Physique pour tous

Briques & Fabriques nucléaires

Mardi 11 octobre 2022

À la recherche de nouveaux éléments

Voyage aux limites du monde atomique et isotopique. Combien d'éléments existent ? Comment et qui peut les produire ? Où peut-on les trouver ? Auront-ils de nouvelles propriétés ? Ont-ils existé ?

USIAS

Benoît GALL

Faculté de Physique & Ingénierie

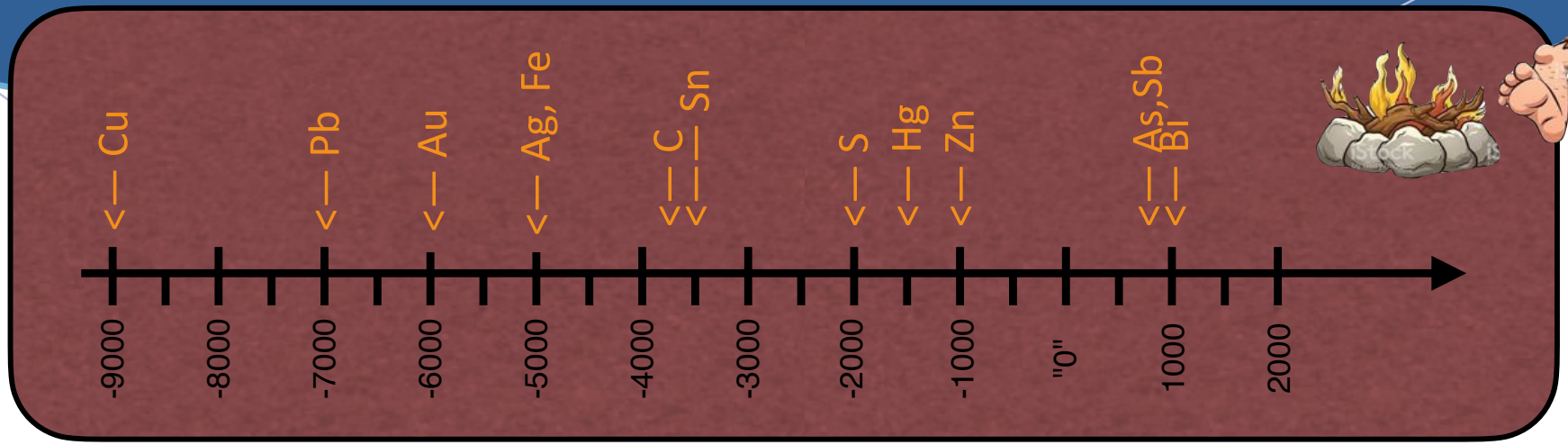
IPHC Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

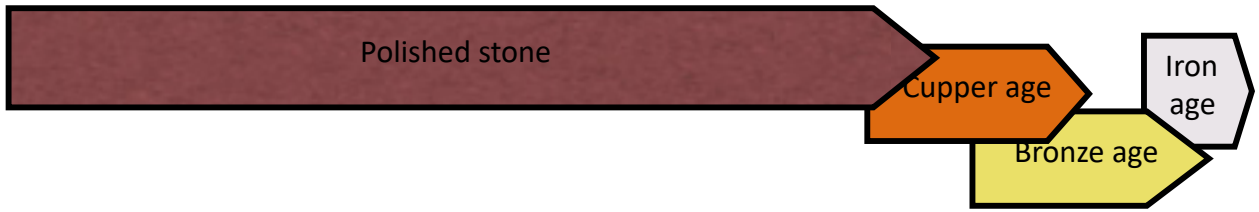
Université de Strasbourg

Known elements classification

Prehistoric, antiquity and middle age elements (13) …

… mainly metals, were used for weapons, tools and jewelry …





Medieval discoveries

* real timeline depends on the place, moved from rent to europe …

Sub-Saharan Africa
Earlier Stone Age
Middle Stone Age
Later Stone Age
Neolithic c. 4000 BCE
Bronze Age (3500 – 600 BCE)
Iron Age (550 BC – 700 CE)
Classic Middle Ages (c. 700 – 1700 CE)

Japan Periods
Paleolithic c. 100,000 – c. 10,000 BCE
Jōmon period c. 10,000 – 300 BCE
Yayoi period c. 300 BCE – 250 CE
Yamato period c. 250 – 710 CE

Western Europe
Paleolithic (pre c. 8800 BCE)
Mesolithic (c. 8800 – 4900 BCE)
Neolithic (c. 4900 – 2000 BCE)
Bronze Age (c. 2000 – 800 BCE)
Iron Age (c. late 11th century BCE – 1 BC
Roman (c. 56 BCE – 400 CE)
Early medieval period (c. 400 – 800 CE)
Medieval period (800 – c. 1500)
Post-medieval period (c. 1500 – c. 1800)
Industrial/Modern

… need to wait 17th century for more

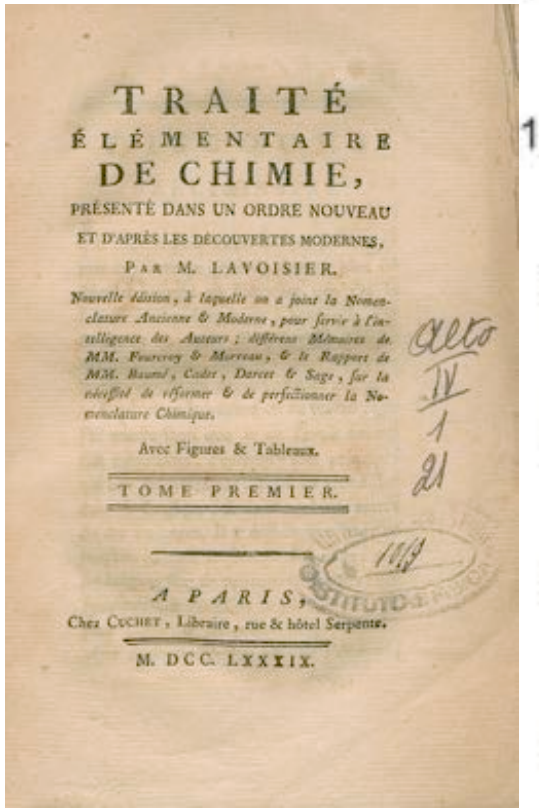
Known elements classification

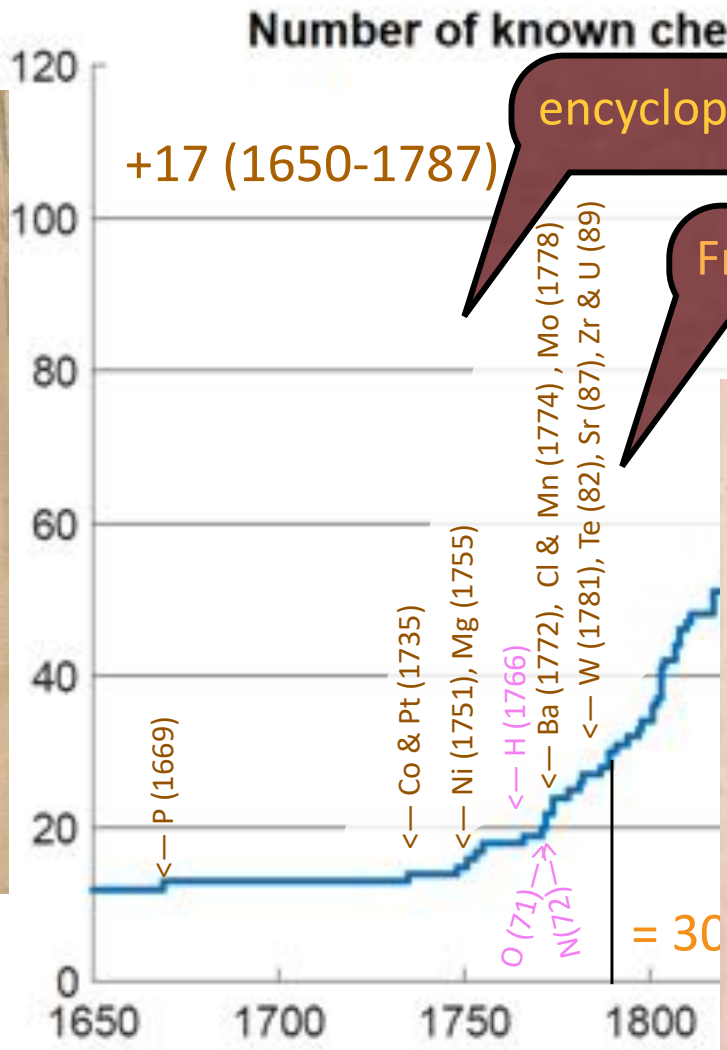
…13 primitives elements
+17 "Lavoisier"

Encyclopedism, « siècle des lumières» 18th century

H. Brand discovered Phosphorous (1669) and Cobalt (1735)
… alchemy / quest for gold and industrialisation accelerated discoveries…

1787 … 1st modern list of 30 elements by A. Lavoisier

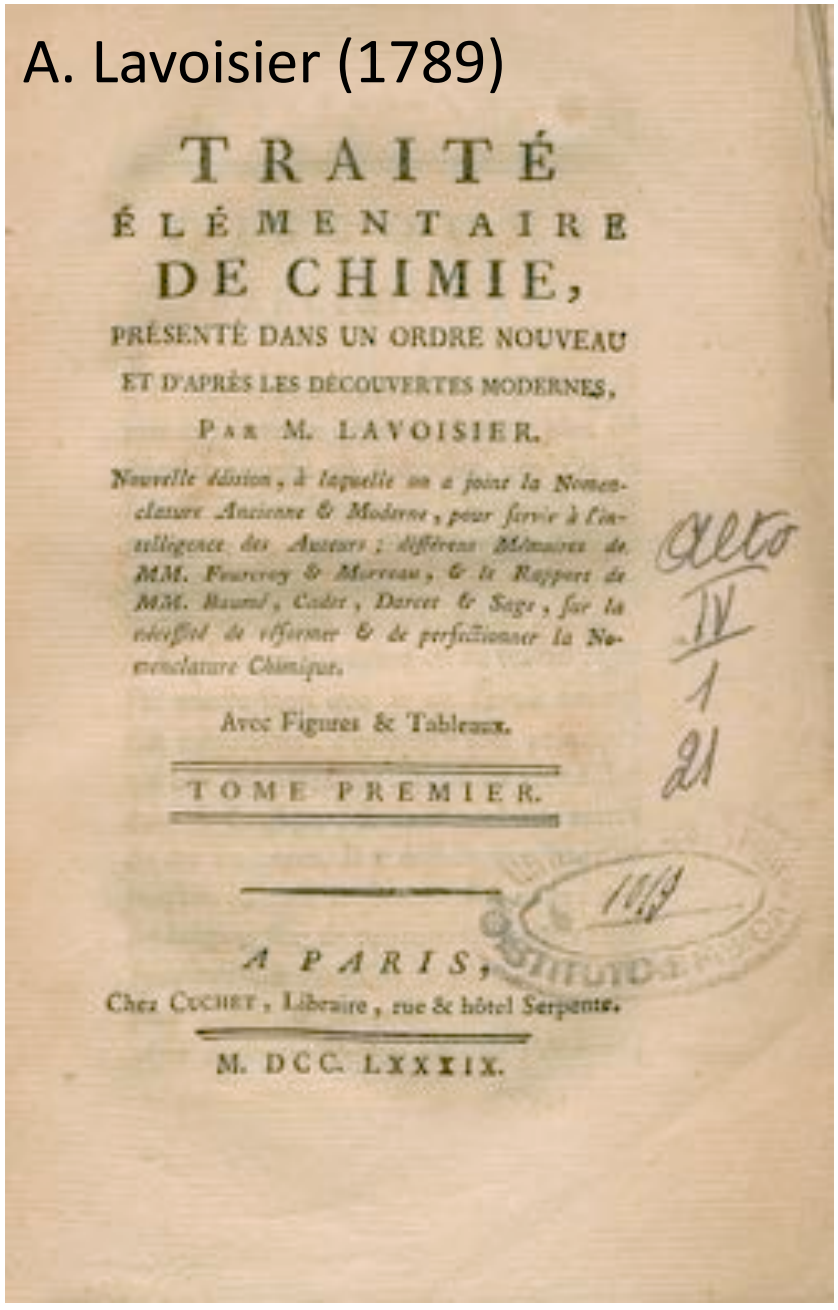

TRAITÉ
ÉLÉMENTAIRE
DE CHIMIE,
PRÉSENTÉ DANS UN ORDRE NOUVEAU
ET D'APRÈS LES DÉCOUVERTES MODERNES,
PAR M. LAVOISIER.
Nouvelle édition, à laquelle on a joint la Nomenclature Ancienne & Moderne, pour servir à l'intelligence des Auteurs; différens Mémoires de MM. Fourcroy & Morveau, & le Rapport de MM. Baumé, Cadet, Darcet & Sage, sur la nécessité de réformer & de perfectionner la Nomenclature Chimique.
Avec Figures & Tableaux.
TOME PREMIER.
A PARIS,
Chez CUCHET, Libraire, rue & hôtel Serpente.
M. DCC. LXXXIX.




192 DES SUBSTANCES SIMPLES.
TABLEAU DES SUBSTANCES SIMPLES.

	Noms nouveaux.	Noms anciens correspondans.
Substances simples qui appartiennent aux trois règnes & qu'on peut regarder comme les élémens des corps.	Lumière	Lumière.
	Calorique	Chaleur. Principe de la chaleur. Fluide igné. Feu. Matière du feu & de la chaleur.
	Oxygène	Air déphlogistiqué. Air empiréal. Air vital. Base de l'air vital.
	Azote	Gaz phlogistiqué. Mofete. Base de la mofete.
	Hydrogène	Gaz inflammable. Base du gaz inflammable.
Substances simples non métalliques oxidables &	Soufre	Soufre.
	Phosphore	Phosphore.
	Carbone	Charbon pur.
	Radical muriatique	Inconnu.
	Radical fluorique	Inconnu.

A. Lavoisier (1789)



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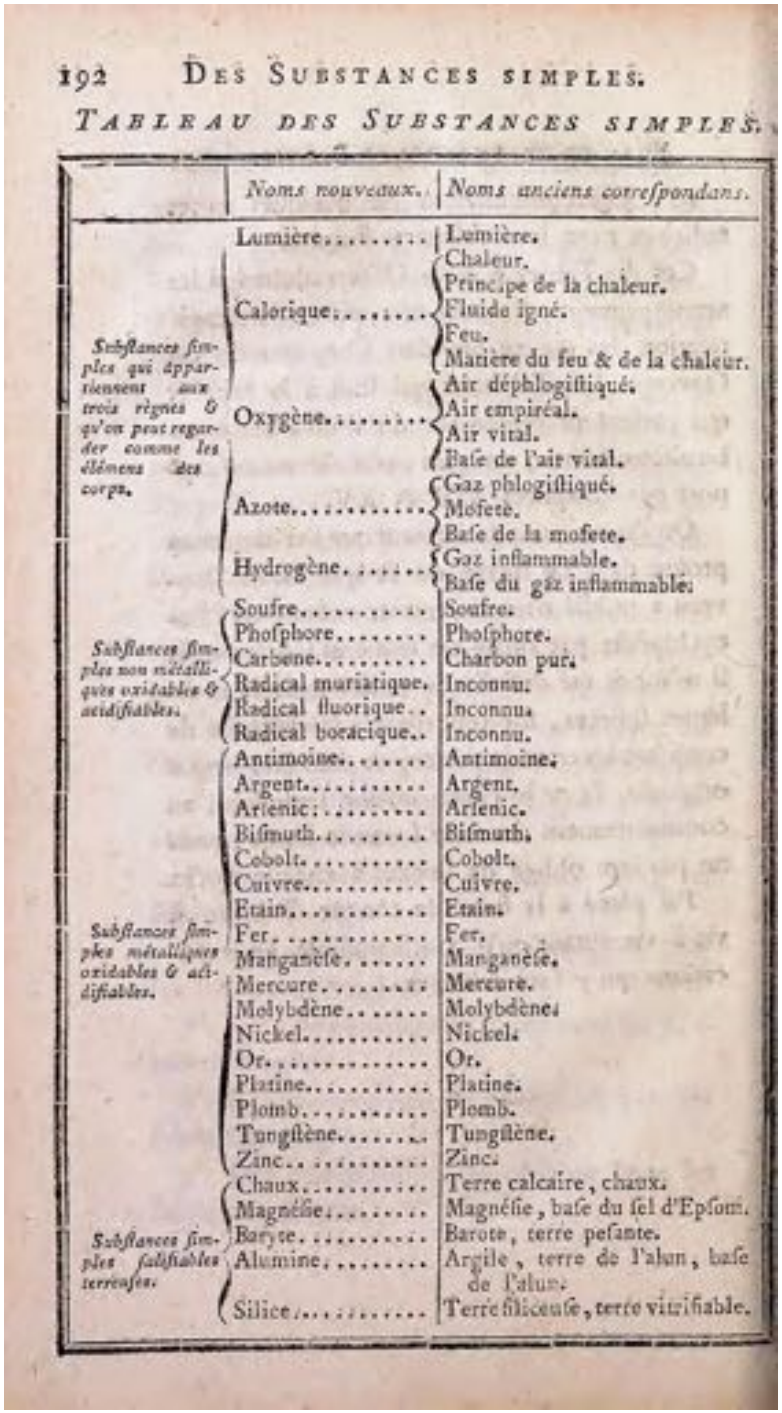

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Substances simples non métalliques oxidables & acidifiables.	Soufre	Soufre.
	Phosphore	Phosphore.
	Carbone	Charbon pur.
	Radical muriatique	Inconnu.
	Radical fluorique	Inconnu.
	Radical boracique	Inconnu.
Substances simples métalliques oxidables & acidifiables.	Antimoine	Antimoine.
	Argent	Argent.
	Arsenic	Arsenic.
	Bismuth	Bismuth.
	Cobolt	Cobolt.
	Cuivre	Cuivre.
	Etain	Etain.
	Fer	Fer.
	Manganèse	Manganèse.
	Mercure	Mercure.
	Molybdène	Molybdène.
	Nickel	Nickel.
	Or	Or.
	Platine	Platine.
	Plomb	Plomb.
	Tungstène	Tungstène.
	Zinc	Zinc.
Substances simples salifiables terreuses.	Chaux	Terre calcaire, chaux.
	Magnésie	Magnésie, base du sel d'Epsom.
	Baryte	Barote, terre pesante.
	Alumine	Argile, terre de l'alun, base de l'alun.
	Silice	Terre siliceuse, terre vitrifiable.

Since 1st modern list of 30 elements scientist are working on analog chemical properties & masses

Known elements classification

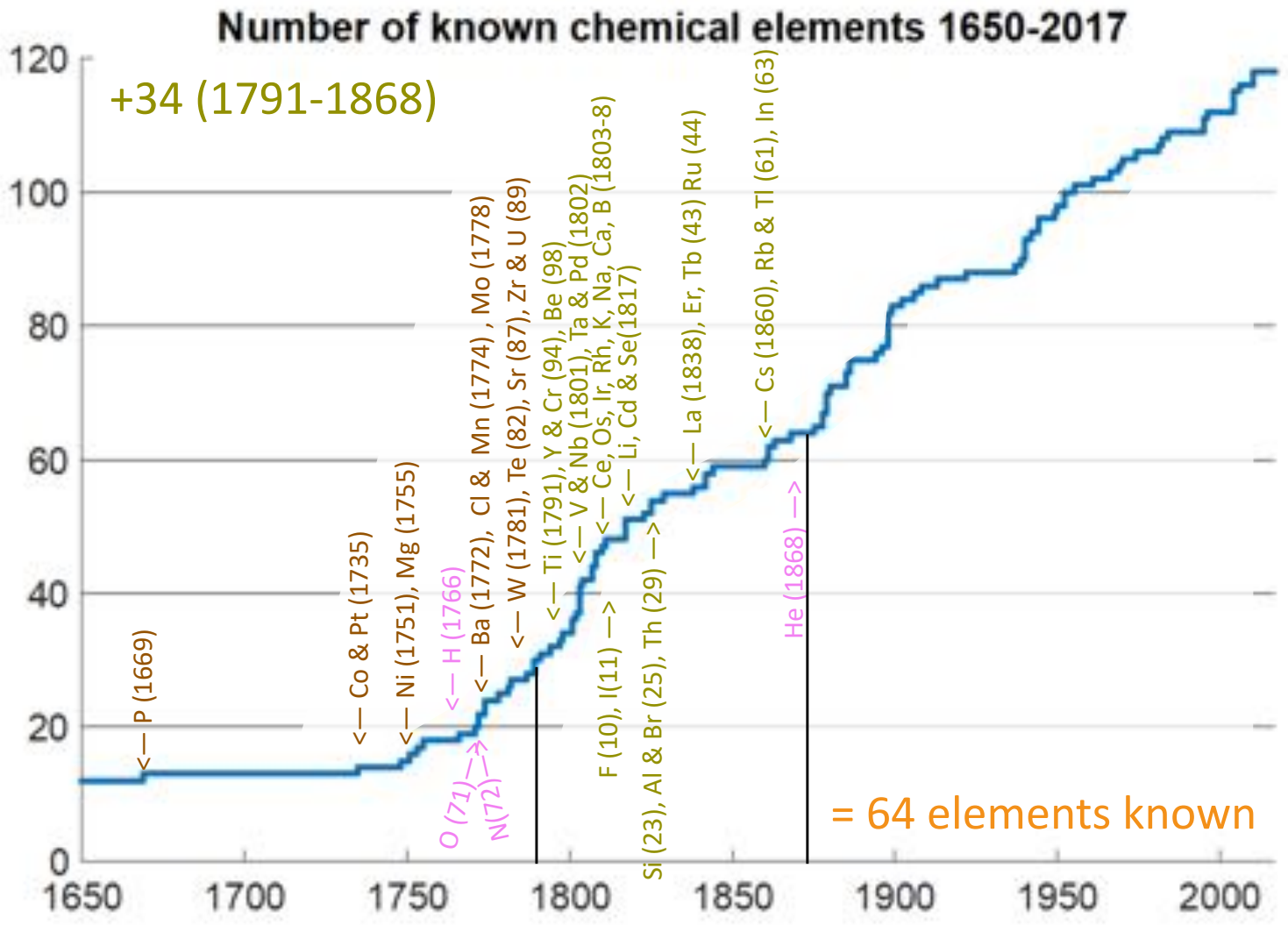
…13 primitives elements
+17 "Lavoisier"
+34 "Mendeleev"

Some « modern chemistry » starts 19th century

H. Brand discovered Phosphorous (1669) and Cobalt (1735)
… alchemy / quest for gold and industrialisation accelerated discoveries…

1787 … 1st modern list of 30 elements by A. Lavoisier

1869 … 1st version of the Mendeleev table (64 elts)



Periodic table of elements

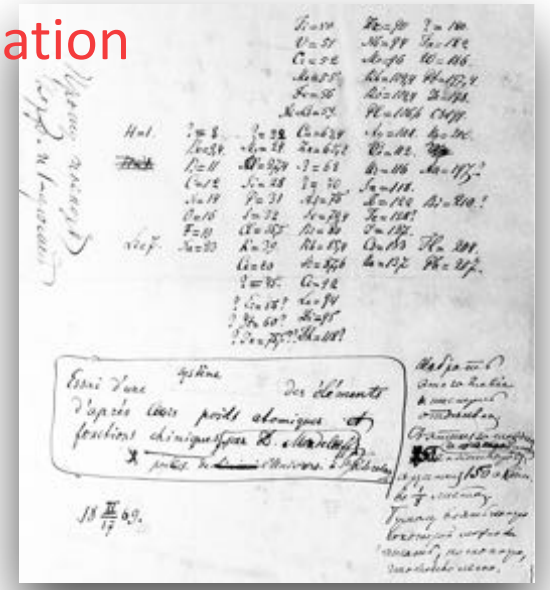
Since 1st modern list of 30 elements by A. Lavoisier (1789)
scientist are working on analog chemical properties & masses

Keep in mind that :
- existence of nucleus is proven by Geiger/Marsden experiments (1908-10) interpreted by Rutherford in 1911
- neutron is only discovered in 1932

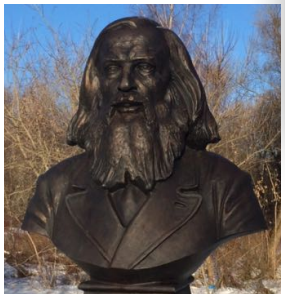
Almost in parallel, 2 scientists will propose a periodic classification

—> in 1869 Dimitri Ivanovich Mendeleev
proposed his first version of periodic table

—> in 1864 Julius Lothar Meyer published his book
about modern theory of chemistry



	4 werthig	3 werthig	2 werthig	1 werthig	1 werthig	2 werthig
	-	-	-	-	Li = 7,03	(Be =9,3?)
Differenz =	-	-	-	-	16,02	(14,7)
	C = 12,0	N = 14,04	O = 16,00	Fl = 19,0	Na = 23,05	Mg = 24,0
Differenz =	16,5	16,96	16,07	16,46	16,08	16,0
	Si = 28,5	P = 31,0	S = 32,07	Cl = 35,46	K = 39,13	Ca = 40,0
Differenz =	89,1 /2 = 44,55	44,0	46,7	44,51	46,3	47,6
	-	As = 75,0	Se = 78,8	Br = 79,97	Rb =85,4	Sr = 87,6
Differenz =	89,1 /2 = 44,55	45,6	49,5	46,8	47,6	49,5
	Sn = 117,6	Sb = 120,6	Te = 128,3	J =126,8	Cs = 133,0	Ba = 137,1
Differenz =	89,4 = 2*44,7	87,4 = 2*43,7	-	-	(71 = 2*35,5)	-
	Pb = 207,0	Bi = 208,0	-	-	(Tl = 204?)	-



Mendeleev's classification was earlier known since he published in a journal !

Meyer's periodic table of elements

	4 werthig	3 werthig	2 werthig	1 werthig	1 werthig	2 werthig
	-	-	-	-	Li = 7,03	(Be =9,3?)
Differenz =	-	-	-	-	16,02	(14,7)
	C = 12,0	N = 14,04	O = 16,00	Fl = 19,0	Na = 23,05	Mg = 24,0
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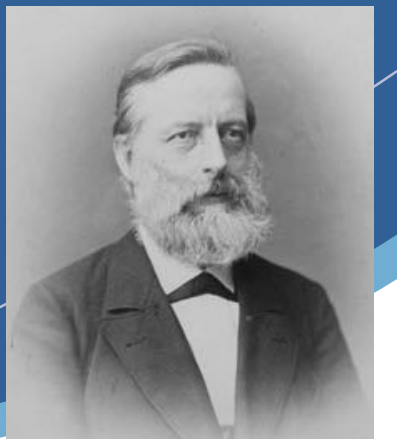
Published in 1864 in Julius Lothar Meyer's book about modern theory of chemistry



and then in 1866 and 1870 in 2 articles.

27	well placed
1	badly placed
0	prediction (1 possible…)
35	known but missing

IUPAC Periodic Table of the Elements

1																	18
1 H hydrogen 1.008 [1.0078, 1.0082]	2		Key: atomic number Symbol name conventional atomic weight standard atomic weight									13	14	15	16	17	2 He helium 4.0026
3 Li lithium 6.94 [6.938, 6.997]	4 Be beryllium 9.0122											5 B boron 10.81 [10.806, 10.821]	6 C carbon 12.011 [12.009, 12.012]	7 N nitrogen 14.007 [14.006, 14.008]	8 O oxygen 15.999 [15.999, 16.000]	9 F fluorine 18.998	10 Ne neon 20.180
11 Na sodium 22.990	12 Mg magnesium 24.305 [24.304, 24.307]	3	4	5	6	7	8	9	10	11	12	13 Al aluminium 26.982	14 Si silicon 28.085 [28.084, 28.086]	15 P phosphorus 30.974	16 S sulfur 32.06 [32.059, 32.076]	17 Cl chlorine 35.45 [35.446, 35.457]	18 Ar argon 39.95 [39.792, 39.963]
19 K potassium 39.098	20 Ca calcium 40.078(4)	21 Sc scandium 44.956	22 Ti titanium 47.867	23 V vanadium 50.942	24 Cr chromium 51.996	25 Mn manganese 54.938	26 Fe iron 55.845(2)	27 Co cobalt 58.933	28 Ni nickel 58.693	29 Cu copper 63.546(3)	30 Zn zinc 65.38(2)	31 Ga gallium 69.723	32 Ge germanium 72.630(8)	33 As arsenic 74.922	34 Se selenium 78.971(8)	35 Br bromine 79.904 [79.901, 79.907]	36 Kr krypton 83.798(2)
37 Rb rubidium 85.468	38 Sr strontium 87.62	39 Y yttrium 88.906	40 Zr zirconium 91.224(2)	41 Nb niobium 92.906	42 Mo molybdenum 95.95	43 Tc technetium	44 Ru ruthenium 101.07(2)	45 Rh rhodium 102.91	46 Pd palladium 106.42	47 Ag silver 107.87	48 Cd cadmium 112.41	49 In indium 114.82	50 Sn tin 118.71	51 Sb antimony 121.76	52 Te tellurium 127.60(3)	53 I iodine 126.90	54 Xe xenon 131.29
55 Cs caesium 132.91	56 Ba barium 137.33	57-71 lanthanoids	72 Hf hafnium 178.49(2)	73 Ta tantalum 180.95	74 W tungsten 183.84	75 Re rhenium 186.21	76 Os osmium 190.23(3)	77 Ir iridium 192.22	78 Pt platinum 195.08	79 Au gold 196.97	80 Hg mercury 200.59	81 Tl thallium 204.38 [204.38, 204.39]	82 Pb lead 207.2	83 Bi bismuth 208.98	84 Po polonium	85 At astatine	86 Rn radon
87 Fr francium	88 Ra radium	89-103 actinoids	104 Rf rutherfordium	105 Db dubnium	106 Sg seaborgium	107 Bh bohrium	108 Hs hassium	109 Mt meitnerium	110 Ds darmstadtium	111 Rg roentgenium	112 Cn copernicium	113 Nh nihonium	114 Fl flerovium	115 Mc moscovium	116 Lv livermorium	117 Ts tennessine	118 Og oganesson

57 La lanthanum 138.91	58 Ce cerium 140.12	59 Pr praseodymium 140.91	60 Nd neodymium 144.24	61 Pm promethium	62 Sm samarium 150.36(2)	63 Eu europium 151.96	64 Gd gadolinium 157.25(3)	65 Tb terbium 158.93	66 Dy dysprosium 162.50	67 Ho holmium 164.93	68 Er erbium 167.26	69 Tm thulium 168.93	70 Yb ytterbium 173.05	71 Lu lutetium 174.97
89 Ac actinium	90 Th thorium 232.04	91 Pa protactinium 231.04	92 U uranium 238.03	93 Np neptunium	94 Pu plutonium	95 Am americium	96 Cm curium	97 Bk berkelium	98 Cf californium	99 Es einsteinium	100 Fm fermium	101 Md mendelevium	102 No nobelium	103 Lr lawrencium

For notes and updates to this table, see www.iupac.org. This version is dated 1 December 2018.

INTERNATIONAL UNION OF PURE AND APPLIED CHEMISTRY

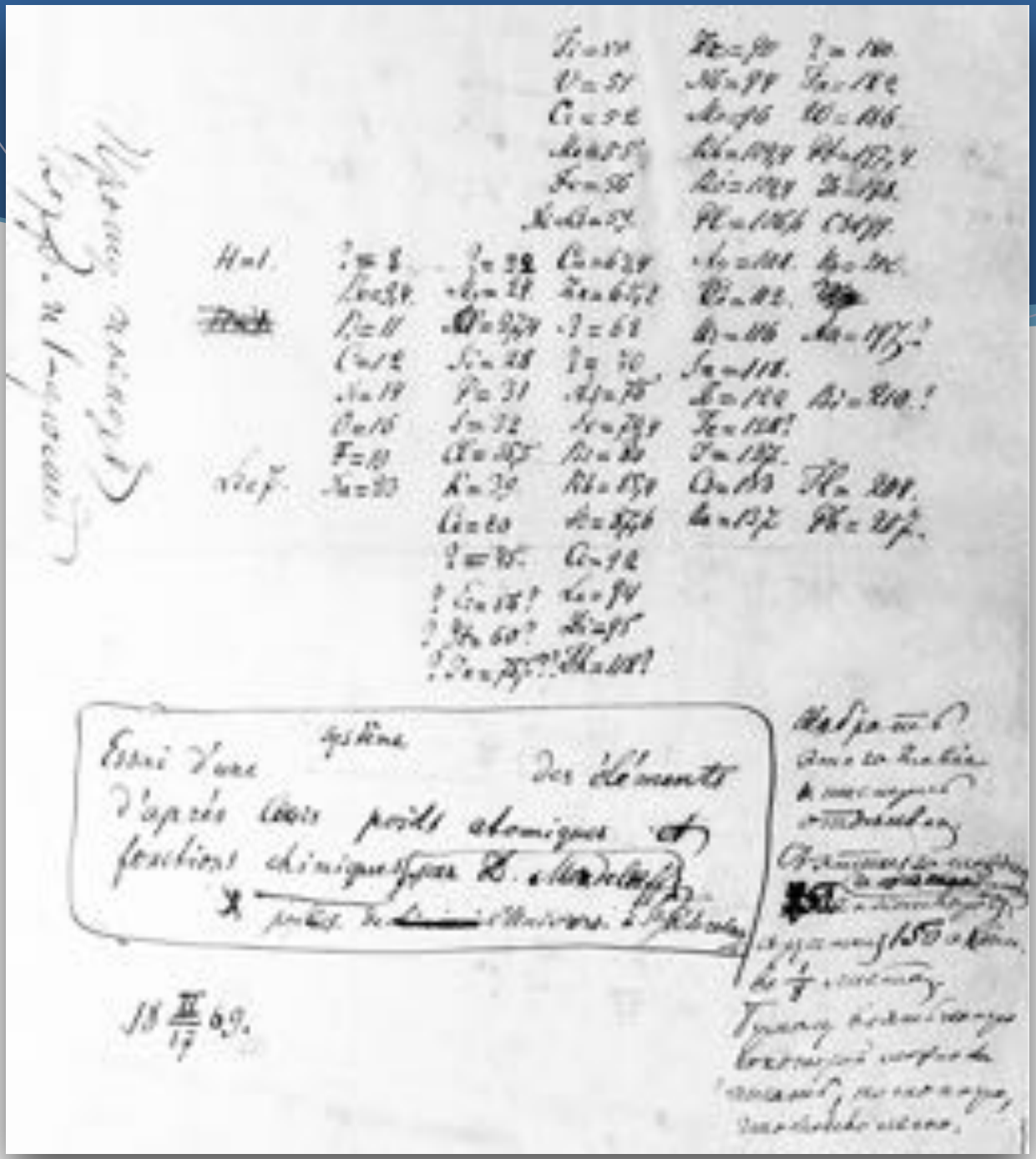
It includes
- 27 elements well placed
- 6 columns completed …

UNESCO United Nations Educational, Scientific and Cultural Organization

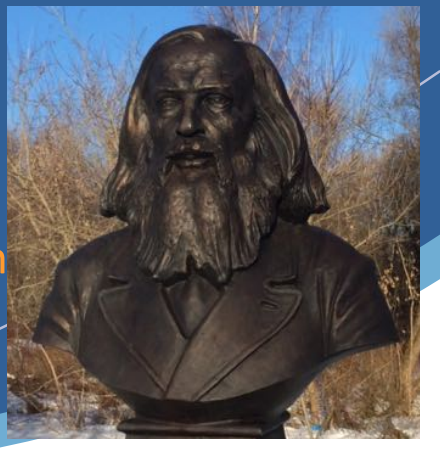
2019 IYPT International Year of the Periodic Table of Chemical Elements

IUPAC

Mendeleev's periodic table of elements



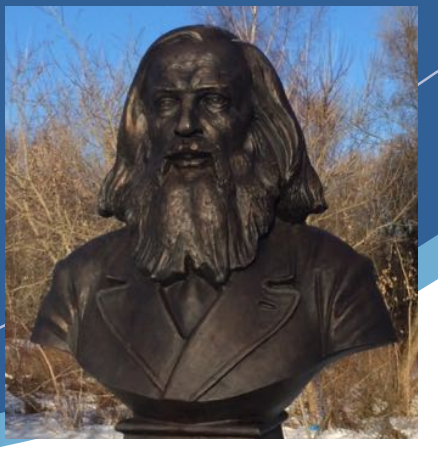
1st version sent in 1869 to Russian Chemical Society.



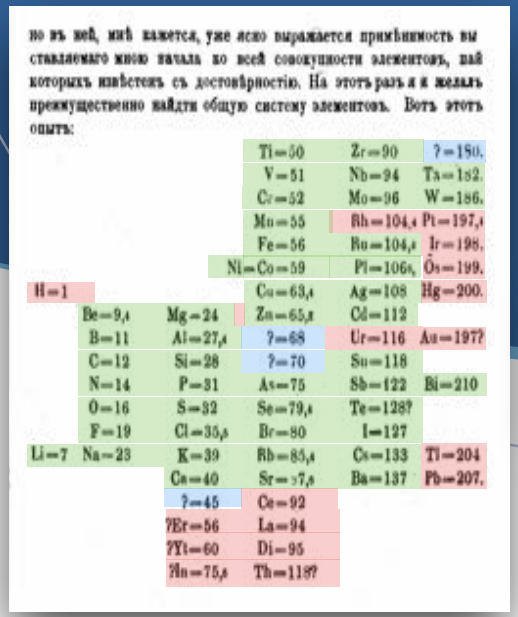
« Essai d'une ~~classification~~ système des éléments d'après leurs poids atomiques et fonctions chimiques par D. Mendeleeff profess. de ~~chimie à~~ l'Univers. à St Petersburg ,
17 II 1869»

« Trial of a system for elements following their atomic weight and chemical functions by D Mendeleev prof. at University at St Petersburg,
17 II 1869»

Mendeleev's periodic table of elements

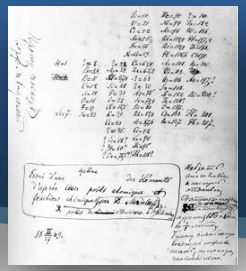


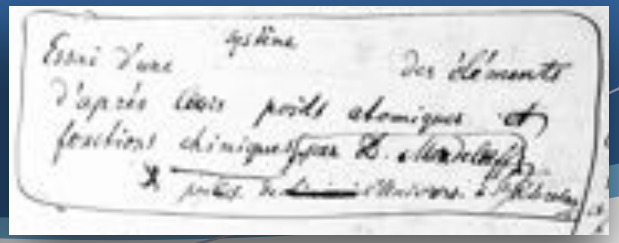
17 II 1869 (Julan calendar, = 1 III 1969 in Greg. cal.)
D.I. Mendeleev sent a single page to Russian Chemical Society:



но въ ней, мнѣ кажется, уже ясно выражается примѣнимость вы
ставляемаго мною начала ко всей совокупности элементовъ, изъ
которыхъ извѣстенъ съ достовѣрностію. На этотъ разъ я и желалъ
преимущественно найдти общую систему элементовъ. Вотъ этотъ
опытъ:

			Ti=50	Zr=90	?=180.	
			V=51	Nb=94	Ta=182.	
			Cr=52	Mo=96	W=186.	
			Mn=55	Rh=104,4	Pt=197,4	
			Fe=56	Ru=104,4	Ir=198.	
			Ni=Co=59	Pl=106,6	Os=199.	
H=1			Cu=63,4	Ag=108	Hg=200.	
	Be=9,4	Mg=24	Zn=65,2	Cd=112		
	B=11	Al=27,4	?=68	Ur=116	Au=197?	
	C=12	Si=28	?=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.	
		?=45	Ce=92			
		?Er=56	La=94			
		?Yt=60	Di=95			
		?In=75,6	Th=118?			





He then sent for publication in *Zeitschrift für Chemie* (**12** 405)

47	well placed (incl. H …)
15	badly placed
4	predictions
2	known but missing

It includes
- 47 elements well placed
- some columns, but not fully clear …
- 4 predictions (Eka-B, Eka-Al, & Eka-Si)
- He is missing, he did not believe in He but added it later in row 0 with Ar

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87 Fr francium	88 Ra radium	89-103 actinoids	104 Rf rutherfordium	105 Db dubnium	106 Sg seaborgium	107 Bh bohrium	108 Hs hassium	109 Mt meitnerium	110 Ds darmstadtium	111 Rg roentgenium	112 Cn copernicium	113 Nh nihonium	114 Fl flerovium	115 Mc moscovium	116 Lv livermorium	117 Ts tennessine	118 Og oganesson

Key: atomic number **Symbol** name conventional atomic weight standard atomic weight

57 La lanthanum 138.91	58 Ce cerium 140.12	59 Pr praseodymium 140.91	60 Nd neodymium 144.24	61 Pm promethium	62 Sm samarium 150.36(2)	63 Eu europium 151.96	64 Gd gadolinium 157.25(3)	65 Tb terbium 158.93	66 Dy dysprosium 162.50	67 Ho holmium 164.93	68 Er erbium 167.26	69 Tm thulium 168.93	70 Yb ytterbium 173.05	71 Lu lutetium 174.97
89 Ac actinium	90 Th thorium 232.04	91 Pa protactinium 231.04	92 U uranium 238.03	93 Np neptunium	94 Pu plutonium	95 Am americium	96 Cm curium	97 Bk berkelium	98 Cf californium	99 Es einsteinium	100 Fm fermium	101 Md mendelevium	102 No nobelium	103 Lr lawrencium

INTERNATIONAL UNION OF PURE AND APPLIED CHEMISTRY

For notes and updates to this table, see www.iupac.org. This version is dated 1 December 2018.

Di Didyniyum (was shown later to be mixture of Pr & Nd used to filter out yellow light)

United Nations Educational, Scientific and Cultural Organization

2019 IYPT International Year of the Periodic Table of Chemical Elements

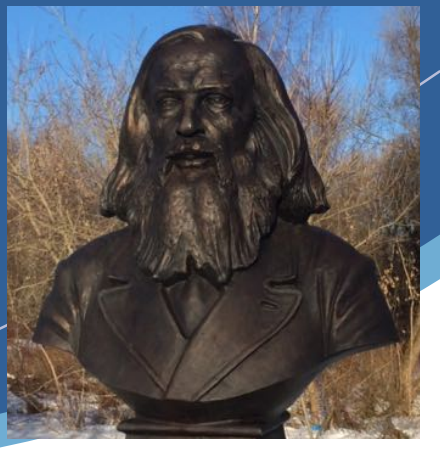
IUPAC

Mendeleev's periodic table of elements

1st version proposed in 1869 is considered as the first periodic table

но въ ней, мнѣ кажется, уже ясно выражается примѣнимость вы ставляемаго мною начала ко всей совокупности элементовъ, ней которыхъ извѣстенъ съ достовѣрностію. На этотъ разъ я и желалъ преимущественно найдти общую систему элементовъ. Вотъ этотъ опытъ:

			Ti=50	Zr=90	?=180.	
			V=51	Nb=94	Ta=182.	
			Cr=52	Mo=96	W=186.	
			Mn=55	Rh=104,4	Pt=197,4	
			Fe=56	Ru=104,4	Ir=198.	
			Ni=Co=59	Pl=106,6	Os=199.	
H=1			Cu=63,4	Ag=108	Hg=200.	
	Be=9,4	Mg=24	Zn=65,2	Cd=112		
	B=11	Al=27,4	?=68	Ur=116	Au=197?	
	C=12	Si=28	?=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.	
		?=45	Ce=92			
		?Er=56	La=94			
		?Yt=60	Di=95			
		?In=75,6	Th=118?			



missing
- notion of Nucleus (E.Rutherford 1911)
- neutron (J. Chadwick 1932)
- isotopes (Frederick Soddy 1921)
- Quantum mechanics

It predicts unknown elements such as
- eka-Borium (?=44) —> Sc m=43,79, disc. 1879
- eka-aluminum (?=68) —> Ga m=69.723, disc. 1875
- eka-silicon (?=70) —> Ge m=72.630, disc. 1886

… and later
- -eka-Manganese —> Tc no stable, disc. 1937
- -dvi-Manganese —> Rh m=186,21, disc. 1908

eka, dvi, tri
for 1 2 3
in sanskrit

(Ogawa-sensei discovered Rhenium (Z=75) called "Nipponium" but was missassigned at Tc (Z=43) place …

Known elements classification

…13 primitives elements
+17 "Lavoisier"
+34 "Mendeleev"

Some « modern chemistry » starts 17th century

H. Brand discovered Phosphorous (1669) and Cobalt (1735)
… alchemy / quest for gold and industrialisation accelerated discoveries…

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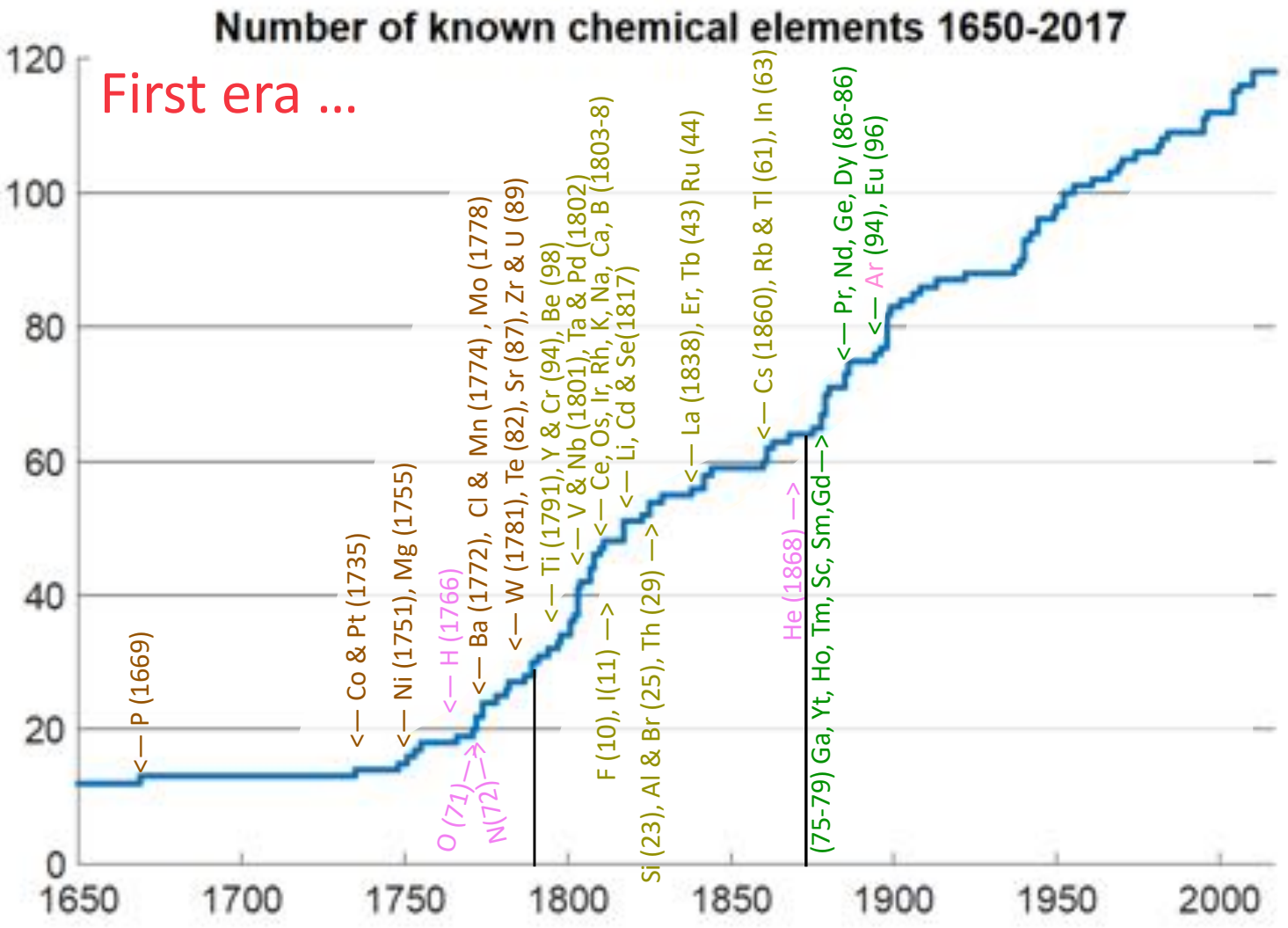
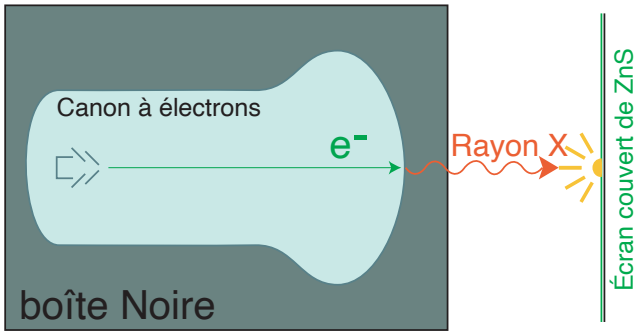
1869 … 1st version of the Mendeleev table

1896 … discovery in U rock of Radioactivity by H. Becquerel



1895 - Découverte des rayon X

Wilhelm Röntgen, (1845-1923)
Nobel de physique 1901



1896 - Découverte de la radioactivité

Antoine Henri Becquerel, (1852-1908)
Nobel de physique 1903

Il étudie des matériaux phosphorescents …
seuls les sels uraniques
impriment le papier photo
et même s'ils n'ont pas
été préalablement soumis
à une lumière intense

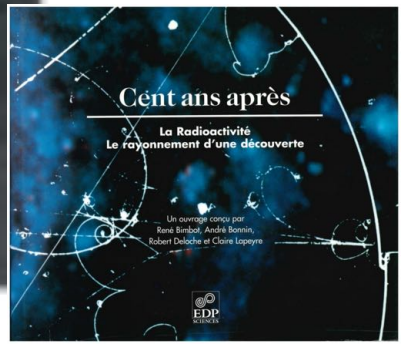
1896 - Découverte du radium et du polonium

Pierre et Marie Curie dans leur laboratoire à Paris (1900).

Marie Curie (1867-1934)
Nobel de physique 1903
Nobel de chimie 1911
Pierre **Curie** (1859-1906)
Nobel de physique 1903

Les rayonnements uraniques sont +/- déviés par un champ électrique & magnétique

rayons uraniques
- alpha,
- beta et
- gamma



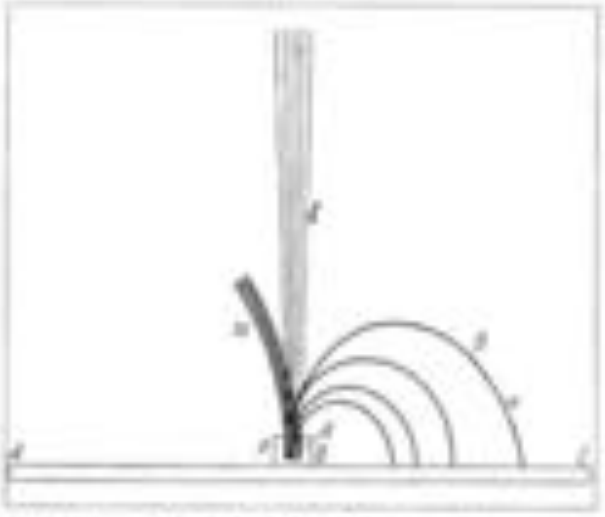
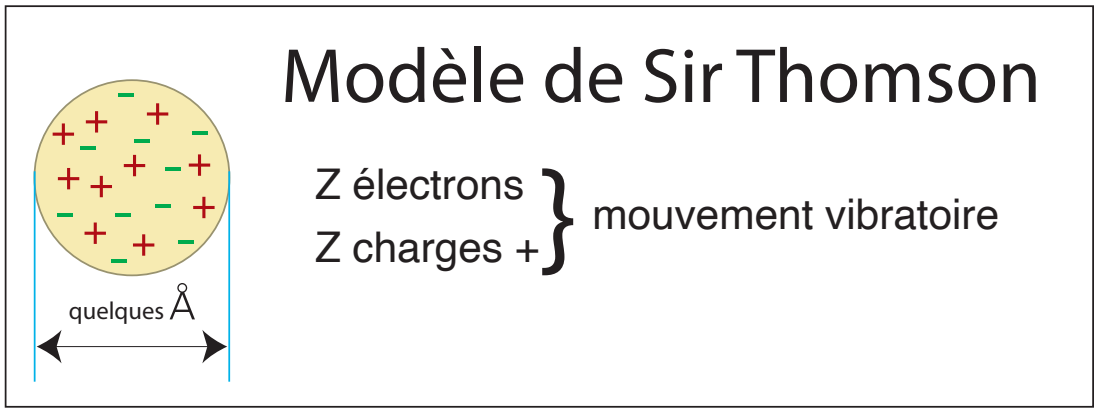


Schéma illustrant l'action d'un champ magnétique sur les rayonnements de radioactivité (Marie Curie, 1904).

1897 - Découverte de l'électron

Sir Joseph John Thomson (1856-1940)
Nobel de physique 1906

On passe du grain de matière au
« bain » de charges + et d'électrons



Atome
"divisible"

Known elements classification

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+34 "Mendeleev"

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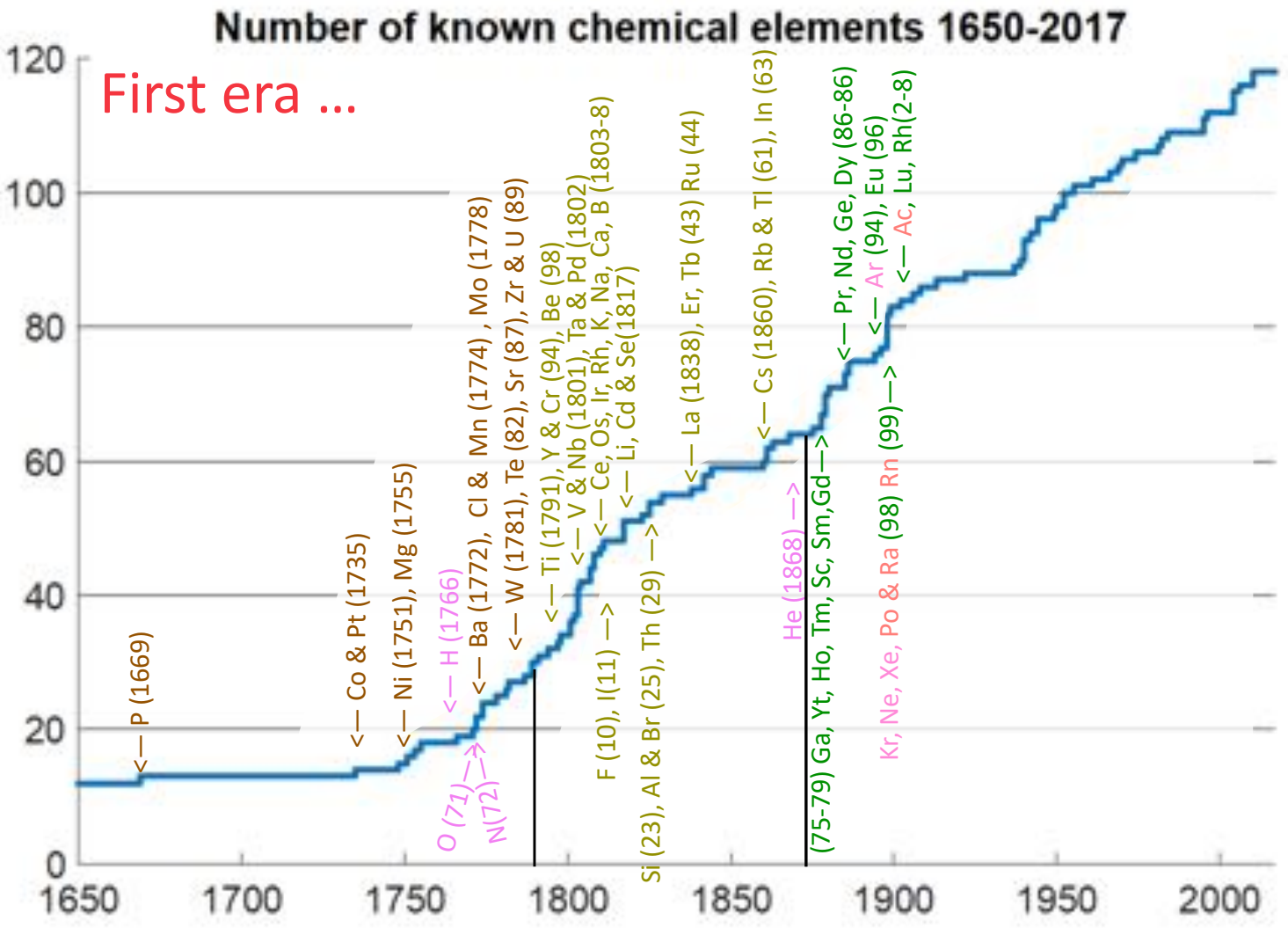


Radioactivité et rayonnements

Radioactivité

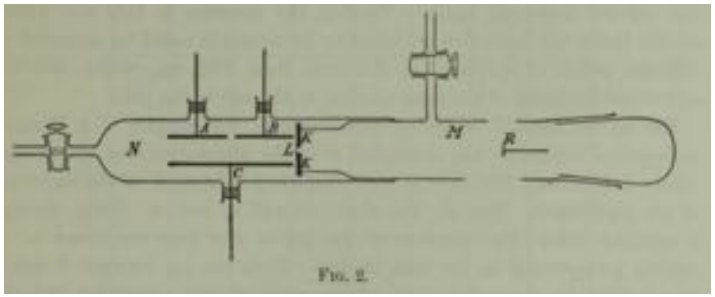
Effet chimique ou physique ?

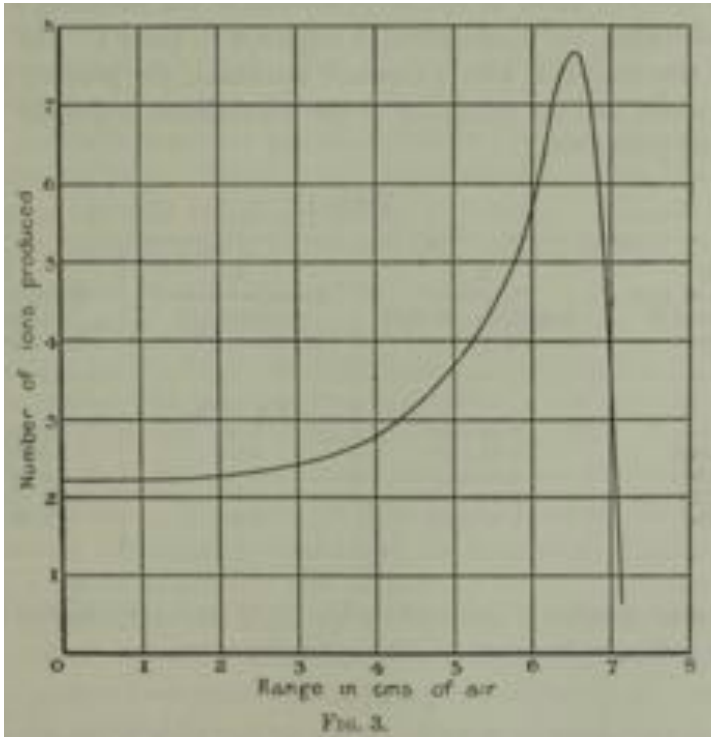
Avec quoi ?

Sources radioactive
électrodes + électromètres
écrans scintillants en ZnS
écrans absorbants (feuilles métalliques)

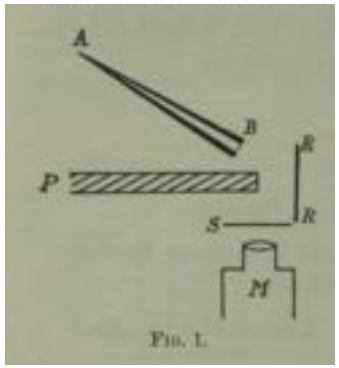
Caractéristiques / types de rayonnements ?

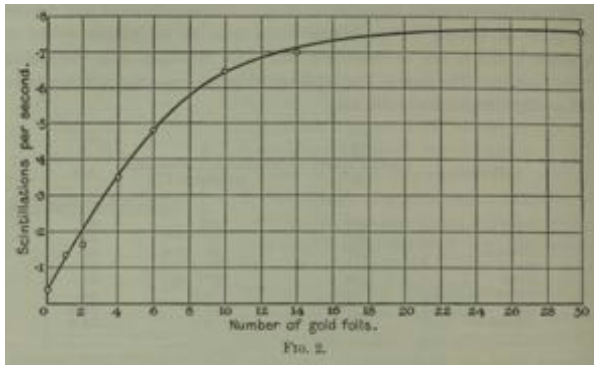
Rayonnements +/- Pénétrants ?
Rayonnements +/- Déviables ?
Loi de Geiger - Nuttal





Geiger Roy. Soc. Proc. A vol 82 issue 557 (1909) 491





1. Metal.	2. Atomic weight, A.	3. Number of scintillations per minute, Z.	4. A/Z.
Lead	207	62	30
Gold	197	67	34
Platinum	195	63	33
Tin	119	34	28
Silver	108	27	25
Copper	64	14·5	23
Iron	56	10·2	18·5
Aluminium	27	2·4	12·5

Geiger & Marsden Roy. Soc. Proc. A vol 82 issue 557 (1909) 495

1908 - Expérience « de Rutherford »


Images wikipedia

Hans Geiger
(1882-1945)

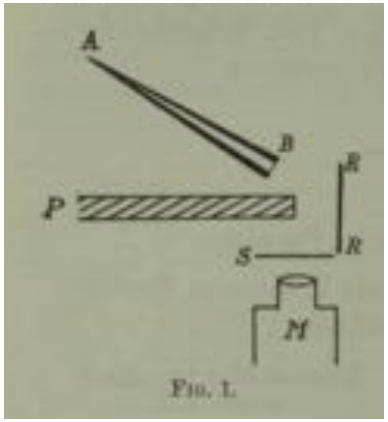
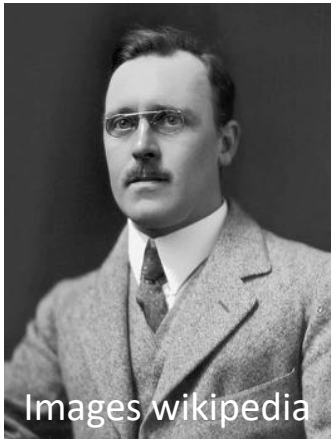
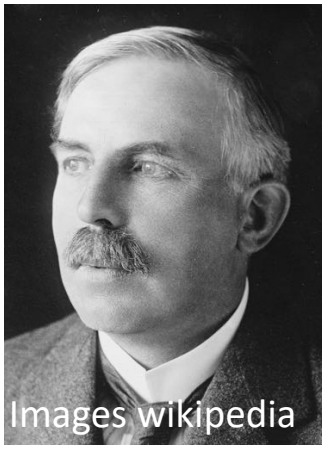


Fig. 1.


Images wikipedia

Ernest Marsden
(1889-1970)


Images wikipedia

Sir Ernest Rutherford (1871-1937)
Nobel de chimie 1908

On a Diffuse Reflection of the α-Particles.

By H. Geiger, Ph.D., John Harling Fellow, and E. Marsden, Hatfield Scholar, University of Manchester.

(Communicated by Prof. E. Rutherford, F.R.S. Received May 19,—Read June 17, 1909.)

When β-particles fall on a plate, a strong radiation emerges from the same side of the plate as that on which the β-particles fall. This radiation is regarded by many observers as a secondary radiation, but more recent experiments seem to show that it consists mainly of primary β-particles, which have been scattered inside the material to such an extent that they emerge again at the same side of the plate.* For α-particles a similar effect has not previously been observed, and is perhaps not to be expected on account of the relatively small scattering which α-particles suffer in penetrating matter.†

In the following experiments, however, conclusive evidence was found of the existence of a diffuse reflection of the α-particles. A small fraction of the α-particles falling upon a metal plate have their directions changed to such an extent that they emerge again at the side of incidence. To form an idea of the way in which this effect takes place, the following three points were investigated :—

(I) The relative amount of reflection from different metals.
(II) The relative amount of reflection from a metal of varying thickness.
(III) The fraction of the incident α-particles which are reflected.

* See Schmidt, 'Jahrbuch der Radioaktivität und Electronik,' vol. 5, p. 471, 1908.
† Rutherford, 'Phil. Mag.,' vol. 12, p. 143, 1906; H. Geiger, 'Roy. Soc. Proc.,' A, vol. 81, p. 174, 1908.

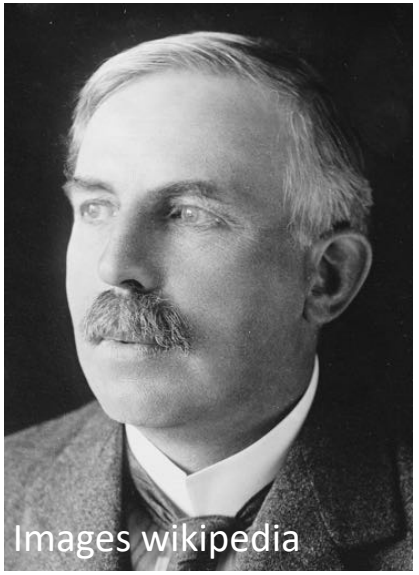
Geiger & Marsden Roy. Soc. Proc. A vol 82 issue 557 (1909) 495

Mise en évidence du noyau atomique en 1911.

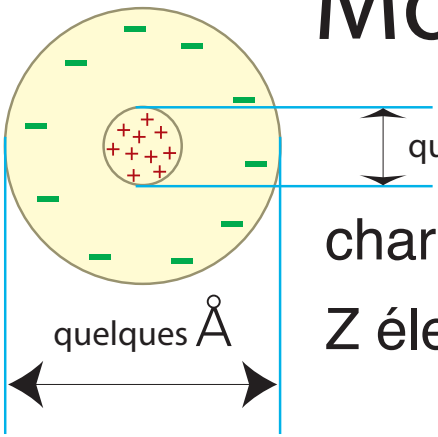
Rutherford E. Philosophical Magazine Series 6, 21 125 (1911) 669 — 688

1908 - Expérience « de Rutherford »

Sir Ernest Rutherford (1871-1937)
Nobel de chimie 1908


Images wikipedia

Modèle de E. Rutherford



charge +Z contenue dans une poche (noyau)

Z électrons liés au noyau

C'est la mise en évidence du noyau atomique en 1911.

Rutherford E. Philosophical Magazine Series 6, 21 125 (1911) 669 — 688

Naissance de la physique nucléaire

Après la mise en évidence du noyau atomique…

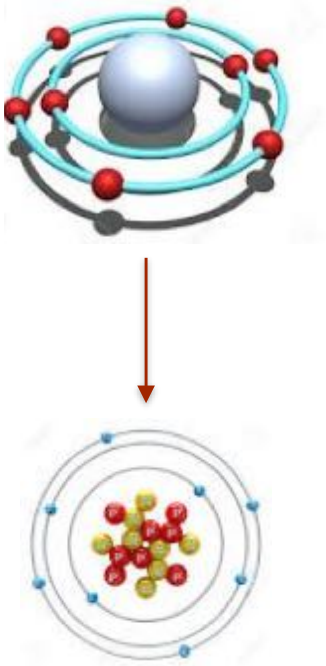
Antonius van den Broek
(1870-1926)

Place d'un élément
dans la classification
= charge du noyau

Henry Moseley
(1887-1915)

Il vérifie en 1913
cette hypothèse

la découverte du neutron …



1. **Expériences de Walther Bothe et Herbert Becker (1930)**
   alpha + Li, Be ou B —> rayonnement neutre et très pénétrant
   rayons gamma ?
2. **Irène & Frédérique Joliot-Curie (1931)**
   Ce rayonnement neutre est assez énergétique pour mettre en mouvement des protons
3. **Sir James Chadwick (1932)**
   refait ces expériences et conclut à l'existence du neutron

Known elements classification

…13 primitives elements
+17 "Lavoisier"
+34 "Mendeleev"
+25 (natural)

Some « modern chemistry » starts 17th century

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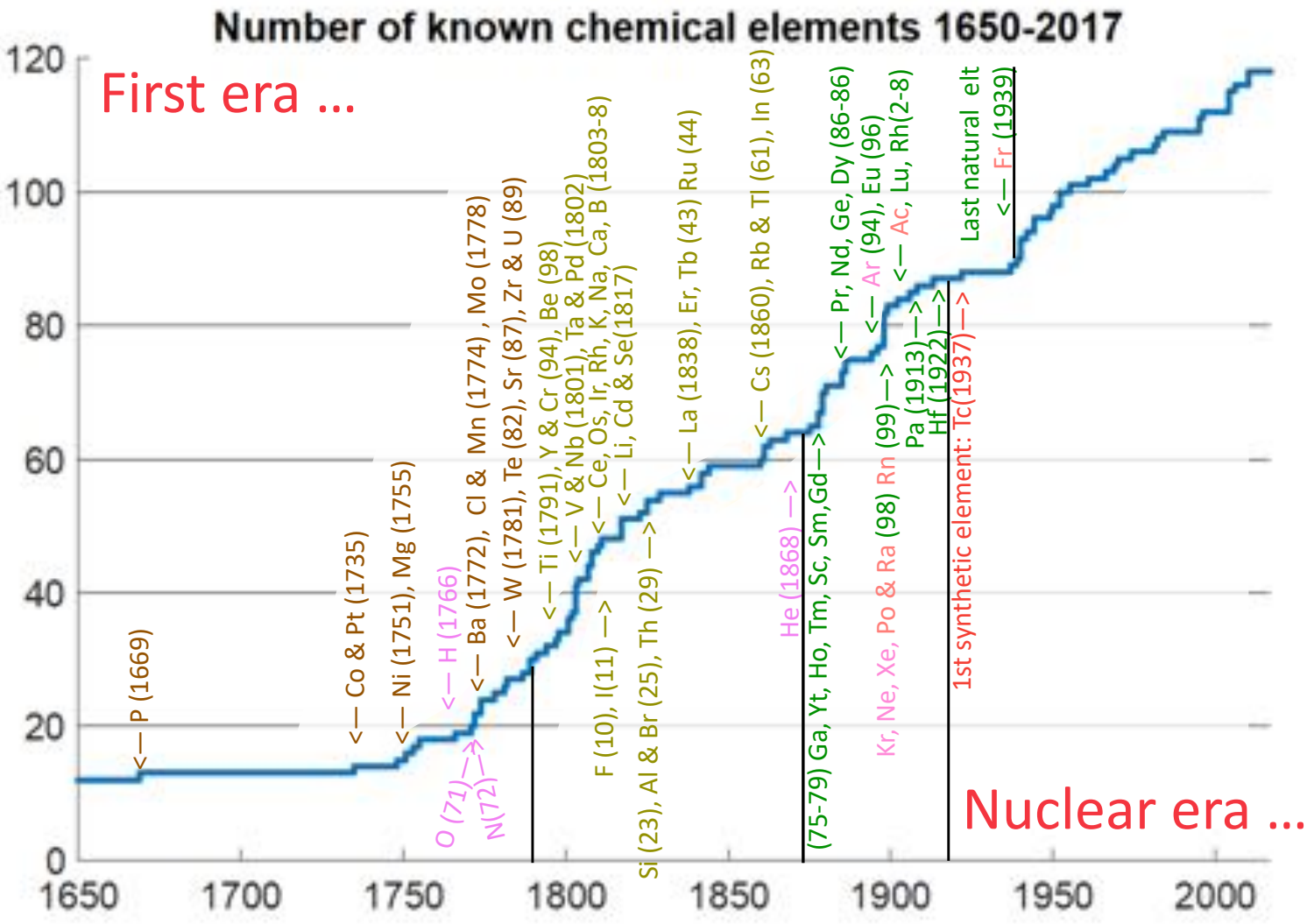
1908 … Geiger-Marsden expt. $^{4}He + {}^{197}Au \longrightarrow$ diffusion

1934 … Artificial radioisotope $^{4}He + {}^{27}Al \longrightarrow {}^{30}P$ (+n) (Joliot)

1937 … 1st synthetic element: Tc (cyclotron)

1939 … last natural element Fr

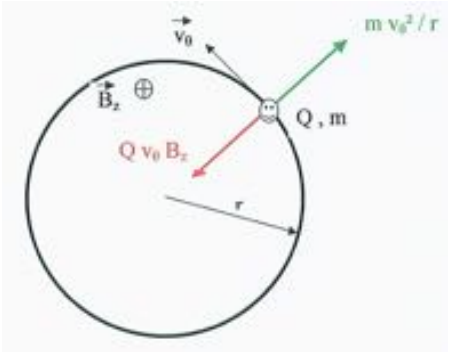


Cyclotrons

2. Le cyclotron en une seule équation

C'est séduisant, mais pas suffisant : dans les années 30, on ne savait faire que des générateurs de tension sinusoïdale à fréquence fixe. Donc, il fallait en plus qu'après ½ tour dans le champ magnétique, les ions reviennent à l'intervalle accélérateur en synchronisme avec cette tension. Là, Ernest a pris son crayon, les lois de la mécanique et de l'électromagnétisme, et il a écrit :

- quand un corps de masse m se déplace sur un cercle de rayon r à une vitesse constante v_θ, il est soumis à une force centrifuge $m v_\theta^2 / r$
- s'il reste sur ce cercle, c'est que cette force est équilibrée à tout instant par une force égale dirigée en sens inverse ; dans le cas d'une particule chargée de masse m, de charge Q se déplaçant dans un champ magnétique B_z perpendiculaire à la vitesse, cette force dite de Laplace vaut $Q v_\theta B_z$.



Il suffit d'écrire l'égalité des deux forces :

$$\boxed{m v_\theta^2 / r = Q\, v_\theta\, B_z} \qquad [1]$$

pour en déduire la vitesse angulaire ω:

$$\omega = \frac{d\theta}{dt} = \frac{v_\theta}{r} = \frac{QB_z}{m} \qquad [2]$$

Donc, dans un champ magnétique constant, ***la vitesse angulaire*** ou, si l'on préfère, ***la fréquence de révolution***

$$f_{rev} = \frac{\omega}{2\pi} \qquad [3]$$

est constante, au moins tant que la masse ne change pas par effet relativiste. C'est ce qu'on appelle ***l'isochronisme***. Le résultat de l'application des lois de la mécanique a donc été bienveillant à l'égard de Lawrence, et la formule [1] résume tout (enfin, presque) le cyclotron.

Cyclotrons

Il suffit en effet d'appliquer à l'électrode d'accélération une tension sinusoïdale dont la fréquence f_{hf} est égale à f_{rev} (ou à un multiple), de façon que l'ion arrive toujours dans l'intervalle d'accélération au sommet de l'onde HF. La figure 3 montre comment ça marche . (noter que, comme on n'a encore rien dit sur l'origine des ions, on a ici juste placé une source d'ions presque au centre de la machine).

Que nous dit encore la formule 1 ? On peut l'écrire aussi :

$$v_\theta = \frac{Q B_z r}{m} \qquad [4]$$

: à tout rayon r dans le cyclotron, correspond une vitesse v_θ. Le rayon grandit au fur et à mesure que la vitesse s'accroît : la trajectoire d'un ion accéléré ressemble fortement à une spirale.

Enfin, cette même équation [1] peut encore s'écrire en séparant les termes relatifs à l'ion et ceux propres à la configuration magnétique. Ce qui nous permet de définir la notion de ***rigidité magnétique*** :

$$B r = \frac{mv}{Q} \quad \text{(en ignorant les indices),} \qquad [5]$$

paramètre souvent désigné sous le sobriquet de Bρ (Bérho), qui permet de déterminer le champ magnétique nécessaire pour donner un rayon de courbure r (ou ρ) à une particule de caractéristiques données.

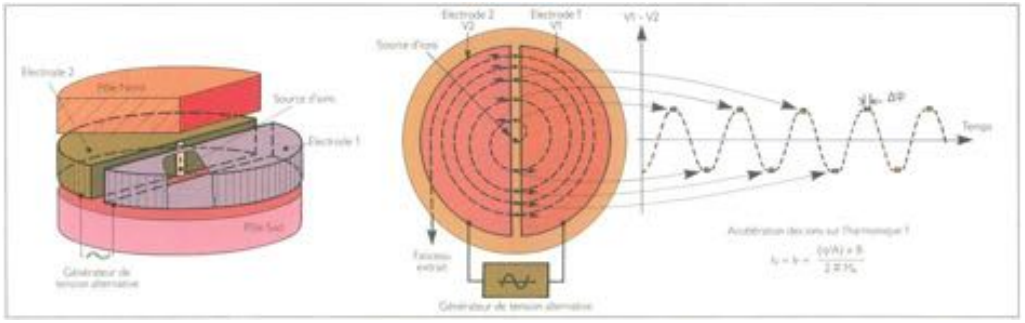


Figure 3

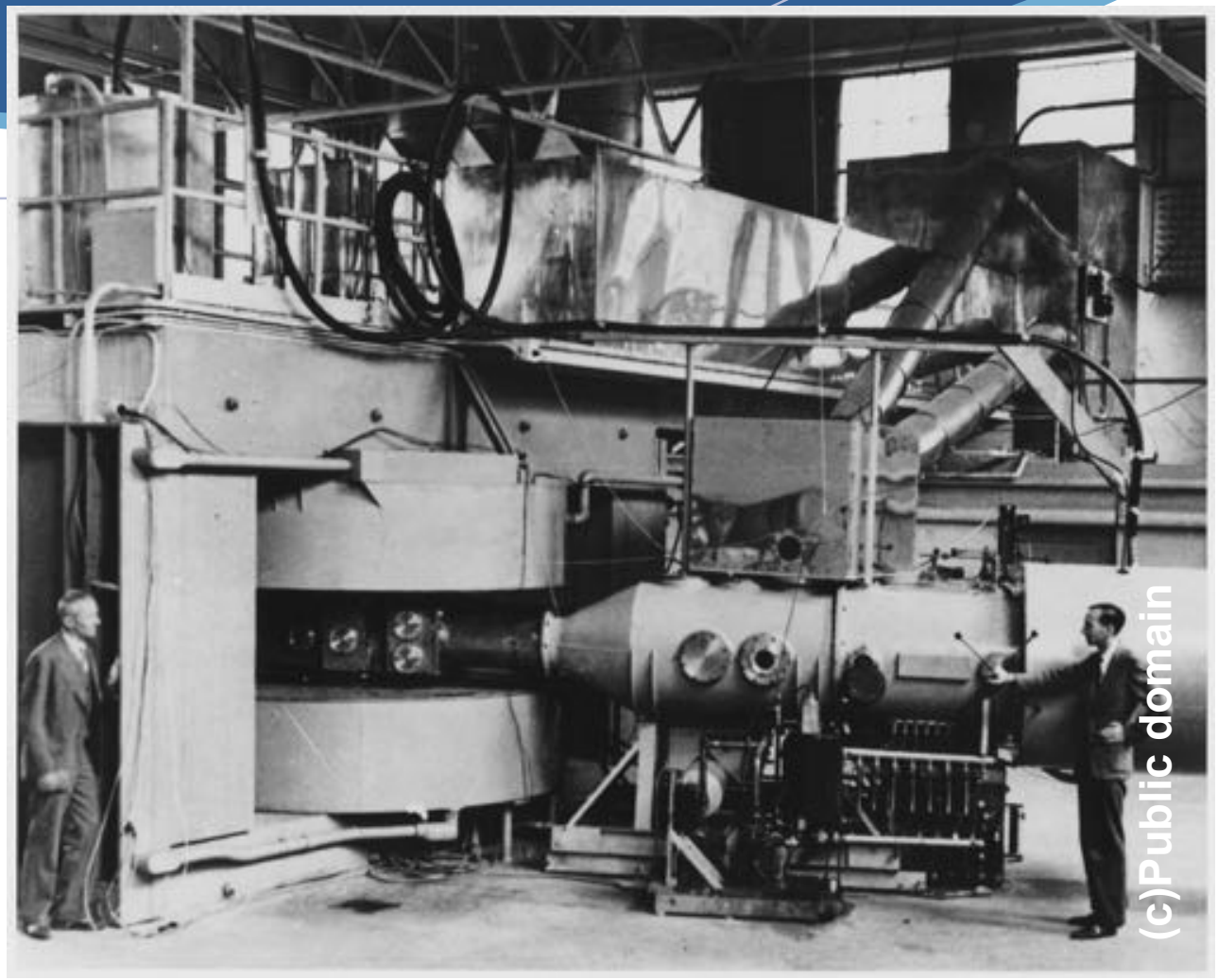
On voit aussi sur la figure 3 qu'on a créé le champ magnétique avec un pôle Nord et un pôle Sud circulaires, avec une parfaite symétrie cylindrique, sans plus de précision pour l'instant. Avant d'entrer dans des considérations un peu pénibles, jetons un coup d'œil sur l'aspect général d'un cyclotron compact (ici, un des deux C0 dans leur première version, car ils ont subi des modifications au cours de l'histoire du GANIL). Sur la figure 4, on distingue

88' cyclotron @ LBNL

Synthesis of elements Z = 93 to 98 in LBNL*

Z	sigle	reaction	year
93	^{239}Np	n + ^{238}U	1940
94	^{240}Pu	d + ^{238}U	1940
95	^{241}Am	2n*+^{239}Pu	1944
96	^{242}Cm	^{4}He + ^{239}Pu	1944
97	^{243}Bk	^{4}He + ^{241}Am	1949
98	^{245}Cf	^{4}He + ^{242}Cm	1950

* **Am was done @ ANL in reactor by two successive n capture followed by radioactive decay**

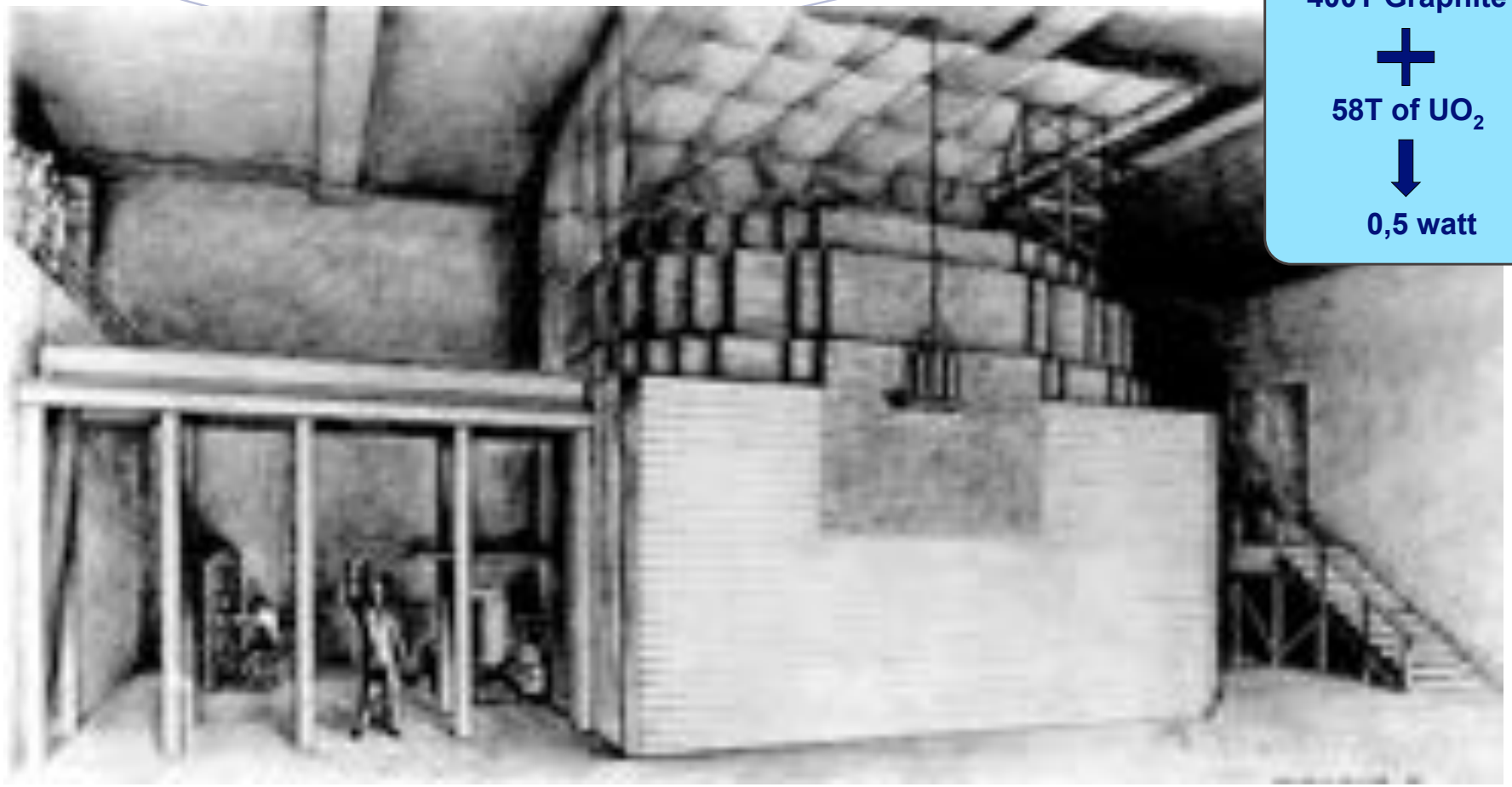


^{239}Pu from LBNL demonstrated the highest interest of plutonium for nuclear fission

First artificial nuclear reactor

After discovery of fission process by Otto Hahn, Fritz Strassmann and Lise Meitner in december 1938

E. Fermi starts CP1 (Chicago Pile 1) in december 1942



400T Graphite

+

58T of UO_2

↓

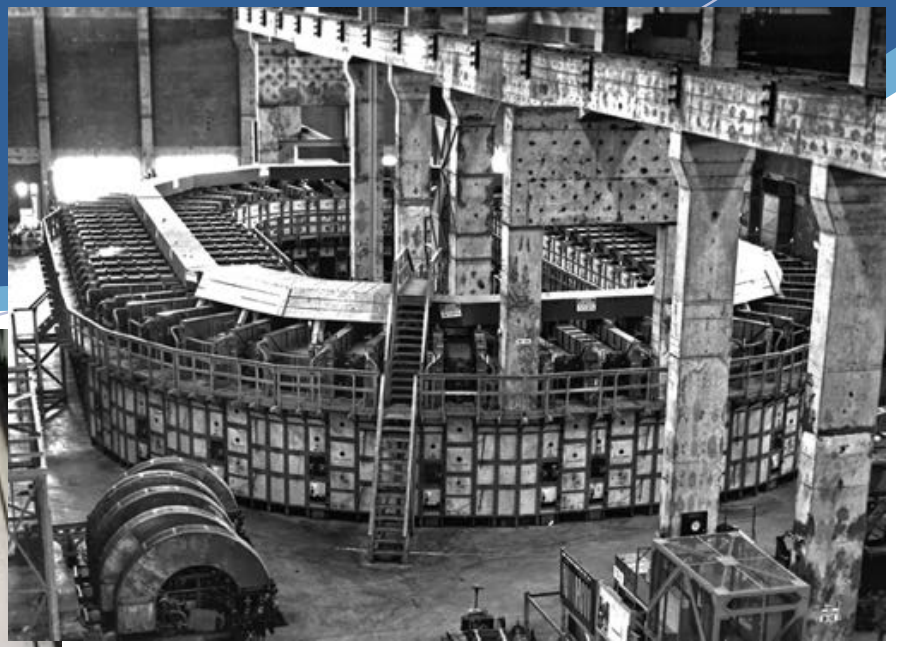
0,5 watt

© Argonne National Laboratory

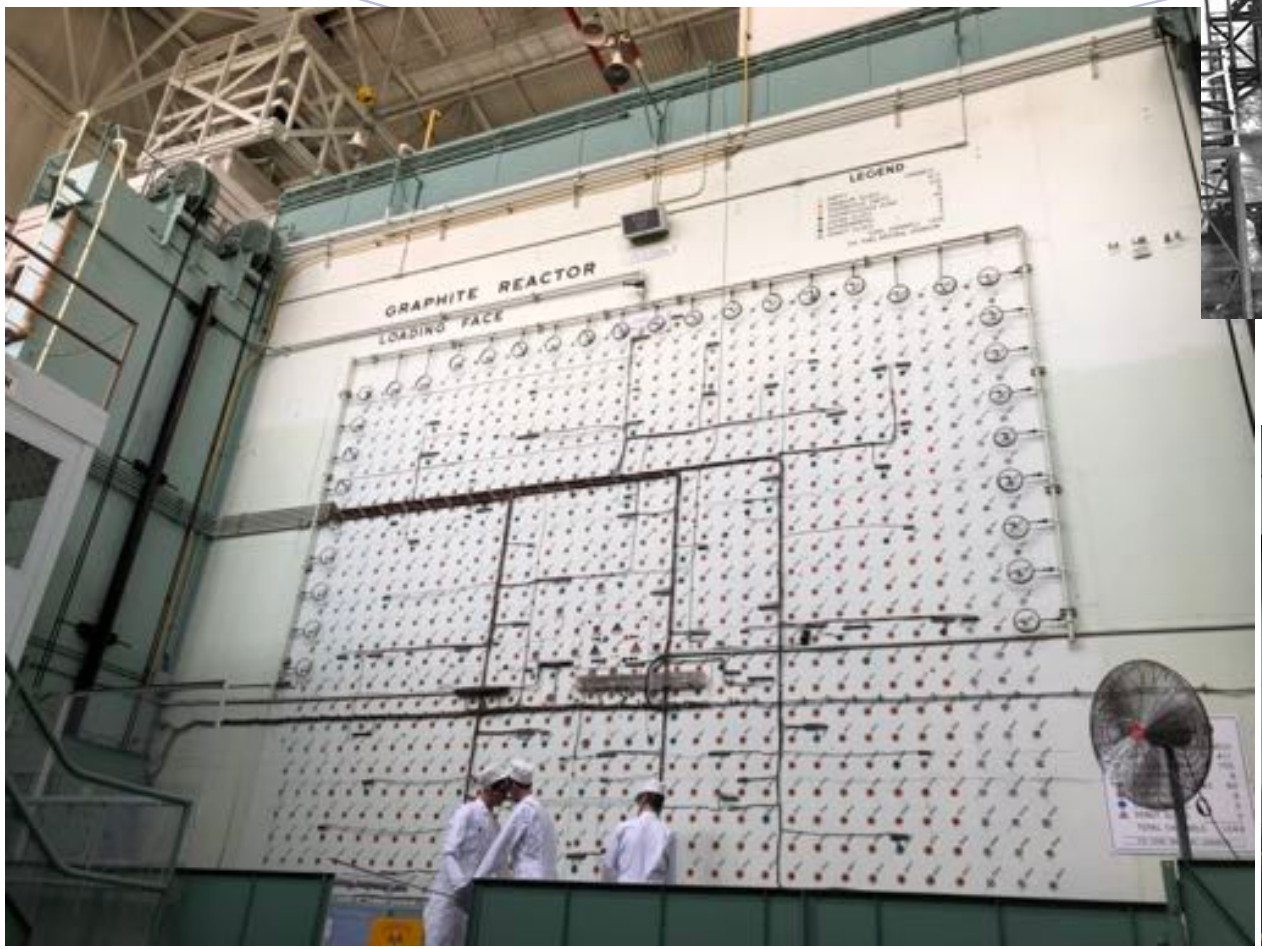
Graphite nuclear reactor @ ORNL

The manhattan project was launched and needed

- **uranium enriched in ^{235}U**
- **significant amount of ^{239}Pu**



Alpha I racetrack, Y-12 (c) public



Graphite reactor X-10 (c) B. GALL

… and first H-bomb Mike (1 Nov 1952)

File:"Ivy Mike" atmospheric nuclear test - November 1952 - Flickr - The Official CTBTO Photostream.jpg

Central flux : 10^{24} n / cm^2

=> Einsteinium (Z=99)

=> Fermium (Z=100)

+ subsequent discovery

1955 $^{4}He + ^{253}Es \longrightarrow ^{256}Md + n$ … the Mendelevium (Z=101)

Known elements classification

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+17 "Lavoisier"
+34 "Mendeleev"
+25 (natural)
+12+2 synthetic, heavy

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1869 … 1st version of the Mendeleev table

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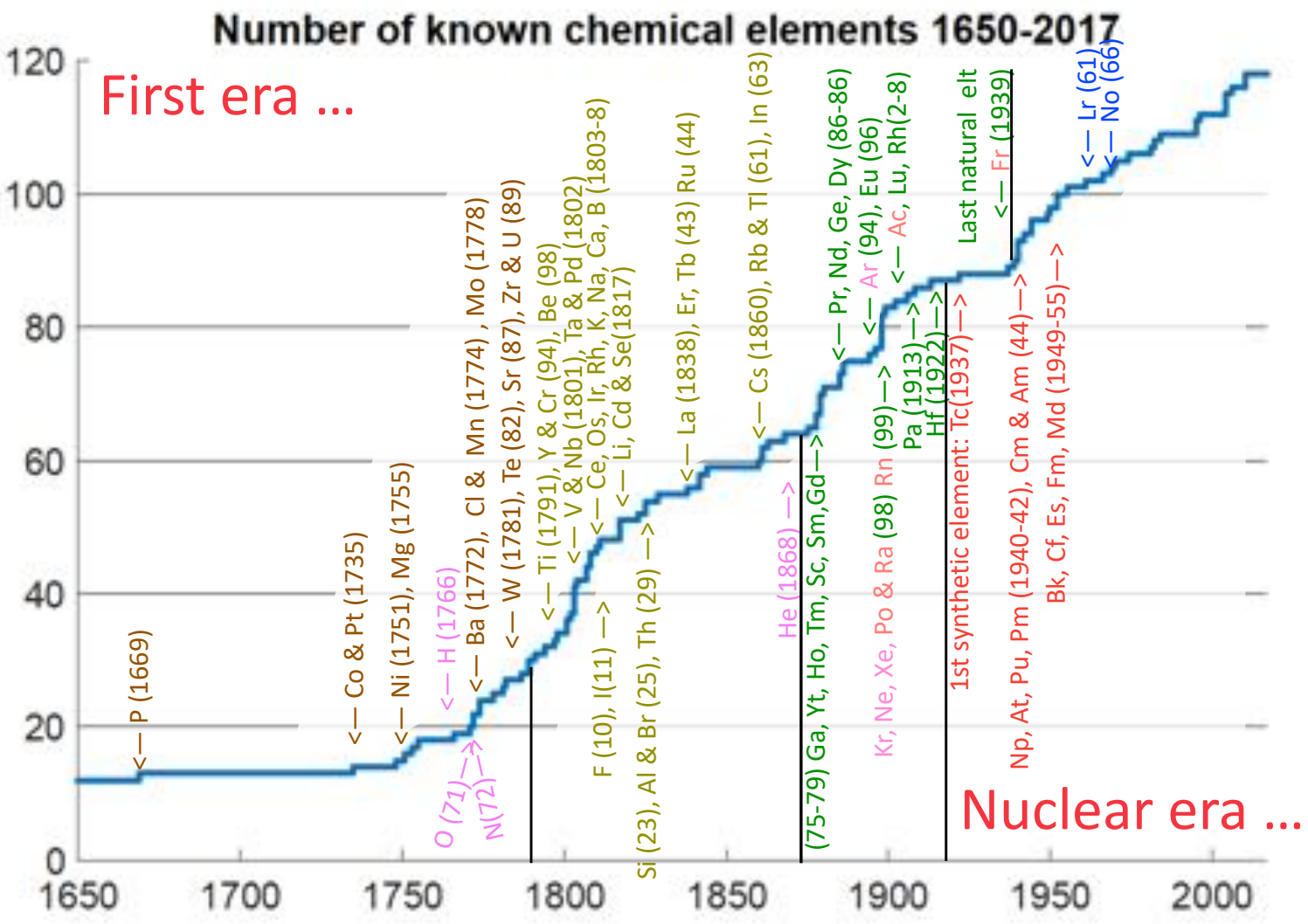
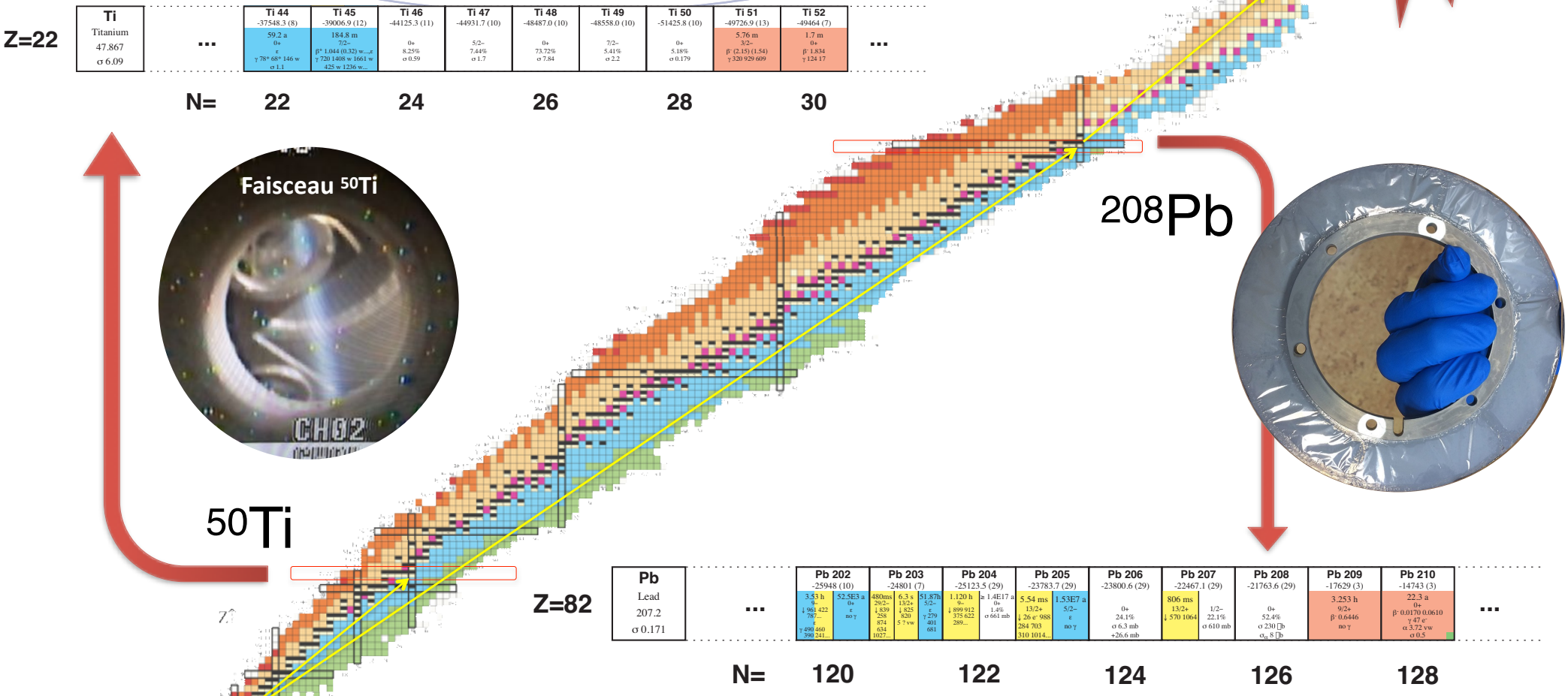


Accélérateurs d'ions

$$^{50}_{22}Ti_{28} + ^{208}_{82}Pb_{126} \Rightarrow ^{258}_{104}Rf_{154}(CN) \Rightarrow ^{256}_{104}Rf_{152} + 2n$$

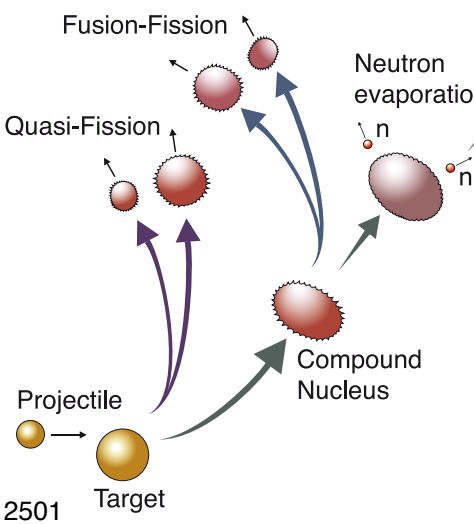
^{256}Rf

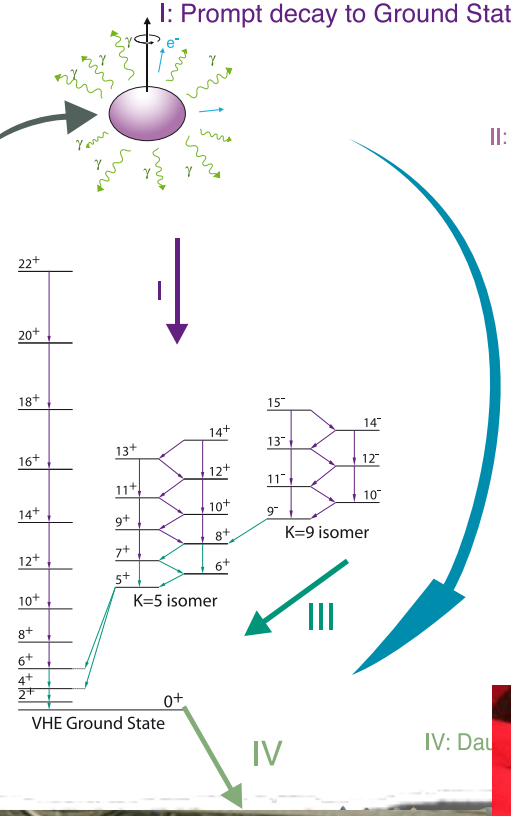


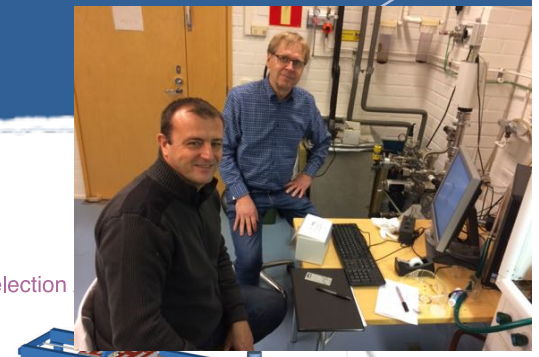
Initial aim: ^{256}Rf prompt spectroscopy

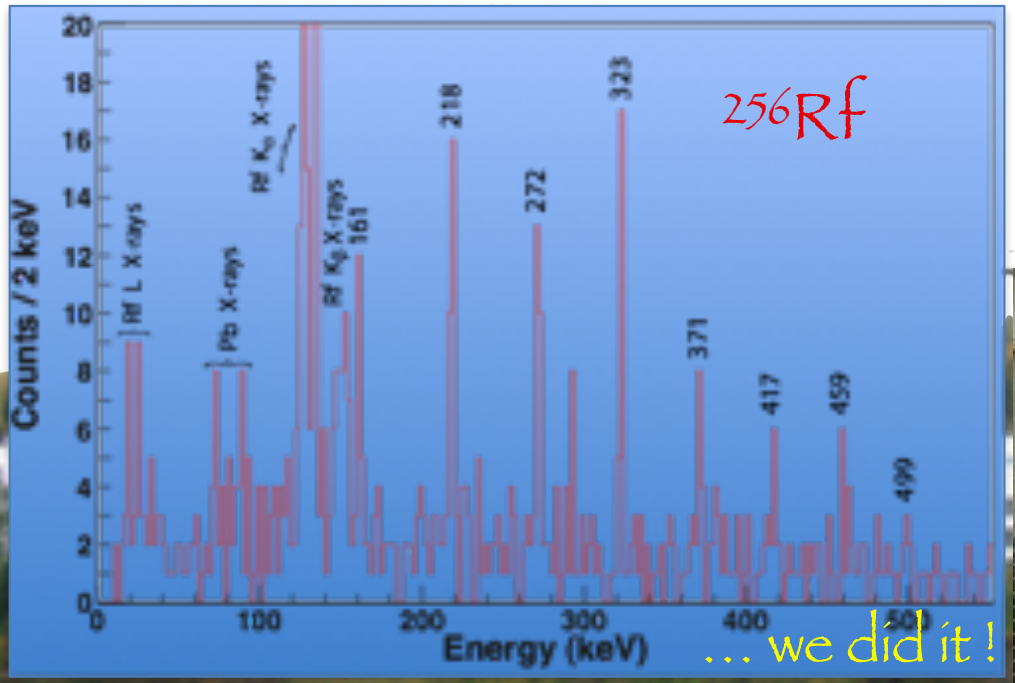
Needed 50 pnA of ^{50}Ti beam … ???

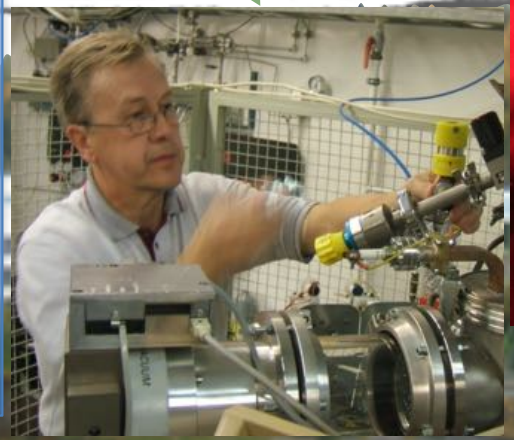
Greenlees, Rubert et al., PRL 109 (2012) 012501





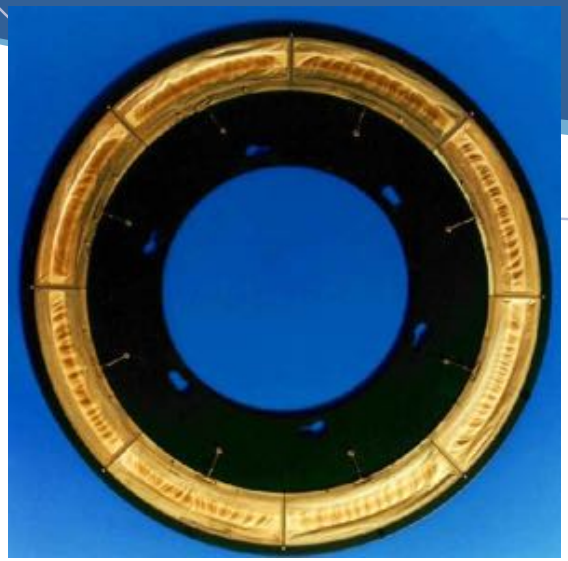


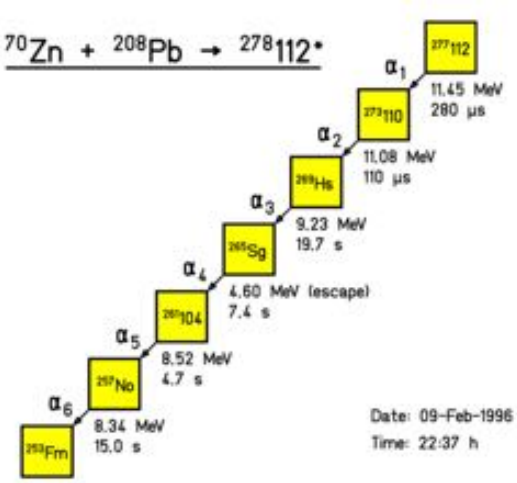


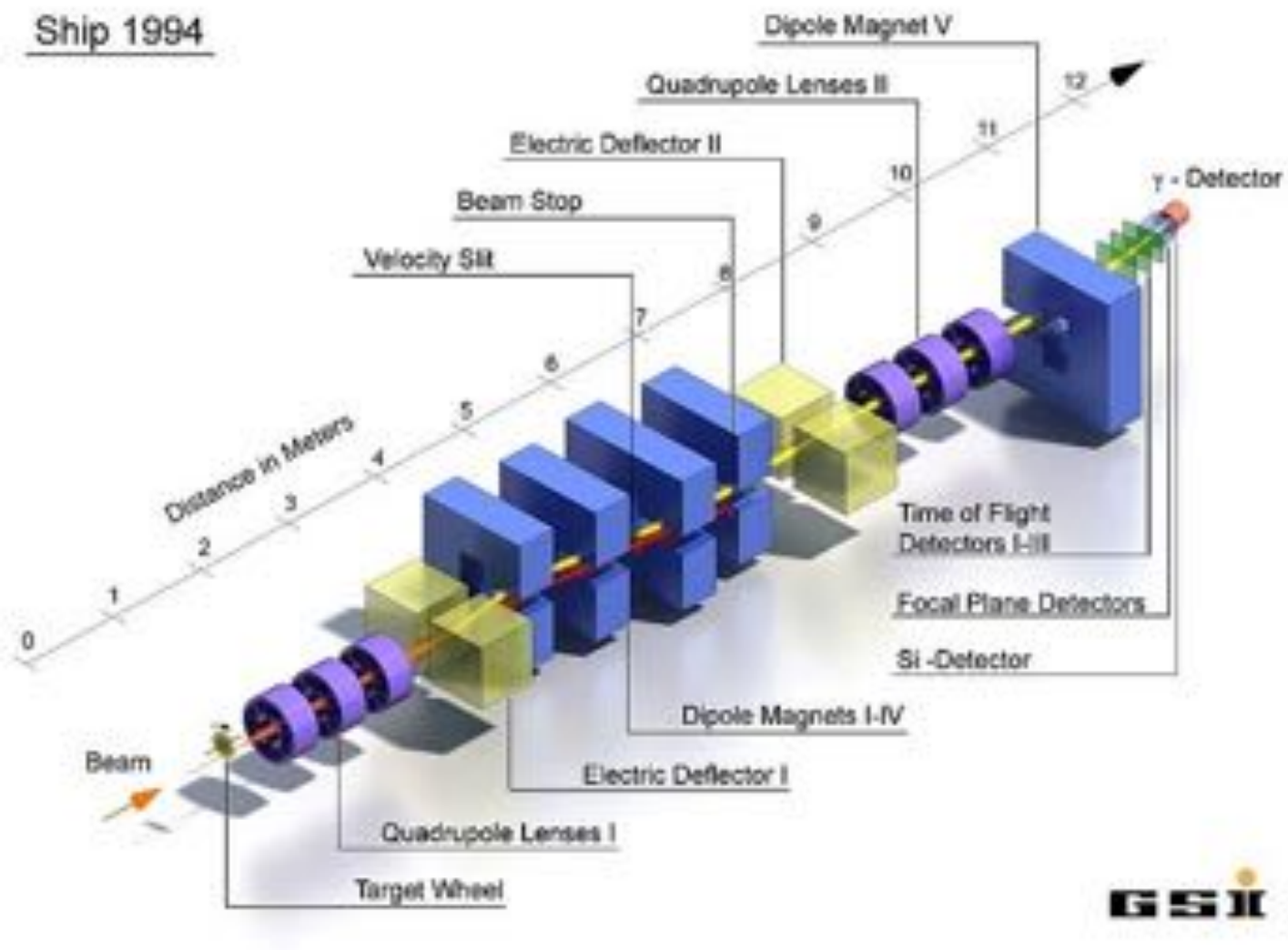


Cold fusion $^{208}Pb/^{209}Bi$

SHIP (@GSI) discovery of elements 107-112

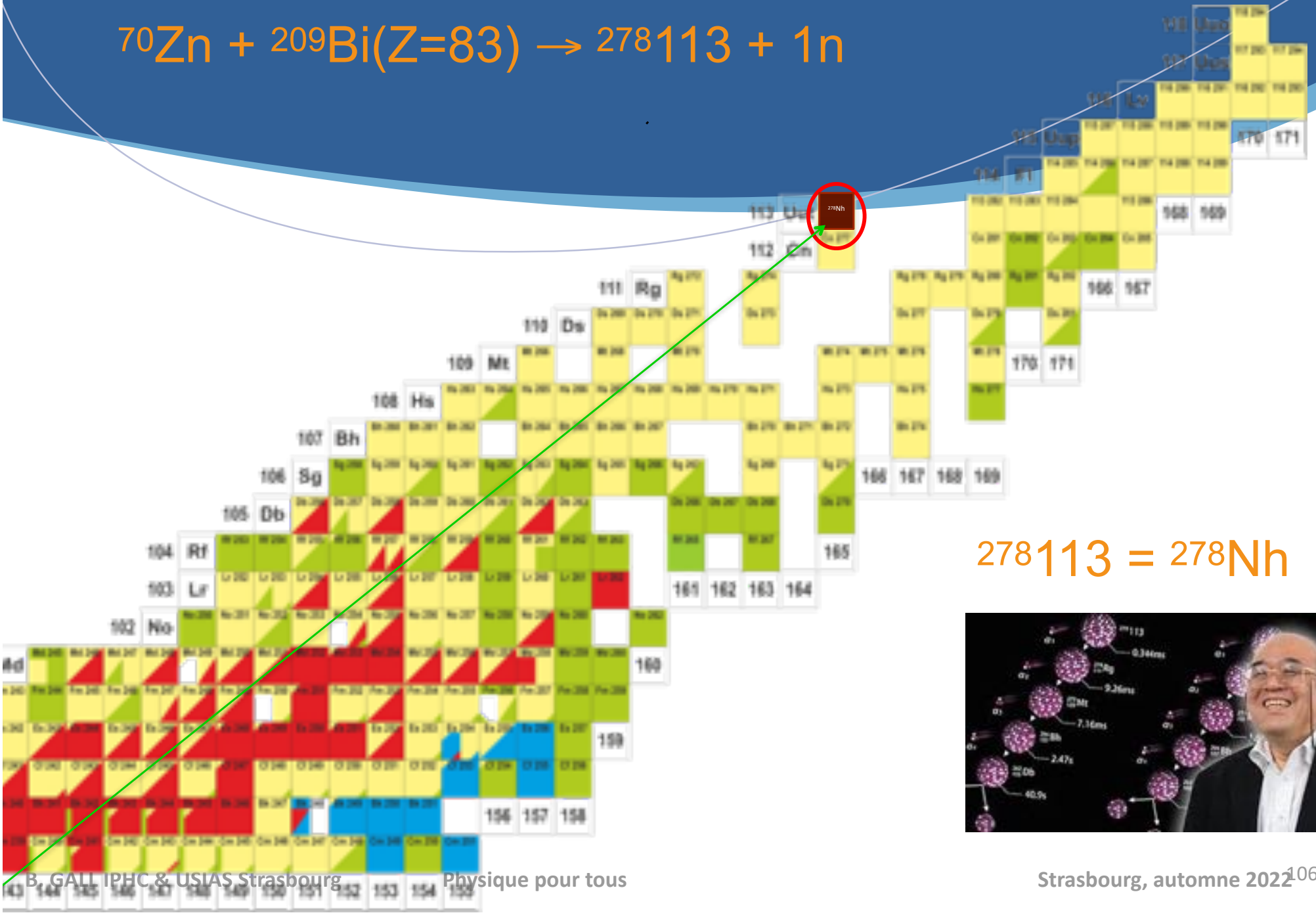






Cold fusion $^{208}Pb/^{209}Bi$

$^{70}Zn + {}^{209}Bi(Z=83) \rightarrow {}^{278}113 + 1n$



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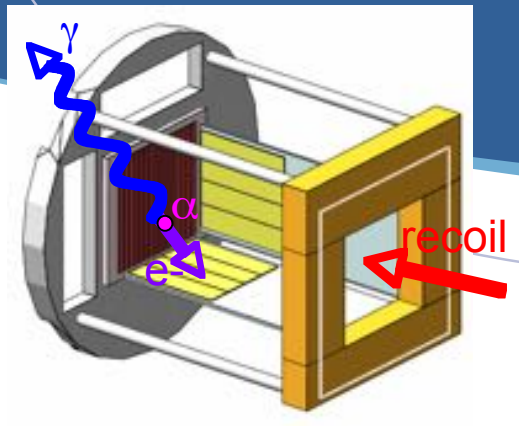

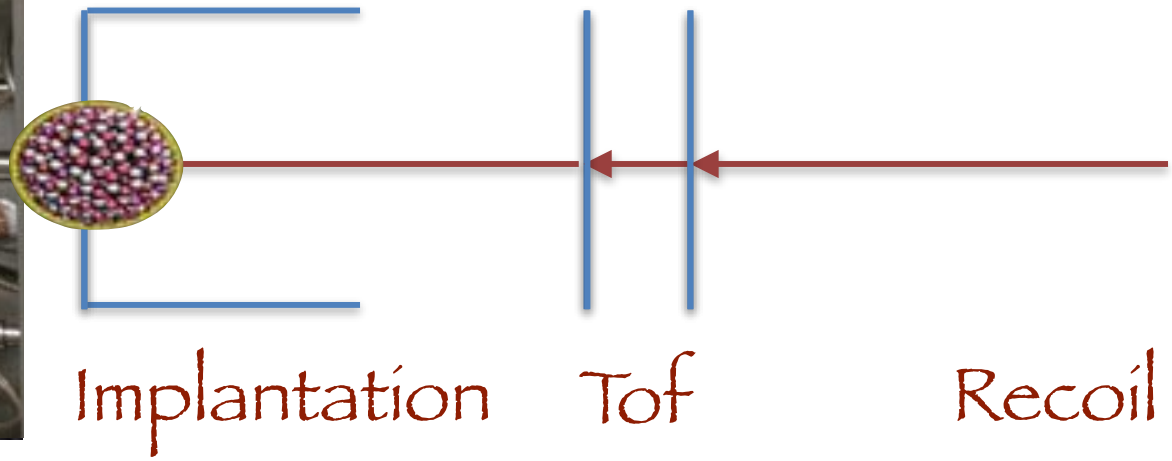

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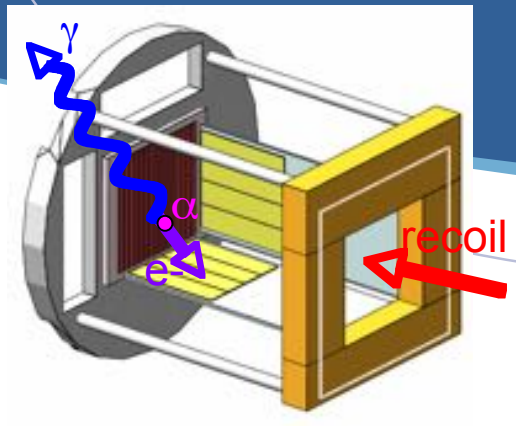

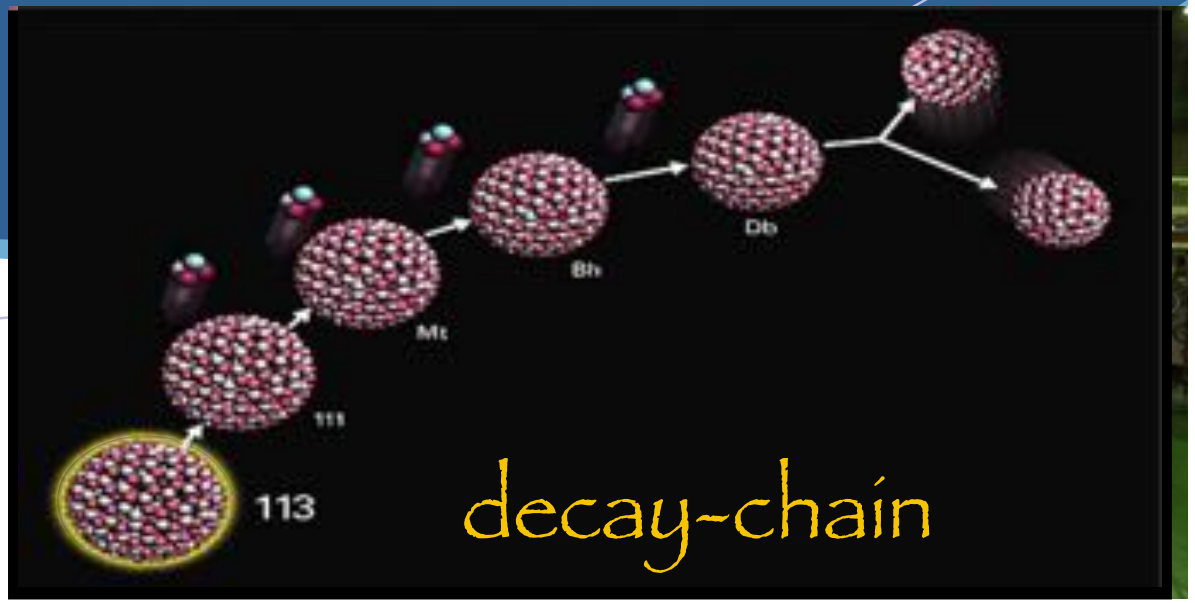

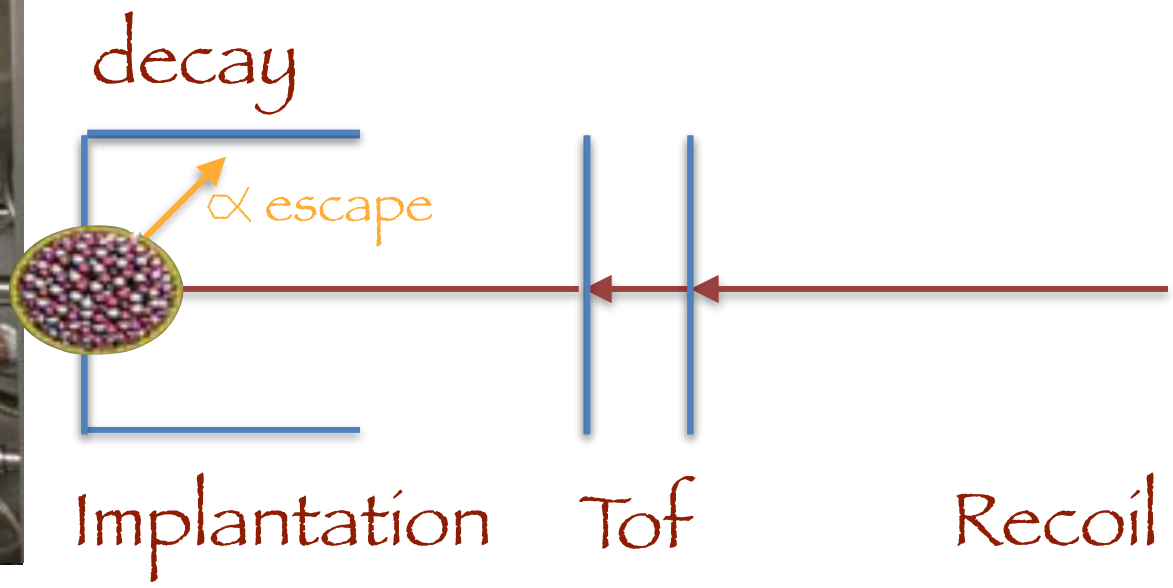

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Three ^{278}Nh (Z=113) observed

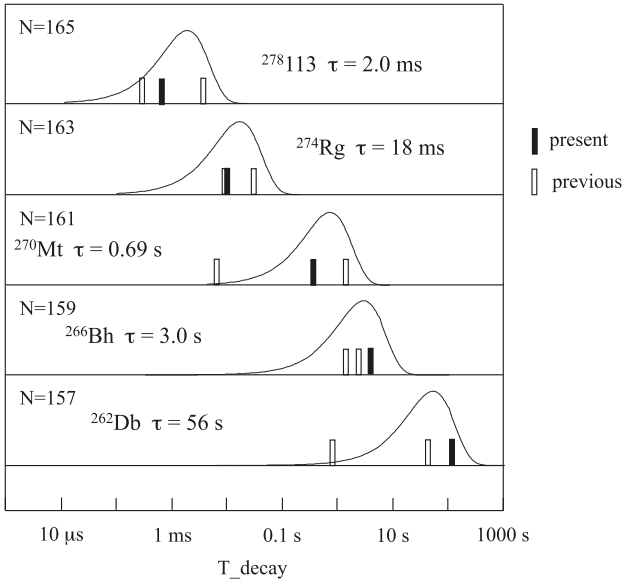

Fig. 2. Decay time (T_decay) distributions of the decay family originating from $^{278}113$ are indicated. The logarithm of the decay times is taken as the abscissa. Mean lifetimes τ determined from three decay chains are shown together with the symbols of the nuclides. Curves in the graphs correspond

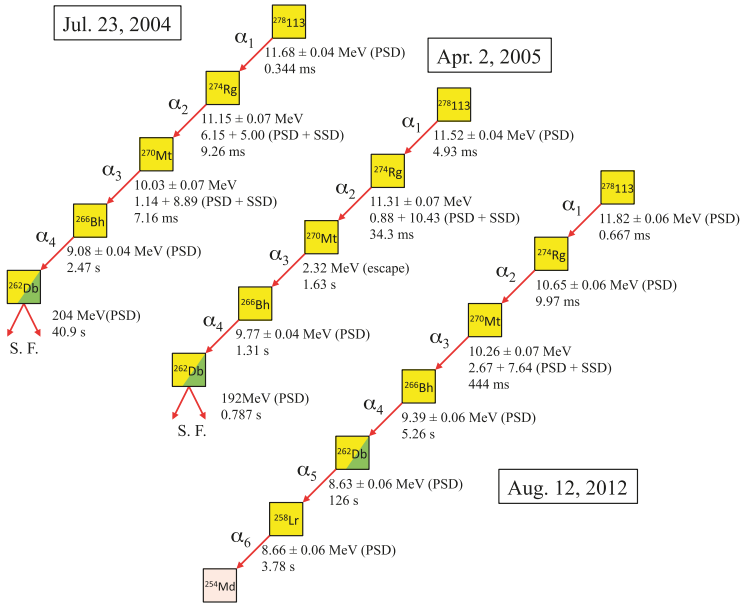

Fig. 3. (Color) Observed decay chain in the present work together with previously observed chains.[1,2)]

GARIS I (@RIKEN) Nh in 3 years of beam time)

Known elements classification

Some « modern chemistry » starts 17th century

…13 primitives elements
+17 "Lavoisier"
+34 "Mendeleev"
+25 (natural)
+12+2 synthetic, heavy

H. Brand discovered Phosphorous (1669) and Cobalt (1735)
… alchemy / quest for gold and industrialisation accelerated discoveries…

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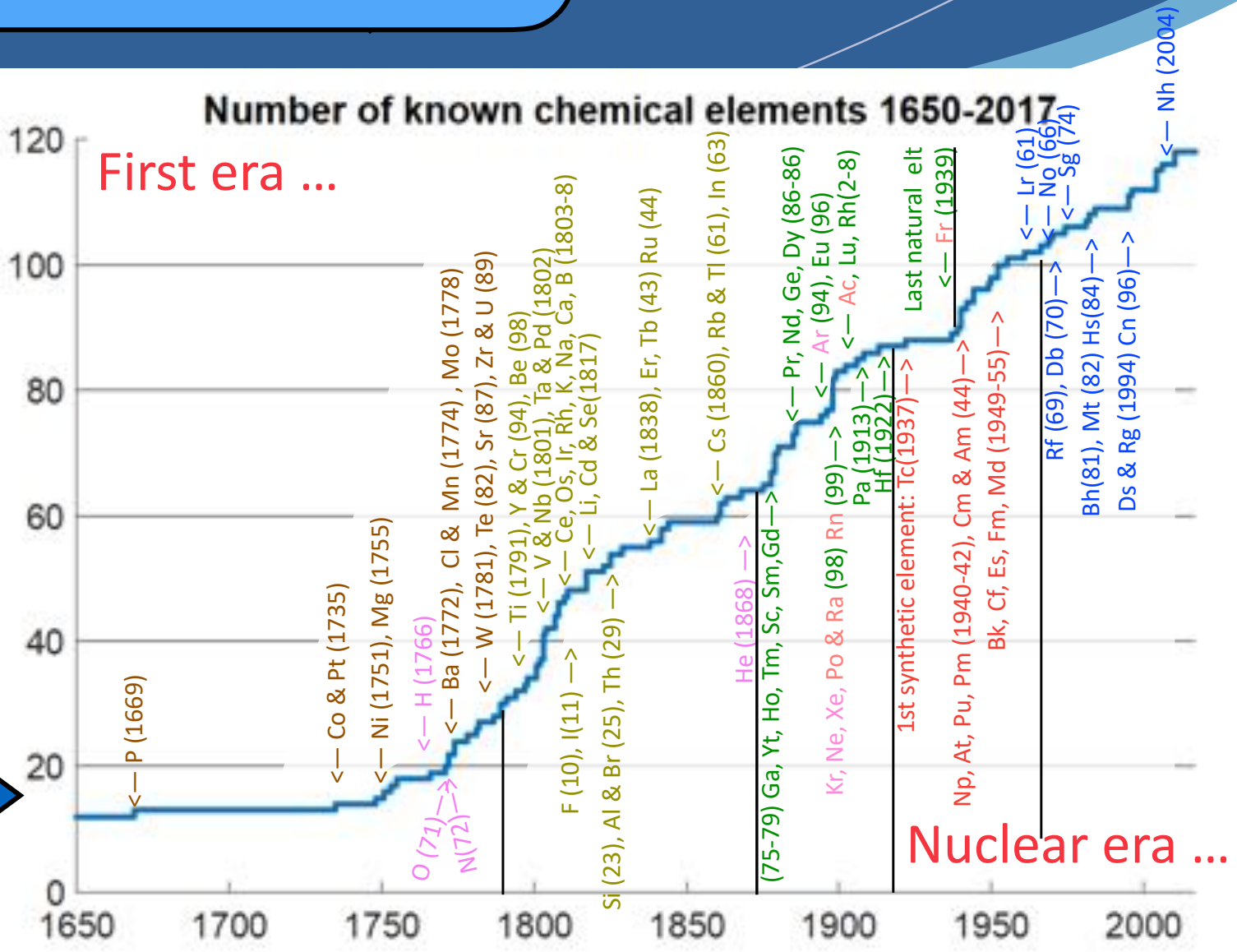
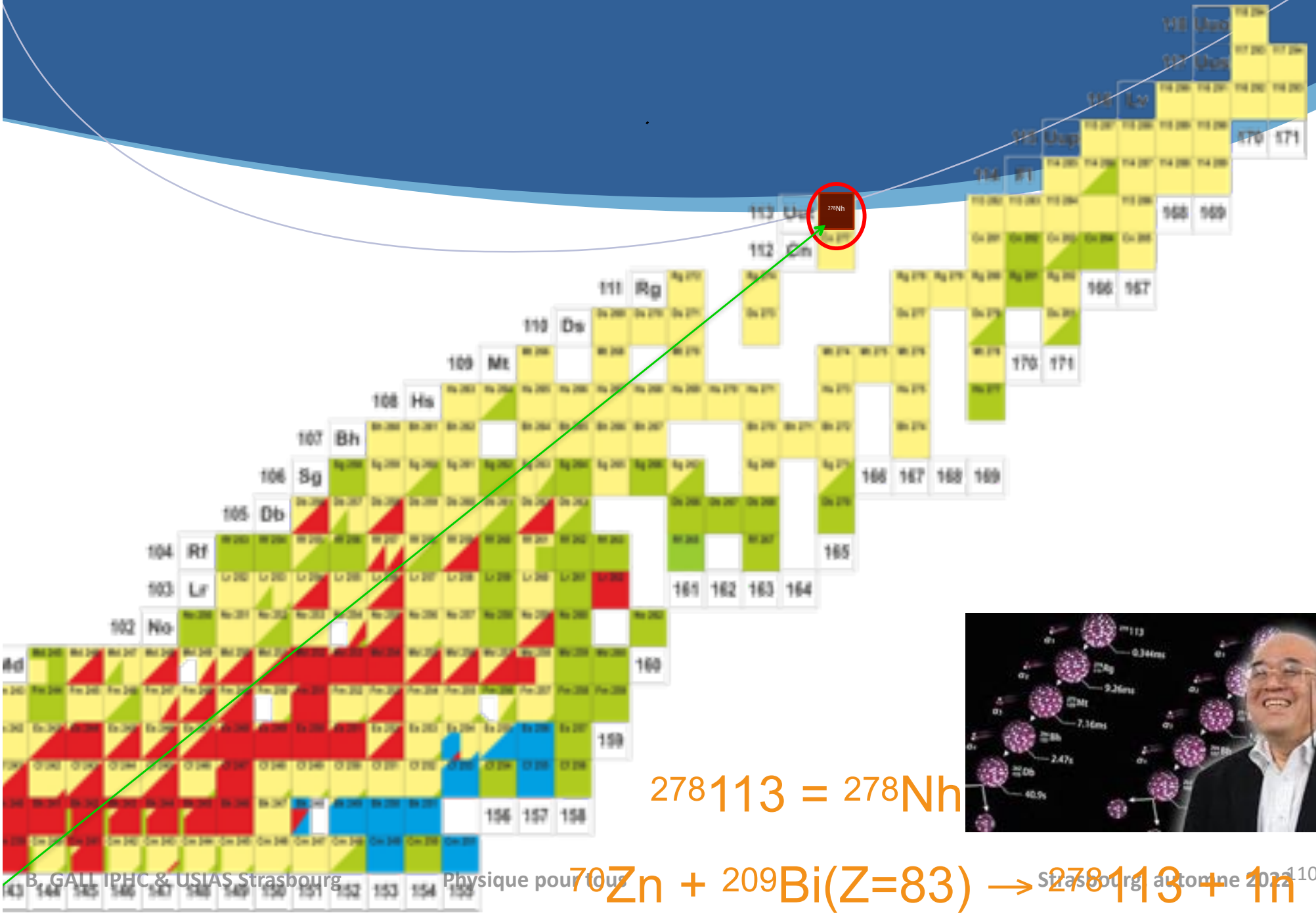
from 1969: quest of SHE (Z≥104)

Cold fusion (beam + ^{208}Pb)



Cold fusion $^{208}Pb/^{209}Bi$



$^{278}113 = {}^{278}Nh$

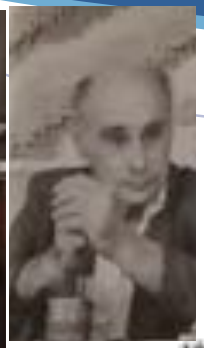
$^{70}Zn + {}^{209}Bi(Z=83) \rightarrow {}^{278}113 + 1n$

Cold fusion $^{208}Pb/^{209}Bi$ / hot fusion ^{48}Ca

$^{48}Ca + {}^{249}Cf(Z=98) \rightarrow {}^{294}118 + 3n$

$^{48}Ca + {}^{249}Bk(Z=97) \rightarrow {}^{294}117 + 3n$

$^{48}Ca + {}^{248}Cm(Z=96) \rightarrow {}^{293}116 + 3n$



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=118

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Cold fusion (beam + ^{208}Pb)

Hot fusion (^{48}Ca + target)

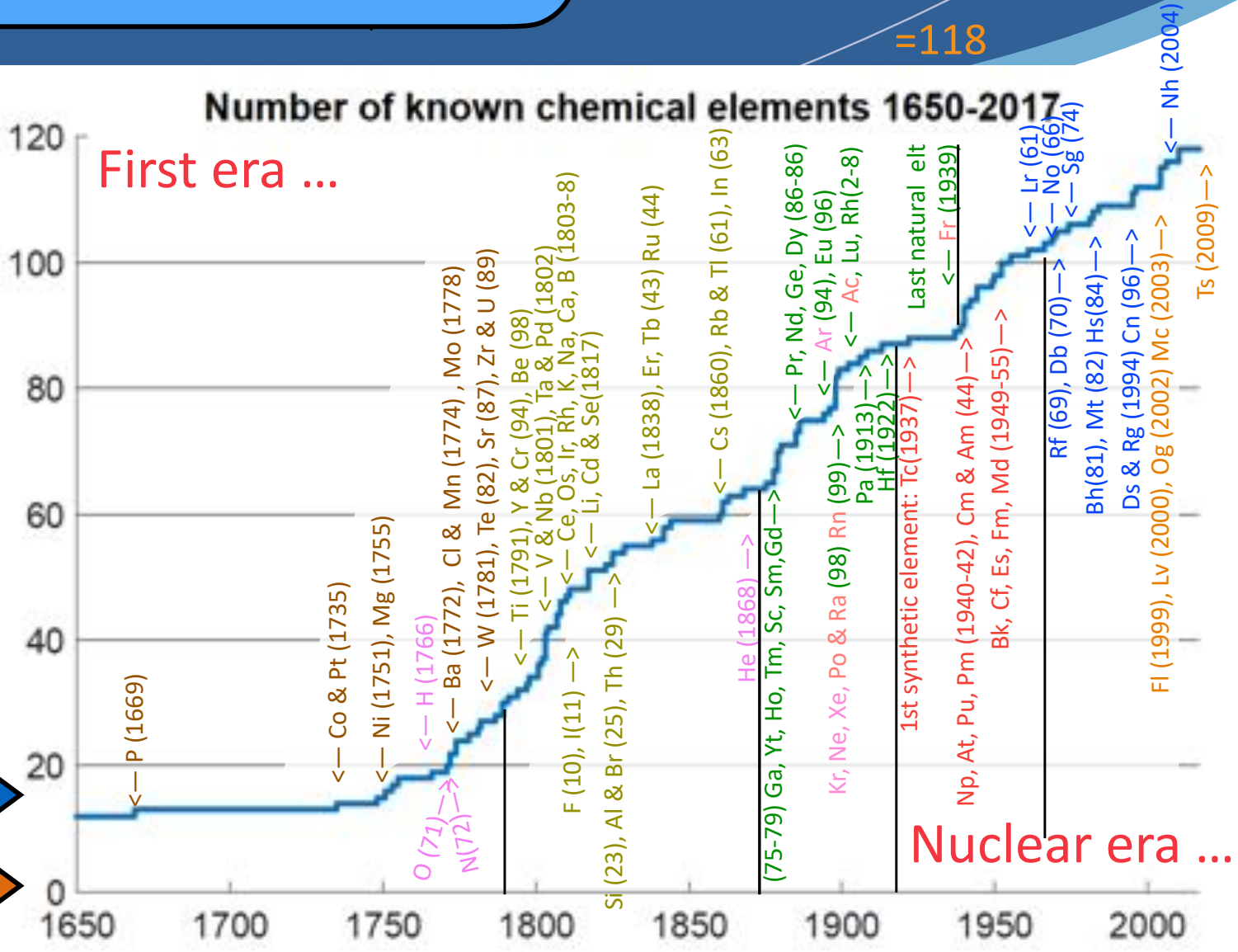
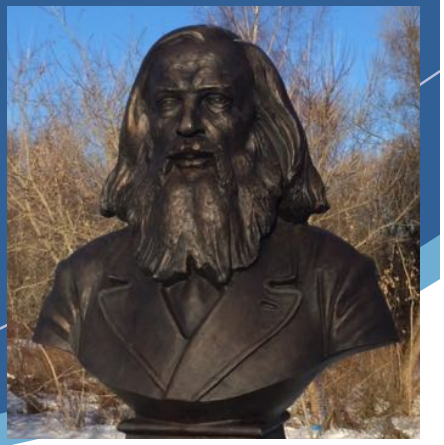


Tableau de Mendeleïev et synthèse des éléments superlourds



1																	18
1 H hydrogen 1.008 [1.0078, 1.0082]	2											13	14	15	16	17	2 He helium 4.0026
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11 Na sodium 22.990	12 Mg magnesium 24.305 [24.304, 24.307]		3	4	5	6	7	8	9	10	11	12	13 Al aluminium 26.982	14 Si silicon 28.085 [28.084, 28.086]	15 P phosphorus 30.974	16 S sulfur 32.06 [32.059, 32.076]	17 Cl chlorine 35.45 [35.446, 35.457]	18 Ar argon 39.95 [39.792, 39.963]
19 K potassium 39.098	20 Ca calcium 40.078(4)		21 Sc scandium 44.956	22 Ti titanium 47.867	23 V vanadium 50.942	24 Cr chromium 51.996	25 Mn manganese 54.938	26 Fe iron 55.845(2)	27 Co cobalt 58.933	28 Ni nickel 58.693	29 Cu copper 63.546(3)	30 Zn zinc 65.38(2)	31 Ga gallium 69.723	32 Ge germanium 72.630(8)	33 As arsenic 74.922	34 Se selenium 78.971(8)	35 Br bromine 79.904 [79.901, 79.907]	36 Kr krypton 83.798(2)
37 Rb rubidium 85.468	38 Sr strontium 87.62		39 Y yttrium 88.906	40 Zr zirconium 91.224(2)	41 Nb niobium 92.906	42 Mo molybdenum 95.95	43 Tc technetium	44 Ru ruthenium 101.07(2)	45 Rh rhodium 102.91	46 Pd palladium 106.42	47 Ag silver 107.87	48 Cd cadmium 112.41	49 In indium 114.82	50 Sn tin 118.71	51 Sb antimony 121.76	52 Te tellurium 127.60(3)	53 I iodine 126.90	54 Xe xenon 131.29
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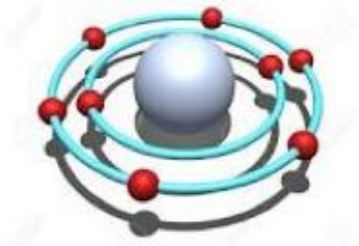
Key: atomic number **Symbol** **name** conventional atomic weight standard atomic weight



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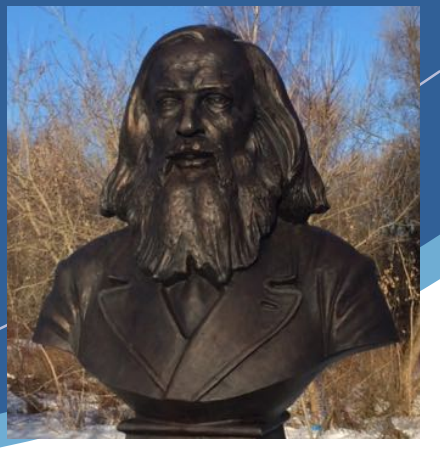
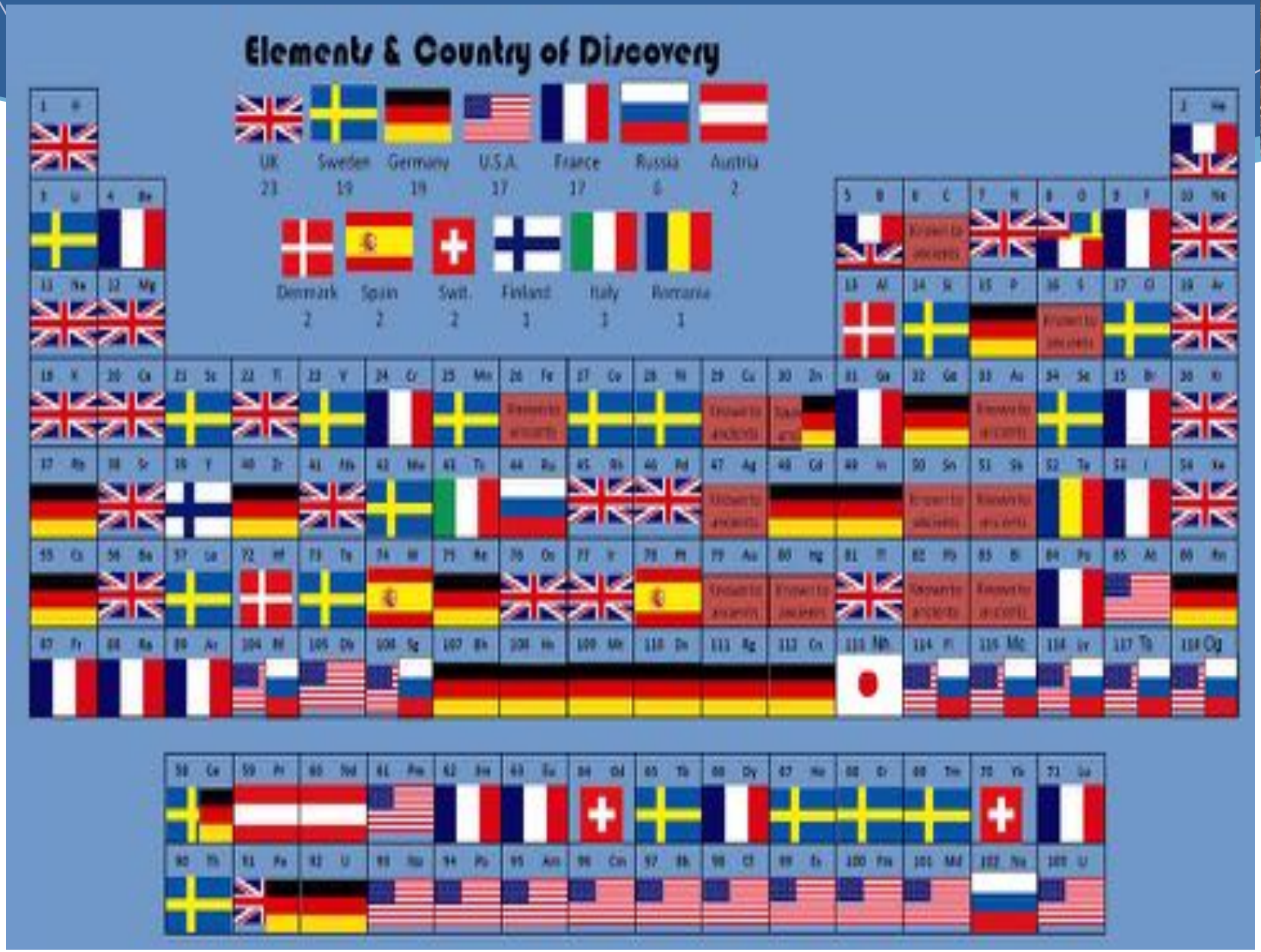
For notes and updates to this table, see www.iupac.org. This version is dated 1 December 2 018.

Periodic table of elements

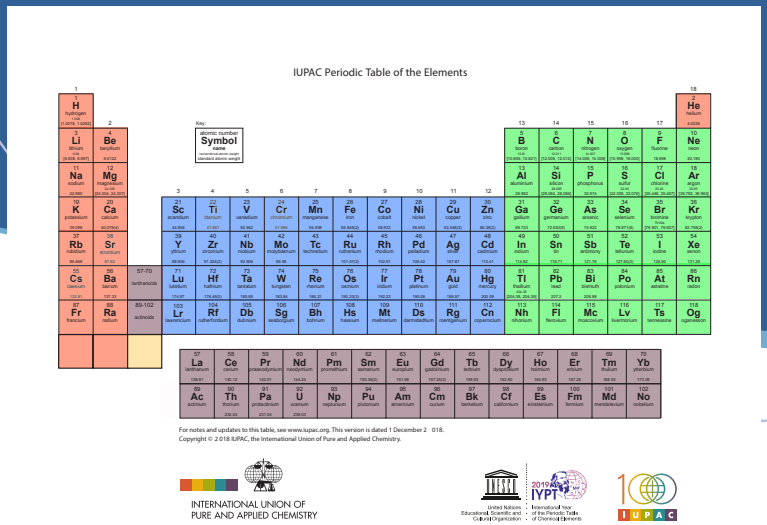
Limits of existence ?



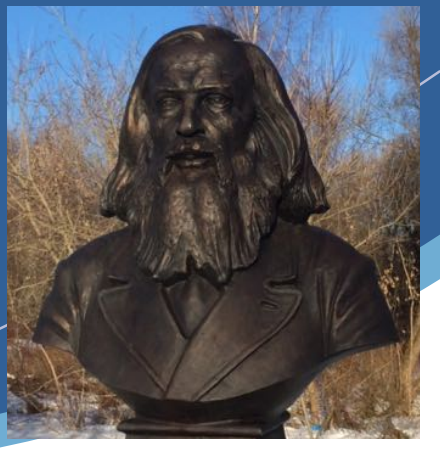


118 elements identified

Our landscape …



Periodic table of elements

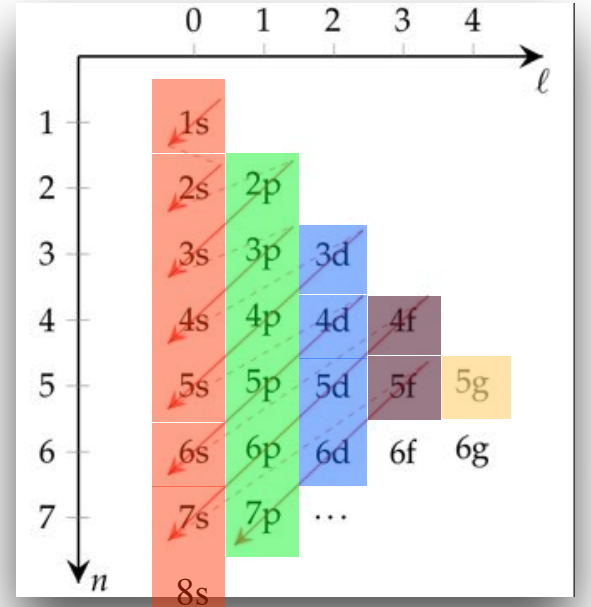


electron shells

name	l	2l+1	2(2l+1)
s	0	1	2
p	1	3	6
d	2	5	10
f	3	7	14
g	4	9	18

We celebrate in 2019
the 150 anniversary

+ Klechkovski filling rule



+ exceptions …

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119 uun	120 ubn	121 ubu															

Key: atomic number **Symbol** name (conventional atomic weight / standard atomic weight)

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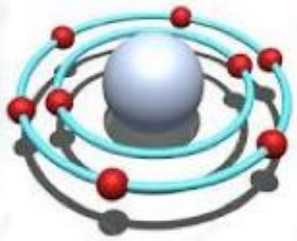


INTERNATIONAL UNION OF PURE AND APPLIED CHEMISTRY

United Nations Educational, Scientific and Cultural Organization

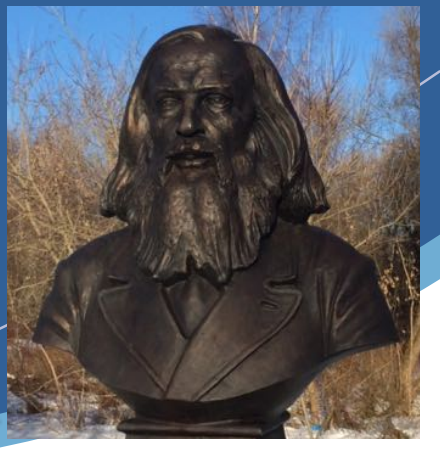
2019 IYPT International Year of the Periodic Table of Chemical Elements

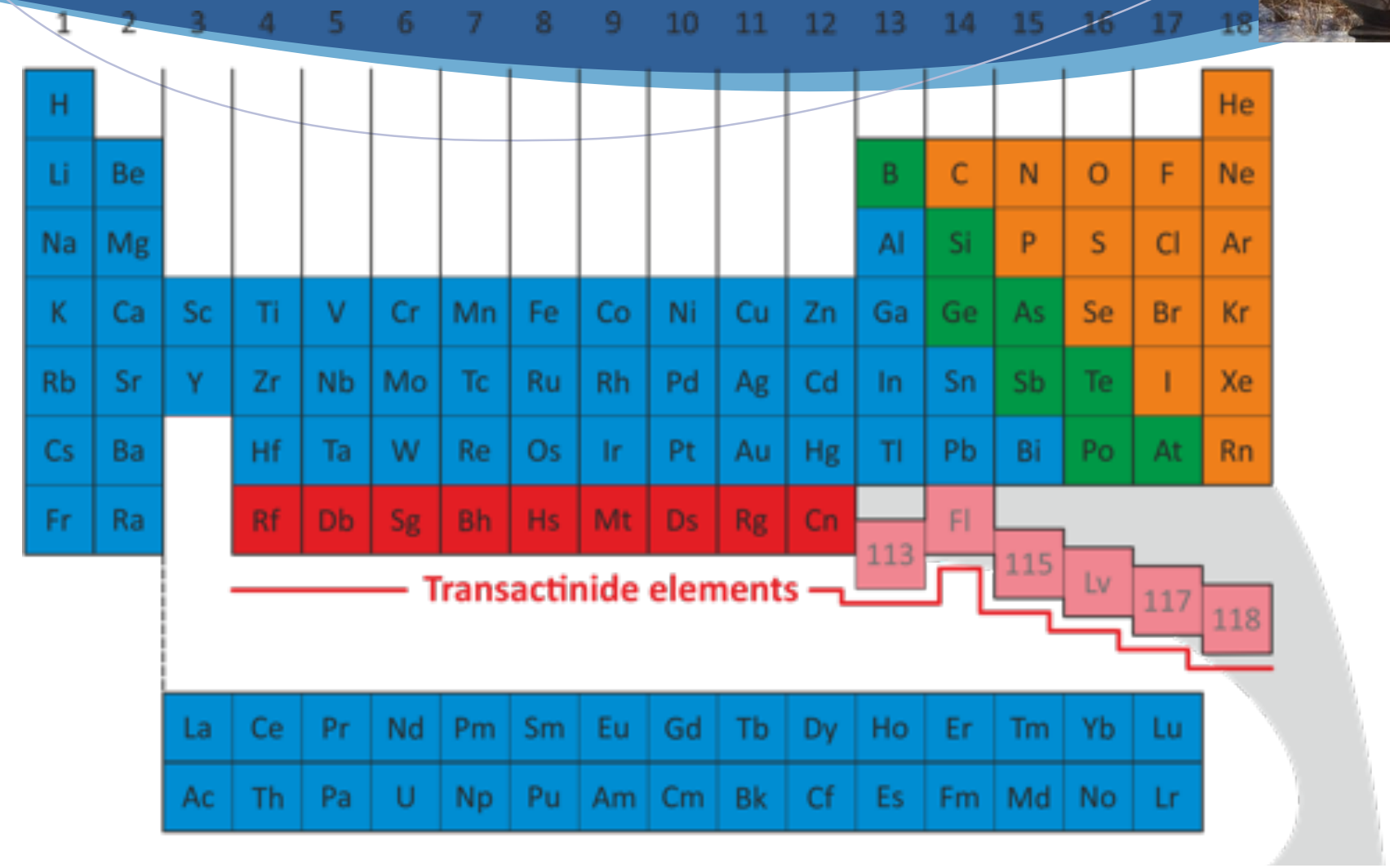
IUPAC

Periodic table of elements

Limits of existence ?

Relativistic effects ???





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Periodic table of elements

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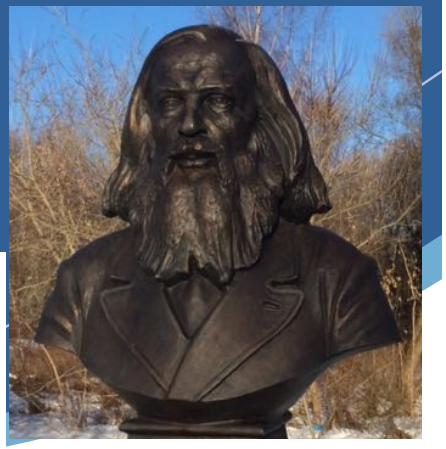
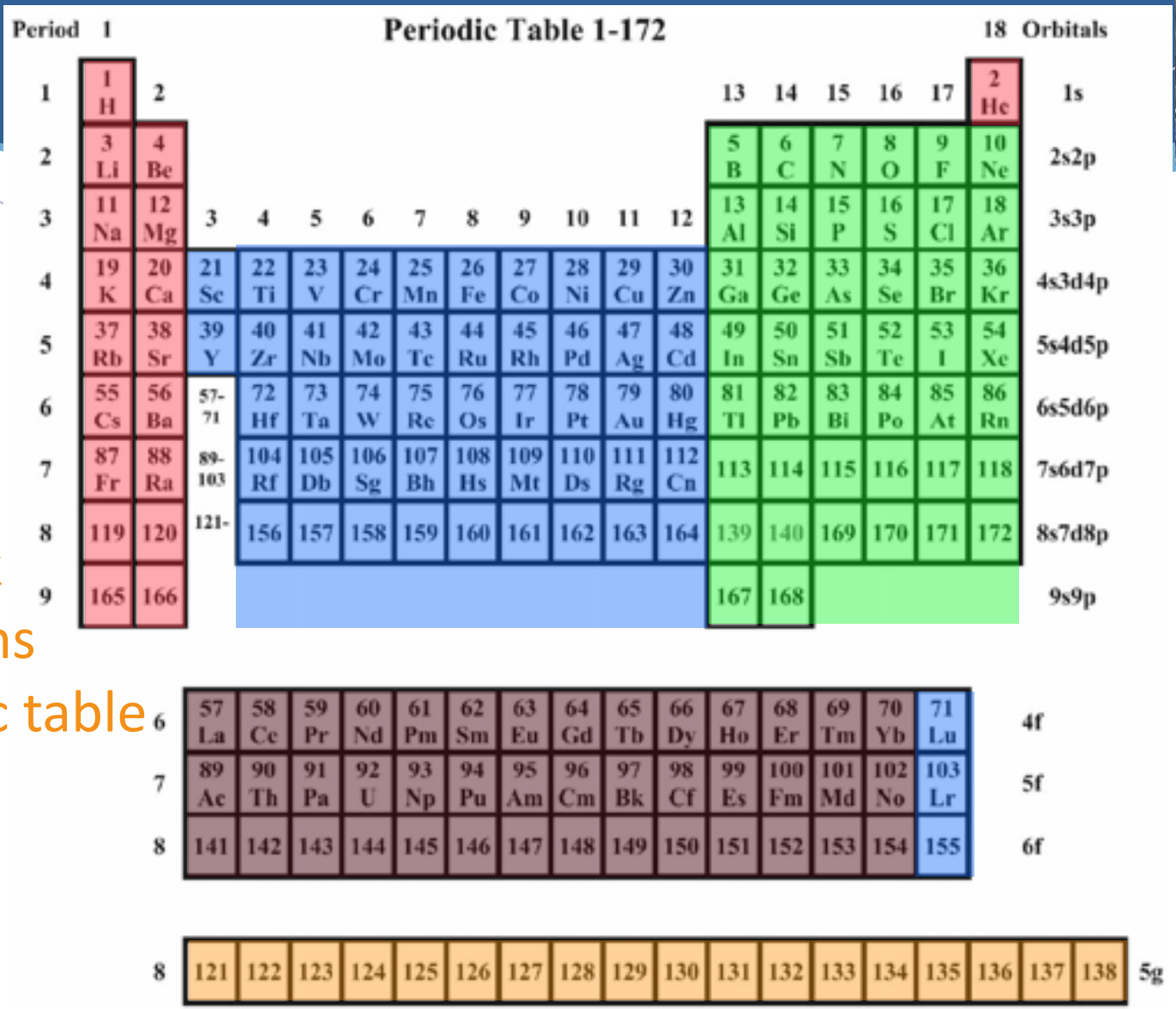


Dirac-Fock calculations of Periodic table



© Pekka Pyykkö A suggested periodic table up to Z= 172, based on Dirac-Fock calculations on atoms and ions", Physical Chemistry Chemical Physics 13(1), pp. 161{168 (2011).

Known elements classification

Some « modern chemistry » starts 17th century

H. Brand discovered Phosphorous (1669) and Cobalt (1735)
… alchemy / quest for gold and industrialisation accelerated discoveries…

1787 … 1st modern list of 30 elements by A. Lavoisier

1869 … 1st version of the Mendeleev table

1896 … discovery in U rock of Radioactivity by H. Becquerel

1908 … Geiger-Marsden expt. $^{4}He + {}^{197}Au \rightarrow$ diffusion

1934 … Artificial radioisotope $^{4}He + {}^{27}Al \rightarrow {}^{30}P + n$ (Joliot)

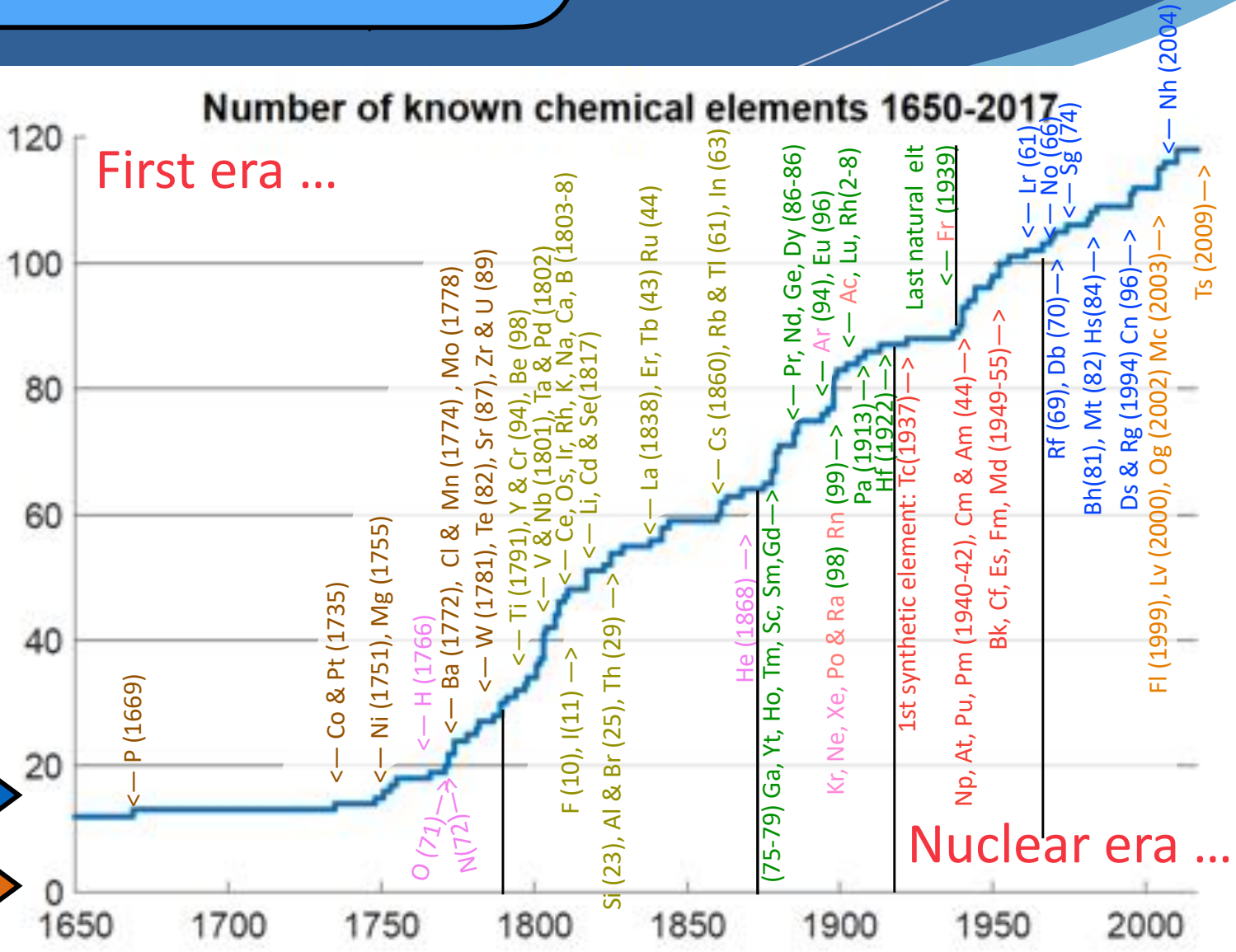
1937 … 1st synthetic element: Tc (cyclotron)

1939 … last natural element Fr

from 1969: quest of SHE (Z≥104)

Cold fusion (beam + ^{208}Pb)

Hot fusion (^{48}Ca + target)

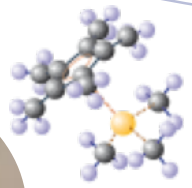


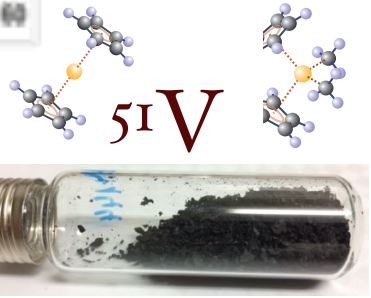
New beams for SHE… ^{50}Ti, ^{51}V, ^{54}Cr

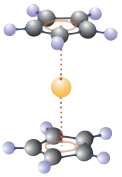
PROGRAM 2019 - 2030 …

^{50}Ti, ^{51}V, ^{54}Cr + ^{248}Cm, ^{249}Bk, ^{249}Cf

& ^{48}Ca + ^{254}Es, ^{257}Fm ???







^{54}Cr

^{51}V

$^{50}Ti + ^{248}Cm \rightarrow ^{295}118 + 3n$

$^{50}Ti + ^{249}Bk \rightarrow ^{296}119 + 3n$

$^{51}V + ^{248}Cm \rightarrow ^{296}119 + 3n$

$^{50}Ti + ^{249}Cf \rightarrow ^{295}120 + 4n$

$^{54}Cr + ^{248}Cm \rightarrow ^{298}120 + 4n$

$^{51}V + ^{249}Cf \rightarrow ^{297}121 + 3n$

$^{54}Cr + ^{249}Cf \rightarrow ^{299}122 + 4n$

NEW MACHINES for SHE

2020 …

Beams … : ^{50}Ti, ^{48}Ca, ^{51}V, ^{54}Cr, ^{238}U

SHE-Fact. commissionned
DGFRS2 commissionned
synth 50Ti …
+ runs SHELS

SHE Factory

-> New machine (SHE Factory)
-> No more foil extraction
-> Higher beam transport efficiency
-> New ECR sources (DECRIS-PM & DECRIS-SC)

n RILAC

-> Upgrade of RILAC to nRILAC (SC sections)
-> New ECR sources (28GHz SC ECRIS)
-> High charge state (^{295}Og run) no more necessary

n RILAC commissionned
GARIS II commissionned
E119 restarted 2-4 m beam/Y

also LINAC + S3 @ GANIL

-> New machine (LINAC)
-> New instrument (S3)

+ NEWGAIN !!!

+ EURO-LABS !!!

E119 campaign: attempt to produce ^{295}Uue

$^{51}V + ^{248}Cm \longrightarrow ^{299-x}Uue + xn$

Beam accelerated by RRC cyclotron

Optimal energy determined by barrier distribution run

Target: pure ^{248}Cm ~500 µg/cm^2

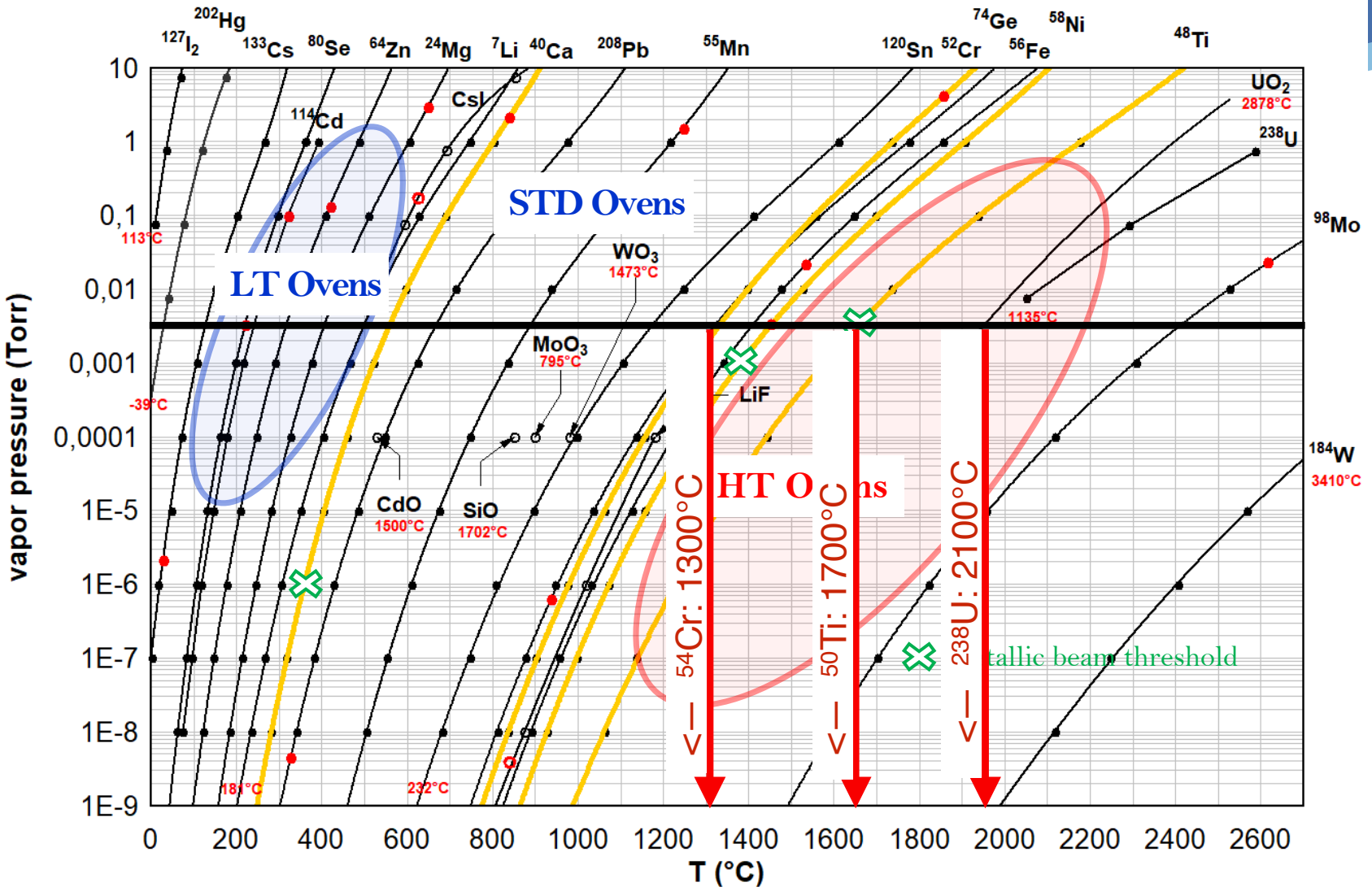
GARIS II gas filled separator (moved to RRC lines)

Already several campaigns since 2017

results unpublished

HIGH INTENSITY METALLIC BEAMS

—> ^{50}Ti & ^{238}U need HT ovens



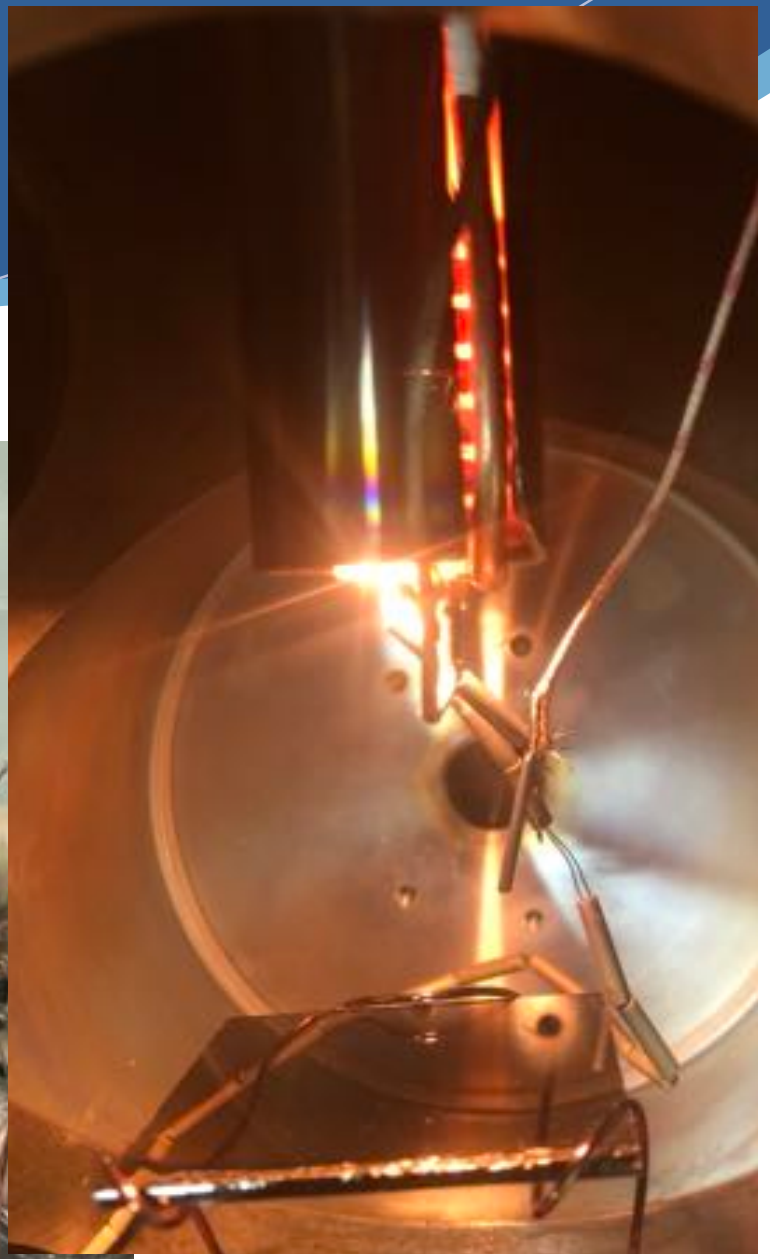
—> ^{54}Cr: 1300°C
—> ^{58}Fe: 1400°C
—> ^{64}Ni: 1450°C
—> ^{50}Ti: 1650°C
—> ^{238}UO$_2$: 1950°C
—> ^{238}U(M): 2050°C

HIGH INTENSITY METALLIC BEAMS

—> Tests @ FLNR

sept 2021

First Chromium & titanium depositions



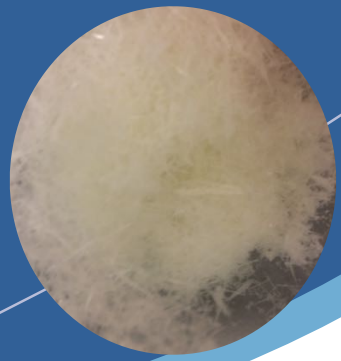
IPHC
Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

PROJECT FROZEN @ DUBNA !

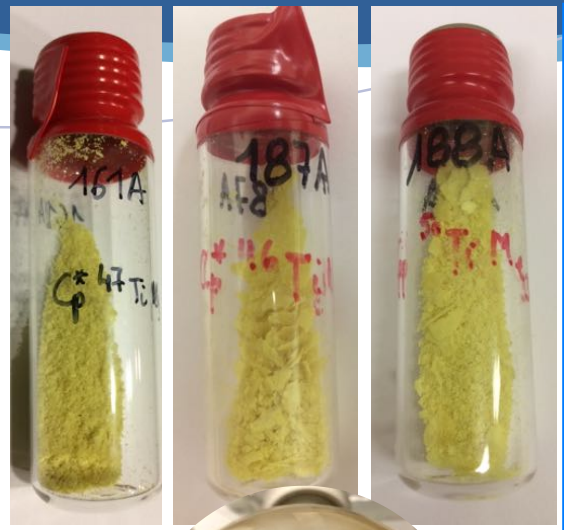
Tests were foreseen but ...

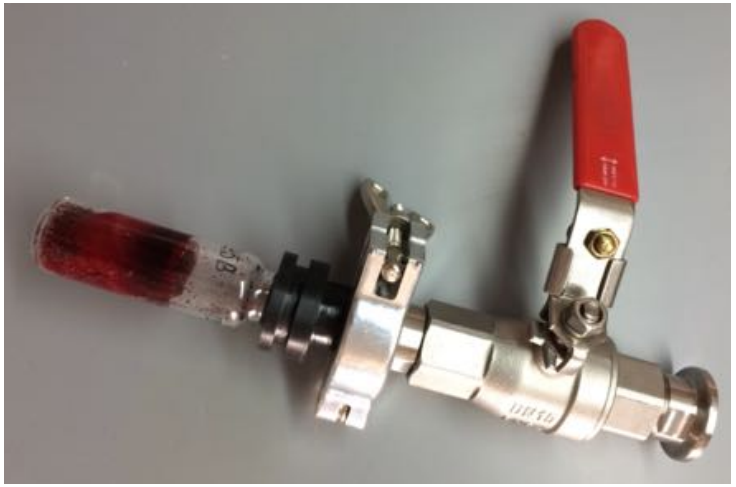
SUMMARY



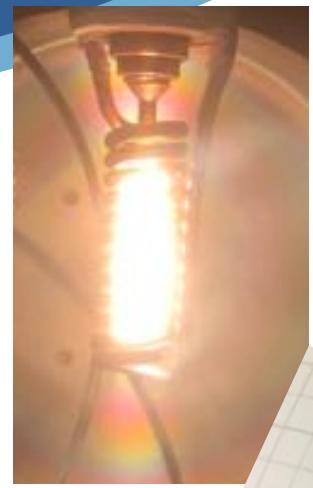
Enabled MIVOC from
- ^{50}Ti (JYFL Sept 2011)
- ^{47}Ti (JYFL April 2017)
- ^{46}Ti (Dubna Sept 2017)
- ^{54}Cr (Dubna Sept 2018)





R&D Uranocene

2-3 µA reached



R&D HTi oven
- ø20 oven tested
- 2500 °C reached
- new ø20 oven

good way to 10 µA