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Unit II - Lecture 8

Chemistry

The Molecular Nature of Matter and Change

Fifth Edition

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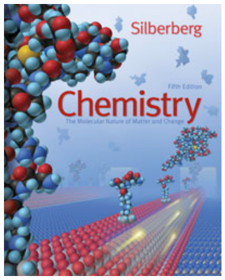


Electron Configuration and Chemical Periodicity

8.1 Development of the Periodic Table

8.2 Characteristics of Many-Electron Atoms

8.3 The Quantum-Mechanical Model and the Periodic Table

Table 8.1 Mendeleev's Predicted Properties of Germanium ("eka Silicon") and Its Actual Properties

Property	Predicted Properties of eka Silicon (E)	Actual Properties of Germanium (Ge)
atomic mass	72 amu	72.61 amu
appearance	gray metal	gray metal
density	5.5 g/cm^3	5.32 g/cm^3
molar volume	13 cm^3/mol	13.65 cm^3/mol
specific heat capacity	0.31 J/g*K	0.32 J/g*K
oxide formula	EO_2	GeO_2
oxide density	4.7 g/cm^3	4.23 g/cm^3
sulfide formula and solubility	ES_2; insoluble in H_2O; soluble in aqueous $(NH_4)_2S$	GeS_2; insoluble in H_2O; soluble in aqueous $(NH_4)_2S$
chloride formula (boiling point)	ECl_4 (<100°C)	$GeCl_4$ (84°C)
chloride density	1.9 g/cm^3	1.844 g/cm^3
element preparation	reduction of K_2EF_6 with sodium	reduction of K_2GeF_6 with sodium

Figure 8.1 Observing the effect of electron spin.

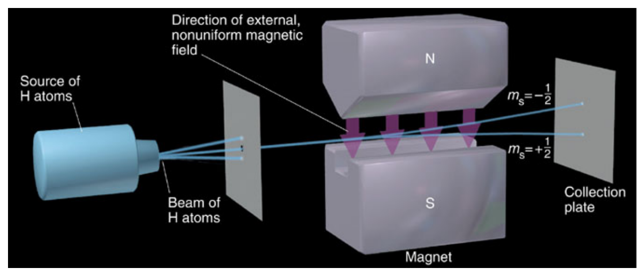
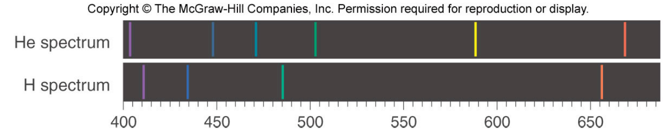


Table 8.2 Summary of Quantum Numbers of Electrons in Atoms

Name	Symbol	Permitted Values	Property
principal	n	positive integers(1, 2, 3, …)	orbital energy (size)
angular momentum	l	integers from 0 to n-1	orbital shape (The l values 0, 1, 2, and 3 correspond to *s*, *p*, *d*, and *f* orbitals, respectively.)
magnetic	m_l	integers from -l to 0 to +l	orbital orientation
spin	m_s	+1/2 or -1/2	direction of e$^-$ spin

Figure 8.2 Spectral evidence of energy-level splitting in many-electron atoms.



Factors Affecting Atomic Orbital Energies

The Effect of Nuclear Charge ($Z_{effective}$)

Higher nuclear charge lowers orbital energy (stabilizes the system) by increasing nucleus-electron attractions.

The Effect of Electron Repulsions (Shielding)

Additional electron in the same orbital

An additional electron raises the orbital energy through electron-electron repulsions.

Additional electrons in inner orbitals

Inner electrons shield outer electrons more effectively than do electrons in the same sublevel.

Figure 8.3 The effect of nuclear charge on orbital energy.

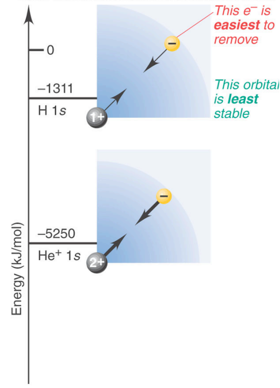


Figure 8.4 Shielding and orbital energy.

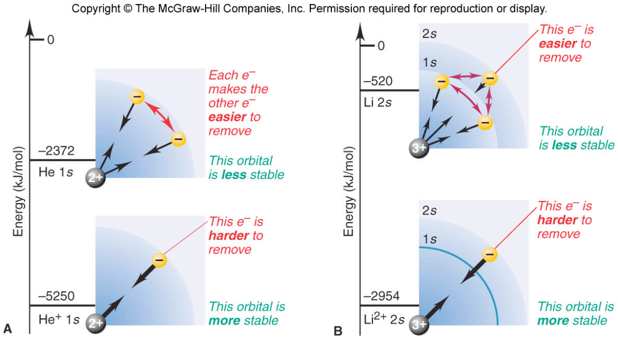
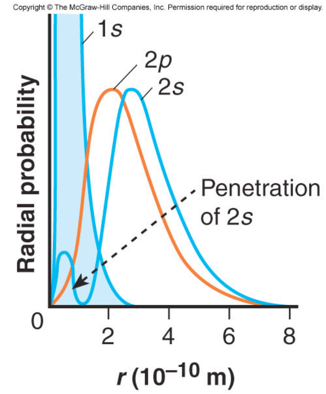


Figure 8.5 Penetration and orbital energy.



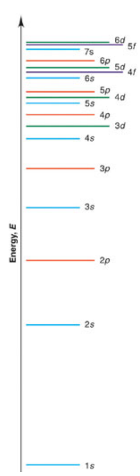


Figure 8.6
Order for filling energy sublevels with electrons.

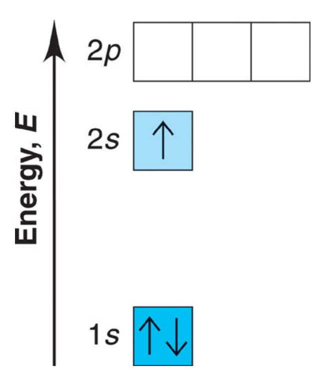
Illustrating Orbital Occupancies

The electron configuration

$n\,l^{\#}$ — # of electrons in the sublevel; l as *s*, *p*, *d*, *f*

The orbital diagram (box or circle)

Figure 8.7 A vertical orbital diagram for the Li ground state.



Sample Problem 8.1 — Determining Quantum Numbers from Orbital Diagrams

PROBLEM: Write a set of quantum numbers for the third electron and a set for the eighth electron of the F atom.

PLAN: Use the orbital diagram to find the third and eighth electrons.

$_9$F ↑↓ (1s) ↑↓ (2s) ↑↓ ↑↓ ↑ (2p)

SOLUTION: The third electron is in the 2*s* orbital. Its quantum numbers are:

$n = 2$ $l = 0$ $m_l = 0$ $m_s = +1/2$

The eighth electron is in a 2*p* orbital. Its quantum numbers are:

$n = 2$ $l = 1$ $m_l = -1, 0, \text{or} +1$ $m_s = -1/2$

Figure 8.8 Orbital occupancy for the first 10 elements, H through Ne.

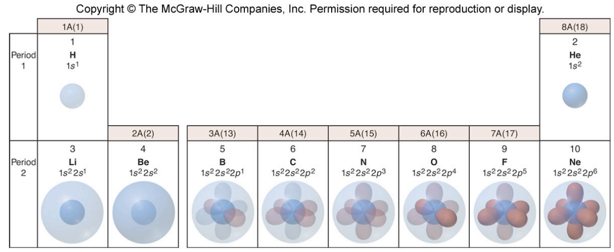


Table 8.3 Partial Orbital Diagrams and Electron Configurations* for the Elements in Period 3

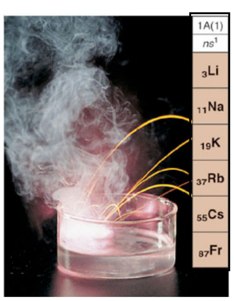
Atomic Number	Element	Partial Orbital Diagram (3s and 3p Sublevels Only): 3s	3p	Full Electron Configuration	Condensed Electron Configuration
11	Na	↑	☐ ☐ ☐	$[1s^22s^22p^6]\ 3s^1$	$[Ne]\ 3s^1$
12	Mg	↑↓	☐ ☐ ☐	$[1s^22s^22p^6]\ 3s^2$	$[Ne]\ 3s^2$
13	Al	↑↓	↑ ☐ ☐	$[1s^22s^22p^6]\ 3s^23p^1$	$[Ne]\ 3s^23p^1$
14	Si	↑↓	↑ ↑ ☐	$[1s^22s^22p^6]\ 3s^23p^2$	$[Ne]\ 3s^23p^2$
15	P	↑↓	↑ ↑ ↑	$[1s^22s^22p^6]\ 3s^23p^3$	$[Ne]\ 3s^23p^3$
16	S	↑↓	↑↓ ↑ ↑	$[1s^22s^22p^6]\ 3s^23p^4$	$[Ne]\ 3s^23p^4$
17	Cl	↑↓	↑↓ ↑↓ ↑	$[1s^22s^22p^6]\ 3s^23p^5$	$[Ne]\ 3s^23p^5$
18	Ar	↑↓	↑↓ ↑↓ ↑↓	$[1s^22s^22p^6]\ 3s^23p^6$	$[Ne]\ 3s^23p^6$

*Colored type indicates the sublevel to which the last electron is added.

Figure 8.9 Condensed ground-state electron configurations in the first three periods.

Period	1A (1)	2A (2)	3A (13)	4A (14)	5A (15)	6A (16)	7A (17)	8A (18)
1	1 **H** $1s^1$							2 **He** $1s^2$
2	3 **Li** [He] $2s^1$	4 **Be** [He] $2s^2$	5 **B** [He] $2s^22p^1$	6 **C** [He] $2s^22p^2$	7 **N** [He] $2s^22p^3$	8 **O** [He] $2s^22p^4$	9 **F** [He] $2s^22p^5$	10 **Ne** [He] $2s^22p^6$
3	11 **Na** [Ne] $3s^1$	12 **Mg** [Ne] $3s^2$	13 **Al** [Ne] $3s^23p^1$	14 **Si** [Ne] $3s^23p^2$	15 **P** [Ne] $3s^23p^3$	16 **S** [Ne] $3s^23p^4$	17 **Cl** [Ne] $3s^23p^5$	18 **Ar** [Ne] $3s^23p^6$

Figure 8.10 Similar reactivities within a group.



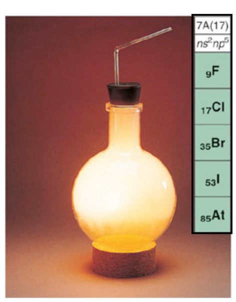


Table 8.4 Partial Orbital Diagrams and Electron Configurations* for the Elements in Period 4

Atomic Number	Element	Partial Orbital Diagram (4s, 3d, and 4p Sublevels Only): 4s	3d	4p	Full Electron Configuration	Condensed Electron Configuration
19	K	↑	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐	$[1s^22s^22p^63s^23p^6]\ 4s^1$	$[Ar]\ 4s^1$
20	Ca	↑↓	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐	$[1s^22s^22p^63s^23p^6]\ 4s^2$	$[Ar]\ 4s^2$
21	Sc	↑↓	↑ ☐ ☐ ☐ ☐	☐ ☐ ☐	$[1s^22s^22p^63s^23p^6]\ 4s^23d^1$	$[Ar]\ 4s^23d^1$
22	Ti	↑↓	↑ ↑ ☐ ☐ ☐	☐ ☐ ☐	$[1s^22s^22p^63s^23p^6]\ 4s^23d^2$	$[Ar]\ 4s^23d^2$
23	V	↑↓	↑ ↑ ↑ ☐ ☐	☐ ☐ ☐	$[1s^22s^22p^63s^23p^6]\ 4s^23d^3$	$[Ar]\ 4s^23d^3$
24	Cr	↑	↑ ↑ ↑ ↑ ↑	☐ ☐ ☐	$[1s^22s^22p^63s^23p^6]\ 4s^13d^5$	$[Ar]\ 4s^13d^5$
25	Mn	↑↓	↑ ↑ ↑ ↑ ↑	☐ ☐ ☐	$[1s^22s^22p^63s^23p^6]\ 4s^23d^5$	$[Ar]\ 4s^23d^5$
26	Fe	↑↓	↑↓ ↑ ↑ ↑ ↑	☐ ☐ ☐	$[1s^22s^22p^63s^23p^6]\ 4s^23d^6$	$[Ar]\ 4s^23d^6$
27	Co	↑↓	↑↓ ↑↓ ↑ ↑ ↑	☐ ☐ ☐	$[1s^22s^22p^63s^23p^6]\ 4s^23d^7$	$[Ar]\ 4s^23d^7$

*Colored type indicates sublevel(s) whose occupancy changes when the last electron is added.

Table 8.4 Partial Orbital Diagrams and Electron Configurations* for the Elements in Period 4

Atomic Number	Element	Partial Orbital Diagram (4s, 3d, and 4p Sublevels Only)	Full Electron Configuration	Condensed Electron Configuration
28	Ni	4s: ↑↓ · 3d: ↑↓ ↑↓ ↑↓ ↑ ↑ · 4p: _ _ _	$[1s^22s^22p^63s^23p^6]\ 4s^23d^8$	$[Ar]\ 4s^23d^8$
29	Cu	4s: ↑ · 3d: ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ · 4p: _ _ _	$[1s^22s^22p^63s^23p^6]\ 4s^13d^{10}$	$[Ar]\ 4s^13d^{10}$
30	Zn	4s: ↑↓ · 3d: ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ · 4p: _ _ _	$[1s^22s^22p^63s^23p^6]\ 4s^23d^{10}$	$[Ar]\ 4s^23d^{10}$
31	Ga	4s: ↑↓ · 3d: ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ · 4p: ↑ _ _	$[1s^22s^22p^63s^23p^6]\ 4s^23d^{10}4p^1$	$[Ar]\ 4s^23d^{10}4p^1$
32	Ge	4s: ↑↓ · 3d: ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ · 4p: ↑ ↑ _	$[1s^22s^22p^63s^23p^6]\ 4s^23d^{10}4p^2$	$[Ar]\ 4s^23d^{10}4p^2$
33	As	4s: ↑↓ · 3d: ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ · 4p: ↑ ↑ ↑	$[1s^22s^22p^63s^23p^6]\ 4s^23d^{10}4p^3$	$[Ar]\ 4s^23d^{10}4p^3$
34	Se	4s: ↑↓ · 3d: ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ · 4p: ↑↓ ↑ ↑	$[1s^22s^22p^63s^23p^6]\ 4s^23d^{10}4p^4$	$[Ar]\ 4s^23d^{10}4p^4$
35	Br	4s: ↑↓ · 3d: ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ · 4p: ↑↓ ↑↓ ↑	$[1s^22s^22p^63s^23p^6]\ 4s^23d^{10}4p^5$	$[Ar]\ 4s^23d^{10}4p^5$
36	Kr	4s: ↑↓ · 3d: ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ · 4p: ↑↓ ↑↓ ↑↓	$[1s^22s^22p^63s^23p^6]\ 4s^23d^{10}4p^6$	$[Ar]\ 4s^23d^{10}4p^6$

*Colored type indicates sublevel(s) whose occupancy changes when the last electron is added.

Figure 8.11 A periodic table of partial ground-state electron configurations.

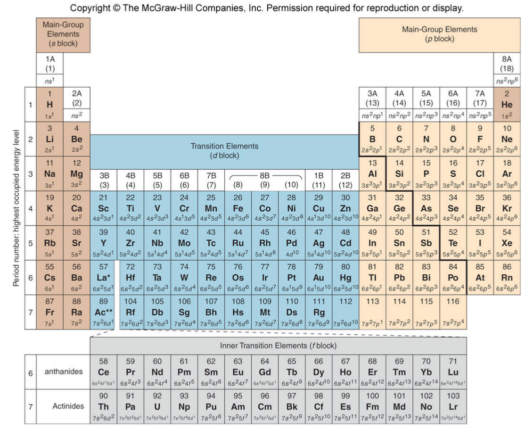


Figure 8.12 The relation between orbital filling and the periodic table.

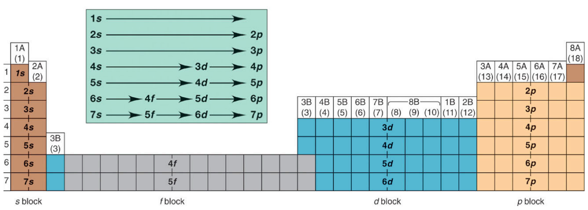
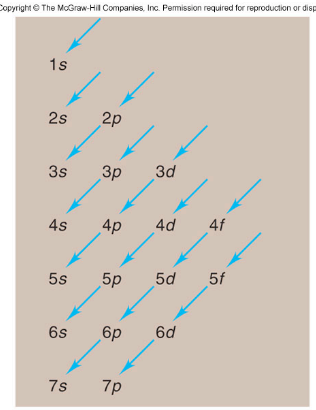


Figure 8.13 Aid to memorizing sublevel filling order.



Sample Problem 8.2 Determining Electron Configurations

PROBLEM: Using the periodic table on the inside cover of the text (not Figure 8.11 or Table 8.4), give the full and condensed electron configurations, partial orbital diagrams showing valence electrons, and number of inner electrons for the following elements:

(a) potassium (K; Z = 19) (b) molybdenum (Mo; Z = 42) (c) lead (Pb; Z = 82)

PLAN: Use the atomic number for the number of electrons and the periodic table for the order of filling for electron orbitals. Condensed configurations consist of the preceding noble gas and outer electrons.

SOLUTION:

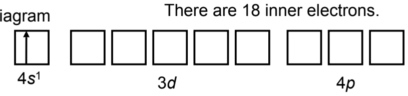
(a) for K: (Z = 19)

full configuration $1s^22s^22p^63s^23p^64s^1$

condensed configuration $[Ar]\ 4s^1$

partial orbital diagram

There are 18 inner electrons.



Sample Problem 8.2 Determining Electron Configurations

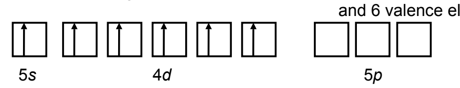
(b) for Mo: (Z = 42)

full configuration $1s^22s^22p^63s^23p^64s^23d^{10}4p^65s^24d^4$

condensed configuration $[Kr]\ 5s^14d^5$

partial orbital diagram

There are 36 inner electrons and 6 valence electrons.



(c) for Pb: (Z = 82)

full configuration $1s^22s^22p^63s^23p^64s^23d^{10}4p^65s^24d^{10}5p^66s^24f^{14}5d^{10}6p^2$

condensed configuration $[Xe]\ 6s^24f^{14}5d^{10}6p^2$

partial orbital diagram

There are 78 inner electrons and 4 valence electrons.