

Physique pour tous

Briques & Fabriques nucléaires

Mardi 11 octobre 2022



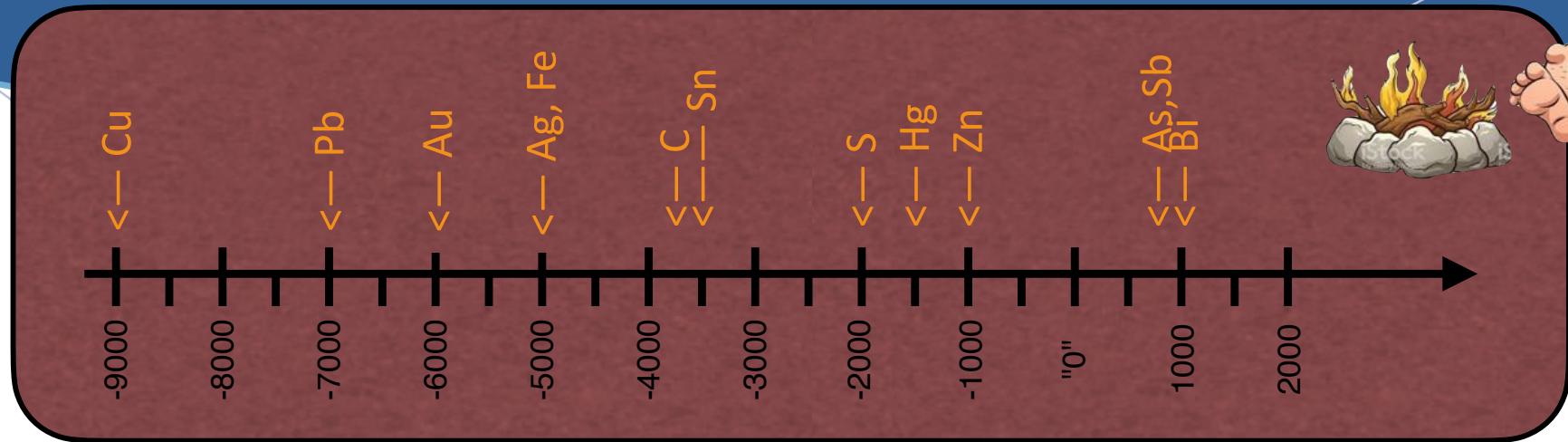
À la recherche de nouveaux éléments

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 ?

Known elements classification

Prehistoric, antiquity and middle age elements (13) ...

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



* 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

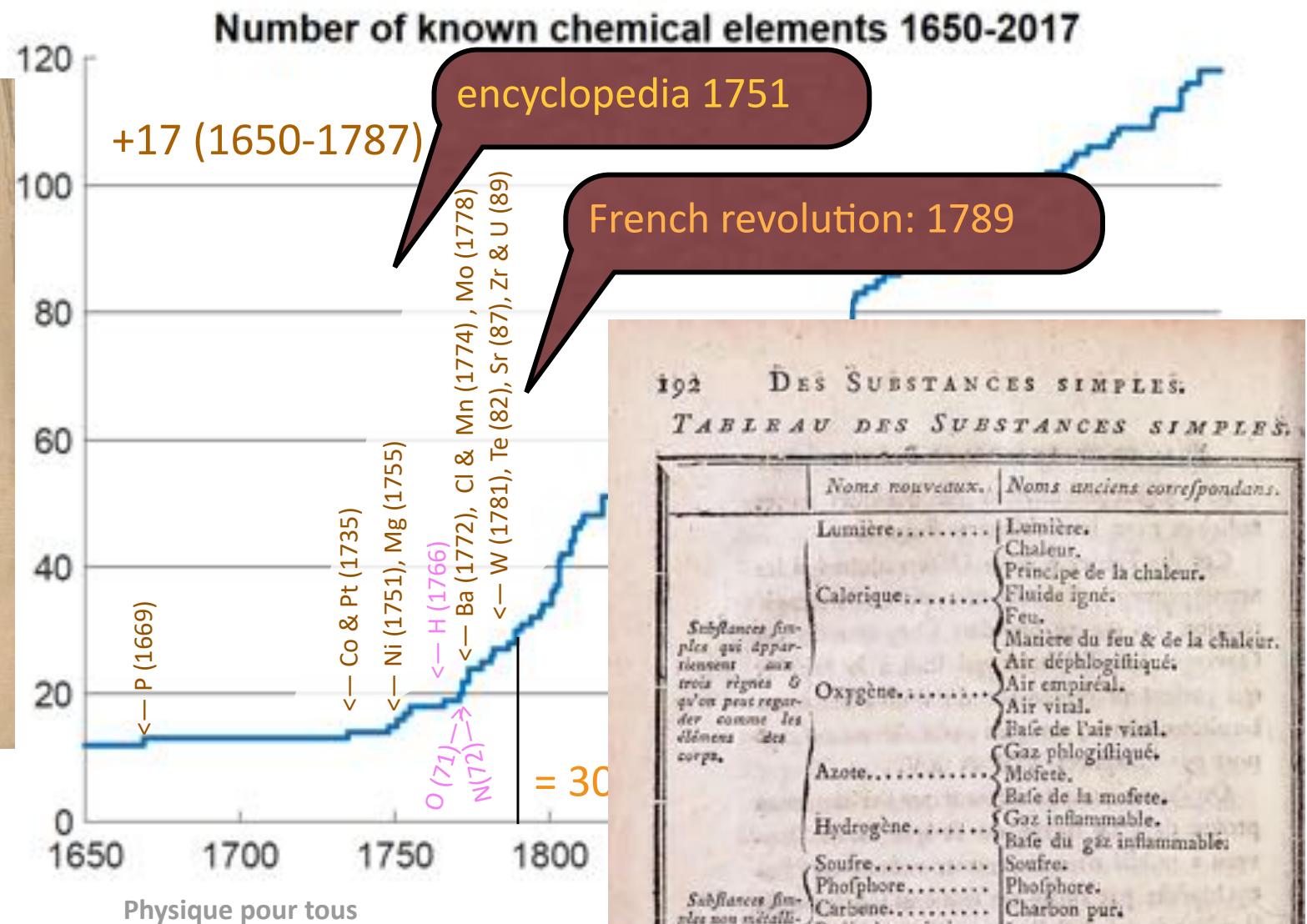
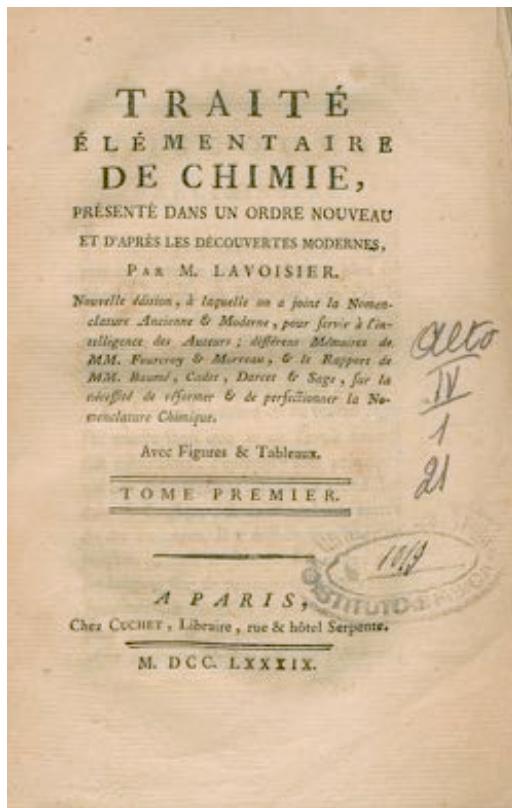
Known elements classification

...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



192 DES SUBSTANCES SIMPLES.
TABLEAU DES SUBSTANCES SIMPLES.

Noms nouveaux.	Noms anciens correspondans.
Lumière.....	Lumière. Chaleur.
Calorique.....	Principe de la chaleur. Fluido igné. Feu.
Oxygène.....	Air déphlogistique. Air empiral. Air viral.
Azote.....	Base de l'air viral. Gaz phlogistique. Mofète.
Hydrogène.....	Base de la mofete. Gaz inflammable.
Soufre.....	Base du gaz inflammable. Soufre.
Phosphore.....	Phosphore.
Carbene.....	Charbon pur.
Radical muriatique.	Inconnu.
Radical fluorine.	Inconnu.

Substances simples qui appartiennent aux trois règnes & qu'on peut regarder comme les éléments des corps.

Substances simples non métalliques oxydables & réductibles.



A. Lavoisier (1789)

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 ; différents Mémoires de MM. Fourcroy & Moreau, & le Rapport de MM. Baumé, Cadet, Darcet & Sage, sur la nécessité d'affirmer & de perfectionner la Nomenclature Chimique.

Avec Figures & Tableaux.

TOME PREMIER.

A PARIS,
Chez COCHET, Libraire, rue & hôtel Serpente.

M. DCC. LXXXIX.

Altar
IV
21

192 DES SUBSTANCES SIMPLES. TABLEAU DES SUBSTANCES SIMPLES.

	Noms nouveaux.	Noms anciens correspondans.
<i>Substances simples qui appartiennent aux trois règnes & qu'on peut regarder comme les éléments des corps.</i>	Lumière.....	Lumièrē. Chaleur. Principe de la chaleur. Fluido ignē.
	Calorique.....	Feu. Matière du feu & de la chaleur. Air déphlogistique. Air empirical.
	Oxygène.....	Air vital. Baie de l'air vital. Gaz phlogistique. Mofète.
	Azote.....	Baie de la mofète. Gaz inflammable. Baie du gaz inflammable.
	Hydrogène.....	Soufre. Phosphore.
<i>Substances simples non métalliques oxidables & acidifiables.</i>	Soufre.....	Soufre.
	Phosphore.....	Phosphore.
	Carbene.....	Charbon pur.
	Radical muriatique.	Inconnu.
	Radical fluorique..	Inconnu.
	Radical boracique..	Inconnu.
	Antimoine.....	Antimoine.
	Argent.....	Argent.
	Arienic.....	Arienic.
	Bismuth.....	Bismuth.
	Cobolt.....	Cobolt.
	Cuivre.....	Cuivre.
	Etain.....	Etain.
	Fer.....	Fer.
	Manganèse.....	Manganèse.
	Mercure.....	Mercure.
	Molybdène.....	Molybdène.
	Nickel.....	Nickel.
	Or.....	Or.
	Platine.....	Platine.
	Ploimb.....	Ploimb.
	Tungstène.....	Tungstène.
	Zinc.....	Zinc.
<i>Substances simples métalliques oxidables & acidifiables.</i>	Chaux.....	Terre calcaire, chaux.
	Magnétie.....	Magnétie, baie du sel d'Epion.
	Baryte.....	Barote, terre pesante.
	Alumine.....	Argile, terre de l'alun, baie de l'alun.
	Silice.....	Terre siliceuse, terre vitrifiable.
<i>Substances simples solubles terrestres.</i>		

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

Known elements classification

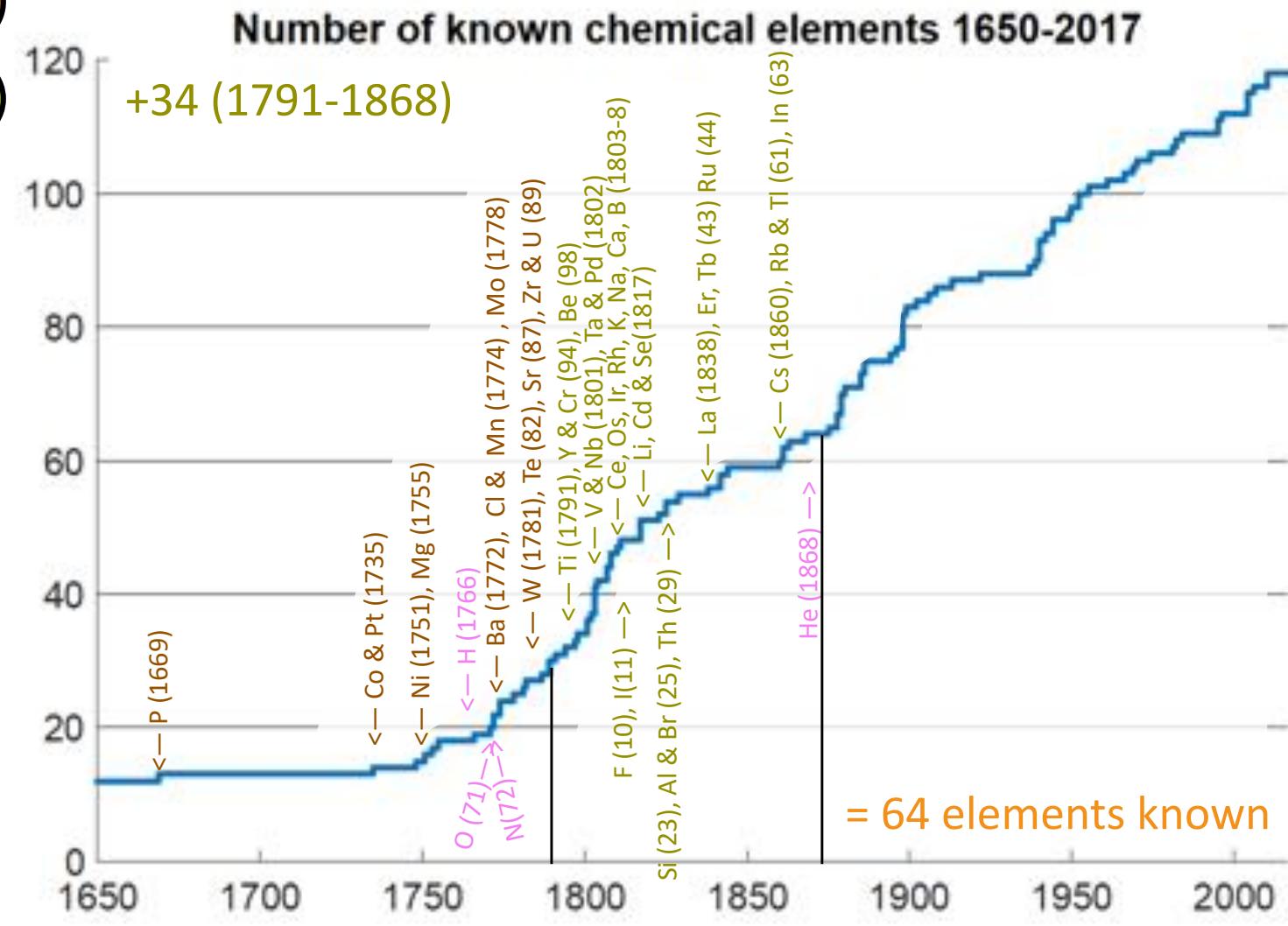
Some « modern chemistry » starts 19th century

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

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



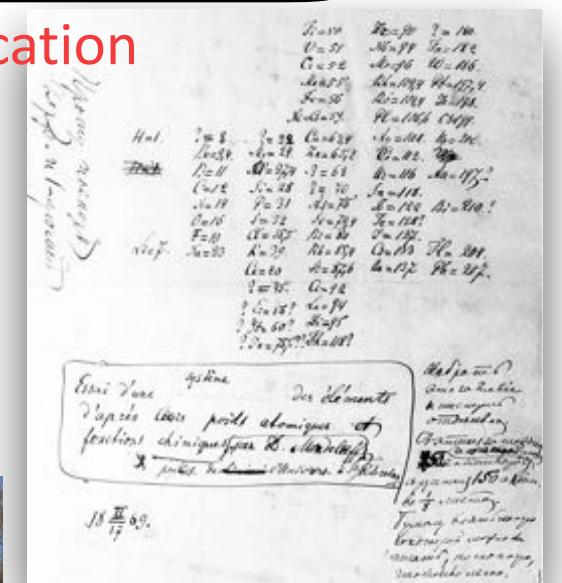
Keep in mind that :

- 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 (Be = 9,3?)	2 werthig
Differenz =	-	-	-	-	Li = 7,03 (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?)	-

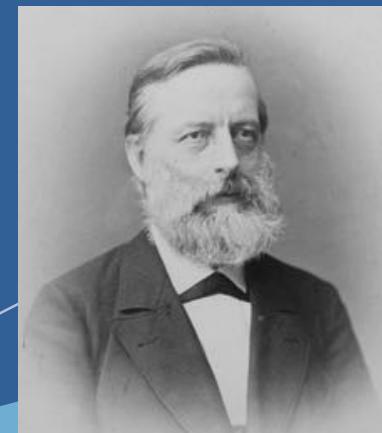


Mendeleev's classification was earlier known since he published in a journal !

Meyer's periodic table of elements

	4 werthig	3 werthig	2 werthig	1 werthig	1 werthig	2 werthig
Differenz =	-	-	-	-	Li = 7,03 (Be = 9,3?)	
Differenz =	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
Differenz =	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
Differenz =	-	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
Differenz =	Sn = 117,6	Sb = 120,6	Te = 128,3	J = 126,8	Ca = 133,0	Ba = 137,1
Differenz =	89,4 = 2*44,7	87,4 = 2*43,7	-	-	(Tl = 2*35,5)	-
Differenz =	Pb = 207,0	Bi = 208,0	-	-	(Tl = 204?)	-

Published in 1864 in
Julius Lothar Meyer's
book about modern
theory of chemistry



and then in 1866 and
1870 in 2 articles.

1 H hydrogen [1.008, 1.0082] [1.0078, 1.0082]	2 Be beryllium [9.0122]
3 Li lithium [6.94] [6.938, 6.997]	4 Mg magnesium [12.93] [12.93, 12.99]
11 Na sodium [22.990]	12 Mg magnesium [24.304, 24.307]
19 K potassium [39.088]	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 Sb antimony [121.76]	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 [101.07(2)]	44 Ru ruthenium [102.91]
45 Rh rhodium [106.42]	46 Pd palladium [107.87]
47 Ag silver [112.41]	48 Cd cadmium [114.82]
49 In indium [118.71]	50 Sn tin [121.76]
51 Sb antimony [127.60(3)]	52 Te tellurium [126.90]
55 Cs caesium [132.91]	56 Ba barium [137.33]
57-71 lanthanoids [178.49(2)]	72 Hf hafnium [180.95]
73 Ta tantalum [183.84]	74 W tungsten [186.21]
75 Re rhenium [190.23(3)]	76 Os osmium [192.22]
77 Ir iridium [195.08]	78 Pt platinum [196.97]
79 Au gold [200.59]	80 Hg mercury [207.2]
81 Tl thallium [204.38, 204.39]	82 Pb lead [208.98]
83 Bi bismuth [208.98]	84 Po polonium [207.2]
85 At astatine [207.2]	86 Rn radon [208.98]
87 Fr francium [232.04]	88 Ra radium [231.04]
89-103 actinoids [238.03]	104 Rf rutherfordium [105.04]
106 Sg seaborgium [107.04]	107 Bh bohrium [108.04]
108 Hs hassium [109.04]	109 Mt meitnerium [110.04]
111 Rg roentgenium [111.04]	110 Ds darmstadtium [112.04]
112 Cn copernicium [113.04]	111 Nh nihonium [114.04]
114 Fl flerovium [115.04]	115 Mc moscovium [116.04]
116 Lv livermorium [117.04]	117 Ts tennessine [118.04]
118 Og oganeson [118.04]	

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



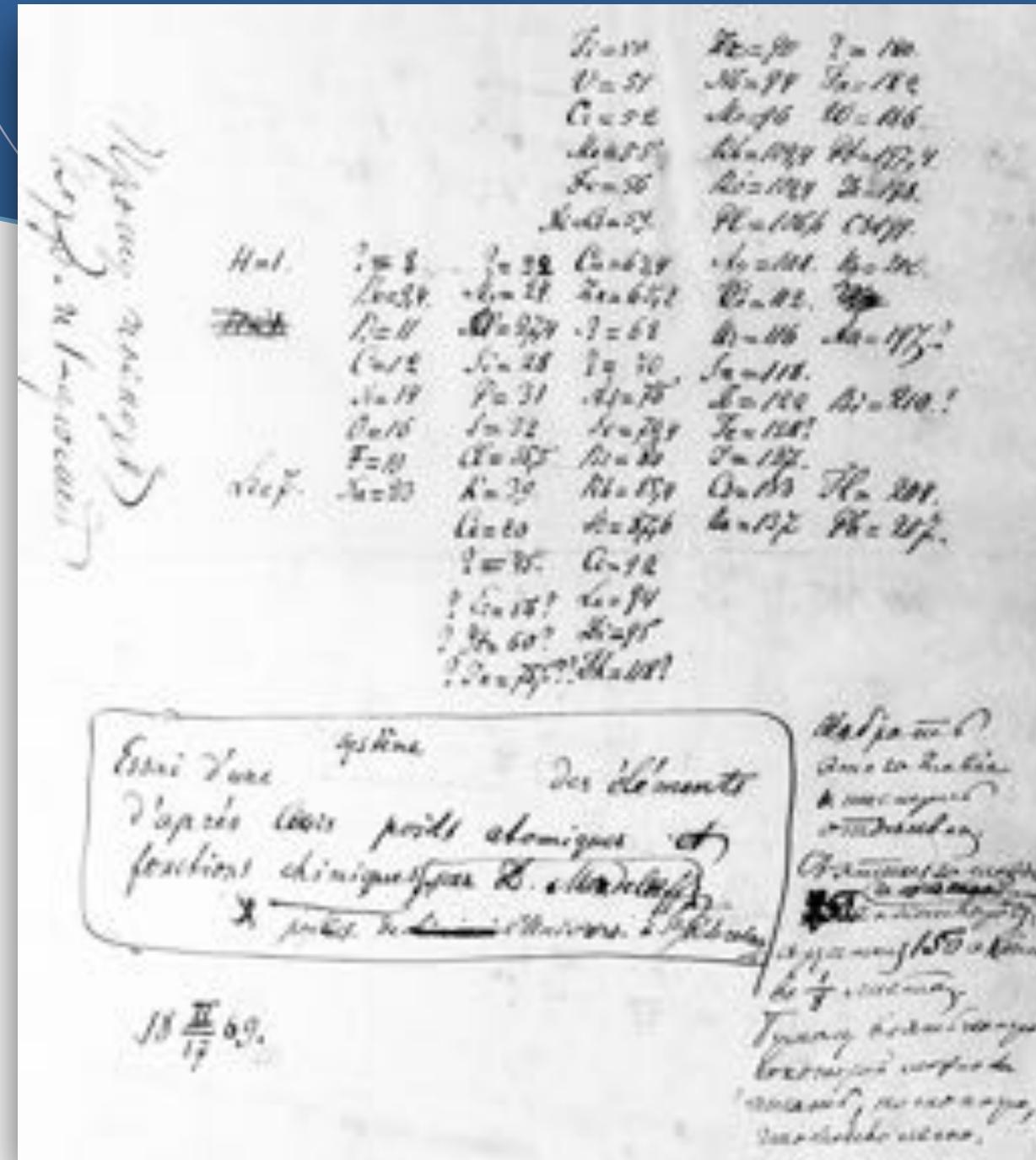
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57 La lanthanum [138.91]	58 Ce cerium [140.12]	59 Pr praseodymium [140.91]	60 Nd neodymium [144.24]	61 Pm promethium [150.36(2)]	62 Sm samarium [151.96]	63 Eu europium [157.25(3)]	64 Gd gadolinium [158.93]	65 Tb terbium [162.50]	66 Dy dysprosium [164.93]	67 Ho holmium [167.26]	68 Er erbium [168.93]	69 Tm thulium [173.05]	70 Yb ytterbium [174.97]	71 Lu lutetium [174.97]
89 Ac actinium [232.04]	90 Th thorium [231.04]	91 Pa protactinium [238.03]	92 U uranium [238.03]	93 Np neptunium [239.03]	94 Pu plutonium [244.03]	95 Am americium [243.03]	96 Cm curium [247.03]	97 Bk berkelium [249.03]	98 Cf californium [251.03]	99 Es einsteinium [252.03]	100 Fm fermium [253.03]	101 Md mendelevium [254.03]	102 No nobelium [255.03]	103 Lr lawrencium [256.03]

For notes and updates to this table, see www.iupac.org. This version is dated 1 December 2018.
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Mendeleev's periodic table of elements

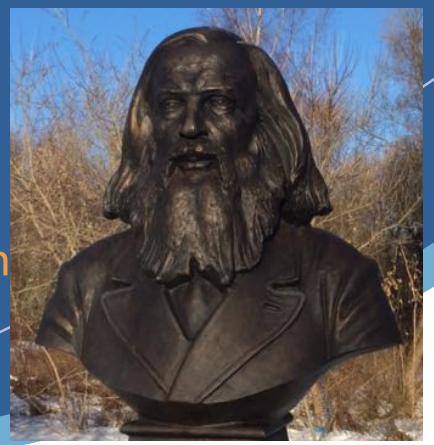


A handwritten periodic table on aged paper. The table is organized into columns and rows, with some elements placed in separate boxes. The text is in French and Russian.

	Li = 7	Be = 9	N = 14	Na = 22	Al = 27	Si = 28	P = 31	S = 32	Cl = 35	Ar = 36	K = 39	Ca = 40	Sc = 43	Ti = 45	V = 51	Cr = 52	Mn = 55	Fe = 56	Co = 57	Ni = 59	Cu = 63	Zn = 65	Ga = 69	In = 75	Tl = 76	Ge = 77	Se = 78	Br = 80	Rb = 85	Sr = 88	Y = 92	Lu = 94	Fr = 95	Pa = 97	U = 98	Np = 99	Fm = 100	Bk = 101	Cf = 104	Hg = 106	Tl = 107	Fr = 108	Rf = 109	Rb = 110	Fr = 111	Fr = 112	Fr = 113	Fr = 114	Fr = 115	Fr = 116	Fr = 117	Fr = 118	Fr = 119	Fr = 120	Fr = 121	Fr = 122	Fr = 123	Fr = 124	Fr = 125	Fr = 126	Fr = 127	Fr = 128	Fr = 129	Fr = 130	Fr = 131	Fr = 132	Fr = 133	Fr = 134	Fr = 135	Fr = 136	Fr = 137	Fr = 138	Fr = 139	Fr = 140	Fr = 141	Fr = 142	Fr = 143	Fr = 144	Fr = 145	Fr = 146	Fr = 147	Fr = 148	Fr = 149	Fr = 150	Fr = 151	Fr = 152	Fr = 153	Fr = 154	Fr = 155	Fr = 156	Fr = 157	Fr = 158	Fr = 159	Fr = 160	Fr = 161	Fr = 162	Fr = 163	Fr = 164	Fr = 165	Fr = 166	Fr = 167	Fr = 168	Fr = 169	Fr = 170	Fr = 171	Fr = 172	Fr = 173	Fr = 174	Fr = 175	Fr = 176	Fr = 177	Fr = 178	Fr = 179	Fr = 180	Fr = 181	Fr = 182	Fr = 183	Fr = 184	Fr = 185	Fr = 186	Fr = 187	Fr = 188	Fr = 189	Fr = 190	Fr = 191	Fr = 192	Fr = 193	Fr = 194	Fr = 195	Fr = 196	Fr = 197	Fr = 198	Fr = 199	Fr = 200	Fr = 201	Fr = 202	Fr = 203	Fr = 204	Fr = 205	Fr = 206	Fr = 207	Fr = 208	Fr = 209	Fr = 210	Fr = 211	Fr = 212	Fr = 213	Fr = 214	Fr = 215	Fr = 216	Fr = 217	Fr = 218	Fr = 219	Fr = 220	Fr = 221	Fr = 222	Fr = 223	Fr = 224	Fr = 225	Fr = 226	Fr = 227	Fr = 228	Fr = 229	Fr = 230	Fr = 231	Fr = 232	Fr = 233	Fr = 234	Fr = 235	Fr = 236	Fr = 237	Fr = 238	Fr = 239	Fr = 240	Fr = 241	Fr = 242	Fr = 243	Fr = 244	Fr = 245	Fr = 246	Fr = 247	Fr = 248	Fr = 249	Fr = 250	Fr = 251	Fr = 252	Fr = 253	Fr = 254	Fr = 255	Fr = 256	Fr = 257	Fr = 258	Fr = 259	Fr = 260	Fr = 261	Fr = 262	Fr = 263	Fr = 264	Fr = 265	Fr = 266	Fr = 267	Fr = 268	Fr = 269	Fr = 270	Fr = 271	Fr = 272	Fr = 273	Fr = 274	Fr = 275	Fr = 276	Fr = 277	Fr = 278	Fr = 279	Fr = 280	Fr = 281	Fr = 282	Fr = 283	Fr = 284	Fr = 285	Fr = 286	Fr = 287	Fr = 288	Fr = 289	Fr = 290	Fr = 291	Fr = 292	Fr = 293	Fr = 294	Fr = 295	Fr = 296	Fr = 297	Fr = 298	Fr = 299	Fr = 300	Fr = 301	Fr = 302	Fr = 303	Fr = 304	Fr = 305	Fr = 306	Fr = 307	Fr = 308	Fr = 309	Fr = 310	Fr = 311	Fr = 312	Fr = 313	Fr = 314	Fr = 315	Fr = 316	Fr = 317	Fr = 318	Fr = 319	Fr = 320	Fr = 321	Fr = 322	Fr = 323	Fr = 324	Fr = 325	Fr = 326	Fr = 327	Fr = 328	Fr = 329	Fr = 330	Fr = 331	Fr = 332	Fr = 333	Fr = 334	Fr = 335	Fr = 336	Fr = 337	Fr = 338	Fr = 339	Fr = 340	Fr = 341	Fr = 342	Fr = 343	Fr = 344	Fr = 345	Fr = 346	Fr = 347	Fr = 348	Fr = 349	Fr = 350	Fr = 351	Fr = 352	Fr = 353	Fr = 354	Fr = 355	Fr = 356	Fr = 357	Fr = 358	Fr = 359	Fr = 360	Fr = 361	Fr = 362	Fr = 363	Fr = 364	Fr = 365	Fr = 366	Fr = 367	Fr = 368	Fr = 369	Fr = 370	Fr = 371	Fr = 372	Fr = 373	Fr = 374	Fr = 375	Fr = 376	Fr = 377	Fr = 378	Fr = 379	Fr = 380	Fr = 381	Fr = 382	Fr = 383	Fr = 384	Fr = 385	Fr = 386	Fr = 387	Fr = 388	Fr = 389	Fr = 390	Fr = 391	Fr = 392	Fr = 393	Fr = 394	Fr = 395	Fr = 396	Fr = 397	Fr = 398	Fr = 399	Fr = 400	Fr = 401	Fr = 402	Fr = 403	Fr = 404	Fr = 405	Fr = 406	Fr = 407	Fr = 408	Fr = 409	Fr = 410	Fr = 411	Fr = 412	Fr = 413	Fr = 414	Fr = 415	Fr = 416	Fr = 417	Fr = 418	Fr = 419	Fr = 420	Fr = 421	Fr = 422	Fr = 423	Fr = 424	Fr = 425	Fr = 426	Fr = 427	Fr = 428	Fr = 429	Fr = 430	Fr = 431	Fr = 432	Fr = 433	Fr = 434	Fr = 435	Fr = 436	Fr = 437	Fr = 438	Fr = 439	Fr = 440	Fr = 441	Fr = 442	Fr = 443	Fr = 444	Fr = 445	Fr = 446	Fr = 447	Fr = 448	Fr = 449	Fr = 450	Fr = 451	Fr = 452	Fr = 453	Fr = 454	Fr = 455	Fr = 456	Fr = 457	Fr = 458	Fr = 459	Fr = 460	Fr = 461	Fr = 462	Fr = 463	Fr = 464	Fr = 465	Fr = 466	Fr = 467	Fr = 468	Fr = 469	Fr = 470	Fr = 471	Fr = 472	Fr = 473	Fr = 474	Fr = 475	Fr = 476	Fr = 477	Fr = 478	Fr = 479	Fr = 480	Fr = 481	Fr = 482	Fr = 483	Fr = 484	Fr = 485	Fr = 486	Fr = 487	Fr = 488	Fr = 489	Fr = 490	Fr = 491	Fr = 492	Fr = 493	Fr = 494	Fr = 495	Fr = 496	Fr = 497	Fr = 498	Fr = 499	Fr = 500	Fr = 501	Fr = 502	Fr = 503	Fr = 504	Fr = 505	Fr = 506	Fr = 507	Fr = 508	Fr = 509	Fr = 510	Fr = 511	Fr = 512	Fr = 513	Fr = 514	Fr = 515	Fr = 516	Fr = 517	Fr = 518	Fr = 519	Fr = 520	Fr = 521	Fr = 522	Fr = 523	Fr = 524	Fr = 525	Fr = 526	Fr = 527	Fr = 528	Fr = 529	Fr = 530	Fr = 531	Fr = 532	Fr = 533	Fr = 534	Fr = 535	Fr = 536	Fr = 537	Fr = 538	Fr = 539	Fr = 540	Fr = 541	Fr = 542	Fr = 543	Fr = 544	Fr = 545	Fr = 546	Fr = 547	Fr = 548	Fr = 549	Fr = 550	Fr = 551	Fr = 552	Fr = 553	Fr = 554	Fr = 555	Fr = 556	Fr = 557	Fr = 558	Fr = 559	Fr = 560	Fr = 561	Fr = 562	Fr = 563	Fr = 564	Fr = 565	Fr = 566	Fr = 567	Fr = 568	Fr = 569	Fr = 570	Fr = 571	Fr = 572	Fr = 573	Fr = 574	Fr = 575	Fr = 576	Fr = 577	Fr = 578	Fr = 579	Fr = 580	Fr = 581	Fr = 582	Fr = 583	Fr = 584	Fr = 585	Fr = 586	Fr = 587	Fr = 588	Fr = 589	Fr = 590	Fr = 591	Fr = 592	Fr = 593	Fr = 594	Fr = 595	Fr = 596	Fr = 597	Fr = 598	Fr = 599	Fr = 600	Fr = 601	Fr = 602	Fr = 603	Fr = 604	Fr = 605	Fr = 606	Fr = 607	Fr = 608	Fr = 609	Fr = 610	Fr = 611	Fr = 612	Fr = 613	Fr = 614	Fr = 615	Fr = 616	Fr = 617	Fr = 618	Fr = 619	Fr = 620	Fr = 621	Fr = 622	Fr = 623	Fr = 624	Fr = 625	Fr = 626	Fr = 627	Fr = 628	Fr = 629	Fr = 630	Fr = 631	Fr = 632	Fr = 633	Fr = 634	Fr = 635	Fr = 636	Fr = 637	Fr = 638	Fr = 639	Fr = 640	Fr = 641	Fr = 642	Fr = 643	Fr = 644	Fr = 645	Fr = 646	Fr = 647	Fr = 648	Fr = 649	Fr = 650	Fr = 651	Fr = 652	Fr = 653	Fr = 654	Fr = 655	Fr = 656	Fr = 657	Fr = 658	Fr = 659	Fr = 660	Fr = 661	Fr = 662	Fr = 663	Fr = 664	Fr = 665	Fr = 666	Fr = 667	Fr = 668	Fr = 669	Fr = 670	Fr = 671	Fr = 672	Fr = 673	Fr = 674	Fr = 675	Fr = 676	Fr = 677	Fr = 678	Fr = 679	Fr = 680	Fr = 681	Fr = 682	Fr = 683	Fr = 684	Fr = 685	Fr = 686	Fr = 687	Fr = 688	Fr = 689	Fr = 690	Fr = 691	Fr = 692	Fr = 693	Fr = 694	Fr = 695	Fr = 696	Fr = 697	Fr = 698	Fr = 699	Fr = 700	Fr = 701	Fr = 702	Fr = 703	Fr = 704	Fr = 705	Fr = 706	Fr = 707	Fr = 708	Fr = 709	Fr = 710	Fr = 711	Fr = 712	Fr = 713	Fr = 714	Fr = 715	Fr = 716	Fr = 717	Fr = 718	Fr = 719	Fr = 720	Fr = 721	Fr = 722	Fr = 723	Fr = 724	Fr = 725	Fr = 726	Fr = 727	Fr = 728	Fr = 729	Fr = 730	Fr = 731	Fr = 732	Fr = 733	Fr = 734	Fr = 735	Fr = 736	Fr = 737	Fr = 738	Fr = 739	Fr = 740	Fr = 741	Fr = 742	Fr = 743	Fr = 744	Fr = 745	Fr = 746	Fr = 747	Fr = 748	Fr = 749	Fr = 750	Fr = 751	Fr = 752	Fr = 753	Fr = 754	Fr = 755	Fr = 756	Fr = 757	Fr = 758	Fr = 759	Fr = 760	Fr = 761	Fr = 762	Fr = 763	Fr = 764	Fr = 765	Fr = 766	Fr = 767	Fr = 768	Fr = 769	Fr = 770	Fr = 771	Fr = 772	Fr = 773	Fr = 774	Fr = 775	Fr = 776	Fr = 777	Fr = 778	Fr = 779	Fr = 780	Fr = 781	Fr = 782	Fr = 783	Fr = 784	Fr = 785	Fr = 786	Fr = 787	Fr = 788	Fr = 789	Fr = 790	Fr = 791	Fr = 792	Fr = 793	Fr = 794	Fr = 795	Fr = 796	Fr = 797	Fr = 798	Fr = 799	Fr = 800	Fr = 801	Fr = 802	Fr = 803	Fr = 804	Fr = 805	Fr = 806	Fr = 807	Fr = 808	Fr = 809	Fr = 810	Fr = 811	Fr = 812	Fr = 813	Fr = 814	Fr = 815	Fr = 816	Fr = 817	Fr = 818	Fr = 819	Fr = 820	Fr = 821	Fr = 822	Fr = 823	Fr = 824	Fr = 825	Fr = 826	Fr = 827	Fr = 828	Fr = 829	Fr = 830	Fr = 831	Fr = 832	Fr = 833	Fr = 834	Fr = 835	Fr = 836	Fr = 837	Fr = 838	Fr = 839	Fr = 840	Fr = 841	Fr = 842	Fr = 843	Fr = 844	Fr = 845	Fr = 846	Fr = 847	Fr = 848	Fr = 849	Fr = 850	Fr = 851	Fr = 852	Fr = 853	Fr = 854	Fr = 855	Fr = 856	Fr = 857	Fr = 858	Fr = 859	Fr = 860	Fr = 861	Fr = 862	Fr = 863	Fr = 864	Fr = 865	Fr = 866	Fr = 867	Fr = 868	Fr = 869	Fr = 870	Fr = 871	Fr = 872	Fr = 873	Fr = 874	Fr = 875	Fr = 876	Fr = 877	Fr = 878	Fr = 879	Fr = 880	Fr = 881	Fr = 882	Fr = 883	Fr = 884	Fr = 885	Fr = 886	Fr = 887	Fr = 888	Fr = 889	Fr = 890	Fr = 891	Fr = 892	Fr = 893	Fr = 894	Fr = 895	Fr = 896	Fr = 897	Fr = 898	Fr = 899	Fr = 900	Fr = 901	Fr = 902	Fr = 903	Fr = 904	Fr = 905	Fr = 906	Fr = 907	Fr = 908	Fr = 909	Fr = 910	Fr = 911	Fr = 912	Fr = 913	Fr = 914	Fr = 915	Fr = 916	Fr = 917	Fr = 918	Fr = 919	Fr = 920	Fr = 921	Fr = 922	Fr = 923	Fr = 924	Fr = 925	Fr = 926	Fr = 927	Fr = 928	Fr = 929	Fr = 930	Fr = 931	Fr = 932	Fr = 933	Fr = 934	Fr = 935	Fr = 936	Fr = 937	Fr = 938	Fr = 939	Fr = 940	Fr = 941	Fr = 942	Fr = 943	Fr = 944	Fr = 945	Fr = 946	Fr = 947	Fr = 948	Fr = 949	Fr = 950	Fr = 951	Fr = 952	Fr = 953	Fr = 954	Fr = 955	Fr = 956	Fr = 957	Fr = 958	Fr = 959	Fr = 960	Fr = 961	Fr = 962	Fr = 963	Fr = 964	Fr = 965	Fr = 966	Fr = 967	Fr = 968	Fr = 969	Fr = 970	Fr = 971	Fr = 972	Fr = 973	Fr = 974	Fr = 975	Fr = 976	Fr = 977	Fr = 978	Fr = 979	Fr = 980	Fr = 981	Fr = 982	Fr = 983	Fr = 984	Fr = 985	Fr = 986	Fr = 987	Fr = 988	Fr = 989	Fr = 990	Fr = 991	Fr = 992	Fr = 993	Fr = 994	Fr = 995	Fr = 996	Fr = 997	Fr = 998	Fr = 999	Fr = 1000
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« 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»



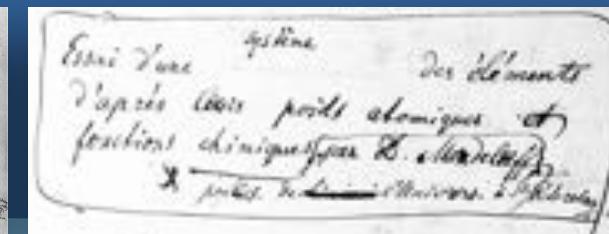
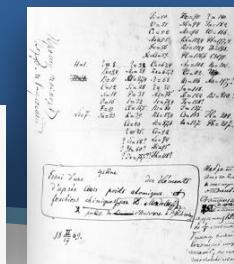
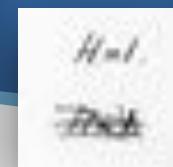
Mendeleev's periodic table of elements

но във вѣдѣ, какъ кажется, уже ясно выражается прѣимущество выставленного живо начала по всей совокупности элементовъ, изъ которыхъ известныъ съ достовѣрностью. На этотъ разъ я и желалъ премеждующею найти общую систему элементовъ. Вотъ этотъ опытъ:

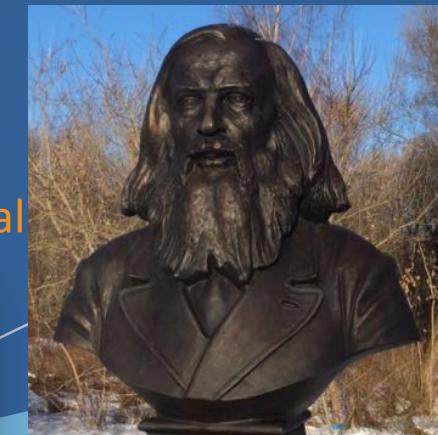
Ti=50	Zr=90	?=150,
V=51	Nb=94	Ta=152,
Cr=52	Mo=96	W=156,
Mn=55	Rh=104,4	Pt=197,
Fe=56	Ru=104,4	Ir=198,
Ni=Co=59	Pt=106,6	Os=199,
H=1	Ca=63,4	Ag=108 Hg=200,
Be=9,4	Mg=24	Zn=65,4 Cd=112
B=11	Al=27,4	?=58 Ur=116 Au=197?
C=12	Si=28	?=70 Sn=118
N=14	P=31	As=75 Sb=122 Bi=210
O=16	S=32	Se=79,4 Te=128?
F=19	Cl=35,5	Br=80 I=127
Li=7	Na=23	K=39 Rb=85,4 Cs=133 Ti=204
		Ca=40 Sr=7,4 Ba=137 Pb=207,
		?=45 Ce=92
		?Er=56 La=94
		?Y=60 Di=95
		?An=75,8 Th=118?

17 II 1869 (Julian calendar, = 1 III 1969 in Greg. cal.)

D.I. Mendeleev sent a single page to Russian Chemical Society:



IUPAC Periodic Table of the Elements



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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1	H	hydrogen	[1.008, 1.0082]	2	3	Li	beryllium	[6.938, 6.997]	4	Be	beryllium	[9.0122]	13	B	boron	[10.806, 10.821]	14	C	carbon	[12.009, 12.012]	15	N	nitrogen	[14.007, 14.008]	16	O	oxygen	[15.999, 16.000]	17	F	fluorine	[18.998]	18	He	helium	[4.0026]																																																																																																																																																																																	
11	Na	sodium	[22.990, 24.307]	12	Mg	magnesium	[24.304, 24.307]	3	4	5	6	7	8	9	10	11	12	13	Al	aluminum	[26.982]	14	Si	silicon	[28.084, 28.086]	15	P	phosphorus	[31.995, 32.076]	16	S	sulfur	[32.059, 32.076]	17	Cl	chlorine	[35.446, 35.457]	18	Ar	argon	[39.792, 39.963]																																																																																																																																																																												
19	K	potassium	[39.088]	20	Ca	calcium	[40.079(4)]	21	Sc	scandium	[44.956]	22	Ti	titanium	[50.942]	23	V	vandium	[51.996]	24	Cr	chromium	[54.938]	25	Mn	manganese	[55.845(2)]	26	Fe	iron	[58.933]	27	Co	cobalt	[58.693]	28	Ni	nickel	[63.546(3)]	29	Cu	copper	[65.38(2)]	30	Zn	zinc	[69.723]	31	Ga	gallium	[72.630(8)]	32	Ge	germanium	[78.971(8)]	33	As	arsenic	[79.901, 79.907]	34	Se	selenium	[79.954]	35	Kr	krypton	[83.799(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	[101.07(2)]	44	Ru	ruthenium	[102.91]	45	Rh	rhodium	[106.42]	46	Pd	palladium	[107.87]	47	Ag	silver	[112.41]	48	Cd	cadmium	[114.82]	49	In	indium	[118.71]	50	Sn	tin	[121.76]	51	Sb	antimony	[127.60(3)]	52	Te	tellurium	[128.90]	53	I	iodine	[131.29]	54	Xe	xenon	[132.91]	55	Cs	caesium	[137.33]	56	Ba	barium	[178.49(2)]	57-71	lanthanoids	[180.95]	72	Hf	hafnium	[183.84]	73	Ta	tantalum	[186.21]	74	W	tungsten	[190.23(3)]	75	Re	rhenium	[192.22]	76	Os	osmium	[195.08]	77	Ir	iridium	[196.97]	78	Pt	platinum	[200.59]	79	Au	gold	[204.38, 204.39]	80	Hg	mercury	[207.2]	81	Tl	thallium	[208.98]	82	Pb	lead	[208.98]	83	Bi	bismuth	[212.76]	84	Po	polonium	[216.93]	85	At	astatine	[217.05]	86	Rn	radon	[217.05]	87	Fr	francium	[223.01]	88	Ra	radium	[226.03]	89-103	actinoids	[229.03]	104	Rf	rutherfordium	[231.04]	105	Db	dubnium	[238.03]	106	Sg	seaborgium	[239.04]	107	Bh	bohrium	[240.04]	108	Hs	hassium	[243.04]	109	Mt	meitnerium	[244.04]	110	Ds	damstadtium	[245.04]	111	Rg	roentgenium	[246.04]	112	Cn	copernicium	[247.04]	113	Nh	nihonium	[248.04]	114	Fl	flerovium	[249.04]	115	Mc	moscovium	[250.04]	116	Lv	livermorium	[251.04]	117	Ts	tennessine	[252.04]	118	Og	oganeson	[253.04]

57	La	lanthanum	[138.91]	58	Ce	cerium	[140.12]	59	Pr	praseodymium	[140.91]	60	Nd	neodymium	[144.24]	61	Pm	promethium	[150.36(2)]	62	Sm	samarium	[151.96]	63	Eu	europtium	[157.25(3)]	64	Gd	gadolinium	[158.93]	65	Tb	terbium	[162.50]	66	Dy	dysprosium	[164.93]	67	Ho	holmium	[167.26]	68	Er	erbium	[168.93]	69	Tm	thulium	[173.05]	70	Yb	ytterbium	[174.97]	71	Lu	lutetium	[174.97]
89	Ac	actinium	[232.04]	90	Th	thorium	[231.04]	91	Pa	protactinium	[238.03]	92	U	uranium	[238.03]	93	Np	neptunium	[239.04]	94	Pu	plutonium	[243.04]	95	Am	americium	[244.04]	96	Cm	curium	[247.04]	97	Bk	berkelium	[249.04]	98	Cf	californium	[251.04]	99	Es	einsteinium	[252.04]	100	Fm	fermium	[253.04]	101	Md	mendelevium	[254.04]	102	No	nobelium	[255.04]	103	Lr	lawrencium	[256.04]

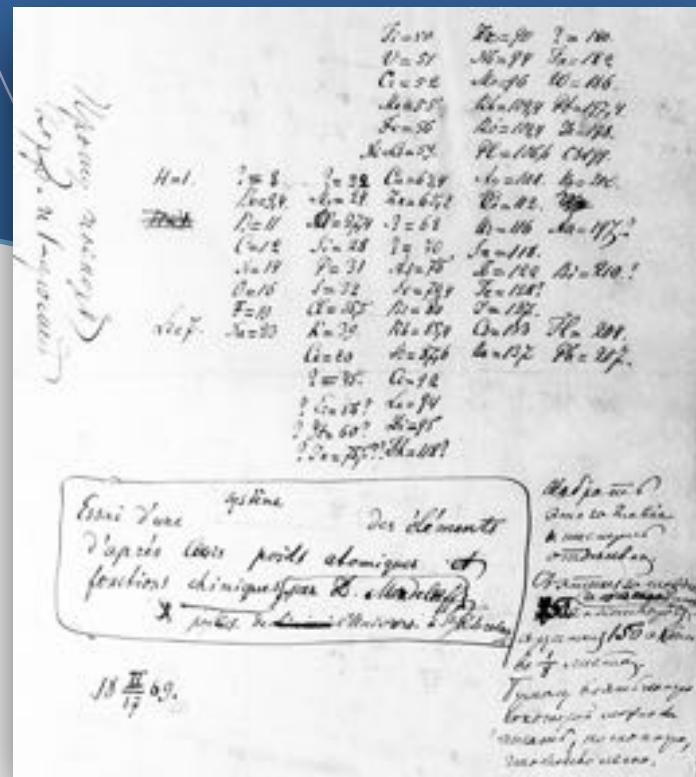
For notes and updates to this table, see www.iupac.org. This version is dated 1 December 2018.

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

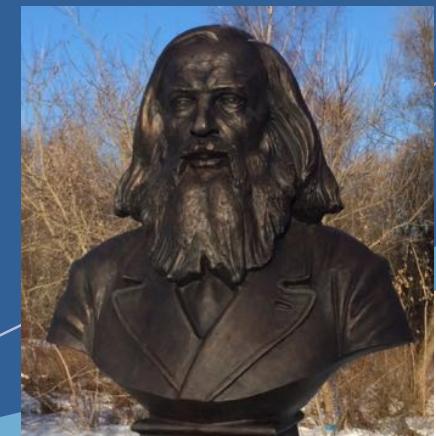


Mendeleev's periodic table of elements



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

<p>но въ видѣ, какъ кажется, уже ясно выражается примѣнность выставленного мною началько по всей совокупности элементовъ, пад которыхъ известны съ достовѣрностью. На этотъ разъ я и желалъ преимущественно найти общую систему элементовъ. Вотъ этотъ опытъ:</p> <table border="0"> <tbody> <tr><td>Ti=50</td><td>Zr=90</td><td>?=150.</td></tr> <tr><td>V=51</td><td>Nb=94</td><td>Ta=1s2.</td></tr> <tr><td>Cr=52</td><td>Mo=96</td><td>W=186.</td></tr> <tr><td>Mn=55</td><td>Rh=104,4</td><td>Pt=197,4</td></tr> <tr><td>Fe=56</td><td>Ru=104,4</td><td>Ir=198.</td></tr> <tr><td>Ni=Co=59</td><td>Pt=106,</td><td>Os=199.</td></tr> <tr><td>Cu=63,4</td><td>Ag=108</td><td>Hg=200.</td></tr> </tbody> </table> <p>H-1</p> <table border="0"> <tbody> <tr><td>Be=9,4</td><td>Mg=24</td><td>Zn=65,8</td><td>Od=112</td></tr> <tr><td>B=11</td><td>Al=27,4</td><td>?=68</td><td>Ur=116</td></tr> <tr><td>C=12</td><td>Si=28</td><td>?=70</td><td>An=197?</td></tr> <tr><td>N=14</td><td>P=31</td><td>As=75</td><td>Su=118</td></tr> <tr><td>O=16</td><td>S=32</td><td>Se=79,4</td><td>Sb=122</td></tr> <tr><td>F=19</td><td>Cl=35,5</td><td>Br=80</td><td>Bi=210</td></tr> <tr><td>Li=7</td><td>Na=23</td><td>K=39</td><td>Te=128?</td></tr> <tr><td></td><td></td><td>Rb=85,4</td><td>I=127</td></tr> <tr><td></td><td></td><td>Ca=40</td><td>Br=80</td></tr> <tr><td></td><td></td><td>Sr=75,8</td><td>Cs=133</td></tr> <tr><td></td><td></td><td>?=45</td><td>Tl=204</td></tr> <tr><td></td><td></td><td>Ce=92</td><td>Pb=207.</td></tr> <tr><td></td><td></td><td>?Er=56</td><td>La=94</td></tr> <tr><td></td><td></td><td>?Y=60</td><td>Di=95</td></tr> <tr><td></td><td></td><td>Lu=75,5</td><td>Th=118?</td></tr> </tbody> </table>	Ti=50	Zr=90	?=150.	V=51	Nb=94	Ta=1s2.	Cr=52	Mo=96	W=186.	Mn=55	Rh=104,4	Pt=197,4	Fe=56	Ru=104,4	Ir=198.	Ni=Co=59	Pt=106,	Os=199.	Cu=63,4	Ag=108	Hg=200.	Be=9,4	Mg=24	Zn=65,8	Od=112	B=11	Al=27,4	?=68	Ur=116	C=12	Si=28	?=70	An=197?	N=14	P=31	As=75	Su=118	O=16	S=32	Se=79,4	Sb=122	F=19	Cl=35,5	Br=80	Bi=210	Li=7	Na=23	K=39	Te=128?			Rb=85,4	I=127			Ca=40	Br=80			Sr=75,8	Cs=133			?=45	Tl=204			Ce=92	Pb=207.			?Er=56	La=94			?Y=60	Di=95			Lu=75,5	Th=118?			
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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 ($Z=44$) —> Sc m=43,79, disc. 1879
- eka-aluminum ($Z=68$) —> Ga m=69.723, disc. 1875
- eka-silicon ($Z=70$) —> 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

Some « modern chemistry » starts 17th century

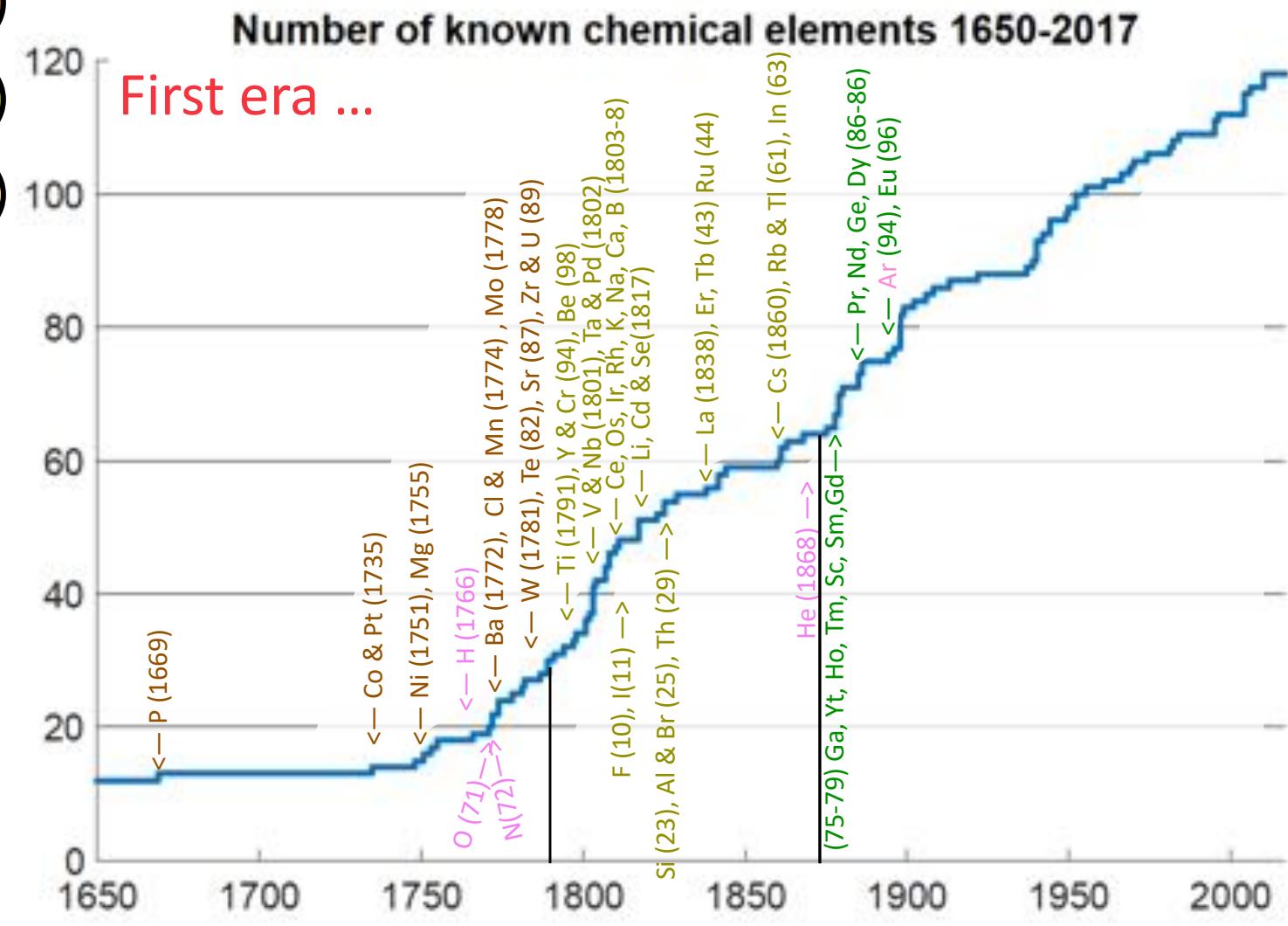
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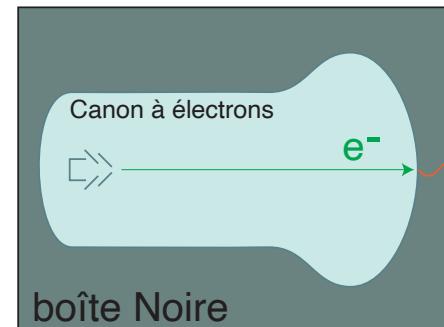
1895 - Découverte des rayon X

Wilhelm Röntgen, (1845-1923)

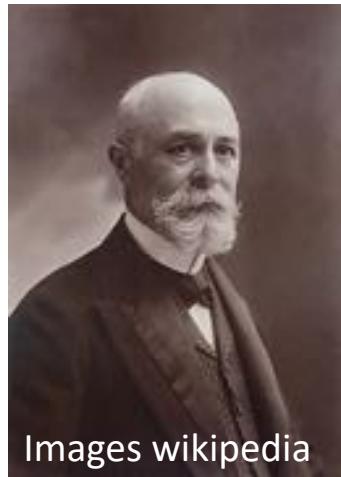
Nobel de physique 1901



Écran couvert de ZnS



1896 - Découverte de la radioactivité



Images wikipedia

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



Sel de l'uranium utilisé par Henri Becquerel pour la découverte de la radioactivité.



Photographie de "La Croix de Molié", impressionnée dans l'obscurité par les rayonnements provenant de l'uranium, et développée le 1^{er} mars 1896 par Henri Becquerel.



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

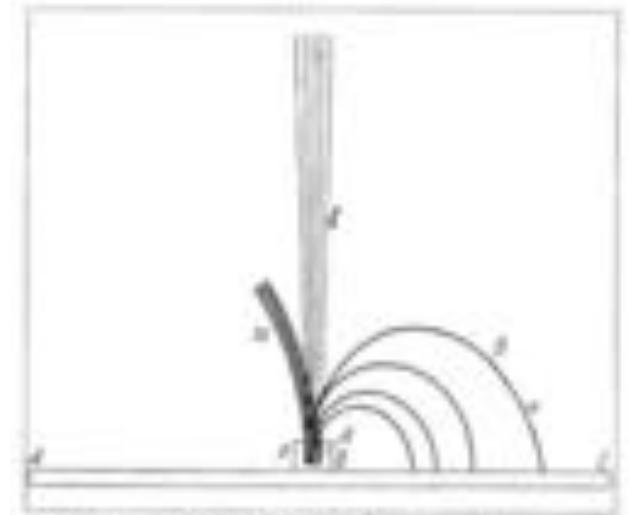
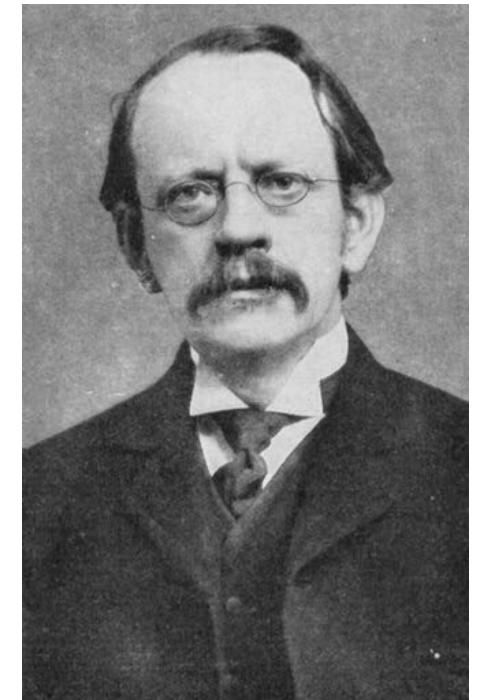


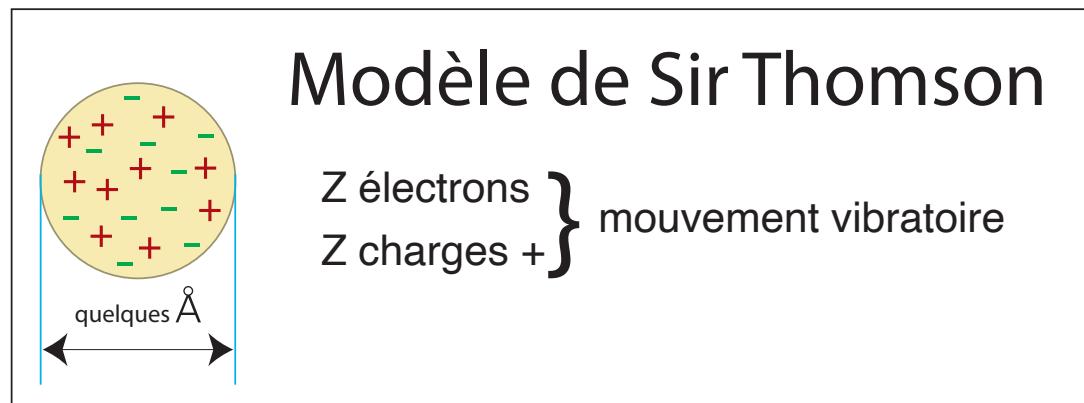
Schéma illustrant l'action d'un champ magnétique sur les rayonnements de radioactivité (Marie Curie, 1903).

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

Some « modern chemistry » starts 17th century

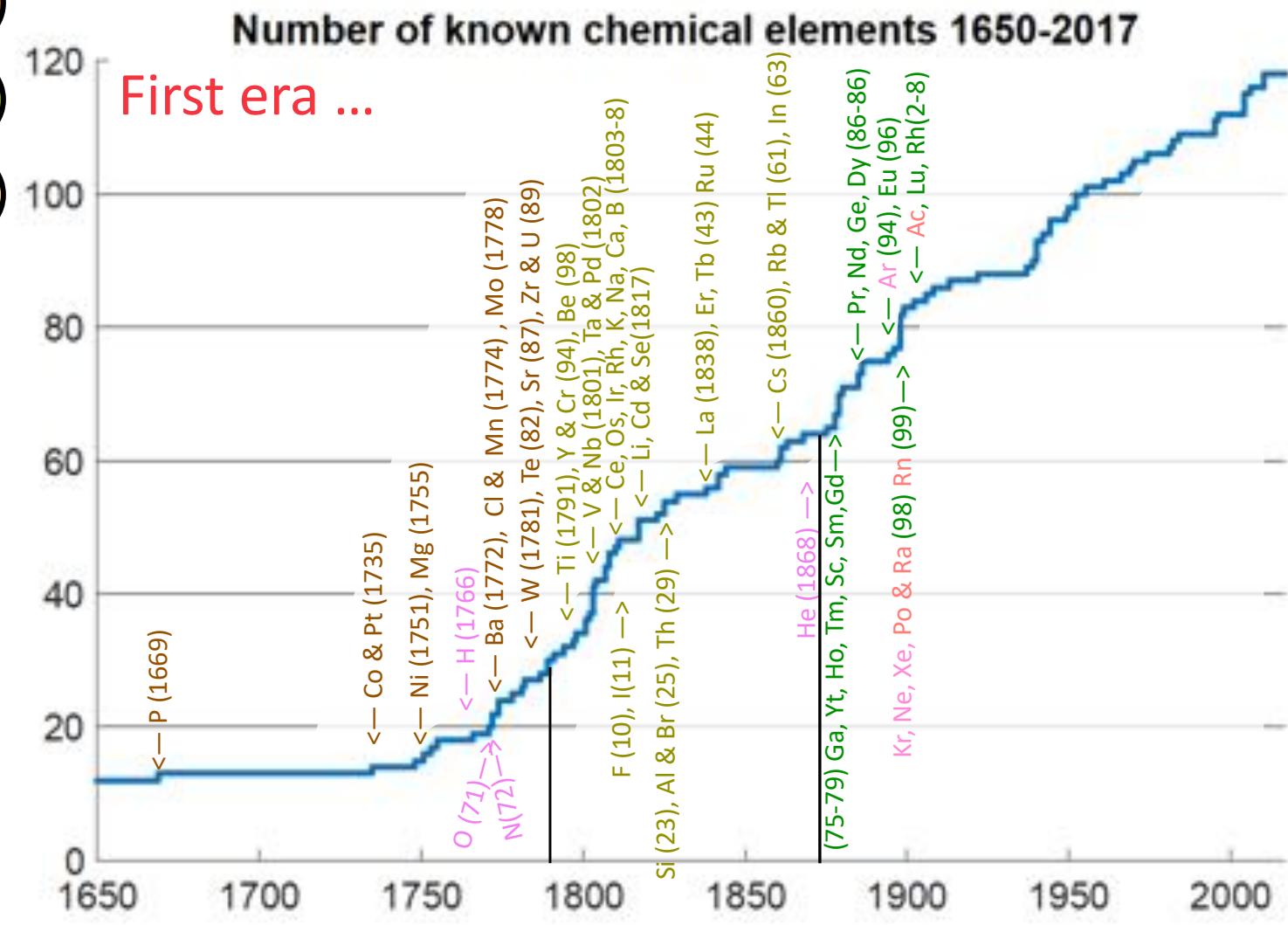
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Radioactivité et rayonnements

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

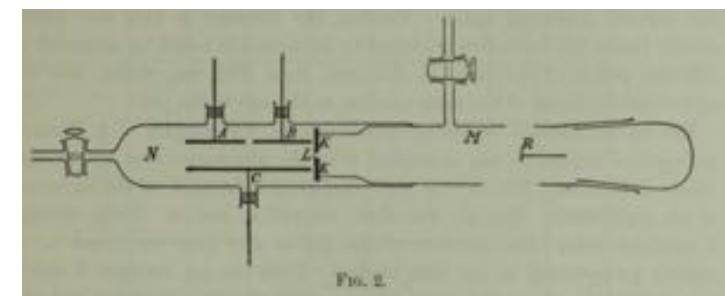
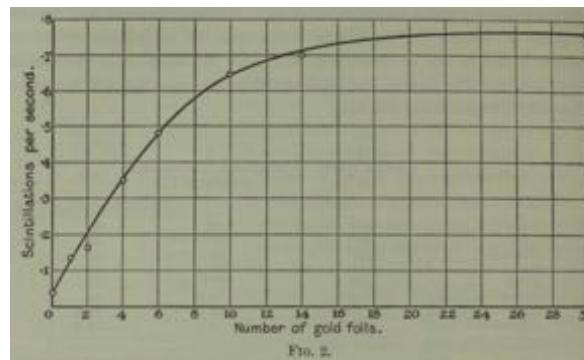
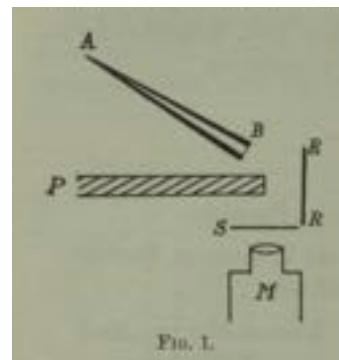


FIG. 2.

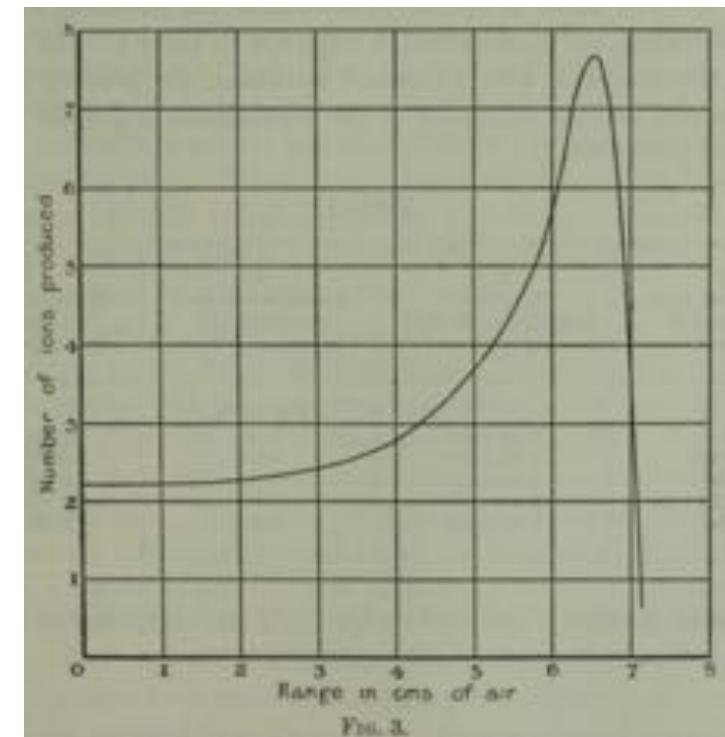


FIG. 3.

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

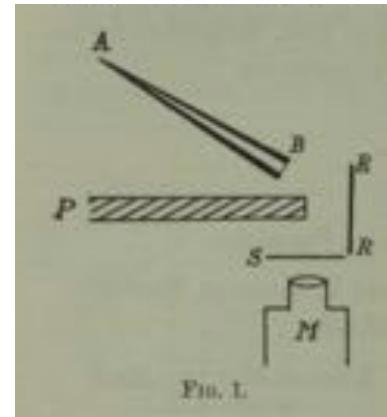
1. Metal.	2. Atomic weight, A.	3. Number of scintillations per minute, Z.	4. A/Z
Lead	207	62	30
Gold	197	57	34
Platinum	195	53	33
Tin	119	34	29
Silver	108	27	25
Copper	64	14.5	23
Iron	56	10.2	18.5
Aluminium	27	3.4	12.5

1908 - Expérience « de Rutherford »

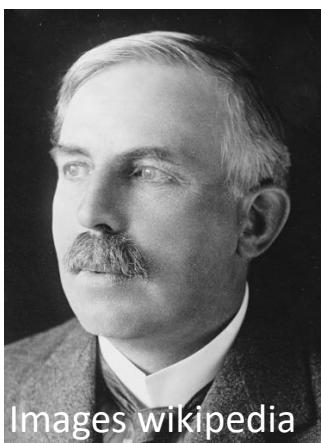


Images wikipedia

Hans Geiger
(1882-1945)



Ernest Marsden
(1889-1970)



Images wikipedia

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 Elektronik," vol. 5, p. 471, 1908.

† Rutherford, "Phil. Mag.," vol. 12, p. 143, 1903; H. Geiger, "Roy. Soc. Proc.," A, vol. 81, p. 174, 1908.

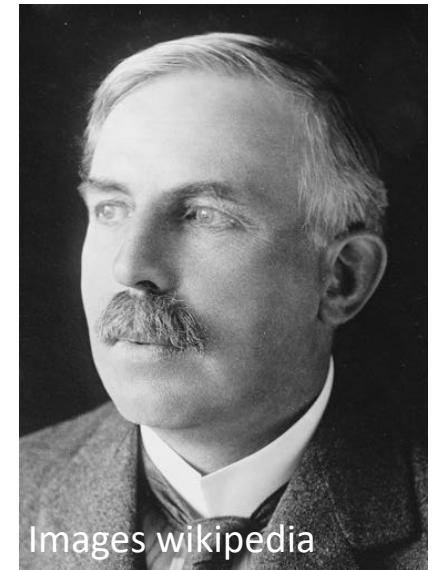
Mise en évidence du noyau atomique en 1911.

Sir Ernest Rutherford (1871-1937)

Nobel de chimie 1908 Rutherford E. Philosophical Magazine Series 6, 21 125 (1911) 669 – 688

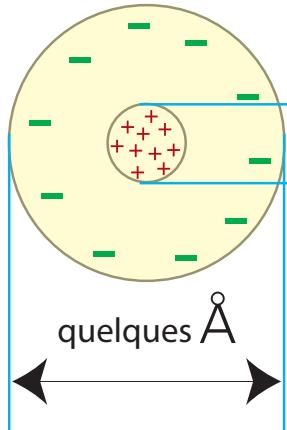
1908 - Expérience « de Rutherford »

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...



Images wikipedia

Antonius van den Broek
(1870-1926)

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

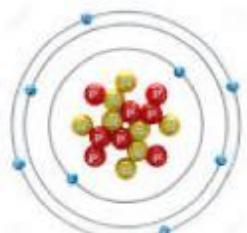
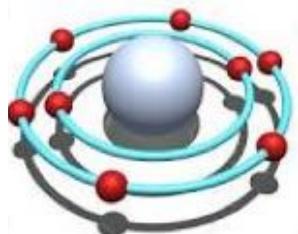


Images wikipedia

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

Some « modern chemistry » starts 17th century

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

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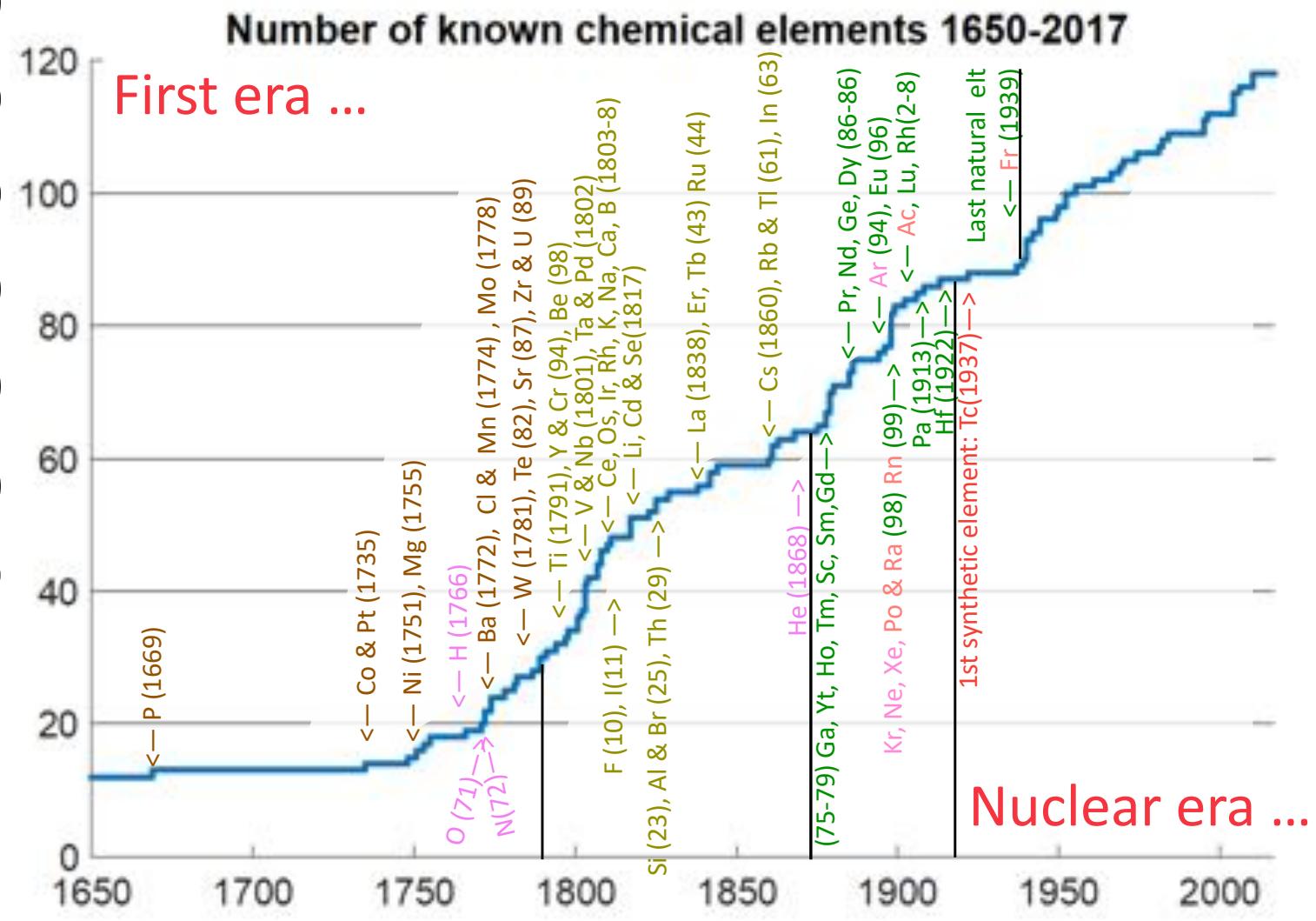
1896 ... discovery in U rock of
Radioactivity by H. Becquerel

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

1934 ... Artificial radioisotope
 ${}^4\text{He} + {}^{27}\text{Al} \rightarrow {}^{30}\text{P} (+n)$ (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 $\frac{1}{2}$ 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 :

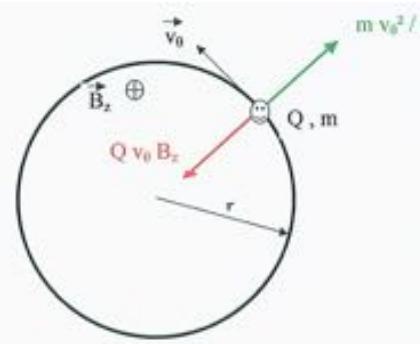
- quand un corps de masse m se déplace sur un cercle de rayon r à une vitesse constante v_θ , il est soumis à une force centrifuge $m v_\theta^2 / r$
- s'il reste sur ce cercle, c'est que cette force est équilibrée à tout instant par une force égale dirigée en sens inverse ; dans le cas d'une particule 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 :

$$m v_\theta^2 / r = Q v_\theta B_z \quad [1]$$

pour en déduire la vitesse angulaire ω :

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



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

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

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 :

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

: 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** :

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

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

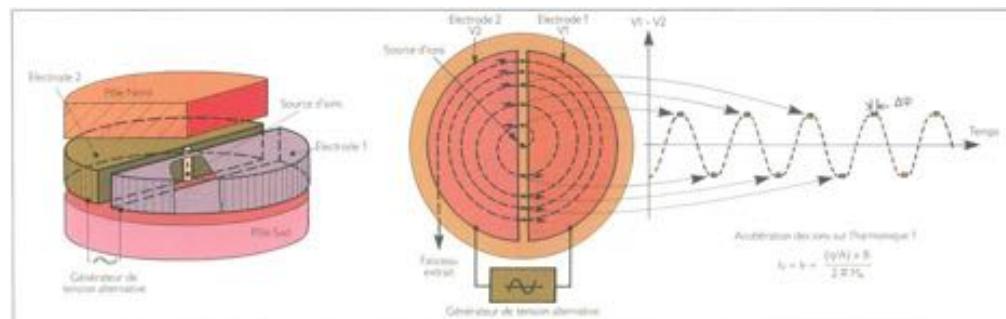


Figure 3

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

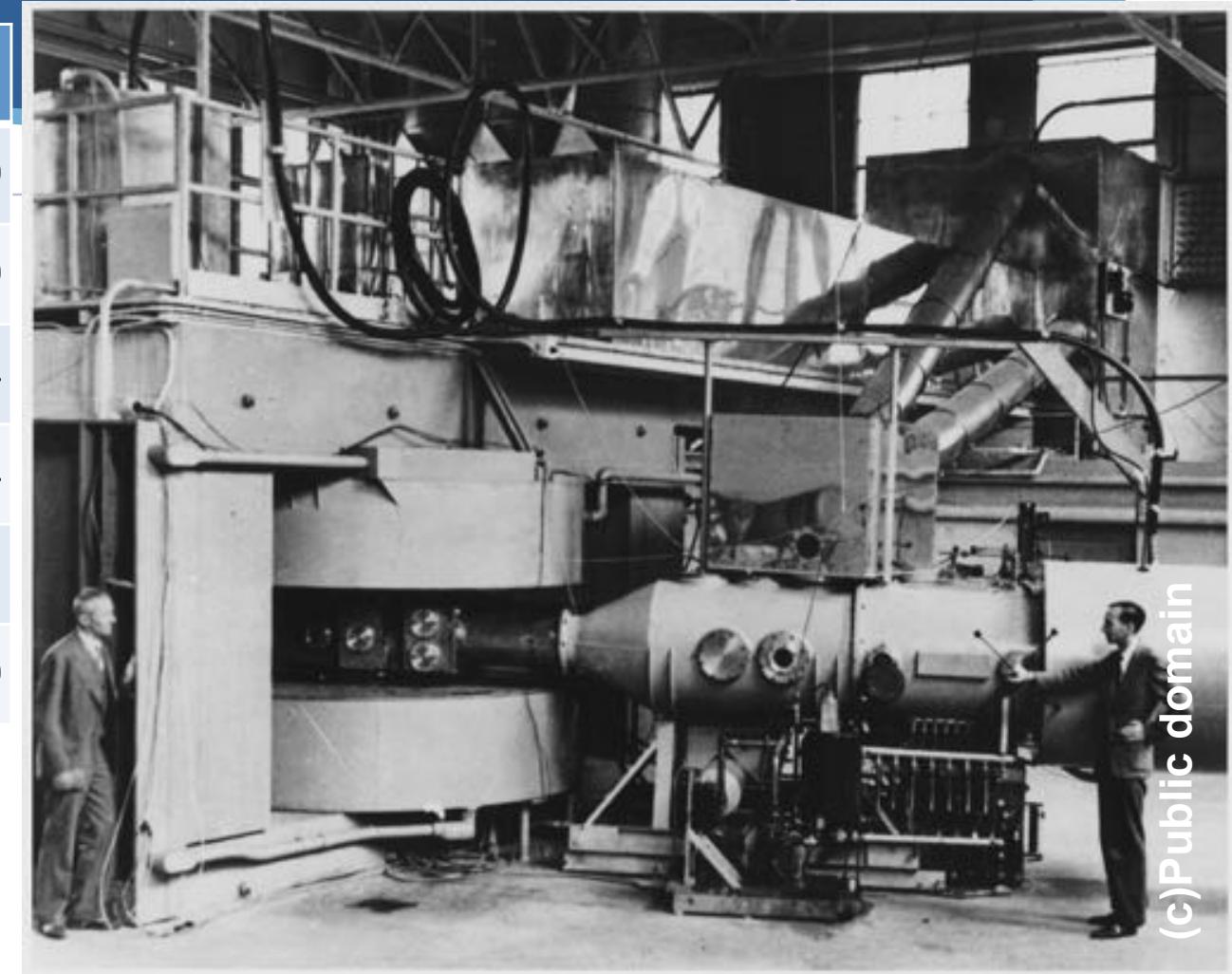


88' cyclotron @ LBNL

Synthesis of elements Z = 93 to 98 in LBNL*

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

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

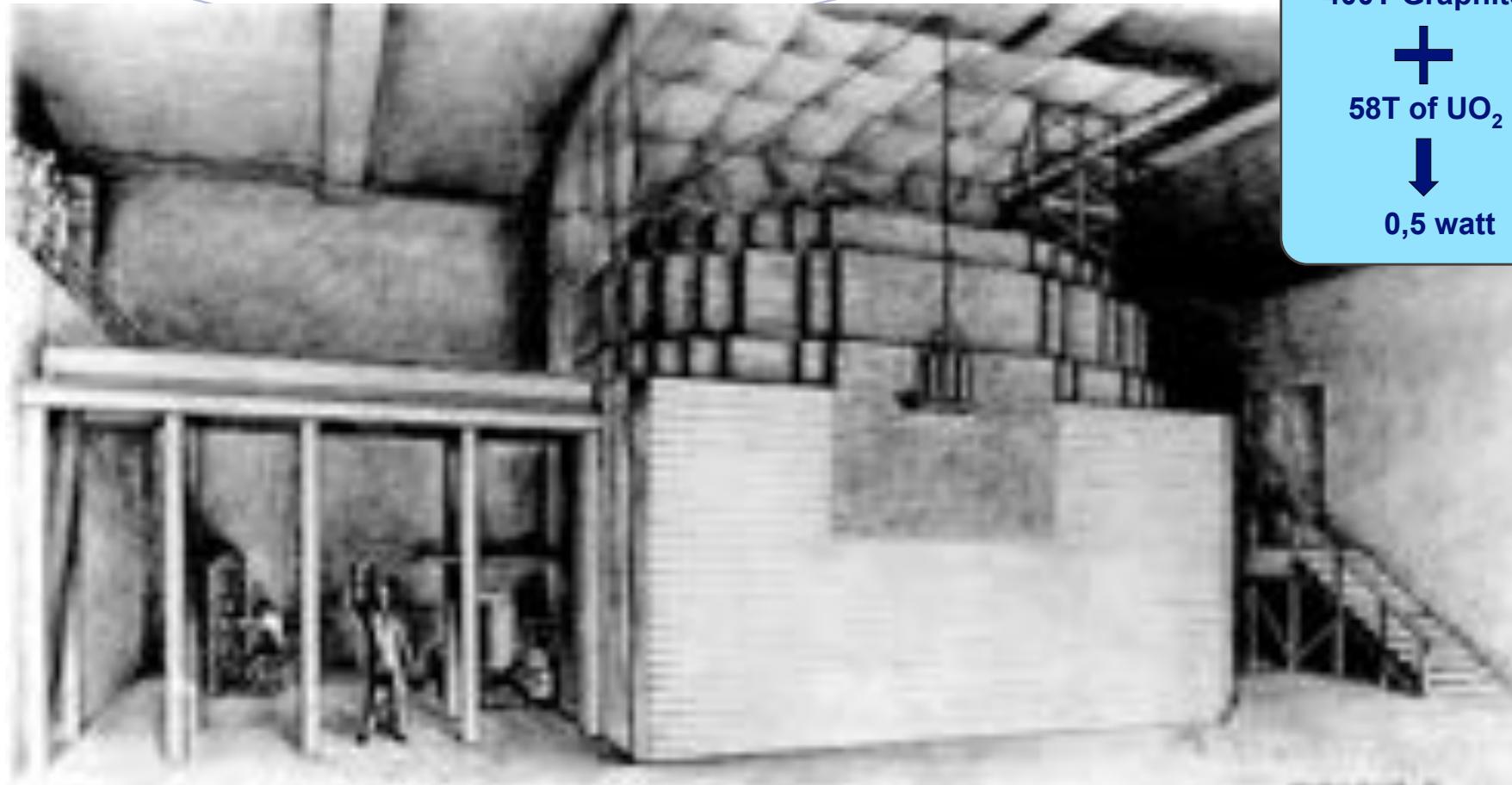


^{239}Pu from LBNL demonstrated the highest interest of plutonium for nuclear fission

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

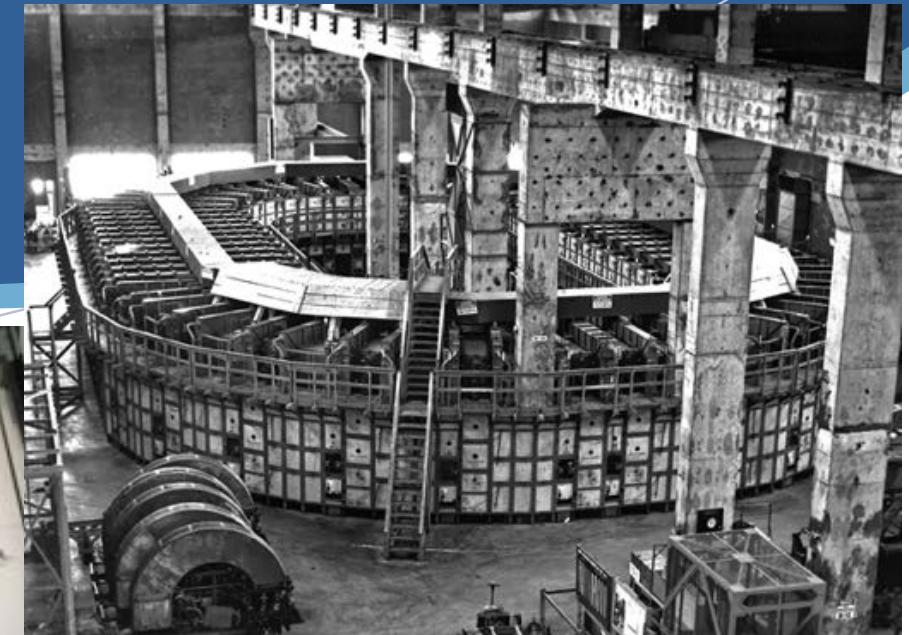
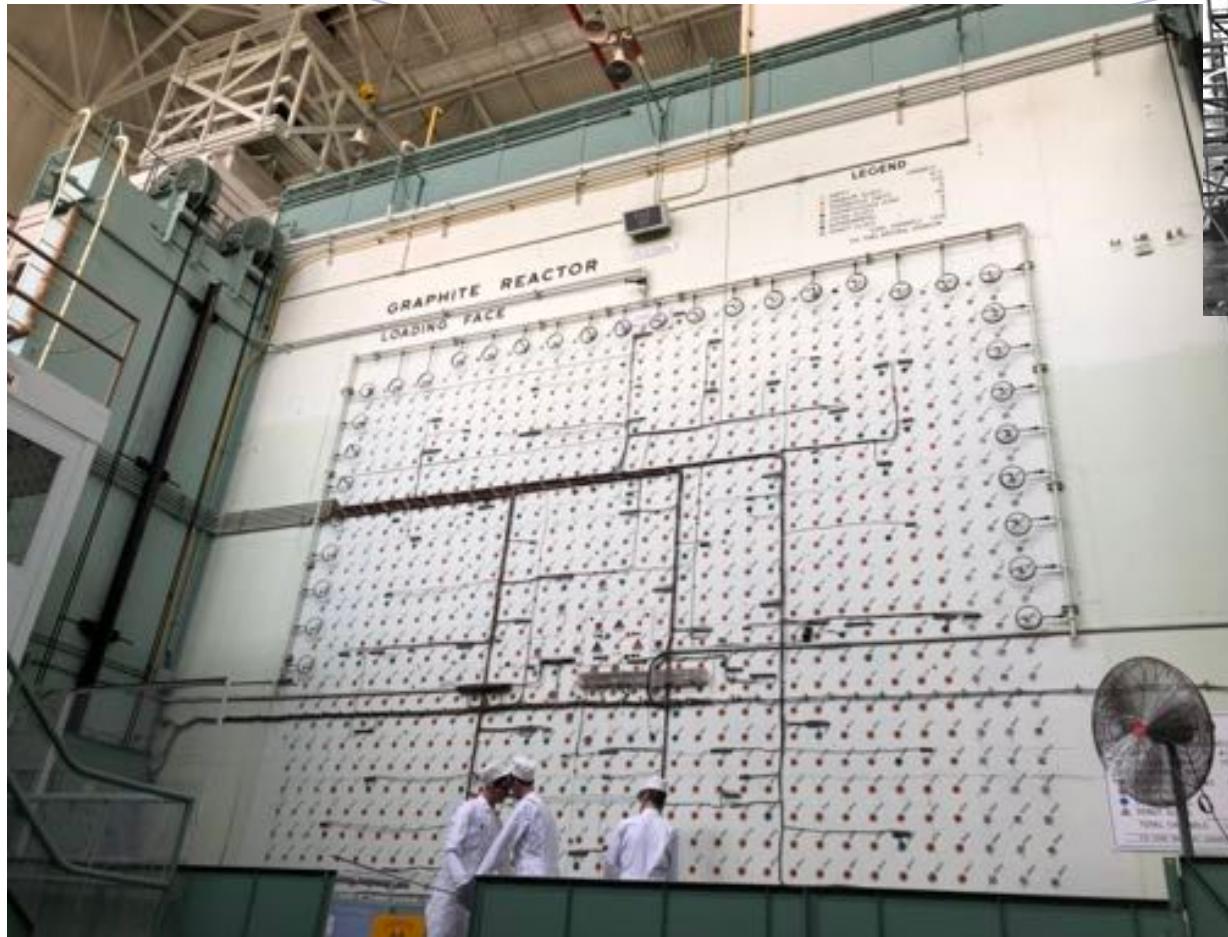
© Argonne National Laboratory

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)

Central flux : 10^{24} n / cm²

=> Einsteinium (Z=99)

=> Fermium (Z=100)

+ subsequent discovery

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



(c) Public domain

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

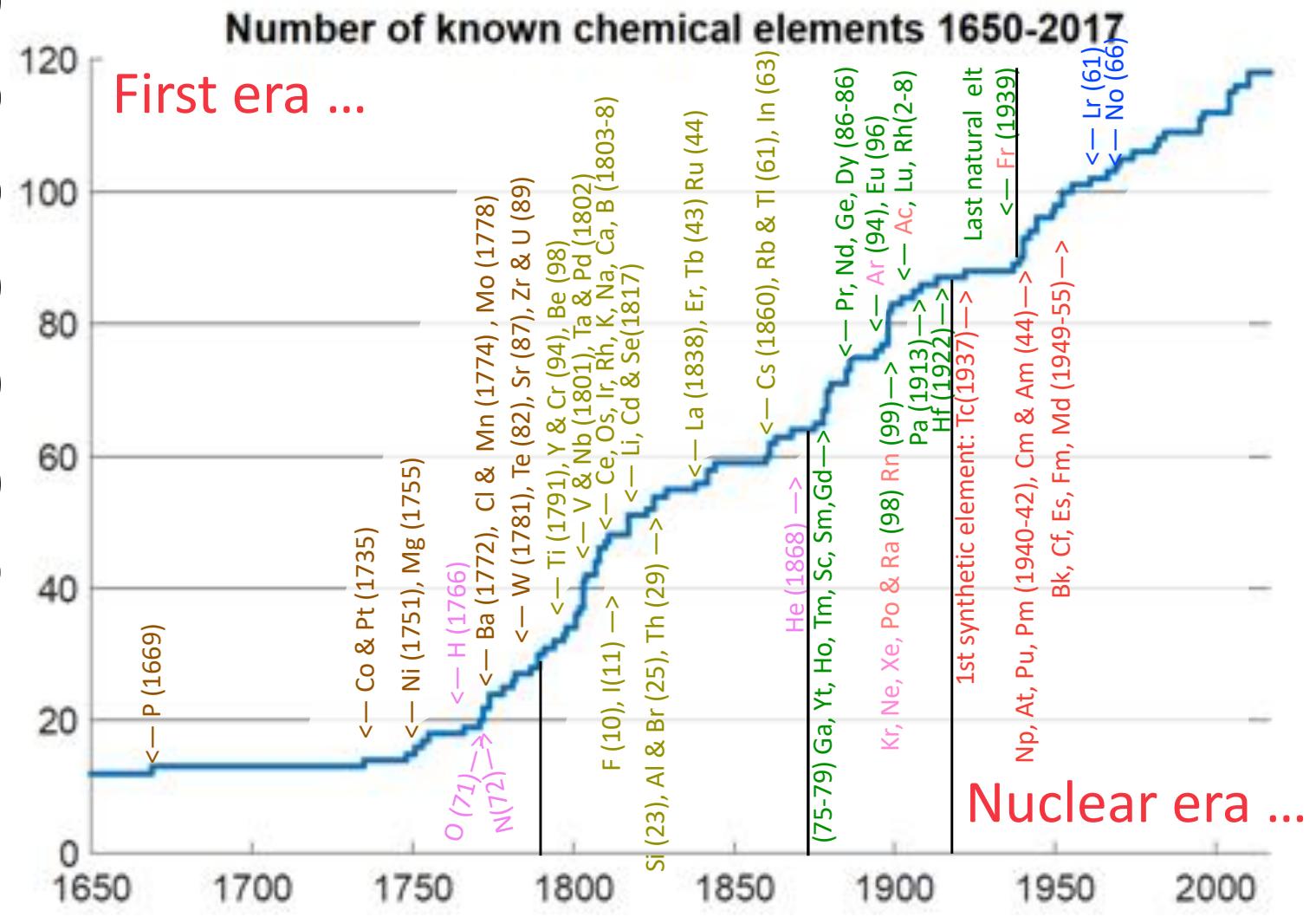
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+12+2 synthetic, heavy

- 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.
 ${}^4\text{He} + {}^{197}\text{Au} \rightarrow$ diffusion
- 1934 ... Artificial radioisotope
 ${}^4\text{He} + {}^{27}\text{Al} \rightarrow {}^{30}\text{P} (+n)$ (Joliot)
- 1937 ... 1st synthetic element:
Tc (cyclotron)
- 1939 ... last natural element Fr



Accélérateurs d'ions





256Rf

Z=22

Ti Titanium 47.867 σ 6.09
--

Ti 44 -37548.3 (8) 59.2 a 0+ β^- 1.04% γ 780 688 146 w σ 1.1

Ti 45 -39006.9 (12) 184.8 m 7/2- β^- 1.20% γ 720 1468 1661 w σ 0.39
--

Ti 46 -44125.3 (11) 0+ 8.25% σ 0.59

Ti 47 -44931.7 (10) 5/2- 7.44% σ 1.7
--

Ti 48 -48487.0 (10) 0+ 73.72% σ 7.84
--

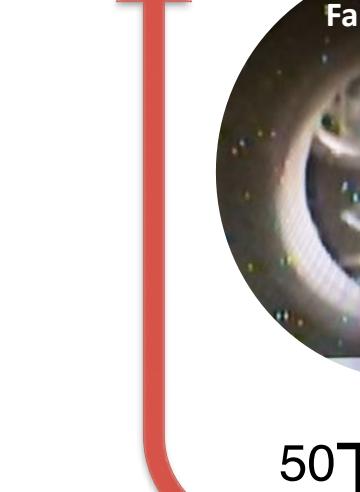
Ti 49 -48558.0 (10) 7/2- 5.41% σ 2.2
--

Ti 50 -51425.8 (10) 0+ 5.18% σ 0.179
--

Ti 51 -49726.9 (13) 5/2- 5.76 m β (2.15) (1.54) γ 320 929 609 σ 1.17

Ti 52 -49464 (7) 1.7 m 0+ β 1.834 γ 124 17

208Pb



50Ti

B. GALL IPHC & USIAS Strasbourg

Z=82

Pb Lead 207.2 σ 0.171
--

N= 120

Pb 202 -25948 (10) 3.5 h 4 961 422 787... γ 490 460 590 241...
--

Pb 203 -24801 (7) 52.5E3 a 480ms 1.839 258 820 1027... γ 299 681

Pb 204 -25123.5 (29) 1.120 h 1.4E17 a 1.4% α 661 mb
--

Pb 205 -23783.7 (29) 5.54 ms 13/2+ 1.26 e 988 284 703 310 1014... γ no γ
--

Pb 206 -23800.6 (29) 0+ 24.1% α 610 mb +26.6 mb
--

Pb 207 -22467.1 (29) 806 ms 13/2+ 1.26 e 1064 γ no γ
--

Pb 208 -21763.6 (29) 0+ 52.4% α 610 mb α 8.1b

Pb 209 -17629 (3) 9/2+ β 0.6446 no γ
--

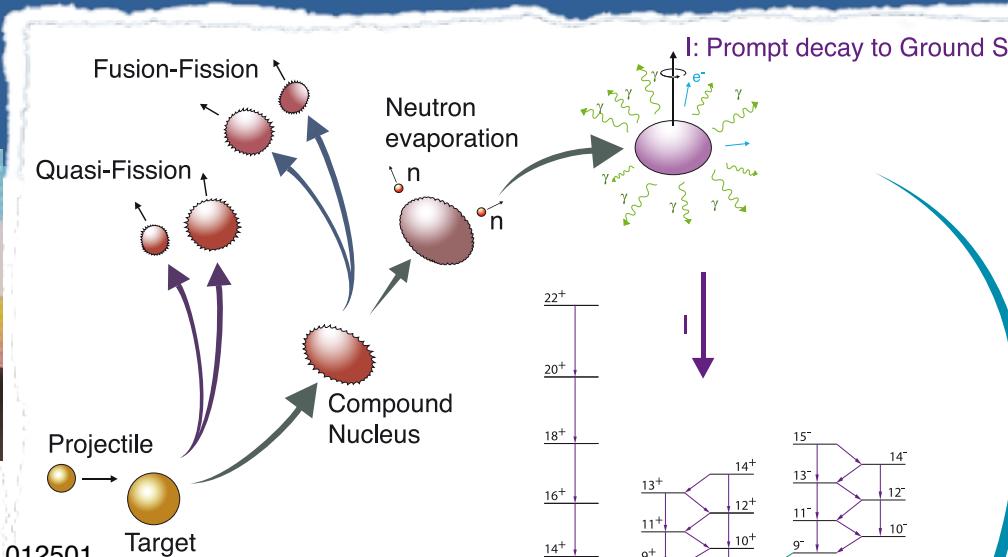
Pb 210 -14743 (3) 22.3 a β 0.0170 0.0610 γ 47 e α 3.72 vw α 0.5

Physique pour tous

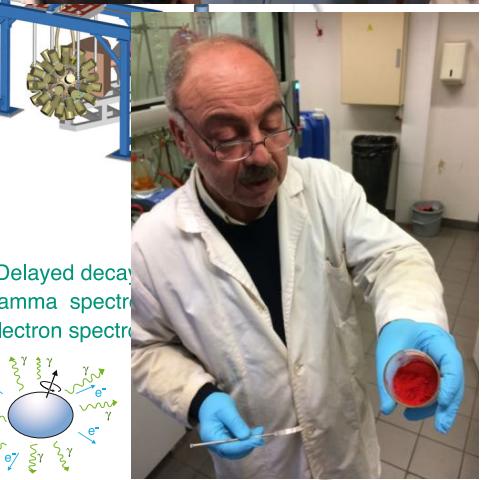
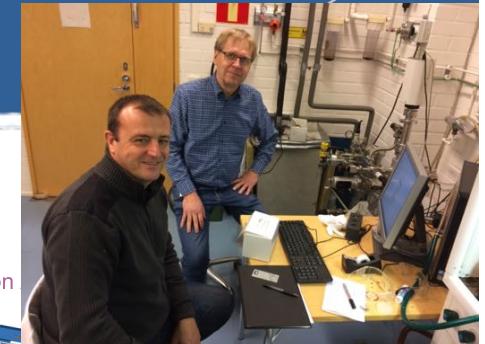
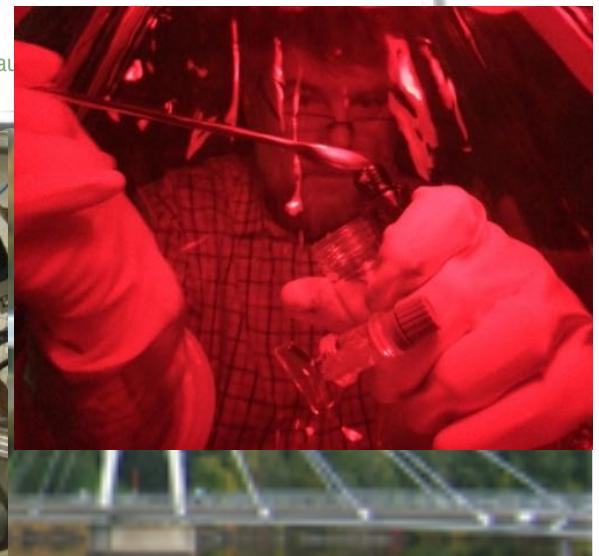
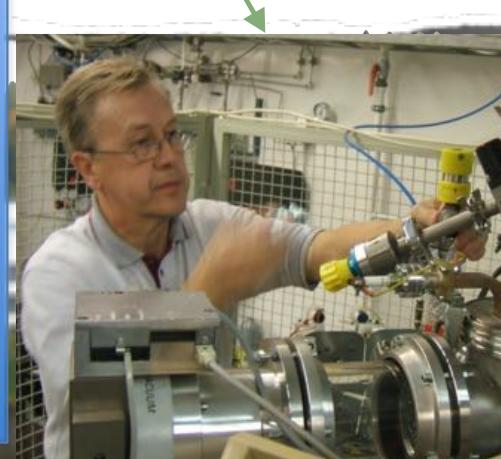
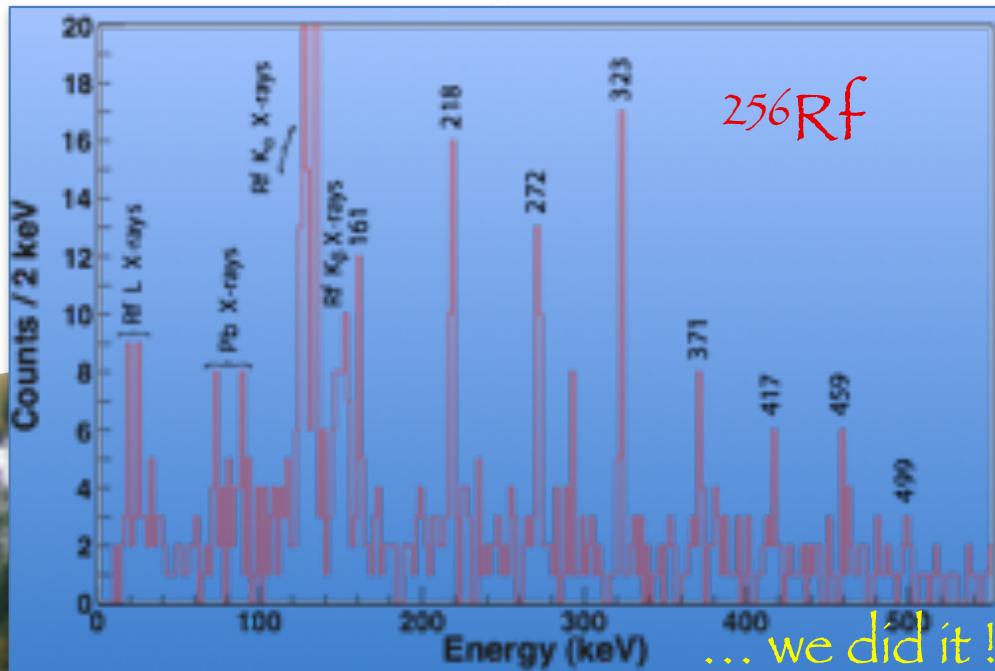
Strasbourg, automne 2022

Initial aim: ^{256}Rf prompt spectroscopy

Needed 50 pnA of ^{50}Ti beam ... ???

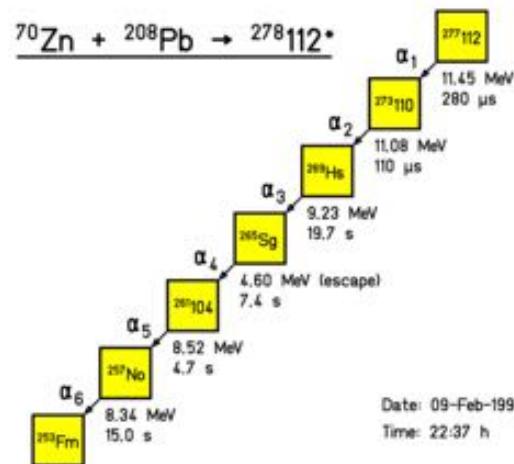


Greenlees, Rubert et al., PRL 109 (2012) 012501

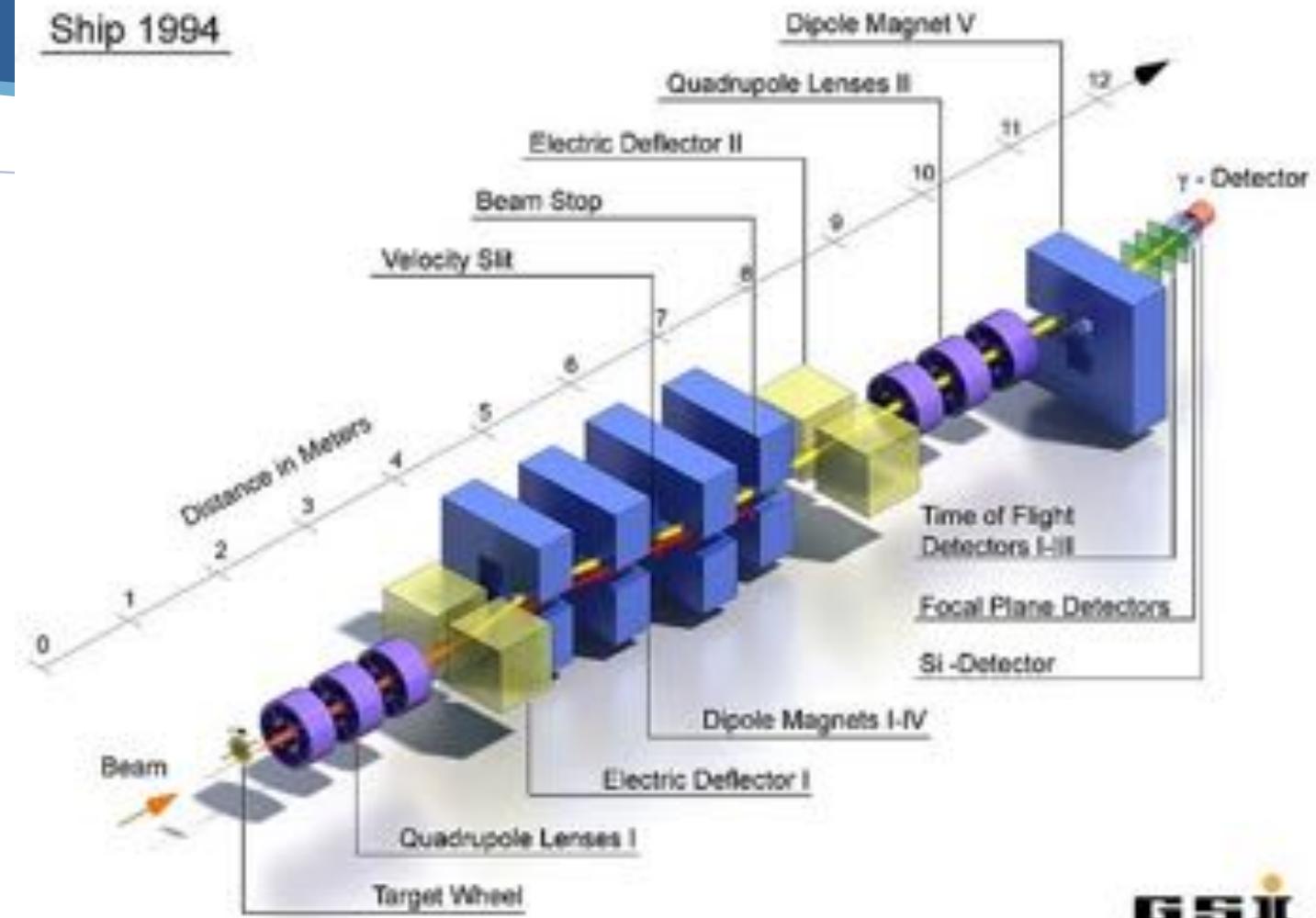


Cold fusion $^{208}\text{Pb}/^{209}\text{Bi}$

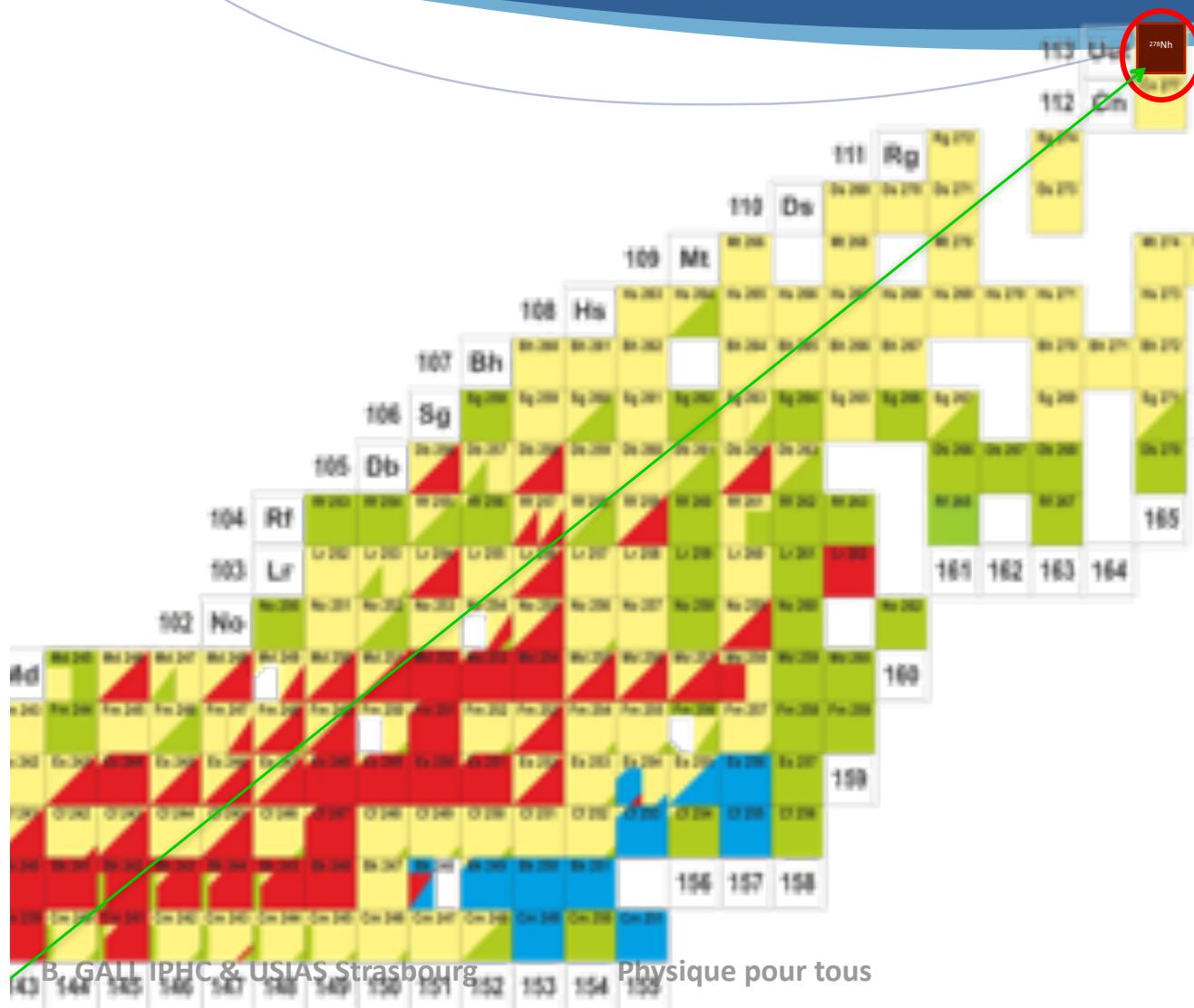
SHIP (@GSI) discovery of elements 107-112



Ship 1994



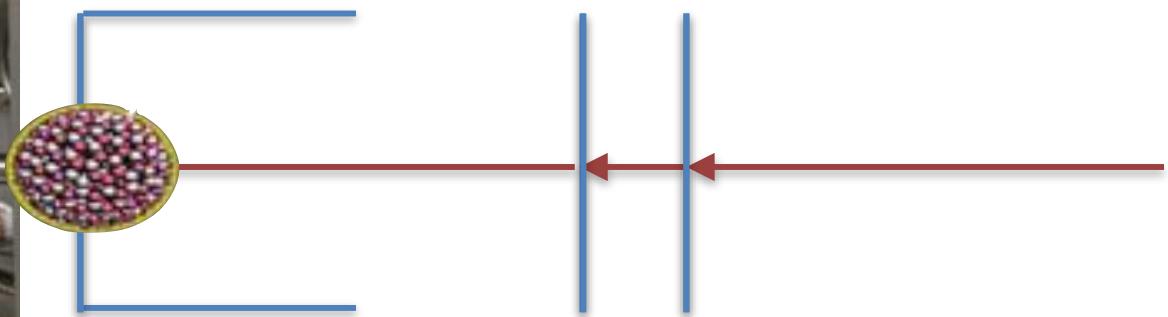
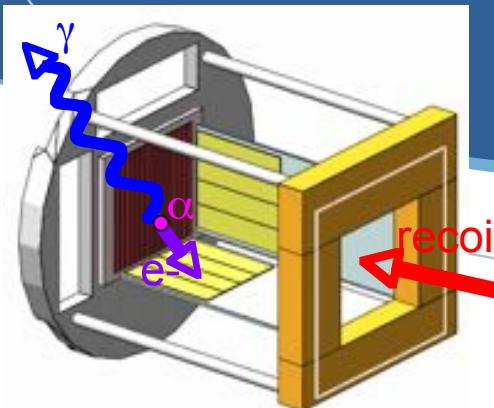
Cold fusion $^{208}\text{Pb}/^{209}\text{Bi}$



278113 = 278Nh



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

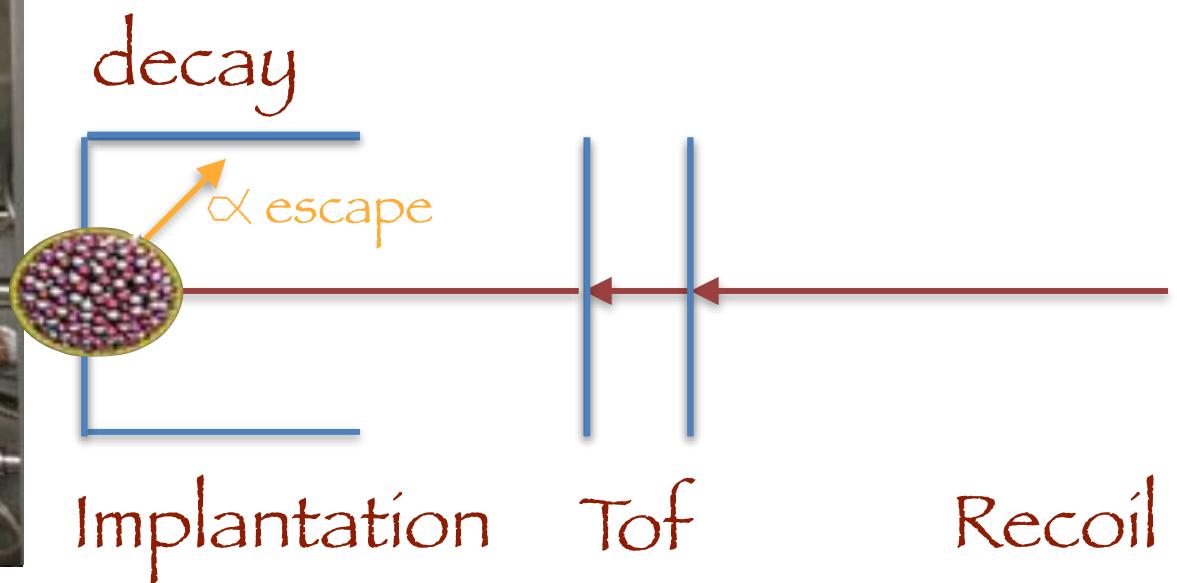
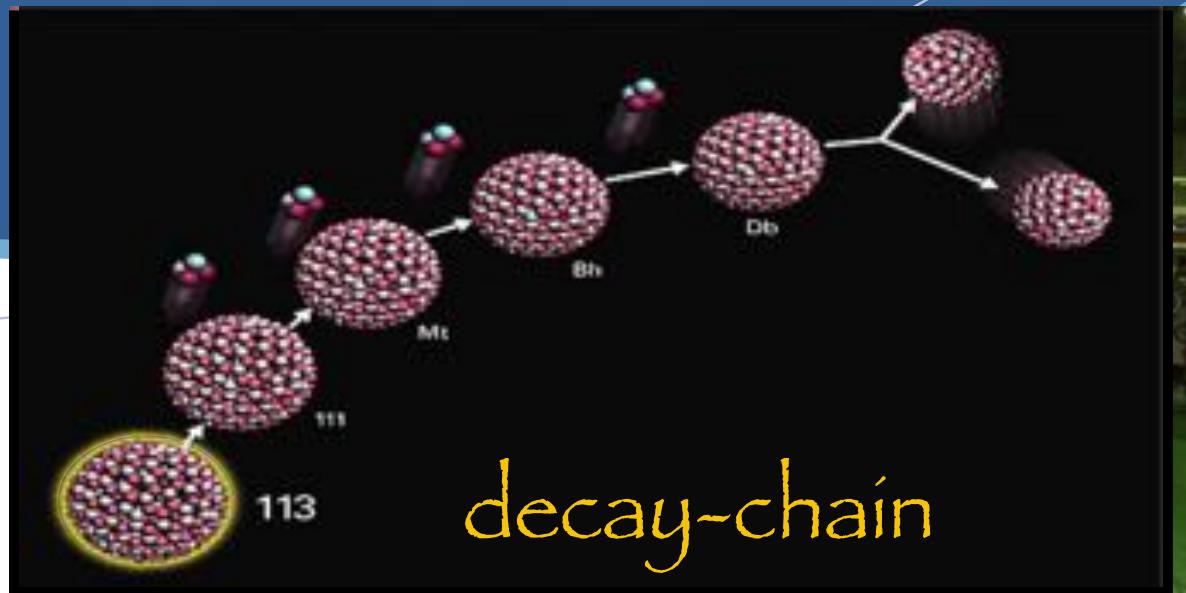
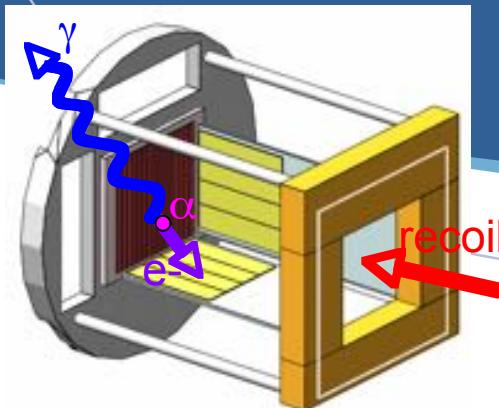


Implantation

Tof

Recoil

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



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



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

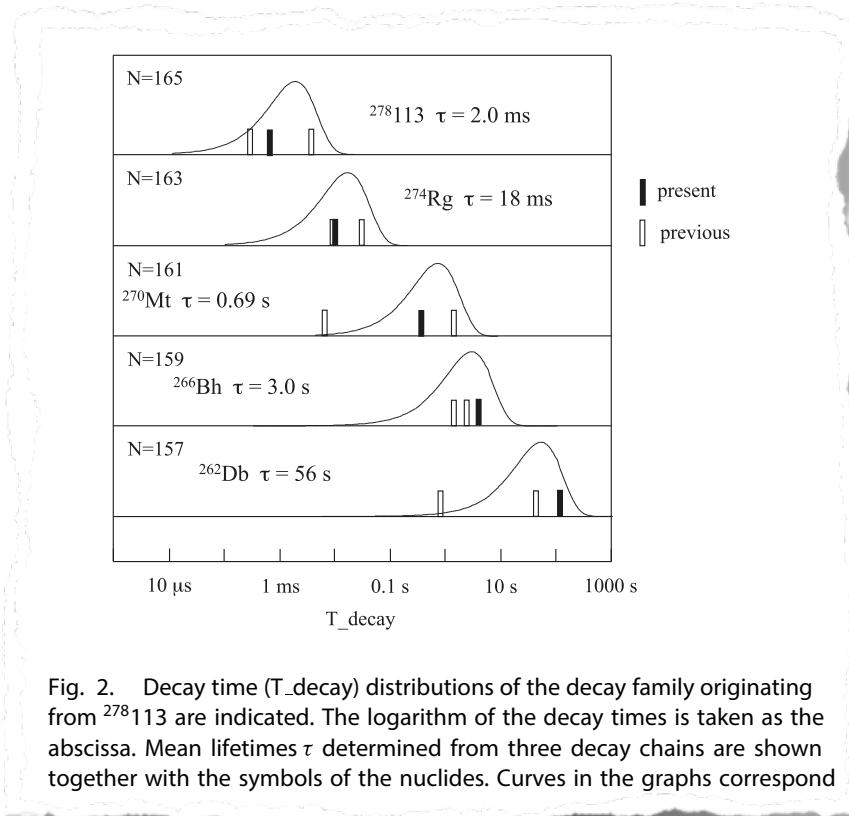


Fig. 2. Decay time (T_{decay}) distributions of the decay family originating from ^{278}Nh are indicated. The logarithm of the decay times is taken as the abscissa. Mean lifetimes τ determined from three decay chains are shown together with the symbols of the nuclides. Curves in the graphs correspond

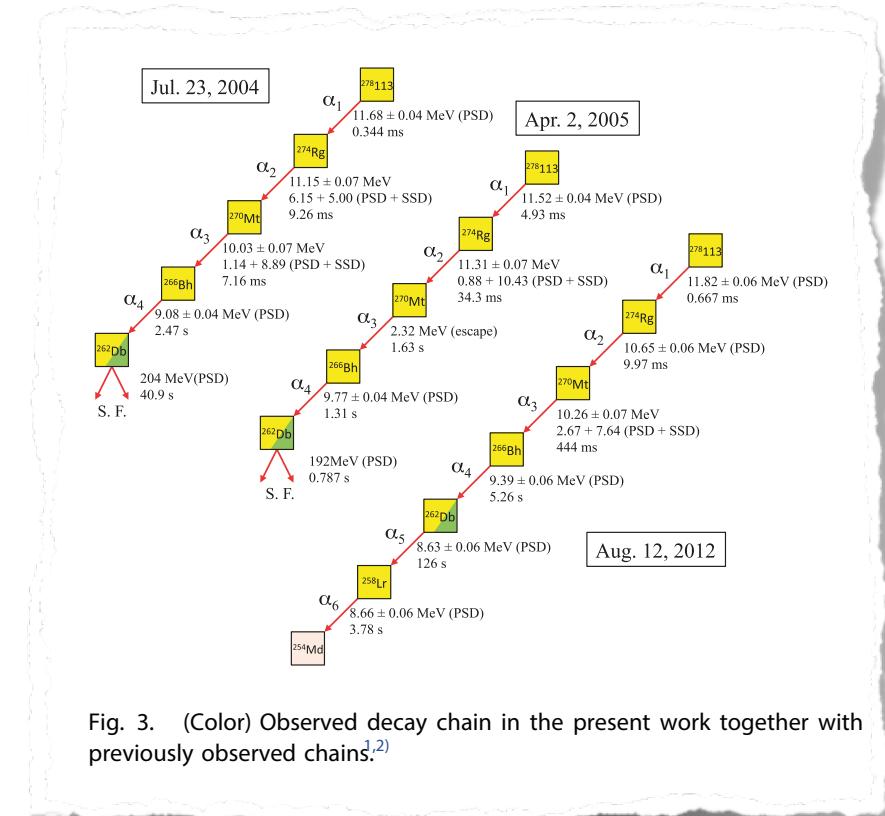


Fig. 3. (Color) Observed decay chain in the present work together with previously observed chains.^[1,2]

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

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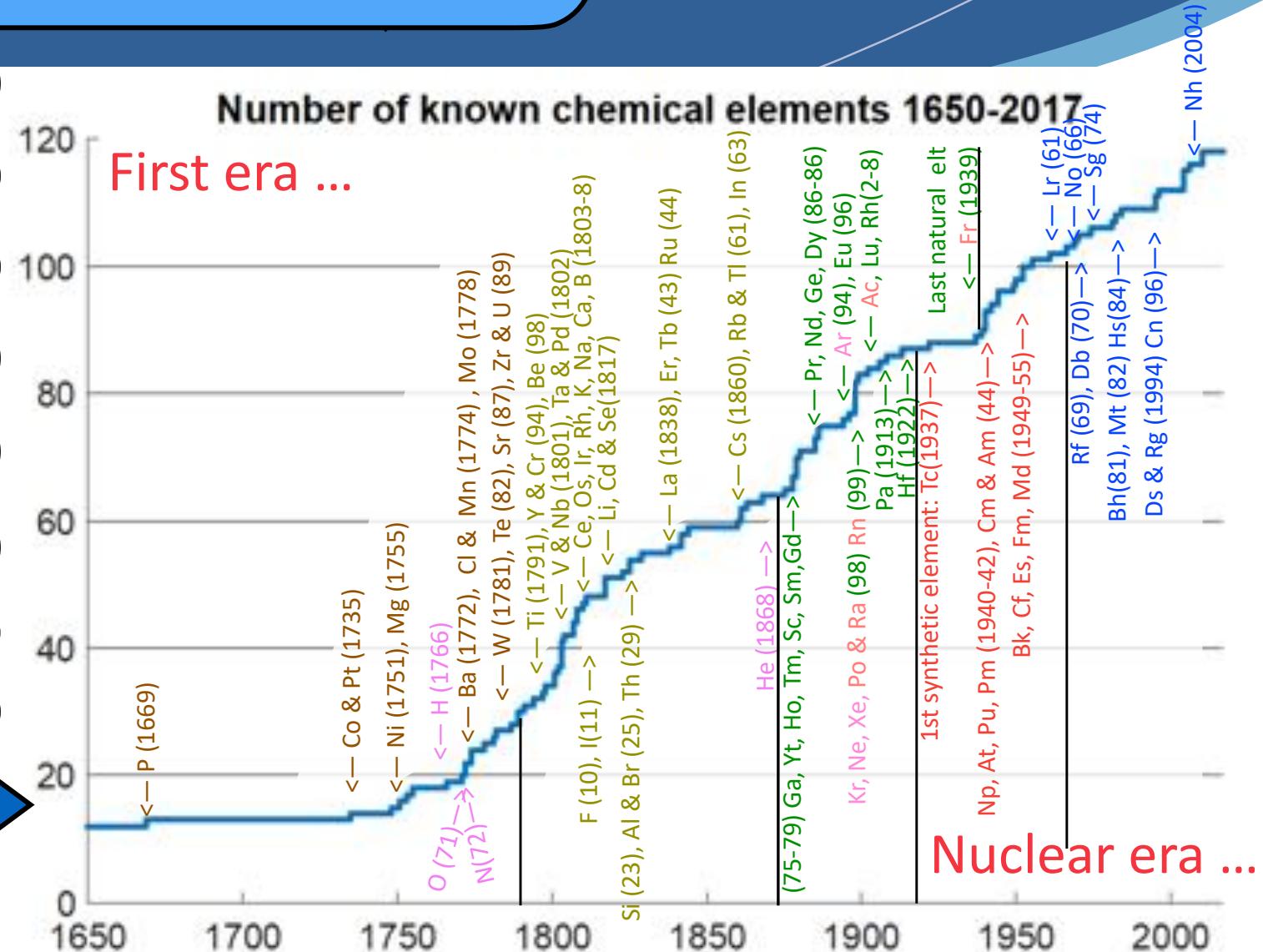
1934 ... Artificial radioisotope
 ${}^4\text{He} + {}^{27}\text{Al} \rightarrow {}^{30}\text{P} (+n)$ (Joliot)

1937 ... 1st synthetic element:
Tc (cyclotron)

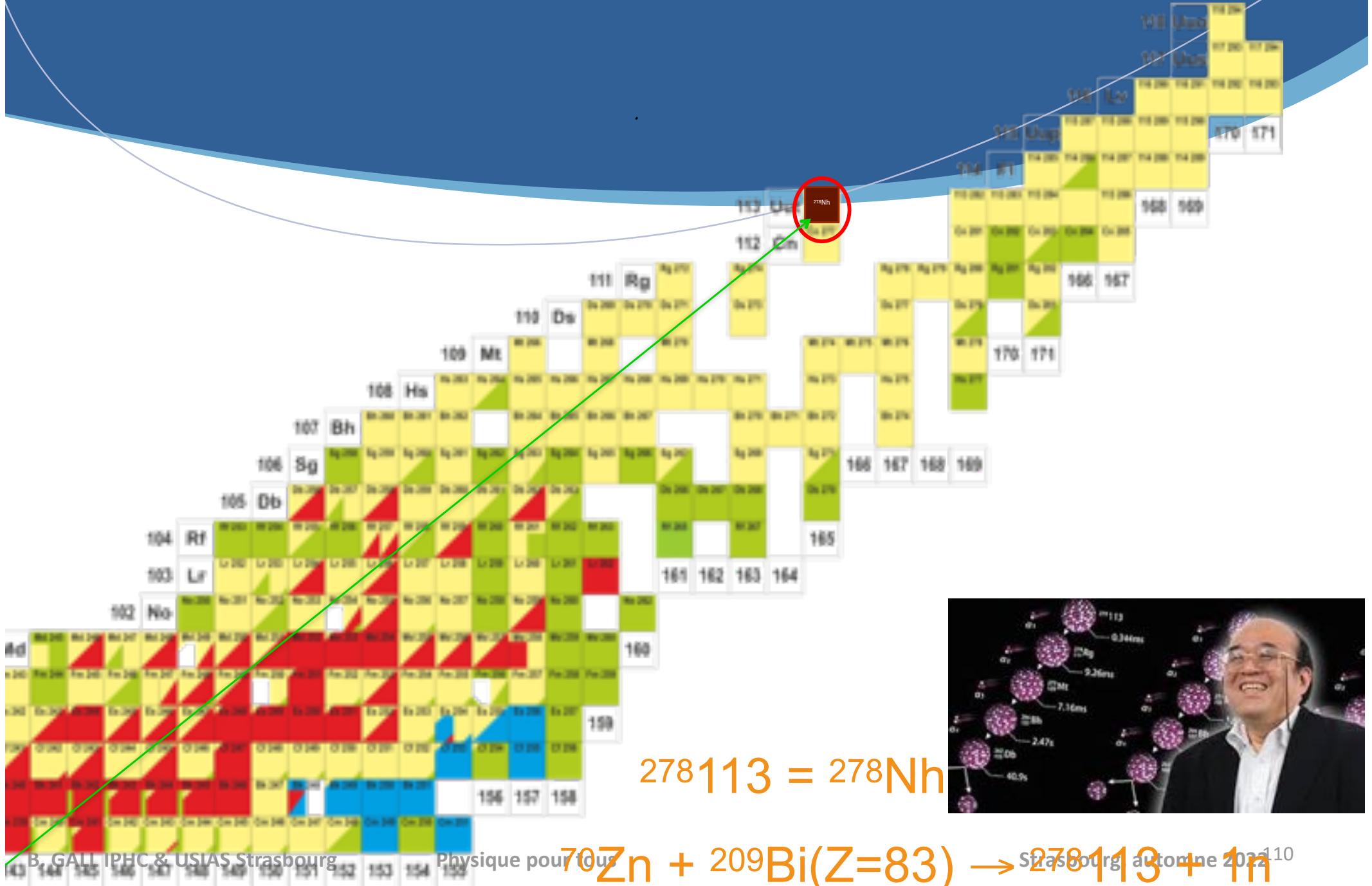
1939 ... last natural element Fr

from 1969: quest of SHE ($Z \geq 104$)

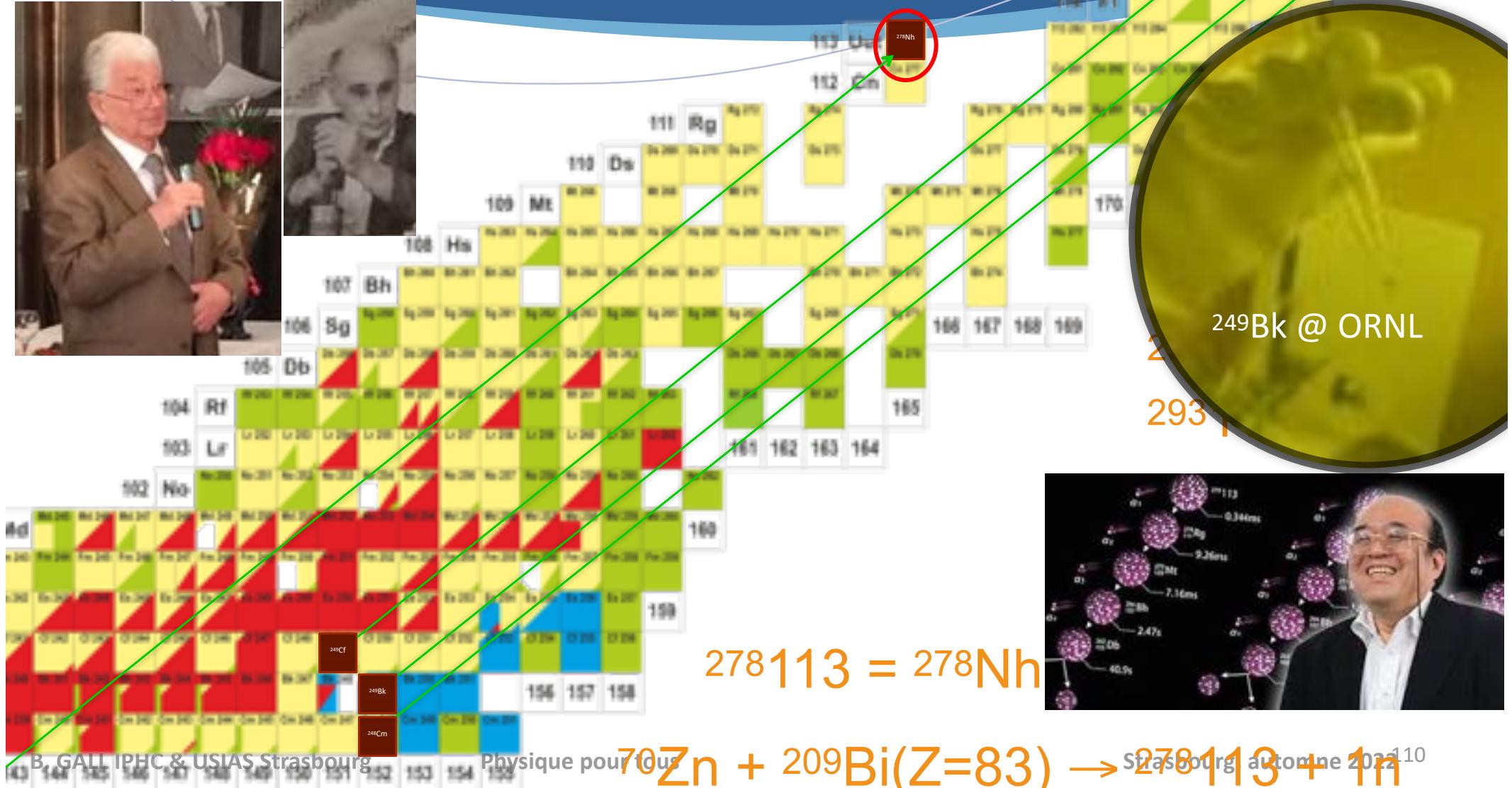
Cold fusion (beam + ${}^{208}\text{Pb}$)



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



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



Known elements classification

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Cold fusion (beam + ${}^{208}\text{Pb}$)

Hot fusion (${}^{48}\text{Ca} + \text{target}$)

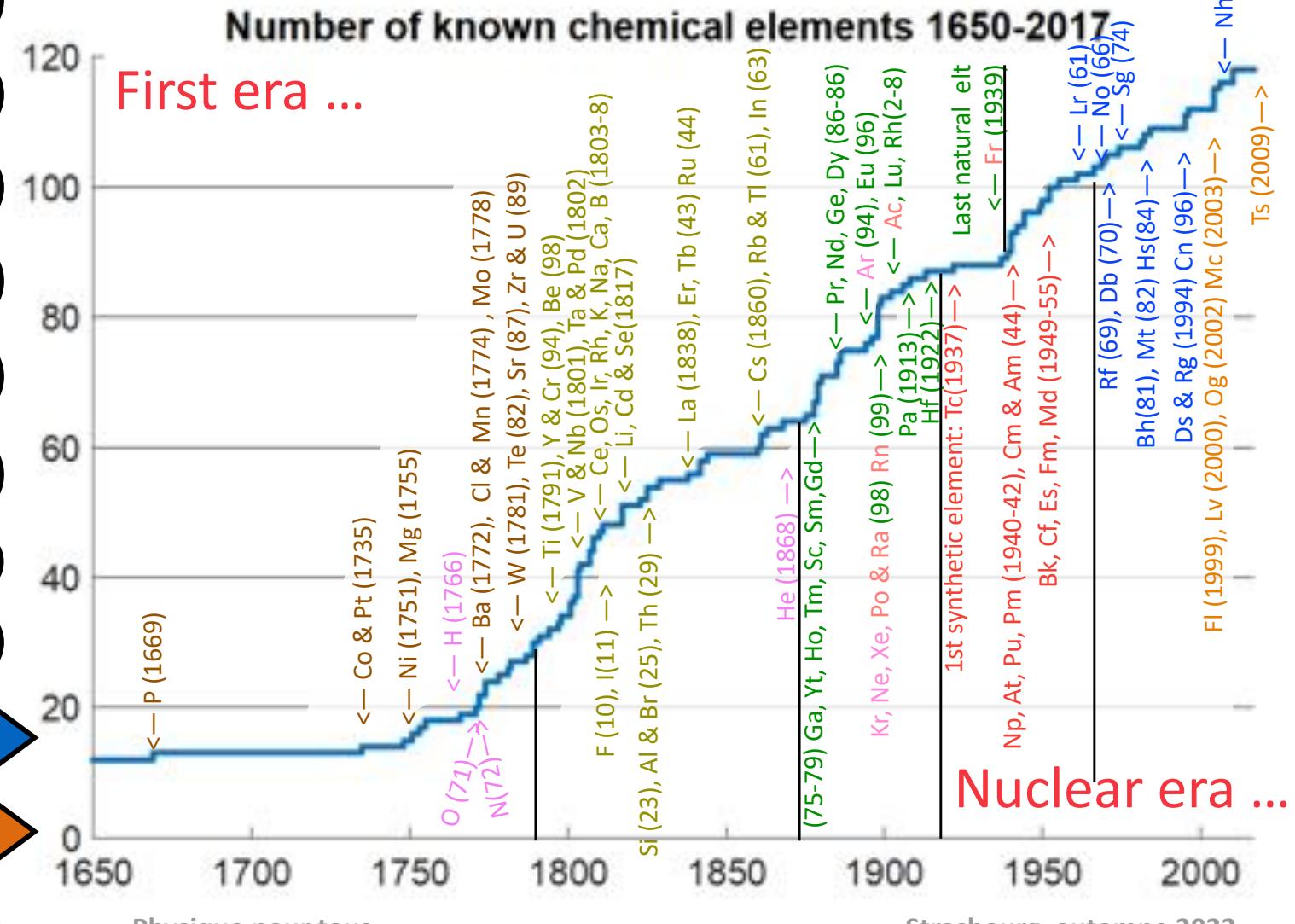
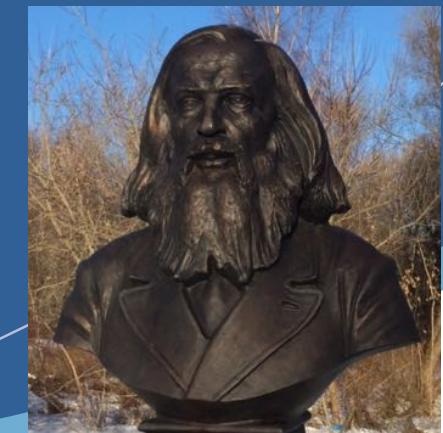
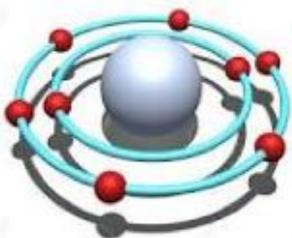


Tableau de Mendeleïev et synthèse des éléments superlourds



1	1 H hydrogen 1.008 [1.0078, 1.0082]	2	2 He helium 4.0026
3 Li lithium 6.94 [6.938, 6.997]	4 Be beryllium 9.0122		
11 Na sodium 22.990 [24.304, 24.307]	12 Mg magnesium 24.305 [24.304, 24.307]		
19 K potassium 39.098 40.078(4)	20 Ca calcium 40.078(4)		
37 Rb rubidium 85.468 87.62	38 Sr strontium 87.62		
55 Cs caesium 132.91 137.33	56 Ba barium 137.33	57-70 lanthanoids	71 Lu lutetium 174.97 178.49(2)
87 Fr francium 89-102 actinoids	88 Ra radium 103 Lr lawrencium 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		22 Ti titanium 47.867 50.942 51.996 54.938 55.845(2) 58.933 58.693 63.546(3) 65.38(2) 69.723 72.630(8) 74.922 78.971(8) 121.76 127.60(3) 126.90 131.29
	23 V vanadium 50.942 51.996 54.938 55.845(2) 58.933 58.693 63.546(3) 65.38(2) 69.723 72.630(8) 74.922 78.971(8) 121.76 127.60(3) 126.90 131.29	3 Sc scandium 44.956 47.867 50.942 51.996 54.938 55.845(2) 58.933 58.693 63.546(3) 65.38(2) 69.723 72.630(8) 74.922 78.971(8) 121.76 127.60(3) 126.90 131.29	21 Cr chromium 24 Mn manganese 25 Fe iron 26 Co cobalt 27 Ni nickel 28 Cu copper 29 Zn zinc 30 Ga gallium 31 Ge germanium 32 As arsenic 33 Se selenium 34 Br bromine 35 Kr krypton 36 Xe xenon
	40 Zr zirconium 88.906 91.224(2) 92.906 95.95 101.07(2) 102.91 106.42 107.87 112.41 114.82 118.71 121.76 127.60(3) 126.90 131.29	41 Nb niobium 92.906 95.95 101.07(2) 102.91 106.42 107.87 112.41 114.82 118.71 121.76 127.60(3) 126.90 131.29	42 Mo molybdenum 95.95 101.07(2) 102.91 106.42 107.87 112.41 114.82 118.71 121.76 127.60(3) 126.90 131.29
	43 Tc technetium 88.906 91.224(2) 92.906 95.95 101.07(2) 102.91 106.42 107.87 112.41 114.82 118.71 121.76 127.60(3) 126.90 131.29	44 Ru ruthenium 101.07(2) 102.91 106.42 107.87 112.41 114.82 118.71 121.76 127.60(3) 126.90 131.29	45 Rh rhodium 102.91 106.42 107.87 112.41 114.82 118.71 121.76 127.60(3) 126.90 131.29
	46 Pd palladium 106.42 107.87 112.41 114.82 118.71 121.76 127.60(3) 126.90 131.29	47 Ag silver 106.42 107.87 112.41 114.82 118.71 121.76 127.60(3) 126.90 131.29	48 Cd cadmium 107.87 112.41 114.82 118.71 121.76 127.60(3) 126.90 131.29
	49 In indium 112.41 114.82 118.71 121.76 127.60(3) 126.90 131.29	50 Sn tin 114.82 118.71 121.76 127.60(3) 126.90 131.29	51 Sb antimony 118.71 121.76 127.60(3) 126.90 131.29
	52 Te tellurium 118.71 121.76 127.60(3) 126.90 131.29	53 I iodine 121.76 127.60(3) 126.90 131.29	54 Xe xenon 126.90 131.29
	55 Cs caesium 132.91 137.33	56 Ba barium 137.33	57 Lu lutetium 174.97 178.49(2)
	58 Ce cerium 140.12 140.12	59 Pr praseodymium 140.91 140.91	60 Nd neodymium 144.24 144.24
	61 Pm promethium 150.36(2) 150.36(2)	62 Sm samarium 151.96 151.96	63 Eu europium 157.25(3) 157.25(3)
	64 Gd gadolinium 158.93 158.93	65 Tb terbium 162.50 162.50	66 Dy dysprosium 164.93 164.93
	67 Ho holmium 167.26 167.26	68 Er erbium 168.93 168.93	69 Tm thulium 173.05 173.05
	70 Yb ytterbium 173.05 173.05		
	89 Ac actinium 232.04 232.04	90 Th thorium 231.04 231.04	91 Pa protactinium 238.03 238.03
	92 U uranium 238.03 238.03	93 Np neptunium 238.03 238.03	94 Pu plutonium 244.03 244.03
	95 Am americium 243.03 243.03	96 Cm curium 247.03 247.03	97 Bk berkelium 249.03 249.03
	98 Cf californium 251.03 251.03	99 Es einsteinium 252.03 252.03	100 Fm fermium 257.03 257.03
	101 Md mendelevium 258.03 258.03	102 No nobelium 259.03 259.03	



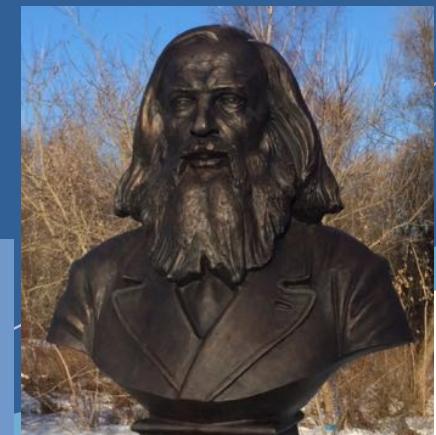
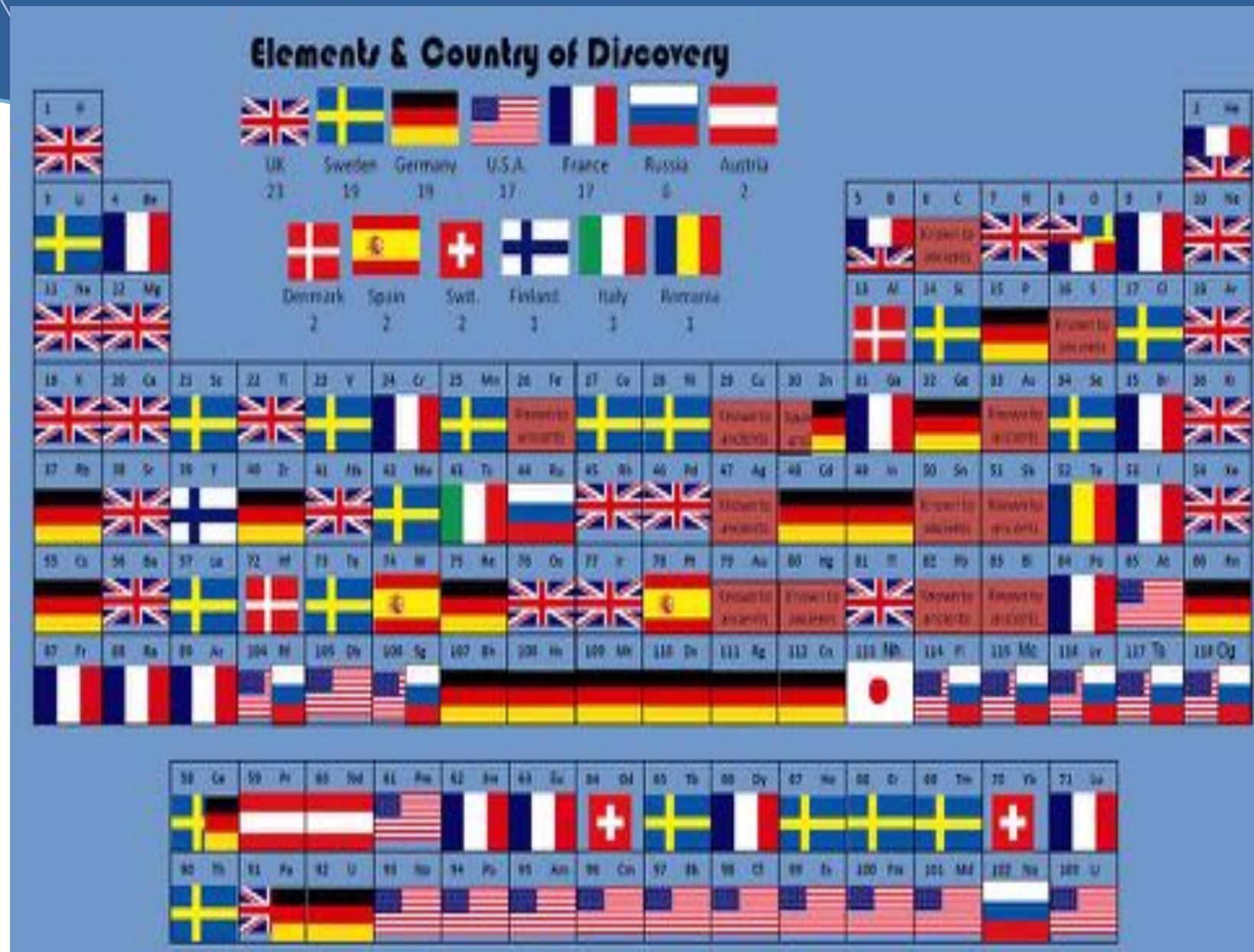
57 La lanthanum 138.91	58 Ce cerium 140.12	59 Pr praseodymium 140.91	60 Nd neodymium 144.24	61 Pm promethium 150.36(2)	62 Sm samarium 151.96	63 Eu europium 157.25(3)	64 Gd gadolinium 158.93	65 Tb terbium 162.50	66 Dy dysprosium 164.93	67 Ho holmium 167.26	68 Er erbium 168.93	69 Tm thulium 173.05	70 Yb ytterbium 173.05
89 Ac actinium 232.04 232.04	90 Th thorium 231.04 231.04	91 Pa protactinium 238.03 238.03	92 U uranium 238.03 238.03	93 Np neptunium 238.03 238.03	94 Pu plutonium 244.03 244.03	95 Am americium 243.03 243.03	96 Cm curium 247.03 247.03	97 Bk berkelium 249.03 249.03	98 Cf californium 251.03 251.03	99 Es einsteinium 252.03 252.03	100 Fm fermium 257.03 257.03	101 Md mendelevium 258.03 258.03	102 No nobelium 259.03 259.03

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

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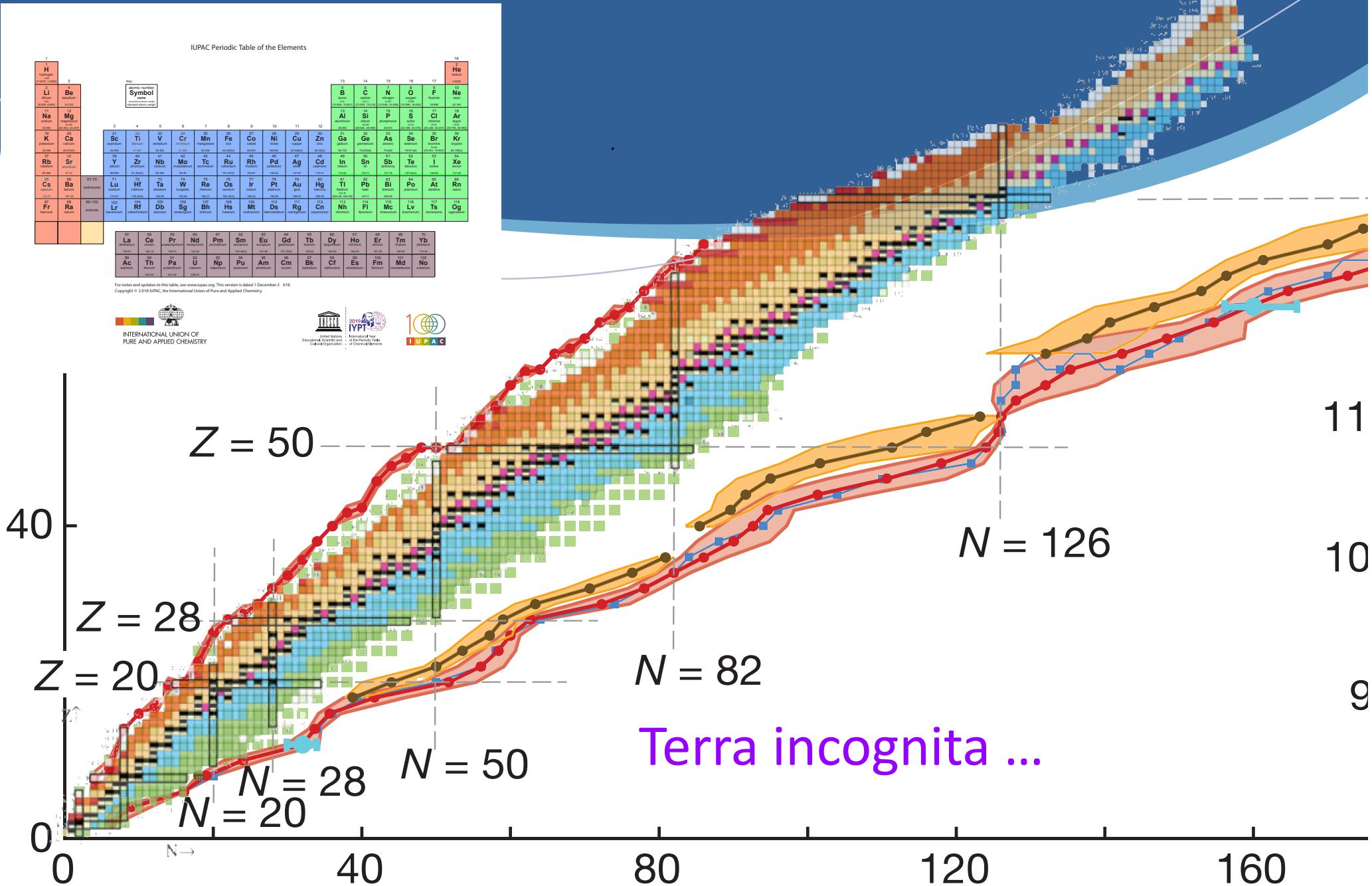
Periodic table of elements

Limits of existence ?



118
elements
identified

Our landscape ...

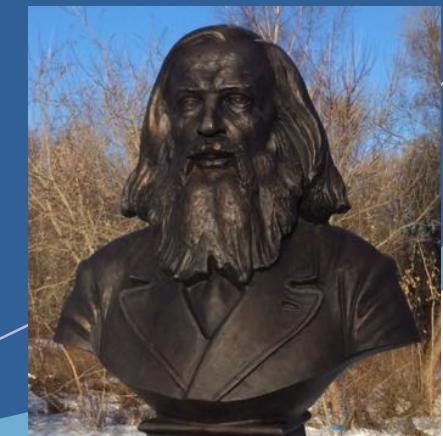


Periodic table of elements

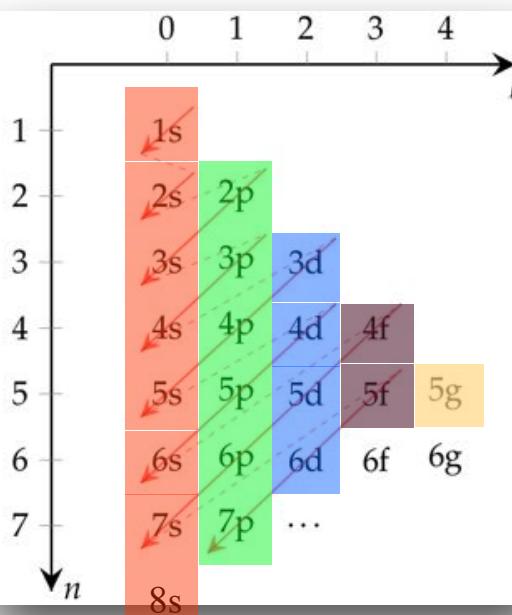
electron shells

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

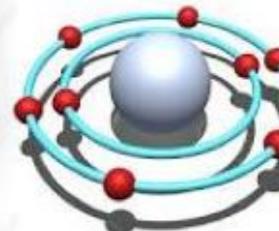
We celebrate in 2019
the 150 anniversary



+ Klechkovski filling rule



1	1 H hydrogen [1.008 1.0082]	2
3	Li lithium 6.94 [6.938, 6.997]	4 Be beryllium 9.0122
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87	Fr francium 119 uun	88 Ra radium 103 Lr lawrencium 120 ubn ... 121 uba

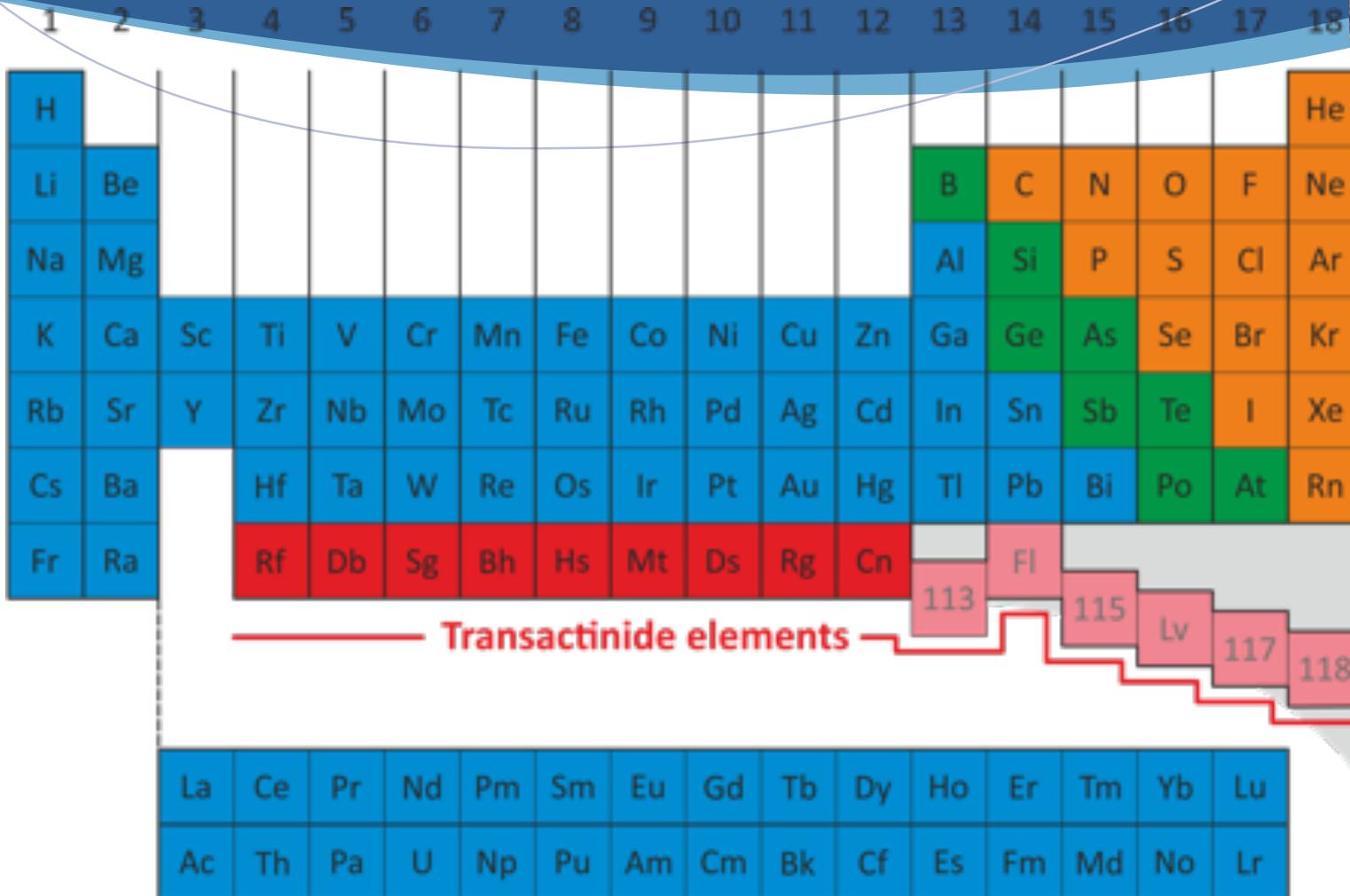
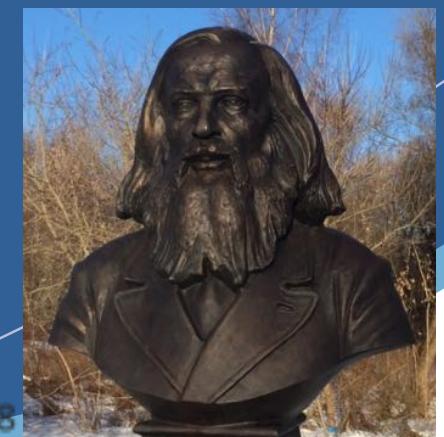


IUPAC Periodic Table of the Elements																			
13	14	15	16	17	18														
5 B boron 10.81 [10.806, 10.821]	6 C carbon 12.011 [12.009, 12.012]	7 N nitrogen 14.027 [14.006, 14.008]	8 O oxygen 15.999 [15.999, 16.000]	9 F fluorine 18.998 [18.998]	10 Ne neon 20.180 [20.180]														
13 Al aluminum 26.982 [26.982]	14 Si silicon 28.085 [28.084, 28.086]	15 P phosphorus 31.00 [31.00]	16 S sulfur 32.06 [32.059, 32.076]	17 Cl chlorine 35.455 [35.446, 35.457]	18 Ar argon 39.963 [39.963]														
31 Ga gallium 69.723 [69.723]	32 Ge germanium 72.630(8) [72.630(8)]	33 As arsenic 74.922 [74.922]	34 Se selenium 78.971(8) [78.971(8)]	35 Br bromine 79.904 [79.904]	36 Kr krypton 83.798(2) [83.798(2)]														
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Periodic table of elements

Limits of existence ?

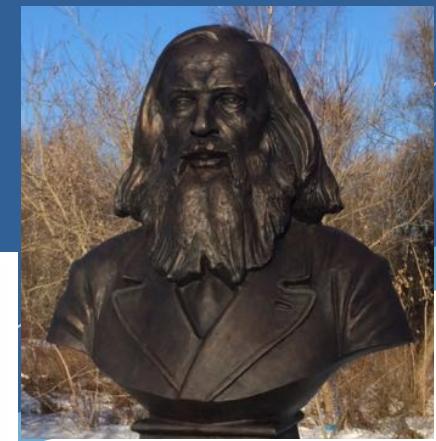
Relativistic effects ???



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Periodic table of elements

Limits of existence ?



Period 1

Periodic Table 1-172

18 Orbitals

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	2 He	1s
1 H	2	3 Li	4 Be	5	6	7	8	9	10	11	12	13	14	15	16	17	2 He	1s
11 Na	12 Mg	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr	2s2p
19 K	20 Ca	39 Y	40 Zr	41 Nb	42 Mo	43 Te	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe	3s3p
37 Rb	38 Sr	57-71 Hf	72 Ta	73 W	74 Re	75 Os	76 Ir	77 Pt	78 Au	79 Hg	80 Tl	81 Pb	82 Bi	83 Po	84 At	85 Rn	4s3d4p	
55 Cs	56 Ba	89-103 Rf	104 Db	105 Sg	106 Bh	107 Hs	108 Mt	109 Ds	110 Rg	111 Cn	113	114	115	116	117	118	5s4d5p	
119	120	121-	156	157	158	159	160	161	162	163	164	139	140	169	170	171	172	6s5d6p
165	166										167	168					7s6d7p	
																	8s7d8p	
																	9s9p	
																	4f	
																	5f	
																	6f	
																	5g	

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.
 ${}^4\text{He} + {}^{197}\text{Au} \rightarrow$ diffusion

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

1937 ... 1st synthetic element:
Tc (cyclotron)

1939 ... last natural element Fr

from 1969: quest of SHE ($Z \geq 104$)

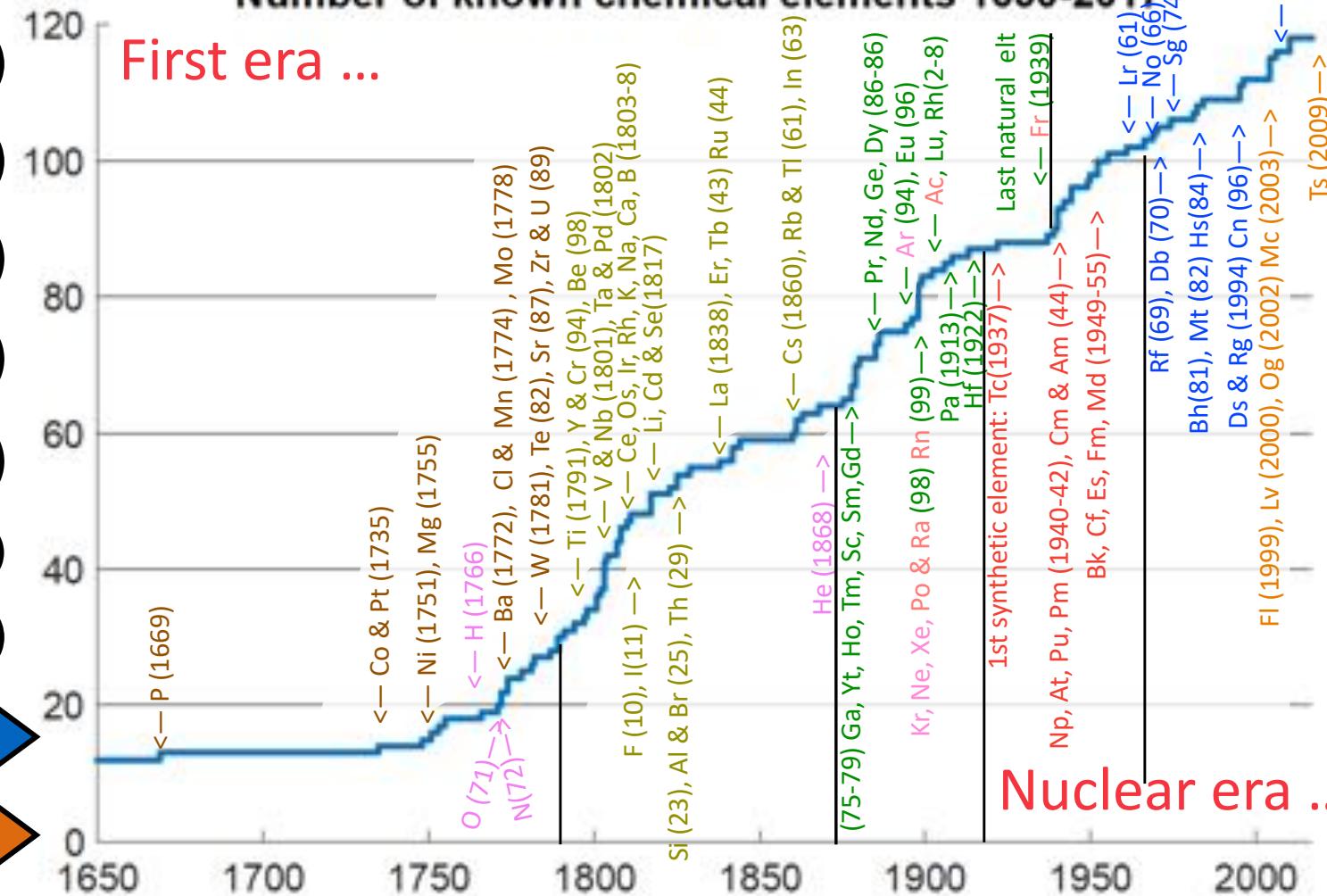
Cold fusion (beam + ${}^{208}\text{Pb}$)

Hot fusion (${}^{48}\text{Ca} + \text{target}$)

Number of known chemical elements 1650-2017

First era ...

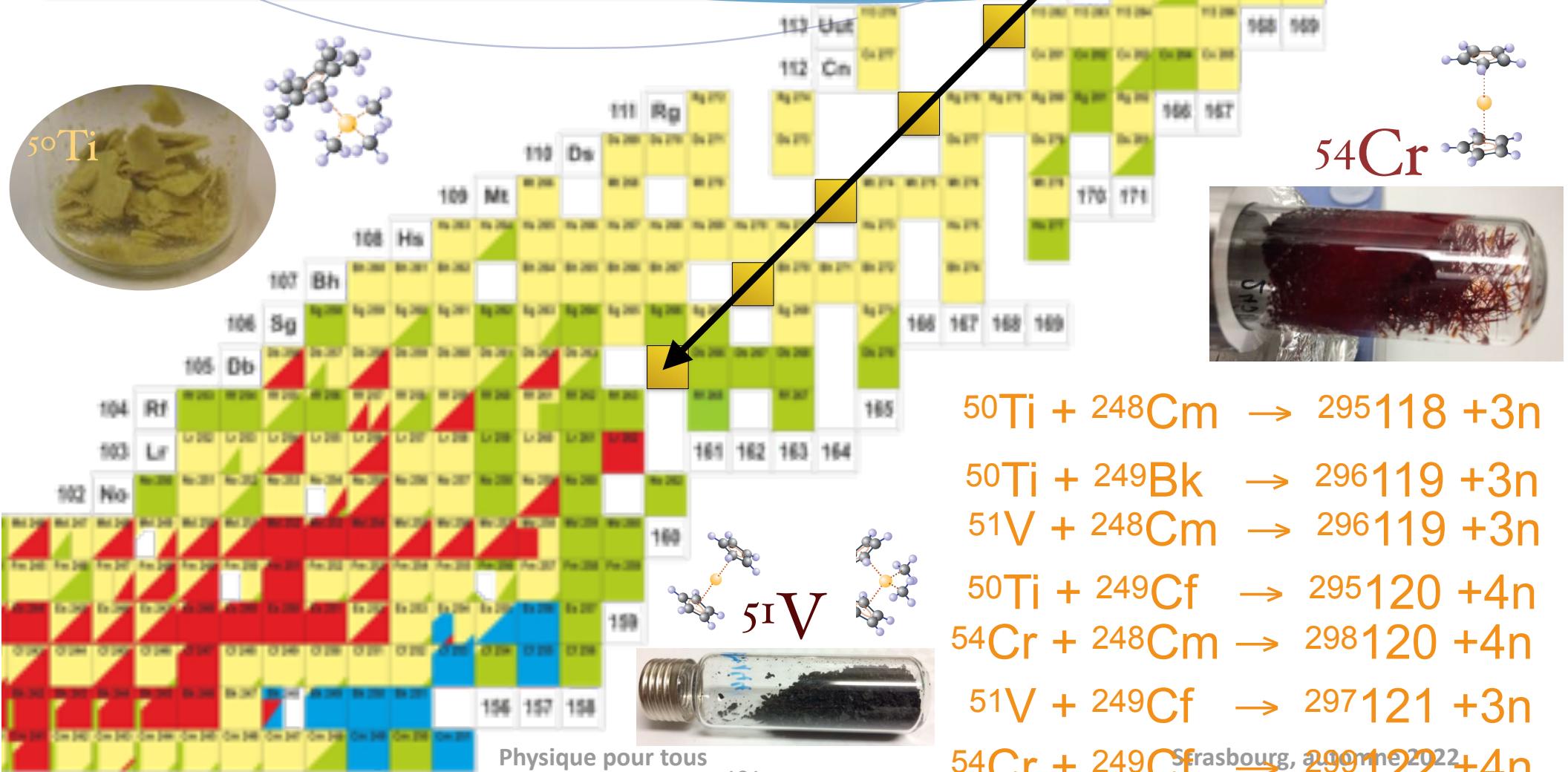
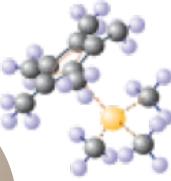
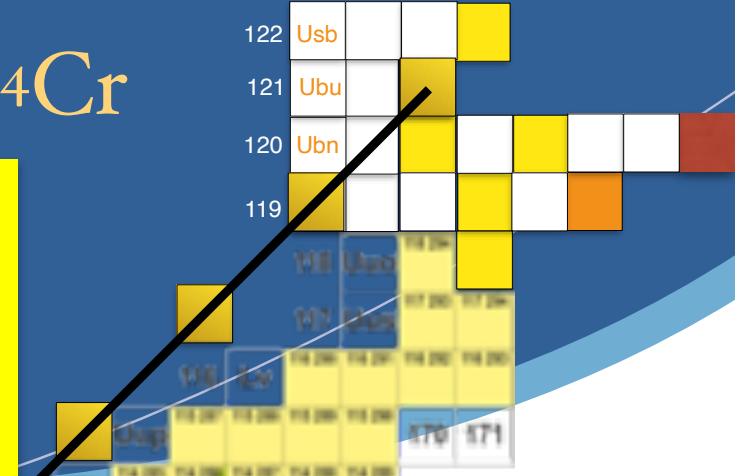
Nuclear era ...



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



Physique pour tous



NEW MACHINES for SHE

2020 ...

Beams ... :
SHE Factory



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

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

SHE-Fact. commissionned
DGFRS2 commissionned
synth ^{50}Ti ...
+ runs SHELS

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

also LINAC + S3 @ GANIL



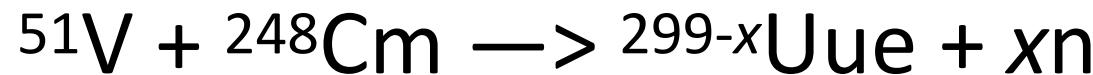
- > New machine (LINAC)
- > New instrument (S3)

+ NEWGAIN !!!

E119 restarted 2-4 m beam/Y

+ EURO-LABS !!!

E119 campaign: attempt to produce ^{295}Uue



Beam accelerated by RRC cyclotron

Optimal energy determined by barrier distribution run

Target: pure ^{248}Cm ~500 $\mu\text{g}/\text{cm}^2$

GARIS II gas filled separator (moved to RRC lines)

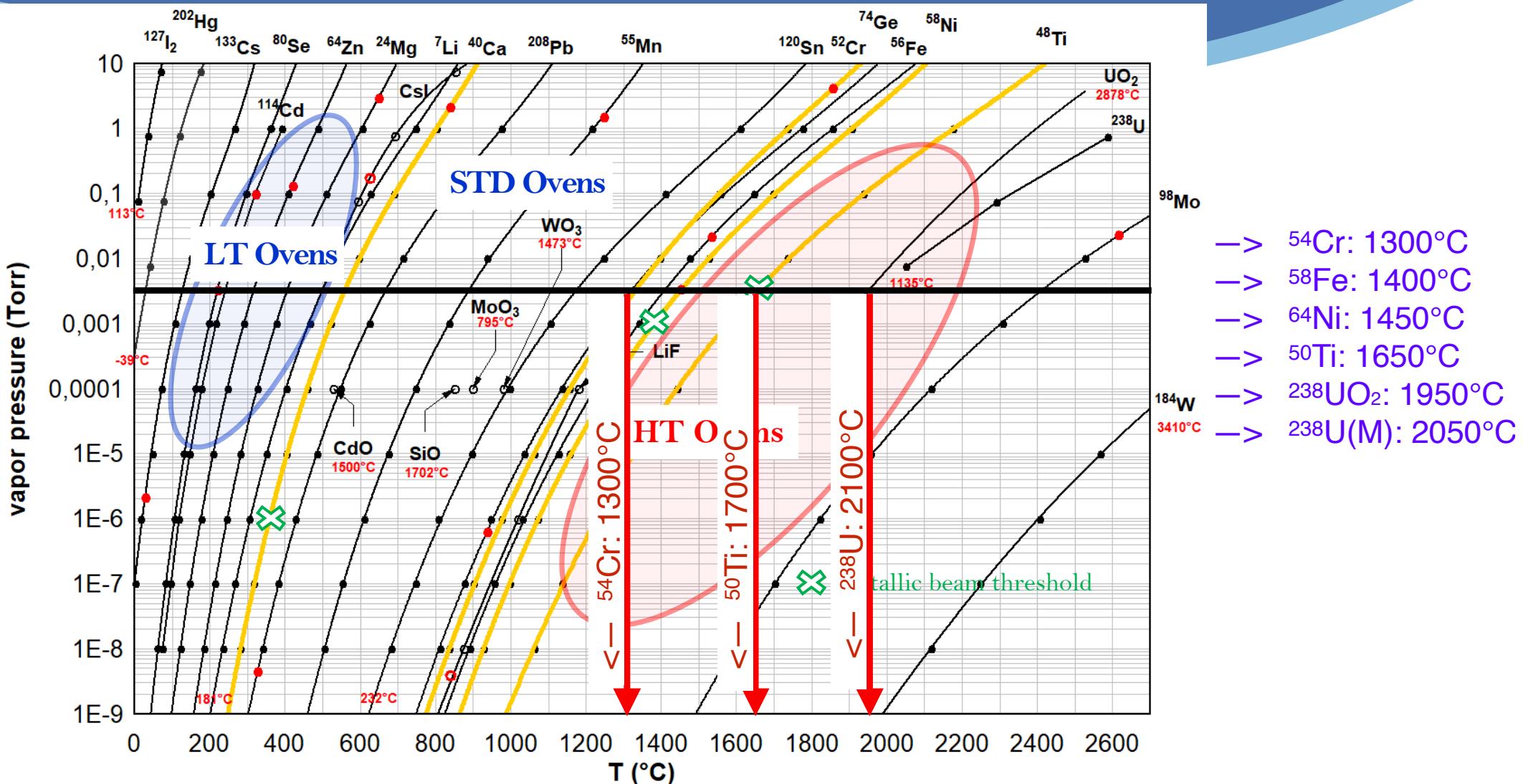
Already several campaigns since 2017

results unpublished



HIGH INTENSITY METALLIC BEAMS

→ ^{50}Ti & ^{238}U need HT ovens

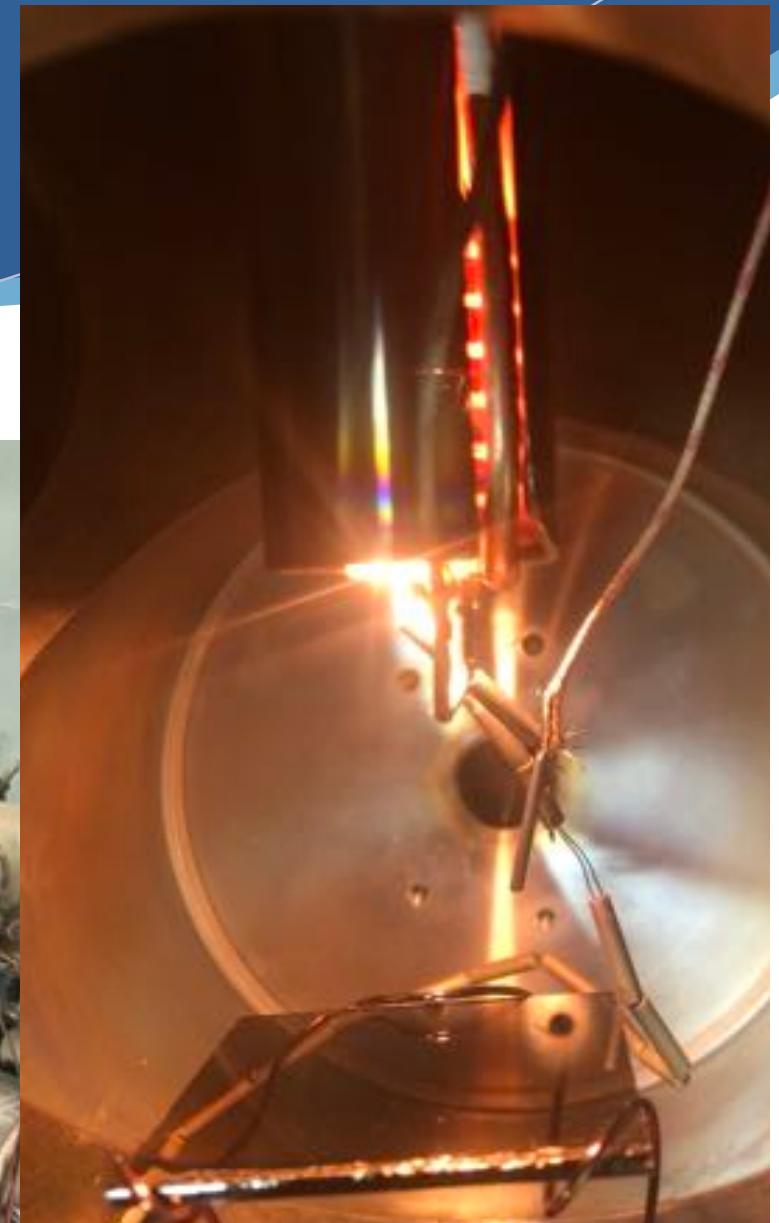


HIGH INTENSITY METALLIC BEAMS

→ Tests @ FLNR

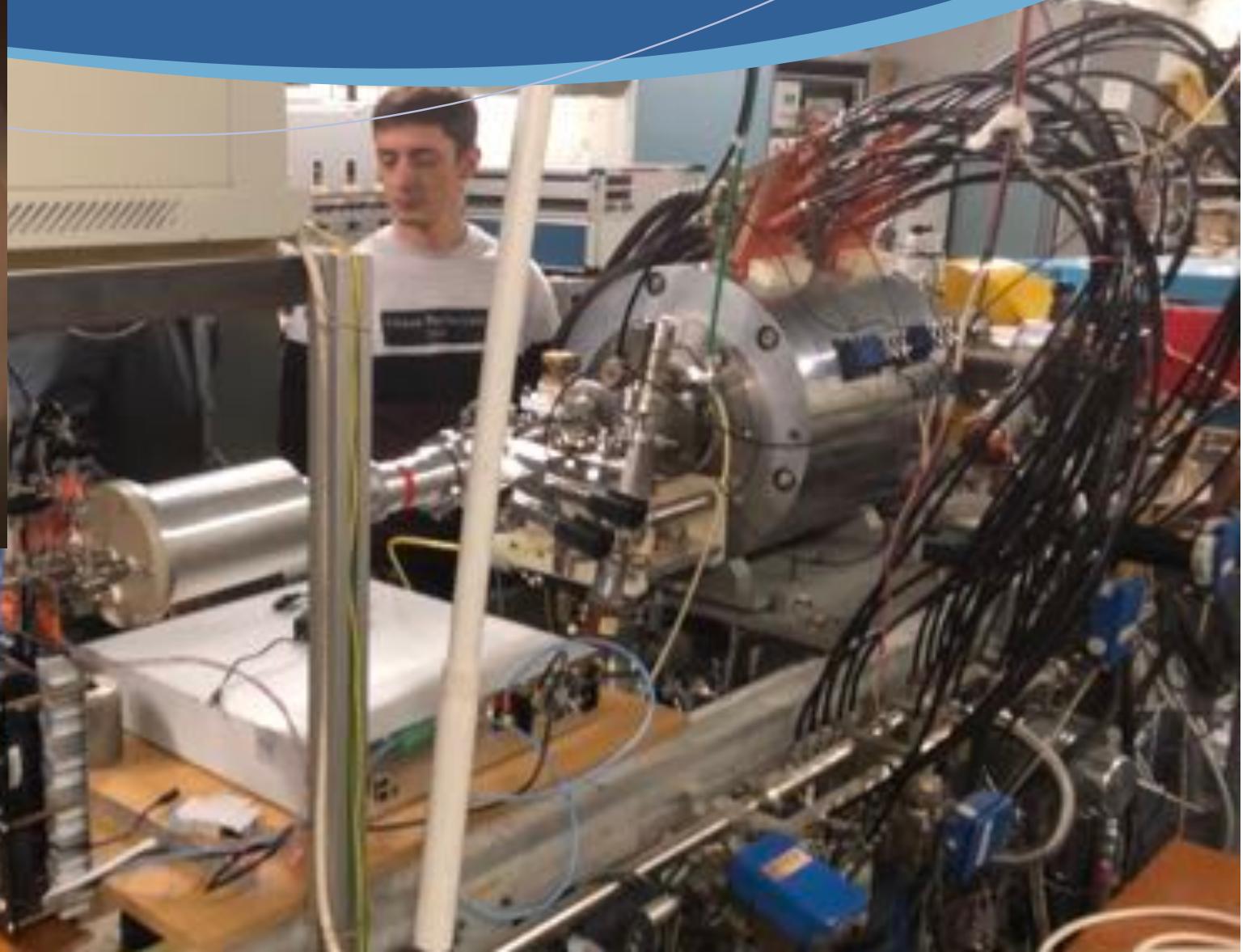
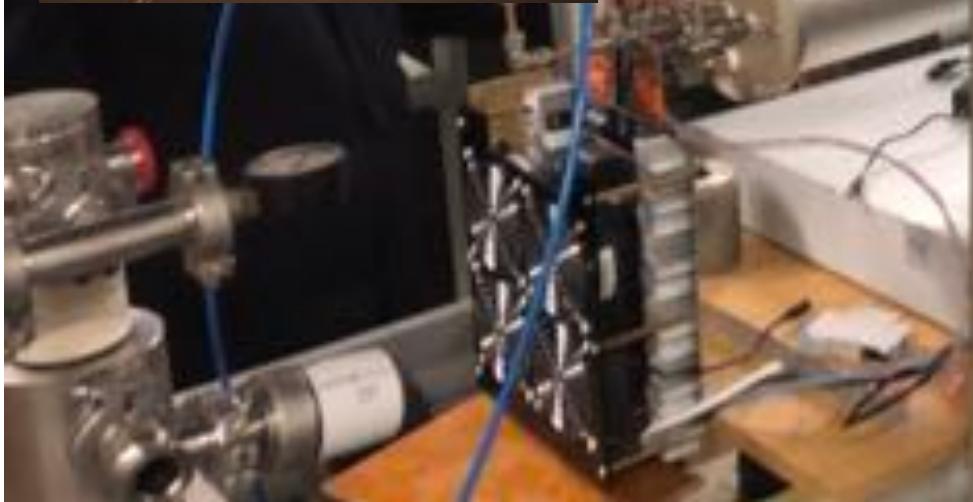
sept 2021

First Chromium & titanium depositions



PROJECT FROZEN @ DUBNA !

Tests were foreseen but ...



SUMMARY

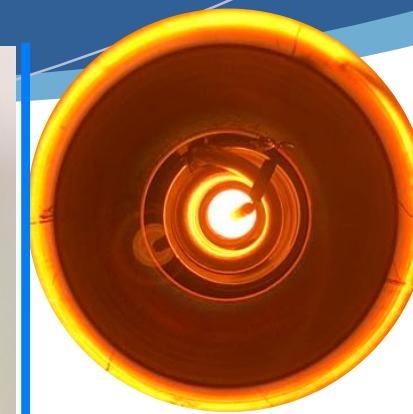


Enabled MIVOC from

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



2-3 μA reached



RGD HTi oven

- $\varnothing 20$ oven tested
- 2500 °C reached
- new $\varnothing 20$ oven

good way to 10 μA

