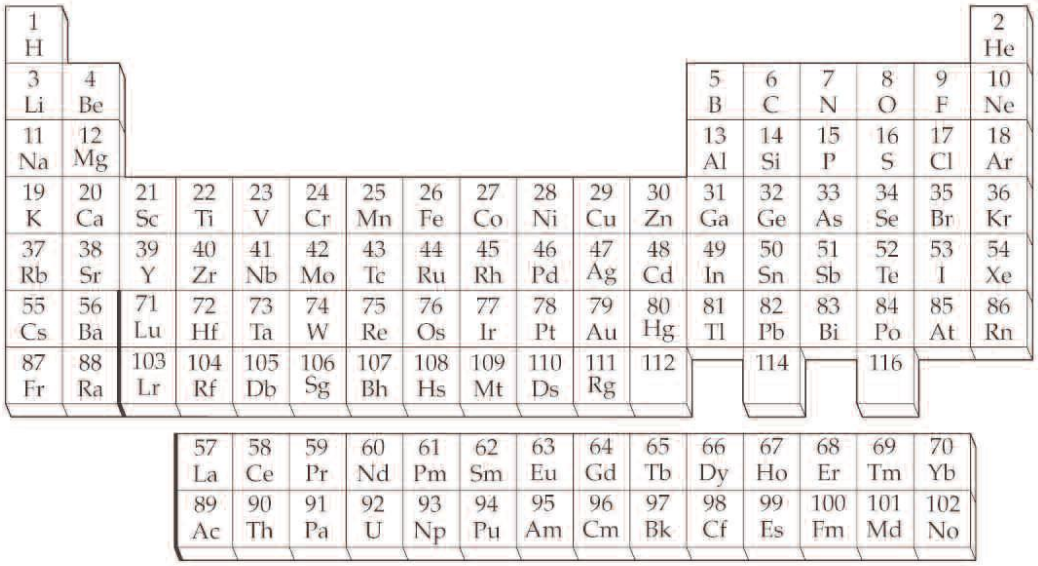
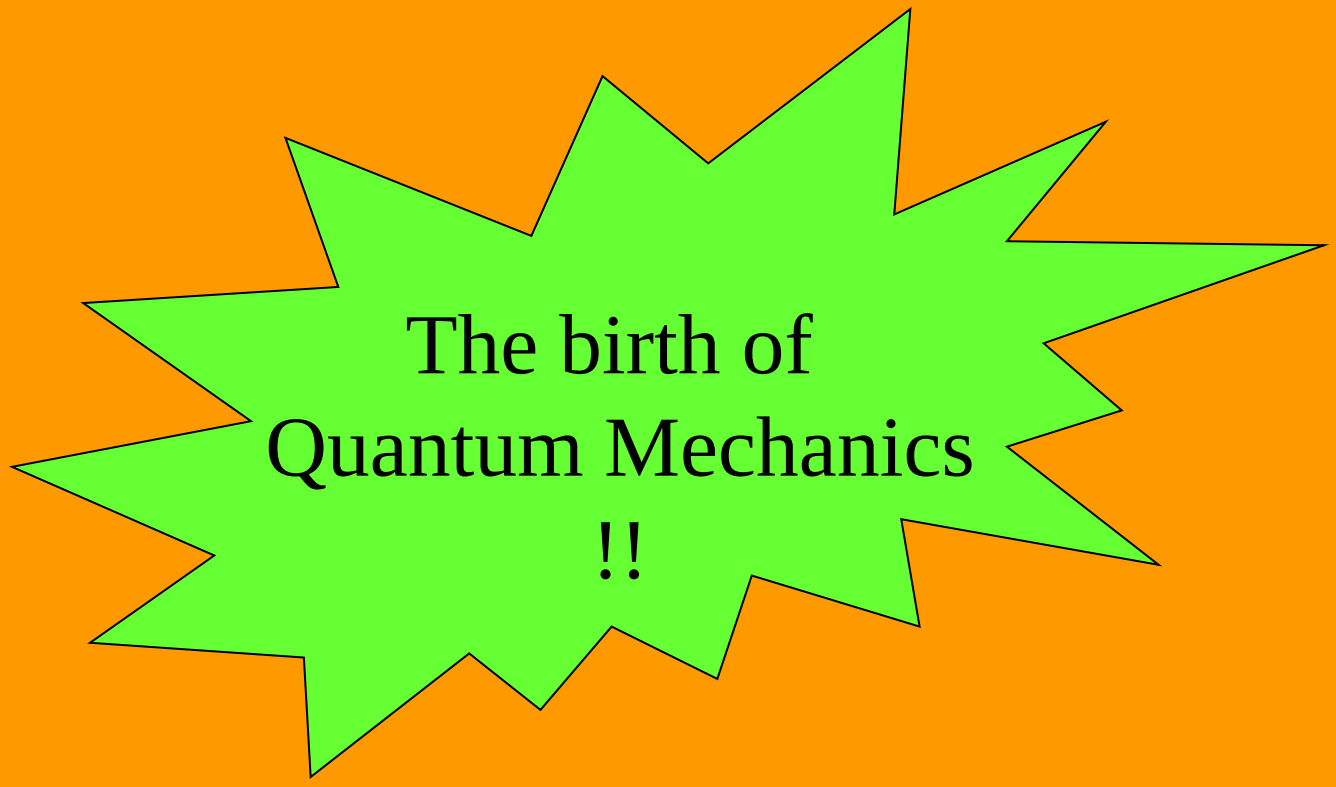
Periodic



1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	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
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112		114		116		

57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb
89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No


The birth of
Quantum Mechanics
!!

Louis de Brogile -- 1924

- French
- Combined the equations of Einstein and Planck to suggest that electrons have a wave nature

$$\lambda = \frac{h}{mv}$$

Wave/Particle Duality

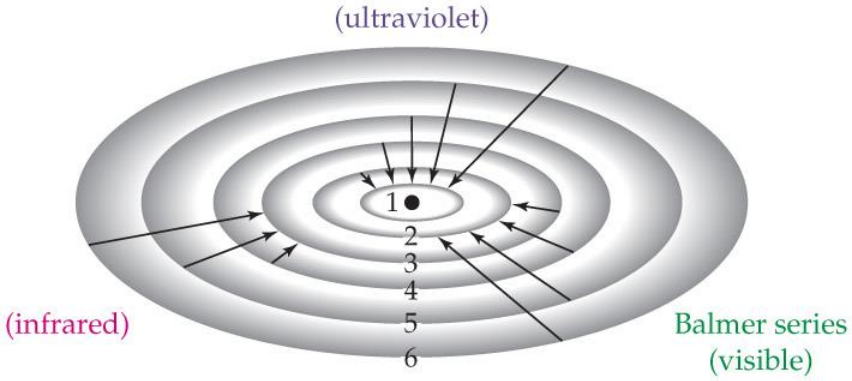
- Light was originally viewed as waves, since it displays diffraction and interference properties. But, it also acts like particles, called *photons* ($h\nu$), in some ways.

- Electrons were originally viewed as particles, with a finite mass. But they have interference and can diffract, so they have wavelike properties too.

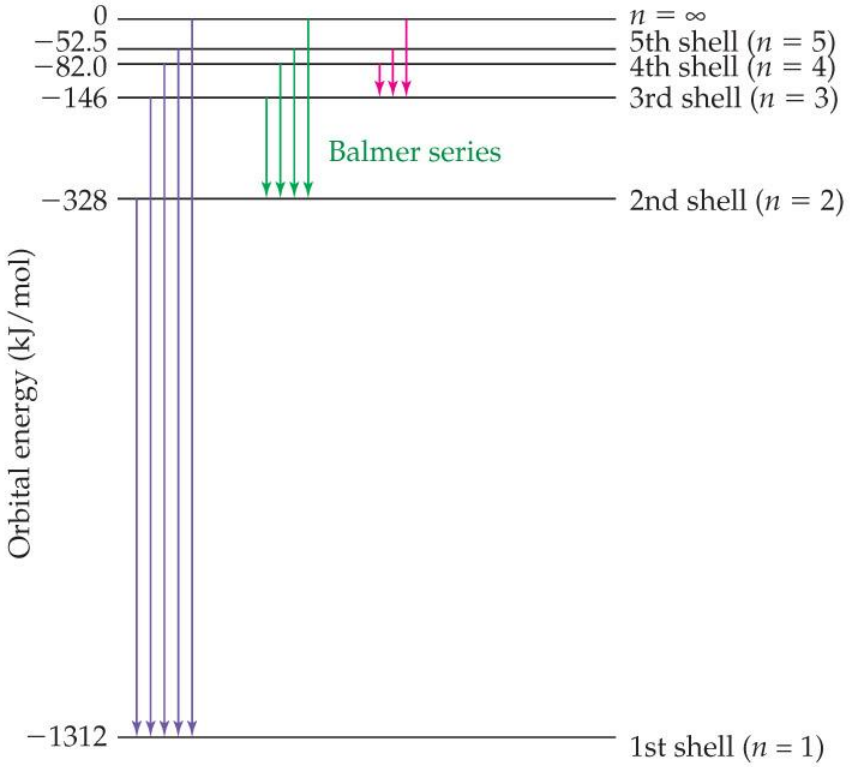
- de Broglie wavelength:

$$\lambda = h/mv$$

where λ = wavelength, h = Planck's constant (6.626×10^{-34} J•s), m = mass, v = velocity



When an electron falls from a higher-energy outer-shell orbital to a lower-energy inner-shell orbital, it emits electromagnetic energy whose frequency corresponds to the energy difference between the orbitals.



The different spectral series correspond to electronic transitions from outer-shell orbitals to different inner-shell orbitals.

$$\frac{1}{\lambda} = R_\infty \left(\frac{1}{m^2} - \frac{1}{n^2} \right)$$

Shell the transition is *to* (inner-shell)

Shell the transition is *from* (outer-shell)

Wolfgang Pauli

Wolfgang Pauli -- 1925

- German
- Determined that no two electrons in the same atom can have exactly the same energy (same set of quantum numbers)
- Pauli Exclusion Principle

Erwin Schrodinger

Erwin Schrodinger -- 1926

- Austrian
- Developed a mathematical expression called a wave function (Ψ)
- Developed the concept of an orbital
- Evaluations of Ψ have lead to specifics such as:

Schrodinger: A Wave Equation for Electrons

$$E\psi = \hbar\omega\psi = -j\hbar\frac{\partial}{\partial t}\psi \qquad p_x\psi = \hbar k\psi = j\hbar\frac{\partial}{\partial x}\psi$$

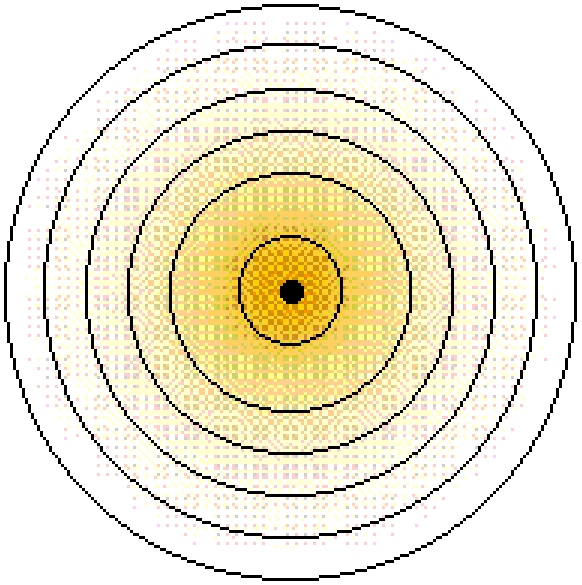
$$E = \frac{p^2}{2m} \quad \text{(free-particle)}$$

$$-j\hbar\frac{\partial}{\partial t}\psi = -\frac{\hbar^2}{2m}\frac{\partial^2\psi}{\partial x^2} \quad \text{(free-particle)}$$

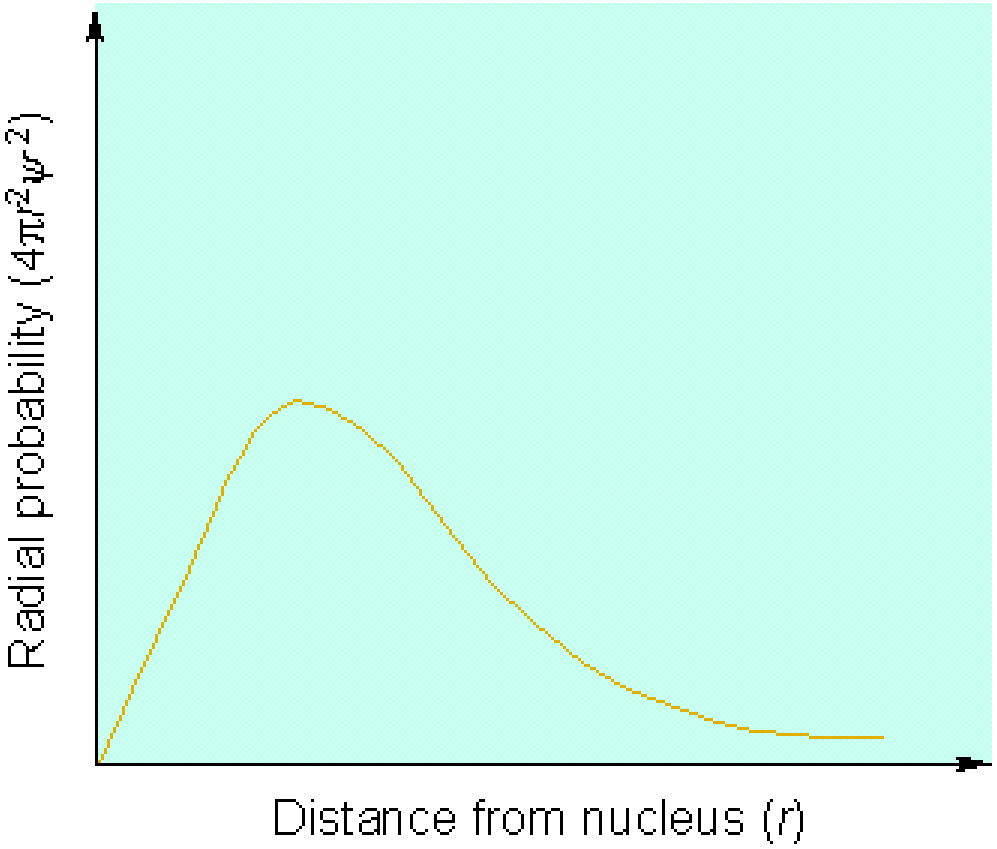
..The Free-Particle Schrodinger Wave Equation !

Erwin Schrödinger (1887–1961)

- distance from the nucleus
- orbital shape
- energy of an electron within a given orbital
- probability of finding an electron within some region of an orbital

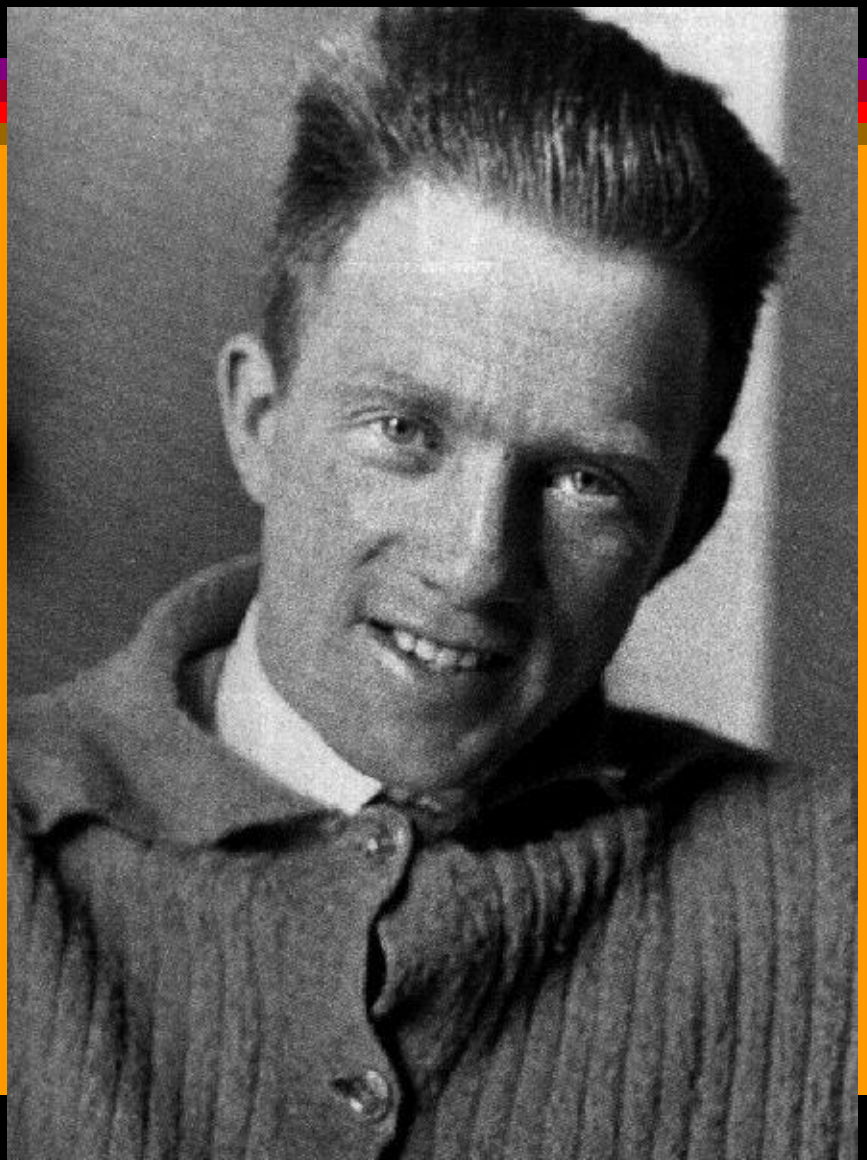


(A)



(B)

Werner Heisenberg



Werner Heisenberg -- 1927

- German
- Determined that the exact position and momentum of an electron cannot be determined simultaneously
- Heisenberg Uncertainty Principle

Quantum Mechanics Conclusions

- The exact location of an electron cannot be determined.
- The energy of an electron is limited to discrete values.
- Orbitals are characterized by the principal quantum number (n).

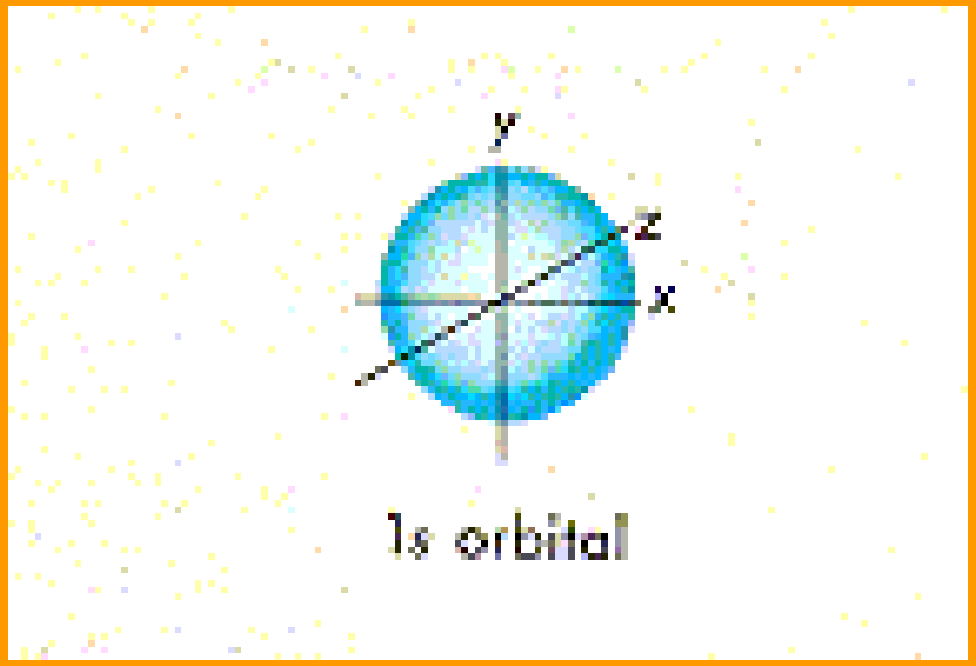
- Orbital shapes are distinguished by a second quantum number, the azimuthal (angular-momentum) quantum number (l).
- Orbitals having the same azimuthal quantum number differ in their orientation about the nucleus. This orientation is characterized by the magnetic quantum number (m).

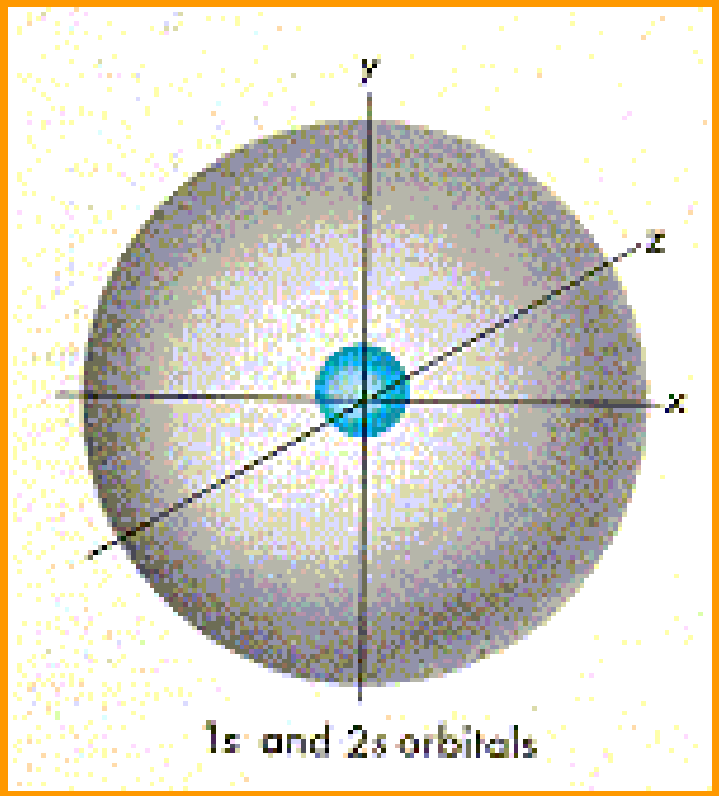
- Electrons within an orbital can rotate clockwise or counterclockwise. The direction of spin is specified by the spin quantum number (s).
- The maximum number of electrons that may be found in a shell of principal quantum number n is $2n^2$.

Allowed Combinations of Quantum Numbers n, l, and m_l for the First Four Shells

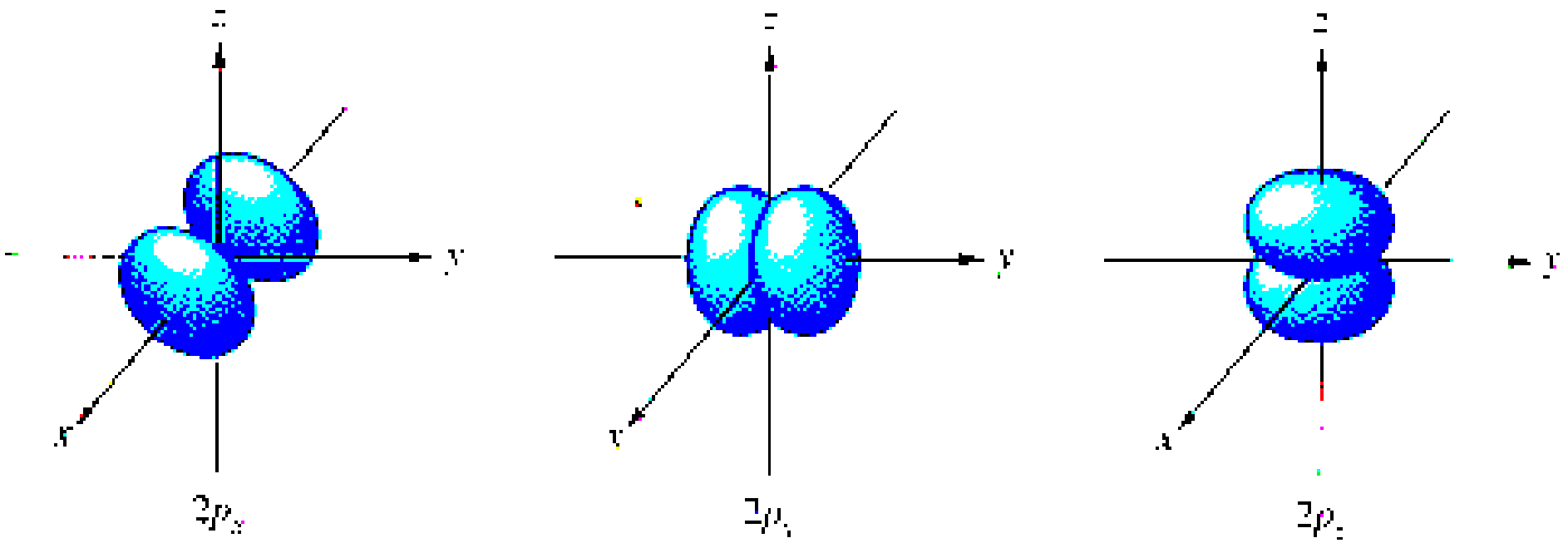
n	l	m_l	Orbital Notation	Number of Orbitals in Subshell	Number of Orbitals in Shell
1	0	0	1*s*	1	1
2	0	0	2*s*	1	4
	1	−1, 0, +1	2*p*	3	
3	0	0	3*s*	1	9
	1	−1, 0, +1	3*p*	3	
	2	−2, −1, 0, +1, +2	3*d*	5	
4	0	0	4*s*	1	16
	1	−1, 0, +1	4*p*	3	
	2	−2, −1, 0, +1, +2	4*d*	5	
	3	−3, −2, −1, 0, +1, +2, +3	4*f*	7	

The “s” Orbital

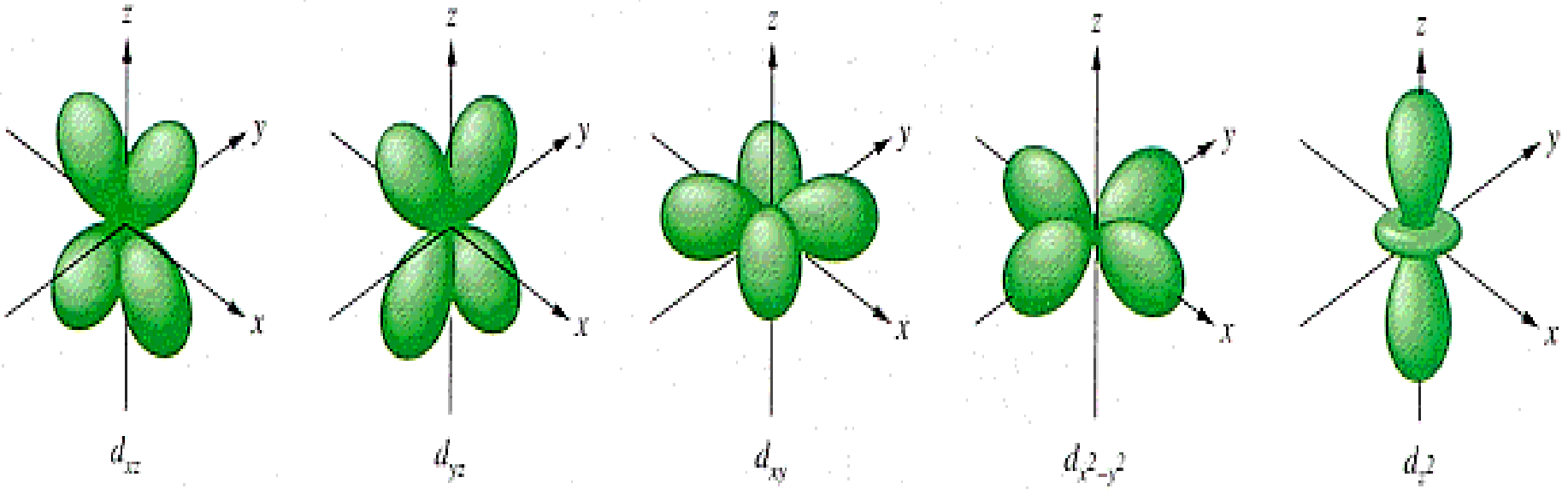




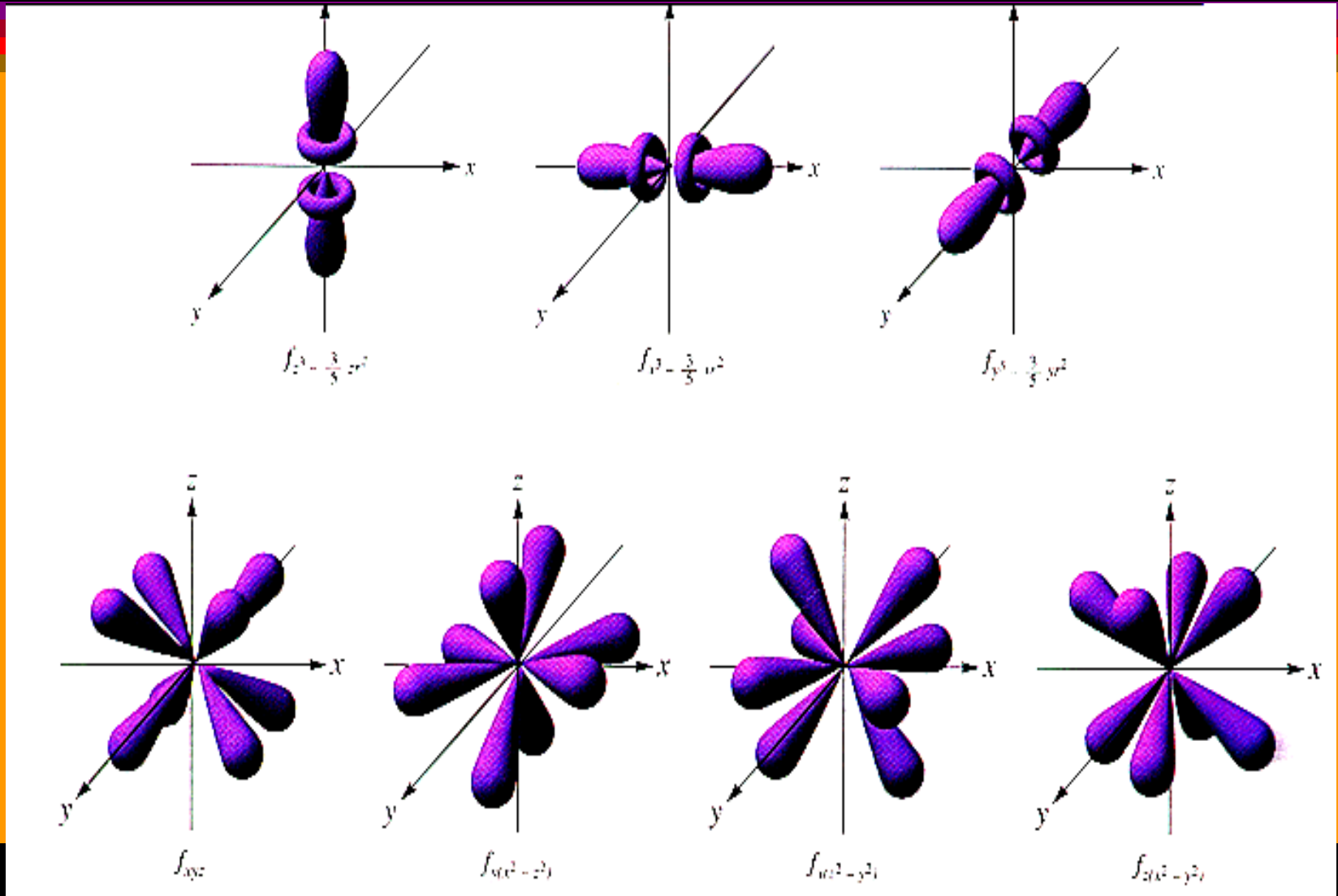
The “p” orbital



The “d” Orbital



The “f” Orbital

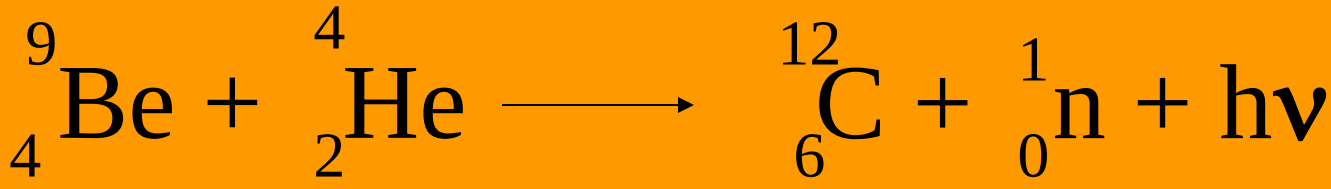


Frederick Hund -- 1927

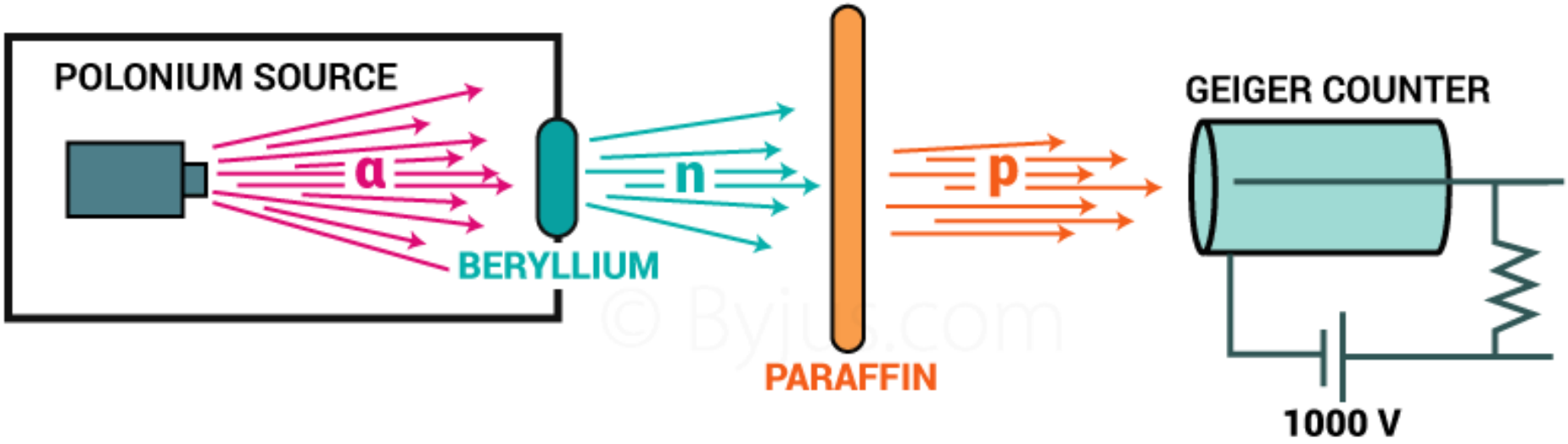
- German
- Determined that subshells will first fill singly with parallel spins
- Once half filled, subshells will then doubly fill
- Hund's Rule

James Chadwick -- 1932

- British
- Identified the neutron
- Particles have no charge
- Mass of 1.0087 amu or 1.675×10^{-27}Kg
- Unstable outside of the nucleus
  - Disintegrates into a proton and an electron


9 4 Be + 4 2 He
12 6 C + 1 0 n + hν

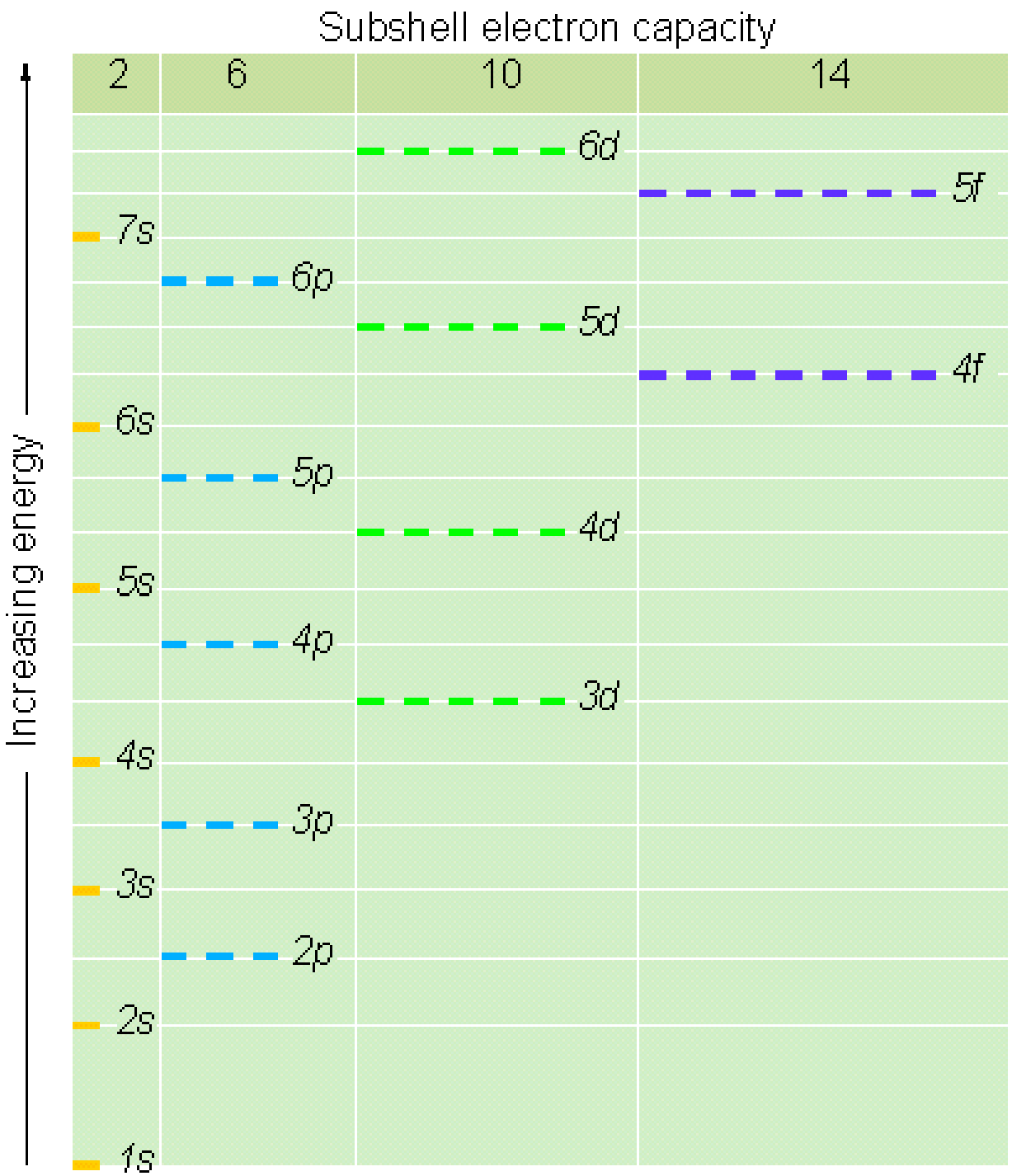
DISCOVERY OF NEUTRON

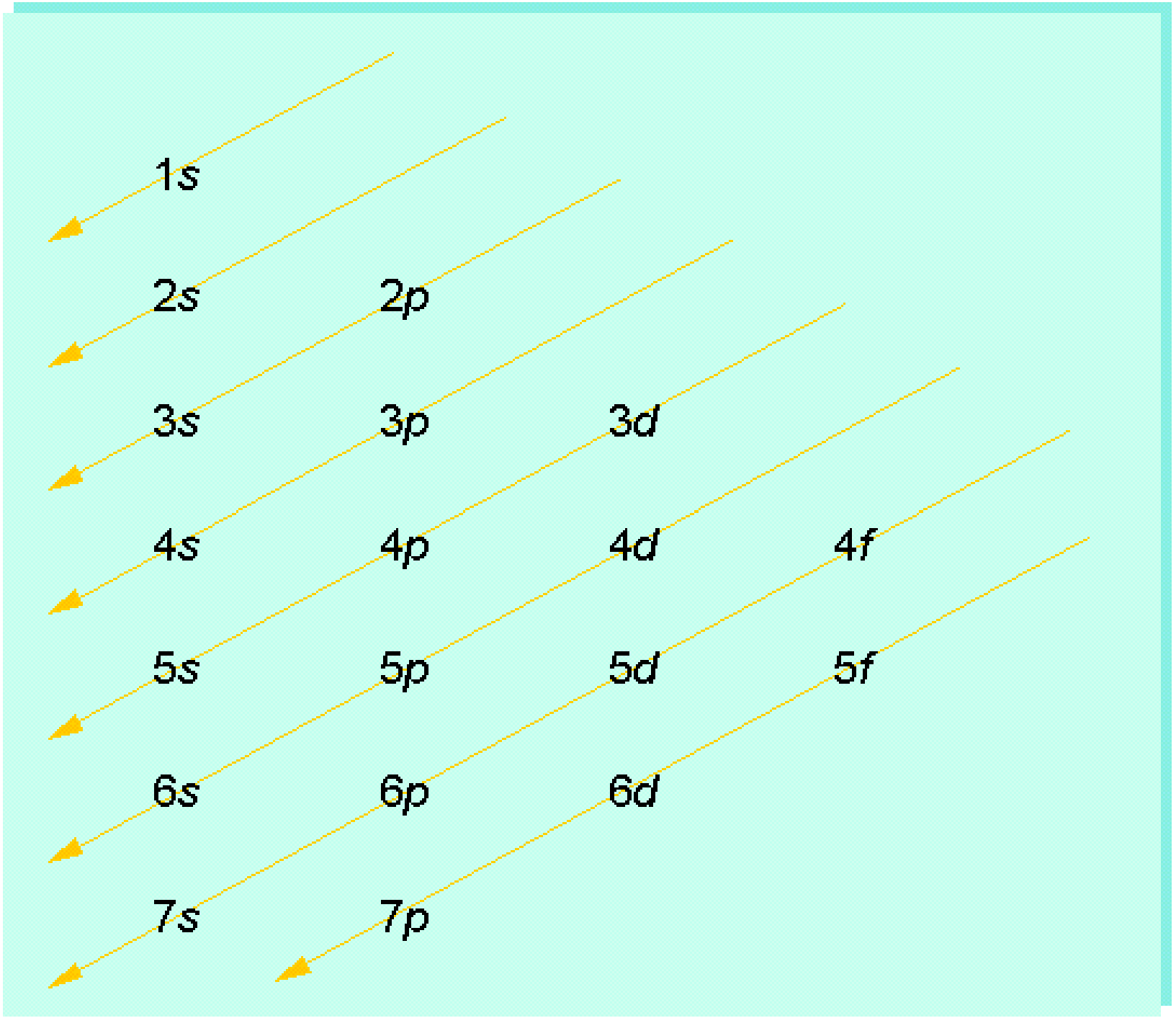


Nucleons

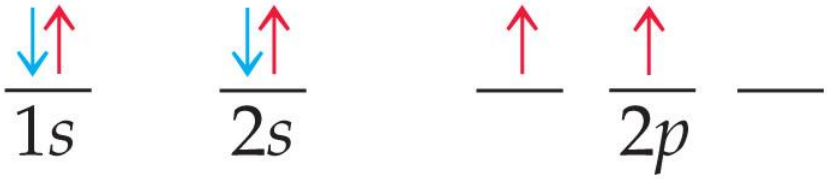
The total of all nuclear particles. Includes both protons & neutrons.

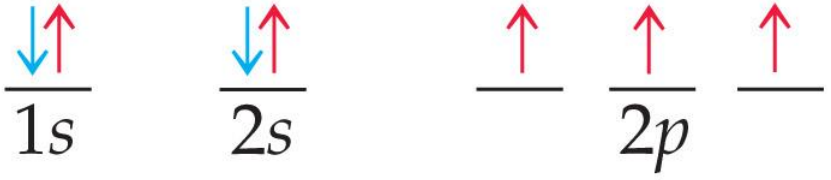
The Aufbau Process


Subshell electron capacity
2
6
10
14
Increasing energy
7s
6p
6d
5f
6s
5p
5d
4f
5s
4p
4d
4s
3p
3d
3s
2p
2s
1s


1s
2s
2p
3s
3p
3d
4s
4p
4d
4f
5s
5p
5d
5f
6s
6p
6d
7s
7p

B: $1s^2\ 2s^2\ 2p^1$ or 

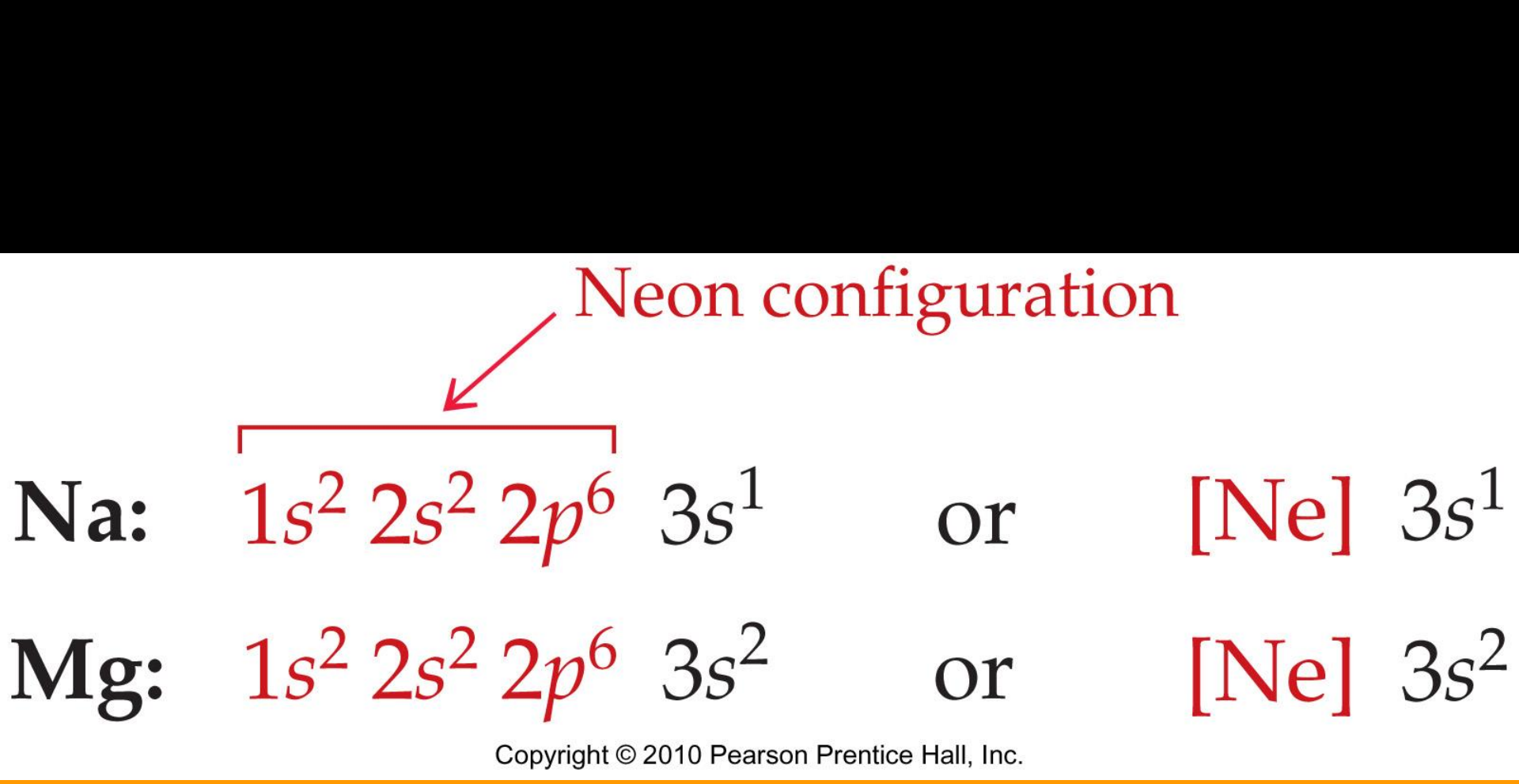
C: $1s^2\ 2s^2\ 2p_x^{\ 1}\ 2p_y^{\ 1}$ or 

N: $1s^2\ 2s^2\ 2p_x^{\ 1}\ 2p_y^{\ 1}\ 2p_z^{\ 1}$ or 

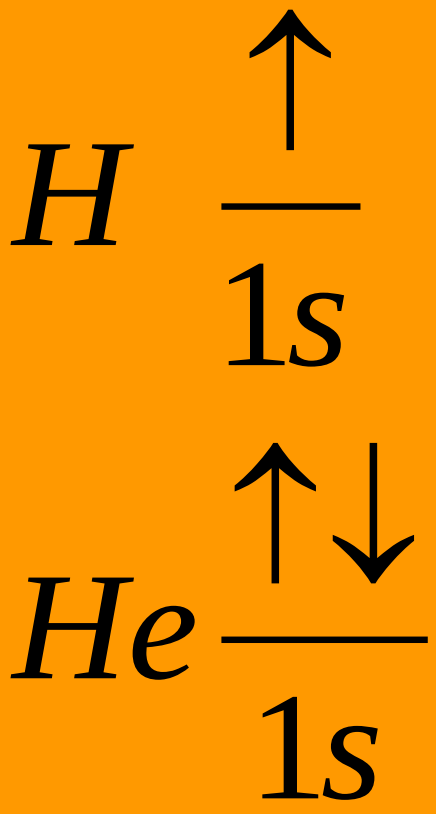
O: $1s^2\ 2s^2\ 2p_x^{\ 2}\ 2p_y^{\ 1}\ 2p_z^{\ 1}$ or 

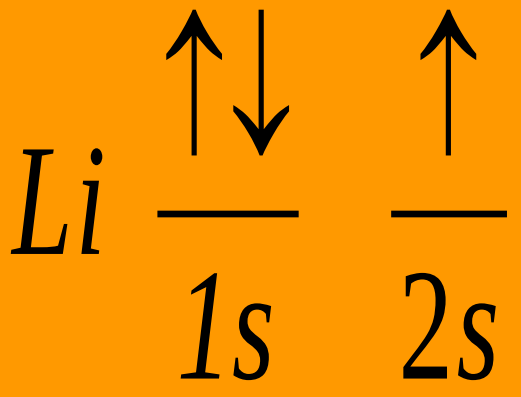
F: $1s^2\ 2s^2\ 2p^5$ or 

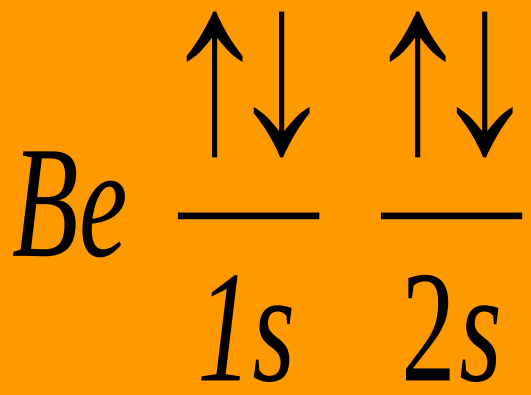
Ne: $1s^2\ 2s^2\ 2p^6$ or 

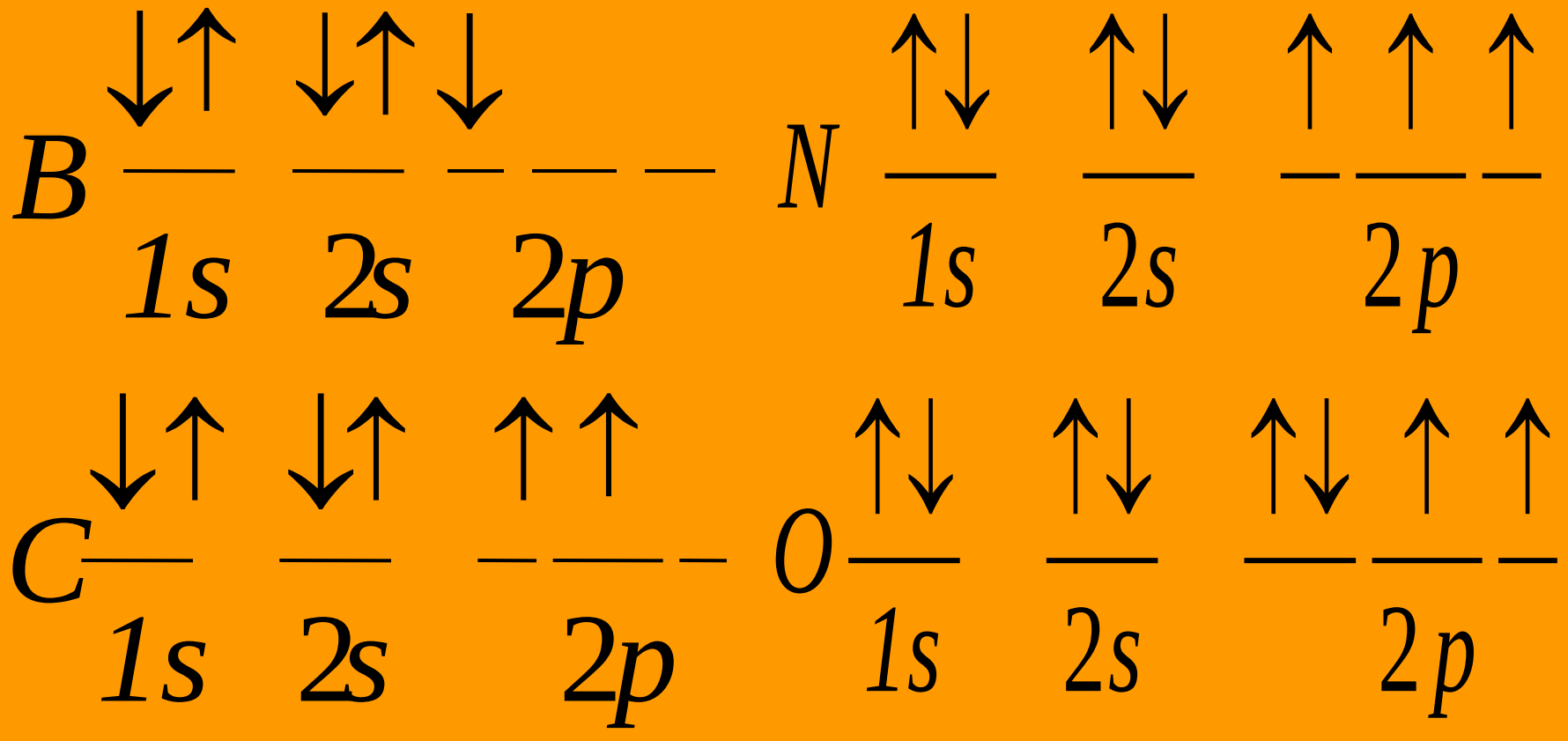


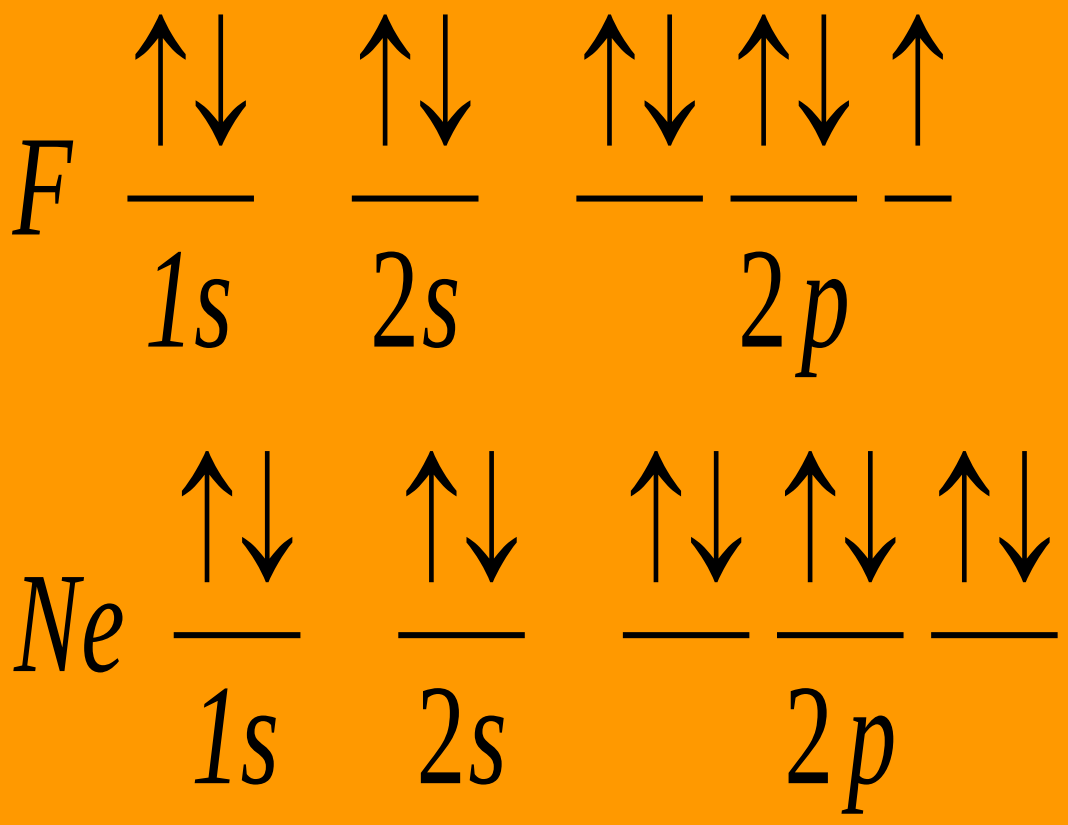
Orbital Notation








B
1s 2s 2p
N
1s 2s 2p
C
1s 2s 2p
O
1s 2s 2p


F
1s
2s
2p
Ne
1s
2s
2p

Electron Configuration

$H \quad 1s^1$ $Li \quad 1s^2 \quad 2s^1$

$He \; 1s^2$ $Be \; 1s^2 \quad 2s^2$

Electron Configuration

$B\ 1s^2 2s^2 2p^1$

$C\ 1s^2 2s^2 2p^2$

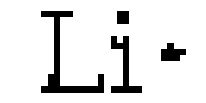
$N\ 1s^2 2s^2 2p^3$

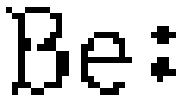
$O\ 1s^2\ 2s^2\ 2p^4$

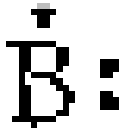
$F\ 1s^2\ 2s^2\ 2p^5$

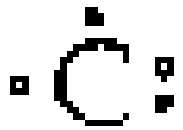
$Ne\ 1s^2\ 2s^2\ 2p^6$

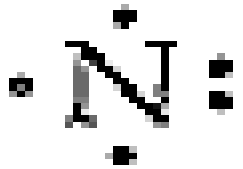
Electron Dot Notation

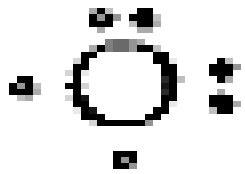


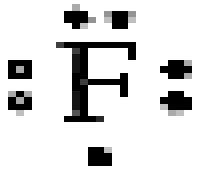


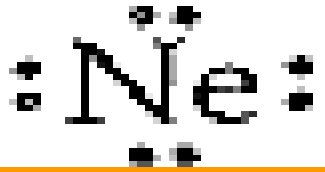












Arrangement of Electrons

Li	$1s^2 2s^1 = [He]2s^1$	Na	$[Ne]3s^1$
Be	$[He]2s^2$	Mg	$[Ne]3s^2$
B	$[He]2s^2 2p^1$	Al	$[Ne]3s^2 3p^1$
C	$[He]2s^2 2p^2$	Si	$[Ne]3s^2 3p^2$
N	$[He]2s^2 2p^3$	P	$[Ne]3s^2 3p^3$
O	$[He]2s^2 2p^4$	S	$[Ne]3s^2 3p^4$
F	$[He]2s^2 2p^5$	Cl	$[Ne]3s^2 3p^5$
Ne	$[He]2s^2 2p^6$	Ar	$[Ne]3s^2 3p^6$

K	[Ar]	$4s^1$	Ni	[Ar]	$4s^2 3d^8$
Ca	[Ar]	$4s^2$	Cu	[Ar]	$4s^1 3d^{10}$
Sc	[Ar]	$4s^2 3d$	Zn	[Ar]	$4s^2 3d^{10}$
Ti	[Ar]	$4s^2 3d$	Ga	[Ar]	$4s^2 3d^{10} 4p^1$
V	[Ar]	$4s^2 3d$	Ge	[Ar]	$4s^2 3d^{10} 4p^2$
Cr	[Ar]	$4s^1 3d$	As	[Ar]	$4s^2 3d^{10} 4p^3$
Mn	[Ar]	$4s^2 3d$	Se	[Ar]	$4s^2 3d^{10} 4p^4$
Fe	[Ar]	$4s^2 3d$	Br	[Ar]	$4s^2 3d^{10} 4p^5$
Co	[Ar]	$4s^2 3d$	Kr	[Ar]	$4s^2 3d^{10} 4p^6$

Rb	$[Kr]5s^1$	Pd	$[Kr]4d^{10}$
Sr	$[Kr]5s^2$	Ag	$[Kr]5s^1 4d^{10}$
Y	$[Kr]5s^2 4d^1$	Cd	$[Kr]5s^2 4d^{10}$
Zr	$[Kr]5s^2 4d^2$	In	$[Kr]5s^2 4d^{10} 5p^1$
Nb	$[Kr]5s^1 4d^4$	Sn	$[Kr]5s^2 4d^{10} 5p^2$
Mo	$[Kr]5s^1 4d^5$	Sb	$[Kr]5s^2 4d^{10} 5p^3$
Tc	$[Kr]5s^1 4d^6$	Te	$[Kr]5s^2 4d^{10} 5p^4$
Ru	$[Kr]5s^1 4d^7$	I	$[Kr]5s^2 4d^{10} 5p^5$
Rh	$[Kr]5s^1 4d^8$	Xe	$[Kr]5s^2 4d^{10} 5p^6$

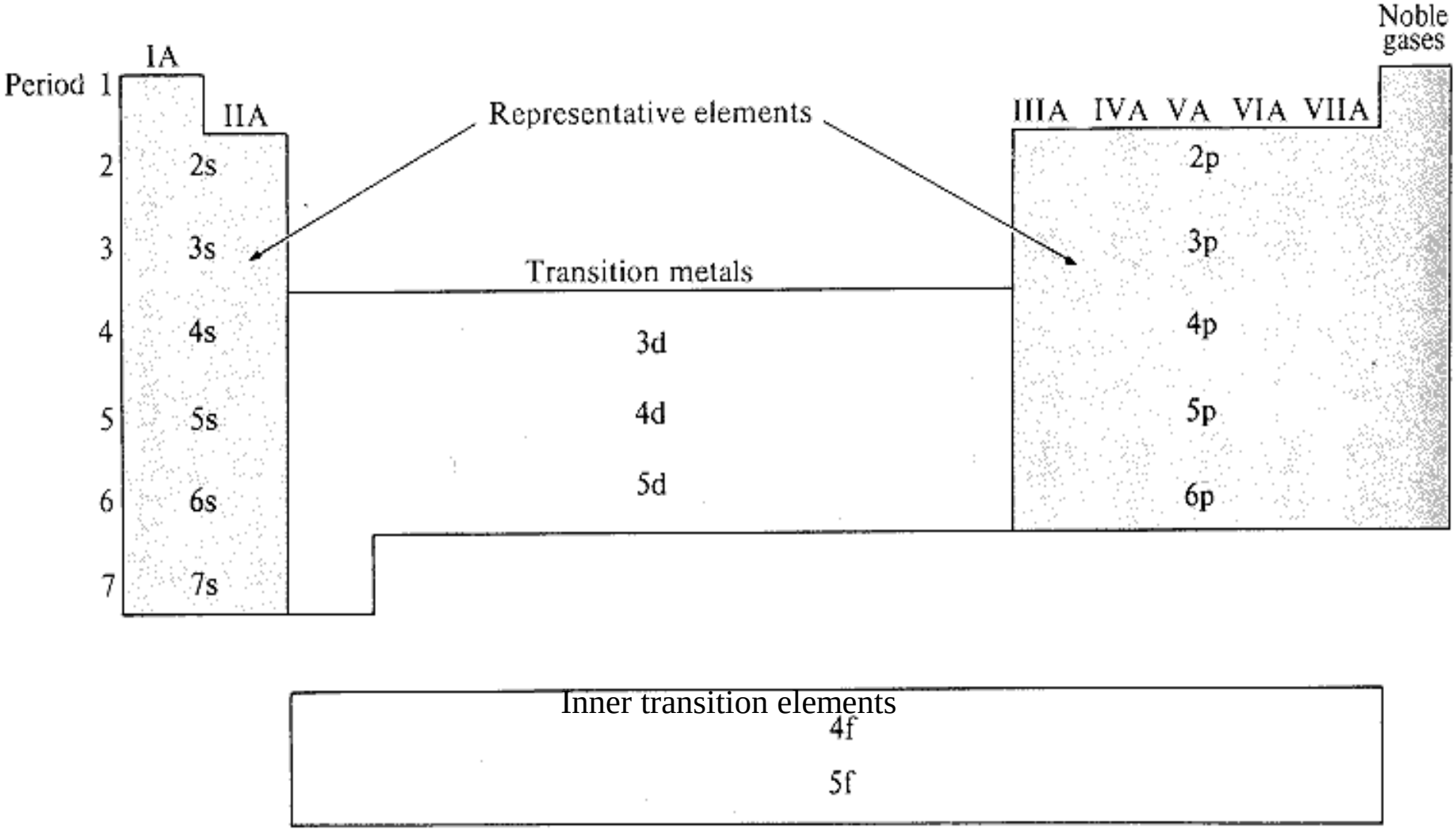
Rb	$[Kr]5s^1$	Pd	$[Kr]4d^{10}$
Sr	$[Kr]5s^2$	Ag	$[Kr]5s^1 4d^{10}$
Y	$[Kr]5s^2 4d^1$	Cd	$[Kr]5s^2 4d^{10}$
Zr	$[Kr]5s^2 4d^2$	In	$[Kr]5s^2 4d^{10} 5p^1$
Nb	$[Kr]5s^1 4d^4$	Sn	$[Kr]5s^2 4d^{10} 5p^2$
Mo	$[Kr]5s^1 4d^5$	Sb	$[Kr]5s^2 4d^{10} 5p^3$
Tc	$[Kr]5s^1 4d^6$	Te	$[Kr]5s^2 4d^{10} 5p^4$
Ru	$[Kr]5s^1 4d^7$	I	$[Kr]5s^2 4d^{10} 5p^5$
Rh	$[Kr]5s^1 4d^8$	Xe	$[Kr]5s^2 4d^{10} 5p^6$

55	Cs	$[Xe]6s^1$
56	Ba	$[Xe]6s^2$
57	La	$[Xe]6s^25d^1$
58	Ce	$[Xe]6s^24f^2$
59	Pr	$[Xe]6s^24f^3$
60	Nd	$[Xe]6s^24f^4$
61	Pm	$[Xe]6s^24f^5$
62	Sm	$[Xe]6s^24f^6$
63	Eu	$[Xe]6s^24f^7$
64	Gd	$[Xe]6s^24f^75d$
65	Tb	$[Xe]6s^24f^9$
66	Dy	$[Xe]6s^24f^{10}$
67	Ho	$[Xe]6s^24f^{11}$
68	Er	$[Xe]6s^24f^{12}$
69	Tm	$[Xe]6s^24f^{13}$
70	Yb	$[Xe]6s^24f^{14}$
71	Lu	$[Xe]6s^24f^{14}5d^1$
72	Hf	$[Xe]6s^24f^{14}5d^2$
73	Ta	$[Xe]6s^24f^{14}5d^3$
74	W	$[Xe]6s^24f^{14}5d^4$
75	Re	$[Xe]6s^24f^{14}5d^5$
76	Os	$[Xe]6s^24f^{14}5d^6$

77	Ir	$[Xe]6s^2 4f^{14} 5d^7$
78	Pt	$[Xe]6s^1 4f^{14} 5d^9$
79	Au	$[Xe]6s^1 4f^{14} 5d^{10}$
80	Hg	$[Xe]6s^2 4f^{14} 5d^{10}$
81	Tl	$[Xe]6s^2 4f^{14} 5d^{10} 6p^1$
82	Pb	$[Xe]6s^2 4f^{14} 5d^{10} 6p^2$
83	Bi	$[Xe]6s^2 4f^{14} 5d^{10} 6p^3$
84	Po	$[Xe]6s^2 4f^{14} 5d^{10} 6p^4$
85	At	$[Xe]6s^2 4f^{14} 5d^{10} 6p^5$
86	Rn	$[Xe]6s^2 4f^{14} 5d^{10} 6p^6$

87	Fr	$[Rn]7s^1$	97	Bk	$[Rn]7s^25f^86d^1$
88	Ra	$[Rn]7s^2$	98	Cf	$[Rn]7s^25f^{10}$
89	Ac	$[Rn]7s^26d^1$	99	Es	$[Rn]7s^25f^{11}$
90	Th	$[Rn]7s^26d^2$	100	Fm	$[Rn]7s^25f^{12}$
91	Pa	$[Rn]7s^25f^26d^1$	101	Md	$[Rn]7s^25f^{13}$
92	U	$[Rn]7s^25f^36d^1$	102	No	$[Rn]7s^25f^{14}$
93	Np	$[Rn]7s^25f^46d^1$	103	Lr	$[Rn]7s^25f^{14}6d^1$
94	Pu	$[Rn]7s^25f^6$	104	Rf	$[Rn]7s^25f^{14}6d^2$
95	Am	$[Rn]7s^25f^7$	105	Ha	$[Rn]7s^25f^{14}6d^3$
96	Cm	$[Rn]7s^25f^76d^1$	106	Sg	$[Rn]7s^25f^{14}6d^4$

107	Ns	$[Rn]7s^2 5f^{14} 6d^5$
108	Hs	$[Rn]7s^2 5f^{14} 6d^6$
109	Mt	$[Rn]7s^2 5f^{14} 6d^7$
110	Uun	$[Rn]7s^2 5f^{14} 6d^8$
111	Uuu	$[Rn]7s^2 5f^{14} 6d^9$
112	Uub	$[Rn]7s^2 5f^{14} 6d^{10}$


Noble gases
IA
Period 1
IIA
Representative elements
IIIA IVA VA VIA VIIA
2
2s
2p
3
3s
3p
Transition metals
4
4s
3d
4p
5
5s
4d
5p
6
6s
5d
6p
7
7s
Inner transition elements
4f
5f

Atomic Radii of the Elements