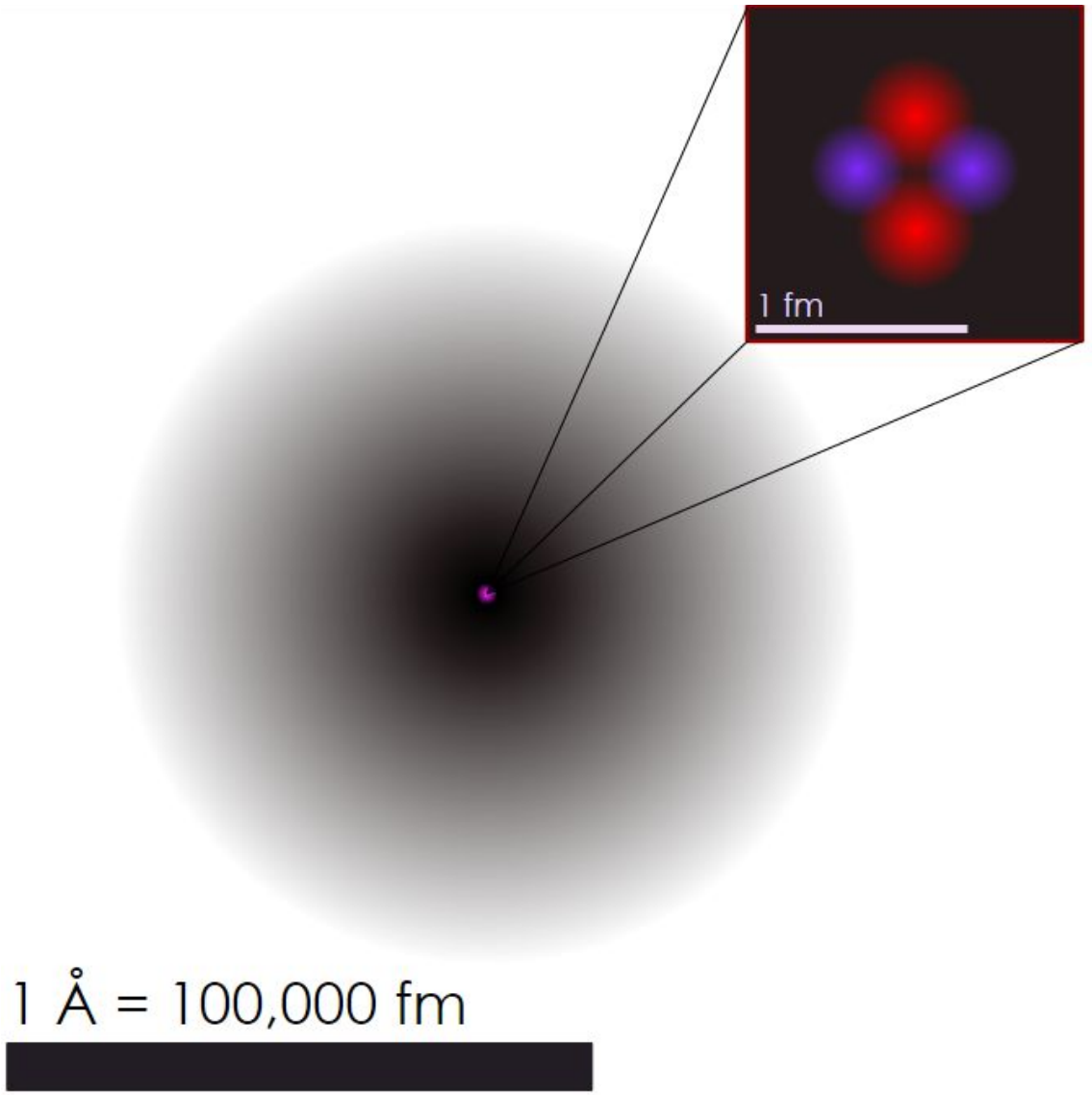
Periodic Table: It's Elementary!

Mikhail V. Kurushkin, PhD

April 8-9, 2017, Sochi

Periodic Table: It's Elementary!



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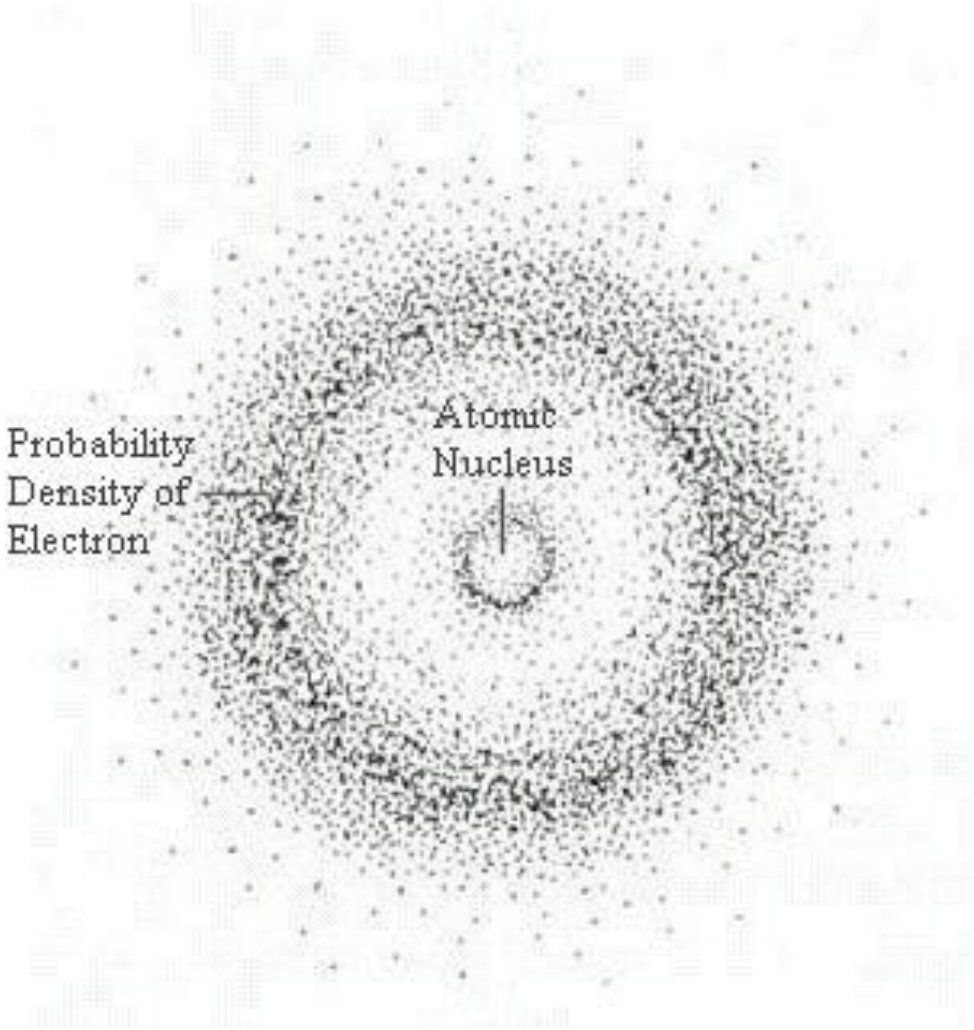
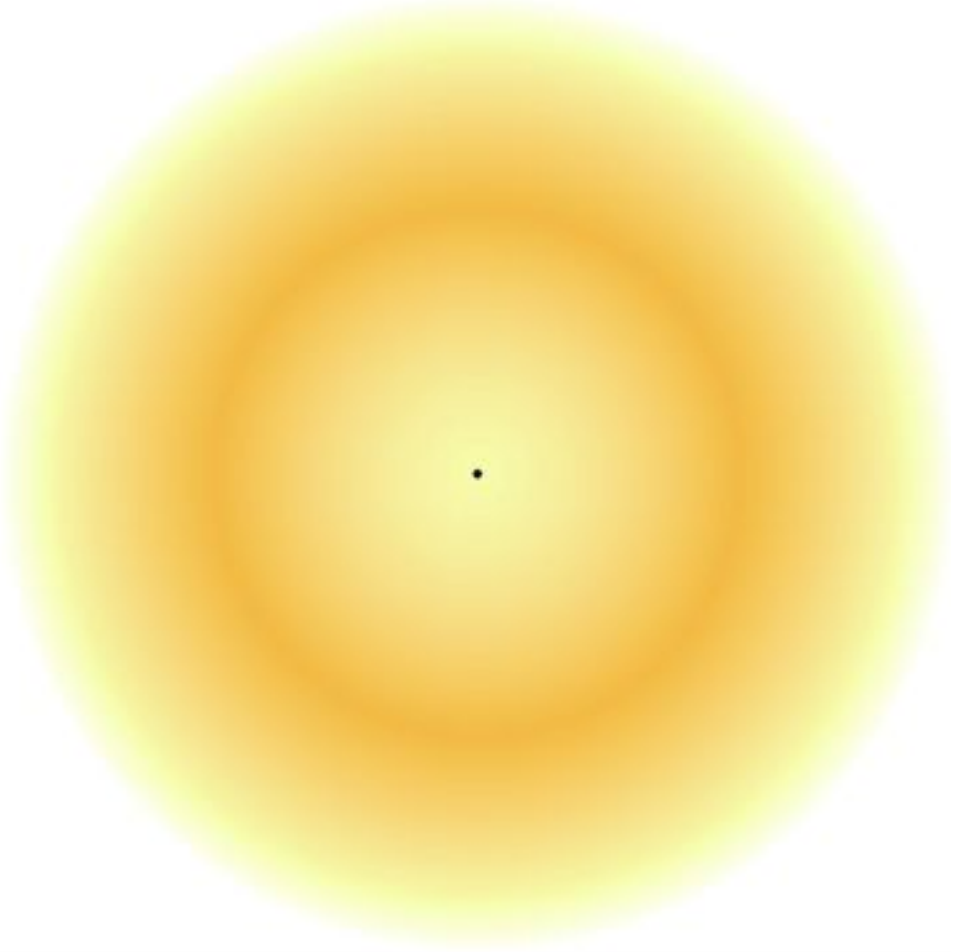


Periodic Table: It's Elementary!

What An Electron Is



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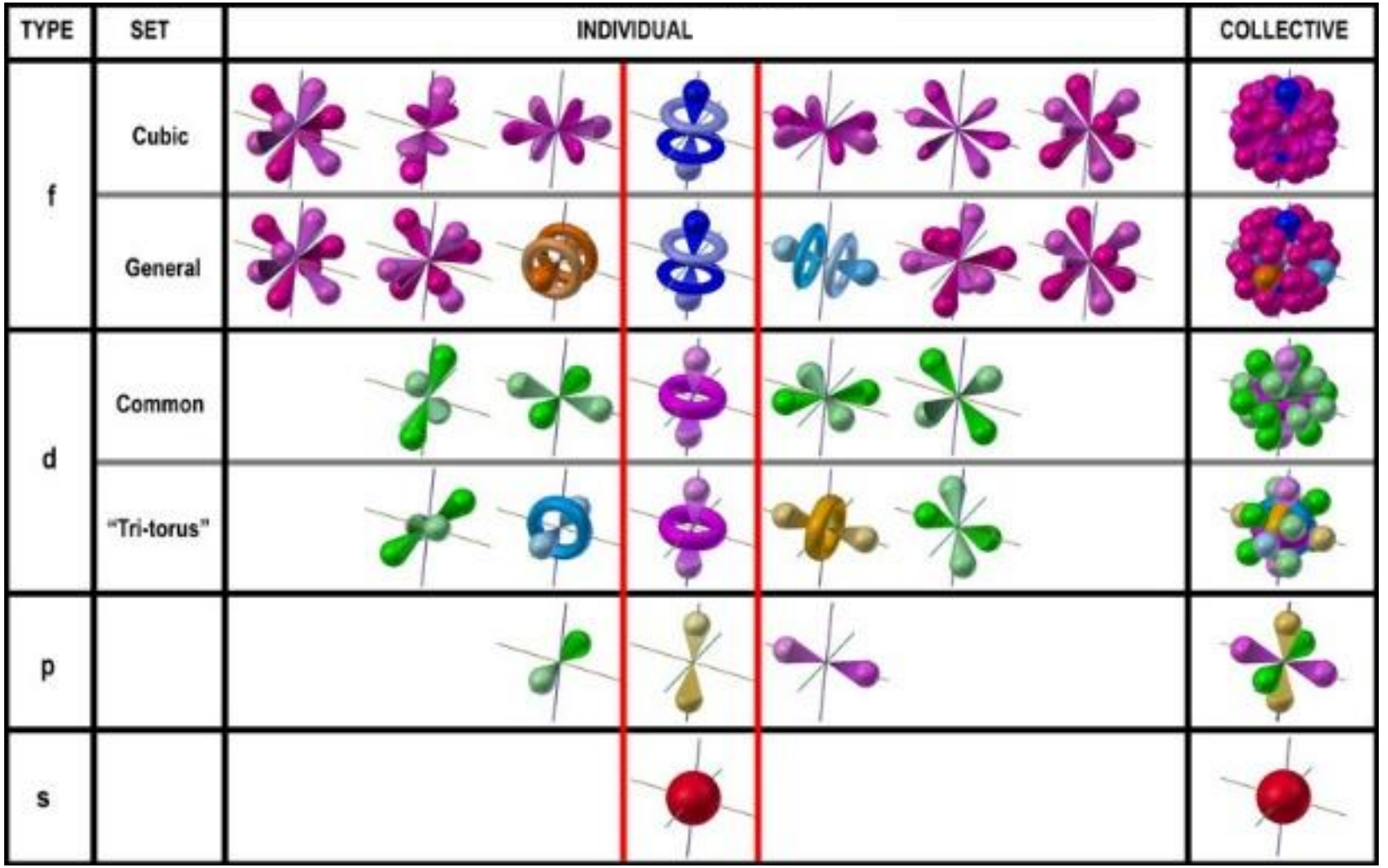

JOURNAL OF CHEMICAL EDUCATION

Communication

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Teaching Atomic Structure: Madelung's and Hund's Rules in One Chart

Mikhail Kurushkin*

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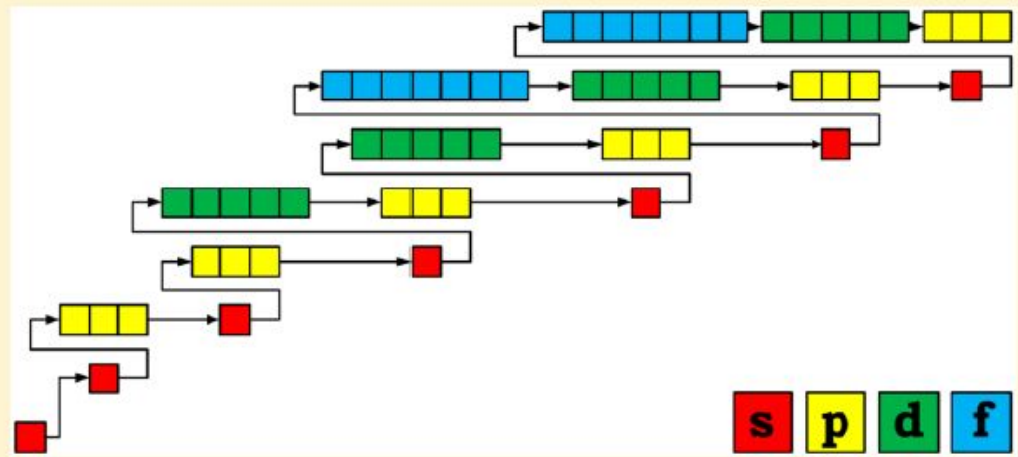
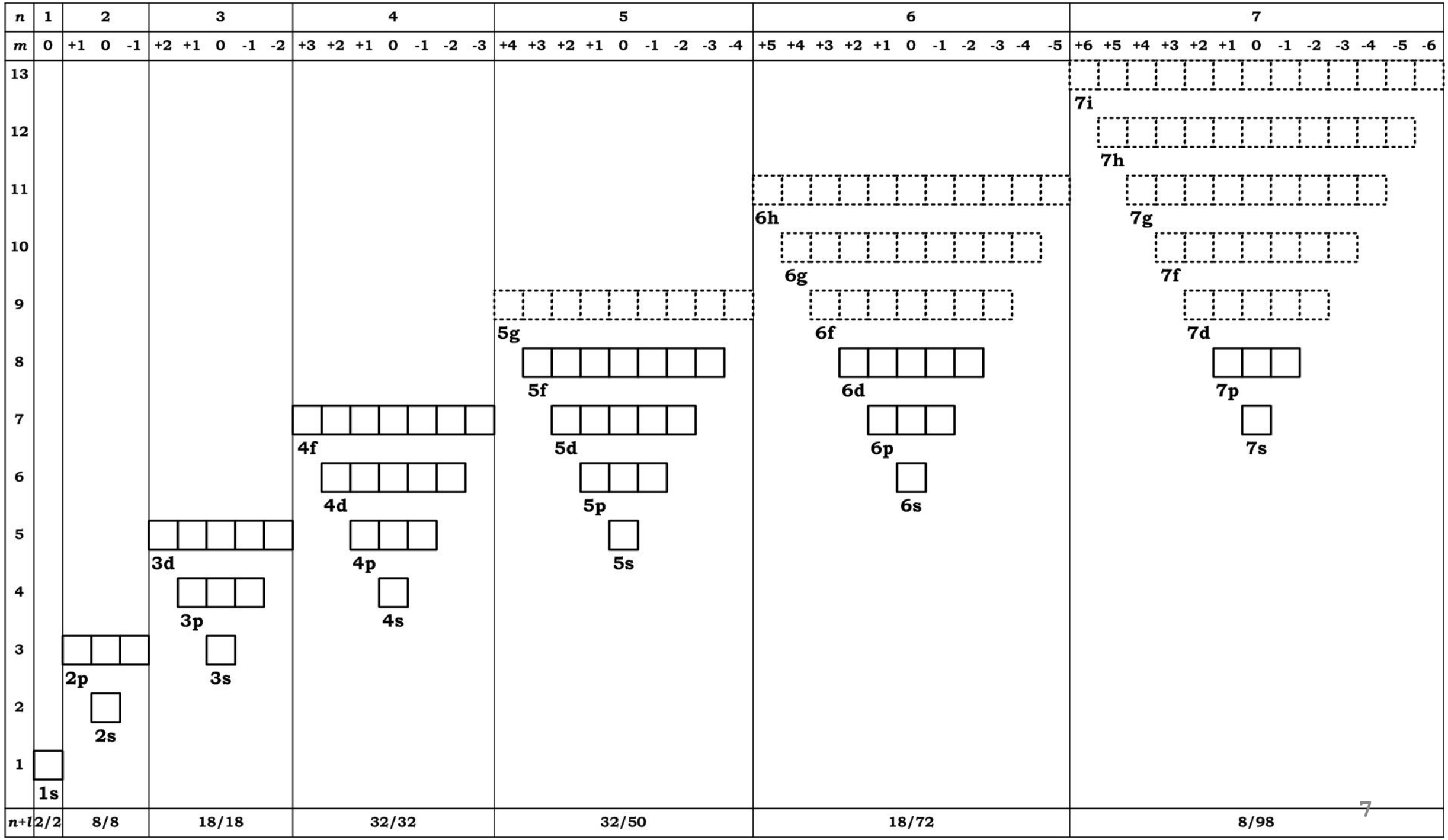
Supporting Information

ABSTRACT: A diagram that represents electron levels and sublevels with the corresponding values of quantum numbers has been designed. The main purpose of the diagram is the explanation of the atomic structure to the students according to Hund's rule and especially Madelung's rule. The diagram represents a specific arrangement of all sublevels' orbital diagrams in order to enhance the understanding of said rules.



KEYWORDS: *High School/Introductory Chemistry, Physical Chemistry, Textbooks/Reference Books, Atomic Properties/Structure*


n 1 2 3 4 5 6 7
m 0 +1 0 -1 +2 +1 0 -1 -2 +3 +2 +1 0 -1 -2 -3 +4 +3 +2 +1 0 -1 -2 -3 -4 +5 +4 +3 +2 +1 0 -1 -2 -3 -4 -5 +6 +5 +4 +3 +2 +1 0 -1 -2 -3 -4 -5 -6
13
12
11
10
9
8
7
6
5
4
3
2
1
1s
2s
2p
3s
3p
3d
4s
4p
4d
4f
5s
5p
5d
5f
5g
6s
6p
6d
6f
6g
6h
7s
7p
7d
7f
7g
7h
7i
n+l 2/2 8/8 18/18 32/32 32/50 18/72 8/98

Periodic Table: It's Elementary!

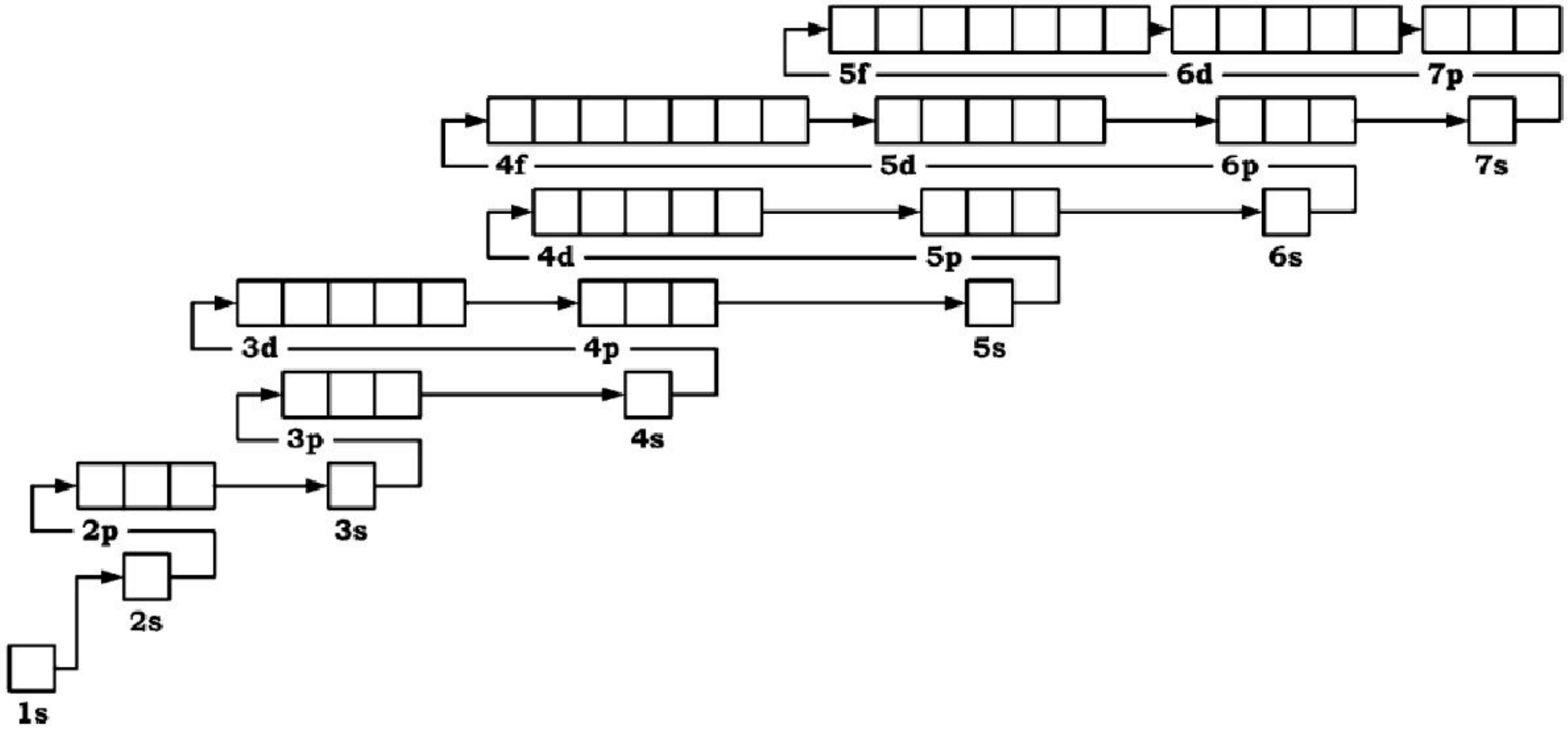
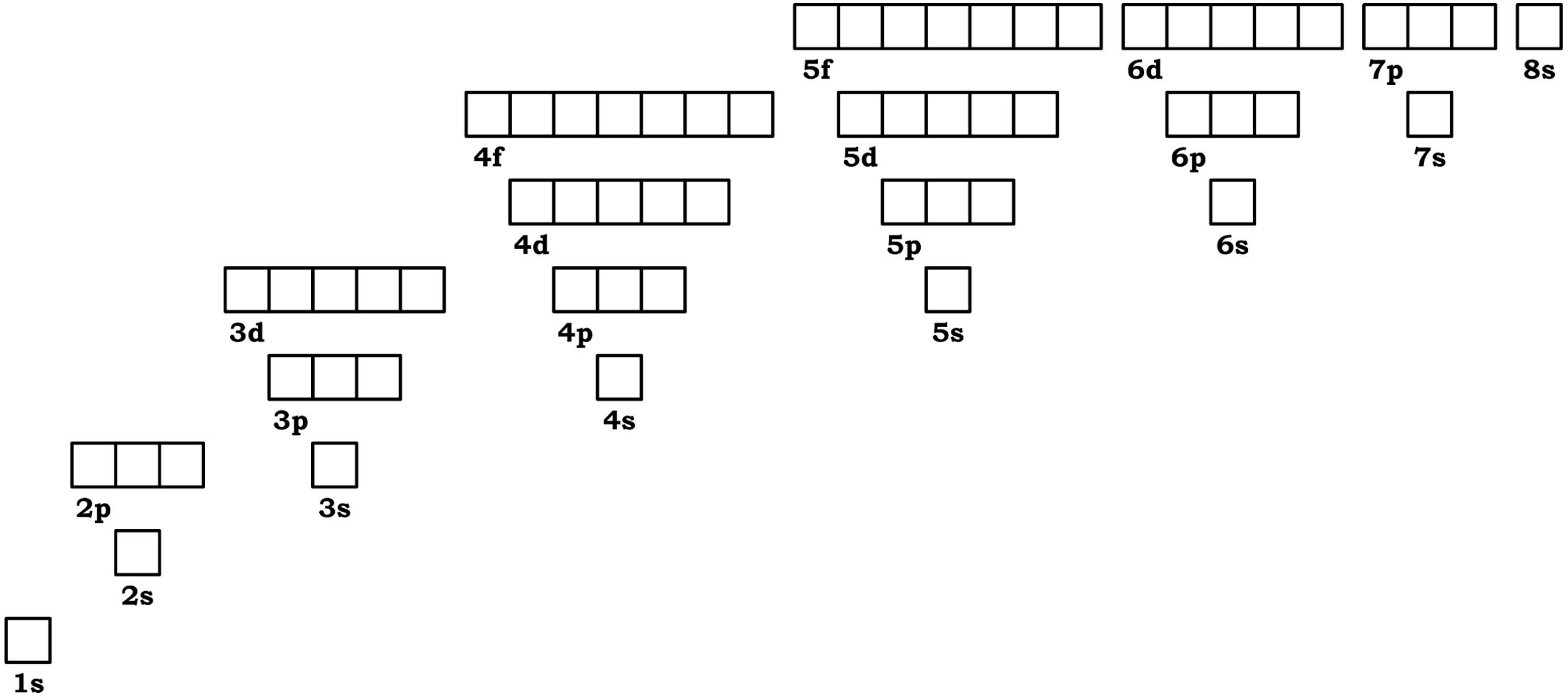


Figure 2. Order for filling the sublevels with electrons according to Madelung's rule.

Periodic Table: It's Elementary!



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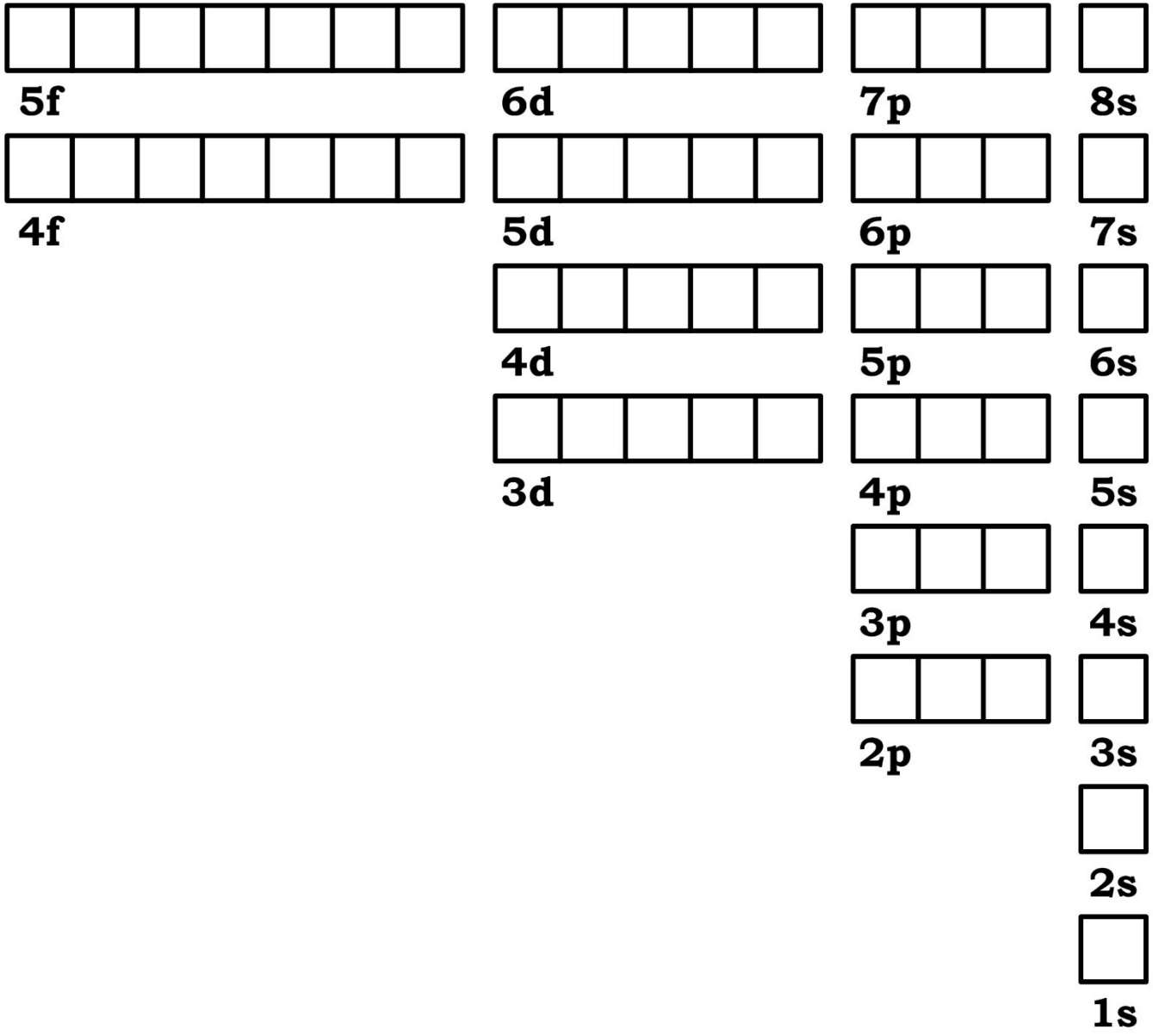

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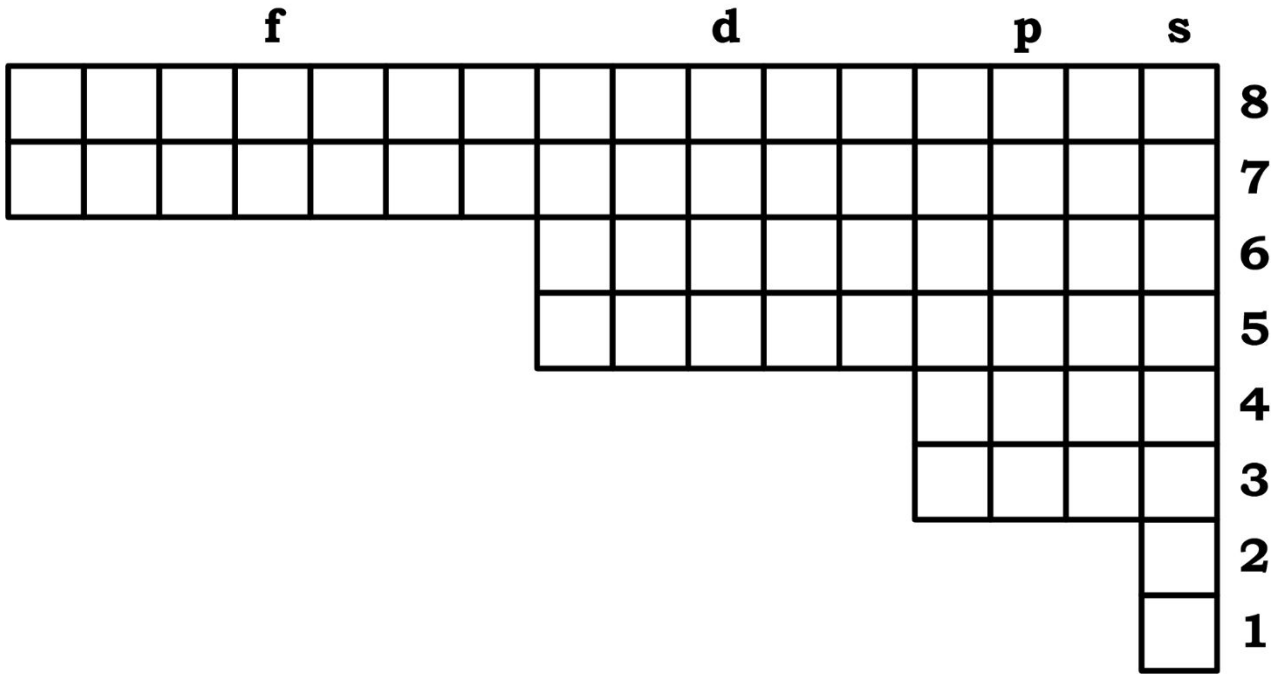

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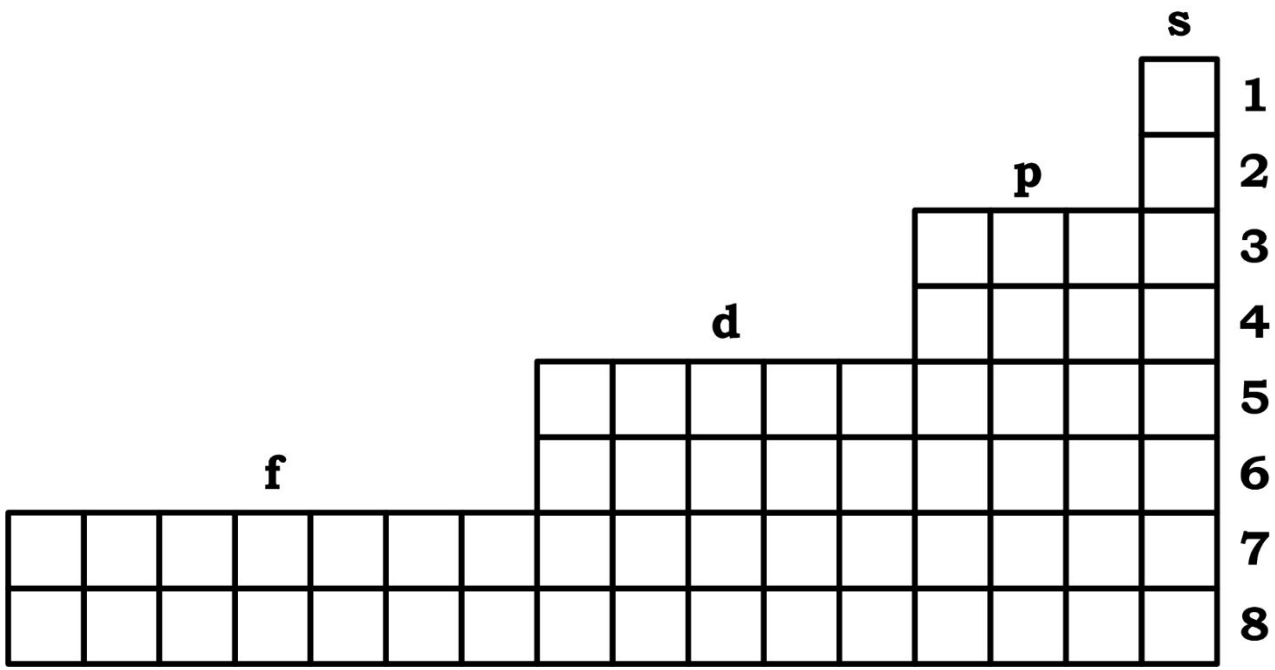

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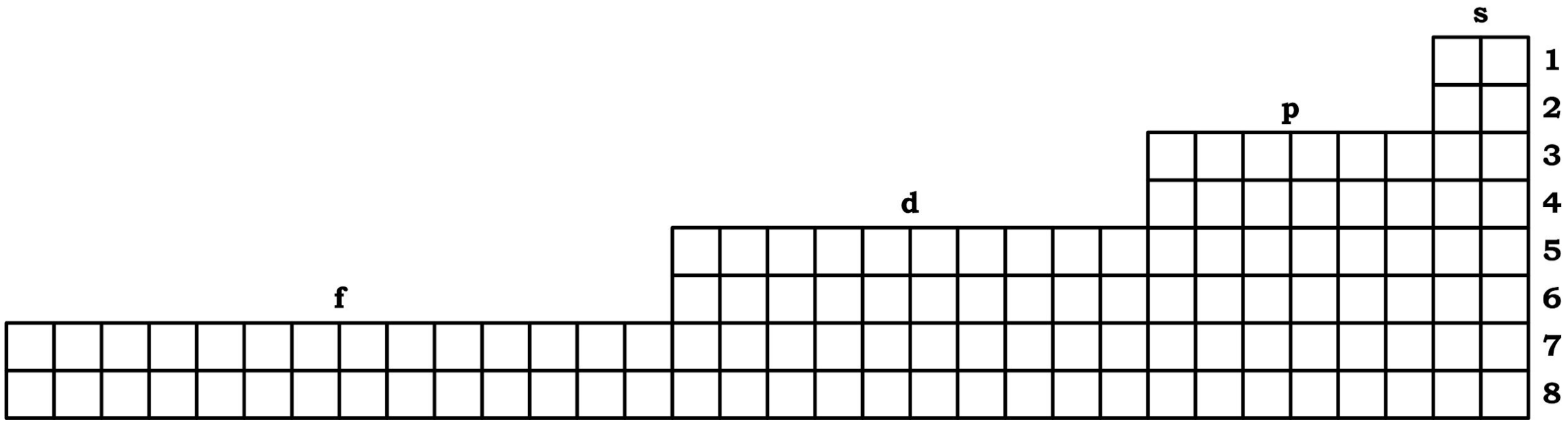


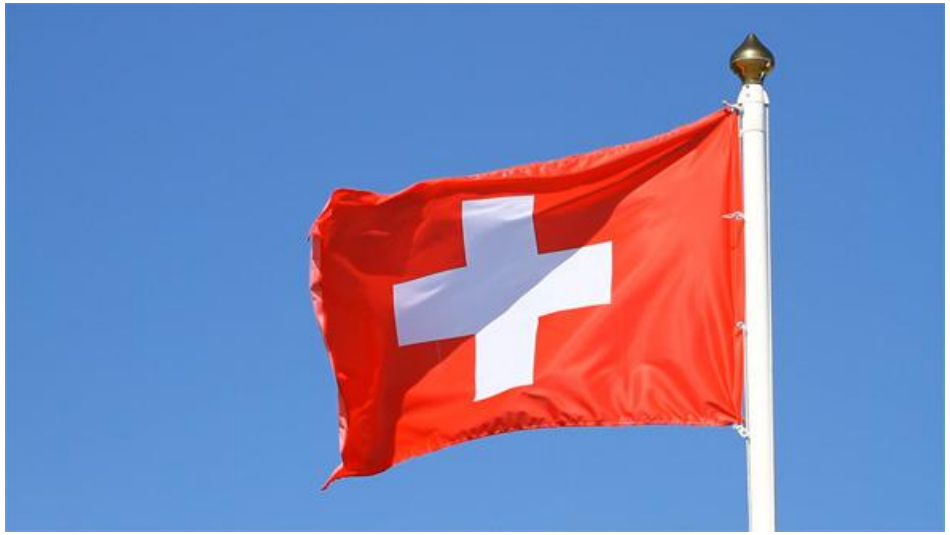
Periodic Table: It's Elementary!

Charles Janet (1926)
Left-step Periodic Table

																						s		
																				H	He	1
																		p		Li	Be	2
														B	C	N	O	F	Ne	Na	Mg	3
												d		Al	Si	P	S	Cl	Ar	K	Ca	4
										Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	Rb	Sr	5
										Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	Cs	Ba	6
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	Fr	Ra	7
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og			8

f

Periodic Table: It's Elementary!



Alfred Werner (1905)
32-column Periodic Table

	s																p						
1	H	He																					
2	Li	Be															B	C	N	O	F	Ne	
3	Na	Mg											d				Al	Si	P	S	Cl	Ar	
4	K	Ca											Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	
5	Rb	Sr											Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	
6	Cs	Ba	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	
7	Fr	Ra	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og	
			f																													

Periodic Table: It's Elementary!

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1	H																He
2	Li	Be											B	C	N	O	F	Ne
3	Na	Mg											Al	Si	P	S	Cl	Ar
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
6	Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
7	Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og

La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Periodic Table: It's Elementary!

IUPAC Periodic Table of the Elements

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H hydrogen 1.008 [1.0078, 1.0082]																	2 He helium 4.0026
3 Li lithium 6.94 [6.938, 6.997]	4 Be beryllium 9.0122											5 B boron 10.81 [10.806, 10.821]	6 C carbon 12.011 [12.009, 12.012]	7 N nitrogen 14.007 [14.006, 14.008]	8 O oxygen 15.999 [15.999, 16.000]	9 F fluorine 18.998	10 Ne neon 20.180
11 Na sodium 22.990	12 Mg magnesium 24.305 [24.304, 24.307]											13 Al aluminium 26.982	14 Si silicon 28.085 [28.084, 28.086]	15 P phosphorus 30.974	16 S sulfur 32.06 [32.059, 32.076]	17 Cl chlorine 35.45 [35.446, 35.457]	18 Ar argon 39.948
19 K potassium 39.098	20 Ca calcium 40.078(4)	21 Sc scandium 44.956	22 Ti titanium 47.867	23 V vanadium 50.942	24 Cr chromium 51.996	25 Mn manganese 54.938	26 Fe iron 55.845(2)	27 Co cobalt 58.933	28 Ni nickel 58.693	29 Cu copper 63.546(3)	30 Zn zinc 65.38(2)	31 Ga gallium 69.723	32 Ge germanium 72.630(8)	33 As arsenic 74.922	34 Se selenium 78.971(8)	35 Br bromine 79.904 [79.901, 79.907]	36 Kr krypton 83.798(2)
37 Rb rubidium 85.468	38 Sr strontium 87.62	39 Y yttrium 88.906	40 Zr zirconium 91.224(2)	41 Nb niobium 92.906	42 Mo molybdenum 95.95	43 Tc technetium	44 Ru ruthenium 101.07(2)	45 Rh rhodium 102.91	46 Pd palladium 106.42	47 Ag silver 107.87	48 Cd cadmium 112.41	49 In indium 114.82	50 Sn tin 118.71	51 Sb antimony 121.76	52 Te tellurium 127.60(3)	53 I iodine 126.90	54 Xe xenon 131.29
55 Cs caesium 132.91	56 Ba barium 137.33	57-71 lanthanoids	72 Hf hafnium 178.49(2)	73 Ta tantalum 180.95	74 W tungsten 183.84	75 Re rhenium 186.21	76 Os osmium 190.23(3)	77 Ir iridium 192.22	78 Pt platinum 195.08	79 Au gold 196.97	80 Hg mercury 200.59	81 Tl thallium 204.38 [204.38, 204.39]	82 Pb lead 207.2	83 Bi bismuth 208.98	84 Po polonium	85 At astatine	86 Rn radon
87 Fr francium	88 Ra radium	89-103 actinoids	104 Rf rutherfordium	105 Db dubnium	106 Sg seaborgium	107 Bh bohrium	108 Hs hassium	109 Mt meitnerium	110 Ds darmstadtium	111 Rg roentgenium	112 Cn copernicium	113 Nh nihonium	114 Fl flerovium	115 Mc moscovium	116 Lv livermorium	117 Ts tennessine	118 Og oganesson

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

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

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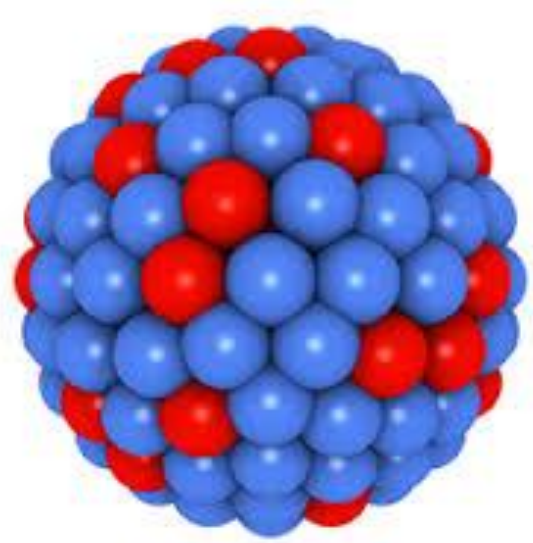
For notes and updates to this table, see www.iupac.org. This version is dated 28 November 2016.

Periodic Table: It's Elementary!

$_{92}U$ U

Chemical Element vs. **Elementary Substance**



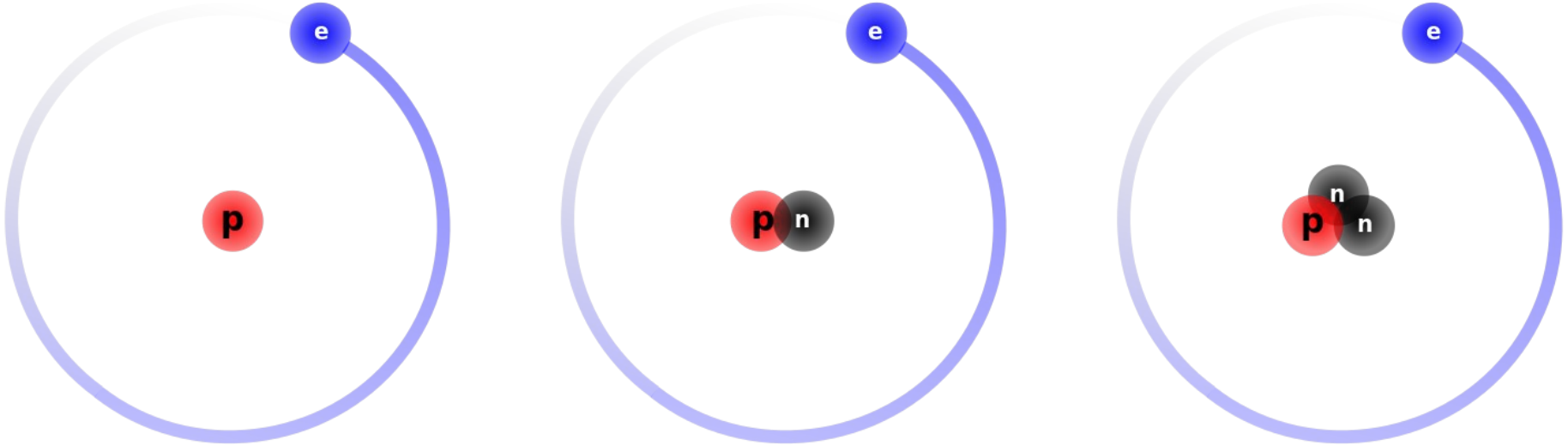
Periodic Table: It's Elementary!

$$_{2}\mathrm{He}$$

$$\mathrm{He}^{0} \quad \mathrm{He}^{+} \quad \mathrm{He}^{++}$$

Chemical Element: Species of Equicharged Atomic Nuclei

Periodic Table: It's Elementary!

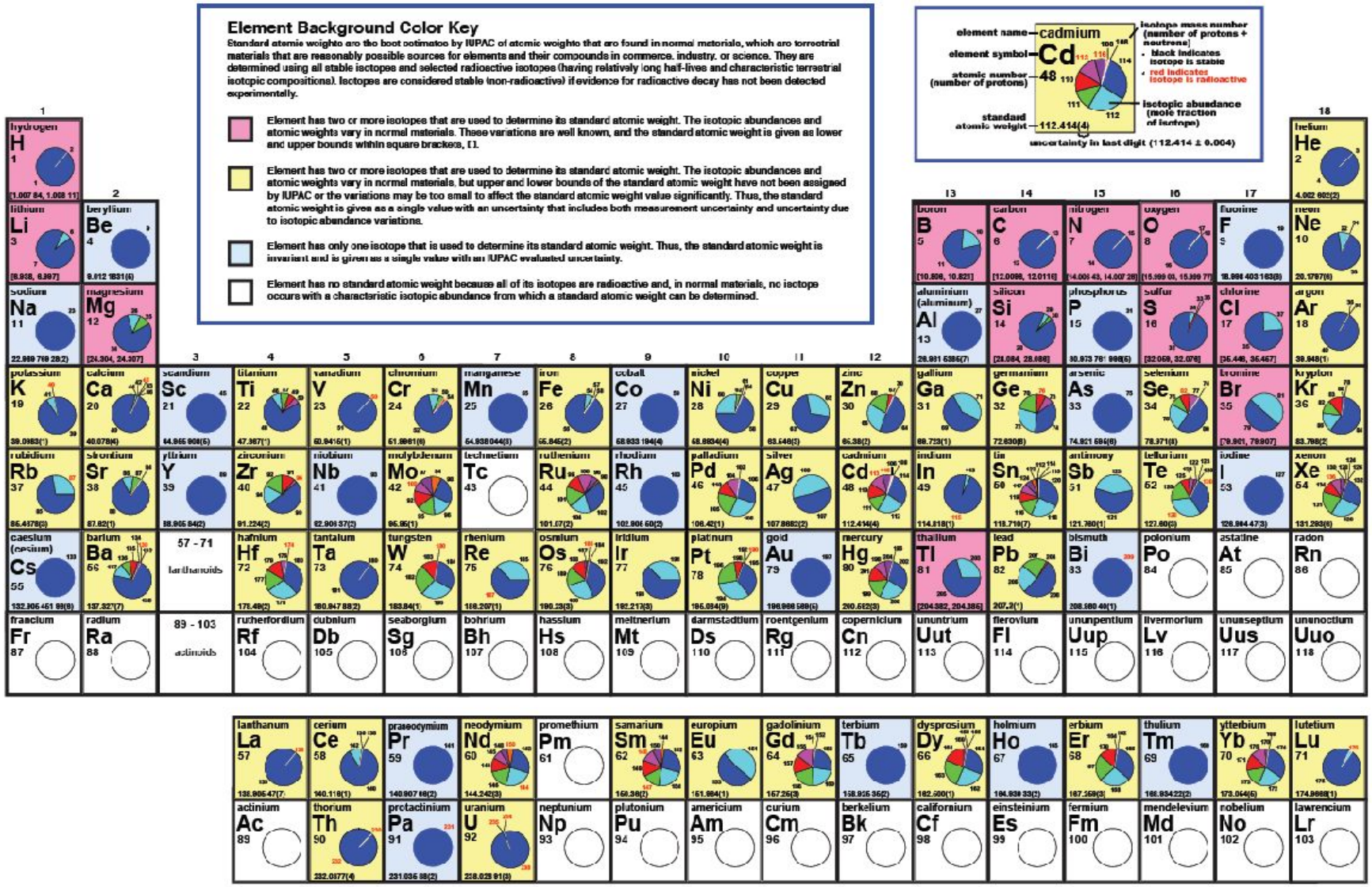


$^{1}_{1}H$ $^{2}_{1}H$ $^{3}_{1}H$

Protium **Deuterium** **Tritium**

Isotopes of Chemical Element: Chemical Element Representatives with different mass number

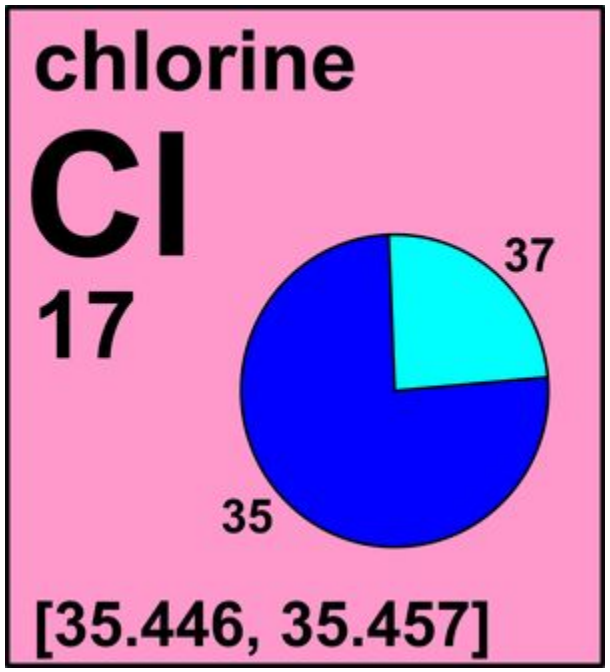
IUPAC Periodic Table of the Isotopes



International Union of Pure and Applied Chemistry (IUPAC) Project 2007-038-3-200, "Development of an isotopic periodic table for the educational community"

October 1, 2013 www.ciaaw.org

Periodic Table: It's Elementary!

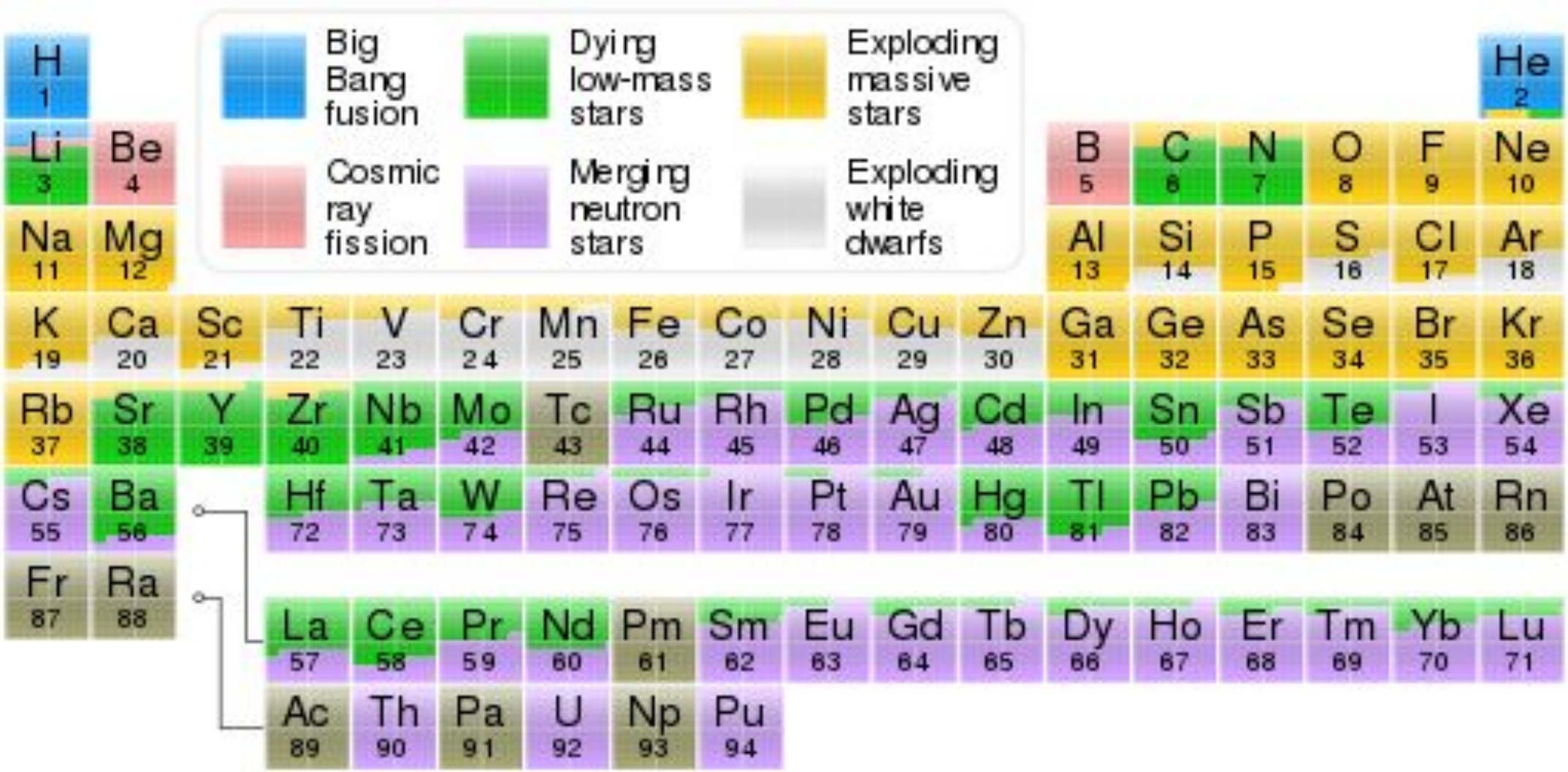


Pie Chart

$$35 \cdot 0.7576 + 37 \cdot 0.2424 = 35.453 \text{ [a.m.u]}$$

Isotopic Abundance

Periodic Table: It's Elementary!



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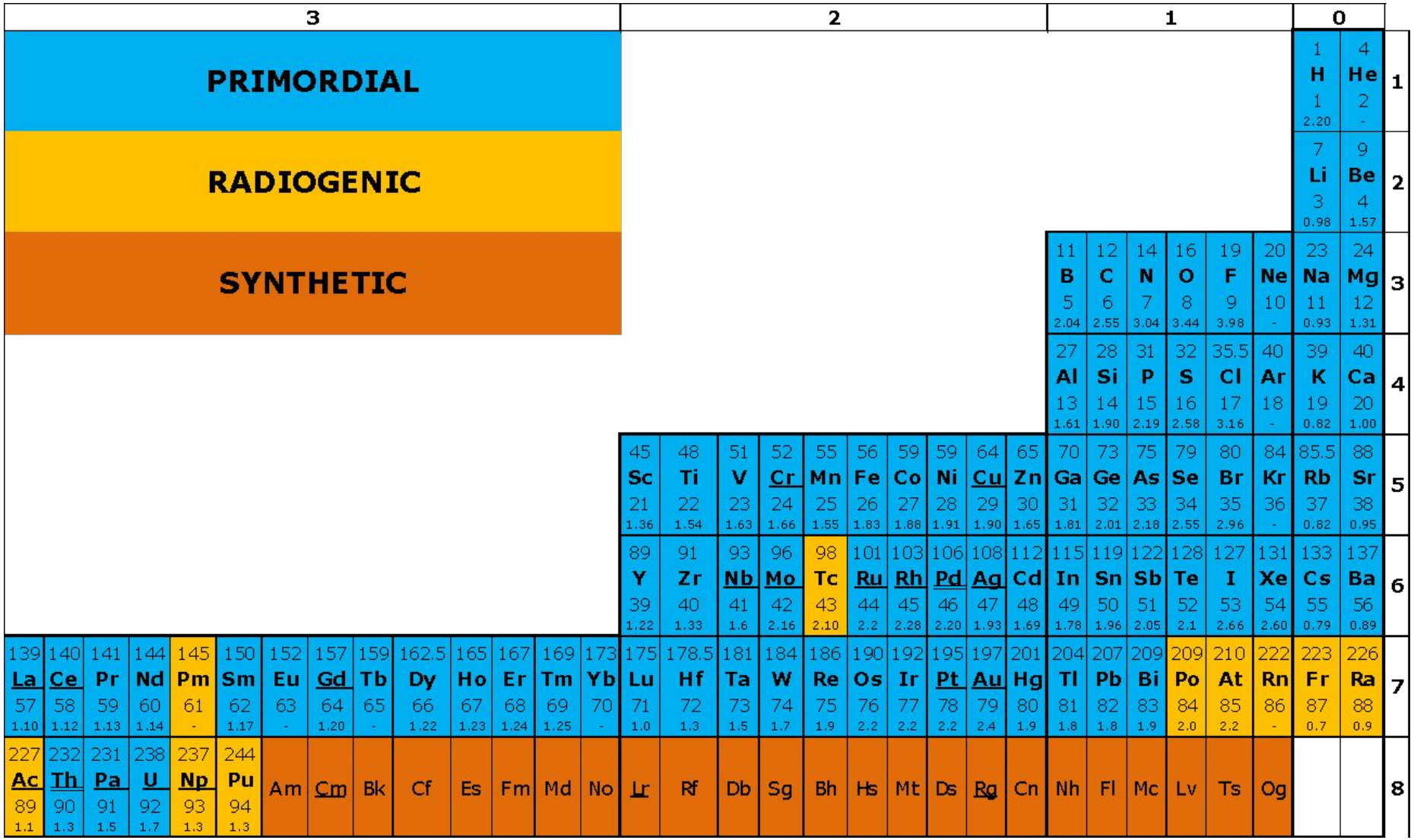
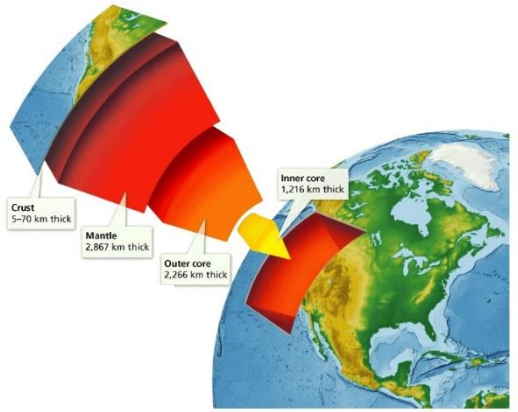
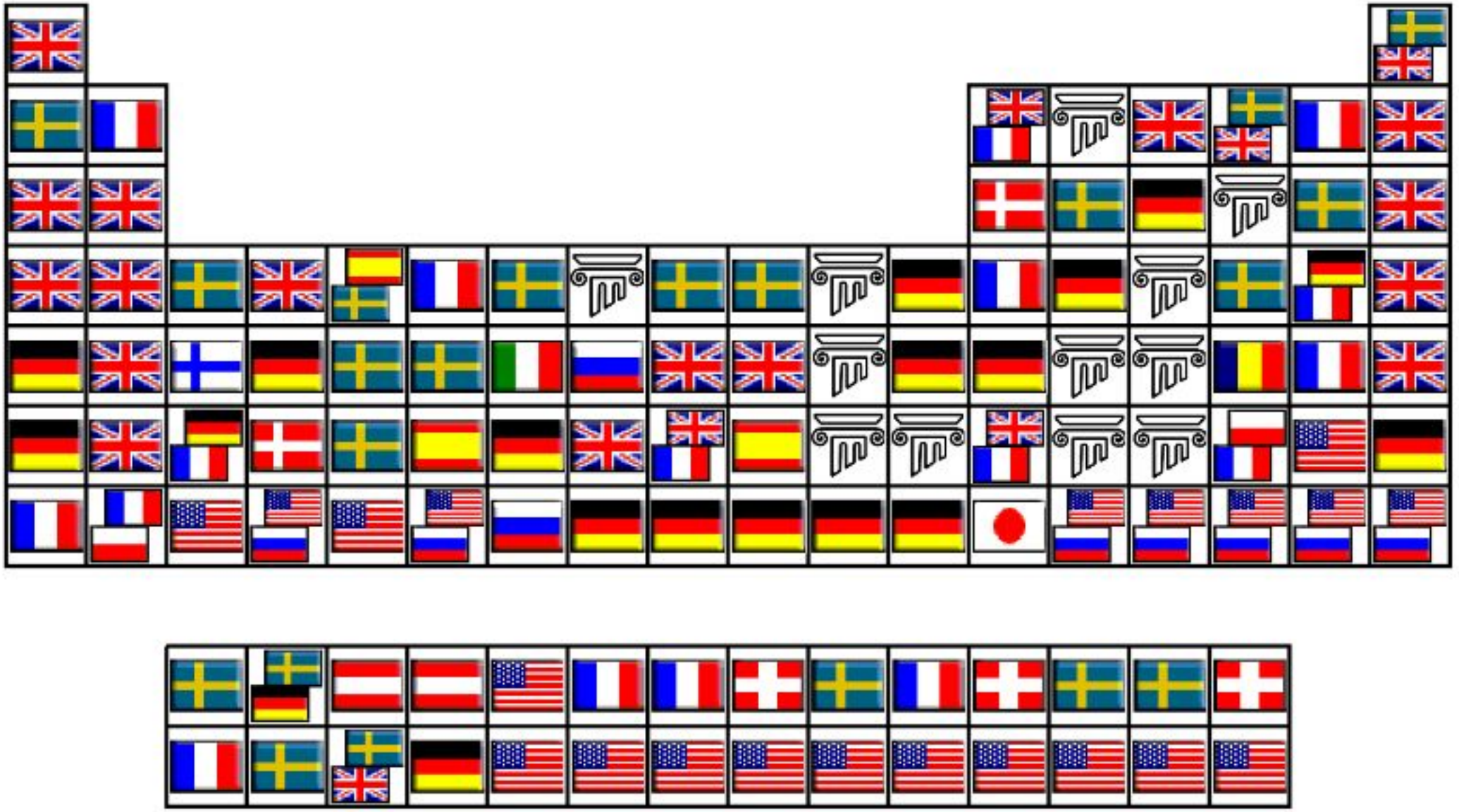


Periodic Table: It's Elementary!

3	2	1	0	
ATMOPHILES			1 H 1 2.20 / 4 He 2 -	1
LITHOPHILES			7 Li 3 0.98 / 9 Be 4 1.57	2
CHALCOPHILES		11 B 5 2.04 / 12 C 6 2.55 / 14 N 7 3.04 / 16 O 8 3.44 / 19 F 9 3.98 / 20 Ne 10 -	23 Na 11 0.93 / 24 Mg 12 1.31	3
SIDEROPHILES		27 Al 13 1.61 / 28 Si 14 1.90 / 31 P 15 2.19 / 32 S 16 2.58 / 35.5 Cl 17 3.16 / 40 Ar 18 -	39 K 19 0.82 / 40 Ca 20 1.00	4
	45 Sc 21 1.36 / 48 Ti 22 1.54 / 51 V 23 1.63 / 52 Cr 24 1.66 / 55 Mn 25 1.55 / 56 Fe 26 1.83 / 59 Co 27 1.88 / 59 Ni 28 1.91 / 64 Cu 29 1.90 / 65 Zn 30 1.65	70 Ga 31 1.81 / 73 Ge 32 2.01 / 75 As 33 2.18 / 79 Se 34 2.55 / 80 Br 35 2.96 / 84 Kr 36 -	85.5 Rb 37 0.82 / 88 Sr 38 0.95	5
	89 Y 39 1.22 / 91 Zr 40 1.33 / 93 Nb 41 1.6 / 96 Mo 42 2.16 / 98 Tc 43 2.10 / 101 Ru 44 2.2 / 103 Rh 45 2.28 / 106 Pd 46 2.20 / 108 Ag 47 1.93 / 112 Cd 48 1.69	115 In 49 1.78 / 119 Sn 50 1.96 / 122 Sb 51 2.05 / 128 Te 52 2.1 / 127 I 53 2.66 / 131 Xe 54 2.60	133 Cs 55 0.79 / 137 Ba 56 0.89	6
139 La 57 1.10 / 140 Ce 58 1.12 / 141 Pr 59 1.13 / 144 Nd 60 1.14 / 145 Pm 61 - / 150 Sm 62 1.17 / 152 Eu 63 - / 157 Gd 64 1.20 / 159 Tb 65 - / 162.5 Dy 66 1.22 / 165 Ho 67 1.23 / 167 Er 68 1.24 / 169 Tm 69 1.25 / 173 Yb 70 -	175 Lu 71 1.0 / 178.5 Hf 72 1.3 / 181 Ta 73 1.5 / 184 W 74 1.7 / 186 Re 75 1.9 / 190 Os 76 2.2 / 192 Ir 77 2.2 / 195 Pt 78 2.2 / 197 Au 79 2.4 / 201 Hg 80 1.9	204 Tl 81 1.8 / 207 Pb 82 1.8 / 209 Bi 83 1.9 / 209 Po 84 2.0 / 210 At 85 2.2 / 222 Rn 86 -	223 Fr 87 0.7 / 226 Ra 88 0.9	7
227 Ac 89 1.1 / 232 Th 90 1.3 / 231 Pa 91 1.5 / 238 U 92 1.7 / 237 Np 93 1.3 / 244 Pu 94 1.3 / Am / Cm / Bk / Cf / Es / Fm / Md / No	Lr / Rf / Db / Sg / Bh / Hs / Mt / Ds / Rg / Cn	Nh / Fl / Mc / Lv / Ts / Og		8

Victor Goldschmidt Geochemical Classification

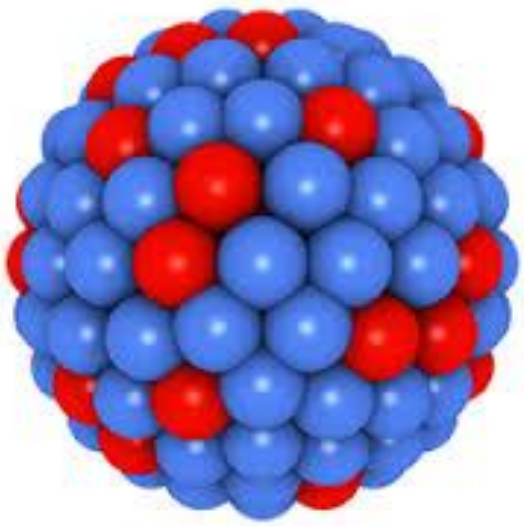
Periodic Table: It's Elementary!



Periodic Table: It's Elementary!

$_{92}U$ U

Chemical Element vs. **Elementary Substance**



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

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

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For notes and updates to this table, see www.iupac.org. This version is dated 28 November 2016.

Periodic Table: It's Elementary!

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April 8-9, 2017, Sochi