

“The scattering of α and β particles by matter and the structure of the atom”

*Philosophical Magazine Series 6,
vol. 21 May 1911, p. 669-688*



1911 Chemistry Nobel Prize
is awarded to Marie Curie

*“in recognition of her services to the
advancement of chemistry by the
discovery of the elements radium and
polonium, by the isolation of radium and
the study of the nature and compounds of
this remarkable element”*



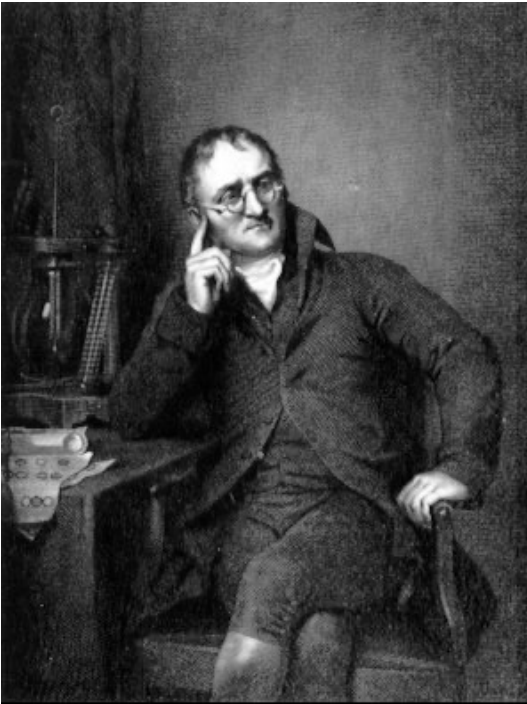
At the dawn of the 20th century



“There is nothing new to be discovered in physics now.
All that remains is more and more precise measurement.”

Phrase attributed to William Thomson (Lord Kelvin), 1900
British Association for the advancement of Science

Constituents of matter



John Dalton

1803 :

- matter is made of **atoms**

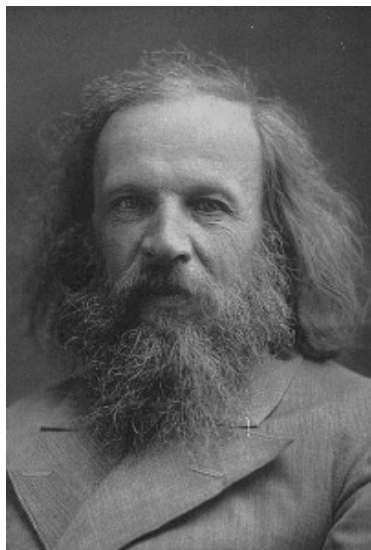
- atoms of the same element are identical

- atoms of an element can combine with those of other elements to form compounds

- atoms of different elements have different masses



Classification of elements



Dmitri Ivanovich
Mendeleev

Regularities in the chemical properties of the elements

ОПЫТЪ СИСТЕМЫ ЭЛЕМЕНТОВЪ.

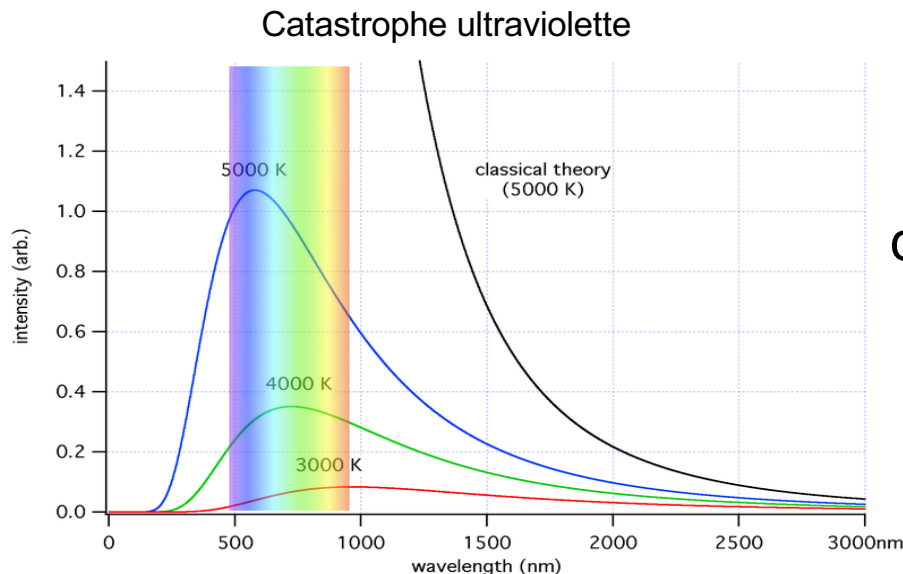
ОСНОВАННОЙ НА ИХЪ АТОМНОМЪ ВѢСѢ И ХИМИЧЕСКОМЪ СХОДСТВѢ.

			Ti = 50	Zr = 90	? = 180.
			V = 51	Nb = 94	Ta = 182.
			Cr = 52	Mo = 96	W = 186.
			Mn = 55	Rh = 104,4	Pt = 197,1.
			Fe = 56	Rn = 104,4	Ir = 198.
			Ni = Co = 59	Pl = 106,6	Os = 199.
			Cu = 63,4	Ag = 108	Hg = 200.
H = 1	Be = 9,4	Mg = 24	Zn = 65,2	Cd = 112	
	B = 11	Al = 27,4	Ga? = 68	Ur = 116	Au = 197?
	C = 12	Si = 28	Ge? = 70	Sn = 118	
	N = 14	P = 31	As = 75	Sb = 122	Bi = 210?
	O = 16	S = 32	Se = 79,4	Te = 128?	
	F = 19	Cl = 35,5	Br = 80	I = 127	
Li = 7	Na = 23	K = 39	Rb = 85,4	Cs = 133	Tl = 204.
		Ca = 40	Sr = 87,6	Ba = 137	Pb = 207.
		Sc? = 45	Ce = 92		
		?Er = 56	La = 94		
		?Yt = 60	Di = 95		
		?In = 75,6	Th = 118?		

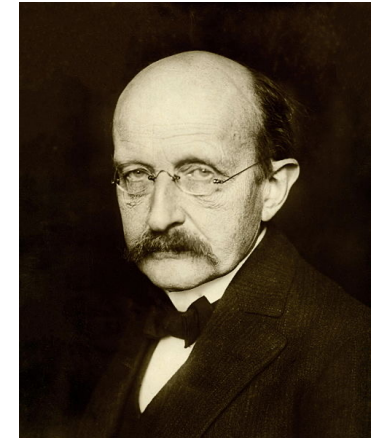
The place of an element in the table is given by the number **Z** (=atomic number, from Atom**Z**ahl)

Д. Менделѣевъ (1869)

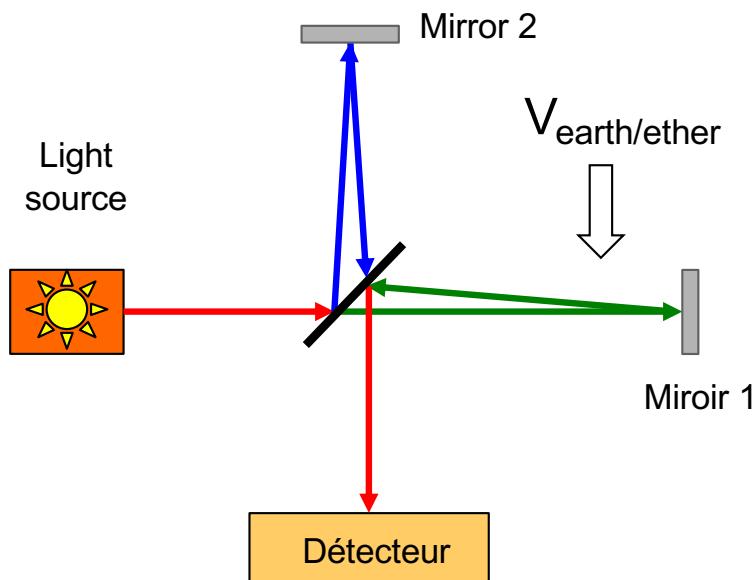
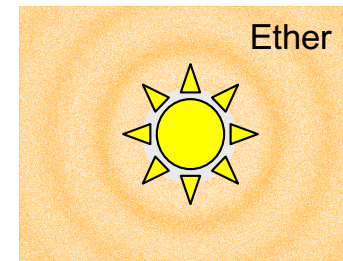
A few clouds in the sky.....



Matter can only absorb or emit radiation energy in discrete packets proportional to the frequency of the radiation: energy **quanta**



Max Planck

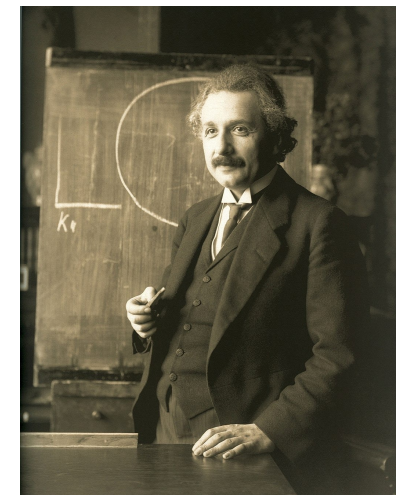


Michelson Morley experiment

Special Relativité :

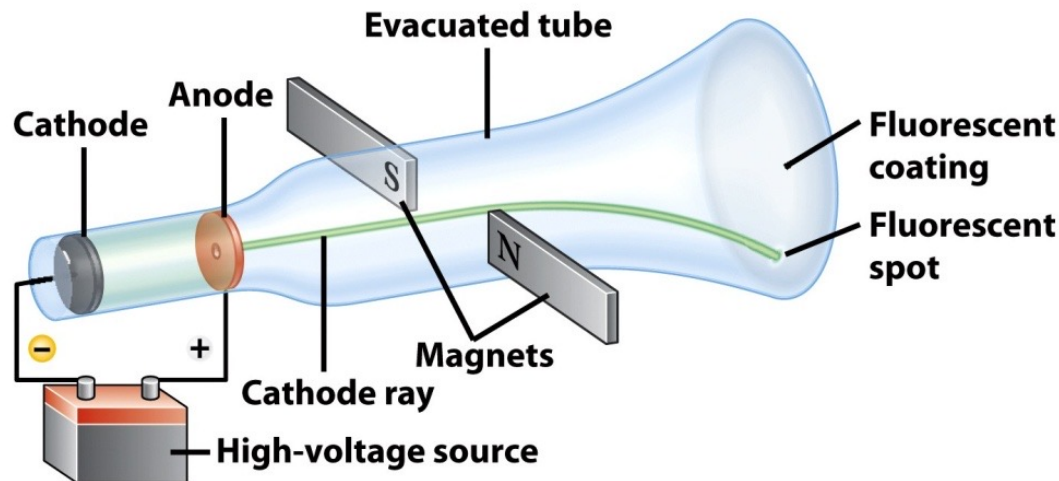
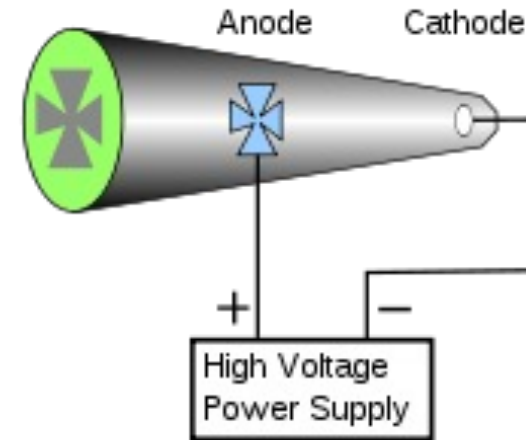
The laws of physics are the same in every inertial frame of reference, and the speed of light is a constant

$$E=mc^2$$



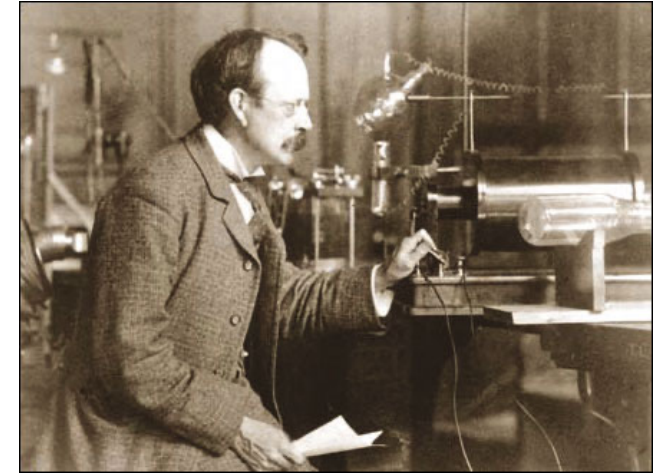
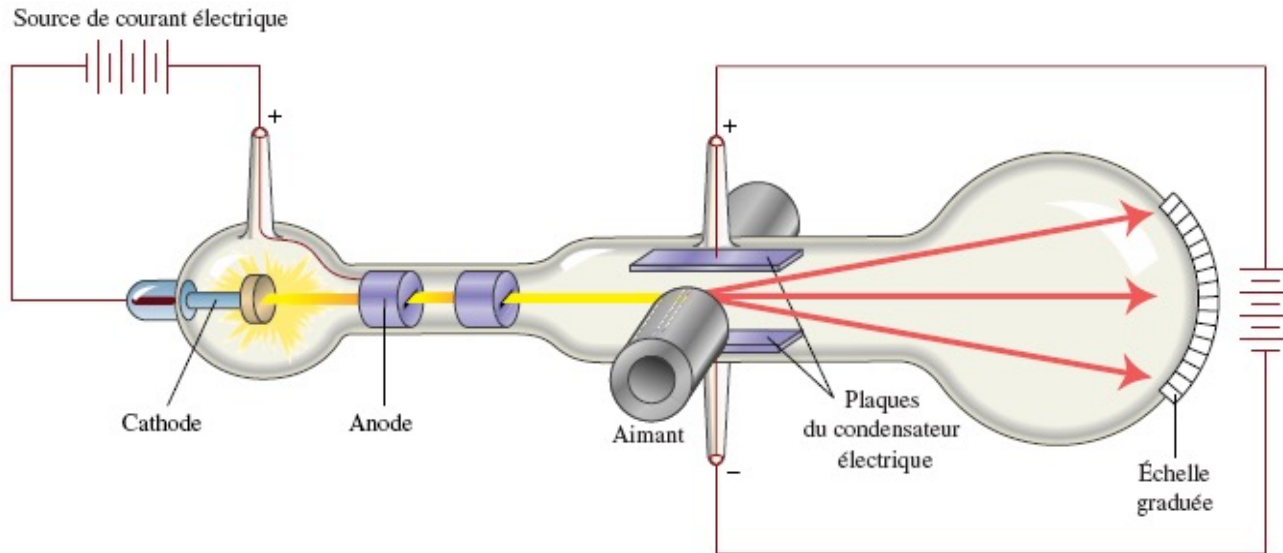
Albert Einstein

The cathode tube leads the revolution



1895: Jean Perrin demonstrates that cathode rays are negatively charged particles

Atoms are no longer indivisible !

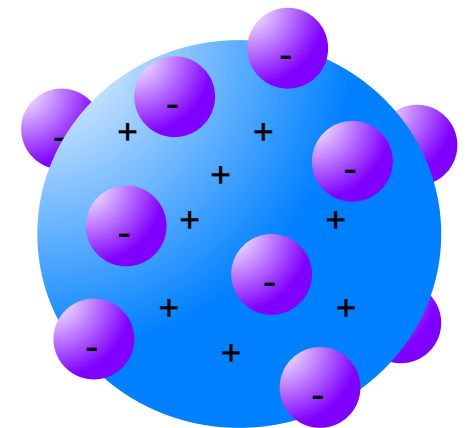


John Joseph Thomson

J.J. Thomson measures the charge/mass ratio of the charged particles

1898: J.J. Thomson concludes that what he calls 'corpuscles' (= electrons) are the constituents of atoms

'plum pudding' model



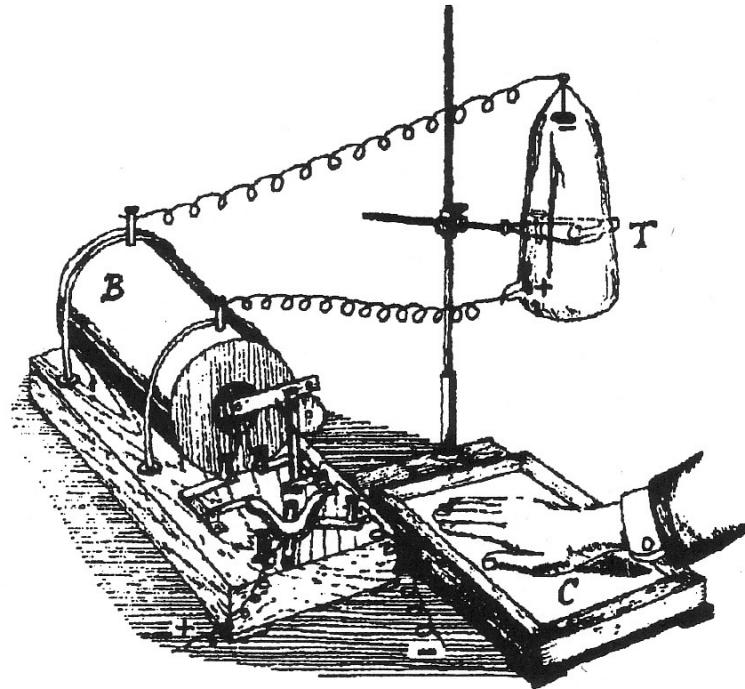
From cathode rays to X rays

1895 W. Röntgen

Discovery of X rays



Wilhelm Röntgen



W. Röntgen receives the 1st Nobel Prize in Physics in 1901



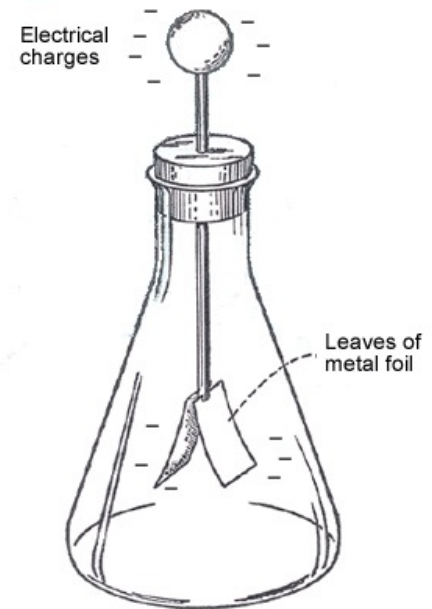
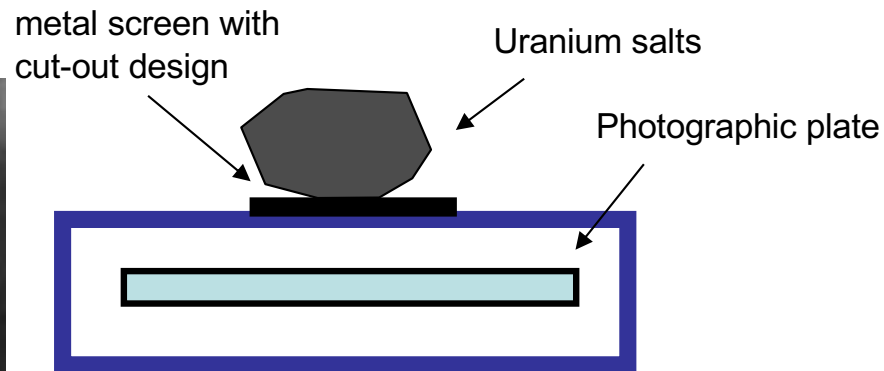
From X rays to Uranium rays

1896 H. Becquerel

Discovery of a new kind of radiation emitted by Uranium



Henri Becquerel



Uranium rays ionize the air and cause the discharge of an electroscope

From Uranium rays to radioactivity

1898 Marie & Pierre Curie

extraction of Polonium (Bismuth fraction)
and Radium (Barium fraction)



Marie Curie

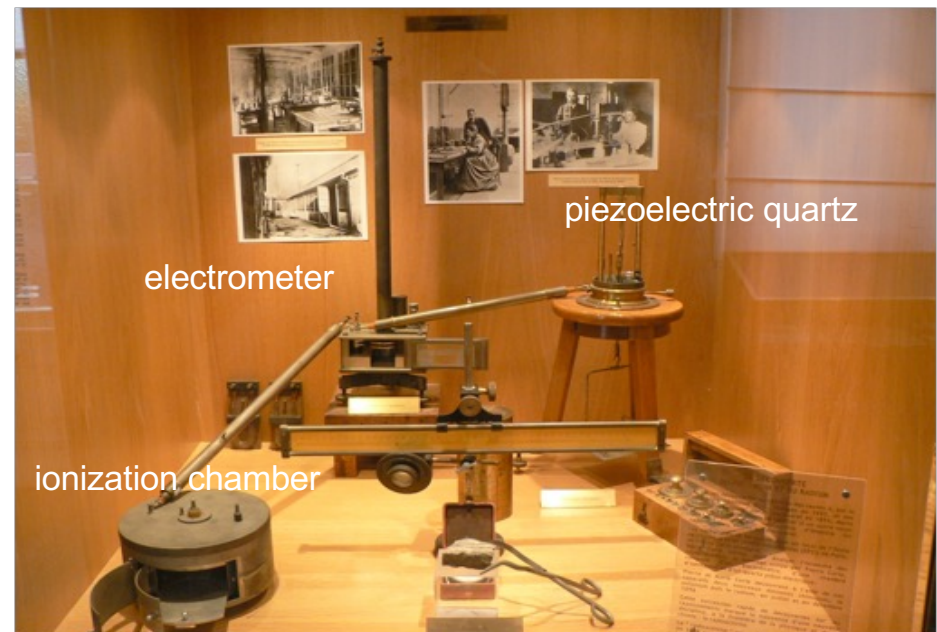


Pierre Curie

M. Curie calls the phenomenon:
'radioactivity'

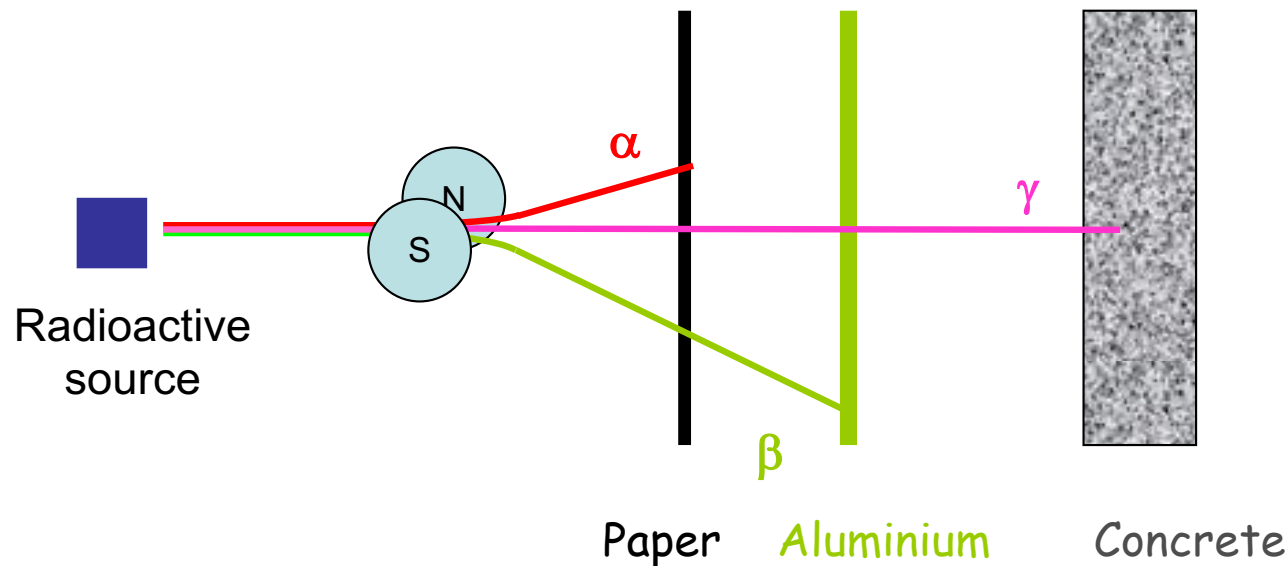


Laboratoire à l'Ecole de Physique et Chimie Industrielle de Paris



Radioactivity is manifold

1898 E. Rutherford alpha, beta radiation
1900 P. Villard gamma radiation



α = Helium ions He^{2+}

β = high-energy e^-

γ = photons – like X rays



Ernest Rutherford

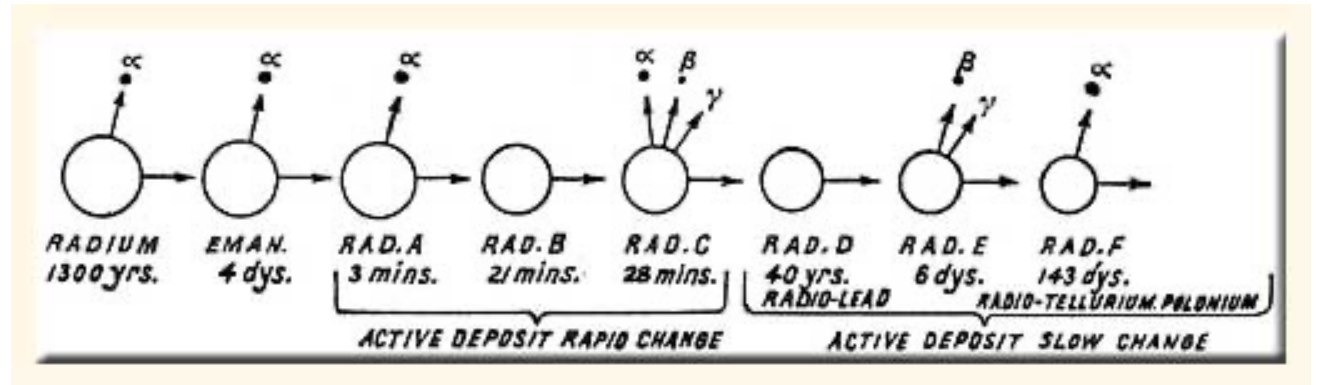
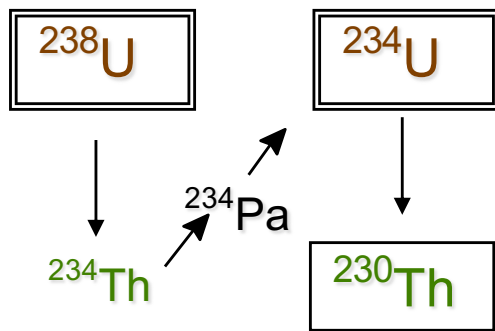


Paul Villard

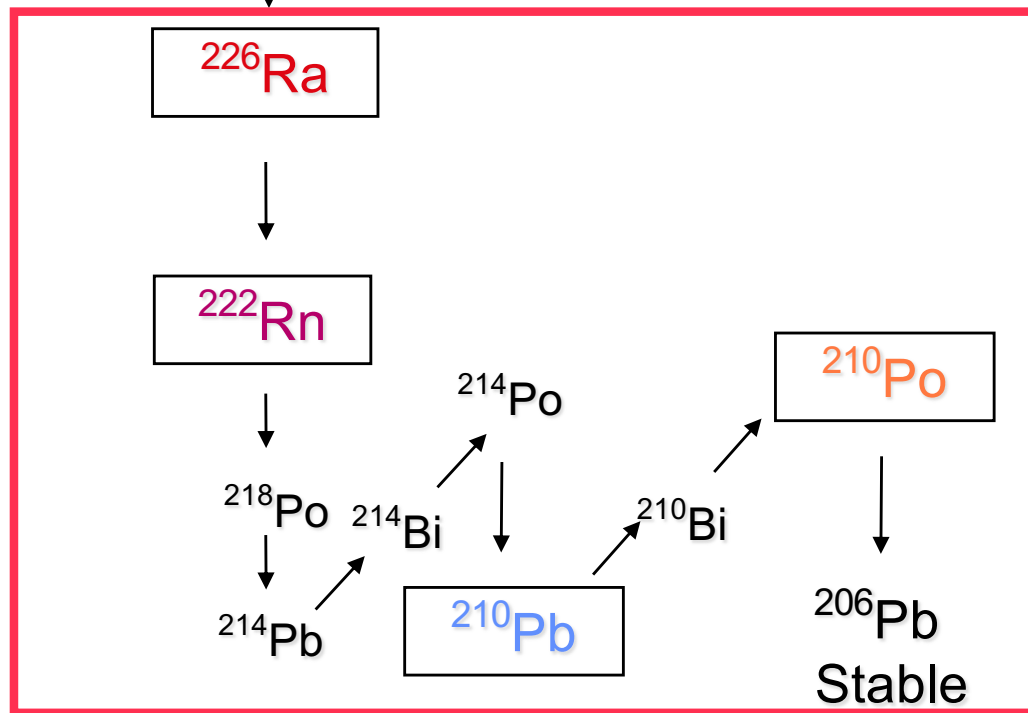
Atoms transform !

1902 E. Rutherford & F. Soddy

transmutation of atoms



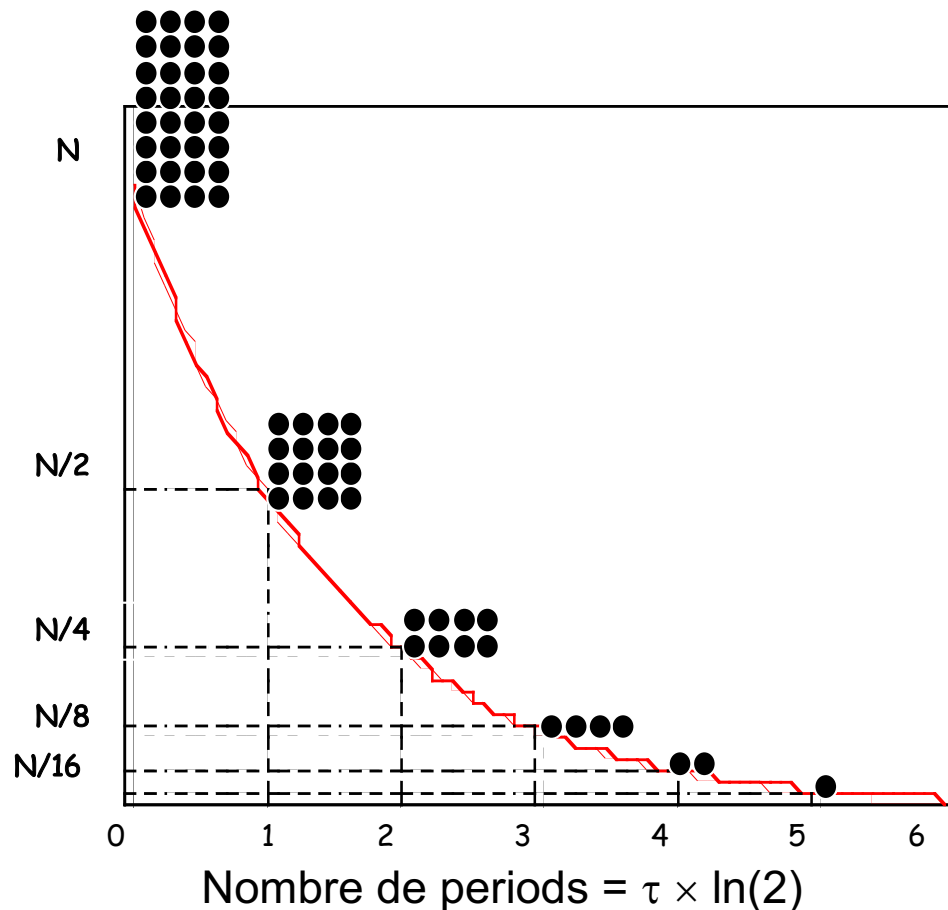
Philosophical Transactions of the Royal Society of London, 1905



β, γ
radioactivity

α radioactivity

Radioactive decay



$$N(t) = N_0 \exp(-\lambda t)$$

$$Activité = \lambda N(t) = N(t)/\tau$$

Some examples of activities:

Man : 130 Bq/kg

House made of granit: 4 billion Bq

Concrete: 500 Bq/kg

Milk: 80 Bq/kg

Thyroid Scintigraphy : 37 million Bq

Spent reactor fuel: 10 billion billion Bq

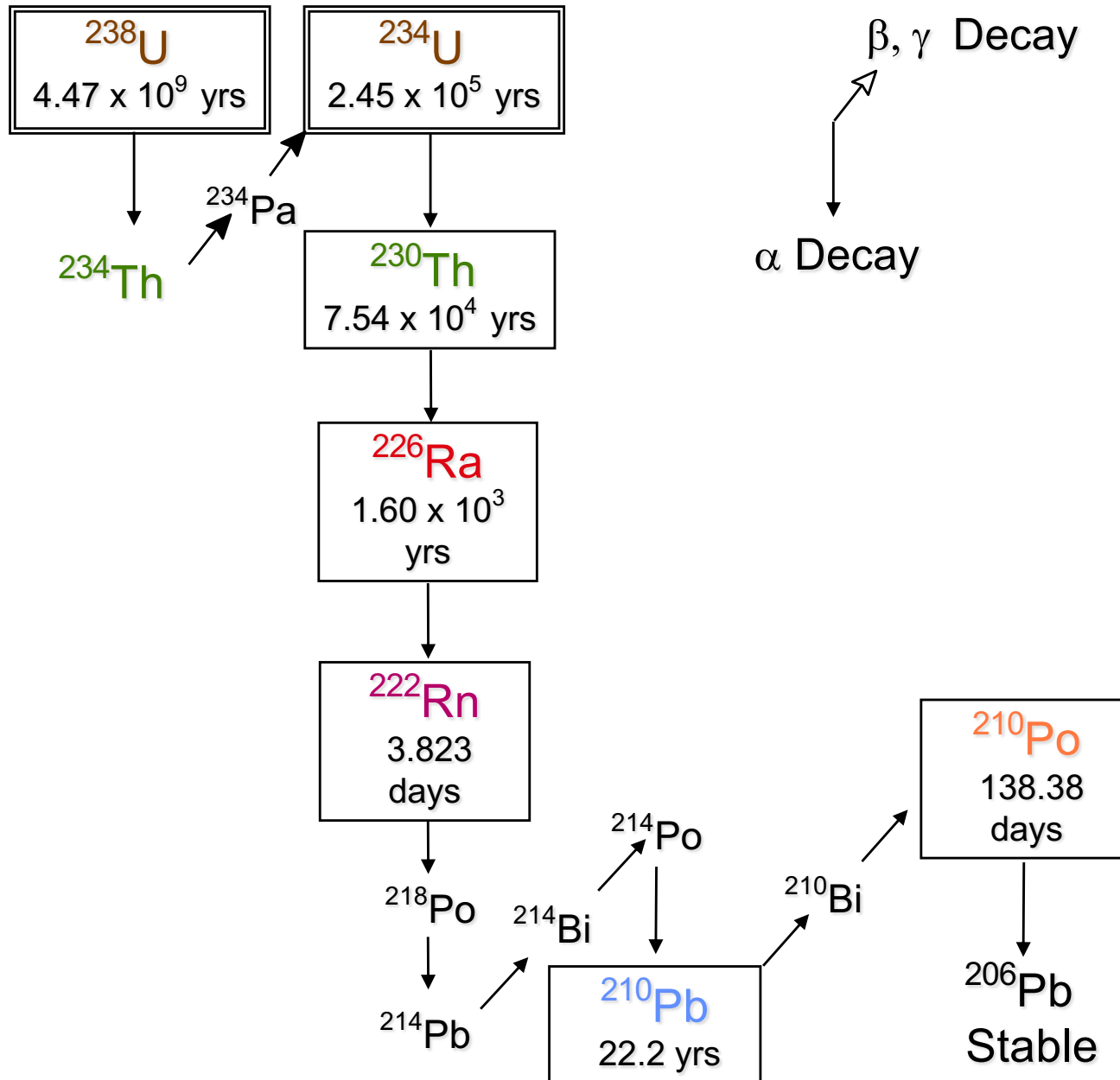
1910:

1 curie (Ci) = activity of 1g of Radium

1 Ci = 37 billion decays/s

1 Bq = 1 decay/s

Telluric radiation



Age of the earth:
~ 4.5×10^9 years

Half-lives:

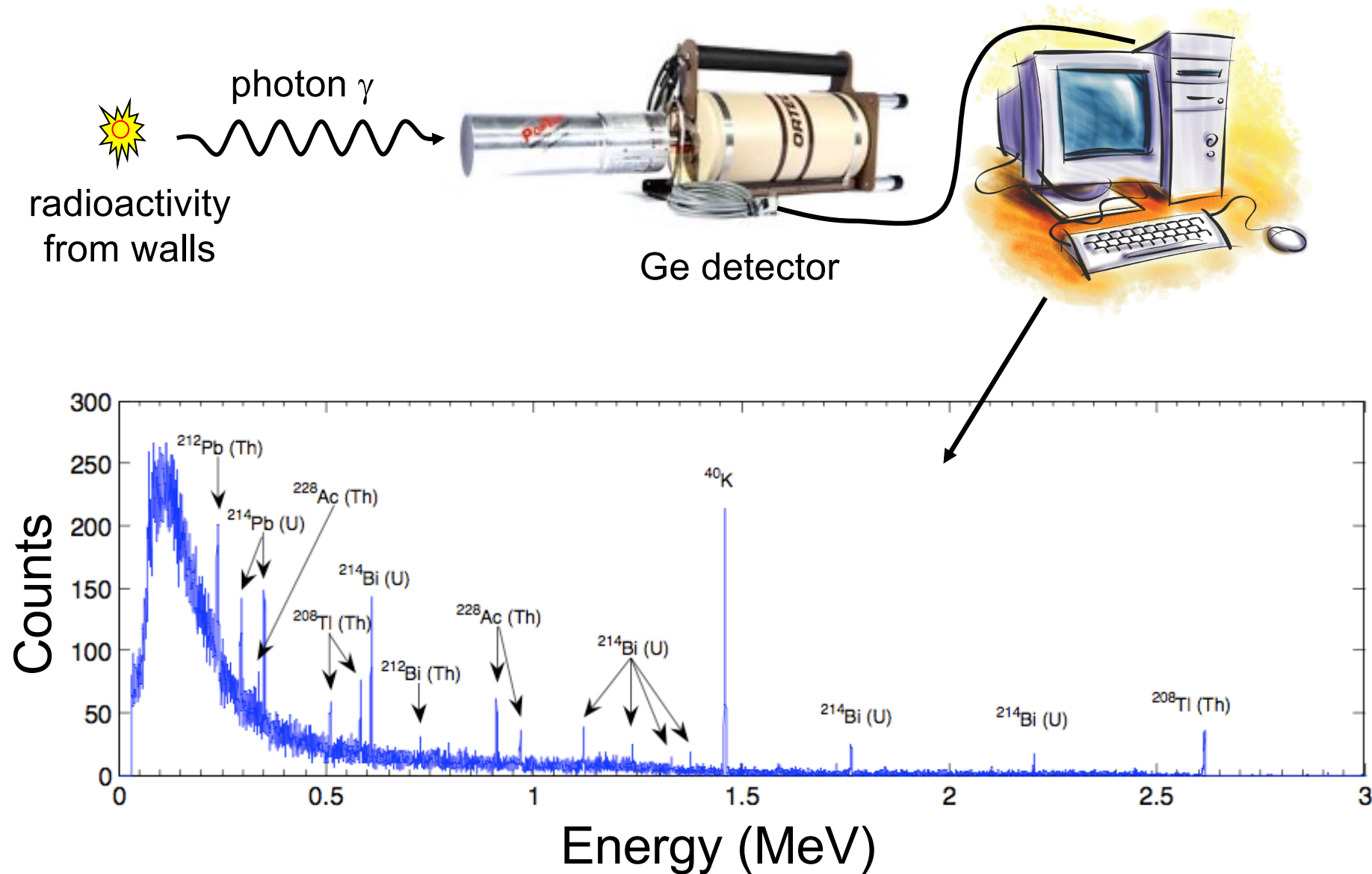
^{232}Th : 1.40×10^{10} y

^{235}U : 7.04×10^8 y

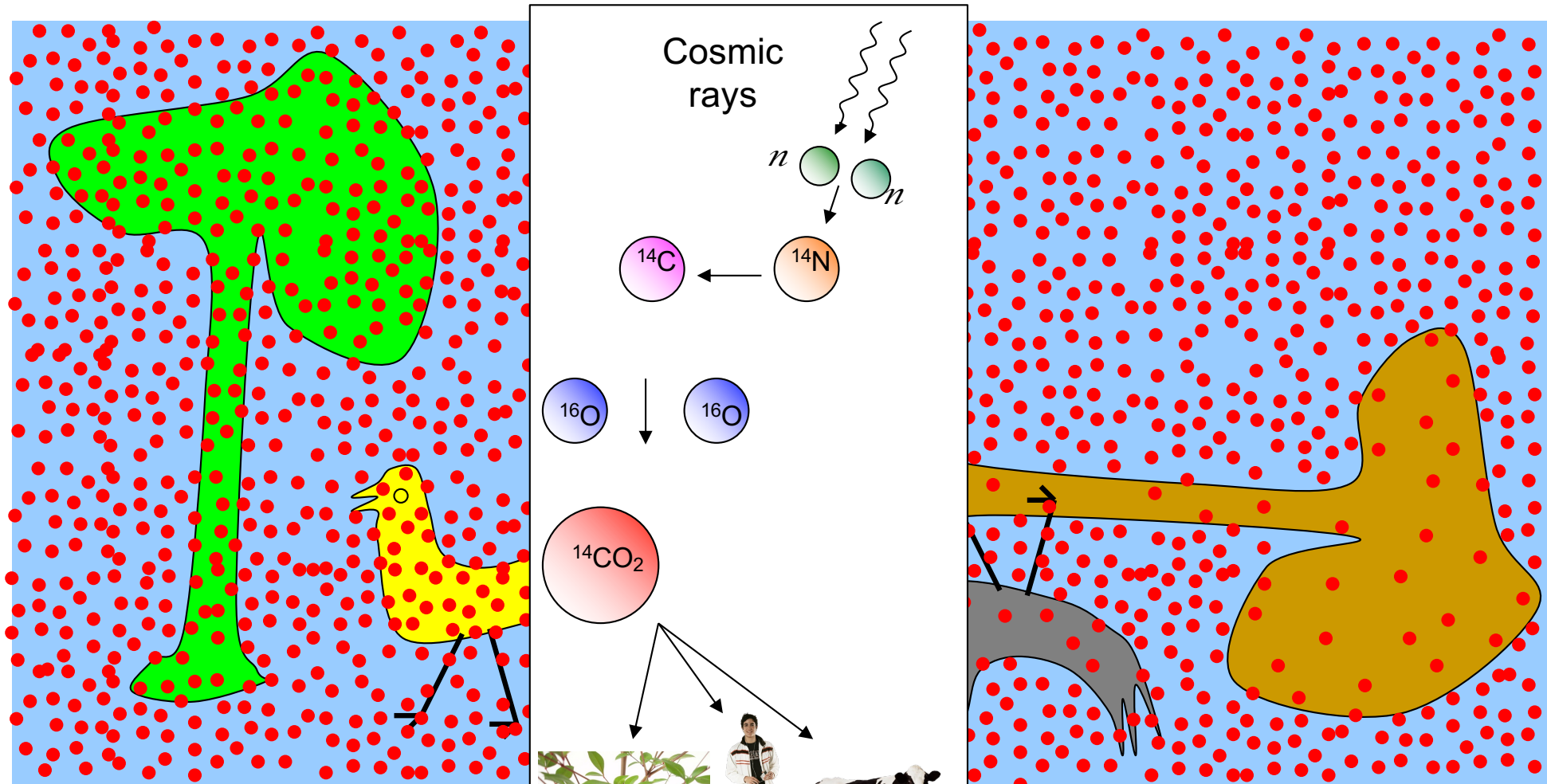
^{238}U : 4.47×10^9 y

^{40}K : 1.2×10^9 y

Telluric radiation



Comogenic radiation



The living world
interacts with the atmosphere

When death occurs, the exchange
stops, and ^{14}C decays with a half-life of
5,730 years: R decreases

Abundance ratio $R = ^{14}\text{C}/^{12}\text{C} \approx 10^{-12}$

Ötzi, the Iceman



In September 1991, hikers discovered Ötzi (the Iceman) in the Italian Alps. An activity of 0.121 Bq per 1 g of C was measured



$t = 4546$ years



South Tyrol Museum of Archaeology, Bolzano

Radioactivity and Energy

1903: Pierre Curie and his collaborator Albert Laborde find that radium gives off enough heat to melt more than its weight of ice in an hour

Where does this energy come from ?

« There is reason to believe that an enormous store of latent energy is resident in the atoms of radioactive elements. If it were ever possible to control at will the rate of disintegration of the radioelements, an enormous amount of energy could be obtained from a small amount of matter. »

‘Radioactivity’, E. Rutherford, Ed. Cambridge at the University Press (1904)

1914: H.G. Wells publishes “The world set free”

Radioactivity and age of the earth

Lord Kelvin:

- ~tens of millions of years
- cooling from an initially molten state
- quantitative arguments

Geologists and biologists:

- ~hundreds of millions of years
- fossils, evolution, speed of sedimentation....
- Qualitative arguments

Discovery of radioactivity:

The decay of radioactive minerals in the earth is a source of heat which helps to invalidate Kelvin's calculations (in addition to the fact that he had not taken convection into account)

Geothermal heat flow: 44.2 ± 1.0 TW
Contribution from radioactive nuclei of ^{238}U , ^{232}Th and ^{40}K : ~50%

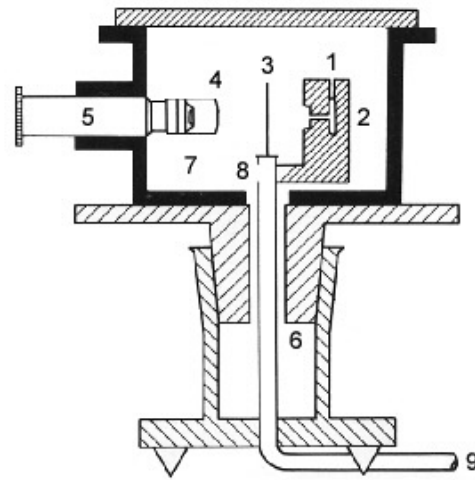
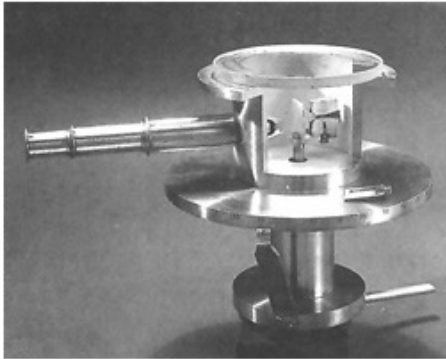
Nature Geoscience 4 (2011) 647



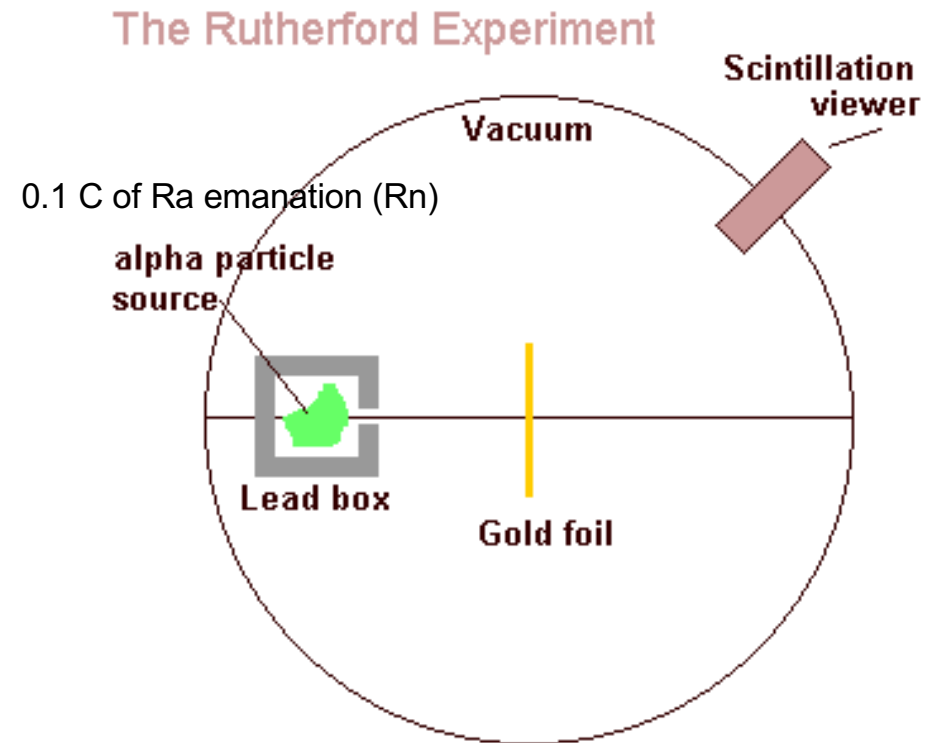
The discovery of radioactivity revolutionized science and society in a profound and lasting way.

But that wasn't the end of it...

Scattering of alpha particles



Experiment performed by H. Geiger and E. Marsden
(1909, University of Manchester)

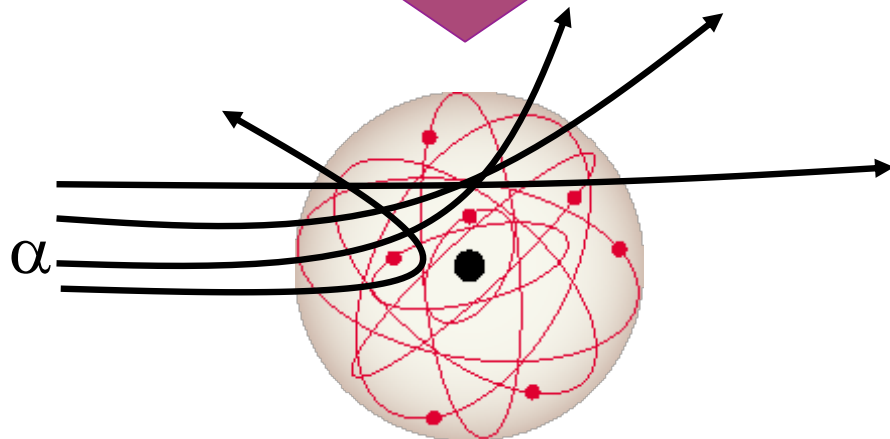
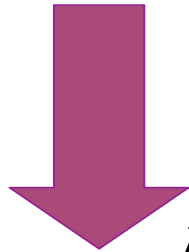
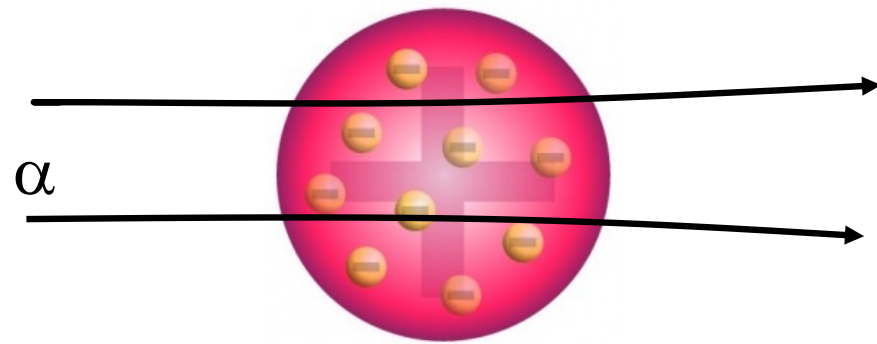


©1999 Science Joy Wagon

“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! ”

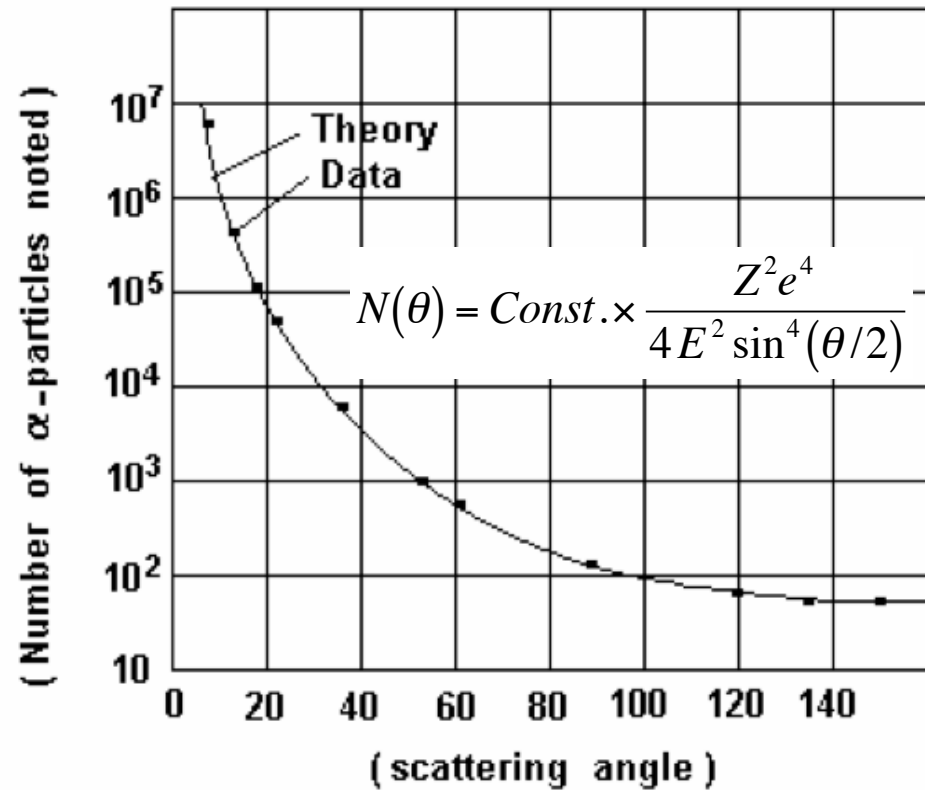
The nucleus is born !

'plum pudding' model

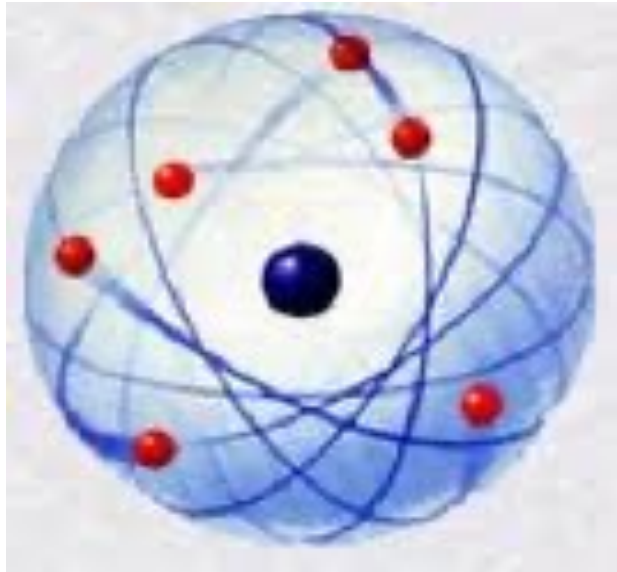


Nuclear model

*Philosophical Magazine Series 6,
vol. 21 May 1911, p. 669-688*



Consequences of Rutherford's model



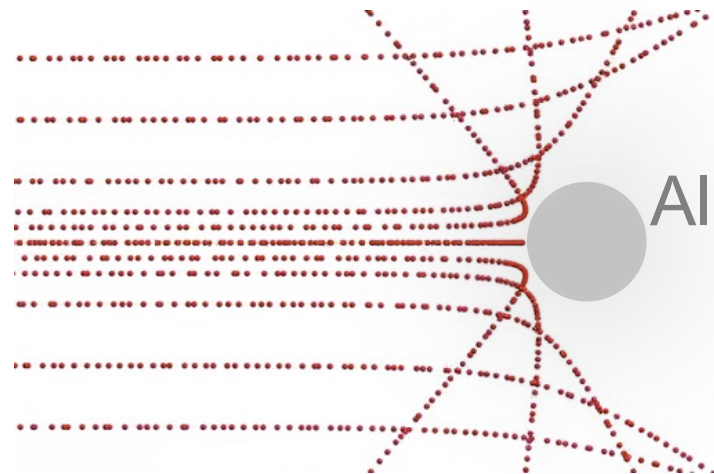
10^{-14} m

10^{-10} m

Matter is empty !



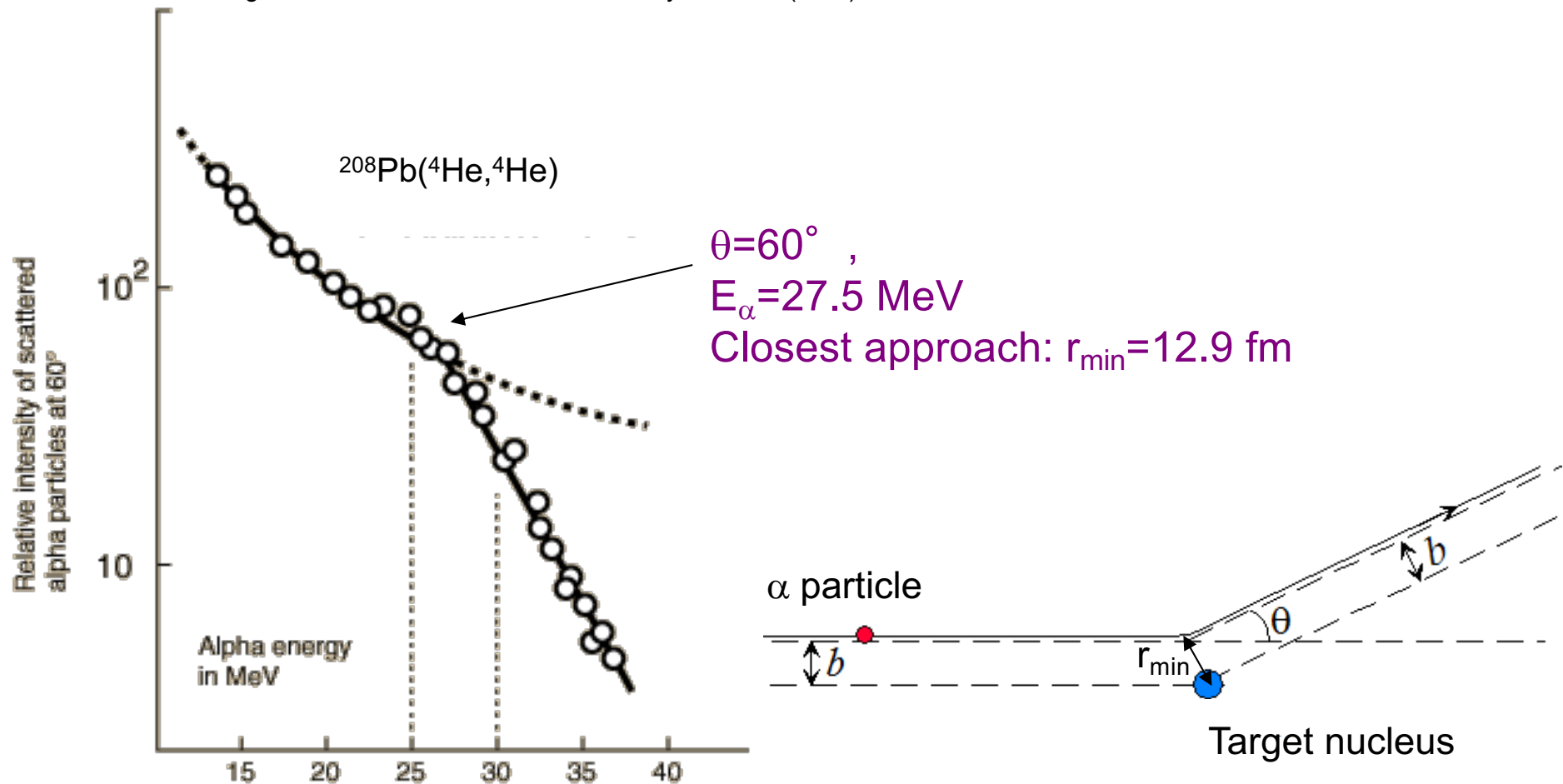
$E_{\alpha}(\text{source}) < 7.7 \text{ MeV}$



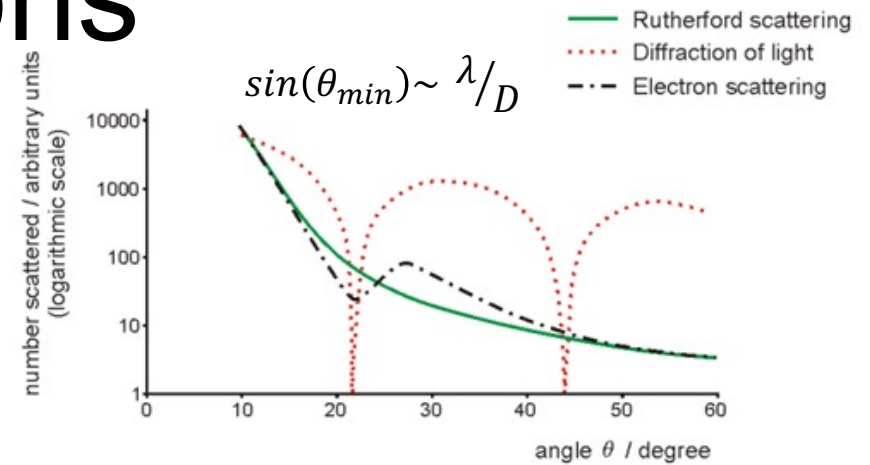
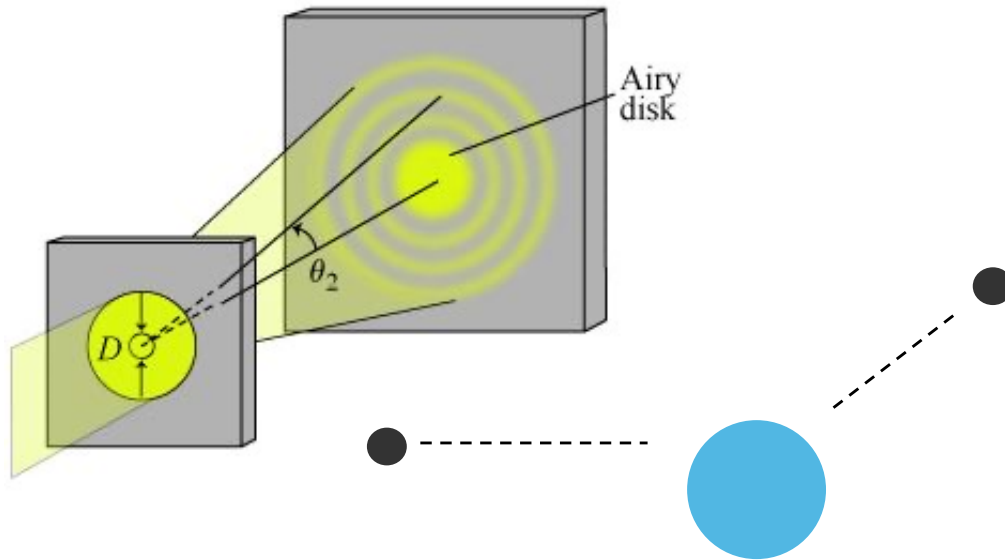
Closer to the nucleus

At higher energies, α particles can get very close to a heavy nucleus and feel the effects of the nuclear force

Eisberg, R. M. and Porter, C. E., Rev. Mod. Phys. 33, 190 (1961)



Scattering experiments with electrons



H.F. Ehrenberg et al., Phys. Rev. 113 (1959) 666

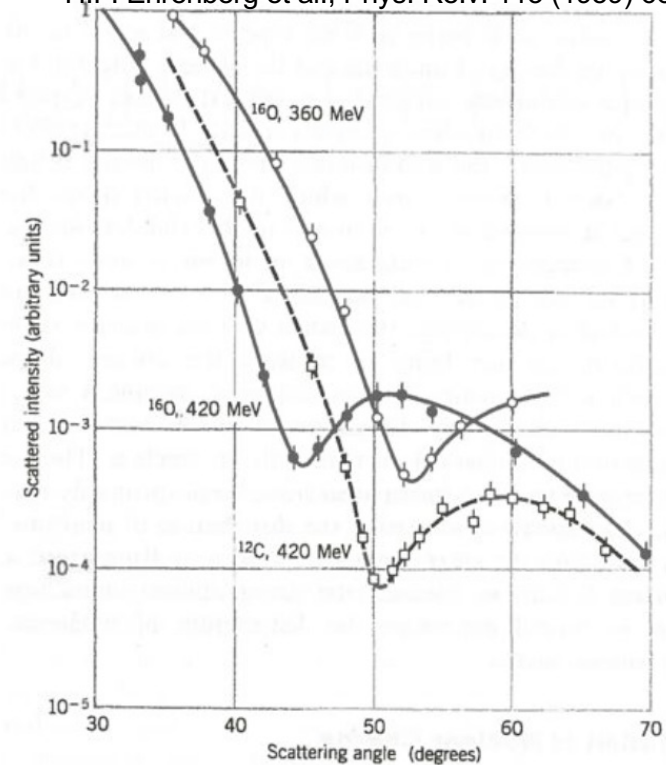
Case of ^{16}O at 360 MeV:

1st minimum at $\theta = 52^\circ \sim \sin^{-1}(\lambda/D)$

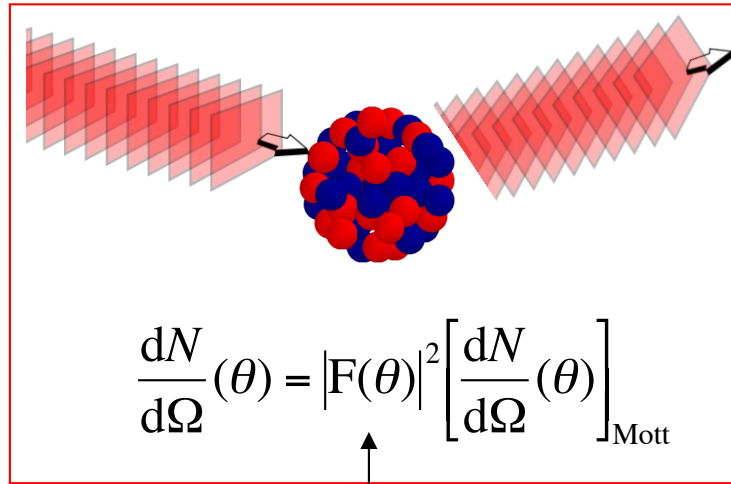
$E_e = 360 \text{ MeV}$

$p = E/c$ ($E \gg mc^2$)

$\lambda = h/p \Rightarrow R = D/2 = 2.6 \text{ fm}$

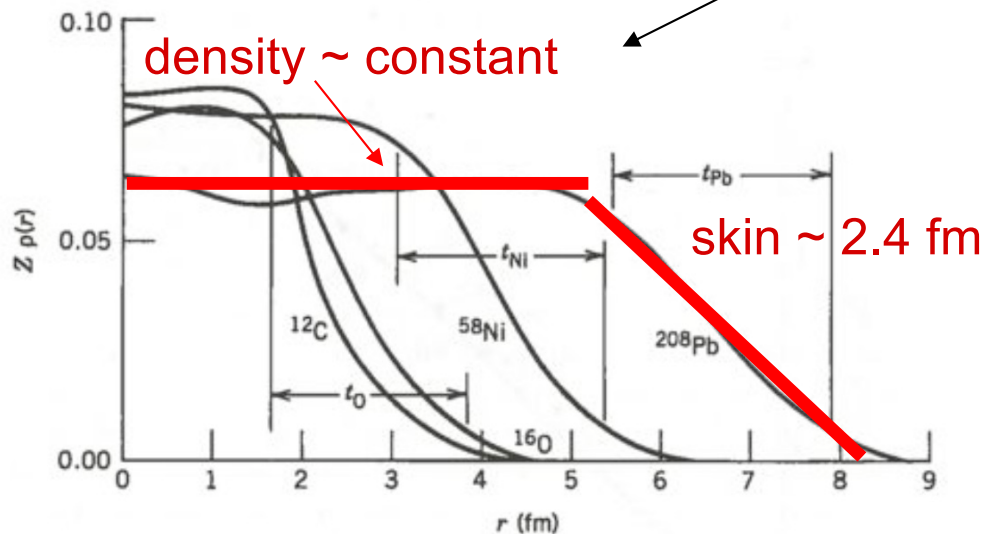


Charge distribution

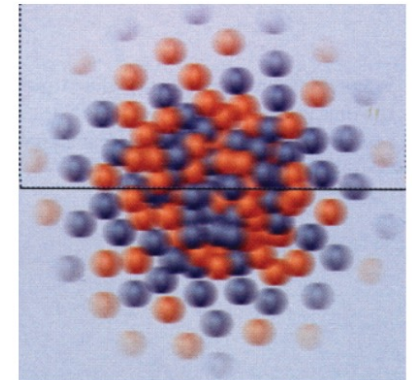


$$\frac{dN}{d\Omega}(\theta) = |F(\theta)|^2 \left[\frac{dN}{d\Omega}(\theta) \right]_{\text{Mott}}$$

Form factor

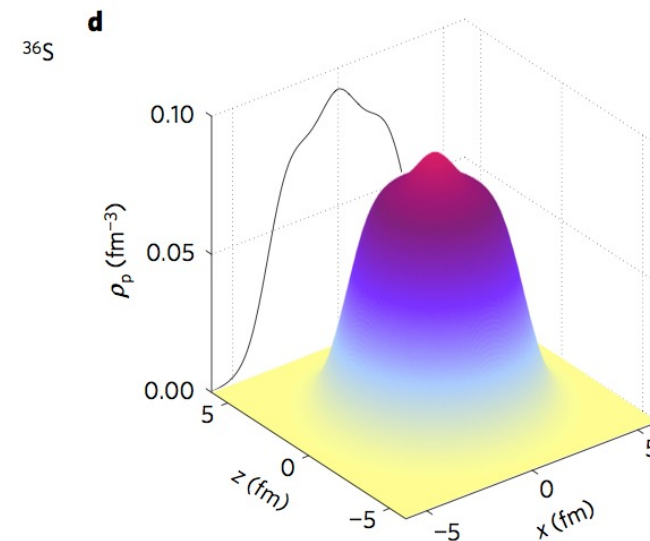
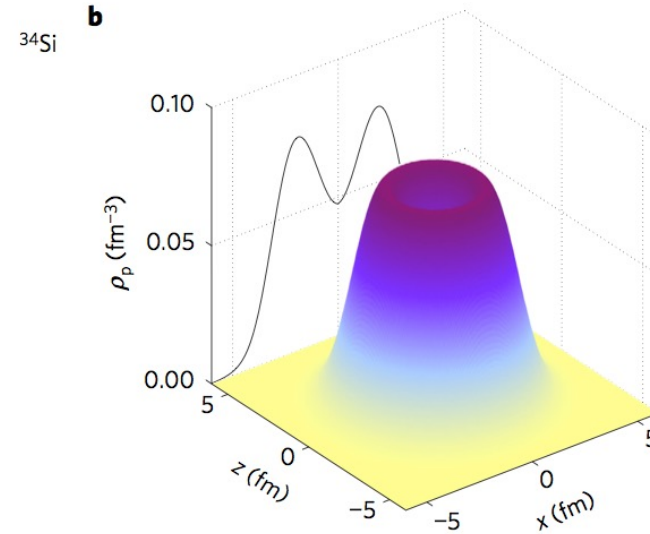
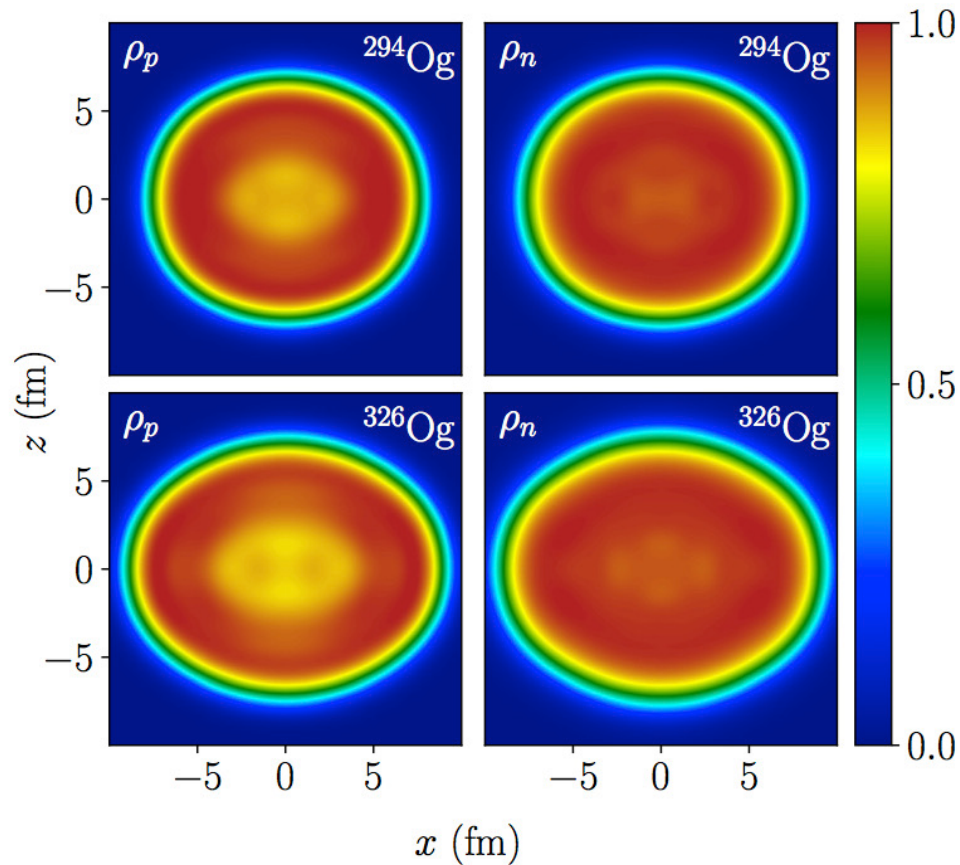


Nuclide	Fraction in "Skin"
¹² C	0.90
²⁴ Mg	0.79
⁵⁶ Fe	0.65
¹⁰⁷ Ag	0.55
¹³⁹ Ba	0.51
²⁰⁸ Pb	0.46
²³⁸ U	0.44



Central depression and bubble nuclei ?

B. Schuetrumpf et al., Phys. Rev. C 96 (2017) 024306

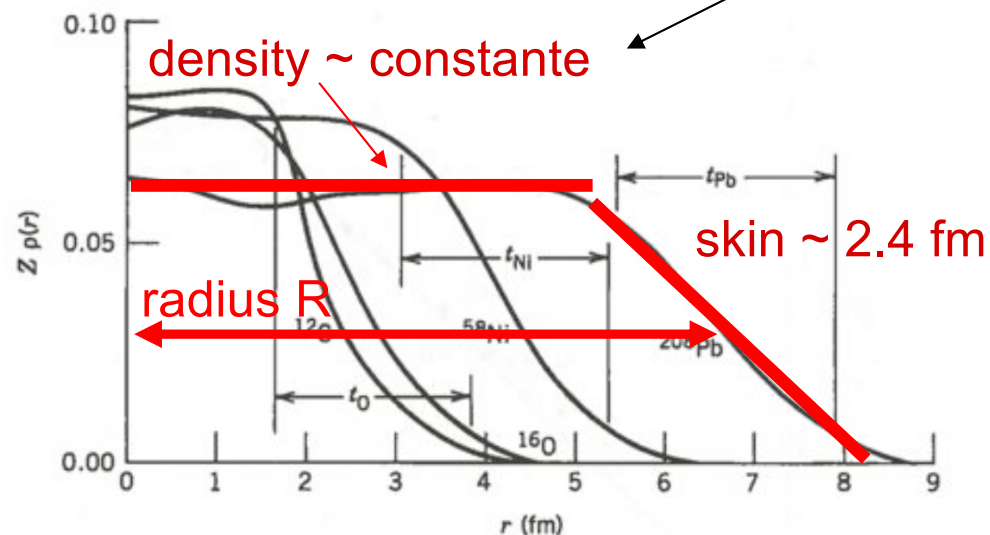


A. Mutschler et al., Nature Physics 13 (2017) 152

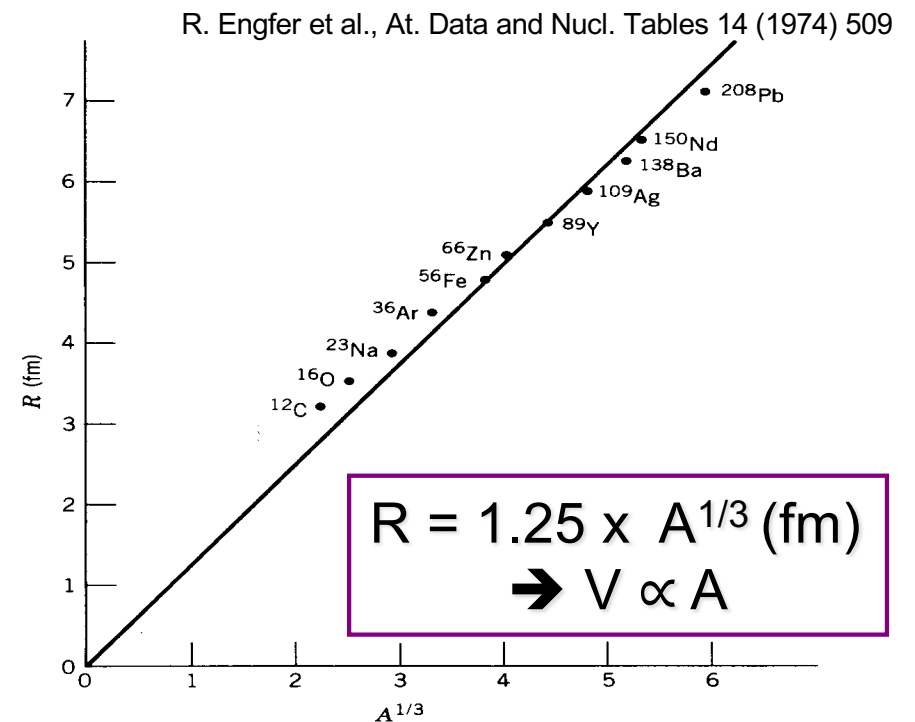
Charge distribution

$$\frac{dN}{d\Omega}(\theta) = |F(\theta)|^2 \left[\frac{dN}{d\Omega}(\theta) \right]_{\text{Mott}}$$

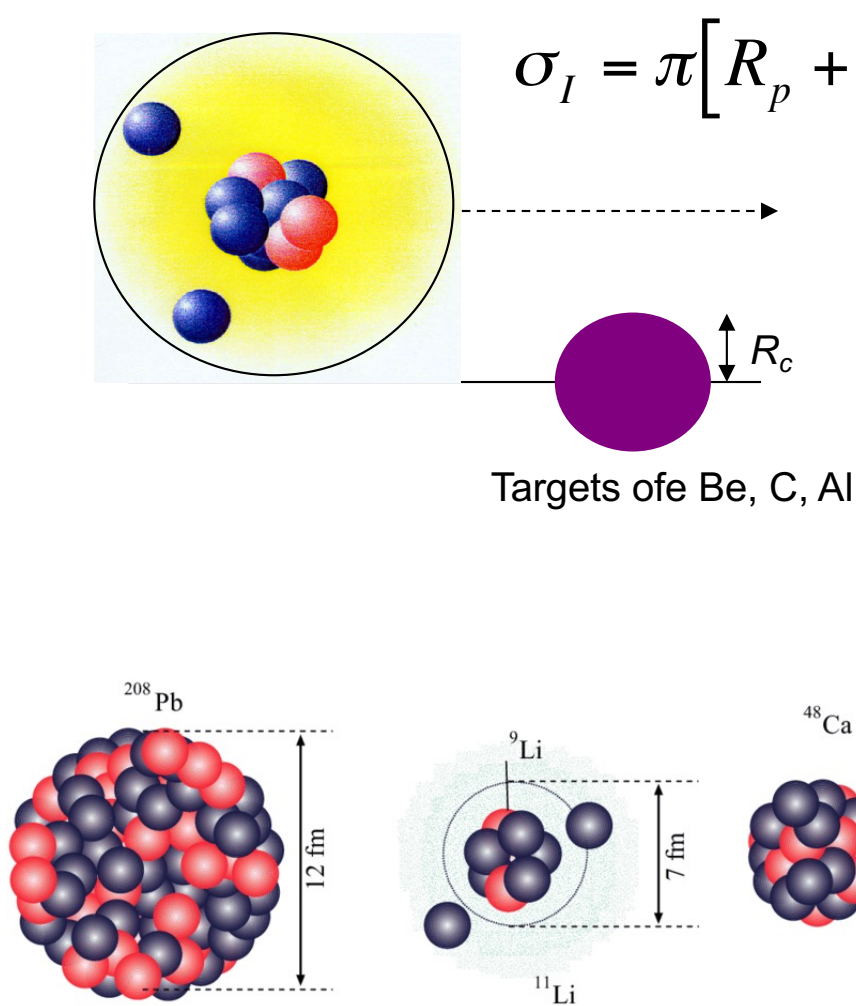
facteur de forme



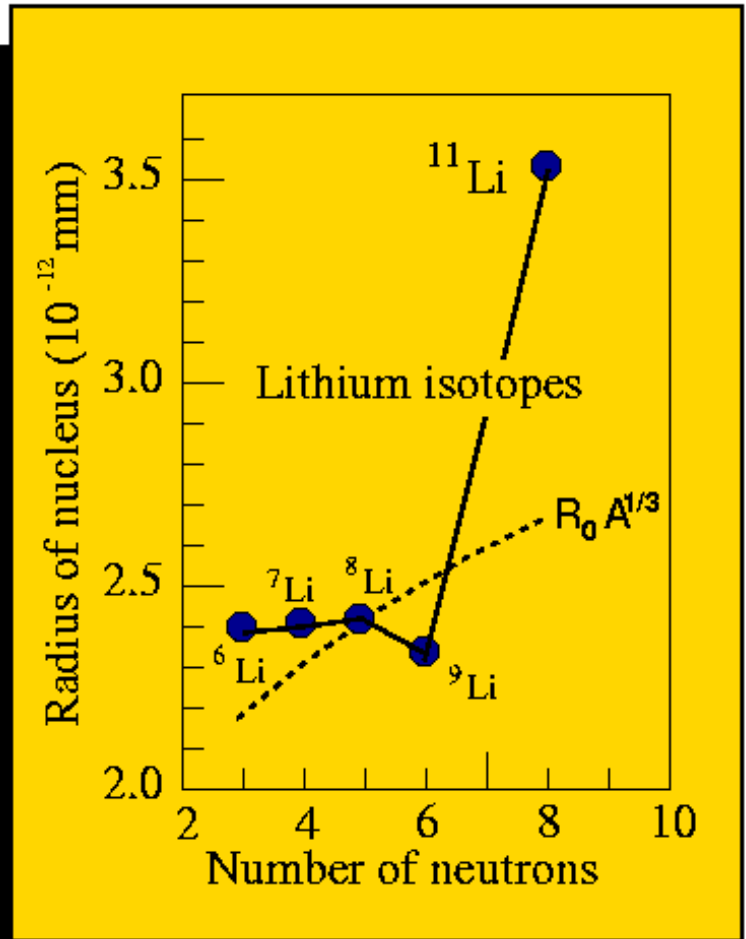
K. S. Krane, Introductory Nuclear Physics, John Wiley & Sons



Some notable exceptions...

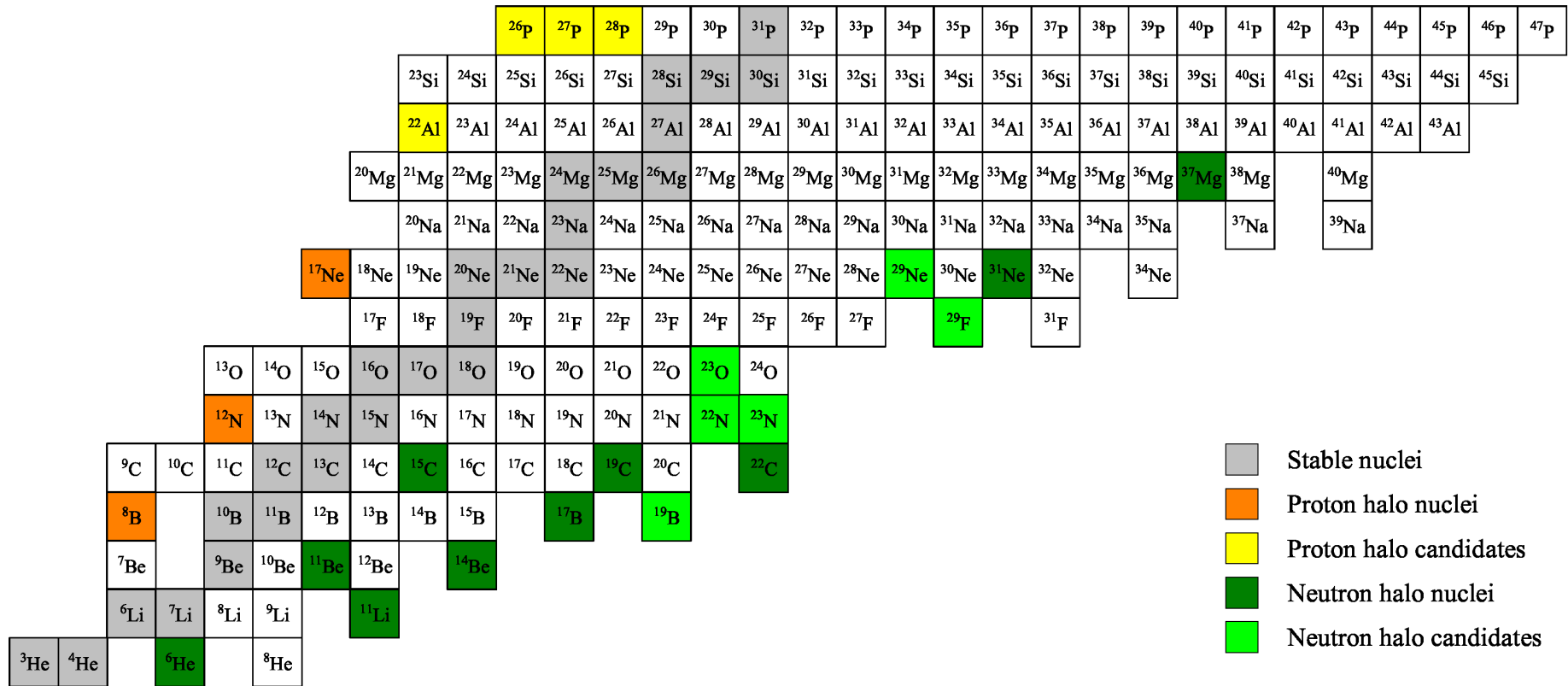


I. Tanihata et al., PRL 55 (1985) 2676



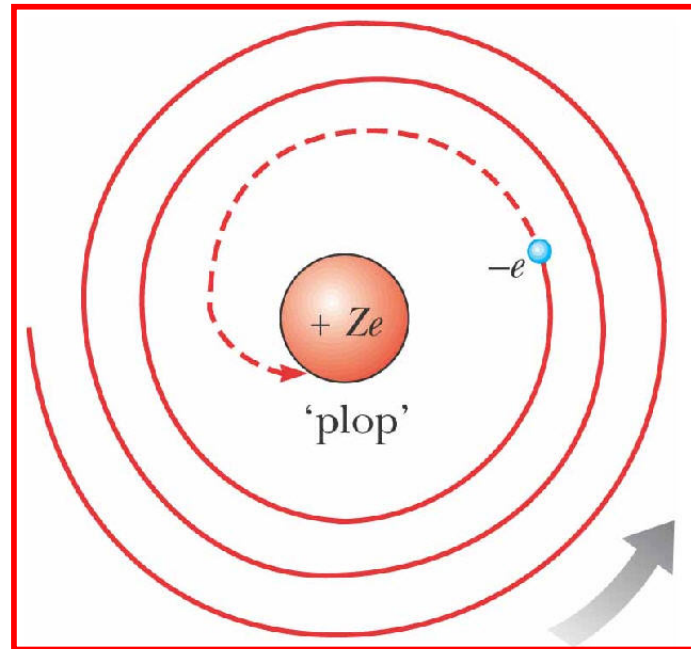
^{11}Li is a Borromean nucleus: if one of the three components is removed, the system is no longer bound (^{10}Li and $2n$ are not bound)

Halo nuclei



Y. Xiang et al., Symmetry **2023**, 15(7), 1420;

Consequences of Rutherford's model



The atom is unstable

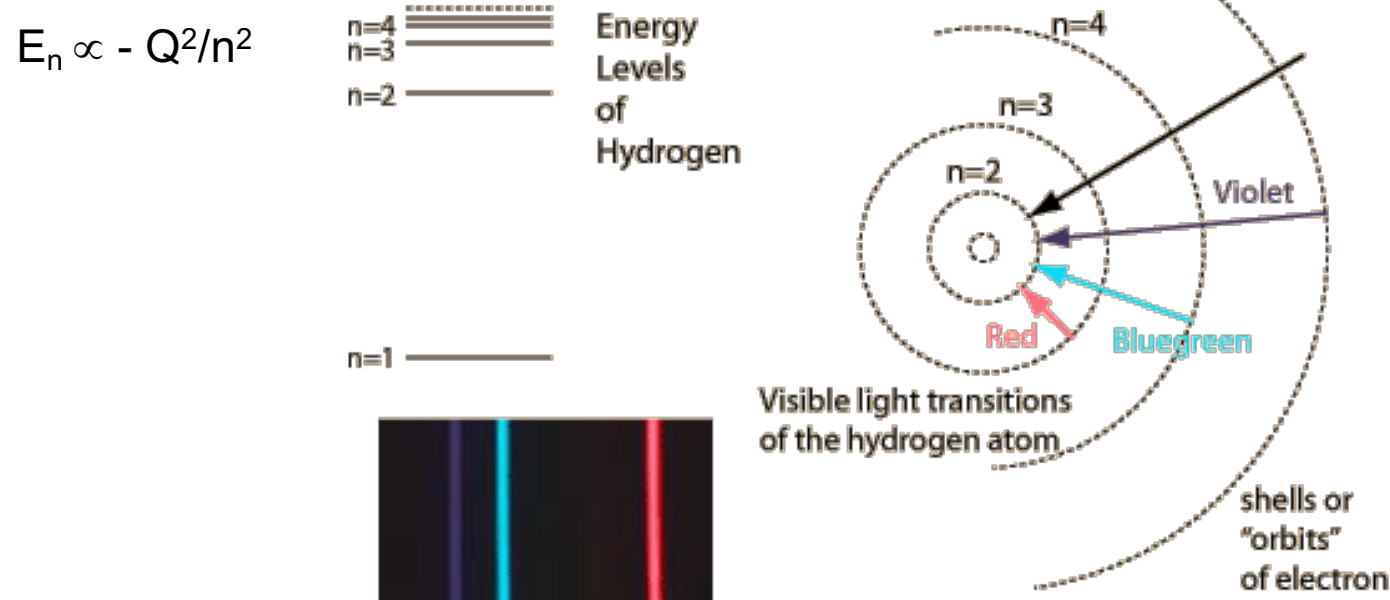
Bohr solves the problem with Planck's quanta

- angular momentum is quantized $\Leftrightarrow$ only certain orbits of energy E_n ($n=1,2,3,\dots$) are allowed
- n is the principal quantum number
- electronic jumps from one orbit to another are accompanied by the emission (or absorption) of a photon of given wavelength



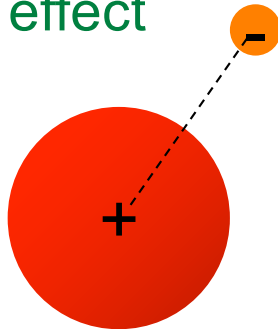
Niels Bohr

Philosophical Magazine **26**, 1-25 (1913)



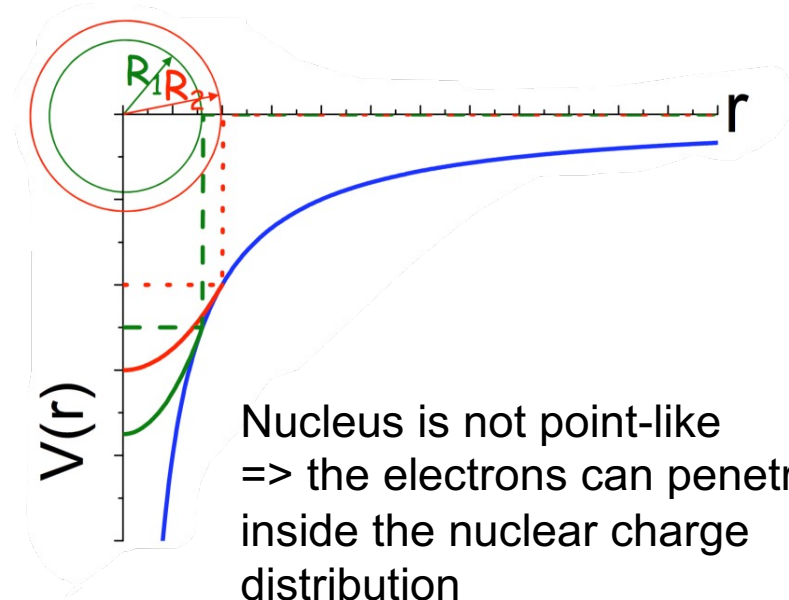
Isotopic shifts

Mass effect

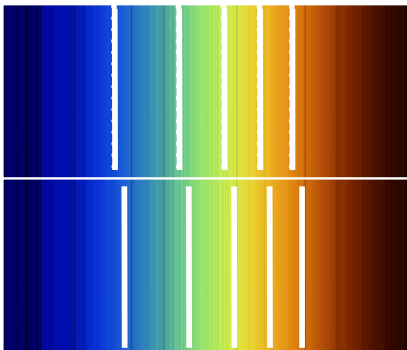


Nucleus is not infinitely massive
=> reduced electronic mass

Field effect



Isotope A



Isotope A'

Mass effect

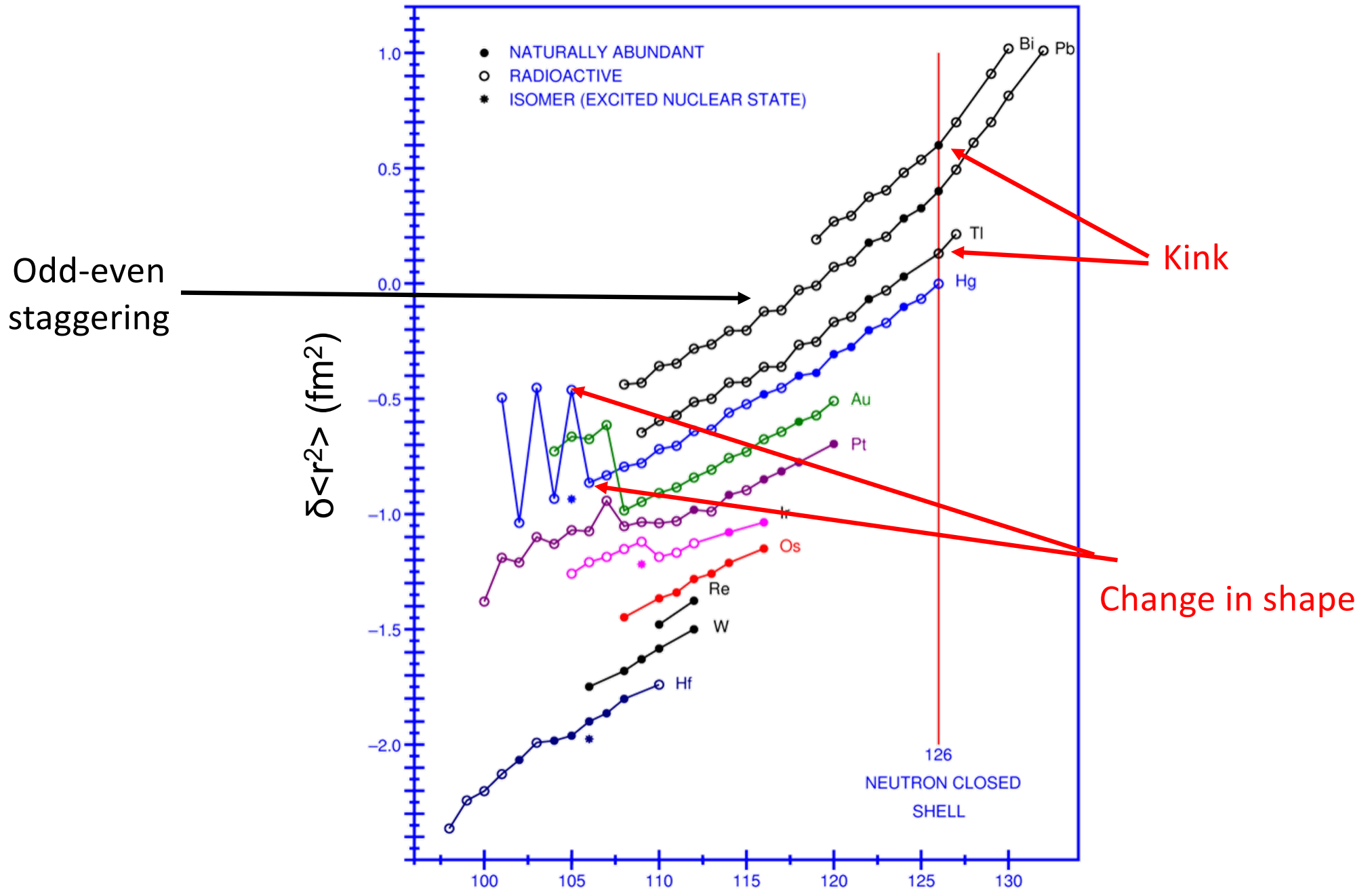
$$\delta \nu^{A,A'} = M \frac{A' - A}{AA'} + F \delta \langle r^2 \rangle^{A,A'}$$

Atomic factors

Field effect

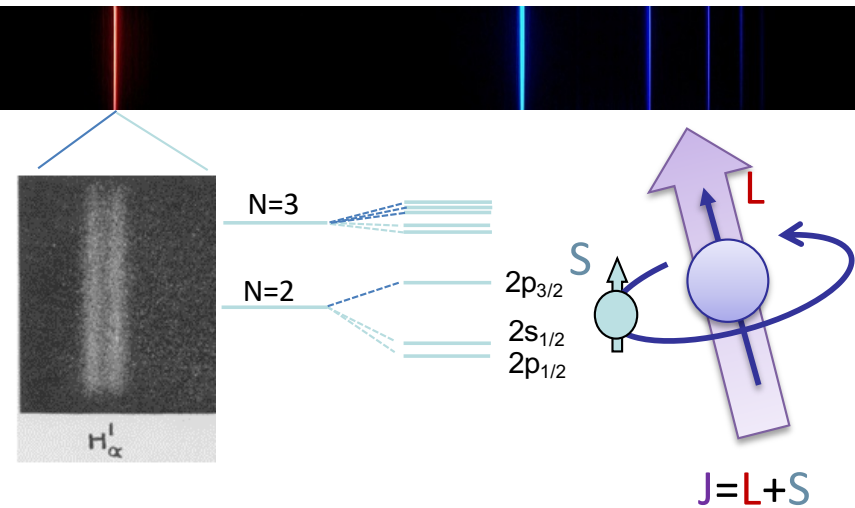
→ small energy shifts in atomic transitions when A changes: **isotopic shift**

Mean squared radius

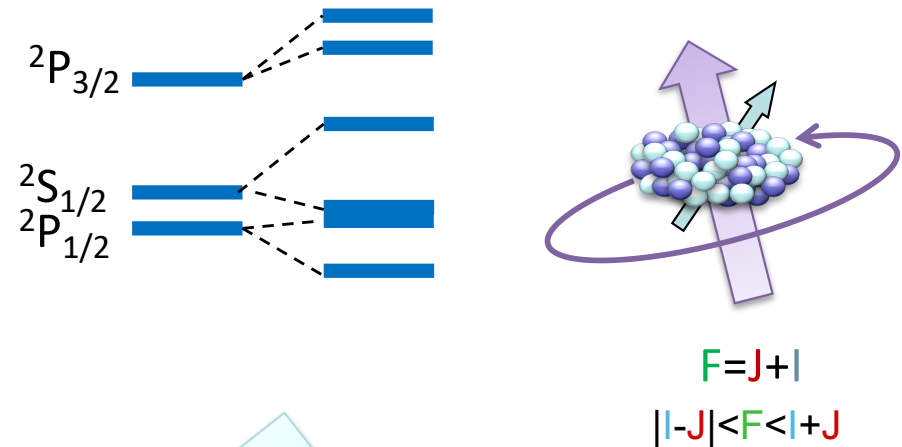


Fine and Hyperfine structure

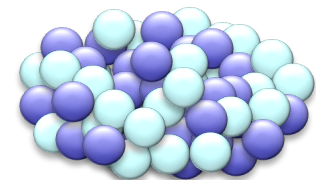
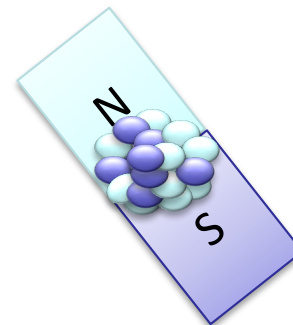
- A resolution $\sim 5,000$ times higher reveals a fine structure in the hydrogen spectrum due to spin-orbit interaction



- A 1,000-fold increase in resolution reveals an even finer structure due to the coupling of the nucleus with the electron's orbit



→ The hyperfine structure of atomic spectra provides information about the spin and the magnetic and electric moments of the nucleus



The spin of the nucleus

PRL **110**, 172503 (2013)

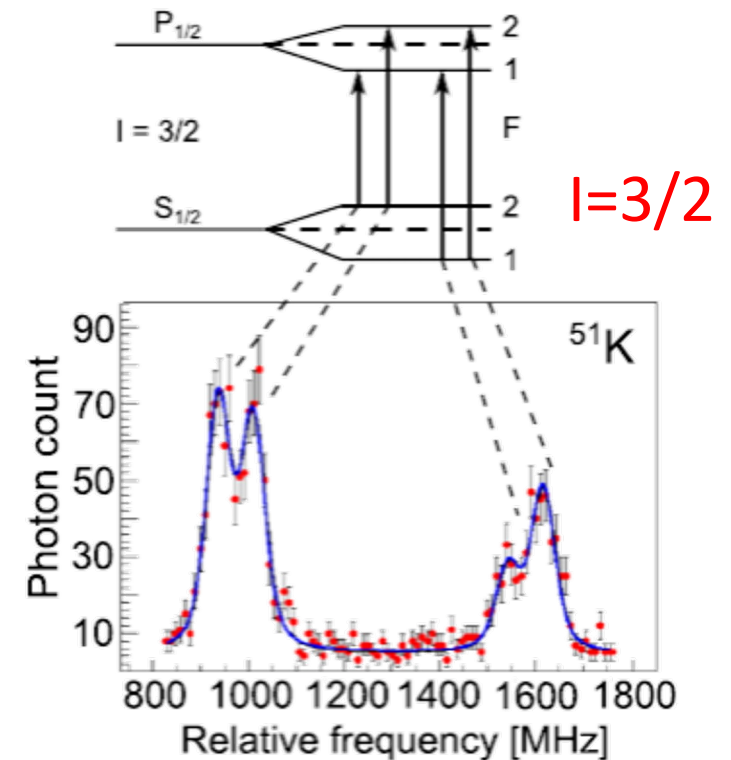
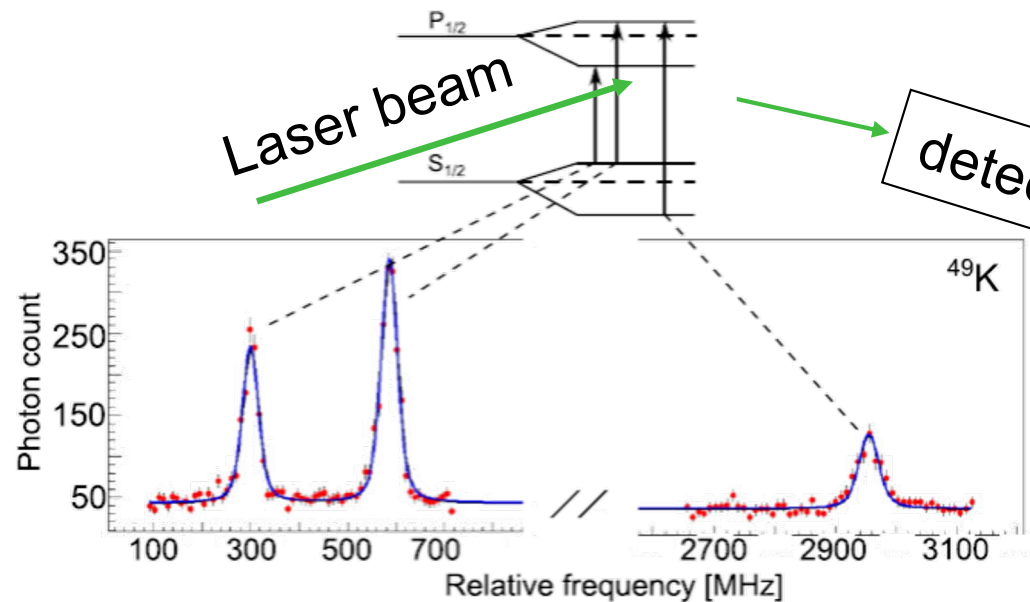
PHYSICAL REVIEW LETTERS

week ending
26 APRIL 2013

J. Papuga et al.,

Spins and Magnetic Moments of ^{49}K and ^{51}K : Establishing the $1/2^+$ and $3/2^+$ Level Ordering Beyond $N = 28$

$I=1/2$: only 3 transitions are authorized because the $F_i=0 \rightarrow F_j=0$ is forbidden



Deformation of the nucleus

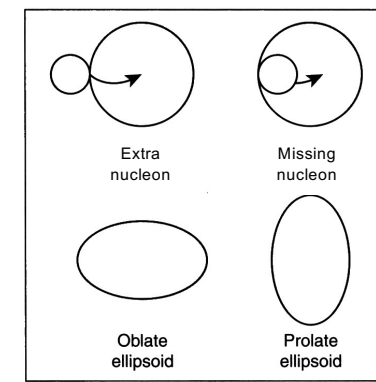
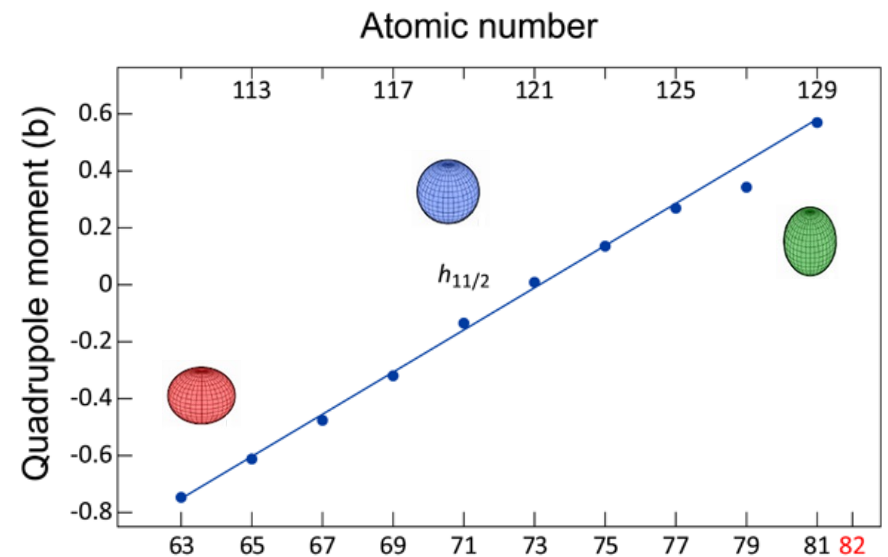
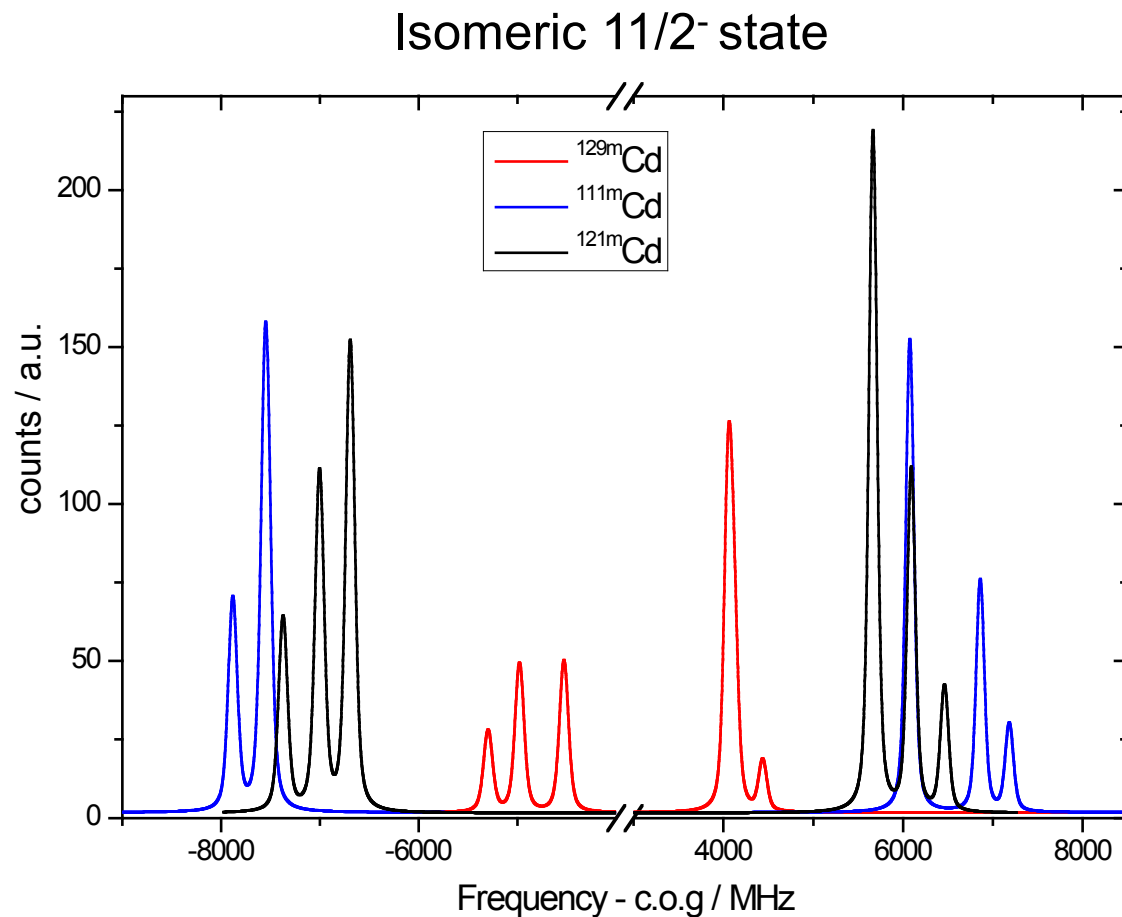
PRL **110**, 192501 (2013)

Selected for a **Viewpoint** in *Physics*
PHYSICAL REVIEW LETTERS

week ending
10 MAY 2013

D. T. Yordanov et al.,

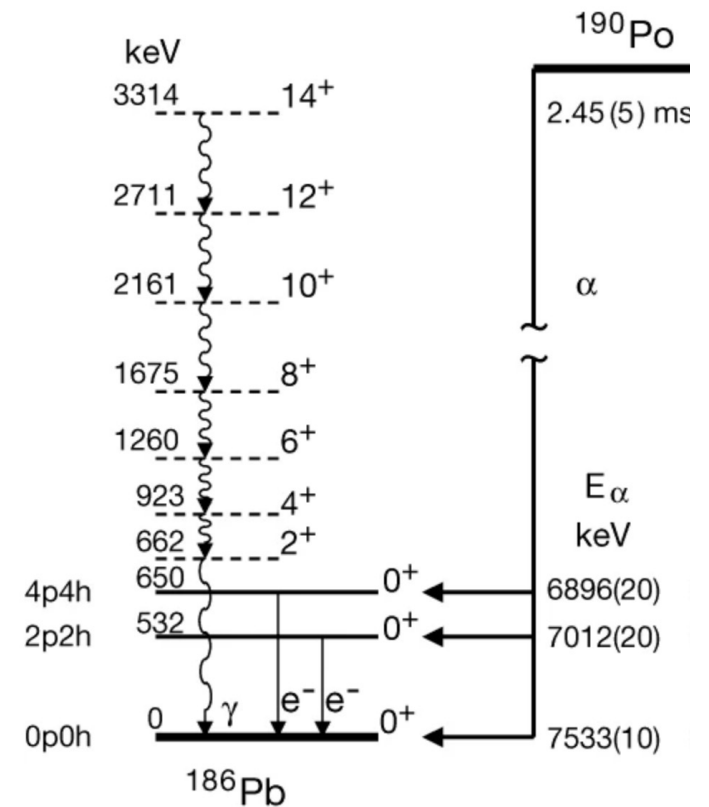
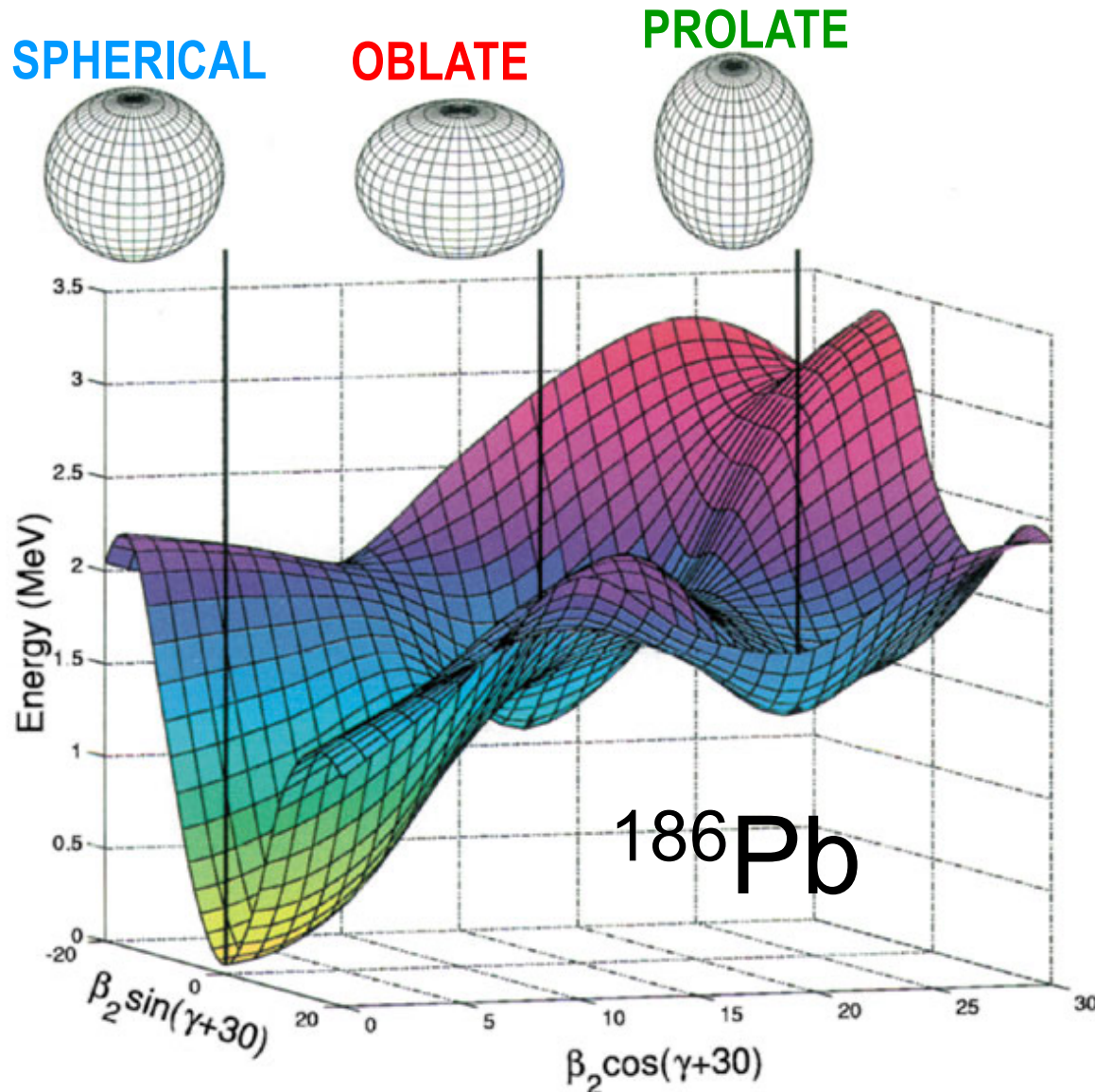
Spins, Electromagnetic Moments, and Isomers of $^{107-129}\text{Cd}$



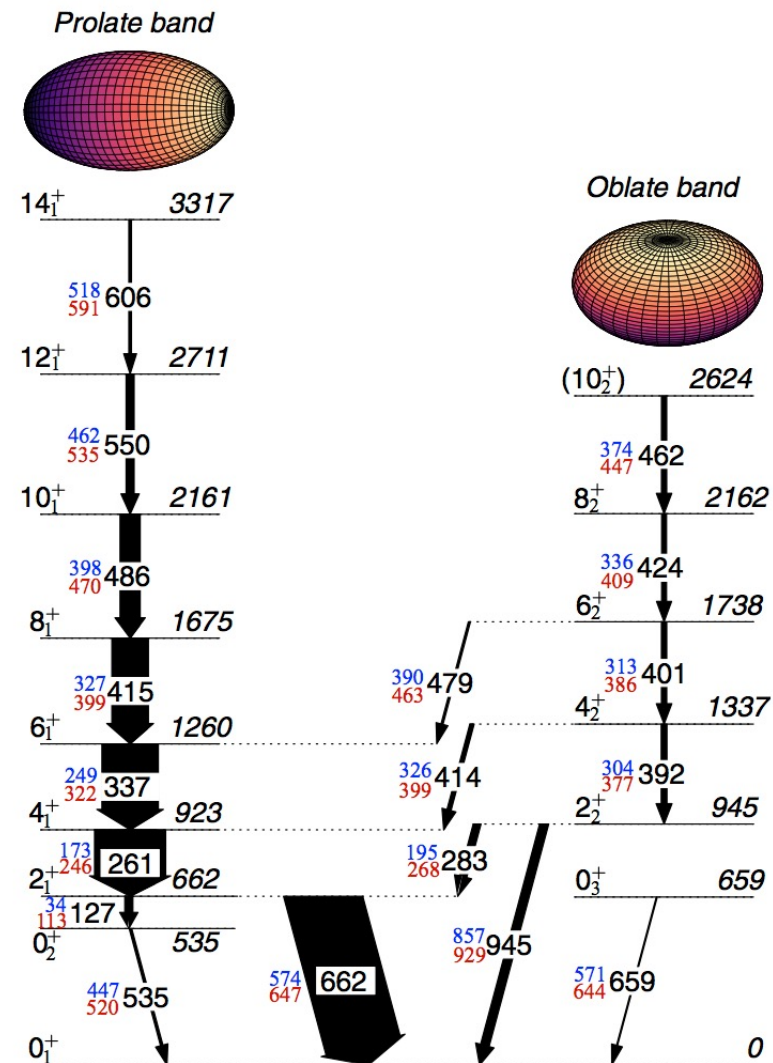
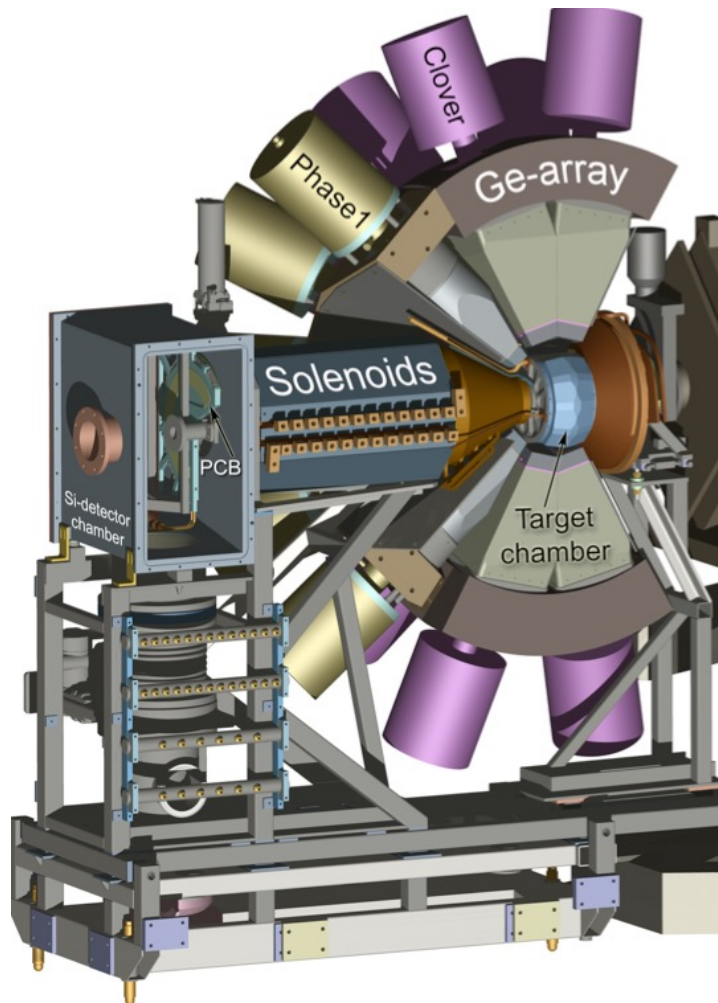
Behaviour expected in the extreme shell model: linear variation of Q due to filling of $h_{11/2}$ shell

Coexisting shapes

Three 0^+ states observed at low energy in the α decay of ^{190}Po

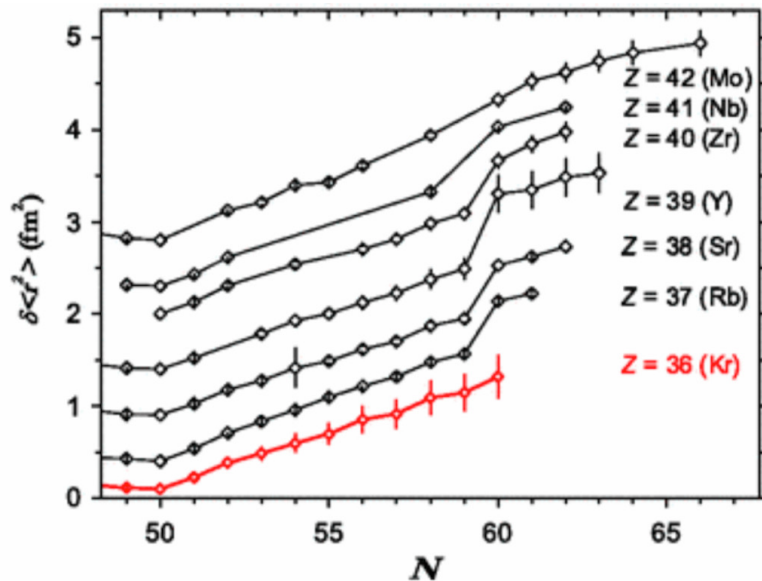


Reassigning shapes in ^{186}Pb



Changing shapes

S. Naimi *et al.*, Phys. Rev. L 105, 032502 (2010)

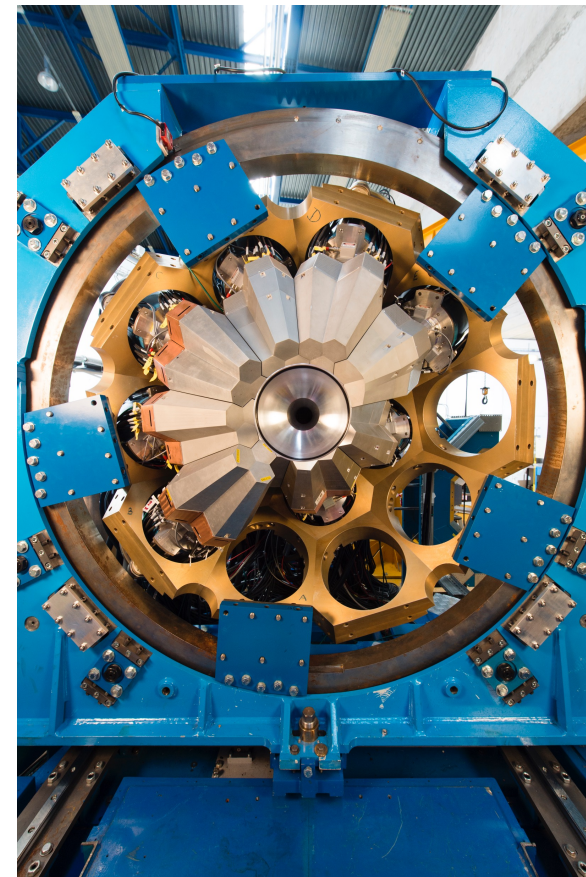
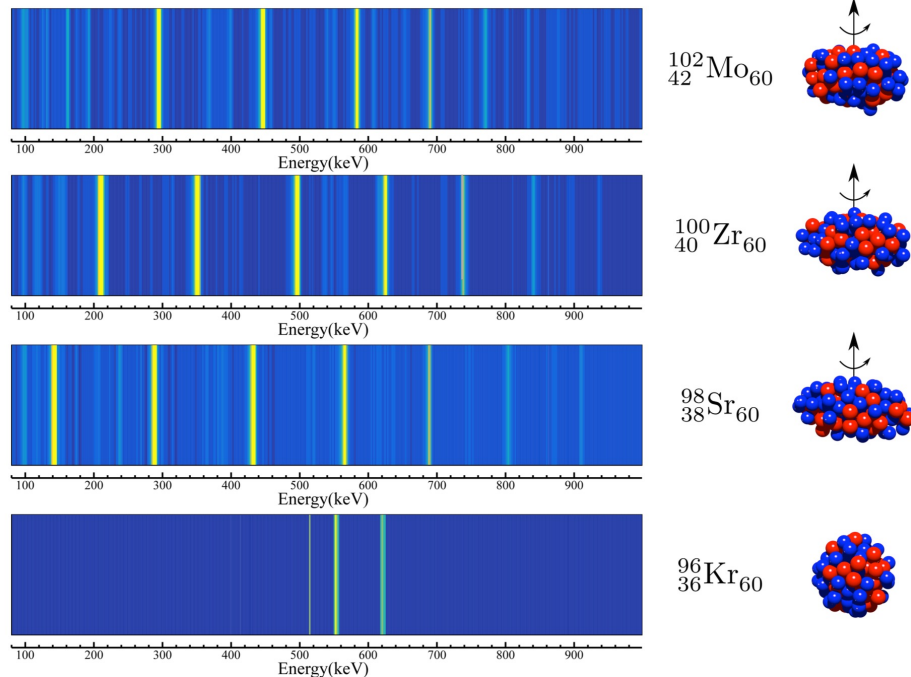


Mass and mean squared radius measurements:
Shape change at $N=60$ from Mo $\rightarrow$ Rb

What about Kr ?

γ -ray spectroscopy of ^{96}Kr with AGATA

J. Dudouet *et al.*, Phys. Rev. Lett. 118, 162501 (2017)

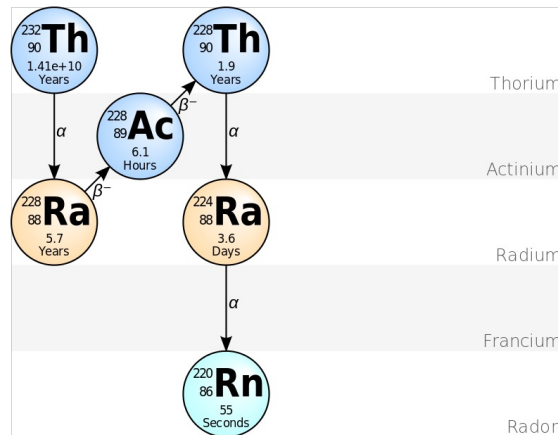
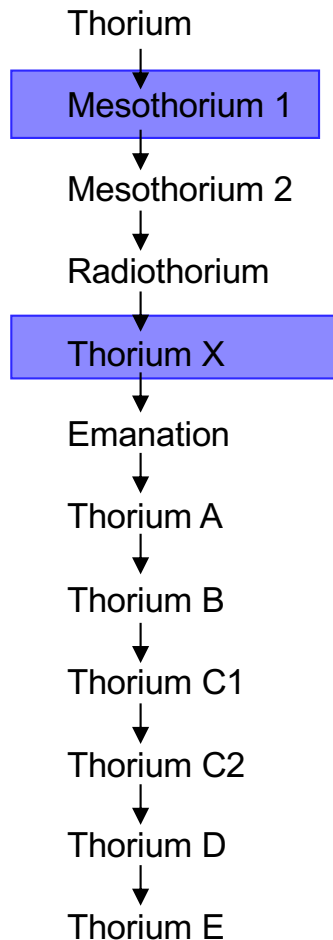


Dalton's atom undermined

More than 40 radioelements discovered in 15 years

Problem: only 7 cases unoccupied slots in the periodic table

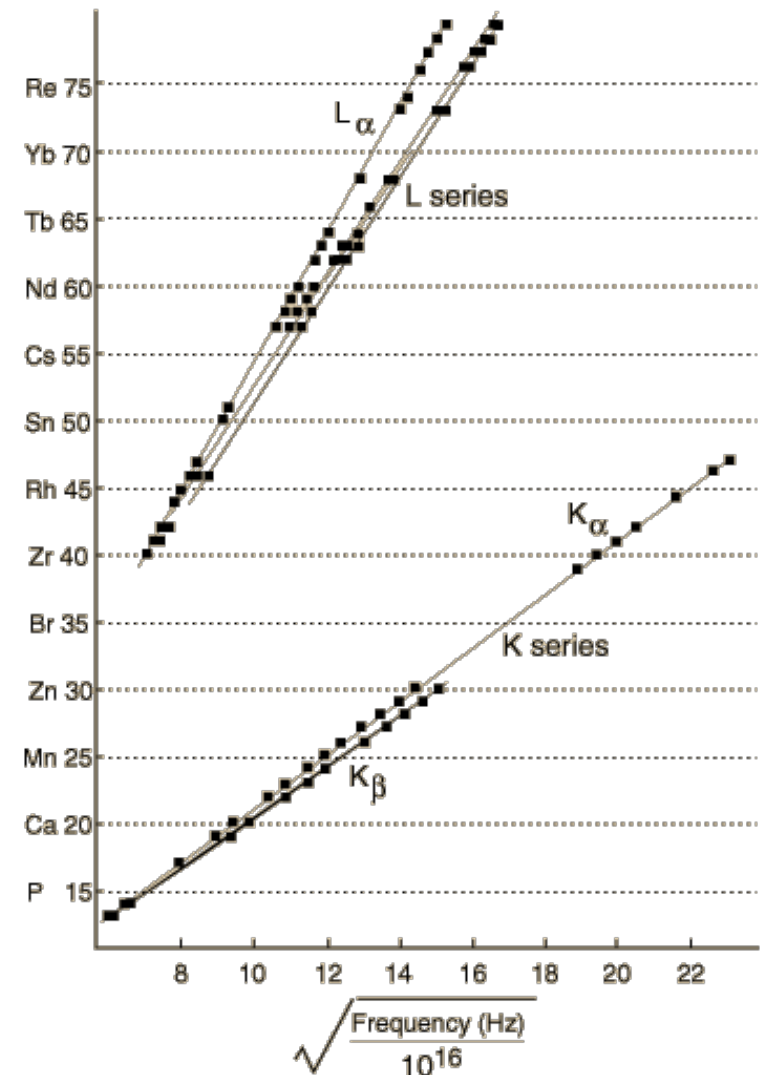
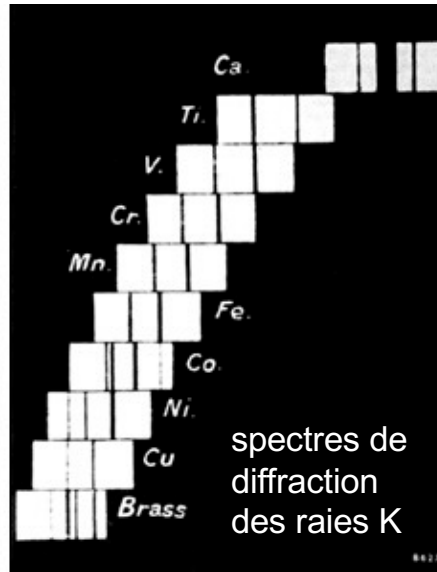
Inseparability of certain radioelements



Frederick Soddy

1913: Isotope concept: radioactive elements can have different masses but the same chemical properties

The periodic table finds its thread



Adapted from Moseley's original data (H. G. J. Moseley, Philos. Mag. (6) 27:703, 1914)

1914 Henry Moseley

Measurement of the high frequency X-ray spectra of many elements

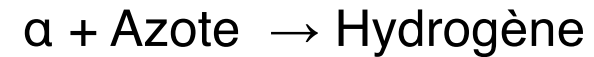
⇒ atomic number Z = charge of the nucleus

⇒ regularities of the periodic table explained in terms of filling of electronic shells

The alchemists of the 20th century

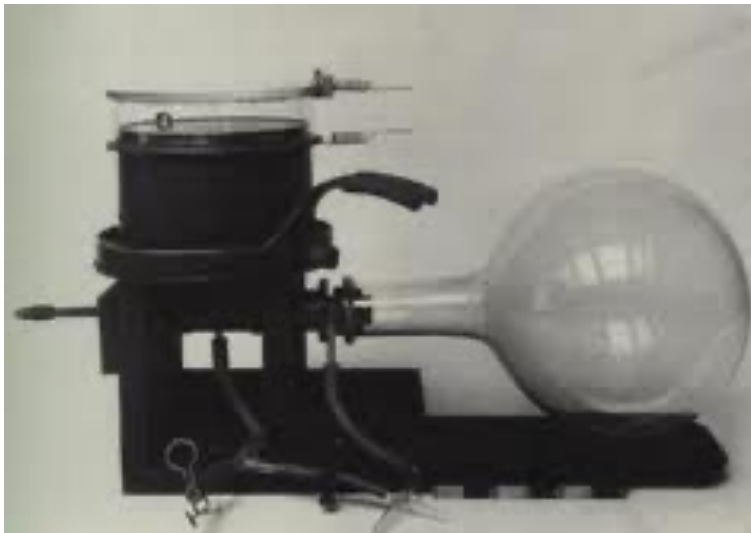
1919 E. Rutherford

1st artificial transmutation

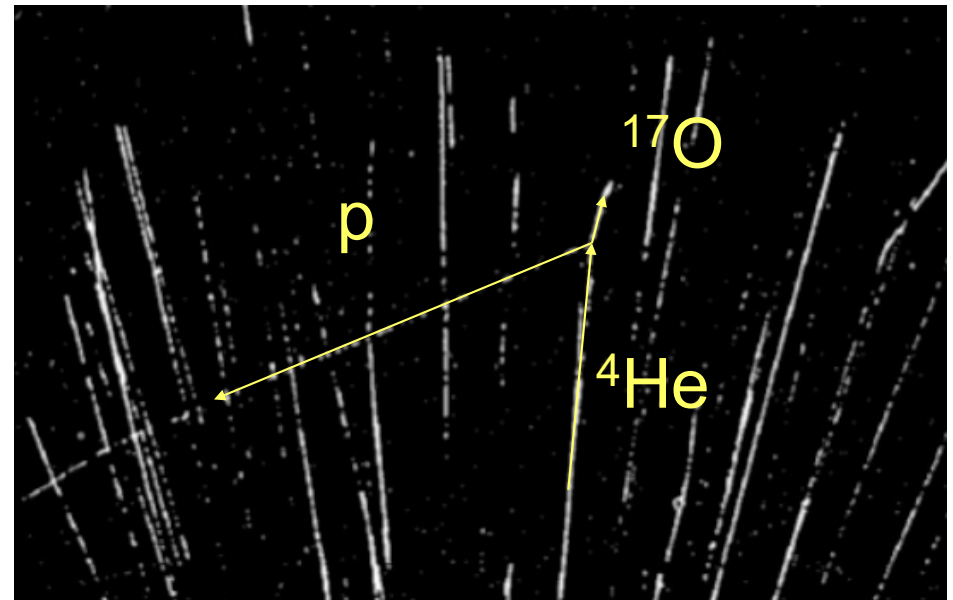


Rutherford calls H^+ proton

1924 P. Blackett visualizes the transmutation $\alpha + {}^{14}\text{N} \rightarrow {}^{17}\text{F}^* \rightarrow {}^{17}\text{O} + \text{p}$



Cloud chamber (C.T.R. Wilson, 1912)

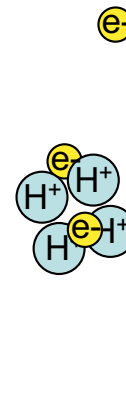


Structure of the nucleus (1920)

The nucleus is thought to be composed of A protons and $(A-Z)$ electrons

E. Rutherford suggests the existence of an e^- - p pair, which would have all the characteristics of a neutral particle

Bakerian Lecture, Proc. Roy. Soc. A, 97, 374 (1920)



This information goes unnoticed around the world, except at the Cavendish Laboratory in Cambridge, where Rutherford is appointed director...