JQI | PHYSICS FRONTIER CENTER

JOINT QUANTUM INSTITUTE

80 years of Francium

USTC, Hefei China
July 2019
Luis A. Orozco
www.jqi.umd.edu

UNIVERSITY OF MARYLAND 1856

NIST

The slides are available at:

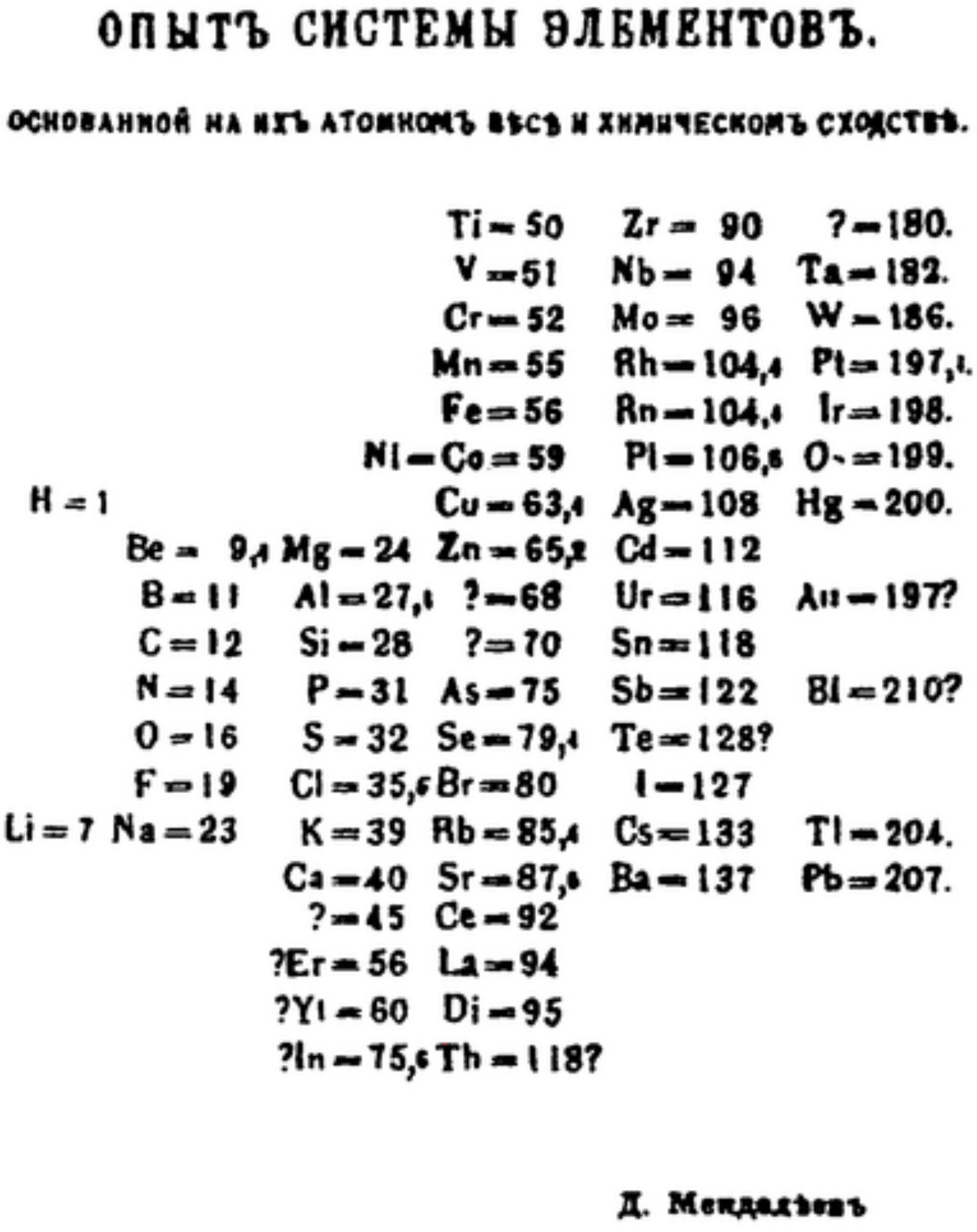
http://www.physics.umd.edu/rgroups/amo/orozco/results/2019/Results19.htm

UNESCO

United Nations
Educational, Scientific and
Cultural Organization

2019
IYPT

International Year
of the Periodic Table
of Chemical Elements



ОПЫТЪ СИСТЕМЫ ЭЛЕМЕНТОВЪ.

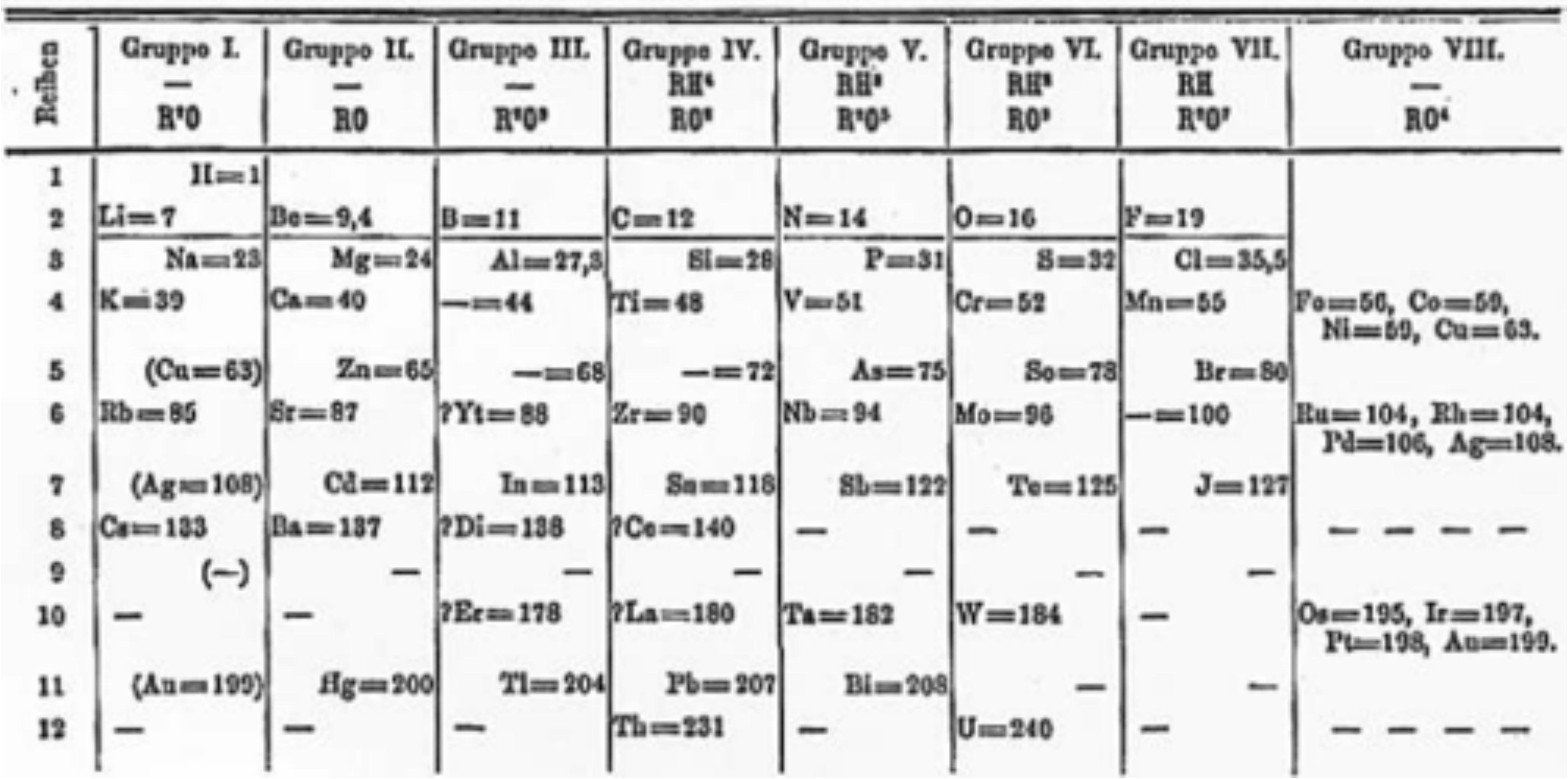
ОСНОВАННОЙ НА ИХЪ АТОМНОМЪ ВѢСѢ И ХИМИЧЕСКОМЪ СХОДСТВѢ.

			Ti=50	Zr=90	?=180.
			V=51	Nb=94	Ta=182.
			Cr=52	Mo=96	W=186.
			Mn=55	Rh=104,4	Pt=197,1.
			Fe=56	Rn=104,4	Ir=198.
			Ni=Co=59	Pl=106,6	Os=199.
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?		

Д. Менделѣевъ

Tentative System of Elements, Mendeleev 1869

The periodic table of elements



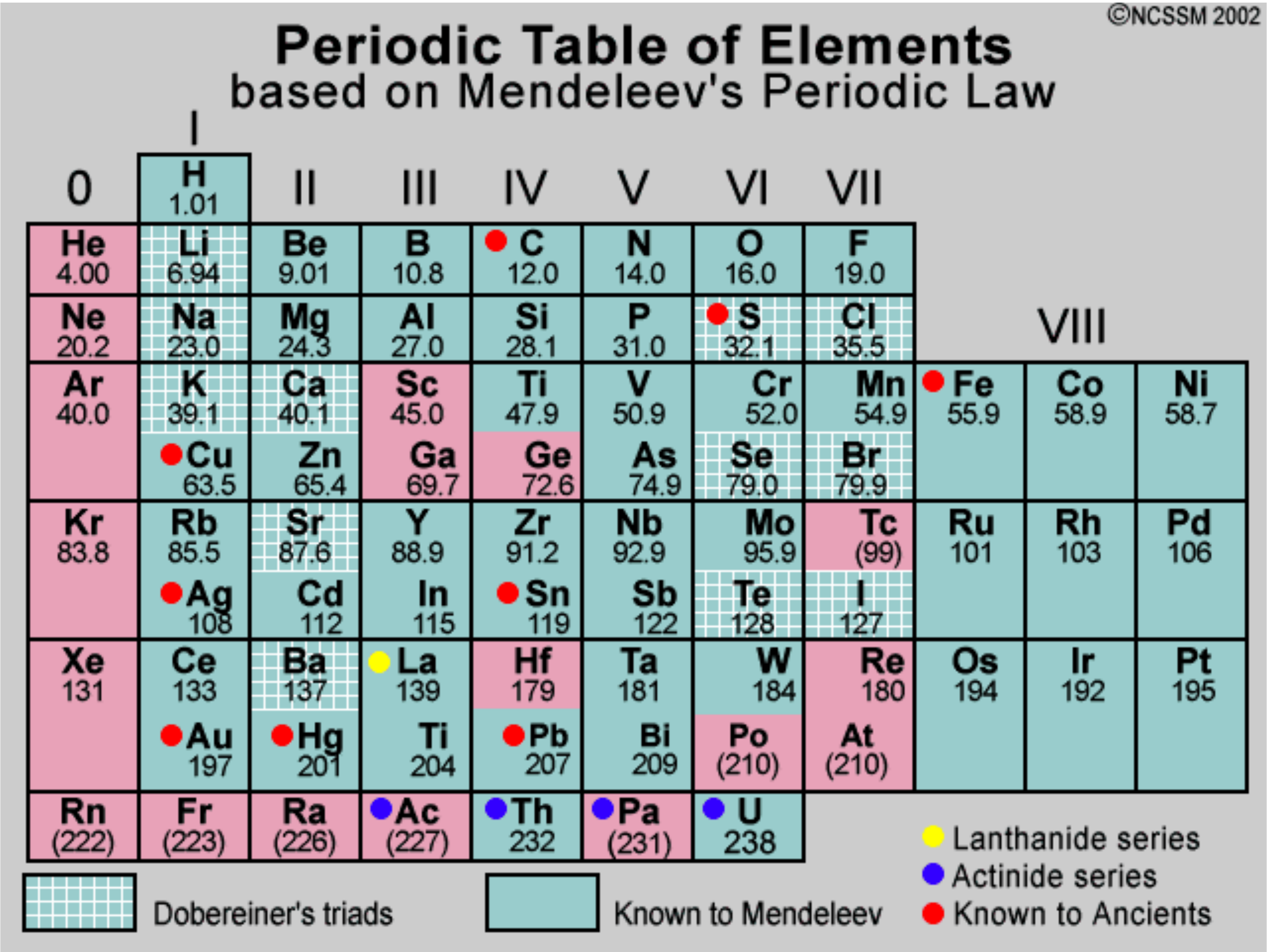
Reihen	Gruppe I. — R^2O	Gruppe II. — RO	Gruppe III. — R^2O^3	Gruppe IV. RH^4 RO^2	Gruppe V. RH^3 R^2O^5	Gruppe VI. RH^2 RO^3	Gruppe VII. RH R^2O^7	Gruppe VIII. — RO^4
1	H=1							
2	Li=7	Be=9,4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27,3	Si=28	P=31	S=32	Cl=35,5	
4	K=39	Ca=40	—=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Co=59, Ni=59, Cu=63.
5	(Cu=63)	Zn=65	—=68	—=72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	—=100	Ru=104, Rh=104, Pd=106, Ag=108.
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140	—	—	—	— — — —
9	(—)	—	—	—	—	—	—	
10	—	—	?Er=178	?La=180	Ta=182	W=184	—	Os=195, Ir=197, Pt=198, Au=199.
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	—	—	
12	—	—	—	Th=231	—	U=240	—	— — — —

Mendeleev 1871

He moved the elements around to make their chemical properties similar. He positioned Iodine correctly.

The dashed lines indicated a missing element that he named eka- (eka-silicon, *germanium*; eka-aluminium, *gallium*, eka-boron, *scandium*) and he predicted some properties for those elements missing but that should in the table.

People started looking for eka-caesium



Periodic Table of Elements

based on Mendeleev's Periodic Law

0	I	II	III	IV	V	VI	VII	VIII		
	H 1.01									
He 4.00	Li 6.94	Be 9.01	B 10.8	🔴 C 12.0	N 14.0	O 16.0	F 19.0			
Ne 20.2	Na 23.0	Mg 24.3	Al 27.0	Si 28.1	P 31.0	🔴 S 32.1	Cl 35.5			
Ar 40.0	K 39.1	Ca 40.1	Sc 45.0	Ti 47.9	V 50.9	Cr 52.0	Mn 54.9	🔴 Fe 55.9	Co 58.9	Ni 58.7
	🔴 Cu 63.5	Zn 65.4	Ga 69.7	Ge 72.6	As 74.9	Se 79.0	Br 79.9			
Kr 83.8	Rb 85.5	Sr 87.6	Y 88.9	Zr 91.2	Nb 92.9	Mo 95.9	Tc (99)	Ru 101	Rh 103	Pd 106
	🔴 Ag 108	Cd 112	In 115	🔴 Sn 119	Sb 122	Te 128	I 127			
Xe 131	Ce 133	Ba 137	🟡 La 139	Hf 179	Ta 181	W 184	Re 180	Os 194	Ir 192	Pt 195
	🔴 Au 197	🔴 Hg 201	Ti 204	🔴 Pb 207	Bi 209	Po (210)	At (210)			
Rn (222)	Fr (223)	Ra (226)	🔵 Ac (227)	🔵 Th 232	🔵 Pa (231)	🔵 U 238				

▦ Dobereiner's triads

🟦 Known to Mendeleev

🟡 Lanthanide series

🔵 Actinide series

🔴 Known to Ancients

PERIODIC TABLE

Atomic Properties of the Elements

NIST National Institute of Standards and Technology
U.S. Department of Commerce

Physical Measurement Laboratory www.pml.nist.gov
Standard Reference Data www.nist.gov/srd

FREQUENTLY USED FUNDAMENTAL PHYSICAL CONSTANTS§

1 second = 9 192 631 770 periods of radiation corresponding to the transition between the two hyperfine levels of the ground state of ^{133}Cs

speed of light in vacuum	c	$299\,792\,458 \text{ m s}^{-1}$	(exact)
Planck constant	h	$6.626\,070 \times 10^{-34} \text{ J s}$	($\hbar = h/2\pi$)
elementary charge	e	$1.602\,177 \times 10^{-19} \text{ C}$	
electron mass	m_e	$9.109\,384 \times 10^{-31} \text{ kg}$	
	m_ec^2	$0.510\,999 \text{ MeV}$	
proton mass	m_p	$1.672\,622 \times 10^{-27} \text{ kg}$	
fine-structure constant	α	$1/137.035\,999$	
Rydberg constant	R_∞	$10\,973\,731.569 \text{ m}^{-1}$	
	$R_\infty c$	$3.289\,841\,960 \times 10^{15} \text{ Hz}$	
	$R_\infty hc$	$13.605\,693 \text{ eV}$	
electron volt	eV	$1.602\,177 \times 10^{-19} \text{ J}$	
Boltzmann constant	k	$1.380\,65 \times 10^{-23} \text{ J K}^{-1}$	
molar gas constant	R	$8.314\,5 \text{ J mol}^{-1} \text{ K}^{-1}$	

§ For the most accurate values of these and other constants, visit pml.nist.gov/constants

⬜ **Solids**
🟥 **Liquids**
🟦 **Gases**
🟩 **Artificially Prepared**

Period	Group 1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIII	9	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 $^2S_{1/2}$ **H** Hydrogen 1.008* $1s$ 13.5984																	2 $^1S_0$ **He** Helium 4.002602 $1s^2$ 24.5874
2	3 $^2S_{1/2}$ **Li** Lithium 6.94* $1s^2 2s$ 5.3917	4 $^1S_0$ **Be** Beryllium 9.0121831 $1s^2 2s^2$ 9.3227											5 $^2P^\circ_{1/2}$ **B** Boron 10.81* $1s^2 2s^2 2p$ 8.2980	6 $^3P_0$ **C** Carbon 12.011* $1s^2 2s^2 2p^2$ 11.2603	7 $^4S^\circ_{3/2}$ **N** Nitrogen 14.007* $1s^2 2s^2 2p^3$ 14.5341	8 $^3P_2$ **O** Oxygen 15.999* $1s^2 2s^2 2p^4$ 13.6181	9 $^2P^\circ_{3/2}$ **F** Fluorine 18.99840316* $1s^2 2s^2 2p^5$ 17.4228	10 $^1S_0$ **Ne** Neon 20.1797 $1s^2 2s^2 2p^6$ 21.5645
3	11 $^2S_{1/2}$ **Na** Sodium 22.98976928 $[\mathrm{Ne}]3s$ 5.1391	12 $^1S_0$ **Mg** Magnesium 24.305* $[\mathrm{Ne}]3s^2$ 7.6462											13 $^2P^\circ_{1/2}$ **Al** Aluminum 26.9815385 $[\mathrm{Ne}]3s^2 3p$ 5.9858	14 $^3P_0$ **Si** Silicon 28.085* $[\mathrm{Ne}]3s^2 3p^2$ 8.1517	15 $^4S^\circ_{3/2}$ **P** Phosphorus 30.97376199* $[\mathrm{Ne}]3s^2 3p^3$ 10.4867	16 $^3P_2$ **S** Sulfur 32.06* $[\mathrm{Ne}]3s^2 3p^4$ 10.3600	17 $^2P^\circ_{3/2}$ **Cl** Chlorine 35.45* $[\mathrm{Ne}]3s^2 3p^5$ 12.9676	18 $^1S_0$ **Ar** Argon 39.948 $[\mathrm{Ne}]3s^2 3p^6$ 15.7596
4	19 $^2S_{1/2}$ **K** Potassium 39.0983 $[\mathrm{Ar}]4s$ 4.3407	20 $^1S_0$ **Ca** Calcium 40.078 $[\mathrm{Ar}]4s^2$ 6.1132	21 $^2D_{3/2}$ **Sc** Scandium 44.955908 $[\mathrm{Ar}]3d4s^2$ 6.5615	22 $^3F_2$ **Ti** Titanium 47.867 $[\mathrm{Ar}]3d^2 4s^2$ 6.8281	23 $^4F_{3/2}$ **V** Vanadium 50.9415 $[\mathrm{Ar}]3d^3 4s^2$ 6.7462	24 $^7S_3$ **Cr** Chromium 51.9961 $[\mathrm{Ar}]3d^5 4s$ 6.7665	25 $^6S_{5/2}$ **Mn** Manganese 54.938044 $[\mathrm{Ar}]3d^5 4s^2$ 7.4340	26 $^5D_4$ **Fe** Iron 55.845 $[\mathrm{Ar}]3d^6 4s^2$ 7.9025	27 $^4F_{9/2}$ **Co** Cobalt 58.933194 $[\mathrm{Ar}]3d^7 4s^2$ 7.8810	28 $^3F_4$ **Ni** Nickel 58.6934 $[\mathrm{Ar}]3d^8 4s^2$ 7.6399	29 $^2S_{1/2}$ **Cu** Copper 63.546 $[\mathrm{Ar}]3d^{10}4s$ 7.7264	30 $^1S_0$ **Zn** Zinc 65.38 $[\mathrm{Ar}]3d^{10}4s^2$ 9.3942	31 $^2P^\circ_{1/2}$ **Ga** Gallium 69.723 $[\mathrm{Ar}]3d^{10}4s^2 4p$ 5.9993	32 $^3P_0$ **Ge** Germanium 72.630 $[\mathrm{Ar}]3d^{10}4s^2 4p^2$ 7.8994	33 $^4S^\circ_{3/2}$ **As** Arsenic 74.921595 $[\mathrm{Ar}]3d^{10}4s^2 4p^3$ 9.7886	34 $^3P_2$ **Se** Selenium 78.971 $[\mathrm{Ar}]3d^{10}4s^2 4p^4$ 9.7524	35 $^2P^\circ_{3/2}$ **Br** Bromine 79.904* $[\mathrm{Ar}]3d^{10}4s^2 4p^5$ 11.8138	36 $^1S_0$ **Kr** Krypton 83.798 $[\mathrm{Ar}]3d^{10}4s^2 4p^6$ 13.9996
5	37 $^2S_{1/2}$ **Rb** Rubidium 85.4678 $[\mathrm{Kr}]5s$ 4.1771	38 $^1S_0$ **Sr** Strontium 87.62 $[\mathrm{Kr}]5s^2$ 5.6949	39 $^2D_{3/2}$ **Y** Yttrium 88.90584 $[\mathrm{Kr}]4d5s^2$ 6.2173	40 $^3F_2$ **Zr** Zirconium 91.224 $[\mathrm{Kr}]4d^2 5s^2$ 6.6339	41 $^6D_{1/2}$ **Nb** Niobium 92.90637 $[\mathrm{Kr}]4d^4 5s$ 6.7589	42 $^7S_3$ **Mo** Molybdenum 95.95 $[\mathrm{Kr}]4d^5 5s$ 7.0924	43 $^6S_{5/2}$ **Tc** Technetium (98) $[\mathrm{Kr}]4d^5 5s^2$ 7.1194	44 $^5F_5$ **Ru** Ruthenium 101.07 $[\mathrm{Kr}]4d^7 5s$ 7.3605	45 $^4F_{9/2}$ **Rh** Rhodium 102.90550 $[\mathrm{Kr}]4d^8 5s$ 7.4589	46 $^1S_0$ **Pd** Palladium 106.42 $[\mathrm{Kr}]4d^{10}$ 8.3369	47 $^2S_{1/2}$ **Ag** Silver 107.8682 $[\mathrm{Kr}]4d^{10}5s$ 7.5762	48 $^1S_0$ **Cd** Cadmium 112.414 $[\mathrm{Kr}]4d^{10}5s^2$ 8.9938	49 $^2P^\circ_{1/2}$ **In** Indium 114.818 $[\mathrm{Kr}]4d^{10}5s^2 5p$ 5.7864	50 $^3P_0$ **Sn** Tin 118.710 $[\mathrm{Kr}]4d^{10}5s^2 5p^2$ 7.3439	51 $^4S^\circ_{3/2}$ **Sb** Antimony 121.760 $[\mathrm{Kr}]4d^{10}5s^2 5p^3$ 8.6084	52 $^3P_2$ **Te** Tellurium 127.60 $[\mathrm{Kr}]4d^{10}5s^2 5p^4$ 9.0097	53 $^2P^\circ_{3/2}$ **I** Iodine 126.90447 $[\mathrm{Kr}]4d^{10}5s^2 5p^5$ 10.4513	54 $^1S_0$ **Xe** Xenon 131.293 $[\mathrm{Kr}]4d^{10}5s^2 5p^6$ 12.1298
6	55 $^2S_{1/2}$ **Cs** Cesium 132.90545196 $[\mathrm{Xe}]6s$ 3.8939	56 $^1S_0$ **Ba** Barium 137.327 $[\mathrm{Xe}]6s^2$ 5.2117		72 $^3F_2$ **Hf** Hafnium 178.49 $[\mathrm{Xe}]4f^{14}5d^2 6s^2$ 6.8251	73 $^4F_{3/2}$ **Ta** Tantalum 180.94788 $[\mathrm{Xe}]4f^{14}5d^3 6s^2$ 7.5496	74 $^5D_0$ **W** Tungsten 183.84 $[\mathrm{Xe}]4f^{14}5d^4 6s^2$ 7.8640	75 $^6S_{5/2}$ **Re** Rhenium 186.207 $[\mathrm{Xe}]4f^{14}5d^5 6s^2$ 7.8335	76 $^5D_4$ **Os** Osmium 190.23 $[\mathrm{Xe}]4f^{14}5d^6 6s^2$ 8.4382	77 $^4F_{9/2}$ **Ir** Iridium 192.217 $[\mathrm{Xe}]4f^{14}5d^7 6s^2$ 8.9670	78 $^3D_3$ **Pt** Platinum 195.084 $[\mathrm{Xe}]4f^{14}5d^9 6s$ 8.9588	79 $^2S_{1/2}$ **Au** Gold 196.966569 $[\mathrm{Xe}]4f^{14}5d^{10}6s$ 9.2256	80 $^1S_0$ **Hg** Mercury 200.592 $[\mathrm{Xe}]4f^{14}5d^{10}6s^2$ 10.4375	81 $^2P^\circ_{1/2}$ **Tl** Thallium 204.38* $[\mathrm{Hg}]6p$ 6.1083	82 $^3P_0$ **Pb** Lead 207.2 $[\mathrm{Hg}]6p^2$ 7.4167	83 $^4S^\circ_{3/2}$ **Bi** Bismuth 208.98040 $[\mathrm{Hg}]6p^3$ 7.2855	84 $^3P_2$ **Po** Polonium (209) $[\mathrm{Hg}]6p^4$ 8.414	85 $^2P^\circ_{3/2}$ **At** Astatine (210) $[\mathrm{Hg}]6p^5$ 9.3175	86 $^1S_0$ **Rn** Radon (222) $[\mathrm{Hg}]6p^6$ 10.7485
7	87 $^2S_{1/2}$ **Fr** Francium (223) $[\mathrm{Rn}]7s$ 4.0727	88 $^1S_0$ **Ra** Radium (226) $[\mathrm{Rn}]7s^2$ 5.2784		104 $^3F_2$ **Rf** Rutherfordium (267) $[\mathrm{Rn}]5f^{14}6d^2 7s^2$ 6.01	105 $^4F_{3/2}$ **Db** Dubnium (268) $[\mathrm{Rn}]5f^{14}6d^3 7s^2$ 6.8	106 $_0$ **Sg** Seaborgium (271) $[\mathrm{Rn}]5f^{14}6d^4 7s^2$ 7.8	107 $_{5/2}$ **Bh** Bohrium (270) $[\mathrm{Rn}]5f^{14}6d^5 7s^2$ 7.7	108 $_4$ **Hs** Hassium (269) $[\mathrm{Rn}]5f^{14}6d^6 7s^2$ 7.6	109 **Mt** Meitnerium (278)	110 **Ds** Darmstadtium (281)	111 **Rg** Roentgenium (282)	112 **Cn** Copernicium (285)	113 **Nh** Nihonium (286)	114 **Fl** Flerovium (289)	115 **Mc** Moscovium (289)	116 **Lv** Livermorium (293)	117 **Ts** Tennessine (294)	118 **Og** Oganesson (294)

Lanthanides	57 $^2D_{3/2}$ **La** Lanthanum 138.90547 $[\mathrm{Xe}]5d6s^2$ 5.5769	58 $^1G^\circ_4$ **Ce** Cerium 140.116 $[\mathrm{Xe}]4f5d6s^2$ 5.5386	59 $^4I^\circ_{9/2}$ **Pr** Praseodymium 140.90766 $[\mathrm{Xe}]4f^3 6s^2$ 5.473	60 $^5I_4$ **Nd** Neodymium 144.242 $[\mathrm{Xe}]4f^4 6s^2$ 5.5250	61 $^6H^\circ_{5/2}$ **Pm** Promethium (145) $[\mathrm{Xe}]4f^5 6s^2$ 5.582	62 $^7F_0$ **Sm** Samarium 150.36 $[\mathrm{Xe}]4f^6 6s^2$ 5.6437	63 $^8S^\circ_{7/2}$ **Eu** Europium 151.964 $[\mathrm{Xe}]4f^7 6s^2$ 5.6704	64 $^9D^\circ_2$ **Gd** Gadolinium 157.25 $[\mathrm{Xe}]4f^7 5d6s^2$ 6.1498	65 $^6H^\circ_{15/2}$ **Tb** Terbium 158.92535 $[\mathrm{Xe}]4f^9 6s^2$ 5.8638	66 $^5I_8$ **Dy** Dysprosium 162.500 $[\mathrm{Xe}]4f^{10}6s^2$ 5.9391	67 $^4I^\circ_{15/2}$ **Ho** Holmium 164.93033 $[\mathrm{Xe}]4f^{11}6s^2$ 6.0215	68 $^3H_6$ **Er** Erbium 167.259 $[\mathrm{Xe}]4f^{12}6s^2$ 6.1077	69 $^2F^\circ_{7/2}$ **Tm** Thulium 168.93422 $[\mathrm{Xe}]4f^{13}6s^2$ 6.1843	70 $^1S_0$ **Yb** Ytterbium 173.045 $[\mathrm{Xe}]4f^{14}6s^2$ 6.2542	71 $^2D_{3/2}$ **Lu** Lutetium 174.9668 $[\mathrm{Xe}]4f^{14}5d6s^2$ 5.4259
Actinides	89 $^2D_{3/2}$ **Ac** Actinium (227) $[\mathrm{Rn}]6d7s^2$ 5.3802	90 $^3F_2$ **Th** Thorium 232.0377 $[\mathrm{Rn}]6d^2 7s^2$ 6.3067	91 $^4K_{11/2}$ **Pa** Protactinium 231.03588 $[\mathrm{Rn}]5f^2 6d7s^2$ 5.89	92 $^5L^\circ_6$ **U** Uranium 238.02891 $[\mathrm{Rn}]5f^3 6d7s^2$ 6.1941	93 $^6L_{11/2}$ **Np** Neptunium (237) $[\mathrm{Rn}]5f^4 6d7s^2$ 6.2655	94 $^7F_0$ **Pu** Plutonium (244) $[\mathrm{Rn}]5f^6 7s^2$ 6.0258	95 $^8S^\circ_{7/2}$ **Am** Americium (243) $[\mathrm{Rn}]5f^7 7s^2$ 5.9738	96 $^9D^\circ_2$ **Cm** Curium (247) $[\mathrm{Rn}]5f^7 6d7s^2$ 5.9914	97 $^6H^\circ_{15/2}$ **Bk** Berkelium (247) $[\mathrm{Rn}]5f^9 7s^2$ 6.1978	98 $^5I_8$ **Cf** Californium (251) $[\mathrm{Rn}]5f^{10}7s^2$ 6.2817	99 $^4I^\circ_{15/2}$ **Es** Einsteinium (252) $[\mathrm{Rn}]5f^{11}7s^2$ 6.3676	100 $^3H_6$ **Fm** Fermium (257) $[\mathrm{Rn}]5f^{12}7s^2$ 6.50	101 $^2F^\circ_{7/2}$ **Md** Mendelevium (258) $[\mathrm{Rn}]5f^{13}7s^2$ 6.58	102 $^1S_0$ **No** Nobelium (259) $[\mathrm{Rn}]5f^{14}7s^2$ 6.65	103 $^2P^\circ_{1/2}$ **Lr** Lawrencium (266) $[\mathrm{Rn}]5f^{14}7s^2 7p$ 4.96

Atomic Number	58
Ground-state Level	$^1G^\circ_4$
Symbol	**Ce**
Name	Cerium
Standard Atomic Weight† (Da)	140.116
Ground-state Configuration	$[\mathrm{Xe}]4f5d6s^2$
Ionization Energy (eV)	5.5386

†Based upon ^{12}C. () indicates the mass number of the longest-lived isotope.

*For the most precise value, visit ciaaw.org.

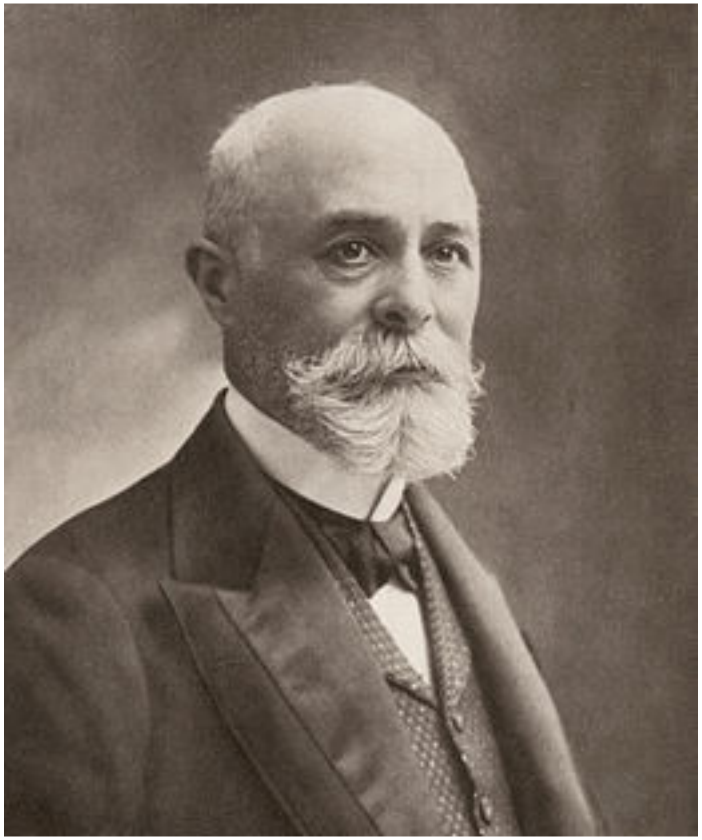
For a description of the data, visit pml.nist.gov/data

NIST SP 966 (February 2017)

Radioactivity: Something probabilistic in nature

February 27 1896

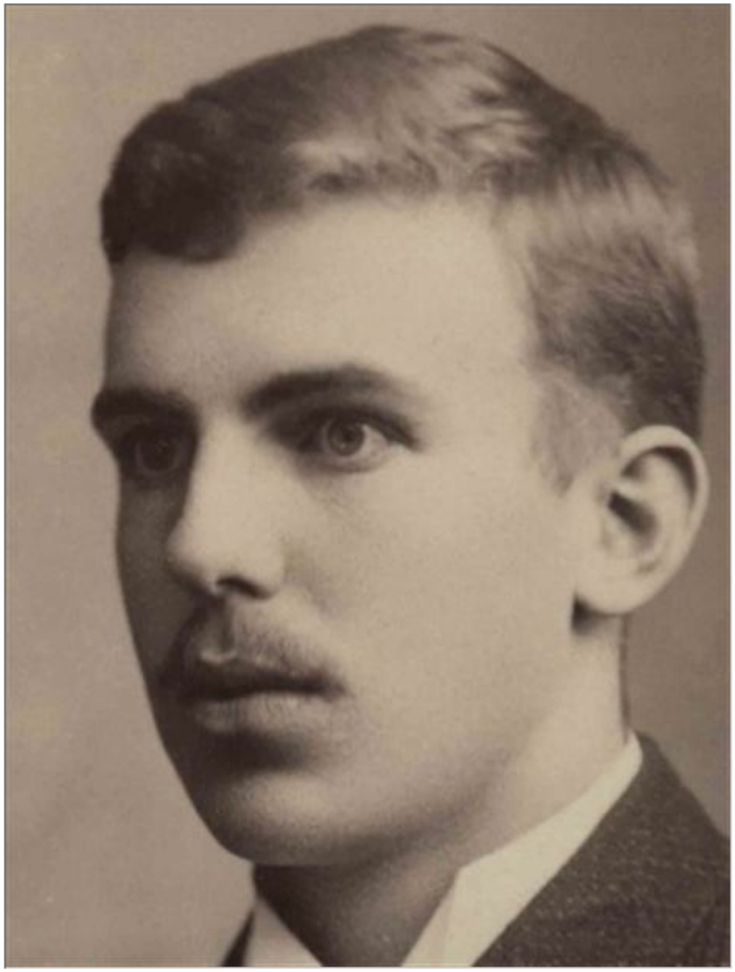
Marie Curie



Henry Becquerel

Pierre Curie

Rutherford discovers there are two kinds of rays in radioactivity (α, β)



Ernest Rutherford

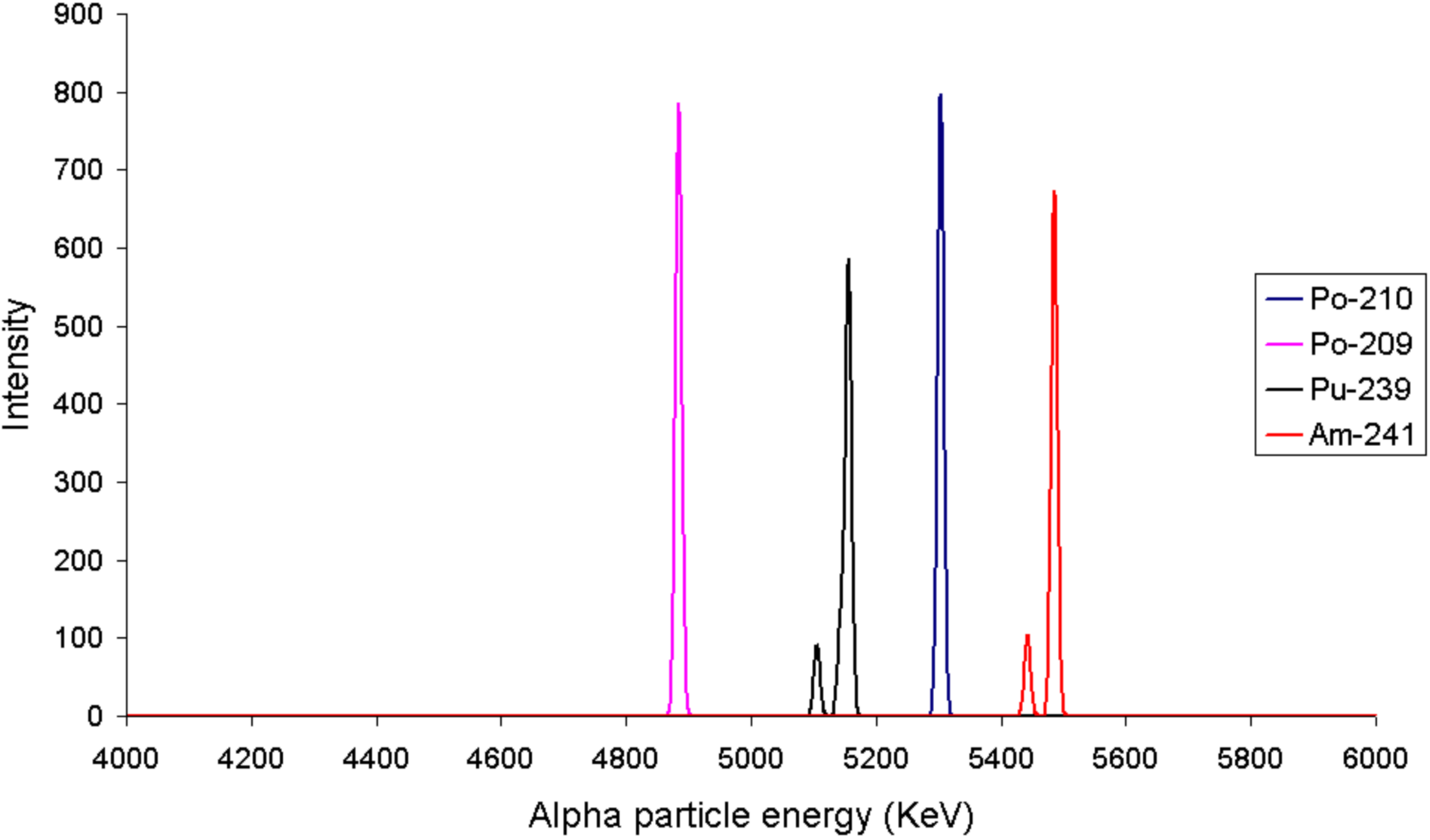
Rutherford determines ~ 1910

- Alpha particle is a helium nucleus
- Beta particle is an electron

The researchers focus on:

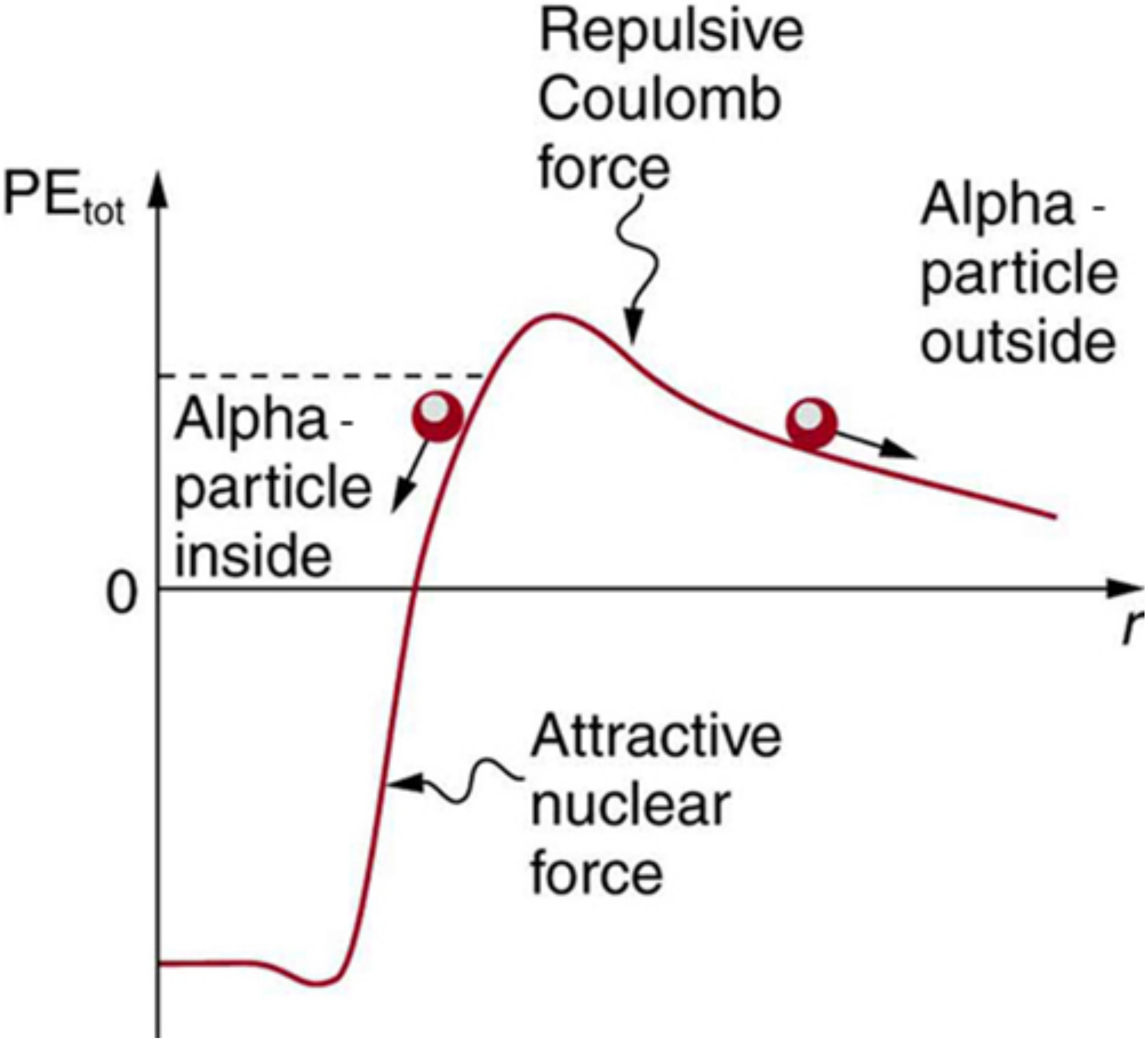
- How quickly an element decays?
- How it decays (alpha or beta)?

Alpha decay spectra



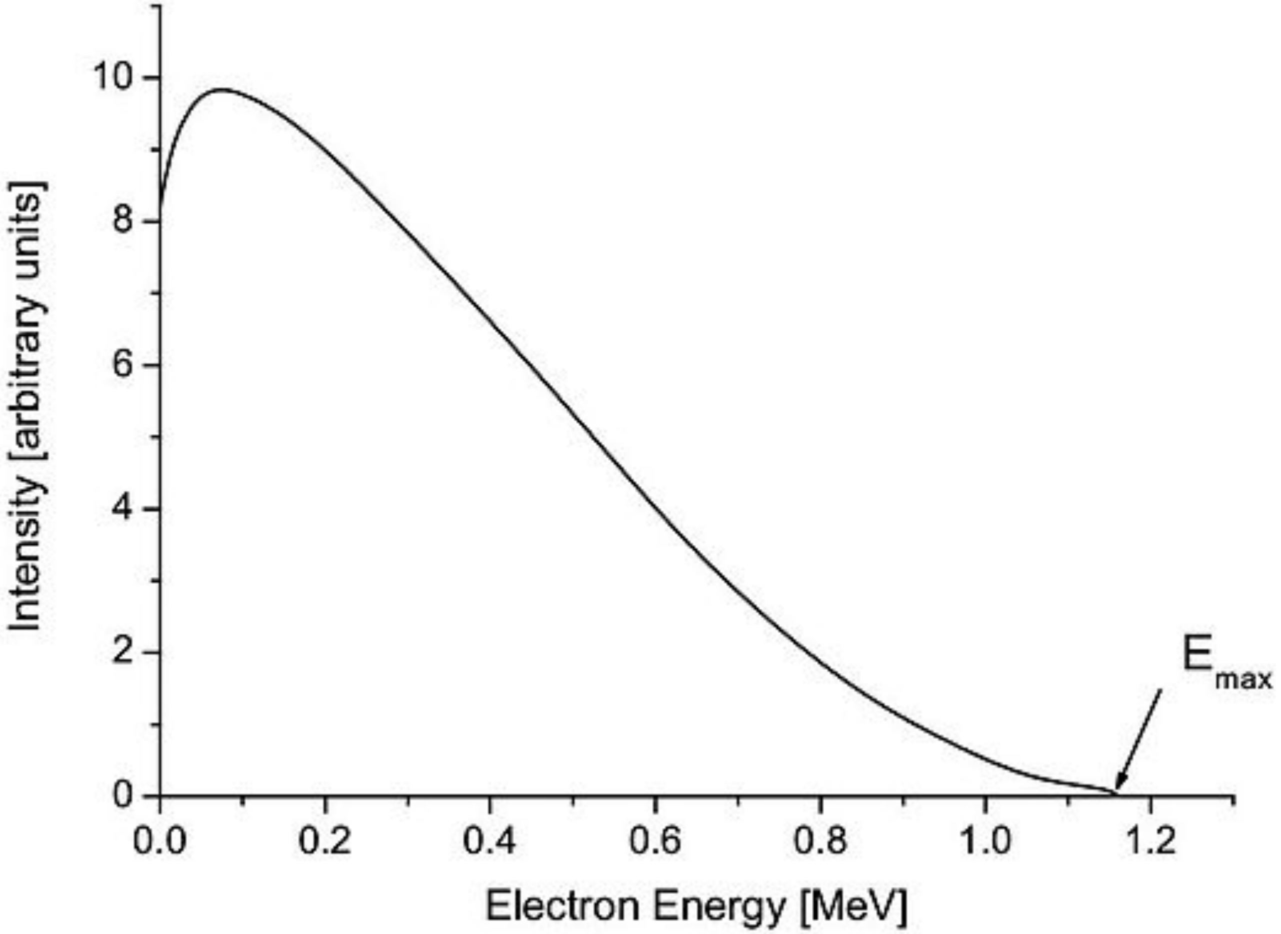
1928 George Gamow explains alpha decay as a tunneling process

Tunneling of alpha particles



Beta decay:

Lise Meitner y Otto Hann (1911), Jean Danysz (1913) and James Chadwick (1914) measure thee spectrum of beta decay and it shows a continuum of energies.

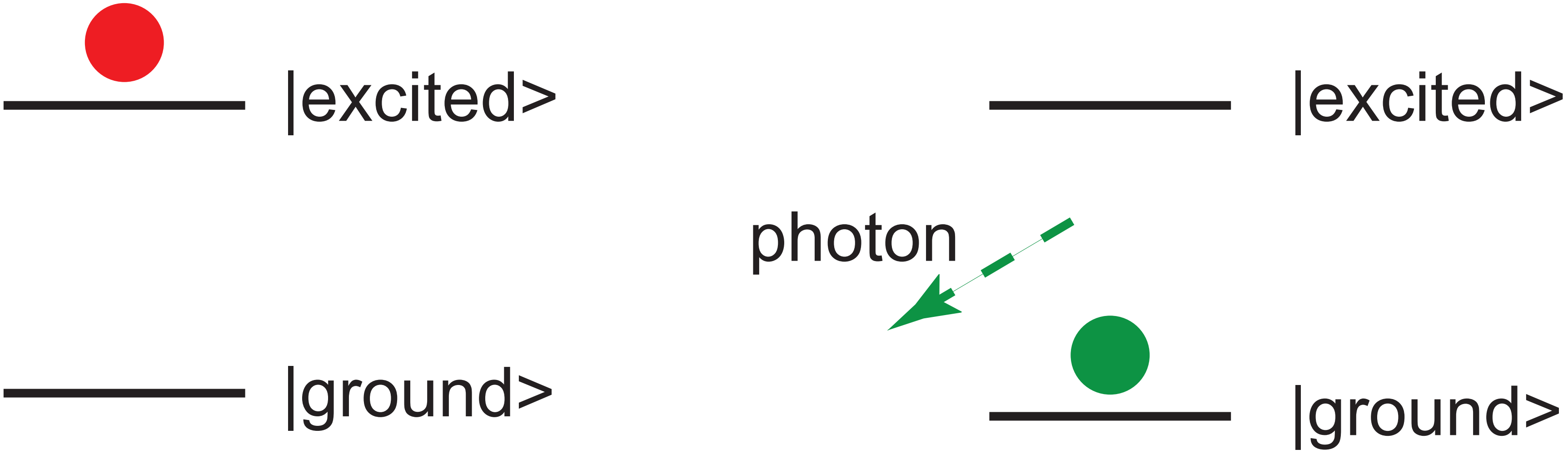


^{210}Bi

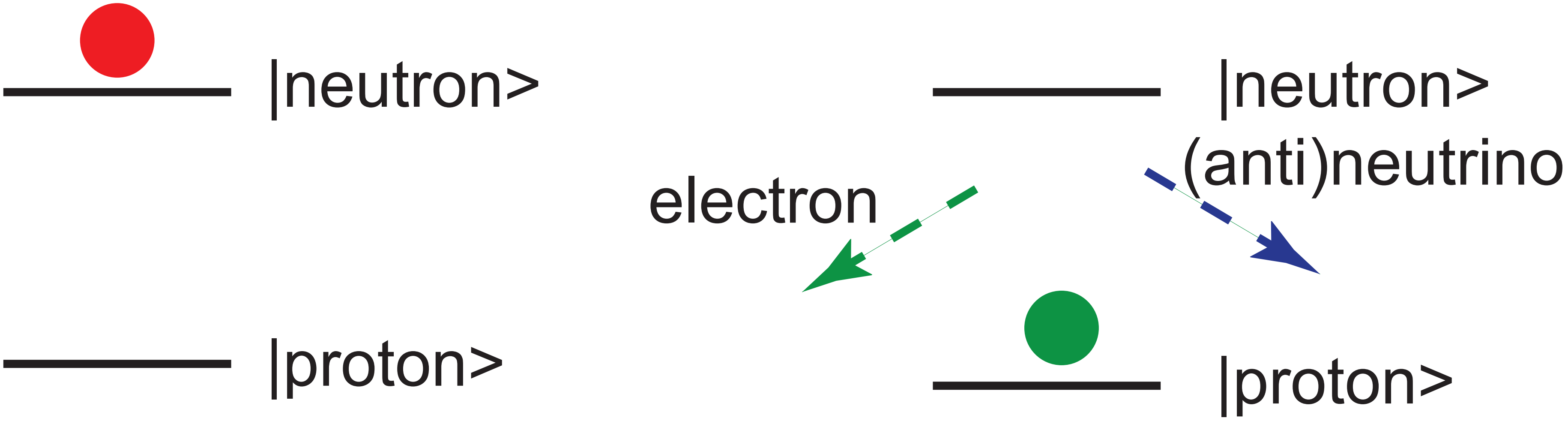
Beta decay theory by Enrico Fermi in 1934, it is just spontaneous emission.

Enrico Fermi

Spontaneous emission



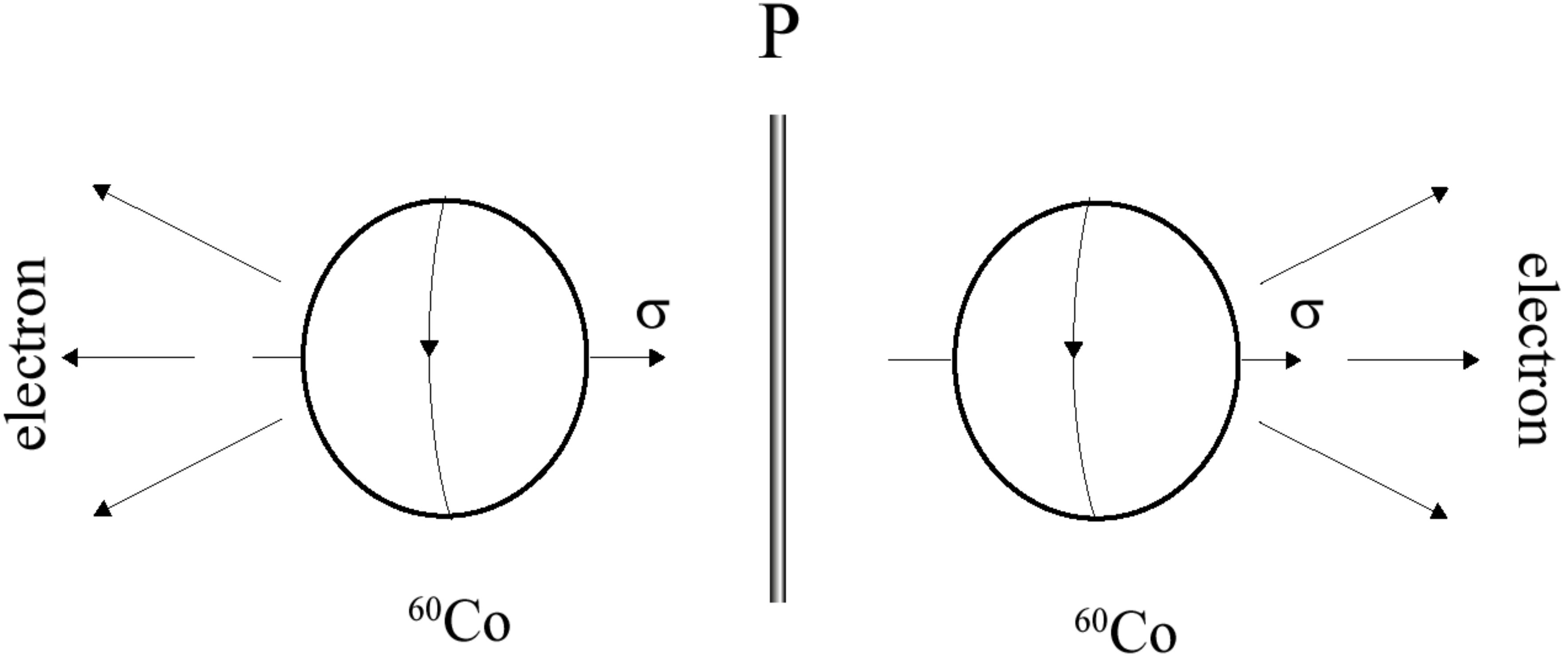
Beta decay



Nature does not have Parity symmetry (1956), C. N. Yang and T. D Lee.

Change x to −x; y to −y and z to −z

From right hand to left hand



The NBS-Columbia Experiment

- The weak interaction changes the “flavor” of a particle: a neutron becomes a proton.

- The inverse process a proton becomes a neutron is the beginning of the solar cycle.

- The weak interaction violates parity and charge-parity (1964).

- Neutrinos have mass and oscillate (~1990-2010)

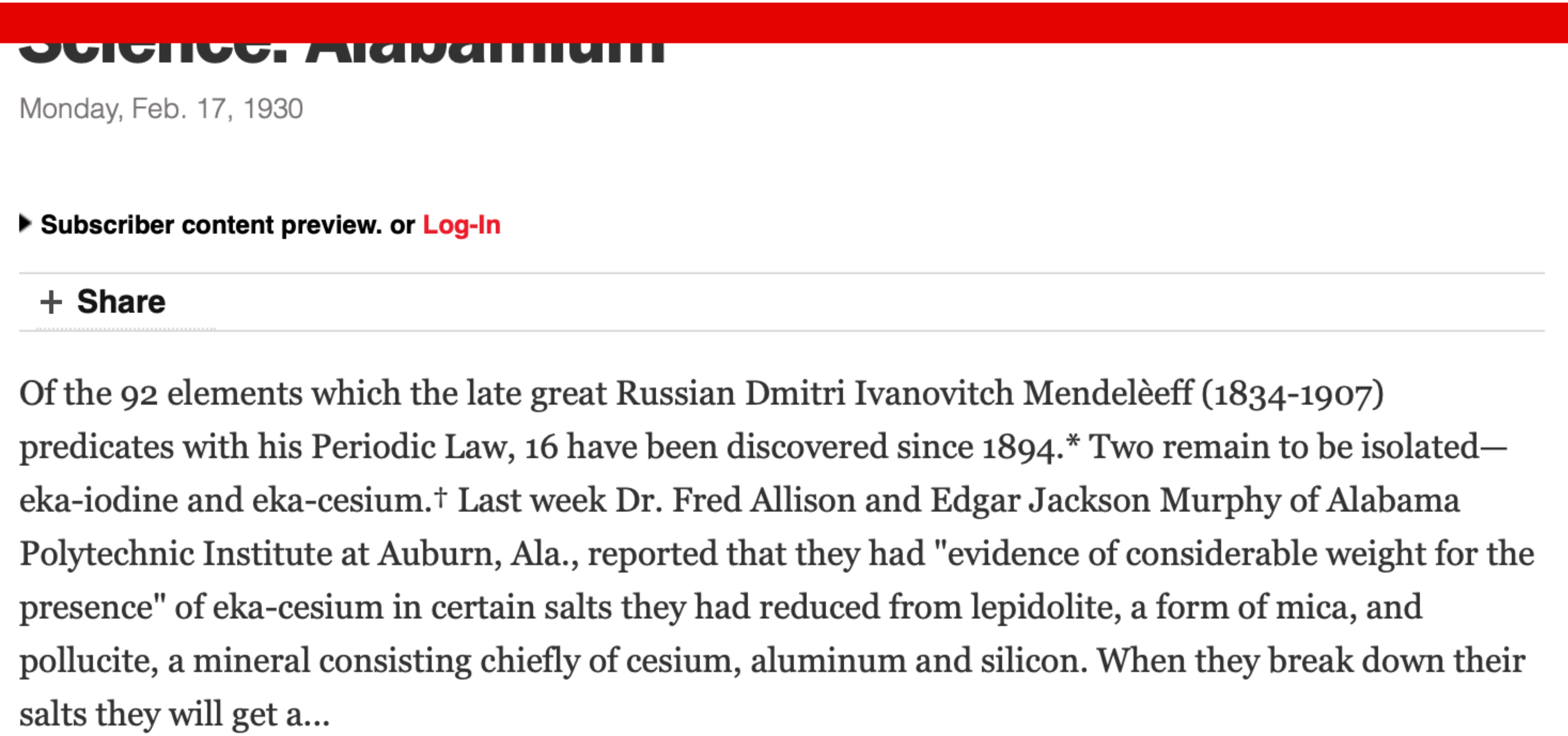
The discovery of Francium

First report of eka-caesium

D. K. Dobroserdov, a soviet chemist, claimed to have found eka-caesium. In 1925 he observed weak radioactivity in a sample of K and incorrectly concluded that eka-caesium was contaminating the sample (it came from ^{40}K)
He published his predictions of the properties of eka-caesium, which he named Russium after his home country. He abandoned any pursue of element 87.

In 1926 Gerald J. F. Druce and Frederick H. Loring (UK) analyzed X ray spectra of manganese sulfate and presumed to see eka-caesium, they proposed to name it alkalinium.

Time Magazine February 1930



Science: Alabamium

Monday, Feb. 17, 1930

▸ **Subscriber content preview. or Log-In**

Of the 92 elements which the late great Russian Dmitri Ivanovitch Mendelèeff (1834-1907) predicates with his Periodic Law, 16 have been discovered since 1894.* Two remain to be isolated—eka-iodine and eka-cesium.† Last week Dr. Fred Allison and Edgar Jackson Murphy of Alabama Polytechnic Institute at Auburn, Ala., reported that they had "evidence of considerable weight for the presence" of eka-cesium in certain salts they had reduced from lepidolite, a form of mica, and pollucite, a mineral consisting chiefly of cesium, aluminum and silicon. When they break down their salts they will get a...

(They wanted to call it Virginium). Report retracted later.

Horia Hulubei and Yvette Cauchois analyzed pollucite (the mineral that was analyzed by Fred Allison) in 1936 using X ray spectra and they presumed they were from element 87, They announced it and proposed Moldavium. By 1937 there was criticism of their work but they were supported by Jean B. Perrin who sided with them, but later changed his mind.

Marguerite Perey (1909-1975)

- Born in Villemomble, east of Paris, youngest of 5 children.
- She studied at Lycée Victor Duruy.
- She wanted to study medicine, but the dead of her father made her look for something more immediate.
- Studied in a vocational college chemistry laboratory technician.
- The Curies often hired the top student from the school as an assistant, and Perey at 19 was called in for an interview.

Lycée Victor Duruy 7th Arr. Paris, for girls opened 1912

Her first impression of Marie Curie in 1924. “Without a sound, someone entered like a shadow. It was a woman dressed entirely in black. She had gray hair, taken up in a bun, and wore thick glasses. She conveyed an impression of extreme frailty and paleness.” A secretary, Perey thought — then realized she was in the presence of Curie herself.

“I left this dark house, persuaded that it was for the first and last time. Everything had seemed melancholy and somber, and I was relieved to think that I would undoubtedly not return there.”

In the garden of the Institut du Radium (1930)

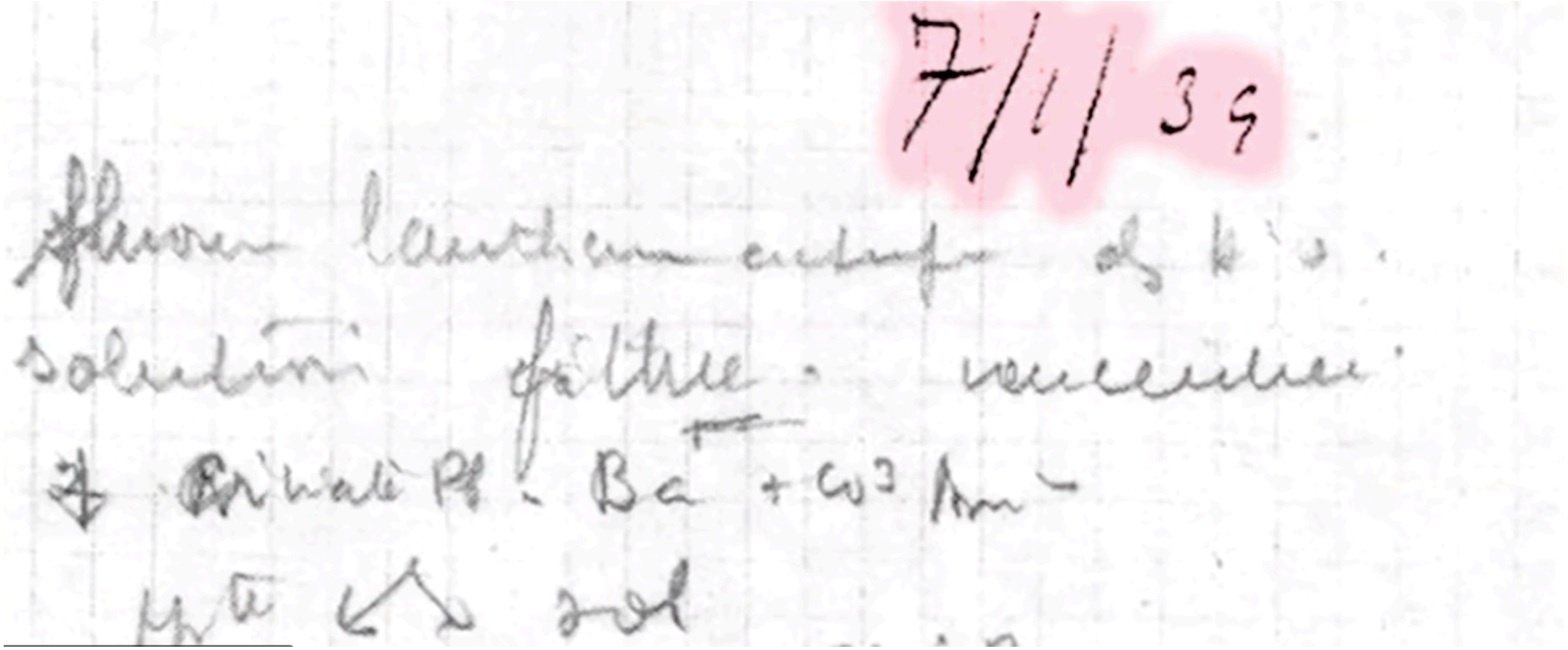
At the Institut du Radium

- Actinium was discovered by looking at the residues left by Pierre and Marie Curie when they discovered Radium.

- Mme. Curie wanted to study Ac and hired M. Perey for the job of purifying the element.

- 1000 Kg of natural Ur mineral contains about 0.2 milligrams of ^{227}Ac (atomic number 89, half life through beta decay of 21.77 years). She was given ten tonnes so she could get a few milligrams.

- She worked many years on the task.
- She discovered that the actinium had two decays after she finished the purification, one at 220 KeV corresponding to actinium and the other at 80 KeV of the daughter with half-life of 21 minutes.



7/1/39

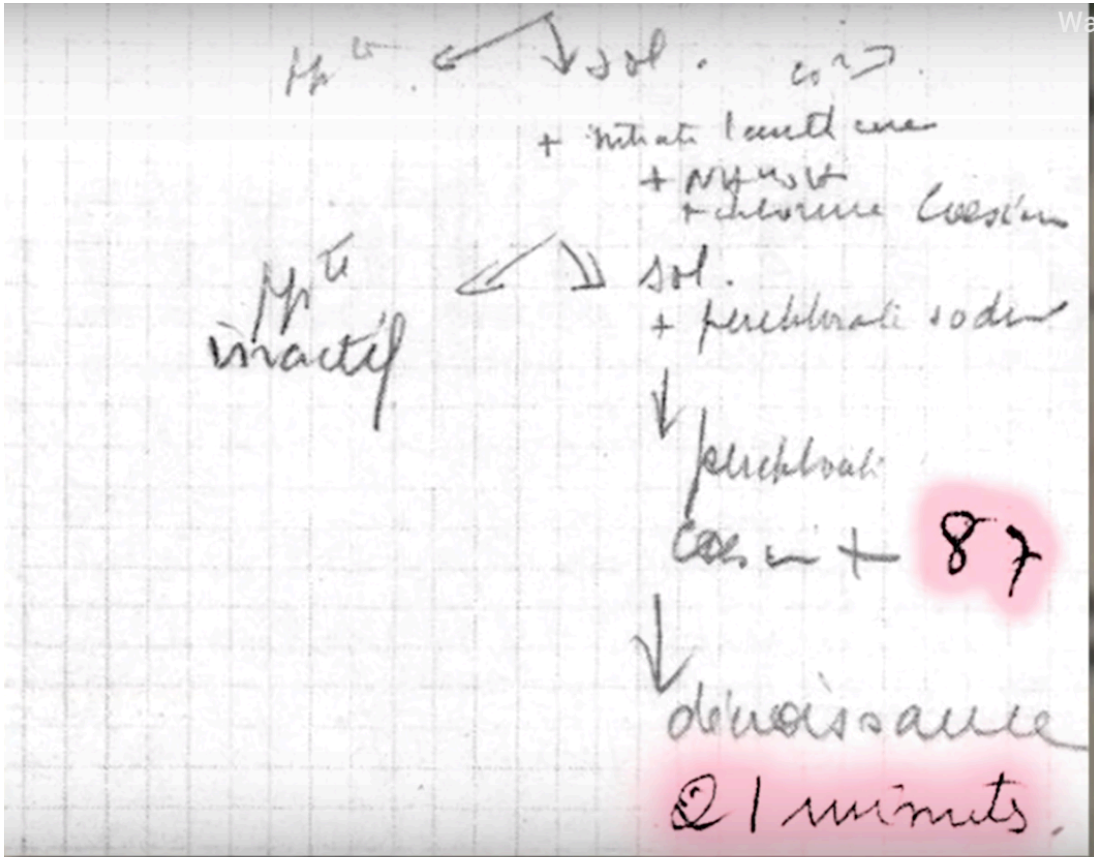
[illegible] lanthane [illegible]

solution filtrée [illegible]

[illegible] Ba + Co3 Am

[illegible]

- Saw that the activity of the daughter behaved like an alkali as it precipitated with some cesium salts.
- She was doing nuclear chemistry of the highest quality.



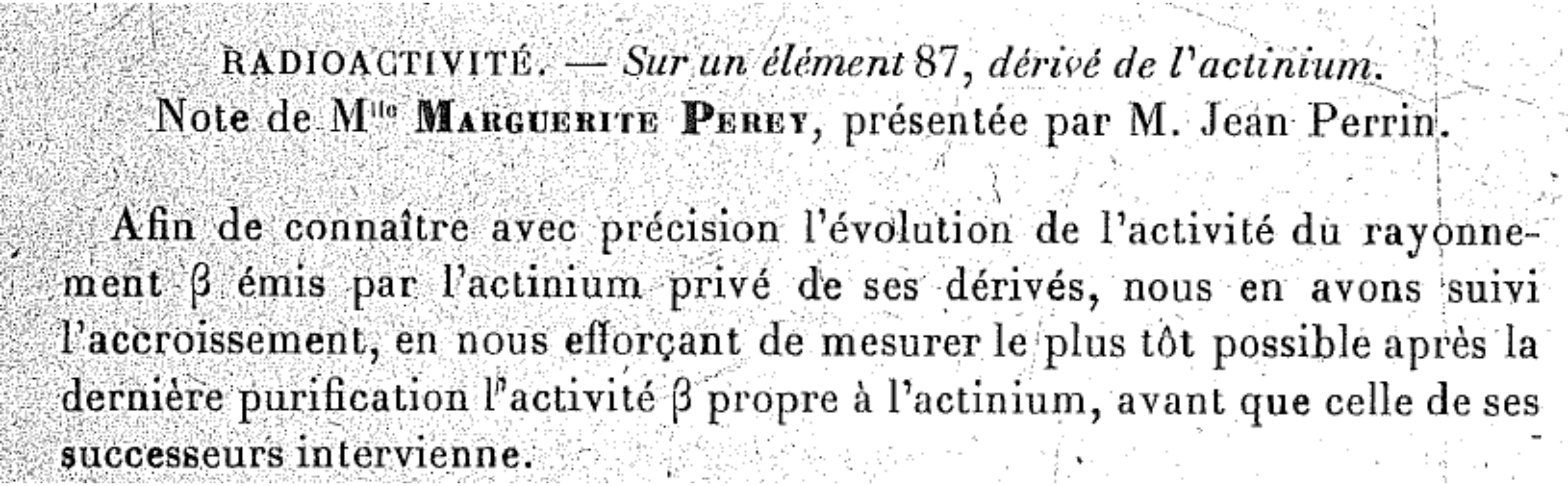
Discovery of Francium as a product of alpha decay of actinium in 1939 (Marguerite Perey)

$$^{227}_{89}\mathrm{Ac} \longrightarrow {}^{223}_{87}\mathrm{Fr} + {}^{4}_{2}\alpha$$

Eka-caesium
(Mendeleeff)

Marguerite Perey, Institut du Radium, Paris~1939

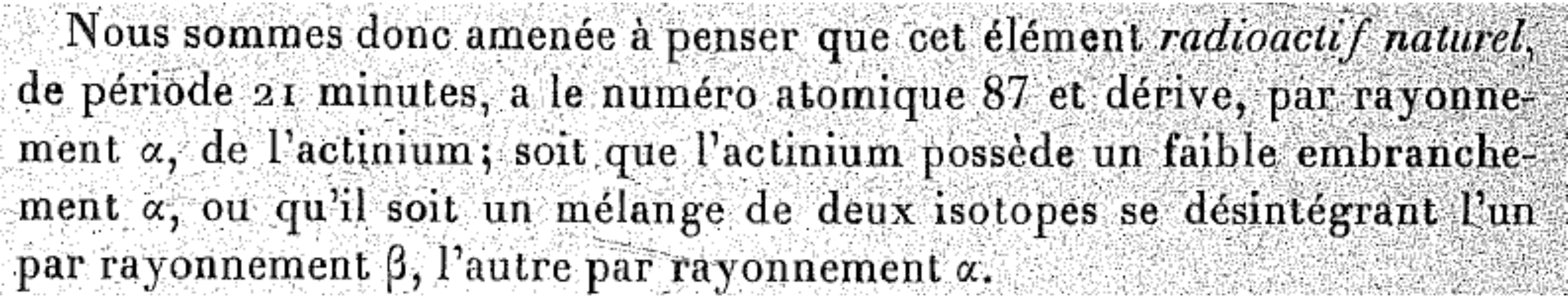
Comptes rendus a L'Academie de Sciences, **208**, 87 (1939)
Séance du 9 Janvier 1939



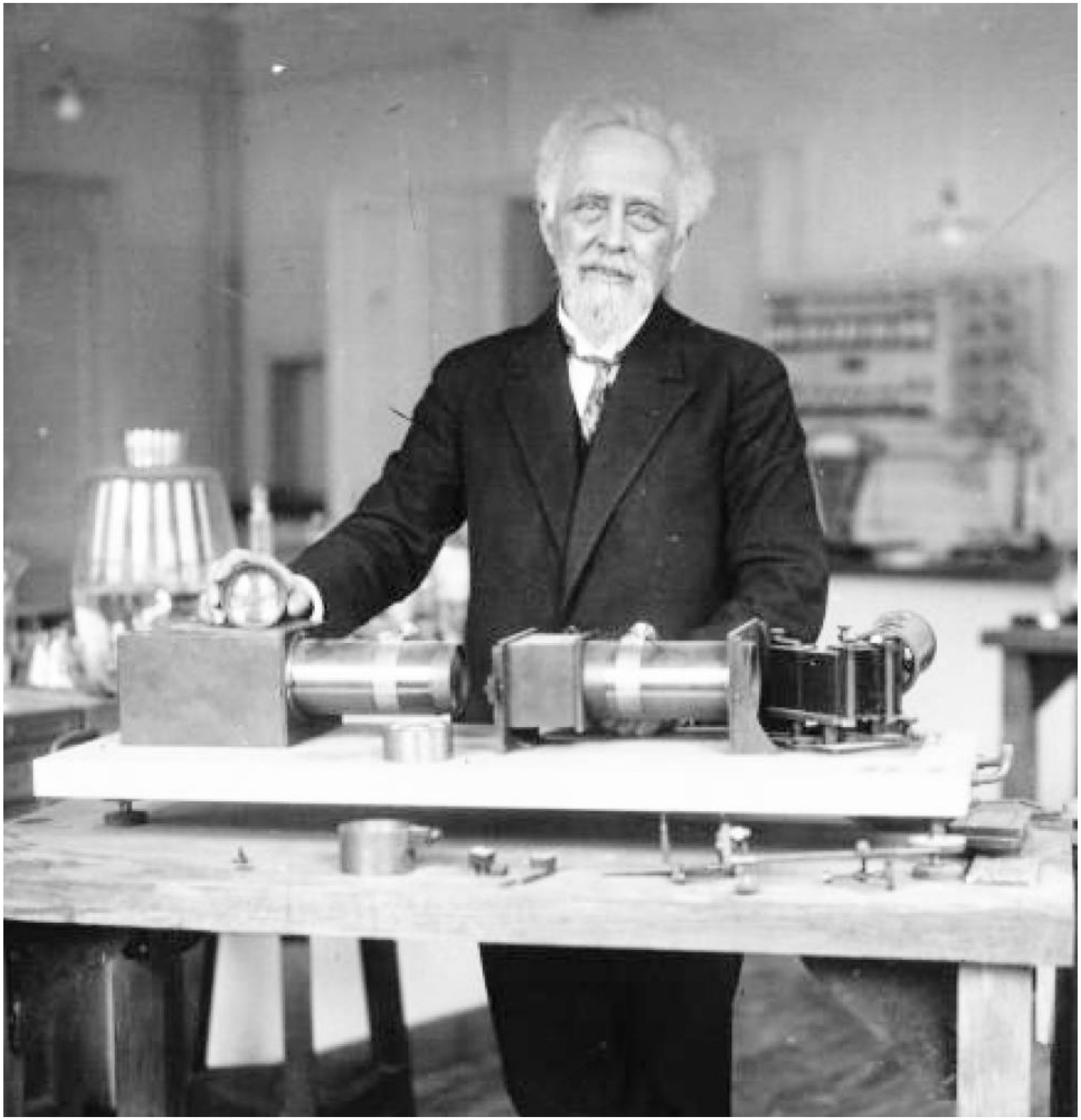
RADIOACTIVITÉ. — *Sur un élément* 87, *dérivé de l'actinium.* Note de M$^{\text{lle}}$ **Marguerite Perey**, présentée par M. Jean Perrin.

Afin de connaître avec précision l'évolution de l'activité du rayonnement β émis par l'actinium privé de ses dérivés, nous en avons suivi l'accroissement, en nous efforçant de mesurer le plus tôt possible après la dernière purification l'activité β propre à l'actinium, avant que celle de ses successeurs intervienne.

…



Nous sommes donc amenée à penser que cet élément *radioactif naturel*, de période 21 minutes, a le numéro atomique 87 et dérive, par rayonnement α, de l'actinium; soit que l'actinium possède un faible embranchement α, ou qu'il soit un mélange de deux isotopes se désintégrant l'un par rayonnement β, l'autre par rayonnement α.



Jean B. Perrin, founding father of CNRS

- She was given a fellowship to study her PhD at La Sorbonne, which she finished in 1946.
- Professor at Strasbourg, head of Nuclear Chemistry (1949).
- First woman elected as a corresponding member of the French Academy of Sciences (1962).

Veronique Greenwood, “My Great-Great-Aunt Discovered Francium. and It Killed Her.” New York Times Magazine Dec. 3, 2014; photographs provided by Jean Trouchaud.

Marguerite Perey in her office in Strasbourg

The origin of the name

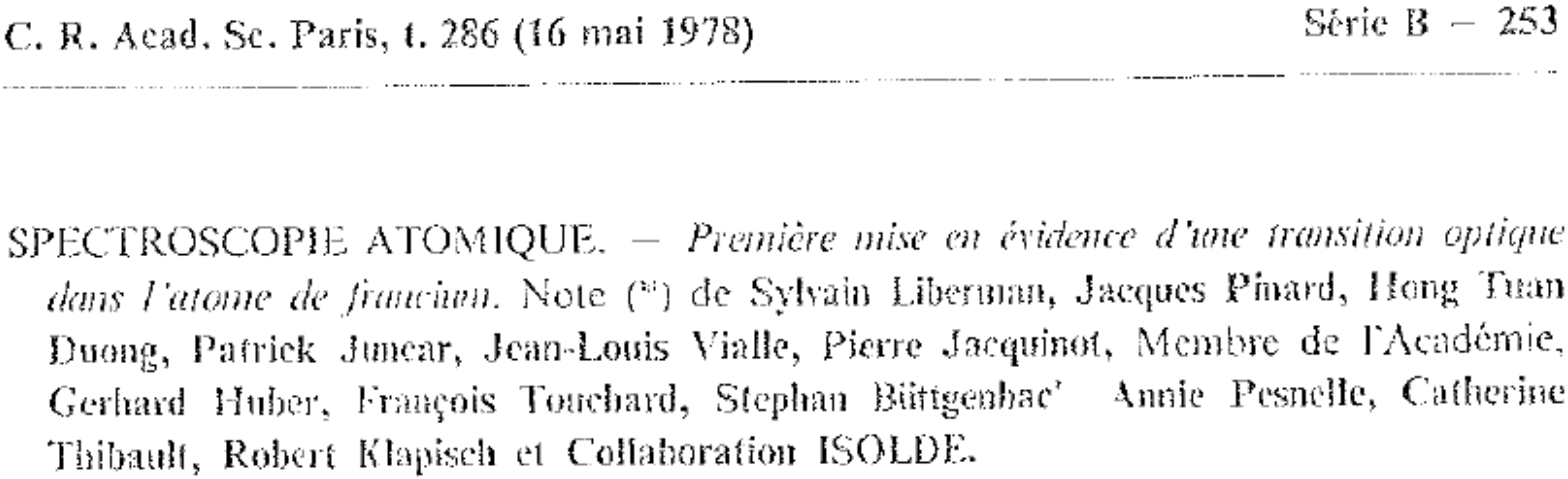
- 1939 Perey proposes Actinium K
- 1946 Perey proposes Catium (Objected by Irène Joliot Curie)
- 1949 Francium (Fa later changed to Fr) making the second element named for the country (Gallium).

The entrance to atomic physics

- ISOLDE (Isotope Spearator On Line DEtector) at CERN produces radioactive atoms using proton beams hitting different targets.

- Study Nuclear and Atomic properties of chains of isotopes.

- Developed a source of radioactive alkali so Rb, Cs, and Fr could be studied.



C. R. Acad. Sc. Paris, t. 286 (16 mai 1978) Série B — 253

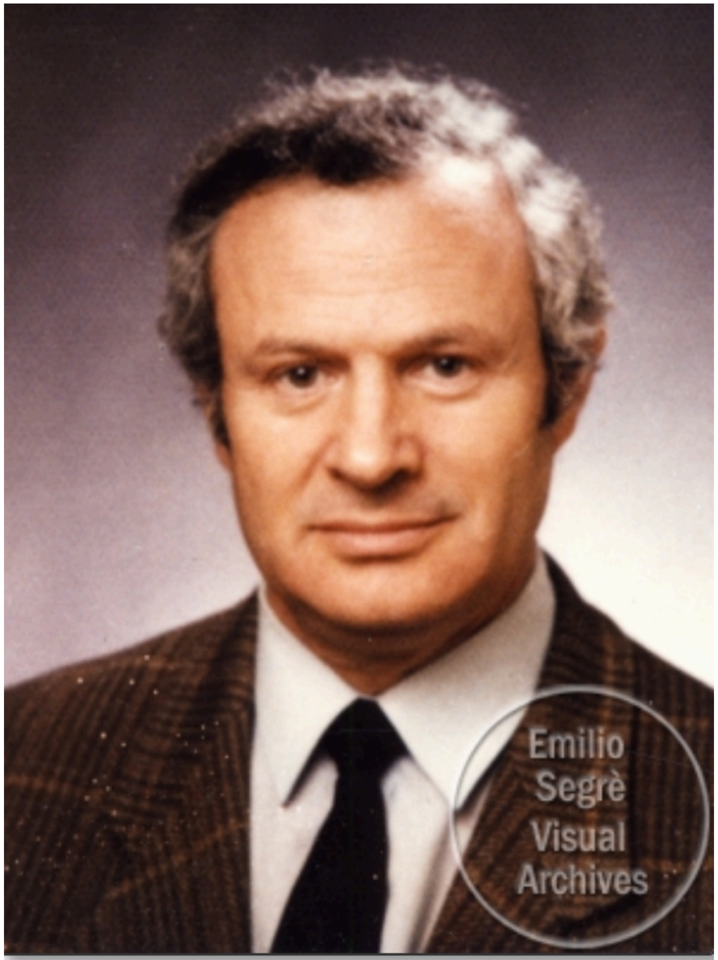
SPECTROSCOPIE ATOMIQUE. — *Première mise en évidence d'une transition optique dans l'atome de francium.* Note (*) de Sylvain Liberman, Jacques Pinard, Hong Tuan Duong, Patrick Juncar, Jean-Louis Vialle, Pierre Jacquinot, Membre de l'Académie, Gerhard Huber, François Touchard, Stephan Büttgenbac' Annie Pesnelle, Catherine Thibault, Robert Klapisch et Collaboration ISOLDE.

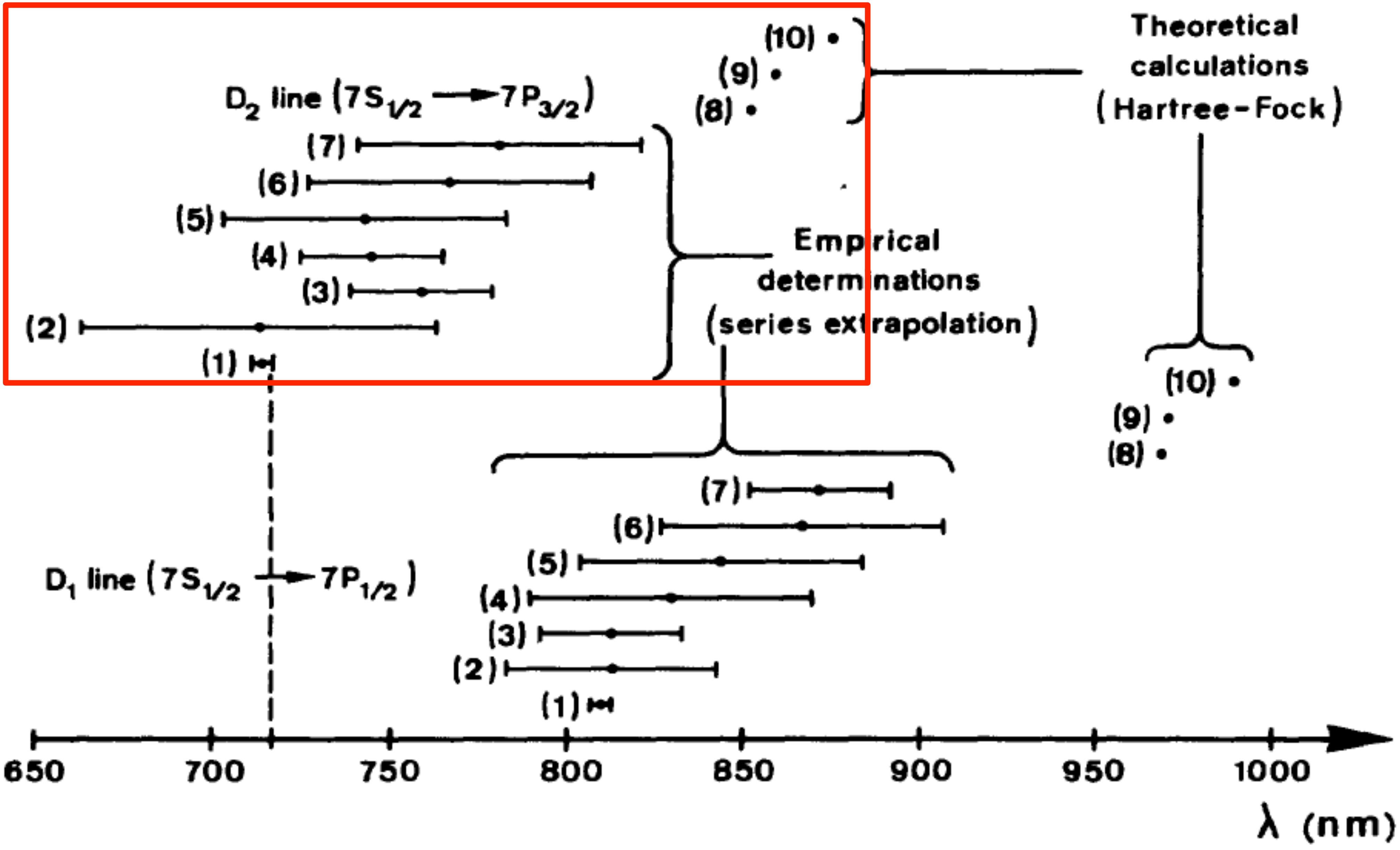
Sylvain Liberman
(1934-1988)

Found the D2 line of Fr (718 nm), working at Isolde CERN.

Try to find a coin between Hefei and Xi'an

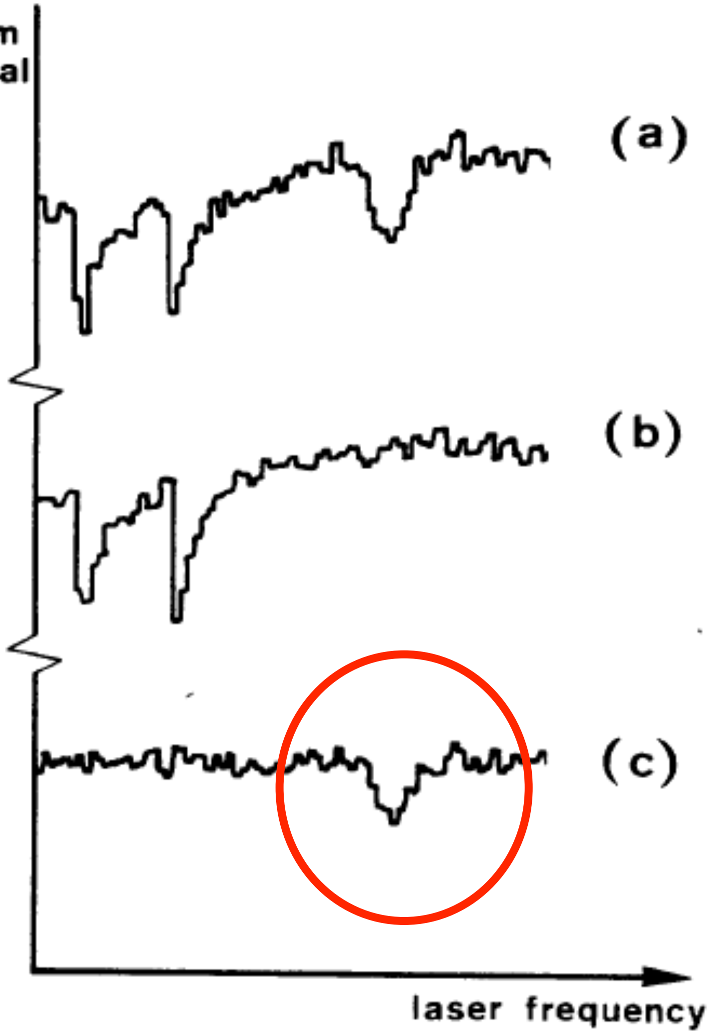
Thanks to Serge Haroche for his interest in Fr



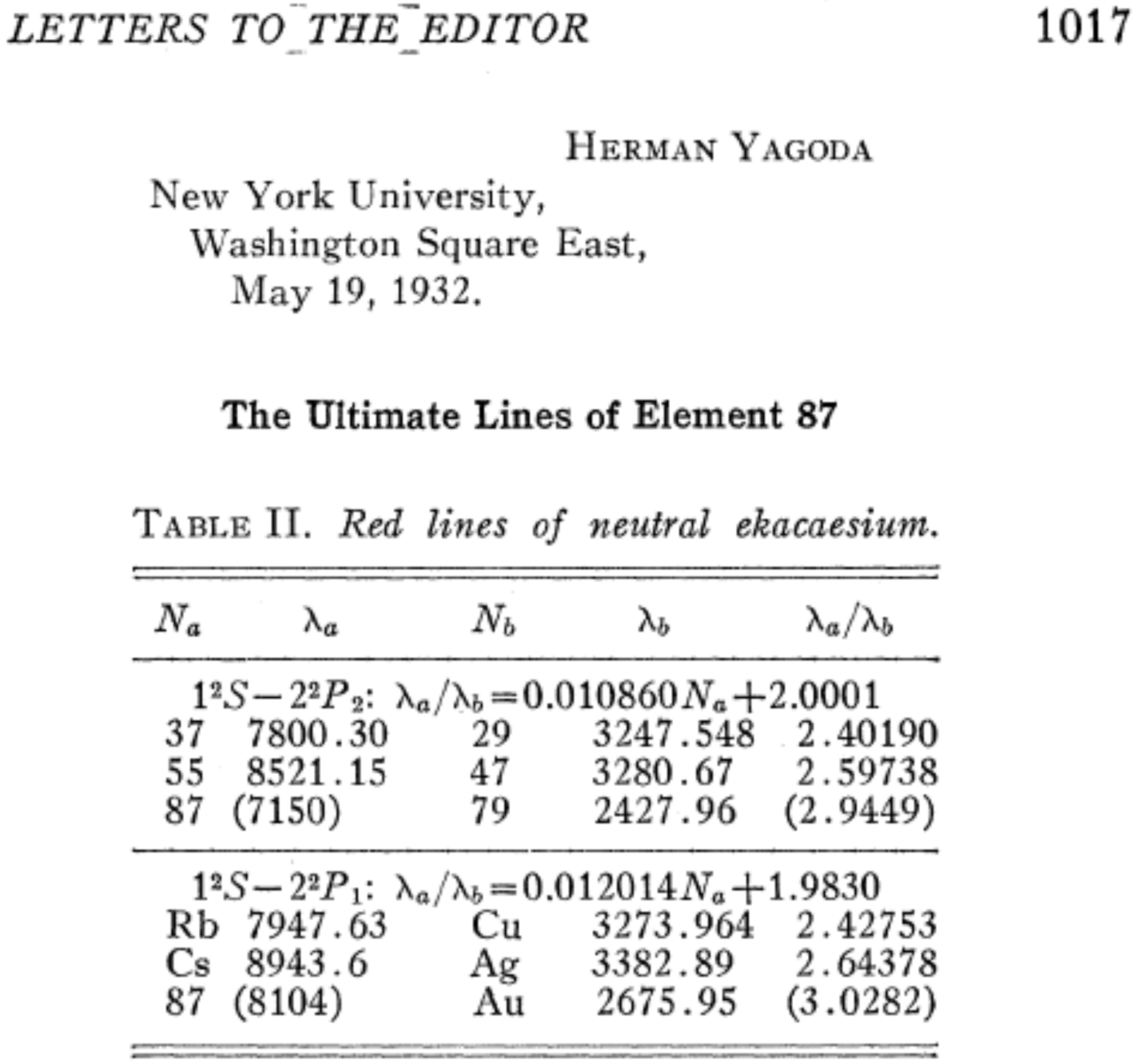


A highly sensitive method of detection coupled with a laser atomic beam experiment using on-line-produced Fr isotopes, has permitted finding and measuring the first optical resonance line of this element and its wavelength: $\lambda = 717.97 \pm 0.01$ nm. A high-resolution optical study has been undertaken, which has led to the determination of the hyperfine structure and isotope shifts for isotopes of mass number 208 to 213.

- Studies in Na, Rb and Cs isotope chains at ISOLDE.
- Radioactive source (ISOLDE): 600 MeV protons on an U target.
- Produced a beam of 10^8 Fr^+ ions neutralized on a cylinder coated with Yttrium.
- Efficiency of about 10^{-5} to the interaction region.
- Tunable lasers (dye lasers) with coarse scanning and fine scanning.
- Detection with a combination of optical pumping, magnetic 6-pole and ion counter.
- Careful about radioactive contamination.



“Laser optical spectroscopy on francium D_2, resonance line.” S. Liberman, J. Pinard, H. T. Duong, P. Juncar, P. Fillet, J.-L. Vialle, P. Jacquinot, F. Touchard, S. Büttgenbach, C. Thibault, M. de Saint-Simon, and R. Klapisch, A. Pesnelle, G. Huber, Phys. Rev. A. 22, 2732 (1980).



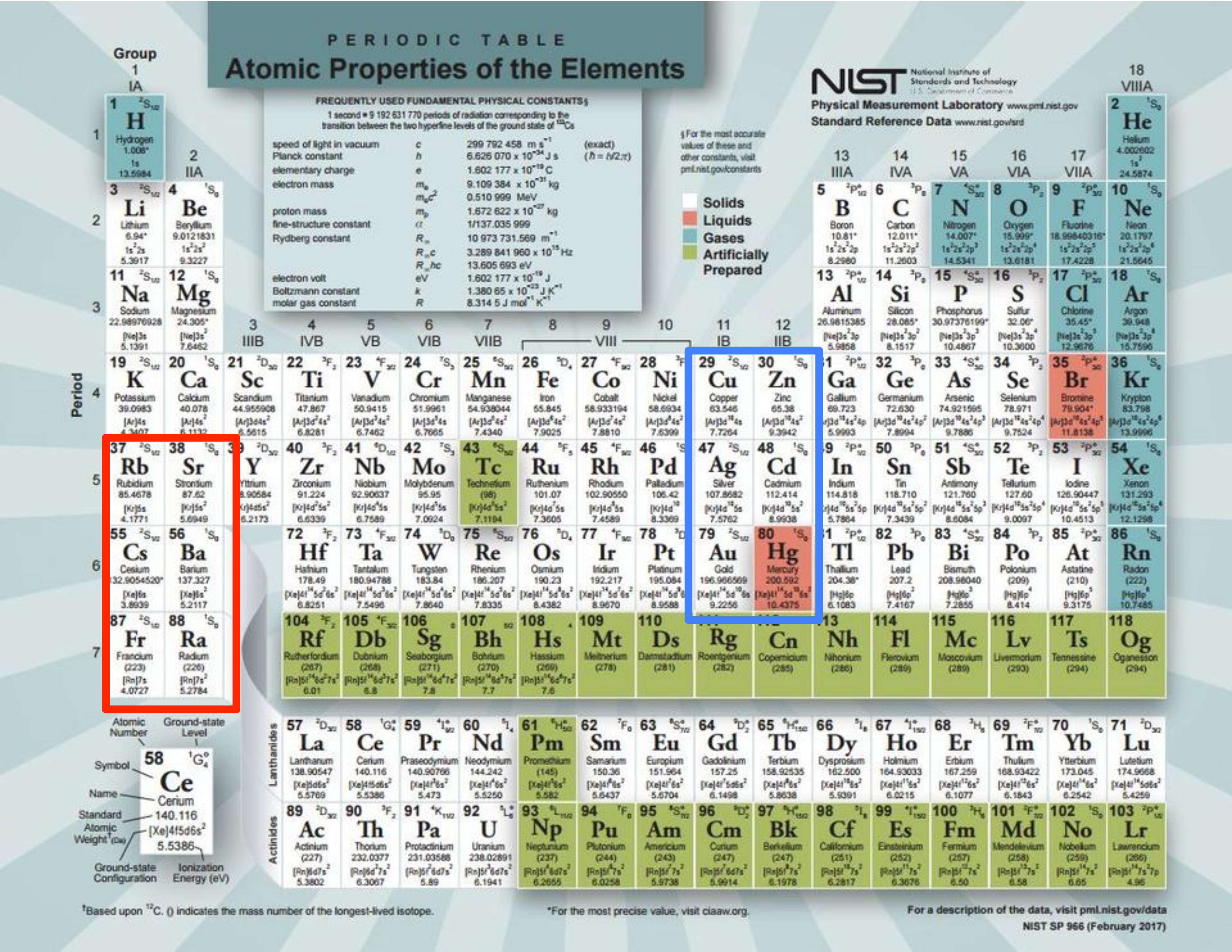
HERMAN YAGODA
New York University,
Washington Square East,
May 19, 1932.

The Ultimate Lines of Element 87

TABLE II. *Red lines of neutral ekacaesium.*

N_a	λ_a	N_b	λ_b	λ_a/λ_b
$1^2S-2^2P_2$: $\lambda_a/\lambda_b=0.010860N_a+2.0001$				
37	7800.30	29	3247.548	2.40190
55	8521.15	47	3280.67	2.59738
87	(7150)	79	2427.96	(2.9449)
$1^2S-2^2P_1$: $\lambda_a/\lambda_b=0.012014N_a+1.9830$				
Rb	7947.63	Cu	3273.964	2.42753
Cs	8943.6	Ag	3382.89	2.64378
87	(8104)	Au	2675.95	(3.0282)

H. Yagoda, Physical Review 40, 1017 (1932)



PERIODIC TABLE

Atomic Properties of the Elements

NIST National Institute of Standards and Technology U.S. Department of Commerce

Physical Measurement Laboratory www.pml.nist.gov

Standard Reference Data www.nist.gov/srd

FREQUENTLY USED FUNDAMENTAL PHYSICAL CONSTANTS§

1 second = 9 192 631 770 periods of radiation corresponding to the transition between the two hyperfine levels of the ground state of ^{133}Cs

speed of light in vacuum	c	299 792 458 m s^{-1}	(exact)
Planck constant	h	6.626 070 x 10^{-34} J s	($\hbar = h/2\pi$)
elementary charge	e	1.602 177 x 10^{-19} C	
electron mass	m_e	9.109 384 x 10^{-31} kg	
	$m_e c^2$	0.510 999 MeV	
proton mass	m_p	1.672 622 x 10^{-27} kg	
fine-structure constant	α	1/137.035 999	
Rydberg constant	R_∞	10 973 731.569 m^{-1}	
	$R_\infty c$	3.289 841 960 x 10^{15} Hz	
	$R_\infty hc$	13.605 693 eV	
electron volt	eV	1.602 177 x 10^{-19} J	
Boltzmann constant	k	1.380 65 x 10^{-23} J K^{-1}	
molar gas constant	R	8.314 5 J mol^{-1} K^{-1}	

§For the most accurate values of these and other constants, visit pml.nist.gov/constants

- Solids
- 🟥 Liquids
- 🟦 Gases
- 🟩 Artificially Prepared

Group 1 IA, 2 IIA, 3 IIIB, 4 IVB, 5 VB, 6 VIB, 7 VIIB, 8, 9, 10 VIII, 11 IB, 12 IIB, 13 IIIA, 14 IVA, 15 VA, 16 VIA, 17 VIIA, 18 VIIIA

Period 1–7

1	${}^2S_{1/2}$	H	Hydrogen	1.008*	$1s$	13.5984
2	${}^1S_0$	He	Helium	4.002602	$1s^2$	24.5874
3	${}^2S_{1/2}$	Li	Lithium	6.94*	$1s^2 2s$	5.3917
4	${}^1S_0$	Be	Beryllium	9.0121831	$1s^2 2s^2$	9.3227
5	${}^2P^\circ_{1/2}$	B	Boron	10.81*	$1s^2 2s^2 2p$	8.2980
6	${}^3P_0$	C	Carbon	12.011*	$1s^2 2s^2 2p^2$	11.2603
7	${}^4S^\circ_{3/2}$	N	Nitrogen	14.007*	$1s^2 2s^2 2p^3$	14.5341
8	${}^3P_2$	O	Oxygen	15.999*	$1s^2 2s^2 2p^4$	13.6181
9	${}^2P^\circ_{3/2}$	F	Fluorine	18.998403163	$1s^2 2s^2 2p^5$	17.4228
10	${}^1S_0$	Ne	Neon	20.1797	$1s^2 2s^2 2p^6$	21.5645
11	${}^2S_{1/2}$	Na	Sodium	22.98976928	[Ne]$3s$	5.1391
12	${}^1S_0$	Mg	Magnesium	24.305*	[Ne]$3s^2$	7.6462
13	${}^2P^\circ_{1/2}$	Al	Aluminum	26.9815385	[Ne]$3s^2 3p$	5.9858
14	${}^3P_0$	Si	Silicon	28.085*	[Ne]$3s^2 3p^2$	8.1517
15	${}^4S^\circ_{3/2}$	P	Phosphorus	30.973761998	[Ne]$3s^2 3p^3$	10.4867
16	${}^3P_2$	S	Sulfur	32.06*	[Ne]$3s^2 3p^4$	10.3600
17	${}^2P^\circ_{3/2}$	Cl	Chlorine	35.45*	[Ne]$3s^2 3p^5$	12.9676
18	${}^1S_0$	Ar	Argon	39.948	[Ne]$3s^2 3p^6$	15.7596
19	${}^2S_{1/2}$	K	Potassium	39.0983	[Ar]$4s$	4.3407
20	${}^1S_0$	Ca	Calcium	40.078	[Ar]$4s^2$	6.1132
21	${}^2D_{3/2}$	Sc	Scandium	44.955908	[Ar]$3d4s^2$	6.5615
22	${}^3F_2$	Ti	Titanium	47.867	[Ar]$3d^2 4s^2$	6.8281
23	${}^4F_{3/2}$	V	Vanadium	50.9415	[Ar]$3d^3 4s^2$	6.7462
24	${}^7S_3$	Cr	Chromium	51.9961	[Ar]$3d^5 4s$	6.7665
25	${}^6S_{5/2}$	Mn	Manganese	54.938044	[Ar]$3d^5 4s^2$	7.4340
26	${}^5D_4$	Fe	Iron	55.845	[Ar]$3d^6 4s^2$	7.9025
27	${}^4F_{9/2}$	Co	Cobalt	58.933194	[Ar]$3d^7 4s^2$	7.8810
28	${}^3F_4$	Ni	Nickel	58.6934	[Ar]$3d^8 4s^2$	7.6399
29	${}^2S_{1/2}$	Cu	Copper	63.546	[Ar]$3d^{10} 4s$	7.7264
30	${}^1S_0$	Zn	Zinc	65.38	[Ar]$3d^{10} 4s^2$	9.3942
1	${}^2P^\circ_{1/2}$	Ga	Gallium	69.723	$3d^{10} 4s^2 4p$	5.9993
32	${}^3P_0$	Ge	Germanium	72.630	[Ar]$3d^{10} 4s^2 4p^2$	7.8994
33	${}^4S^\circ_{3/2}$	As	Arsenic	74.921595	[Ar]$3d^{10} 4s^2 4p^3$	9.7886
34	${}^3P_2$	Se	Selenium	78.971	[Ar]$3d^{10} 4s^2 4p^4$	9.7524
35	${}^2P^\circ_{3/2}$	Br	Bromine	79.904*	[Ar]$3d^{10} 4s^2 4p^5$	11.8138
36	${}^1S_0$	Kr	Krypton	83.798	[Ar]$3d^{10} 4s^2 4p^6$	13.9996
37	${}^2S_{1/2}$	Rb	Rubidium	85.4678	[Kr]$5s$	4.1771
38	${}^1S_0$	Sr	Strontium	87.62	[Kr]$5s^2$	5.6949
3	${}^2D_{3/2}$	Y	Yttrium	8.90584	[Kr]$4d5s^2$	6.2173
40	${}^3F_2$	Zr	Zirconium	91.224	[Kr]$4d^2 5s^2$	6.6339
41	${}^6D_{1/2}$	Nb	Niobium	92.90637	[Kr]$4d^4 5s$	6.7589
42	${}^7S_3$	Mo	Molybdenum	95.95	[Kr]$4d^5 5s$	7.0924
43	${}^6S_{5/2}$	Tc	Technetium	(98)	[Kr]$4d^5 5s^2$	7.1194
44	${}^5F_5$	Ru	Ruthenium	101.07	[Kr]$4d^7 5s$	7.3605
45	${}^4F_{9/2}$	Rh	Rhodium	102.90550	[Kr]$4d^8 5s$	7.4589
46	${}^1S_0$	Pd	Palladium	106.42	[Kr]$4d^{10}$	8.3369
47	${}^2S_{1/2}$	Ag	Silver	107.8682	[Kr]$4d^{10} 5s$	7.5762
48	${}^1S_0$	Cd	Cadmium	112.414	[Kr]$4d^{10} 5s^2$	8.9938
9	${}^2P^\circ_{1/2}$	In	Indium	114.818	$4d^{10} 5s^2 5p$	5.7864
50	${}^3P_0$	Sn	Tin	118.710	[Kr]$4d^{10} 5s^2 5p^2$	7.3439
51	${}^4S^\circ_{3/2}$	Sb	Antimony	121.760	[Kr]$4d^{10} 5s^2 5p^3$	8.6084
52	${}^3P_2$	Te	Tellurium	127.60	[Kr]$4d^{10} 5s^2 5p^4$	9.0097
53	${}^2P^\circ_{3/2}$	I	Iodine	126.90447	[Kr]$4d^{10} 5s^2 5p^5$	10.4513
54	${}^1S_0$	Xe	Xenon	131.293	[Kr]$4d^{10} 5s^2 5p^6$	12.1298
55	${}^2S_{1/2}$	Cs	Cesium	132.9054520*	[Xe]$6s$	3.8939
56	${}^1S_0$	Ba	Barium	137.327	[Xe]$6s^2$	5.2117
72	${}^3F_2$	Hf	Hafnium	178.49	[Xe]$4f^{14} 5d^2 6s^2$	6.8251
73	${}^4F_{3/2}$	Ta	Tantalum	180.94788	[Xe]$4f^{14} 5d^3 6s^2$	7.5496
74	${}^5D_0$	W	Tungsten	183.84	[Xe]$4f^{14} 5d^4 6s^2$	7.8640
75	${}^6S_{5/2}$	Re	Rhenium	186.207	[Xe]$4f^{14} 5d^5 6s^2$	7.8335
76	${}^5D_4$	Os	Osmium	190.23	[Xe]$4f^{14} 5d^6 6s^2$	8.4382
77	${}^4F_{9/2}$	Ir	Iridium	192.217	[Xe]$4f^{14} 5d^7 6s^2$	8.9670
78	${}^3D_3$	Pt	Platinum	195.084	[Xe]$4f^{14} 5d^9 6s$	8.9588
79	${}^2S_{1/2}$	Au	Gold	196.966569	[Xe]$4f^{14} 5d^{10} 6s$	9.2256
80	${}^1S_0$	Hg	Mercury	200.592	[Xe]$4f^{14} 5d^{10} 6s^2$	10.4375
1	${}^2P^\circ_{1/2}$	Tl	Thallium	204.38*	[Hg]$6p$	6.1083
82	${}^3P_0$	Pb	Lead	207.2	[Hg]$6p^2$	7.4167
83	${}^4S^\circ_{3/2}$	Bi	Bismuth	208.98040	[Hg]$6p^3$	7.2855
84	${}^3P_2$	Po	Polonium	(209)	[Hg]$6p^4$	8.414
85	${}^2P^\circ_{3/2}$	At	Astatine	(210)	[Hg]$6p^5$	9.3175
86	${}^1S_0$	Rn	Radon	(222)	[Hg]$6p^6$	10.7485
87	${}^2S_{1/2}$	Fr	Francium	(223)	[Rn]$7s$	4.0727
88	${}^1S_0$	Ra	Radium	(226)	[Rn]$7s^2$	5.2784
104	${}^3F_2$	Rf	Rutherfordium	(267)	[Rn]$5f^{14} 6d^2 7s^2$	6.01
105	${}^4F_{3/2}$	Db	Dubnium	(268)	[Rn]$5f^{14} 6d^3 7s^2$	6.8
106		Sg	Seaborgium	(271)	[Rn]$5f^{14} 6d^4 7s^2$	7.8
107		Bh	Bohrium	(270)	[Rn]$5f^{14} 6d^5 7s^2$	7.7
108		Hs	Hassium	(269)	[Rn]$5f^{14} 6d^6 7s^2$	7.6
109		Mt	Meitnerium	(278)		
110		Ds	Darmstadtium	(281)		
		Rg	Roentgenium	(282)		
		Cn	Copernicium	(285)		
13		Nh	Nihonium	(286)		
114		Fl	Flerovium	(289)		
115		Mc	Moscovium	(289)		
116		Lv	Livermorium	(293)		
117		Ts	Tennessine	(294)		
118		Og	Oganesson	(294)		

Lanthanides

57	${}^2D_{3/2}$	La	Lanthanum	138.90547	[Xe]$5d6s^2$	5.5769
58	${}^1G^\circ_4$	Ce	Cerium	140.116	[Xe]$4f5d6s^2$	5.5386
59	${}^4I^\circ_{9/2}$	Pr	Praseodymium	140.90766	[Xe]$4f^3 6s^2$	5.473
60	${}^5I_4$	Nd	Neodymium	144.242	[Xe]$4f^4 6s^2$	5.5250
61	${}^6H^\circ_{5/2}$	Pm	Promethium	(145)	[Xe]$4f^5 6s^2$	5.582
62	${}^7F_0$	Sm	Samarium	150.36	[Xe]$4f^6 6s^2$	5.6437
63	${}^8S^\circ_{7/2}$	Eu	Europium	151.964	[Xe]$4f^7 6s^2$	5.6704
64	${}^9D^\circ_2$	Gd	Gadolinium	157.25	[Xe]$4f^7 5d6s^2$	6.1498
65	${}^6H^\circ_{15/2}$	Tb	Terbium	158.92535	[Xe]$4f^9 6s^2$	5.8638
66	${}^5I_8$	Dy	Dysprosium	162.500	[Xe]$4f^{10} 6s^2$	5.9391
67	${}^4I^\circ_{15/2}$	Ho	Holmium	164.93033	[Xe]$4f^{11} 6s^2$	6.0215
68	${}^3H_6$	Er	Erbium	167.259	[Xe]$4f^{12} 6s^2$	6.1077
69	${}^2F^\circ_{7/2}$	Tm	Thulium	168.93422	[Xe]$4f^{13} 6s^2$	6.1843
70	${}^1S_0$	Yb	Ytterbium	173.045	[Xe]$4f^{14} 6s^2$	6.2542
71	${}^2D_{3/2}$	Lu	Lutetium	174.9668	[Xe]$4f^{14} 5d6s^2$	5.4259

Actinides

89	${}^2D_{3/2}$	Ac	Actinium	(227)	[Rn]$6d7s^2$	5.3802
90	${}^3F_2$	Th	Thorium	232.0377	[Rn]$6d^2 7s^2$	6.3067
91	${}^4K_{11/2}$	Pa	Protactinium	231.03588	[Rn]$5f^2 6d7s^2$	5.89
92	${}^5L^\circ_6$	U	Uranium	238.02891	[Rn]$5f^3 6d7s^2$	6.1941
93	${}^6L_{11/2}$	Np	Neptunium	(237)	[Rn]$5f^4 6d7s^2$	6.2655
94	${}^7F_0$	Pu	Plutonium	(244)	[Rn]$5f^6 7s^2$	6.0258
95	${}^8S^\circ_{7/2}$	Am	Americium	(243)	[Rn]$5f^7 7s^2$	5.9738
96	${}^9D^\circ_2$	Cm	Curium	(247)	[Rn]$5f^7 6d7s^2$	5.9914
97	${}^6H^\circ_{15/2}$	Bk	Berkelium	(247)	[Rn]$5f^9 7s^2$	6.1978
98	${}^5I_8$	Cf	Californium	(251)	[Rn]$5f^{10} 7s^2$	6.2817
99	${}^4I^\circ_{15/2}$	Es	Einsteinium	(252)	[Rn]$5f^{11} 7s^2$	6.3676
100	${}^3H_6$	Fm	Fermium	(257)	[Rn]$5f^{12} 7s^2$	6.50
101	${}^2F^\circ_{7/2}$	Md	Mendelevium	(258)	[Rn]$5f^{13} 7s^2$	6.58
102	${}^1S_0$	No	Nobelium	(259)	[Rn]$5f^{14} 7s^2$	6.65
103	${}^2P^\circ_{1/2}$	Lr	Lawrencium	(266)	[Rn]$5f^{14} 7s^2 7p$	4.96

†Based upon ^{12}C. () indicates the mass number of the longest-lived isotope.

*For the most precise value, visit ciaaw.org.

For a description of the data, visit pml.nist.gov/data

NIST SP 966 (February 2017)

Why use Cu, Ag, and Au from the IB column?

He had tried to use some quantum defect theory to predict the location of radium lines, but when they were found the prediction was too far. He used then

$$\frac{\lambda_a}{\lambda_b} = m N_a + b$$

The correlation coefficient for IIA, IIB with the new radium data was high (C>0.9999) so he applied it to eka-cesium using IA and IB, the result is remarkable. All column I elements have a single s electron in the outer shell.

The ionization potential of Fr:

Sample use ^{229}Th to implant ^{225}Ra into a foil that then produces actinium and then francium, all with alpha decays. :

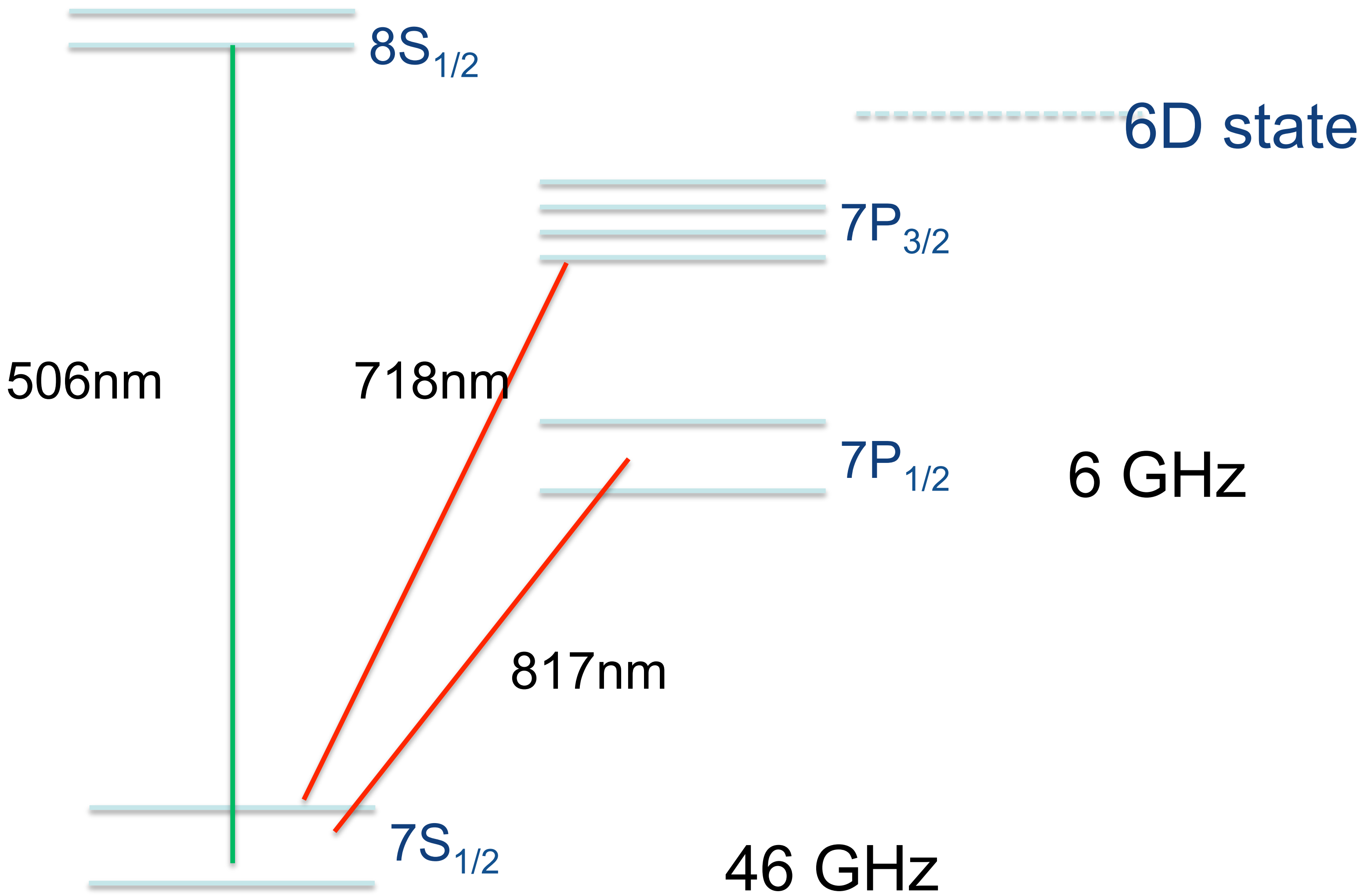
$$^{225}\mathrm{Ra} \xrightarrow[14.8\ \mathrm{days}]{\beta} {}^{225}\mathrm{Ac} \xrightarrow[10\ \mathrm{days}]{\alpha} {}^{221}\mathrm{Fr} \xrightarrow[4.8\ \mathrm{min}]{\alpha}$$

V. S. Letochow (1939-2009)

Excite the D2 line and then bring a laser to almost ionize
Localize the Rydberg series for D and S states
Extrapolate and find I= 32 848.0(3) cm^{-1} or 4.073 eV, more than the 3.89 eV of Cs

“Rydberg levels and ionization potential of francium measured by laser-resonance ionization in a hot cavity”, S. V. Andreev, V. I. Mishin, and V. S. Letokhov J. Opt. Soc. Am. B 5, 2190 (1988).

Francium Atomic Energy Levels

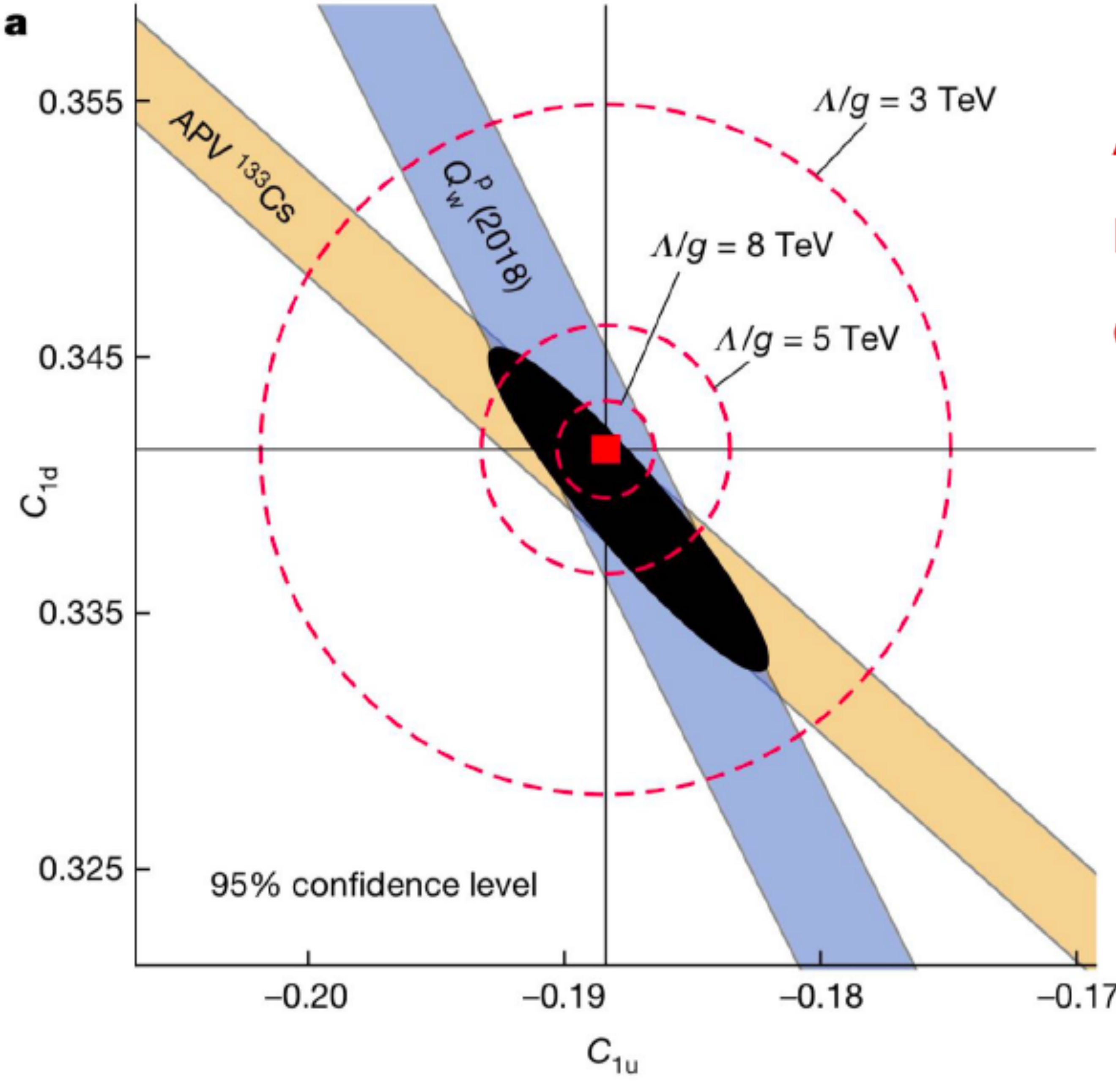


Francium at Stony Brook

Measure Atomic Parity non Conservattion and compare to predictions of the SM and study if the weak interaction gets affected by the presence of lots of nucleons.

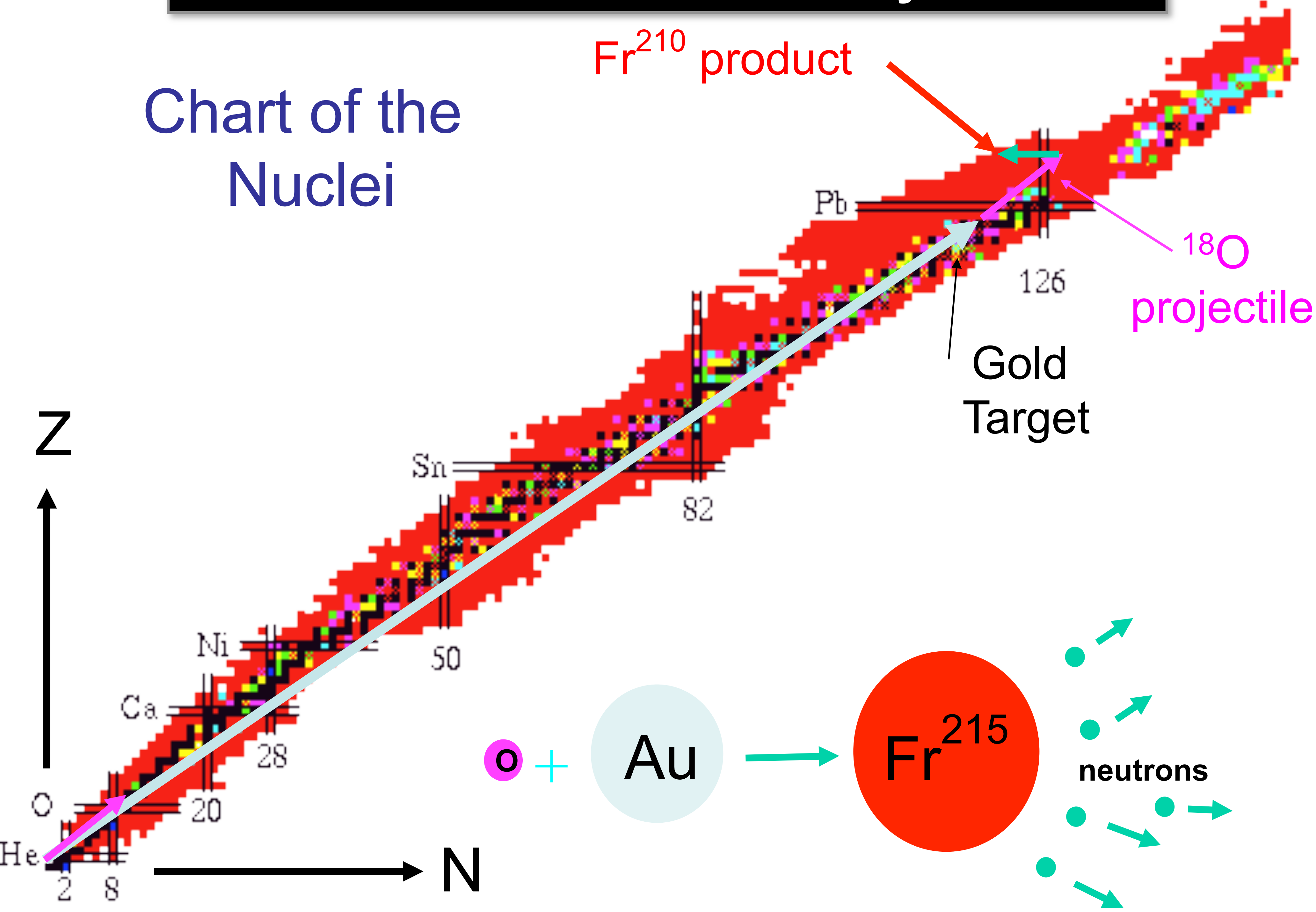
Use a heavy atom (Buchiats) as the measurements scale faster than Z^3 and $Z^{8/3}$

Weak PV electron-quark couplings



Q_{weak} 2018

How did we make Fr at Stony Brook ?

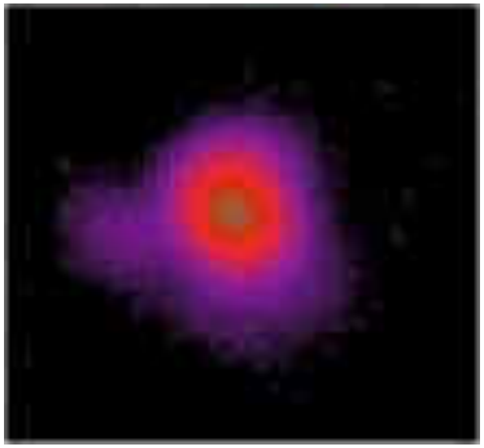


A Brief History of Francium at Stony Brook with Gene D. Sprouse

1991-94: Construction of 1st production and trapping apparatus.

1995: Produced and Trapped Francium in a MOT.

1996-2000: Laser spectroscopy of Francium.



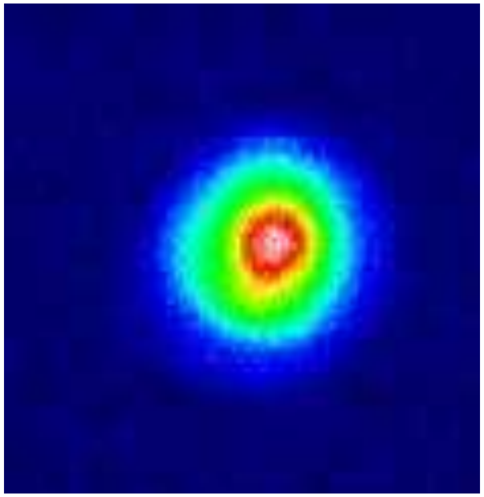
2,000 atoms
Fr MOT

2000-2002: High efficiency trap.

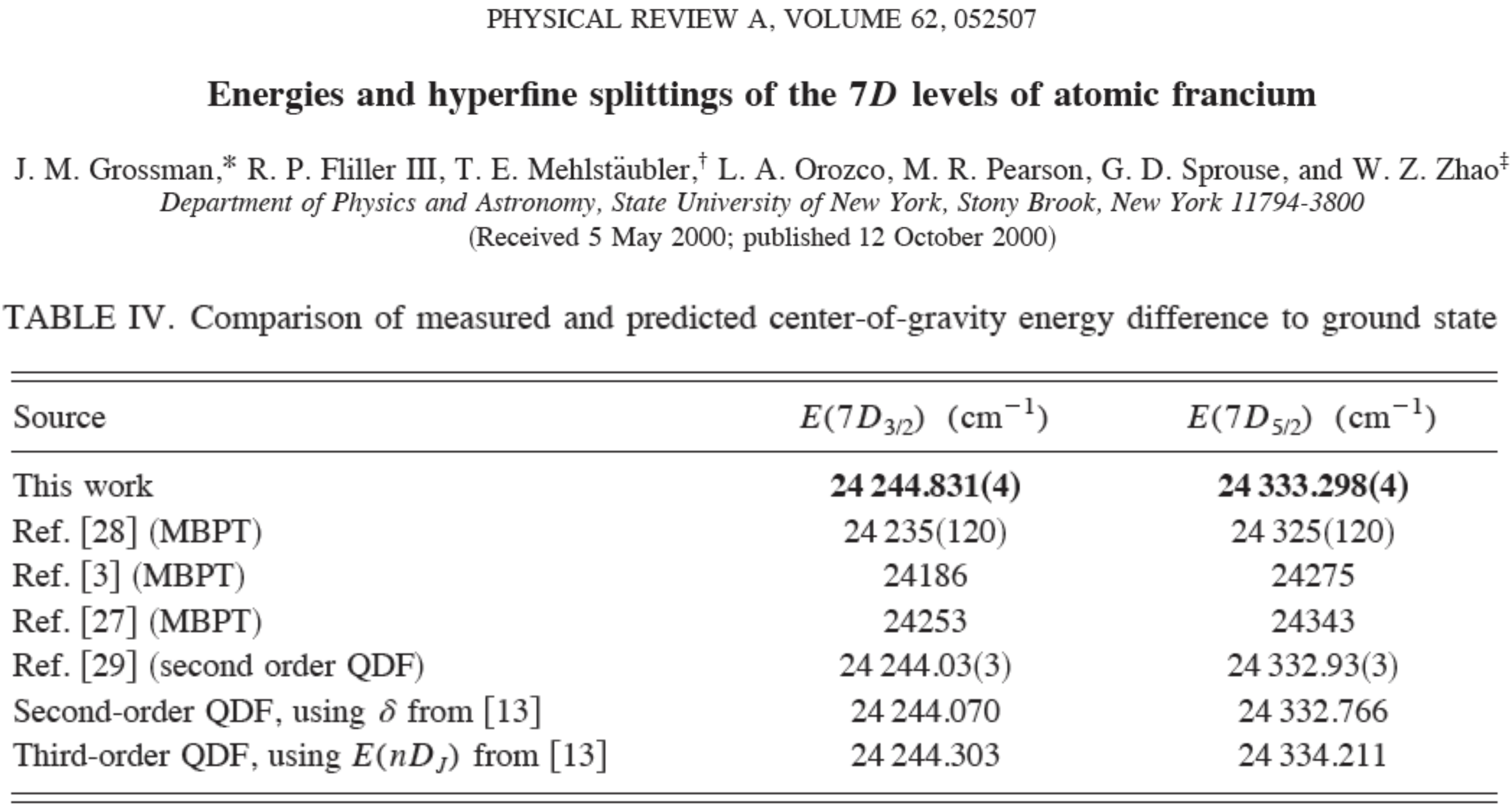
2003: Spectroscopy.

2004: Lifetime of 8S level.

2007: Magnetic moment ^{210}Fr .



250,000 atoms
Fr MOT



PHYSICAL REVIEW A, VOLUME 62, 052507

Energies and hyperfine splittings of the 7*D* levels of atomic francium

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(Received 5 May 2000; published 12 October 2000)

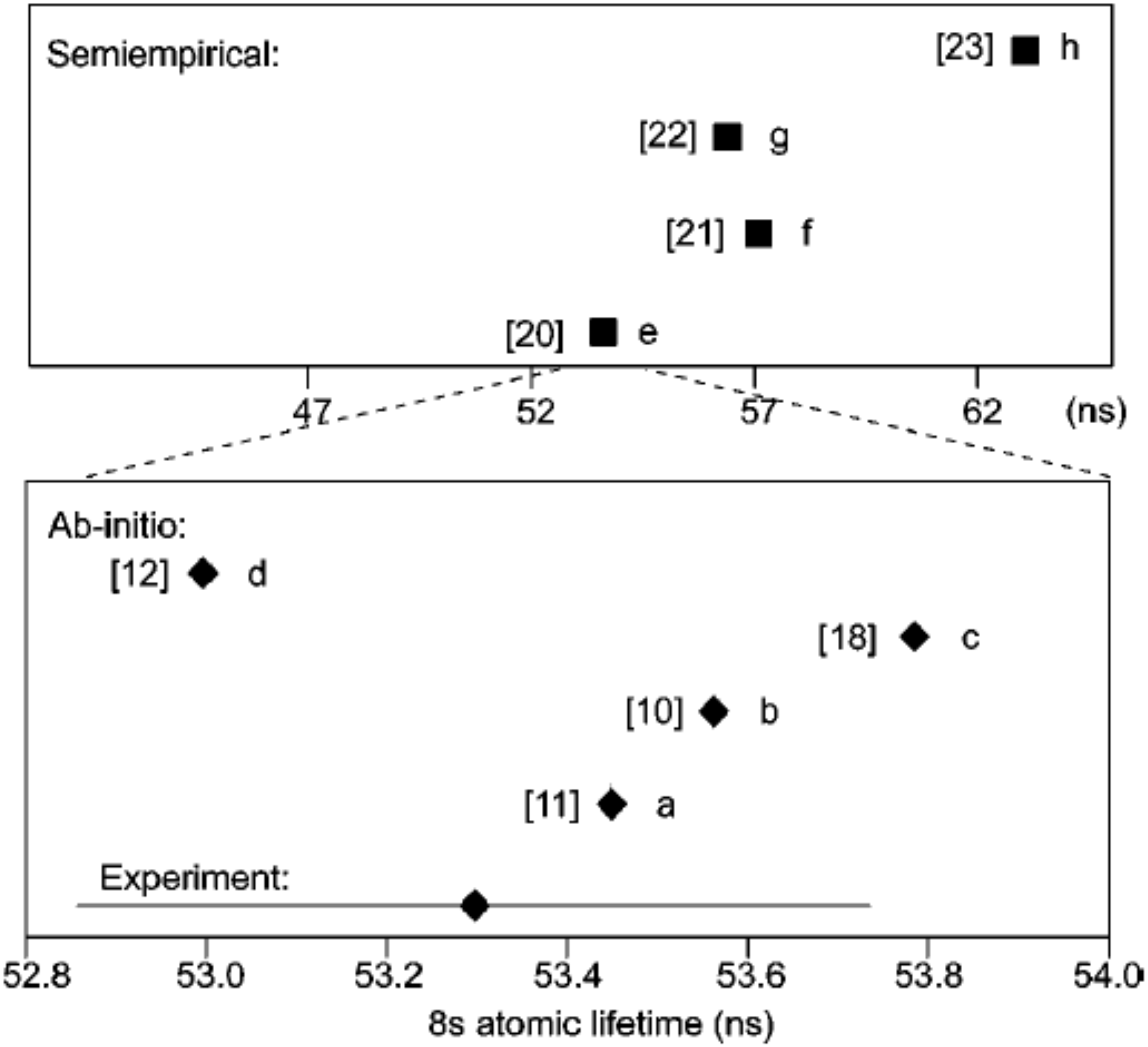
TABLE IV. Comparison of measured and predicted center-of-gravity energy difference to ground state

Source	$E(7D_{3/2})$ (cm^{-1})	$E(7D_{5/2})$ (cm^{-1})
This work	**24 244.831(4)**	**24 333.298(4)**
Ref. [28] (MBPT)	24 235(120)	24 325(120)
Ref. [3] (MBPT)	24186	24275
Ref. [27] (MBPT)	24253	24343
Ref. [29] (second order QDF)	24 244.03(3)	24 332.93(3)
Second-order QDF, using δ from [13]	24 244.070	24 332.766
Third-order QDF, using $E(nD_J)$ from [13]	24 244.303	24 334.211

From 20% (1978) to about $1/10^5$ (2000).

PHYSICAL REVIEW A **71**, 062504 (2005)

Lifetime measurement of the 8*s* level in francium



Uncertainty of 0.8 %

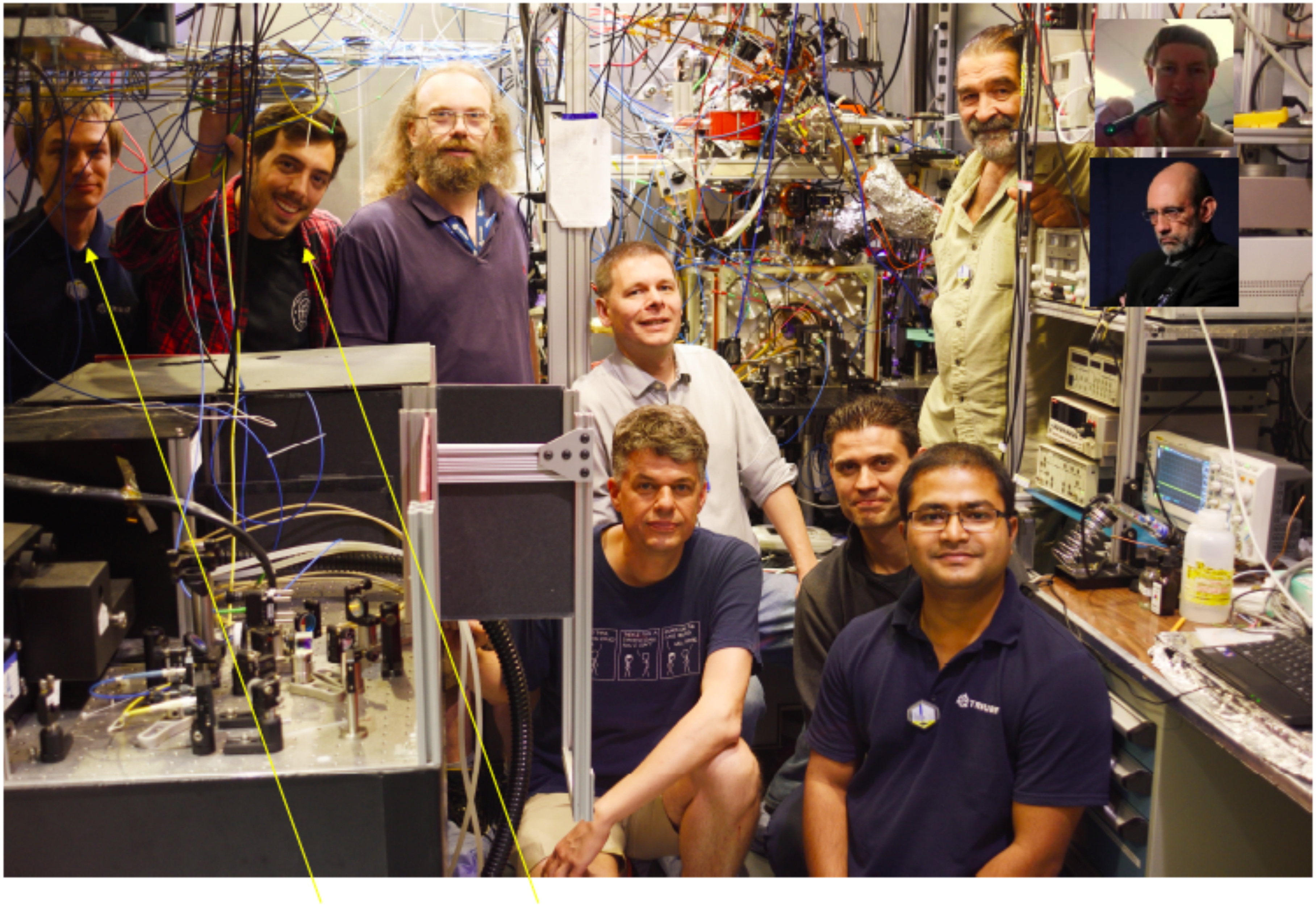
Francium at TRIUMF

FrPNC Colaboration (Winter 2018-2019)

Seth Aubin; College of William and Mary, USA.
John A. Behr, Matt R. Pearson, Alexander Gorolov, Mukut R. Kalita; TRIUMF, Canada.
Victor V. Flambaum; University of New South Wales, Australia.
Eduardo Gómez; Universidad Autónoma de San Luis Potosí, México.
Gerald Gwinner SPOEKESPERSON Tim Hucko, Michael Kossin, ; University of Manitoba, Canada.
Luis A. Orozco; University of Maryland, USA.
Yanting Zhao; Shanxi University, Taiyuan, China.

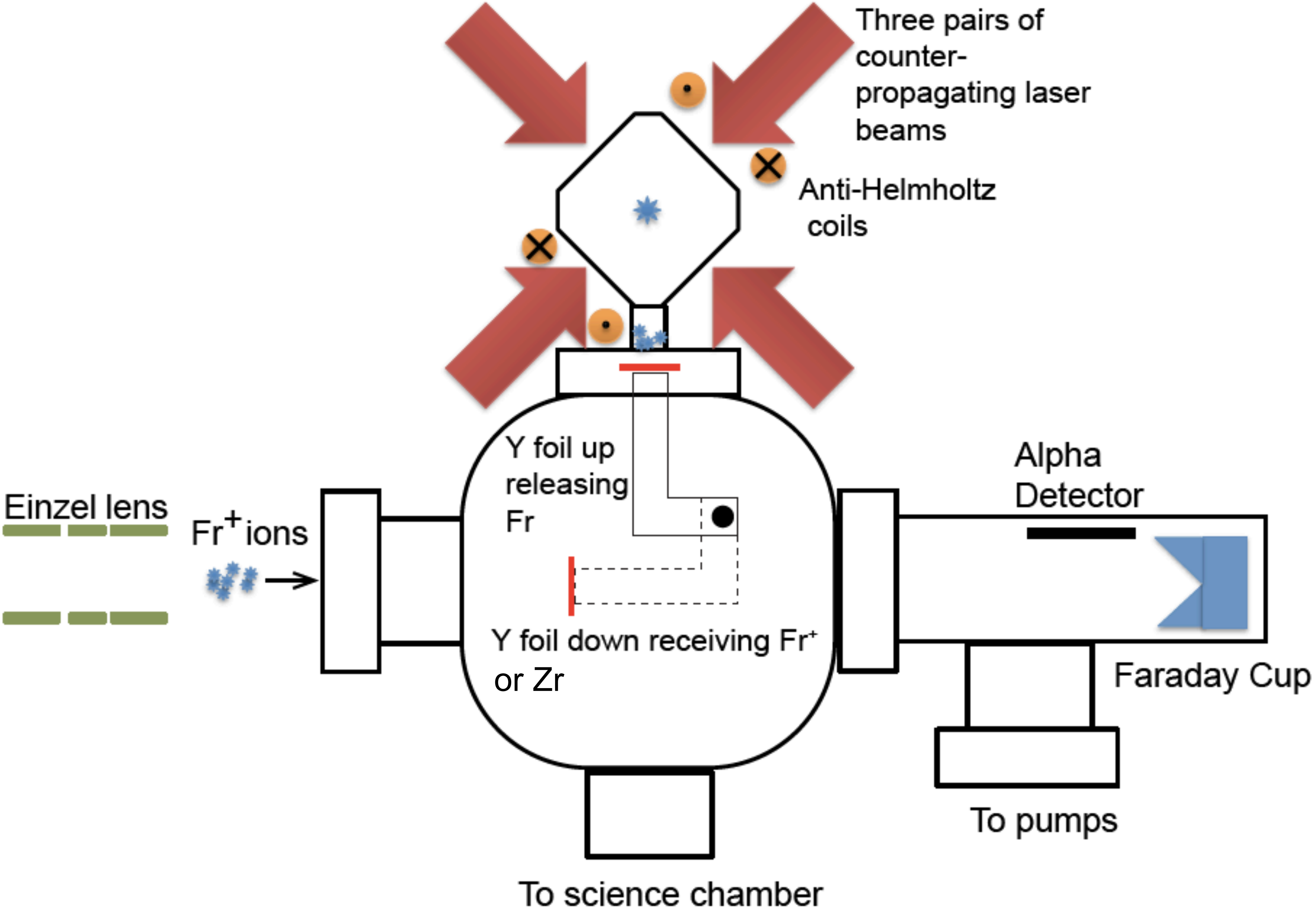
Work supported by: NRC, TRIUMF, and NSERC from Canada, DOE, and NSF of USA, y CONACYT from Mexico.

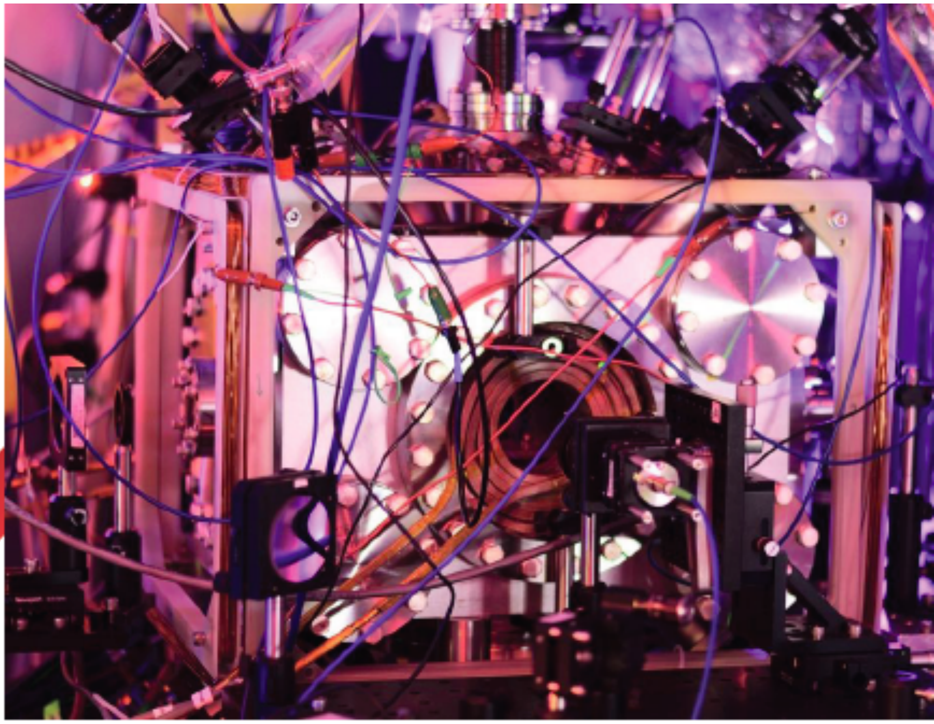
ISAC I hall en TRIUMF, Francium Trapping Facility

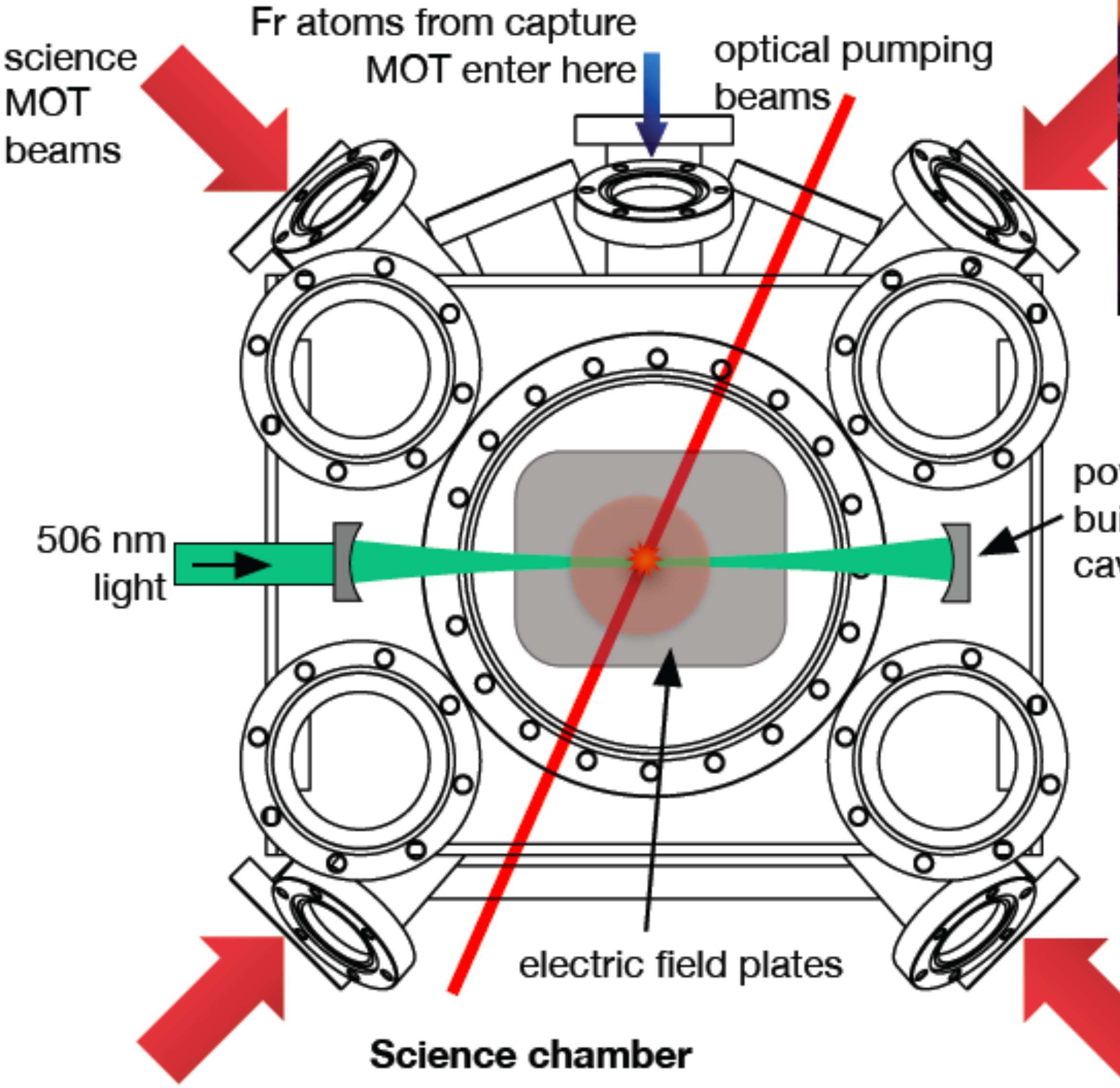


From Left to right: Michael Kossin, Austin deHart, Matt Pearson, Seth Aubin, Gerald Gwinner, Eduardo Gomez, Mukut Kalita, Alexandre Gorelov, John Behr, Luis Orozco.

Fr Trapping Facility capture MOT

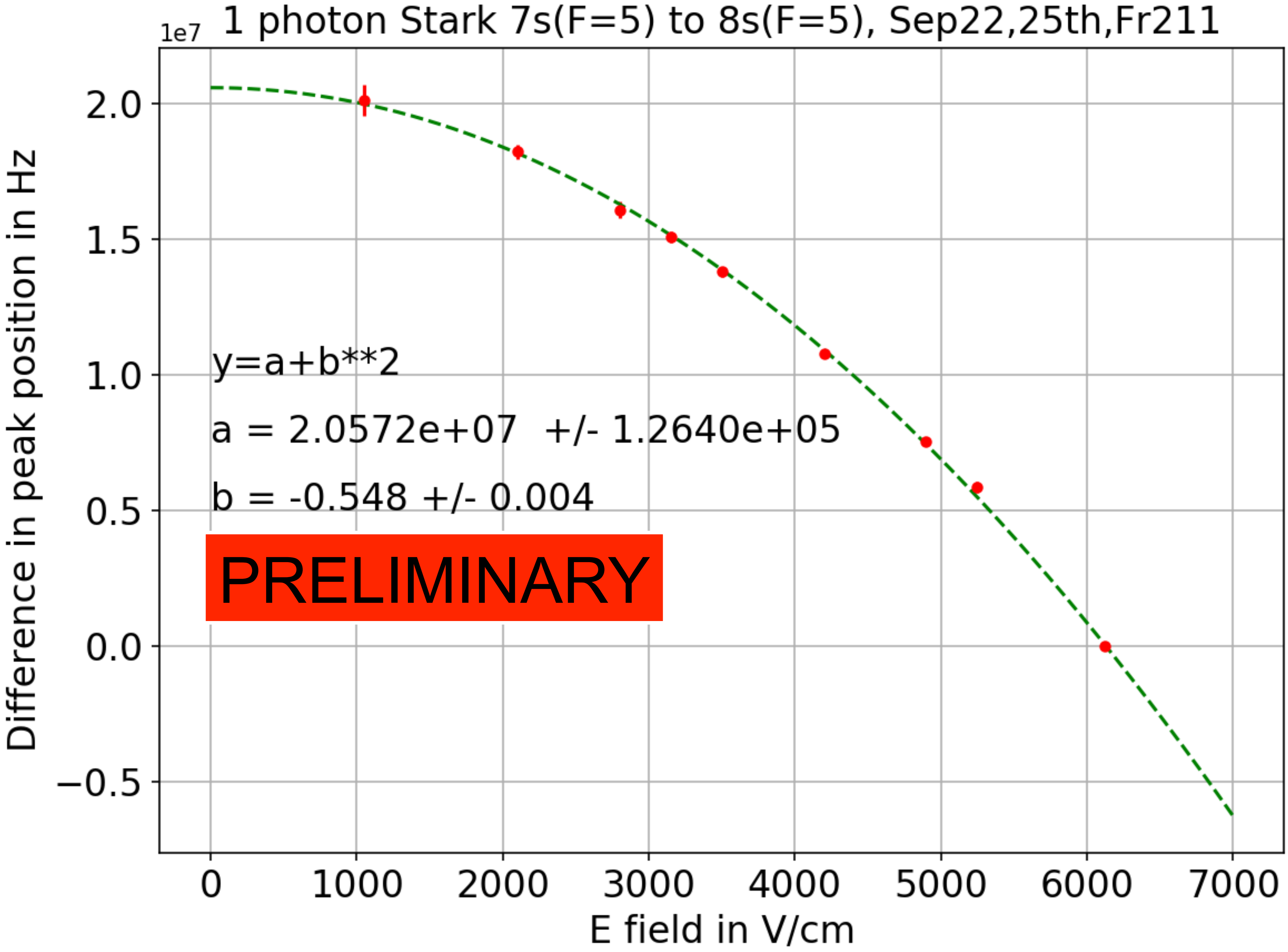




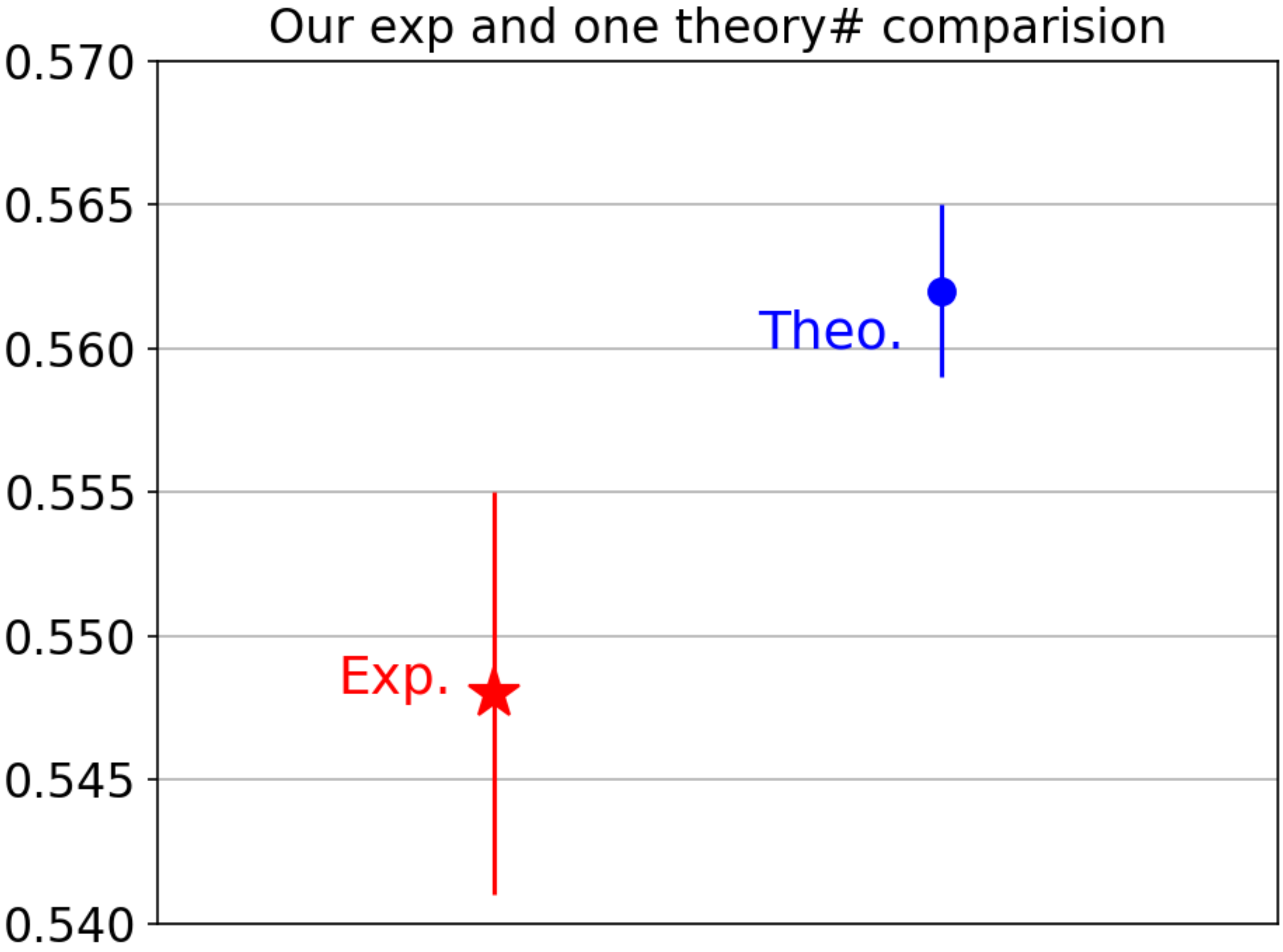


Science chamber

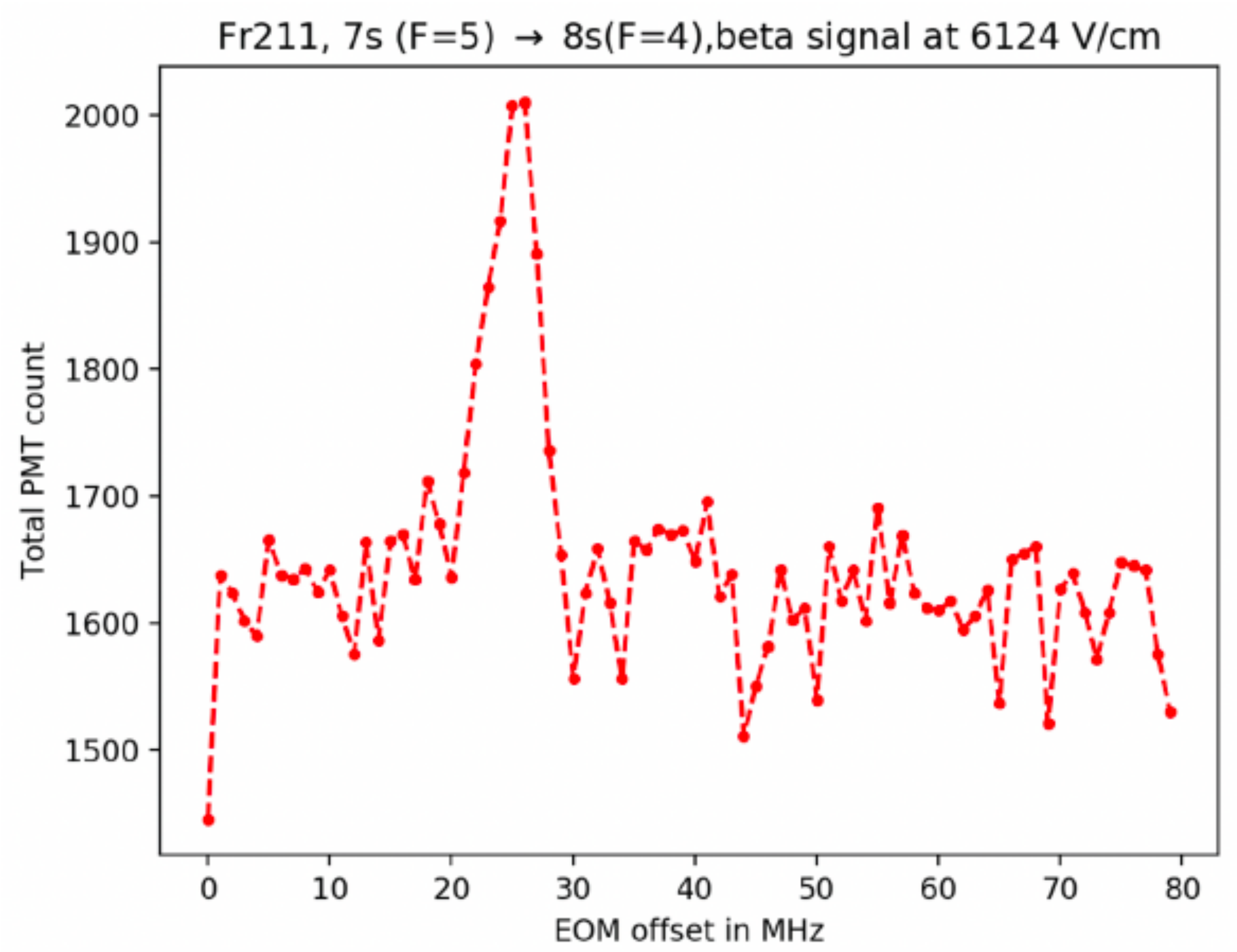
α (scalar) static polarizability in 7s to 8s



Preliminary α static polarizability in 7s to 8s

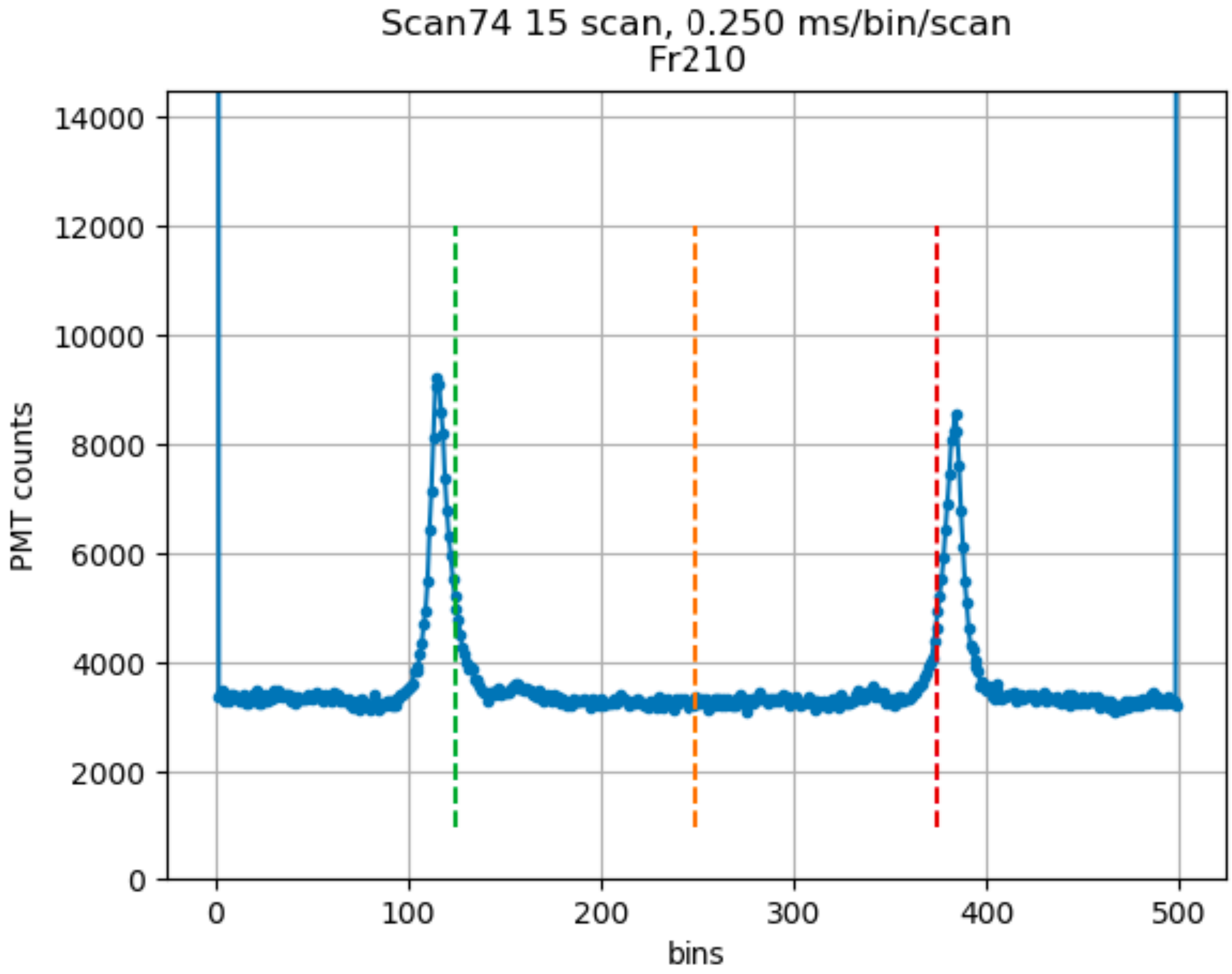


Observation of the ß (vector) Stark induced 7s-8s



10^9 To 10^{10} times weaker than a typical E1 transition.

December 2018 run: Observation of 7s hyperfine splitting in a few Fr isotopes



- The periodic table was crucial in the discovery of francium

- The discovery of Francium by Marguerite Perey is an example of the sensitivity of nuclear methods.

- DC Stark induced transition 7s to 8s for scalar polarizability (measured) and for vector polarizability (observed).

- Closer to Weak interaction studies.

Happy 80th birthday
to Francium
and

谢谢