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BROOKS/COLE
CENGAGE Learning

Chapter 3

Chemical Foundations:
Elements, Atoms, and Ions

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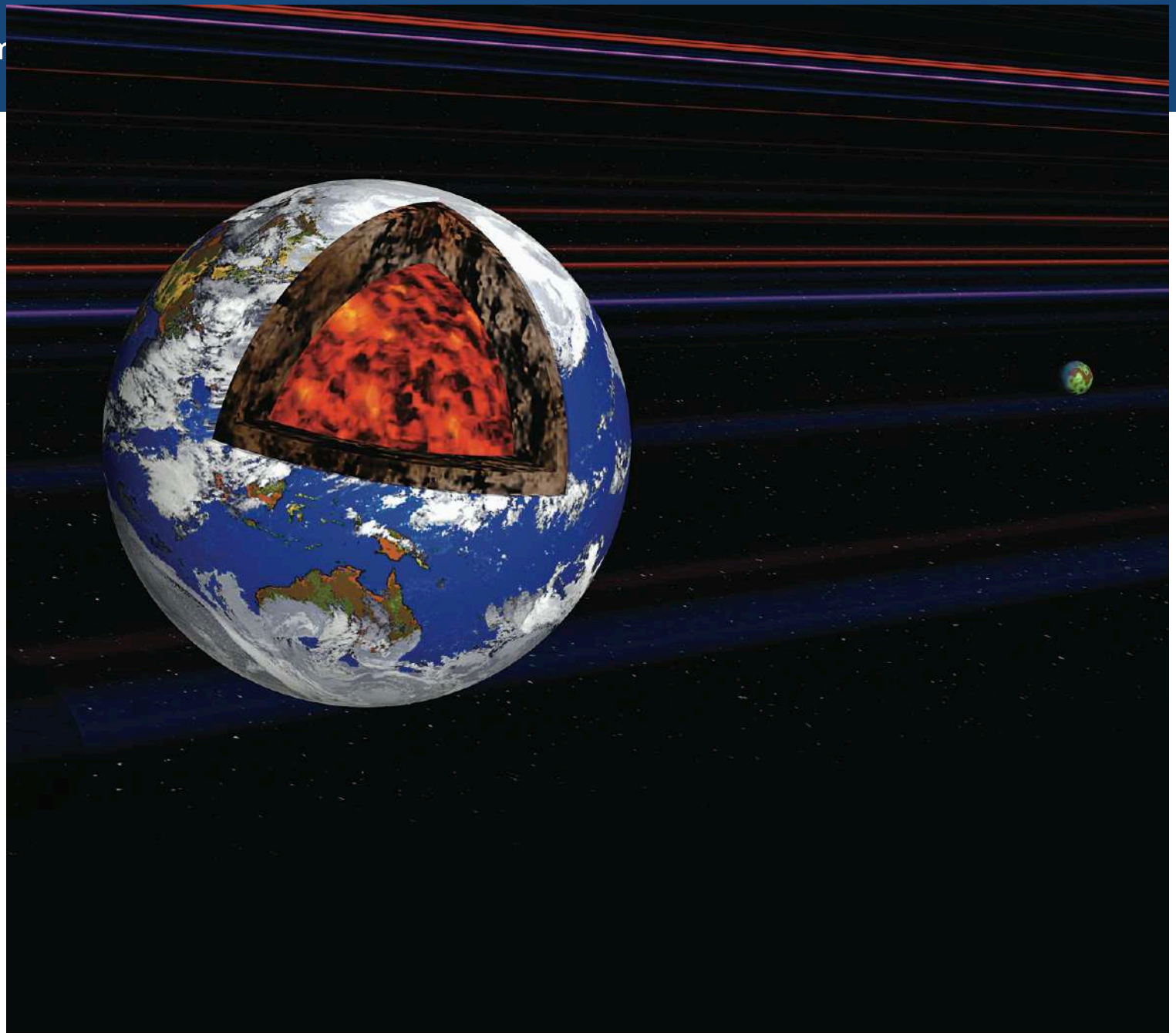
Objectives

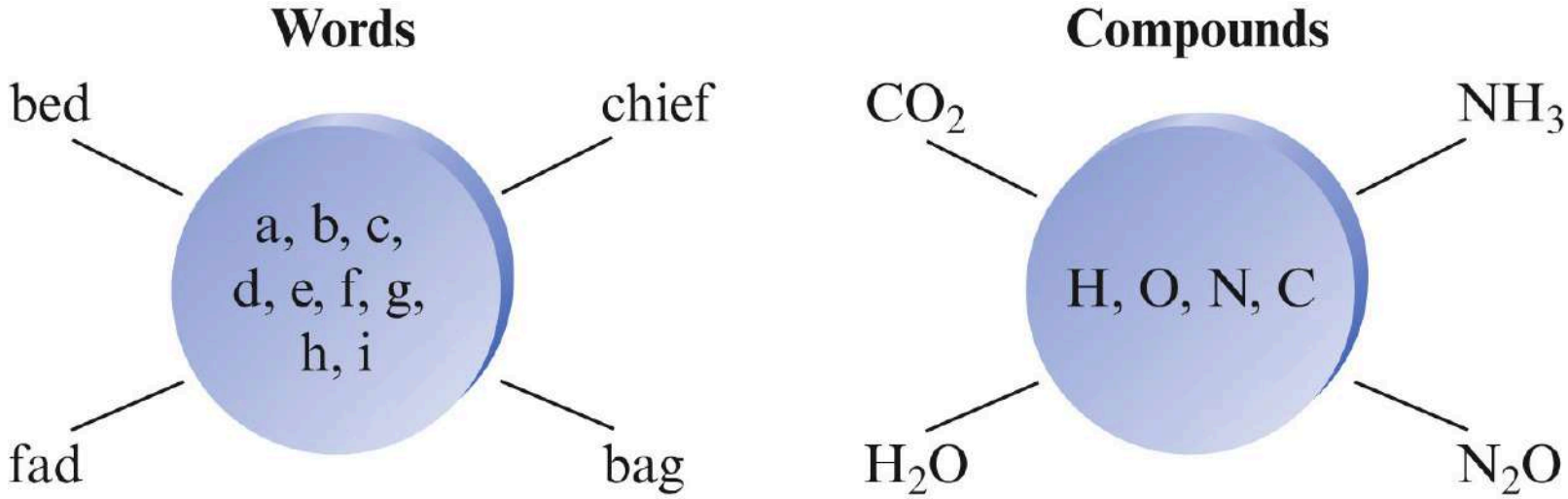
1. To learn about the relative abundances of the elements
2. To learn the names of some elements
3. To learn the symbols of some elements



The Elements

- All of the materials in the universe can be chemically broken down into about 100 different elements.

Compounds are made by combining atoms of the elements just as words are constructed from the letters in the alphabet.



A. Abundances of Elements

- Nine elements account for about 98% of the earth's crust, oceans and atmosphere.

Table 3.1 Distribution (Mass Percent) of the 18 Most Abundant Elements in the Earth's Crust, Oceans, and Atmosphere

Element	Mass Percent	Element	Mass Percent
oxygen	49.2	titanium	0.58
silicon	25.7	chlorine	0.19
aluminum	7.50	phosphorus	0.11
iron	4.71	manganese	0.09
calcium	3.39	carbon	0.08
sodium	2.63	sulfur	0.06
potassium	2.40	barium	0.04
magnesium	1.93	nitrogen	0.03
hydrogen	0.87	fluorine	0.03
		all others	0.49

A. Abundances of Elements

- The elements in living matter are very different from those in the earth's crust.

In the human body, oxygen, carbon, hydrogen and nitrogen are the most abundant elements.

Table 3.2 Top Ten Elements in the Human Body

Element	Mass Percent
oxygen	65.0
carbon	18.0
hydrogen	10.0
nitrogen	3.0
calcium	1.4
phosphorus	1.0
magnesium	0.50
potassium	0.34
sulfur	0.26
sodium	0.14

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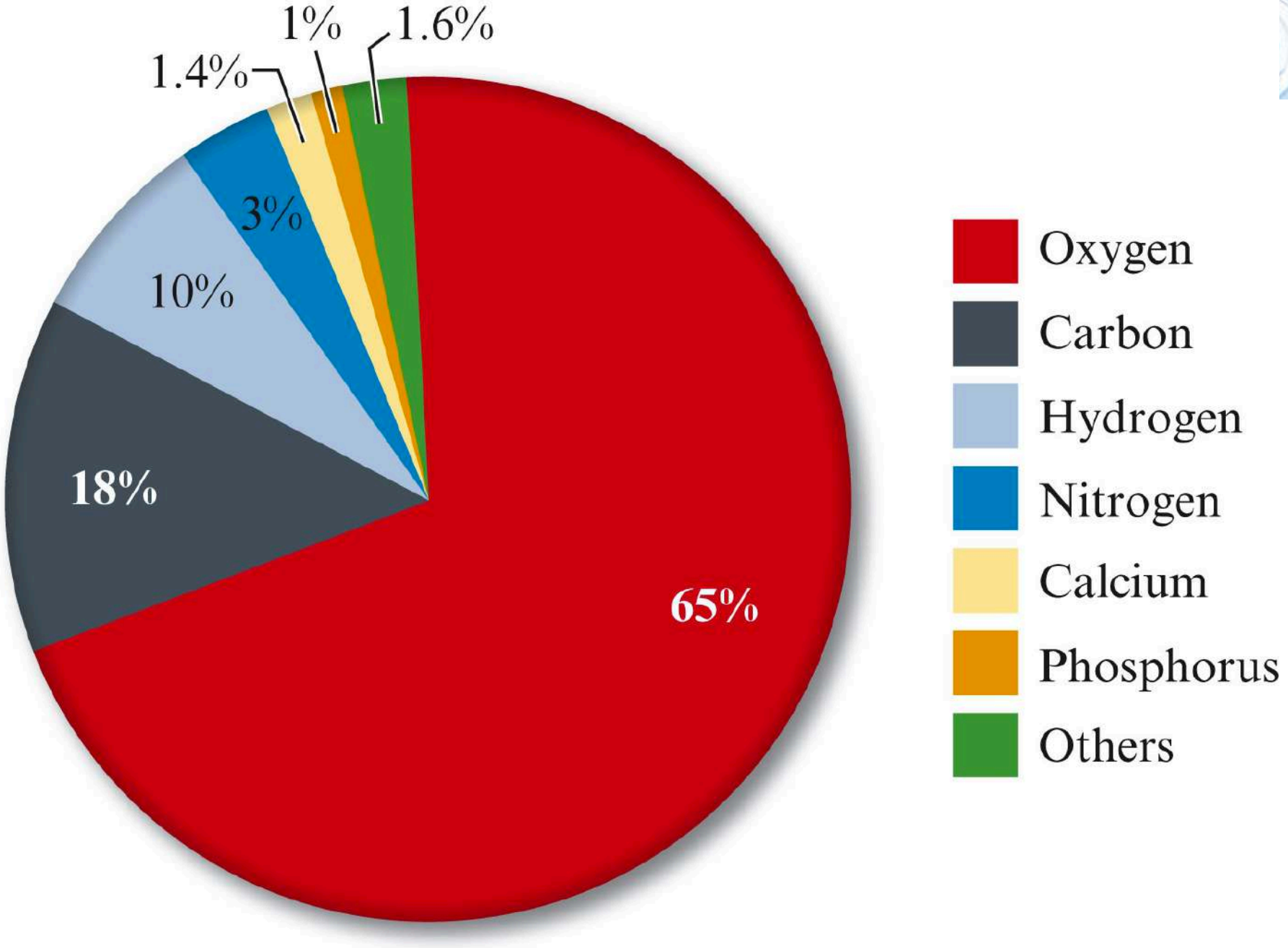
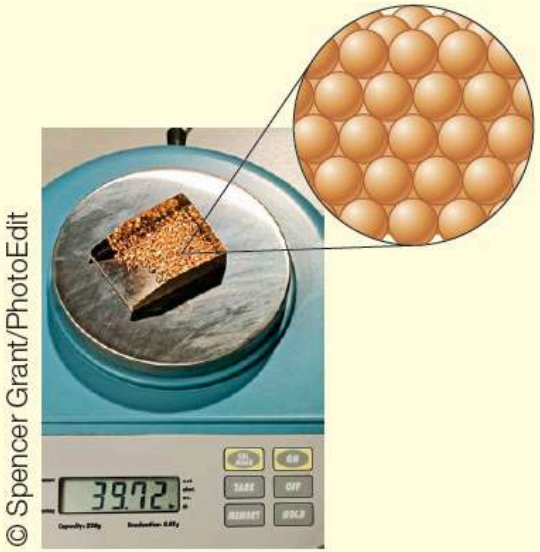

1%
1.6%
1.4%
3%
10%
18%
65%
Oxygen
Carbon
Hydrogen
Nitrogen
Calcium
Phosphorus
Others

Tl

Table 3.3 Trace Elements in the Human Body

Trace Elements
arsenic
chromium
cobalt
copper
fluorine
iodine
manganese
molybdenum
nickel
selenium
silicon
vanadium

Element can have several meanings

Word	Meaning	
Element	**Microscopic form** Single atom of that element	
Element	**Macroscopic form** Sample of that element large enough to weigh on a balance	
Element	**Generic form** When we say the human body contains the element sodium or lithium, we do not mean that free elemental sodium or lithium is present. Rather we mean that atoms of these elements are present in some form.	

B. Names and Symbols for the Elements

- Each element has a name and a symbol.
  - The symbol usually consists of the first one or two letters of the element's name.

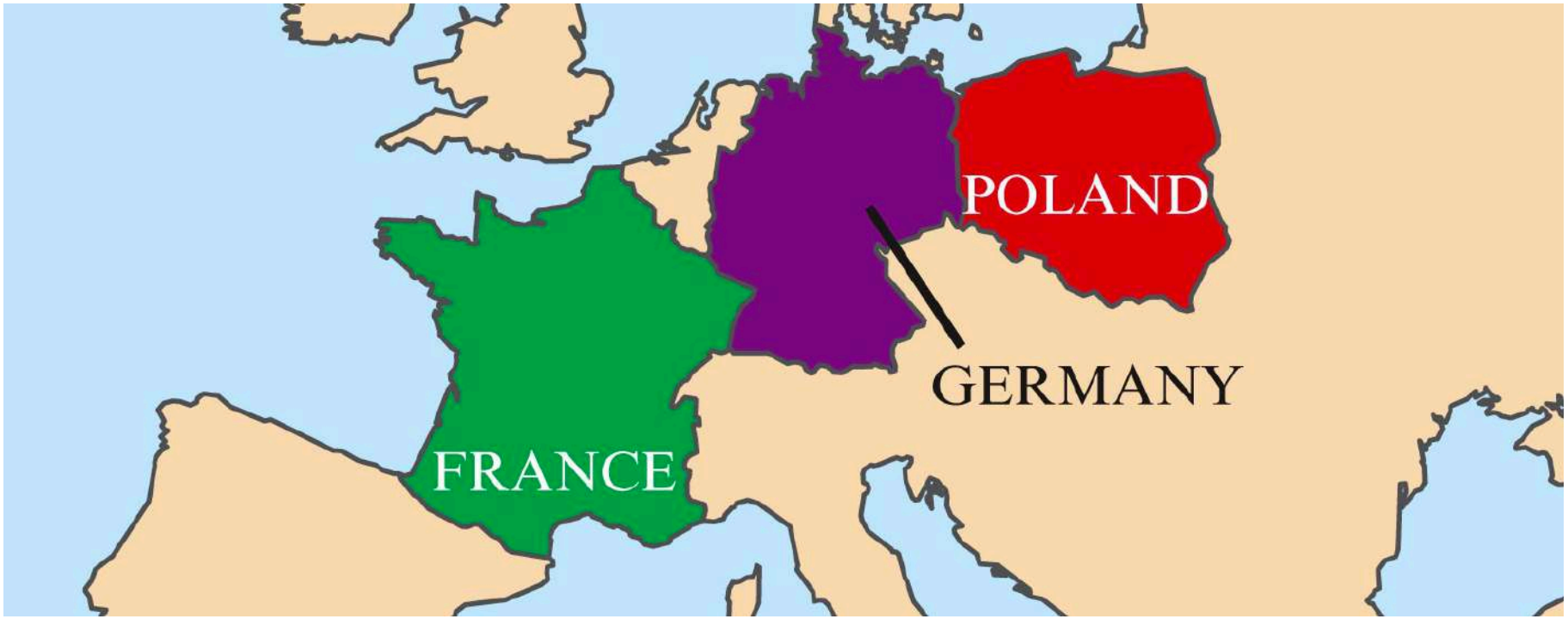
    Examples:

    Oxygen O
    Krypton Kr

  - Sometimes the symbol is taken from the element's original Latin or Greek name.

    Examples:

    gold Au aurum
    lead Pb plumbum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GERMANY
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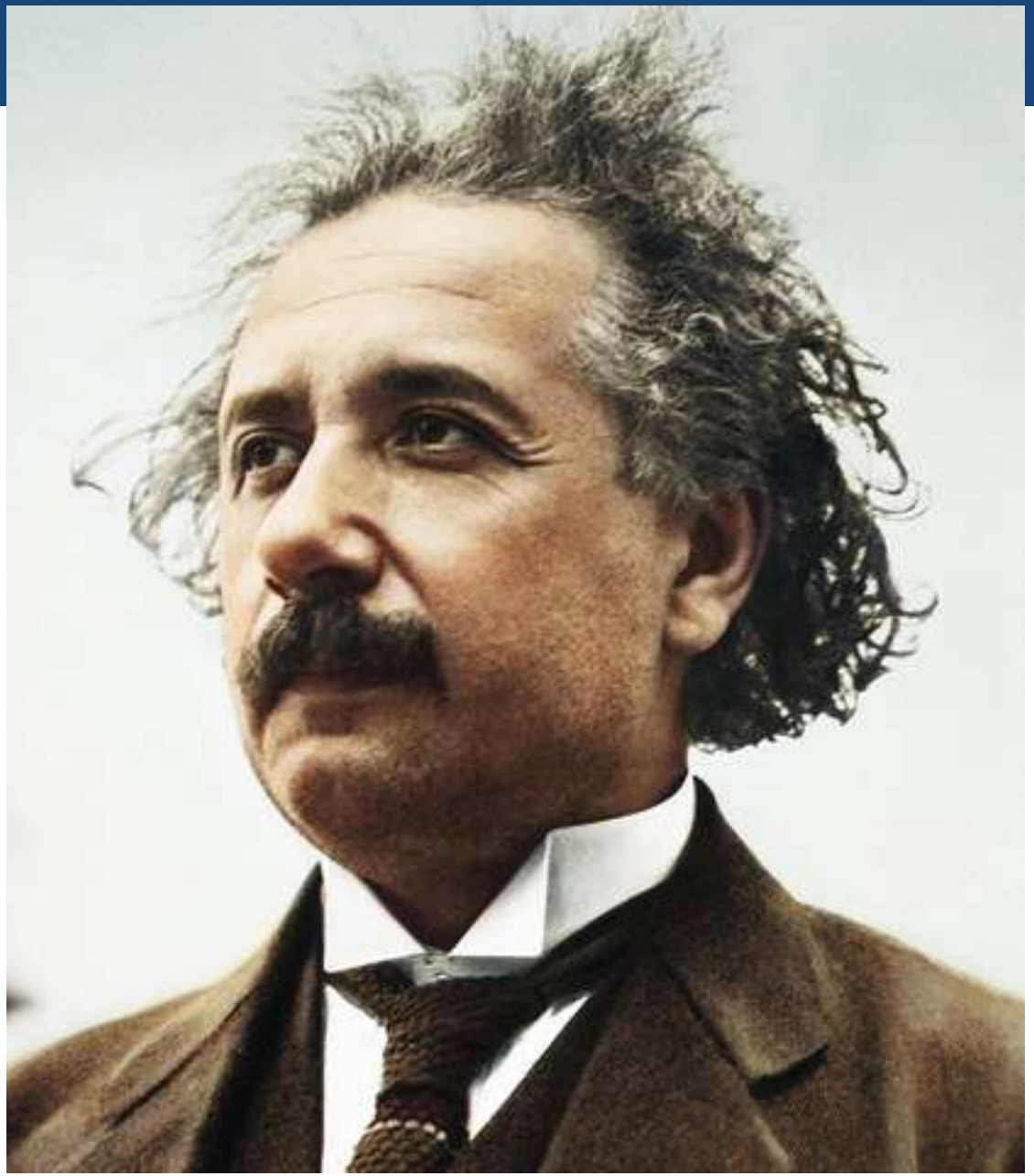


The Elements

Table 3.4 The Names and Symbols of the Most Common Elements*

Element	Symbol	Element	Symbol
aluminum	Al	lithium	Li
arsenic	As	mercury (hydrargyrum)	Hg
barium	Ba	neon	Ne
boron	B	nitrogen	N
bromine	Br	oxygen	O
calcium	Ca	platinum	Pt
carbon	C	potassium (kalium)	K
chromium	Cr	silicon	Si
cobalt	Co	silver (argentium)	Ag
copper (cuprum)	Cu	sodium (natrium)	Na
gold (aurum)	Au	sulfur	S
lead (plumbum)	Pb	zinc	Zn

*Where appropriate, the original name is shown in parentheses so that you can see the sources of some of the symbols.

Objectives

1. To learn about Dalton's theory of atoms
2. To understand and illustrate the law of constant composition
3. To learn how a formula describes a compound's composition

Law of Constant Composition

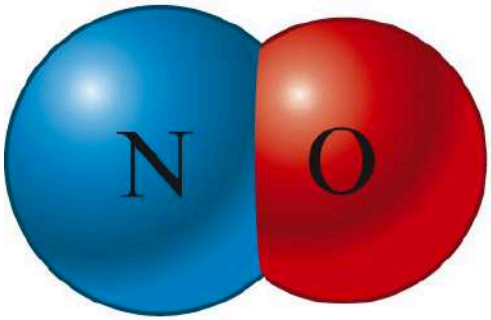
A given compound always contains the same proportion by mass of the elements of which it is composed.

A. Dalton's Atomic Theory

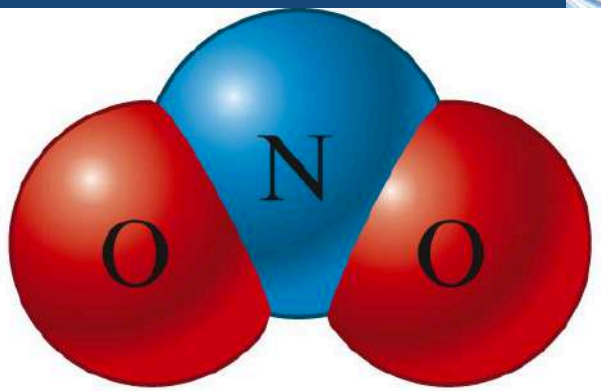
Dalton's Atomic theory states:

- All elements are composed of atoms.
- All atoms of a given element are identical.
- Atoms of different elements are different.
- Compounds consist of the atoms of different elements.
- Atoms are not created or destroyed in a chemical reaction.

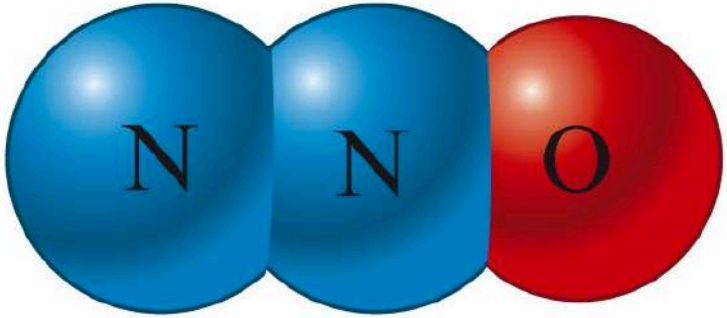
Atoms and Compounds



NO



NO_2



N_2O

Concept Check

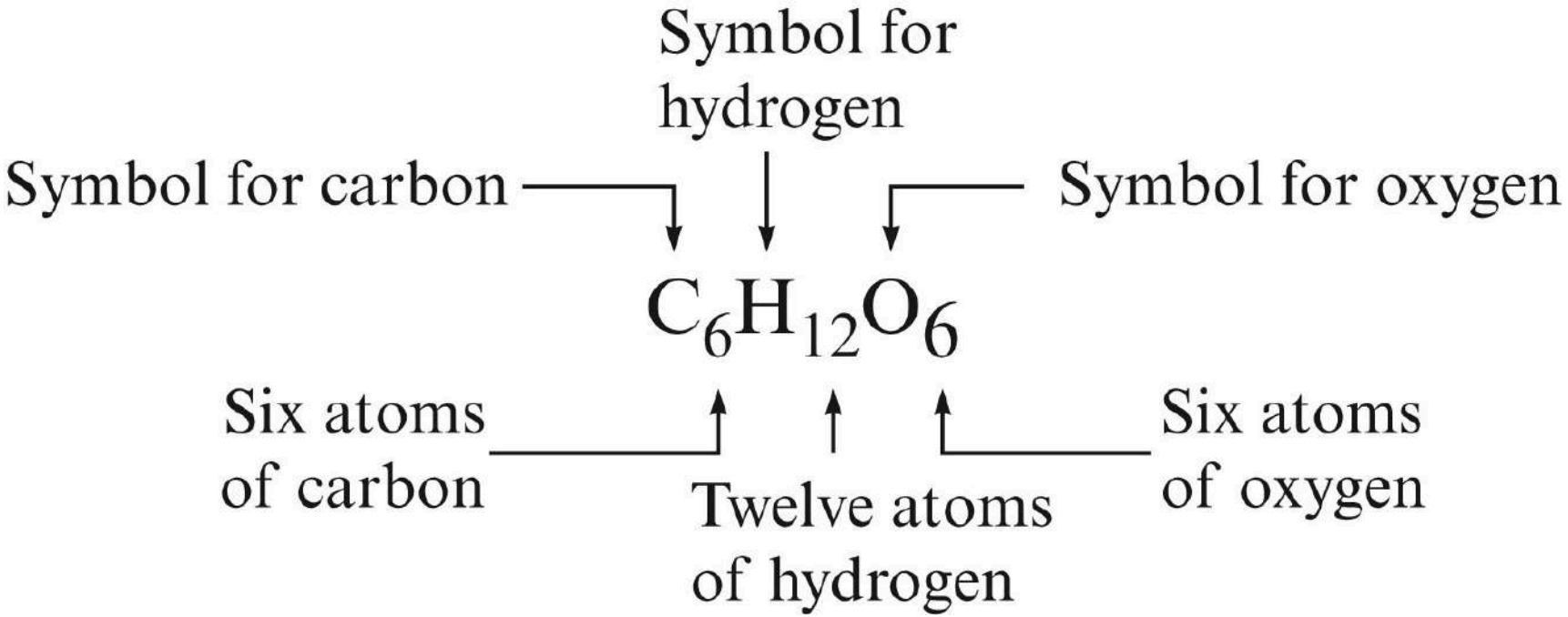
Which of the following statements regarding Dalton's atomic theory are still believed to be true?

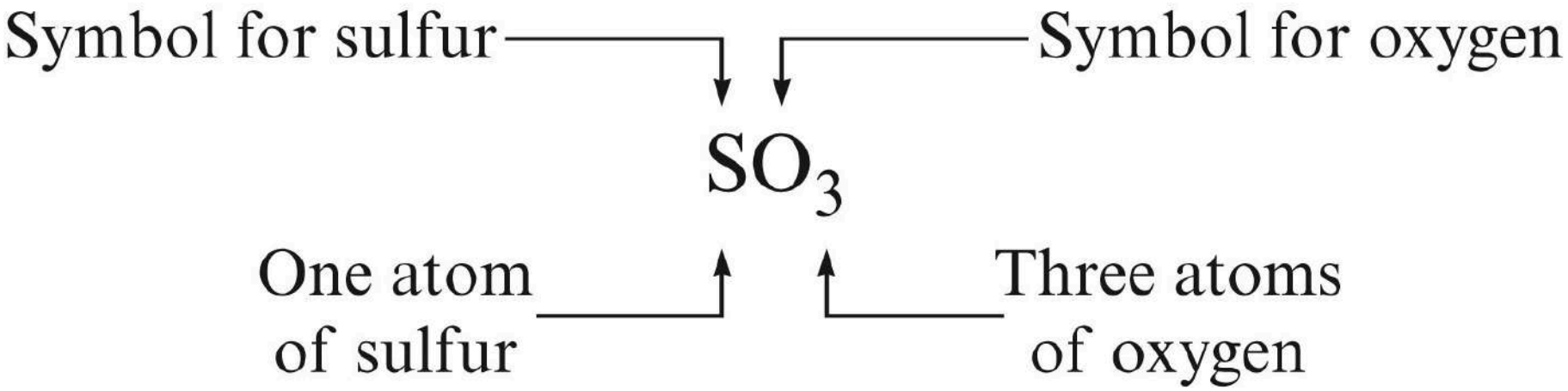
I. Elements are made of tiny particles called atoms.
II. All atoms of a given element are identical.
III. A given compound always has the same relative numbers and types of atoms.
IV. Atoms are indestructible.

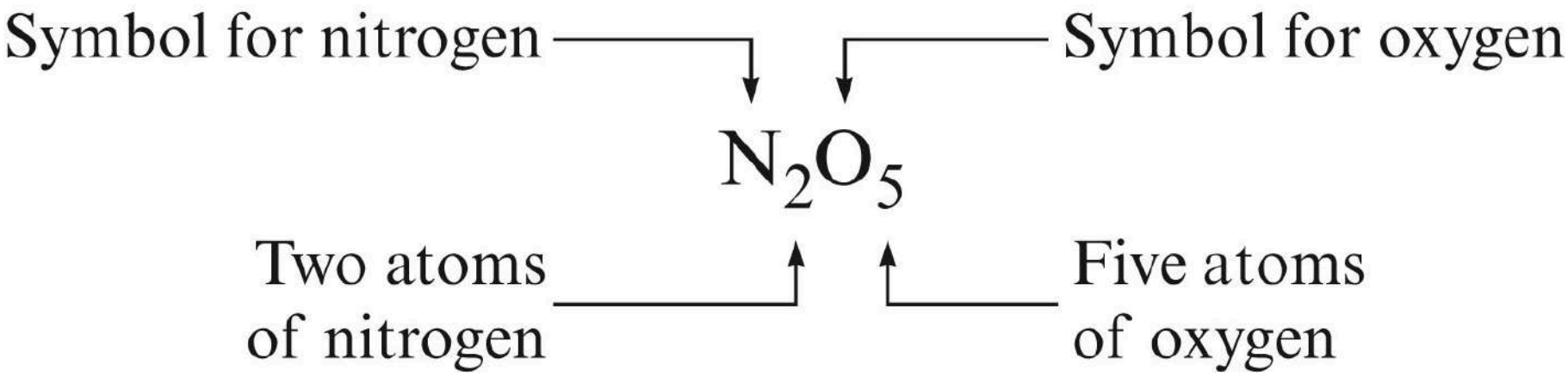
B. Formulas of Compounds

- A compound is represented by a chemical formula in which the number and kind of atoms present is shown by using the element symbols and subscripts.

  Example: the simple sugar, glucose




Symbol for sulfur
Symbol for oxygen
SO_3
One atom of sulfur
Three atoms of oxygen

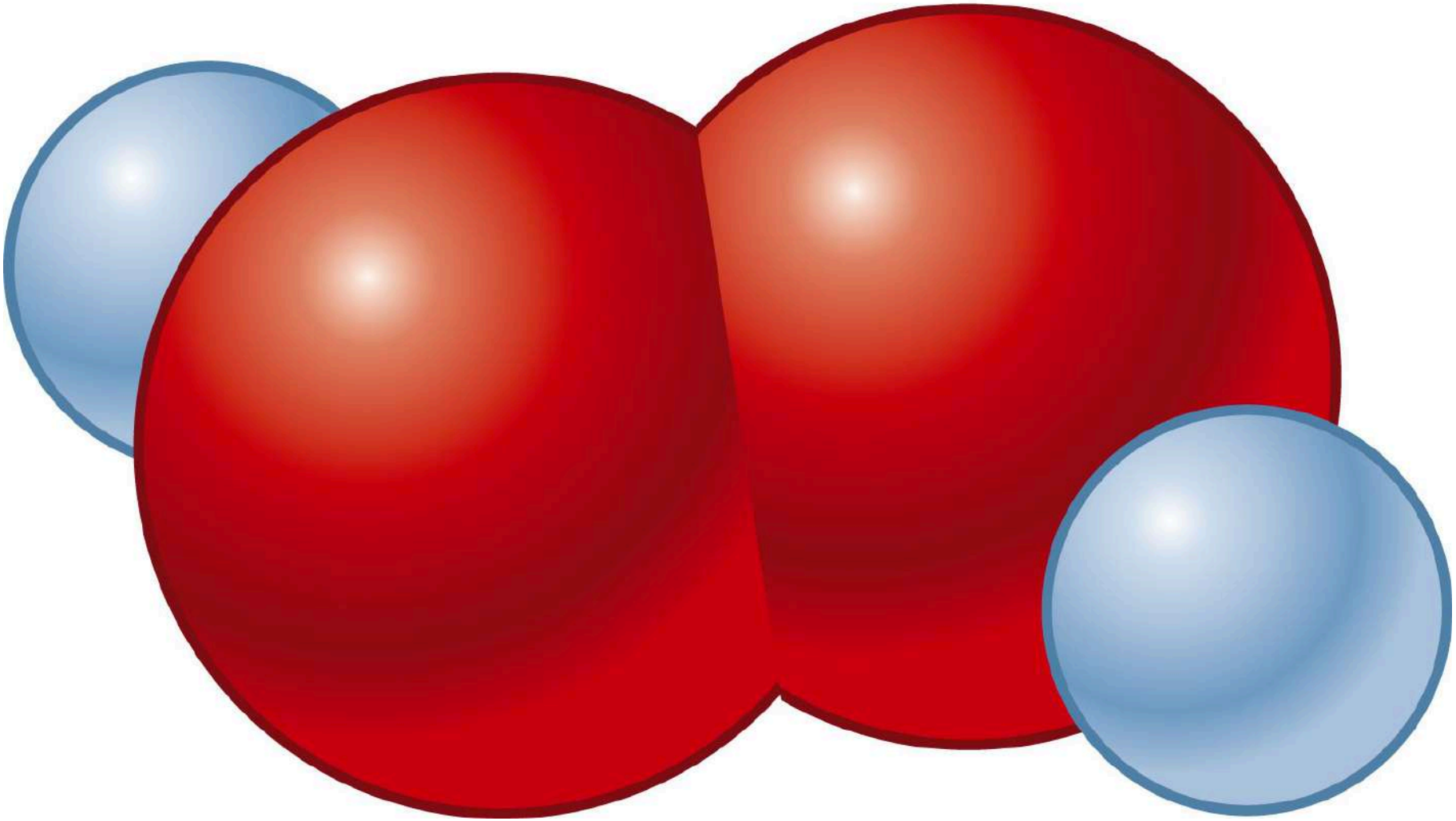

Symbol for nitrogen
Symbol for oxygen
N_2O_5
Two atoms of nitrogen
Five atoms of oxygen

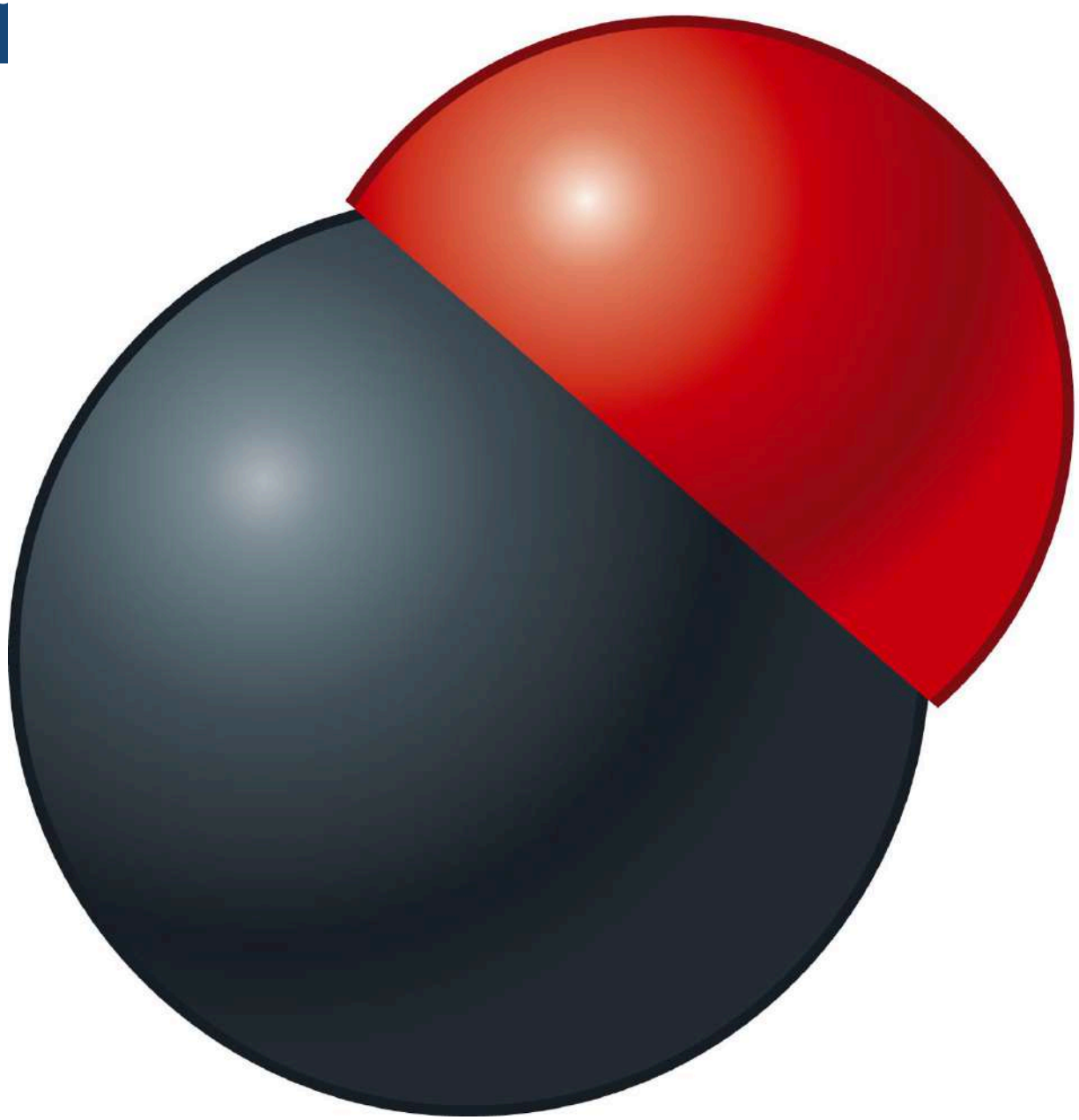
B. Formulas of Compounds

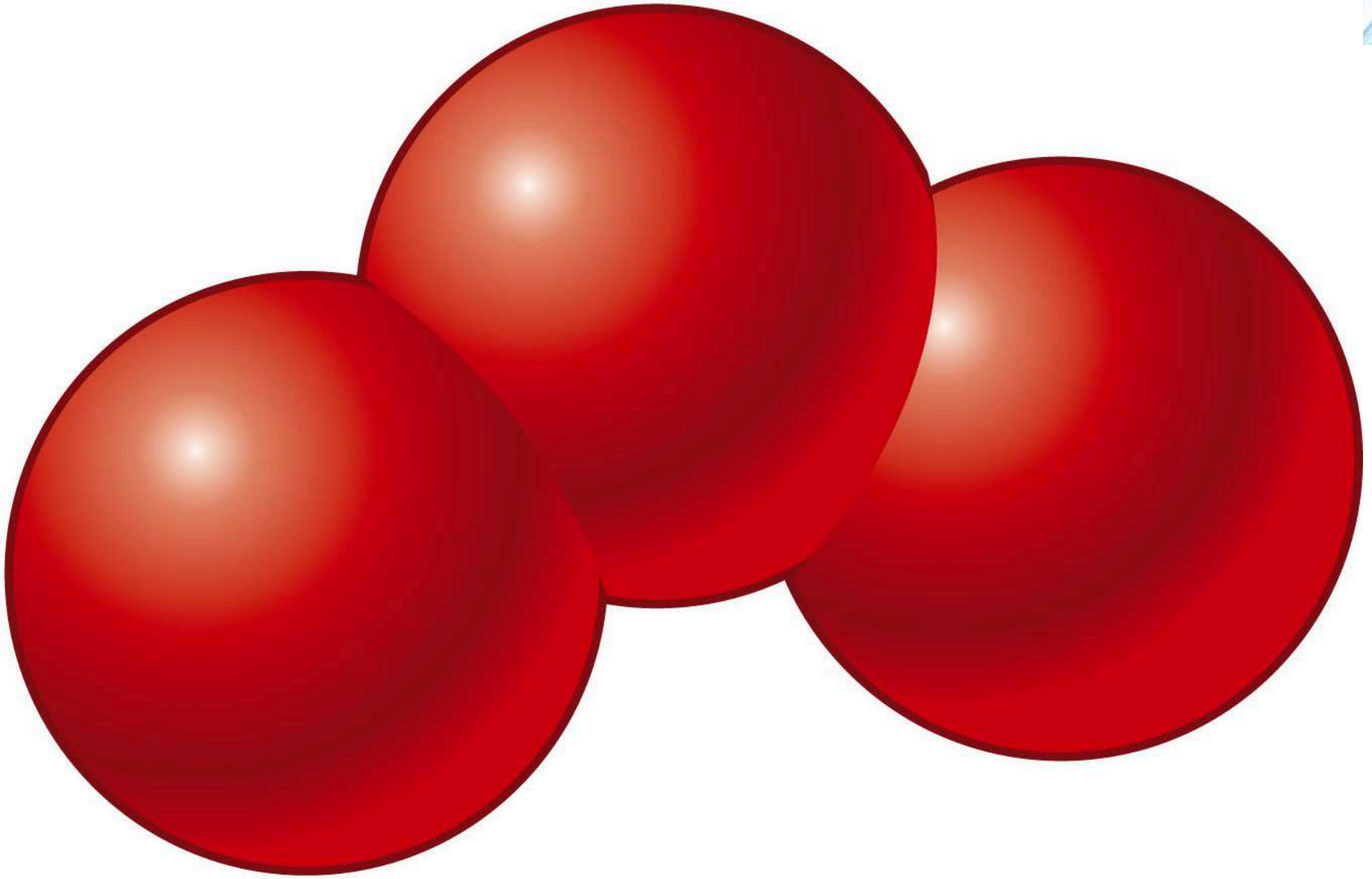
Tools for Writing Formulas

1. Each atom present is represented by its element symbol.
2. The number of each type of atom is indicated by a subscript written to the right of the element symbol.
3. When only one atom of a given type is present, the subscript 1 is not written.

Atoms and Compounds





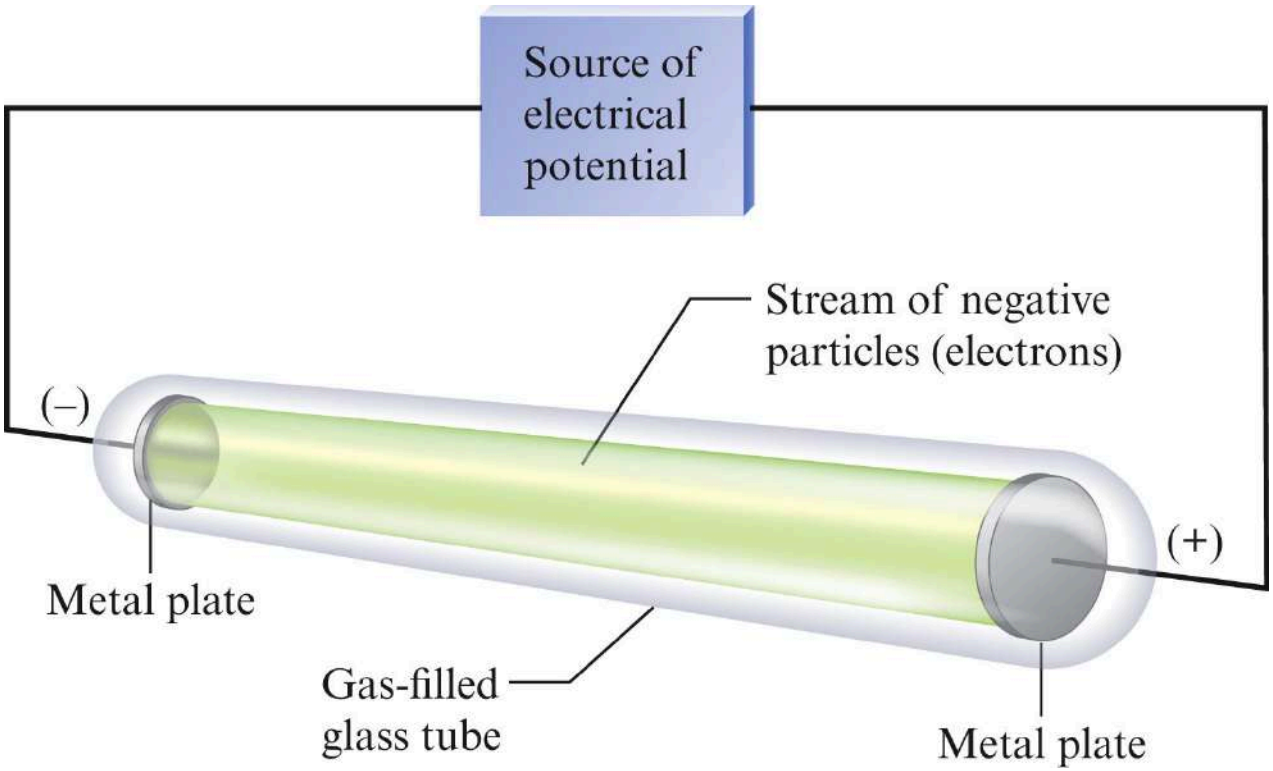


Objectives

1. To learn about the internal parts of an atom
2. To understand Rutherford's experiment
3. To describe some important features of subatomic particles
4. To learn about the terms isotope, atomic number, and mass number
5. To understand the use of the symbol ${}^{A}_{Z}X$ to describe a given atom

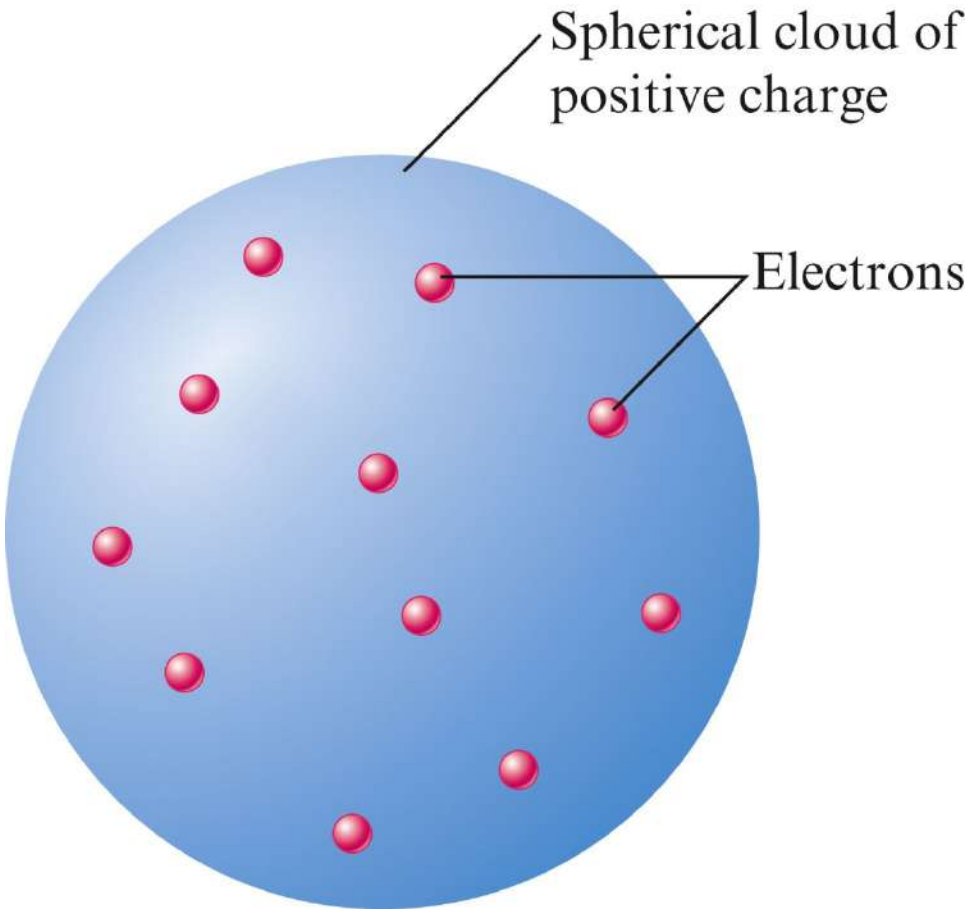
A. The Structure of the Atom

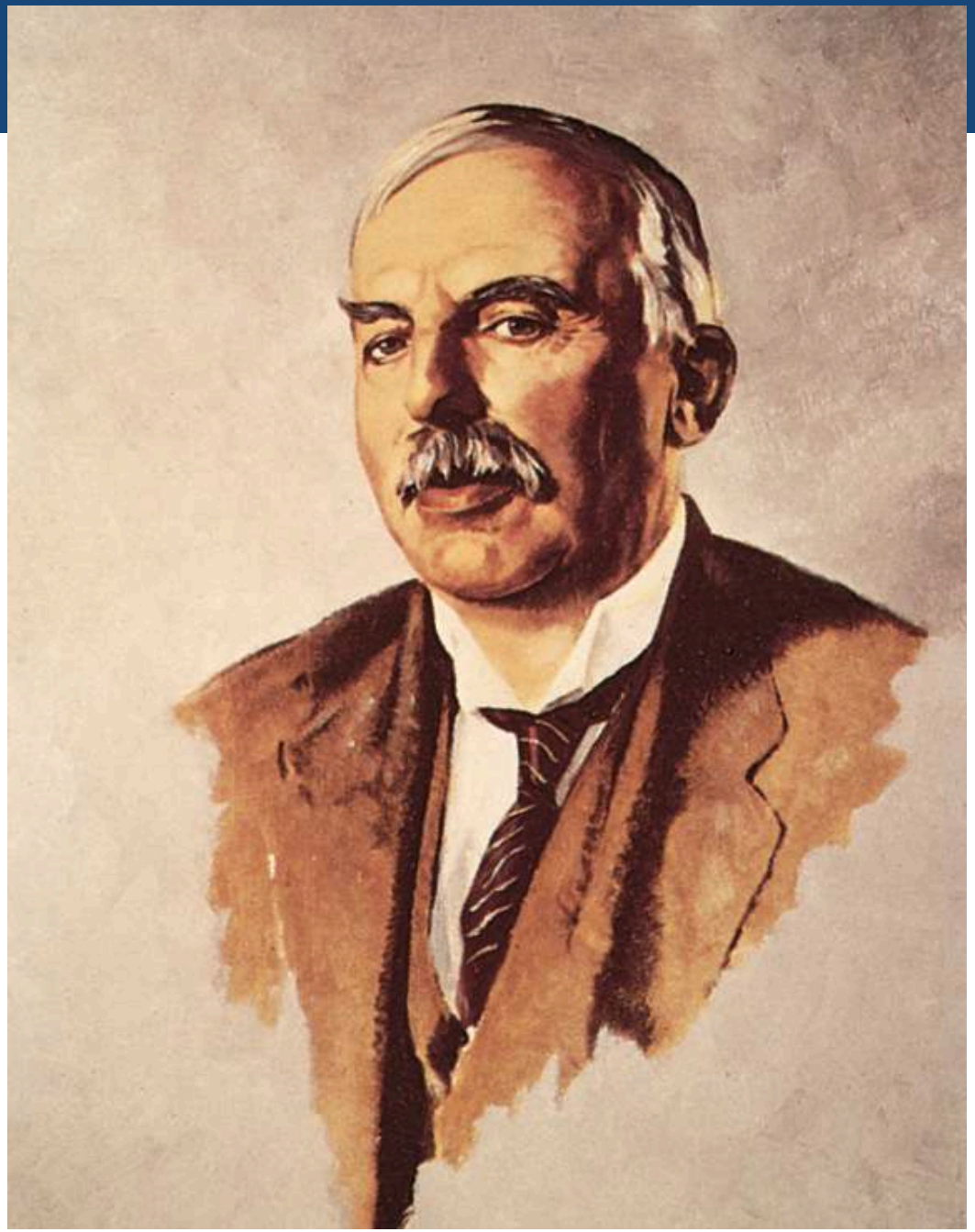
- Experiments by J.J. Thomson showed that atoms contain electrons.
- Cathode ray tube



A. The Structure of the Atom

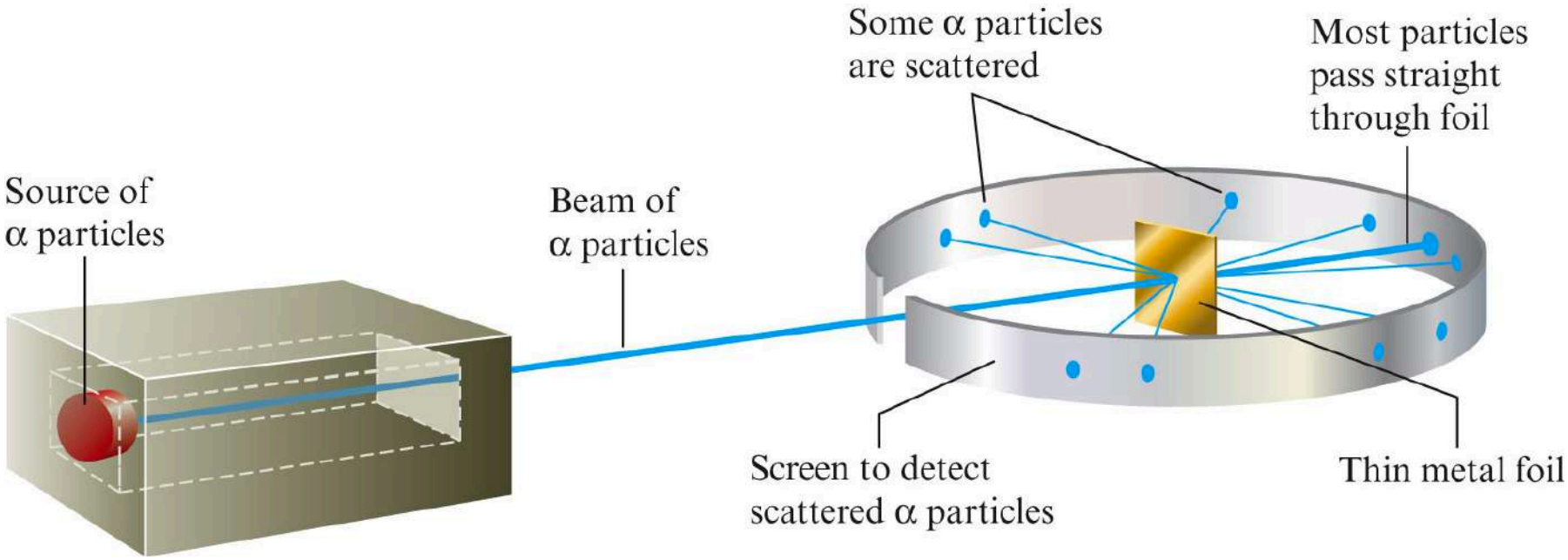
The Plum Pudding Model





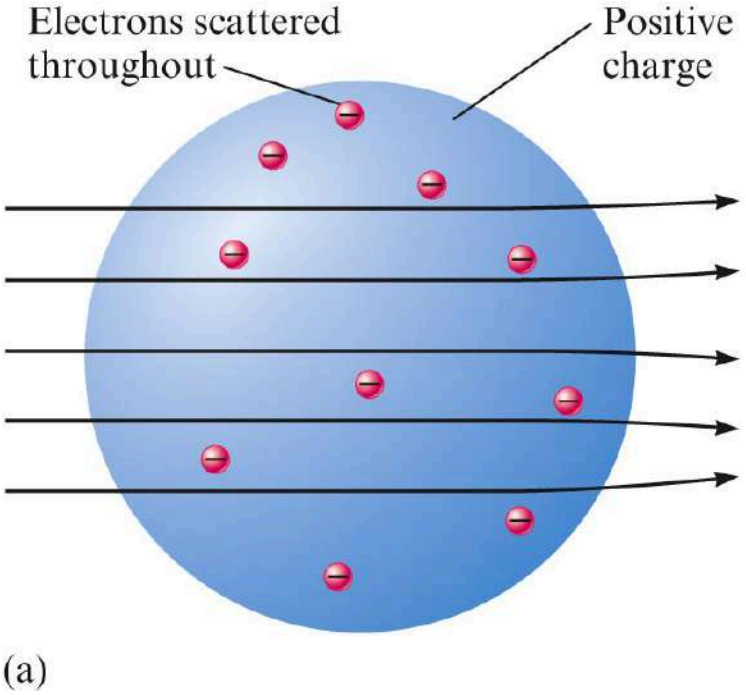
A. The Structure of the Atom

Rutherford's Experiment

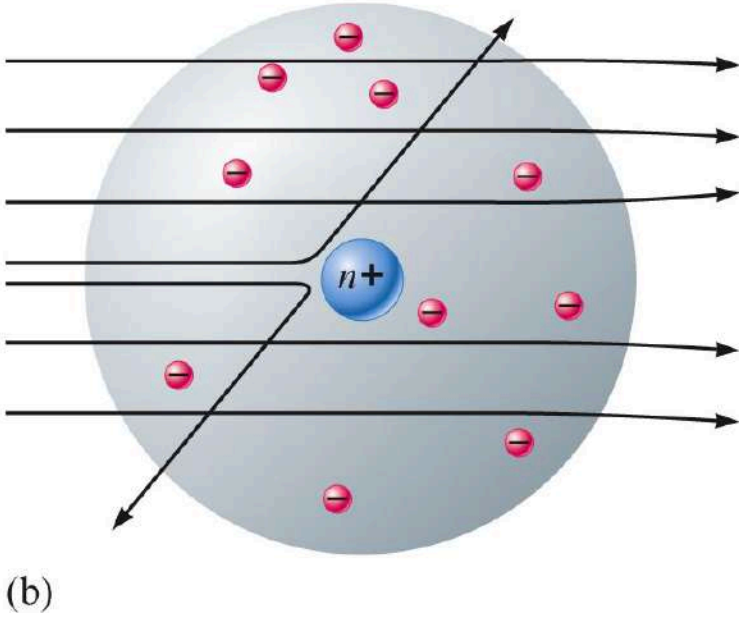


A. The Structure of the Atom

- Results of the Rutherford experiment



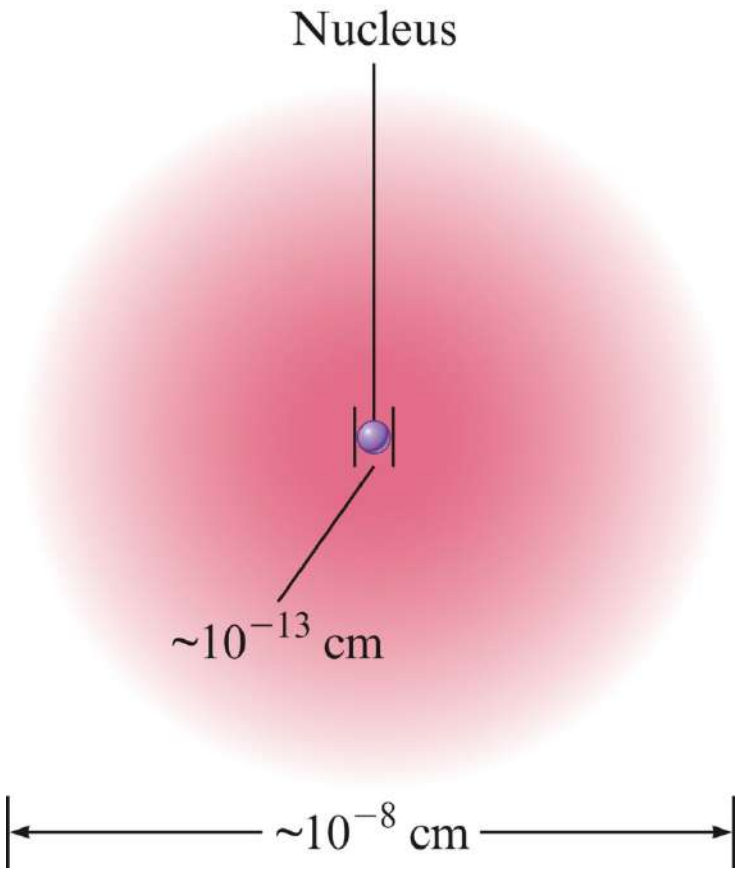
(a) The results that the metal foil experiment would have yielded if the plum pudding model had been correct



(b) Actual results

B. Introduction to the Modern Concept of Atomic Structure

- Ernest Rutherford showed that atoms have internal structure.
  - The nucleus, which is at the center of the atom, contains protons (positively charged) and neutrons (uncharged).
  - Electrons move around the nucleus.



B. Introduction to the Modern Concept of Atomic Structure

Comparing the Parts of an Atom

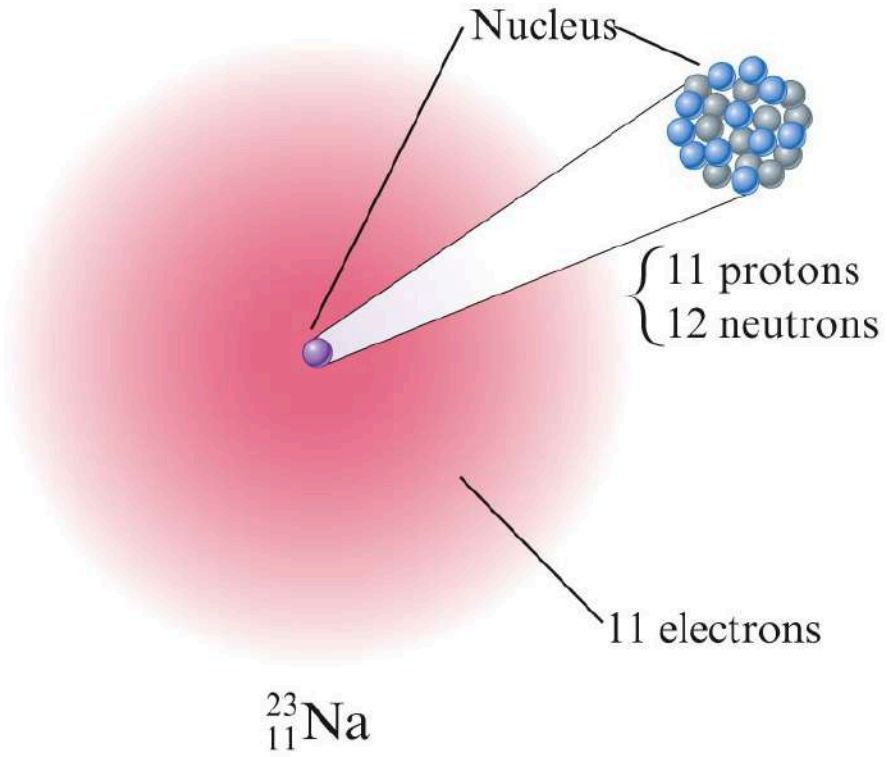
Table 3.5 The Mass and Charge of the Electron, Proton, and Neutron

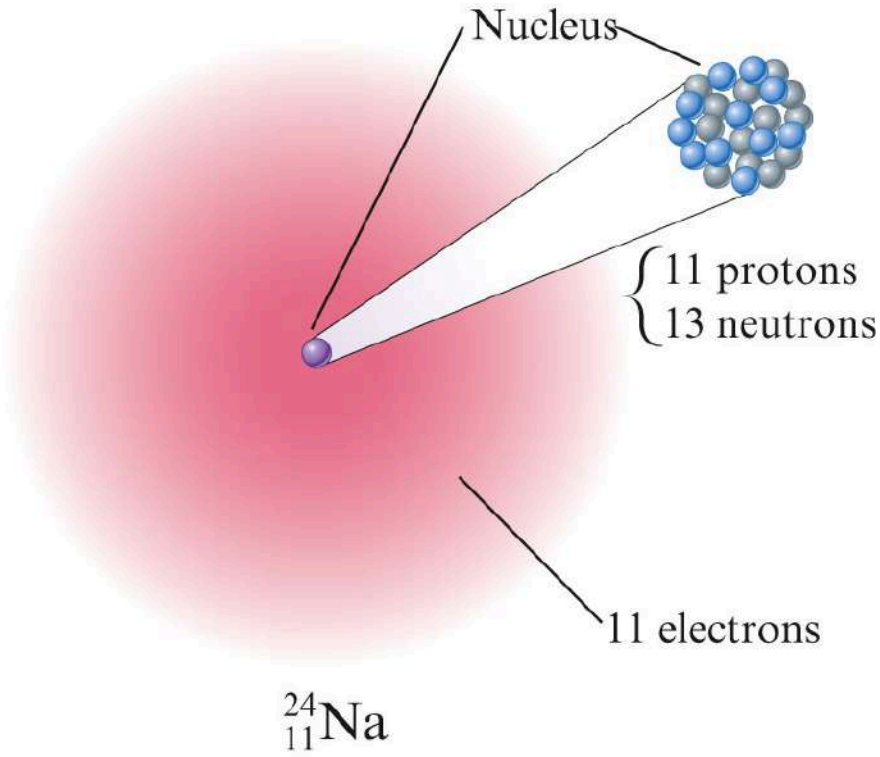
Particle	Relative Mass*	Relative Charge
electron	1	1−
proton	1836	1+
neutron	1839	none

*The electron is arbitrarily assigned a mass of 1 for comparison.

C. Isotopes

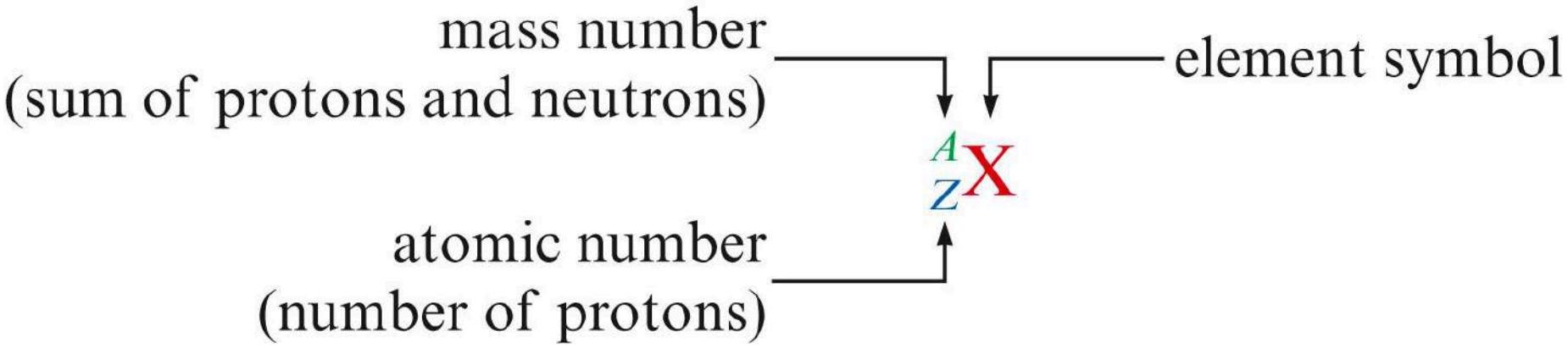
- Isotopes are atoms with the same number of protons but different numbers of neutrons.

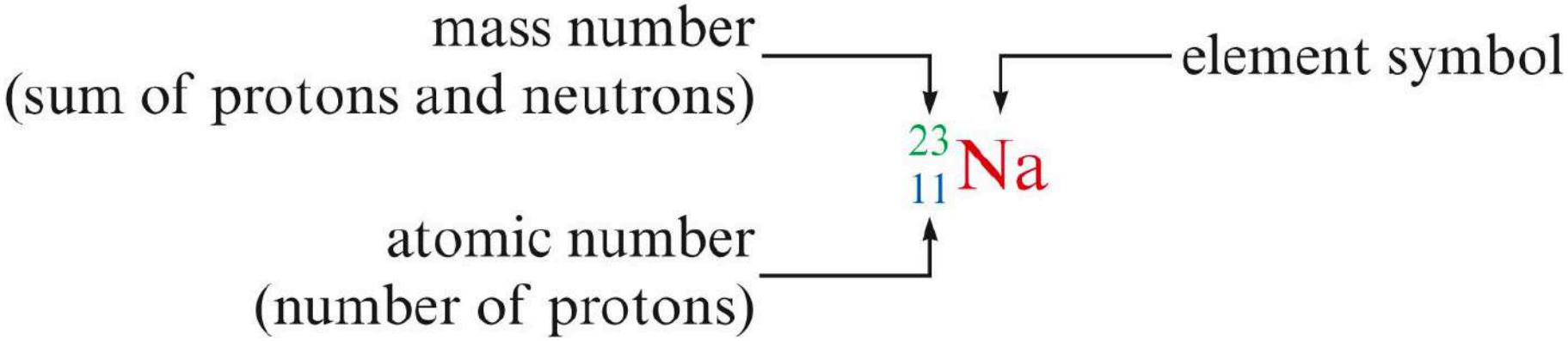


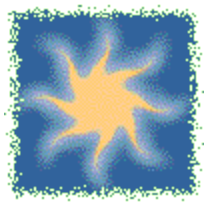


C. Isotopes

- A particular isotope is represented by the symbol ${}^{A}_{Z}X$.




mass number
(sum of protons and neutrons)
element symbol
23
11
Na
atomic number
(number of protons)



Exercise

A certain isotope X contains 23 protons and 28 neutrons.

- What is the mass number of this isotope?
- Identify the element.

Mass Number = 51

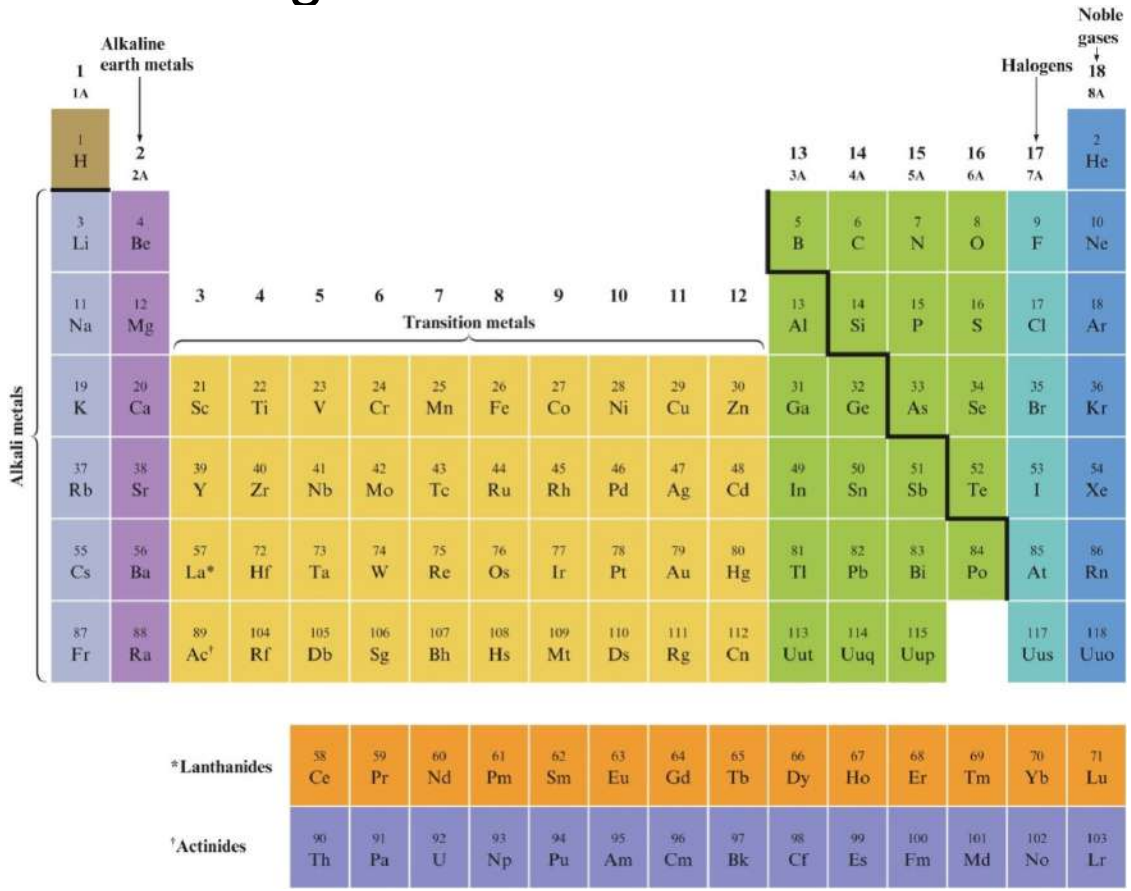
Vanadium

Objectives

1. To learn the various features of the periodic table
2. To learn some of the properties of metals, nonmetals and metalloids
3. To learn the natures of the common elements

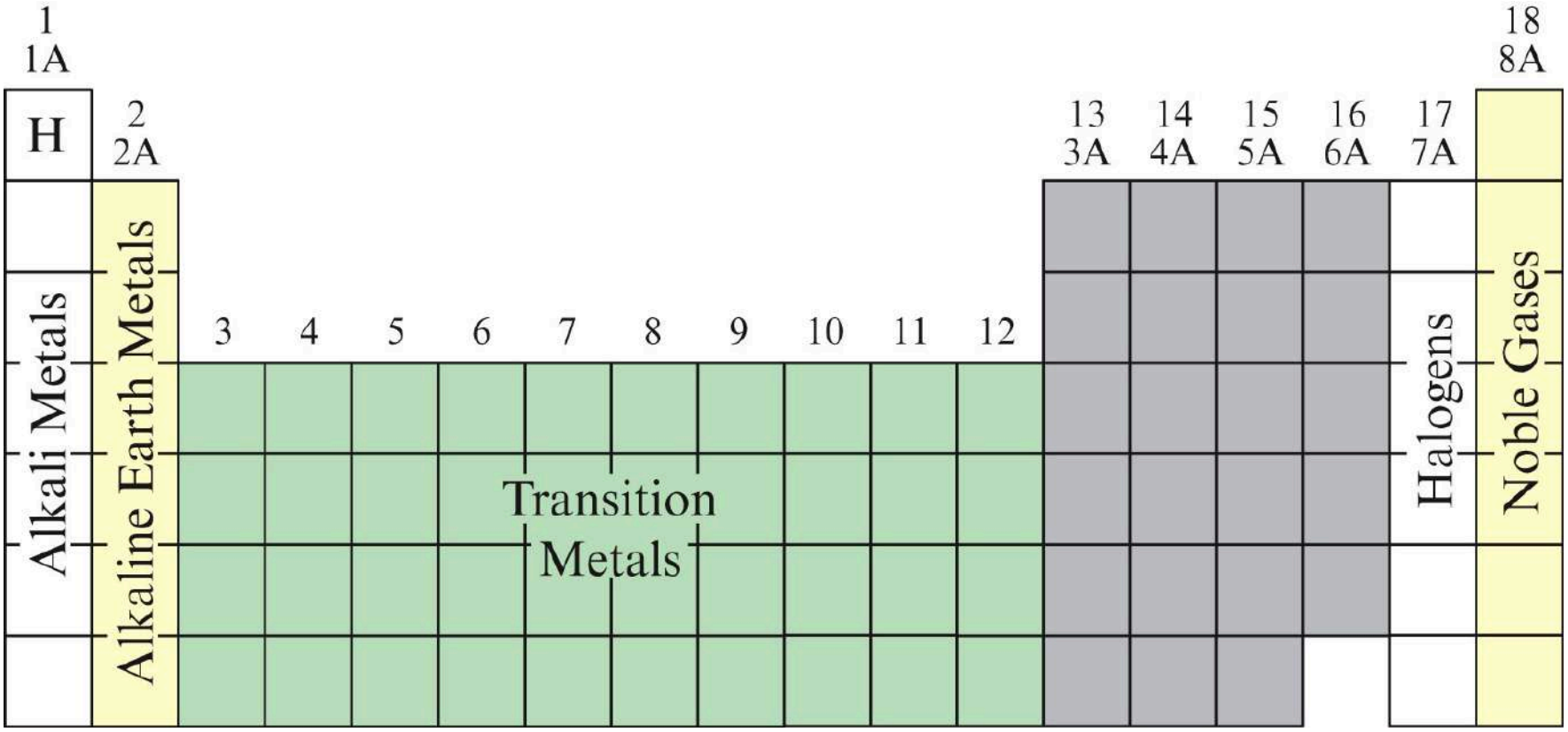
A. Introduction to the Periodic Table

- The periodic table shows all of the known elements in order of increasing atomic number.



A. Introduction to the Periodic Table

- The periodic table is organized to group elements with similar properties in vertical columns.



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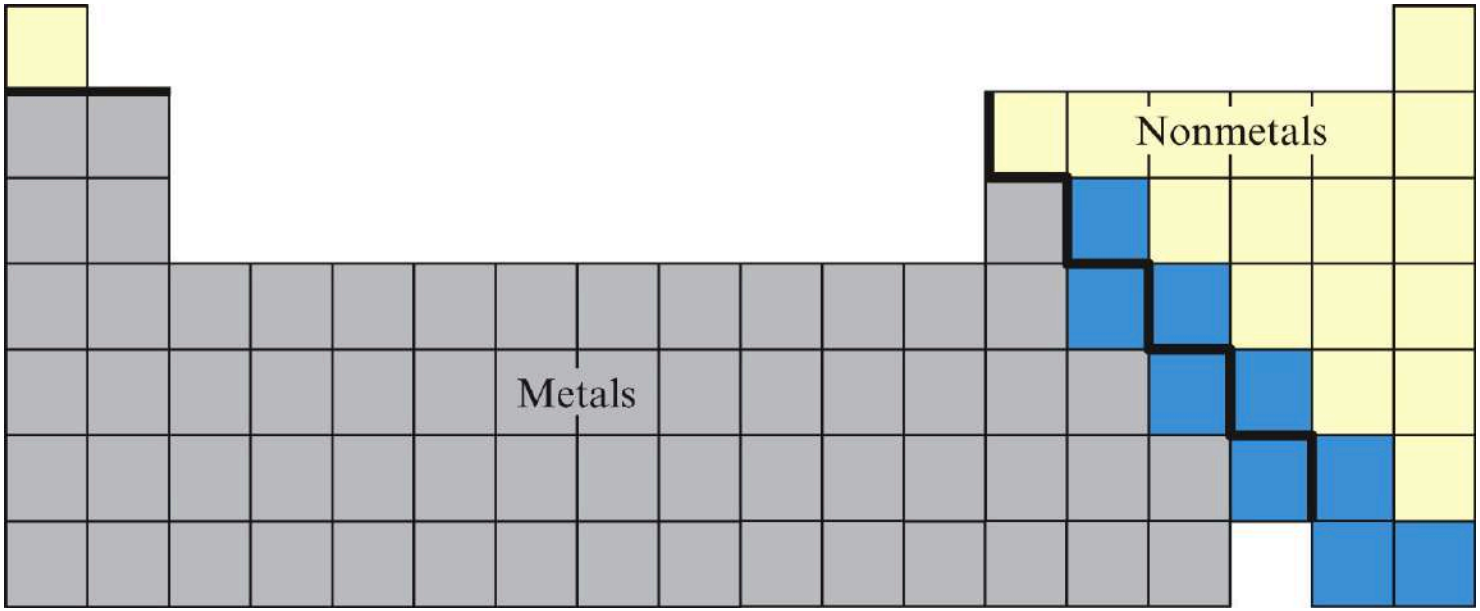
A. Introduction to the Periodic Table



- Most elements are metals and occur on the left side.
- The nonmetals appear on the right side.
- Metalloids are elements that have some metallic and some nonmetallic properties.

A. Introduction to the Periodic Table

- Physical Properties of Metals
  1. Efficient conduction of heat and electricity
  2. Malleability (can be hammered into thin sheets)
  3. Ductility (can be pulled into wires)
  4. A lustrous (shiny) appearance

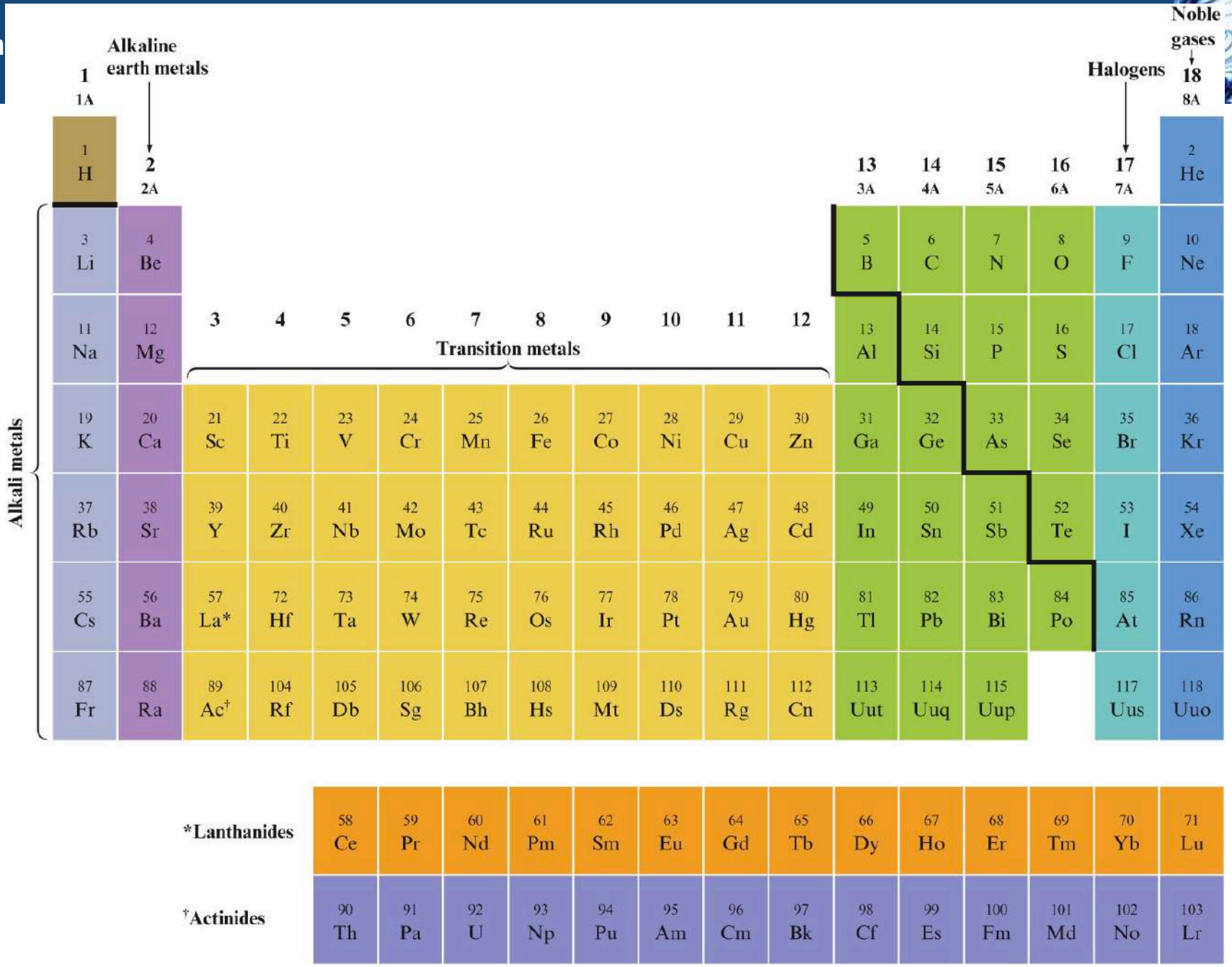


Figure 3-7 p71

B. Natural States of the Elements

- Most elements are very reactive.
- Elements are not generally found in uncombined form.
  - Exceptions are:
    - Noble metals – gold, platinum and silver
    - Noble gases – Group 8

Using the Periodic Table

Group 8
2 He
10 Ne
18 Ar
36 Kr
54 Xe
86 Rn

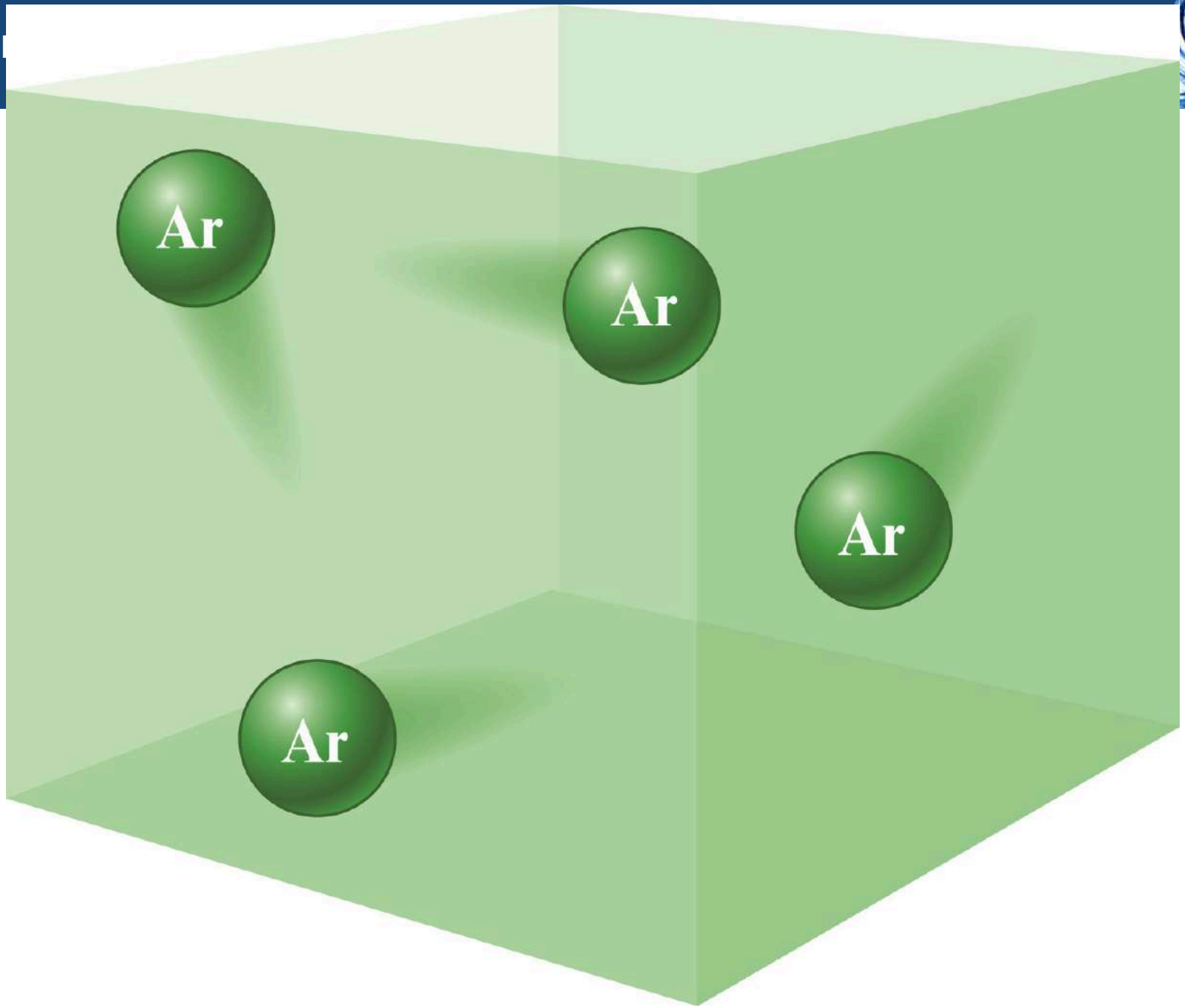
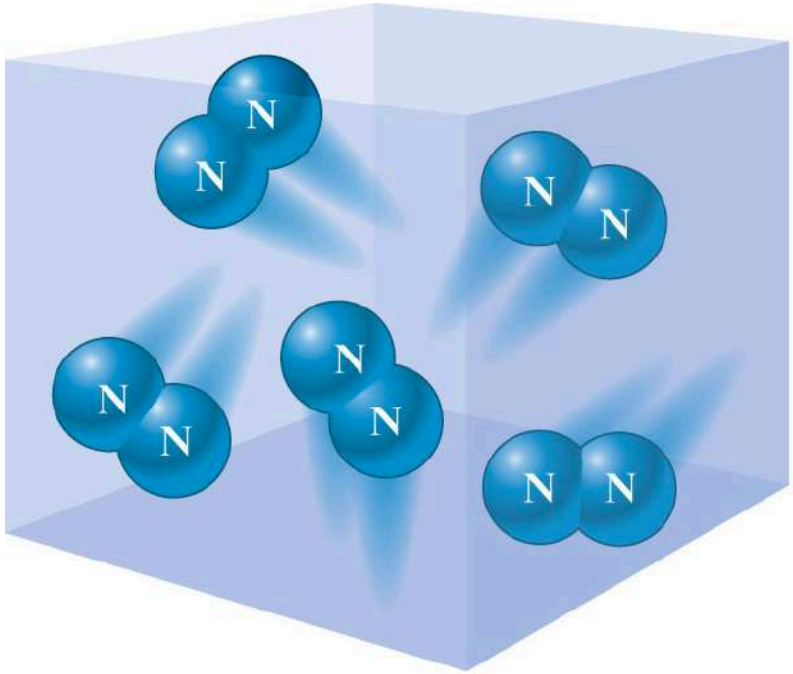


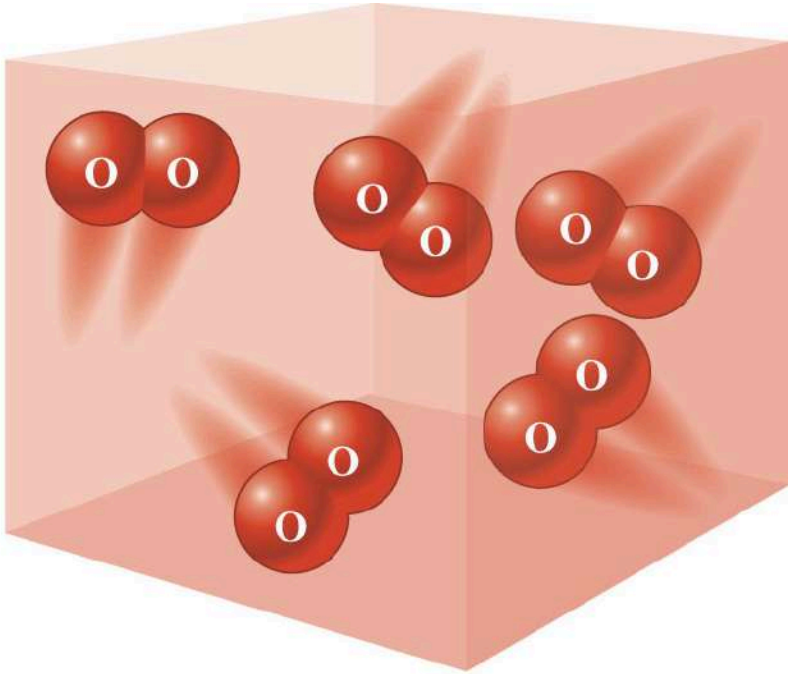
Figure 3-10 p75

B. Natural States of the Elements

- Diatomic Molecules

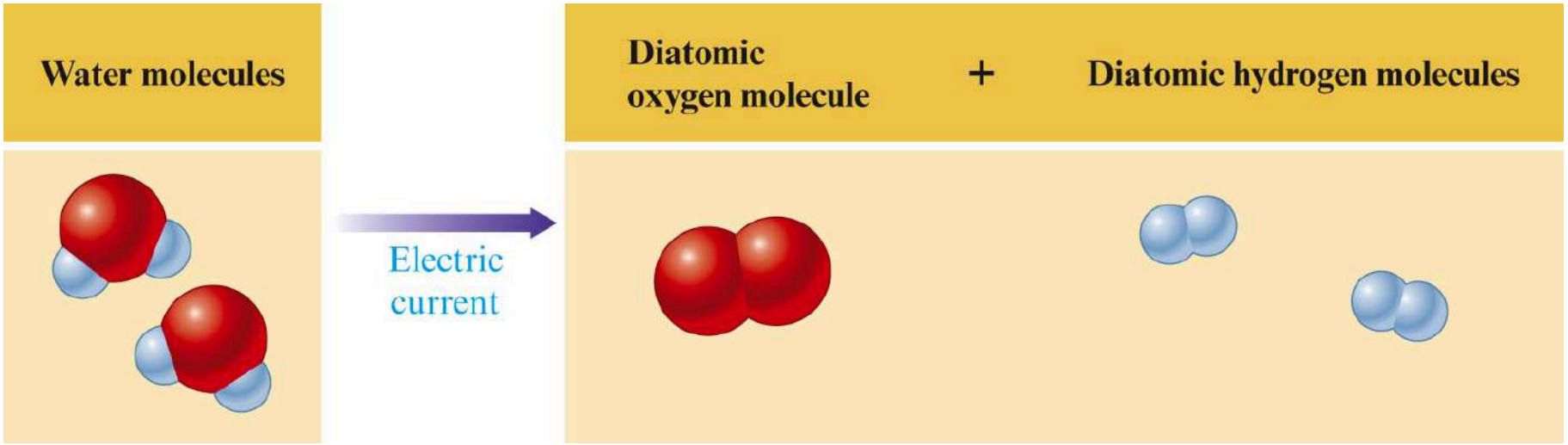


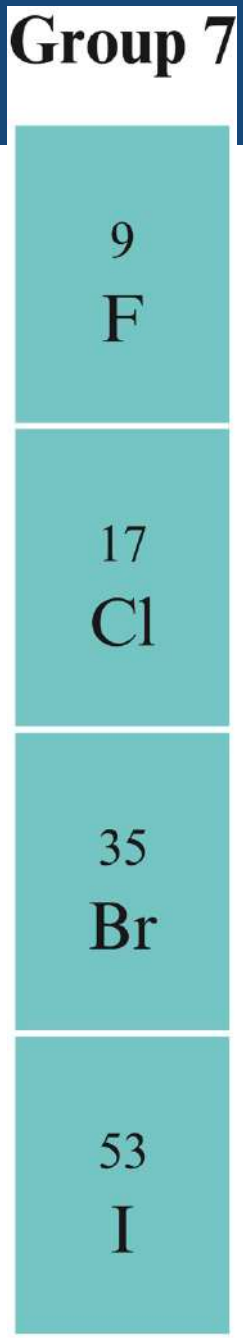
(a)



(b)

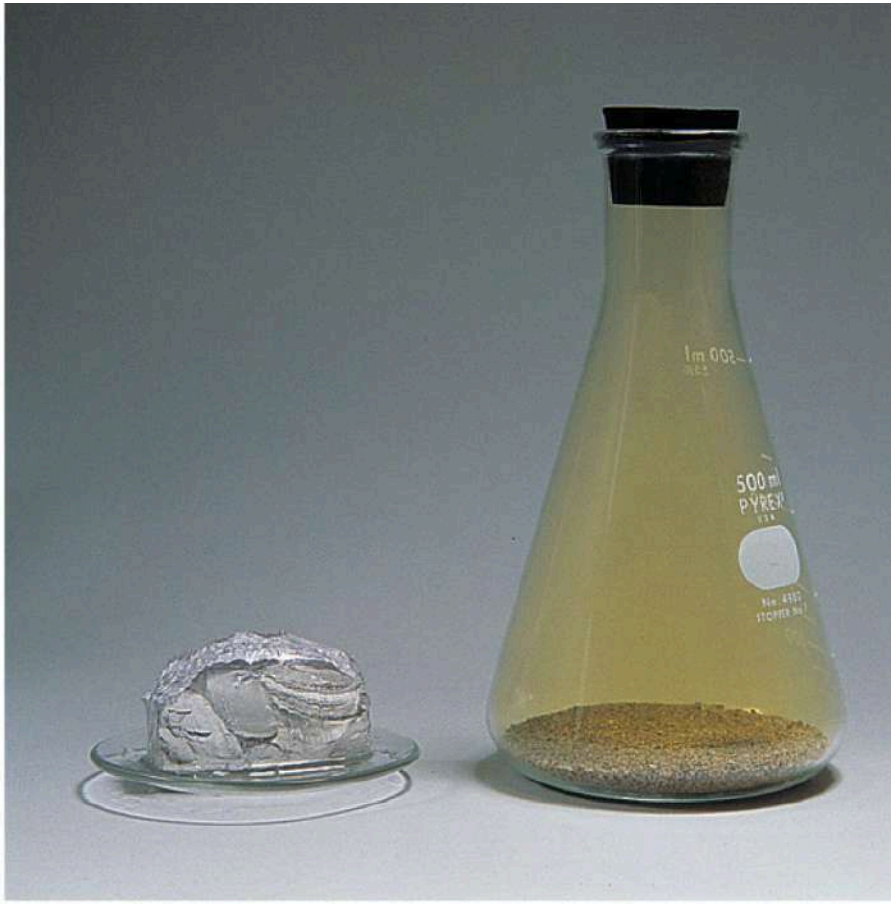
Using the Periodic Table




Group 7
9
F
17
Cl
35
Br
53
I

Using the Periodic Table

(a)



(b)

Figure 3-12 p76

B. Natural States of the Elements

- Diatomic Molecules

Table 3.6 Elements That Exist as Diatomic Molecules in Their Elemental Forms

Element Present	Elemental State at 25°C	Molecule
hydrogen	colorless gas	H_2
nitrogen	colorless gas	N_2
oxygen	pale blue gas	O_2
fluorine	pale yellow gas	F_2
chlorine	pale green gas	Cl_2
bromine	reddish-brown liquid	Br_2
iodine	lustrous, dark purple solid	I_2

Using the Periodic Table

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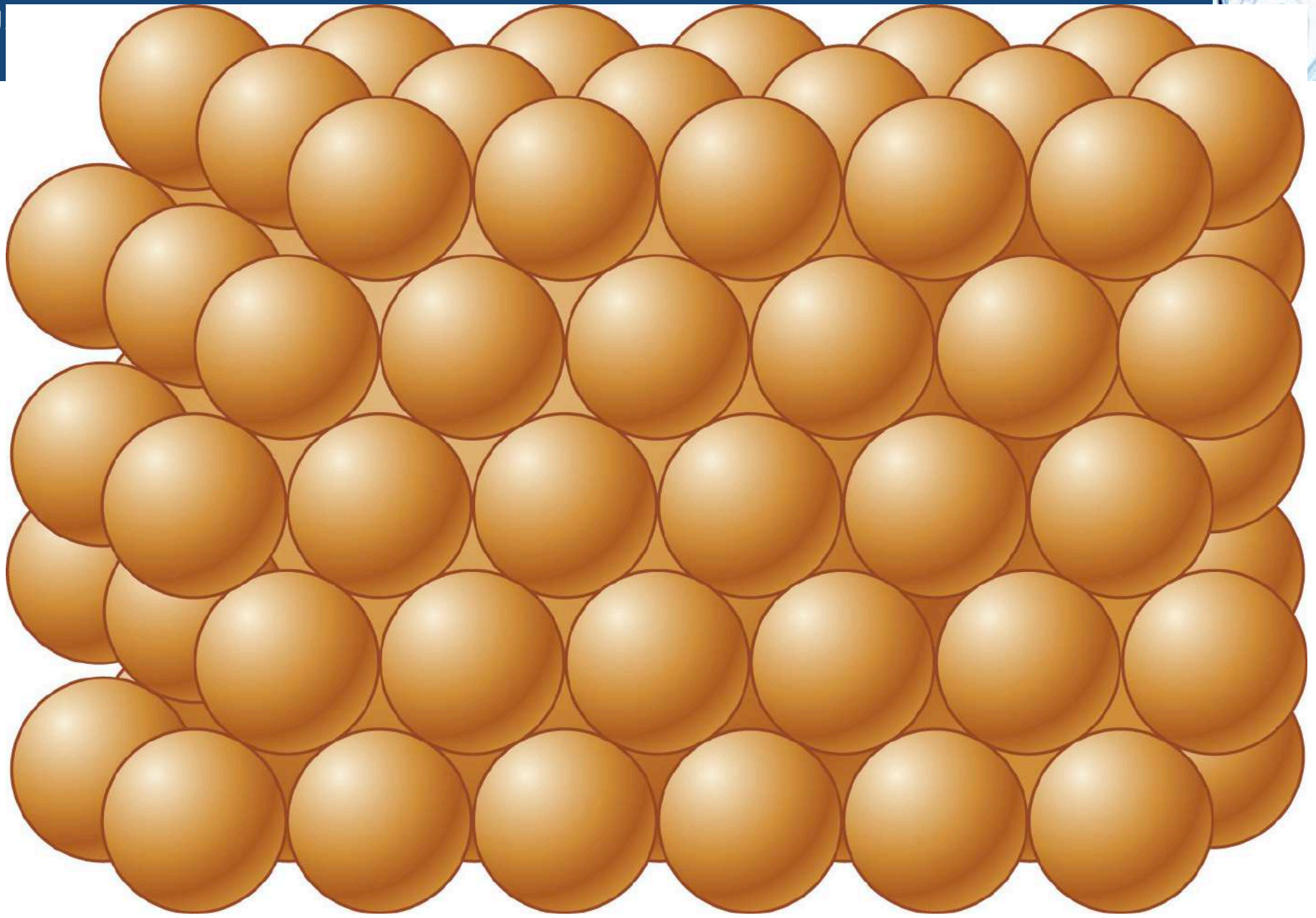
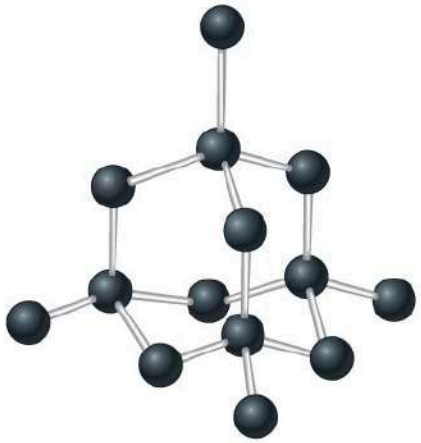


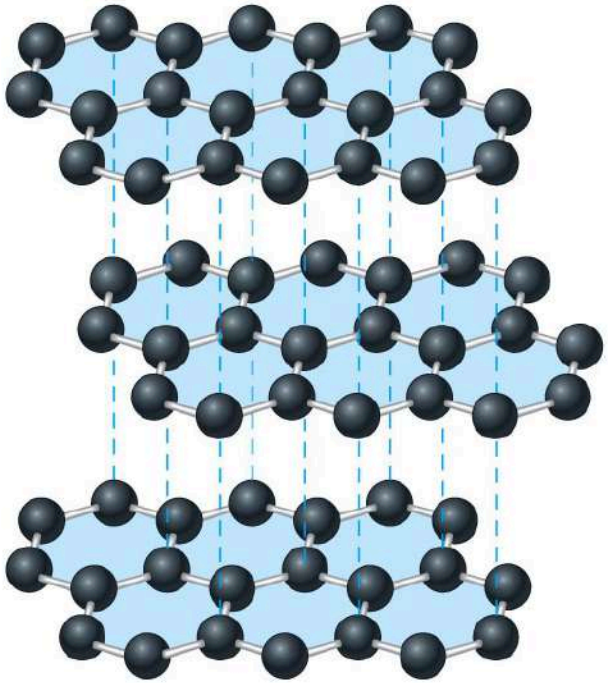
Figure 3-13 p77

B. Natural States of the Elements

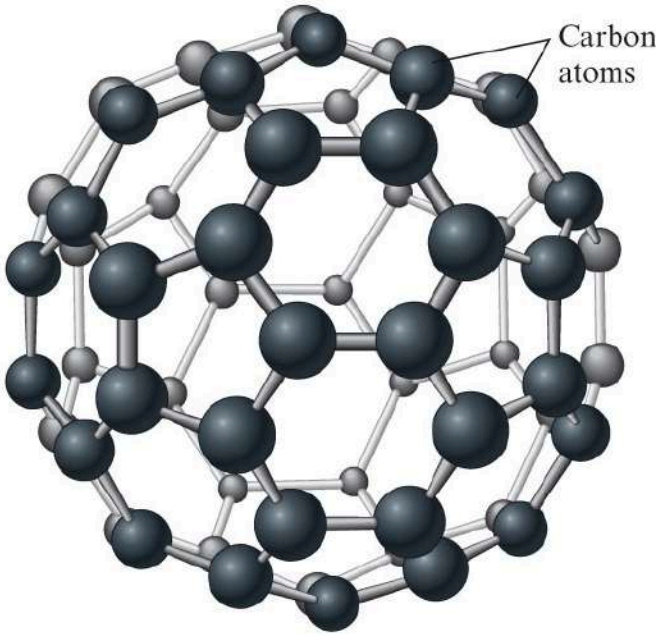
- Elemental Solids



Diamond



Graphite



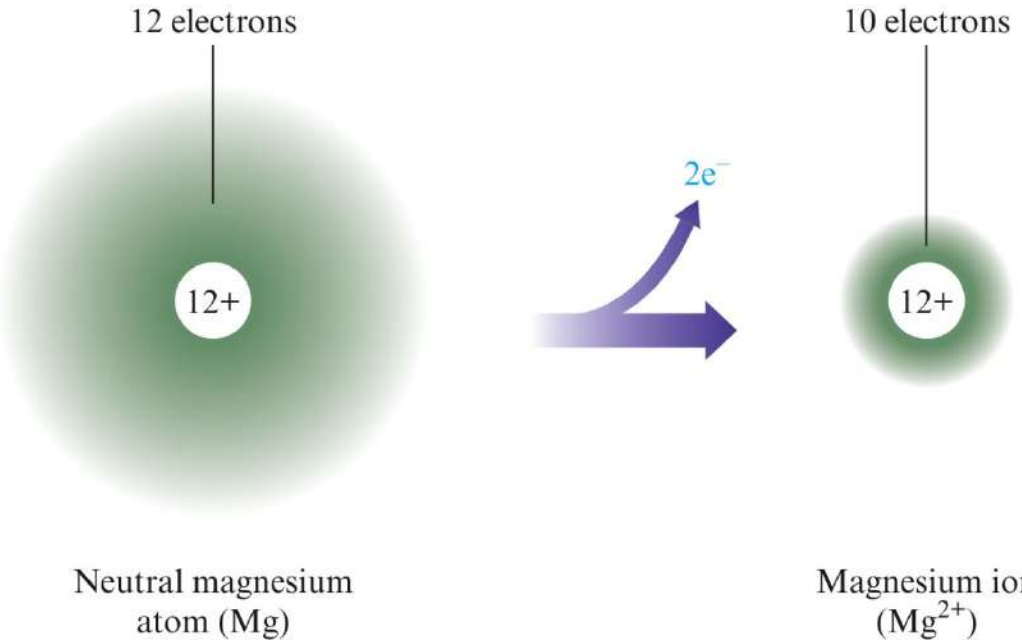
Buckminsterfullerene

Objectives

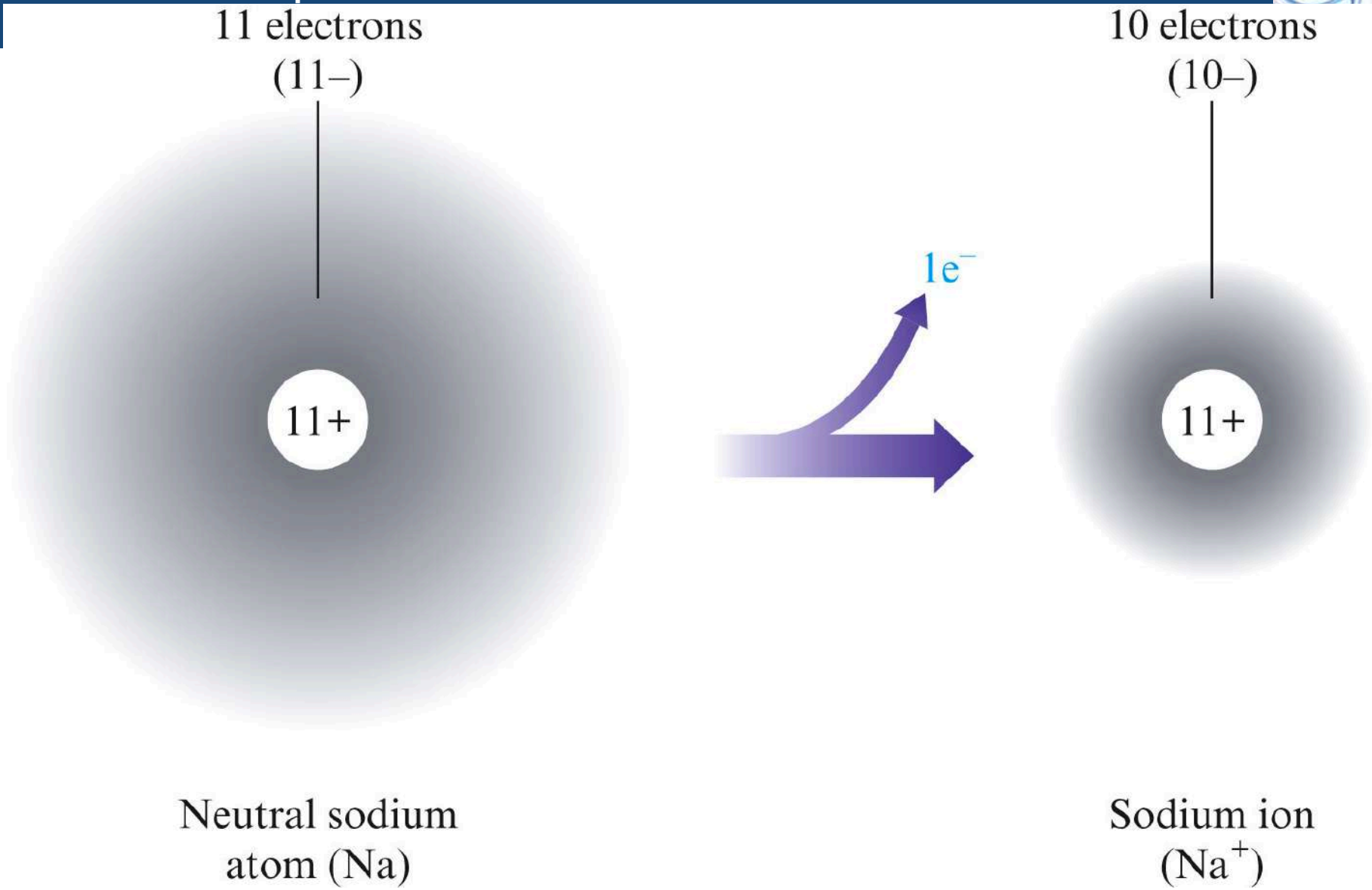
1. To describe the formation of ions from their parent atoms
2. To learn to name ions
3. To predict which ion a given element forms by using the periodic table
4. To describe how ions combine to form neutral compounds

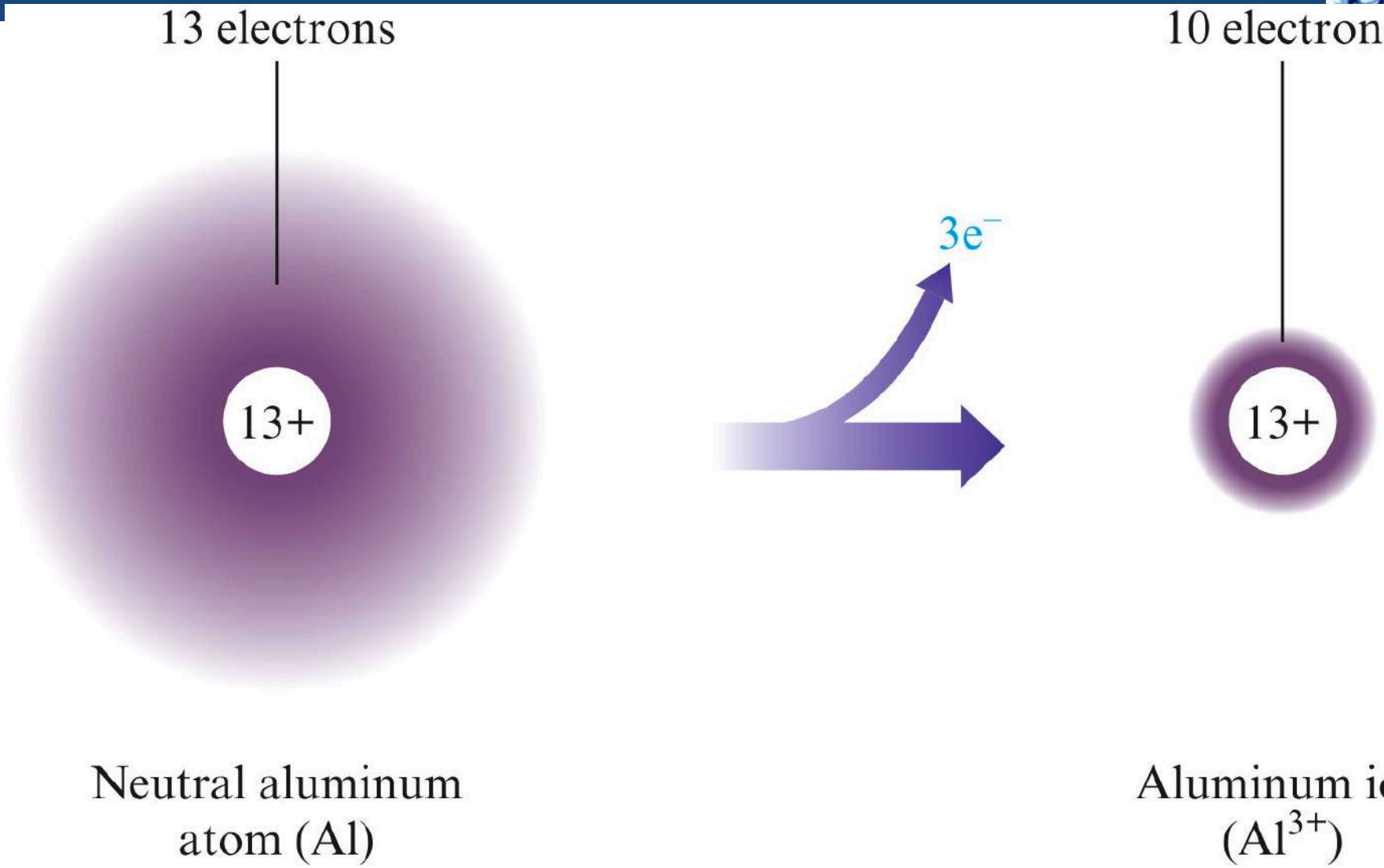
A. Ions

- Atoms can form ions by gaining or losing electrons.
  - Metals tend to lose one or more electrons to form positive ions called cations.



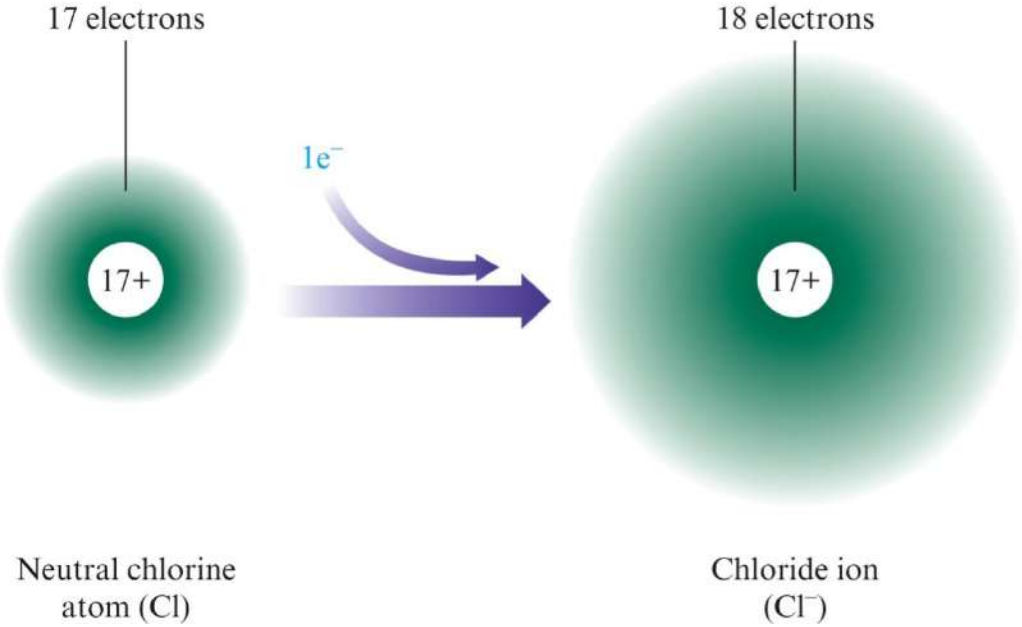
Cations are generally named by using the name of the parent atom.


11 electrons
(11–)
11+
1e⁻
10 electrons
(10–)
11+
Neutral sodium atom (Na)
Sodium ion (Na^+)


13 electrons
13+
3e⁻
10 electrons
13+
Neutral aluminum atom (Al)
Aluminum ion (Al^{3+})

A. Ions

- Nonmetals tend to gain one or more electrons to form negative ions called anions.



Anions are named by using the root of the atom name followed by the suffix *–ide.*

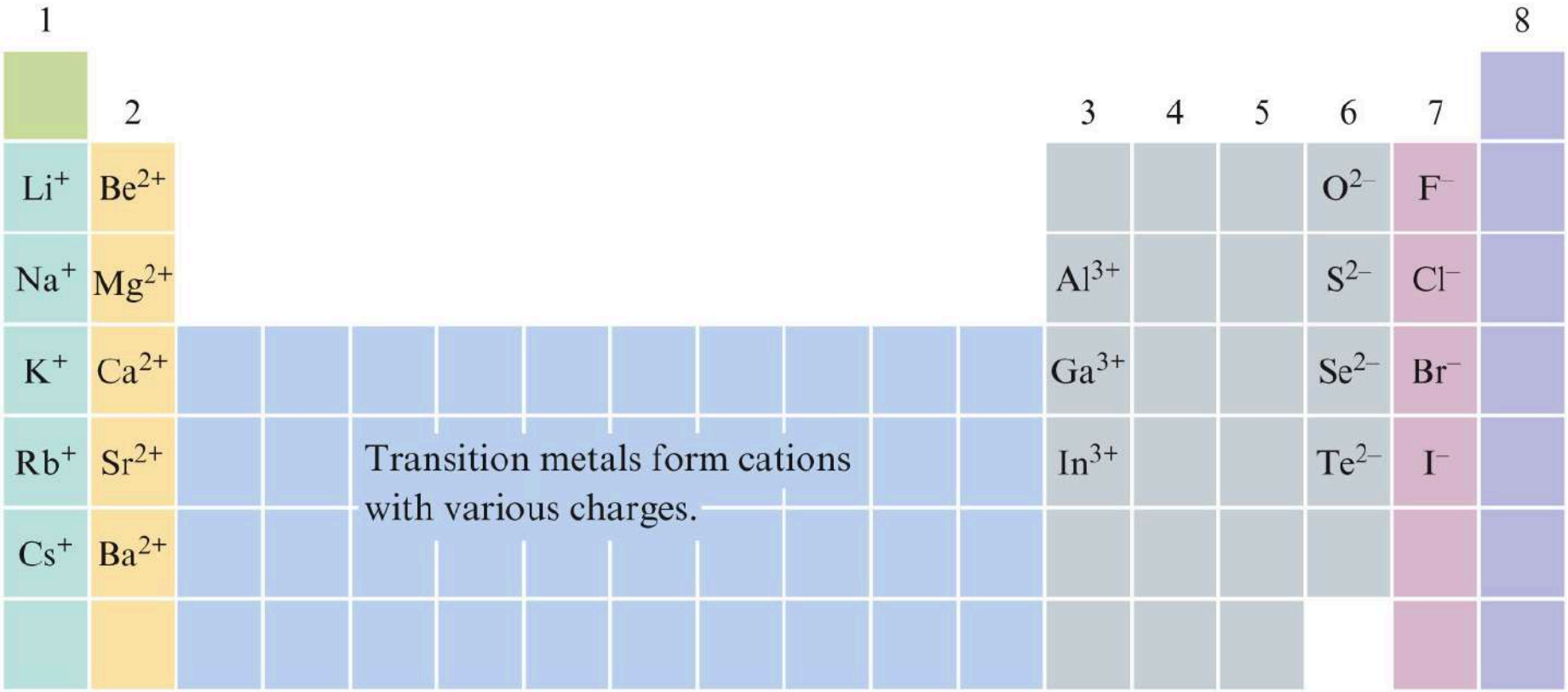
A. Ions

Ion Charges and the Periodic Table

- The ion that a particular atom will form can be predicted from the periodic table.
  - Elements in Group 1 and 2 form 1+ and 2+ ions, respectively
  - Group 7 atoms form anions with 1– charges
  - Group 6 atoms form anions with 2– charges

A. Ions

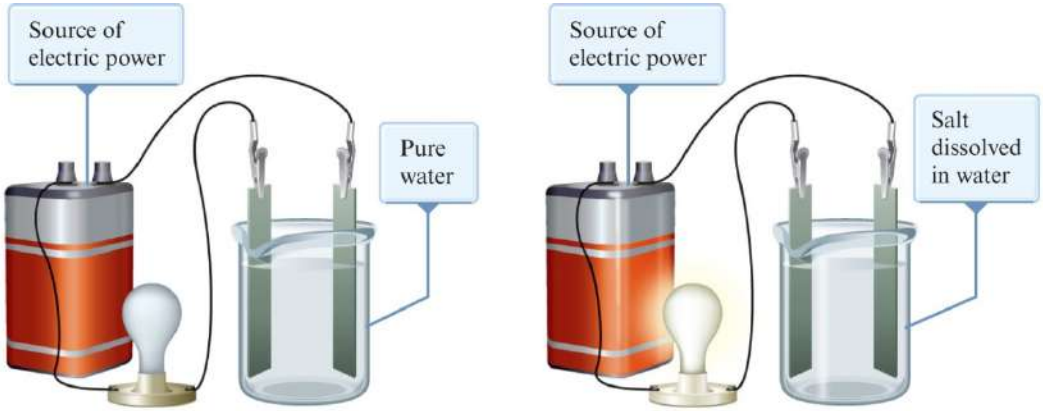
Ion Charges and the Periodic Table



Io

B. Compounds That Contain Ions

- Ions combine to form ionic compounds.
- Properties of ionic compounds
  - High melting points
  - Conduct electricity
    - If melted
    - If dissolved in water

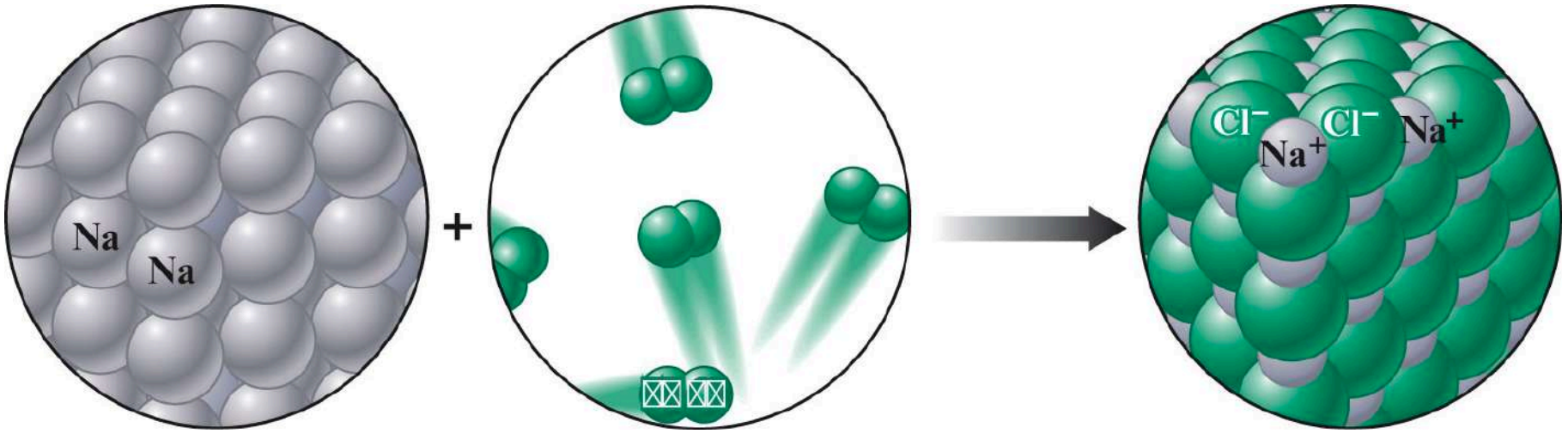


B. Compounds That Contain Ions

- Ionic compounds are electrically neutral.
- The charges on the anions and cations in the compound must sum to zero.

Figure 3-17a p84

Ions and Their Compounds



Io

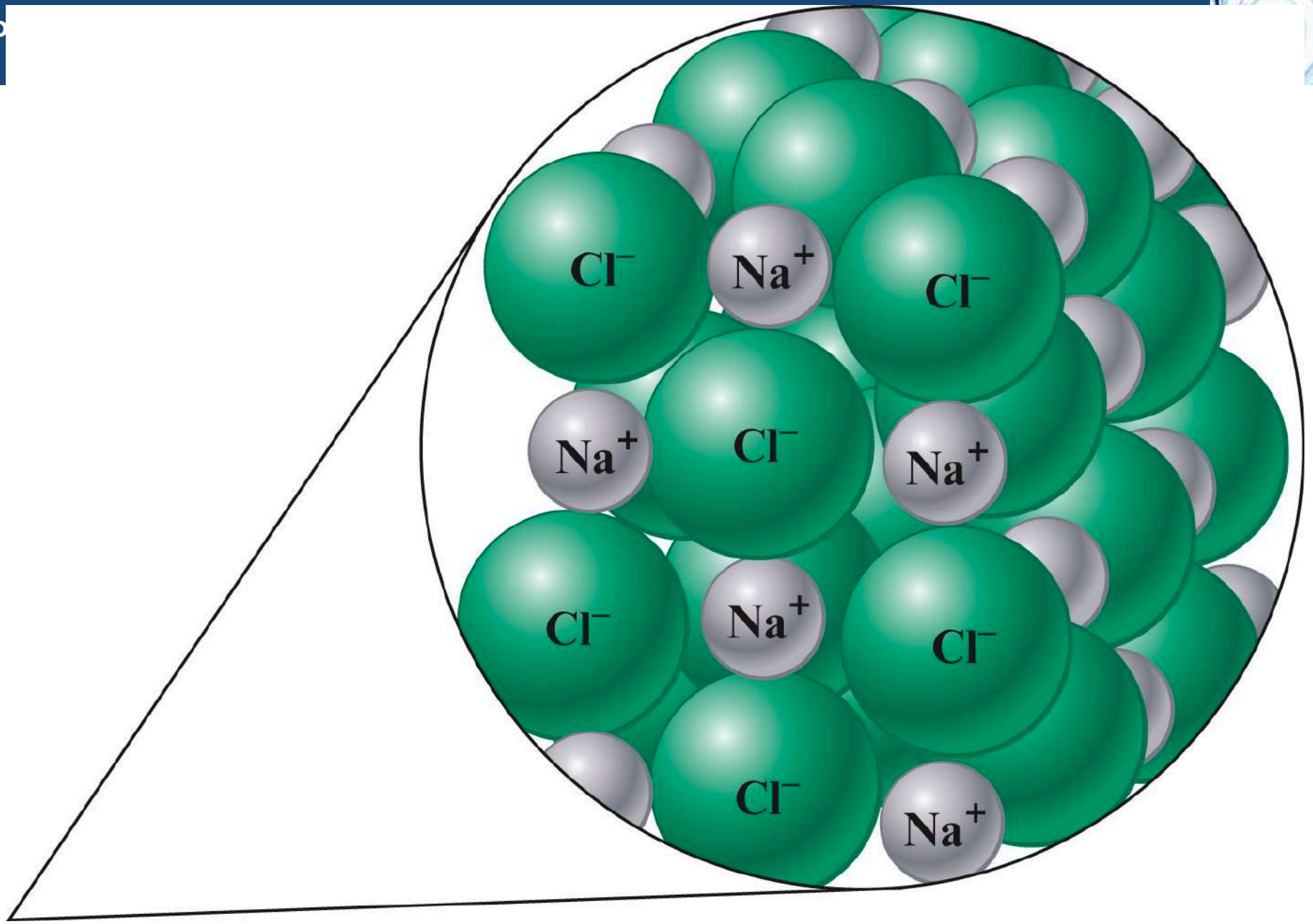


Figure 3-17b p84

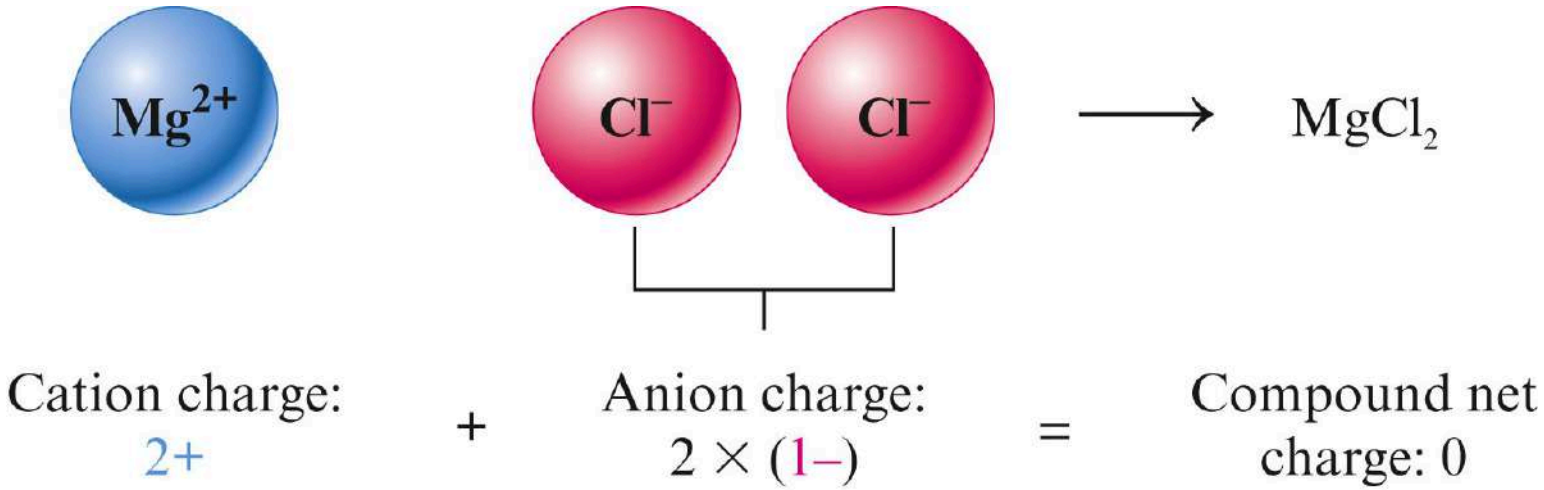
NaCl

Charge: 1+ + Charge: 1– Net charge: 0

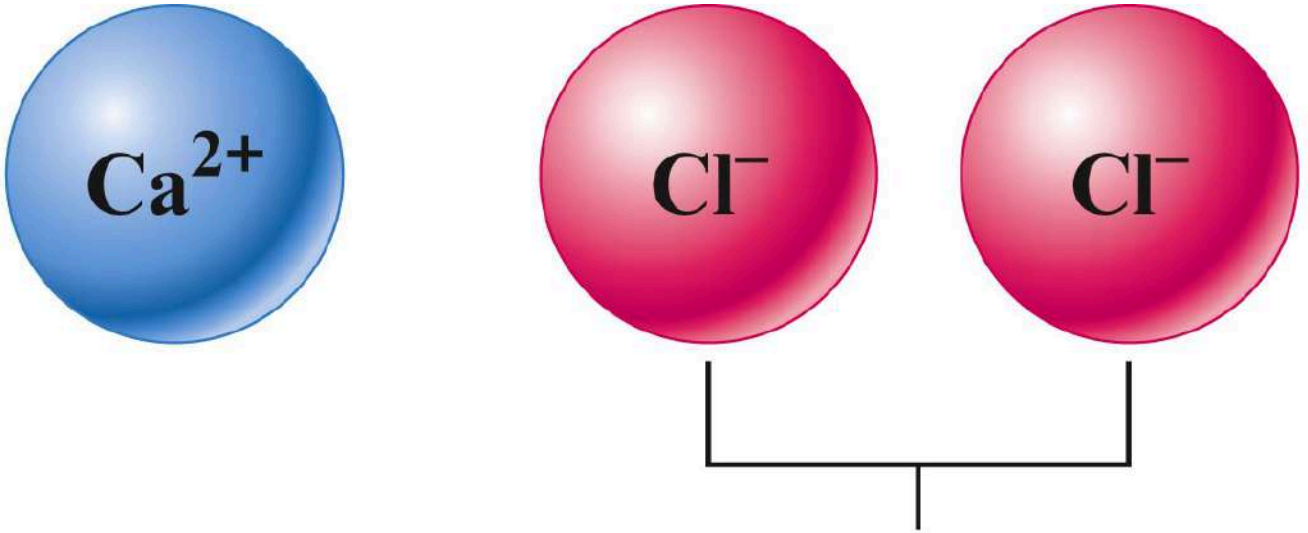
B. Compounds That Contain Ions

Formulas for Ionic compounds

- Write the cation element symbol followed by the anion element symbol.
- The number of cations and anions must be correct for their charges to sum to zero.

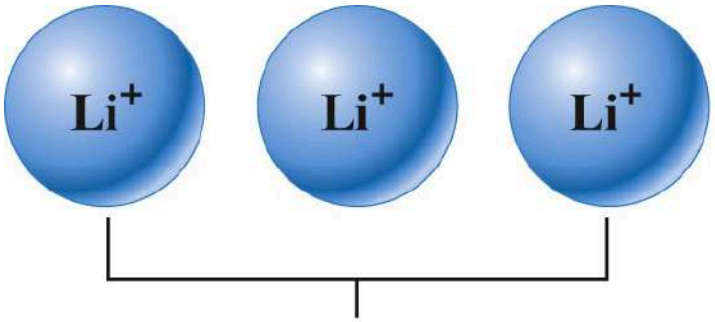


Ions and Their Compounds



where $2+ + 2(1-) = 0$

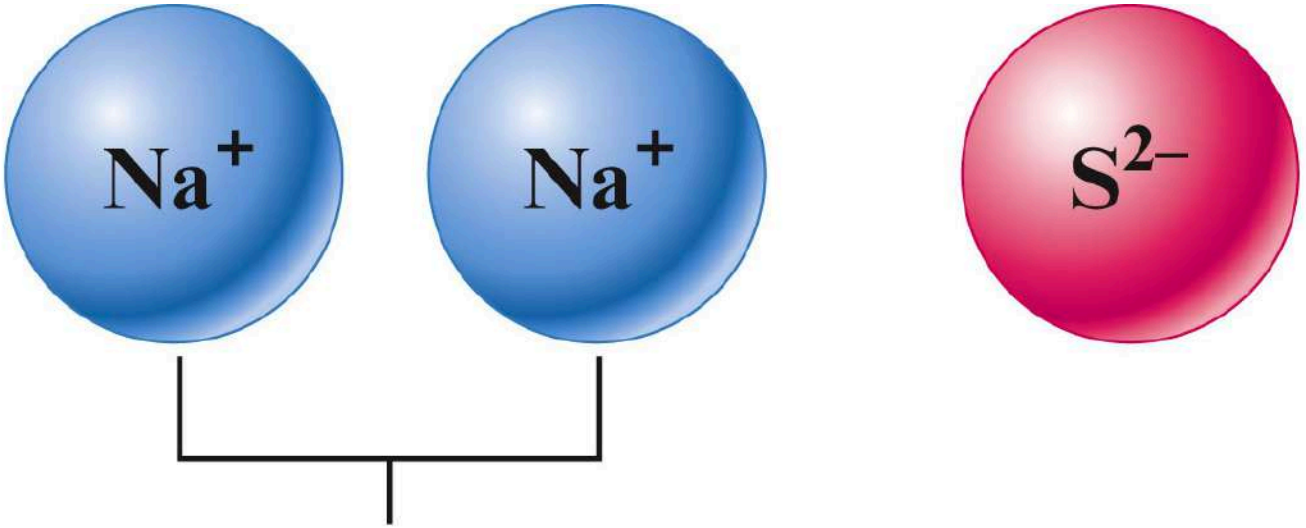
Ions and Their Compounds



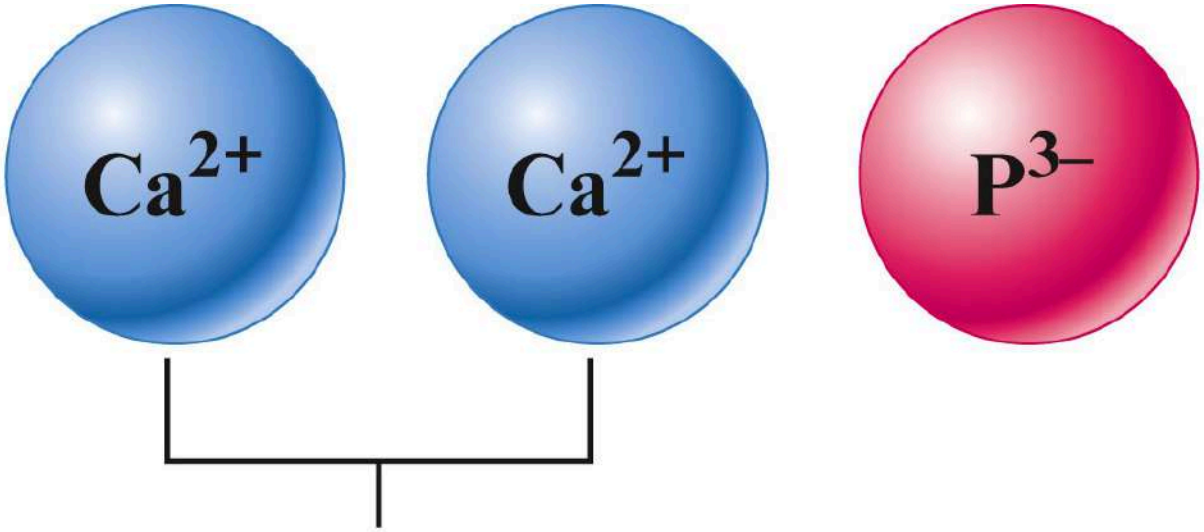
$\longrightarrow$ Li_3N

Positive charge: $3 \times (1+)$ + Negative charge: $(3-)$ = Net charge: 0

Ions and Their Compounds

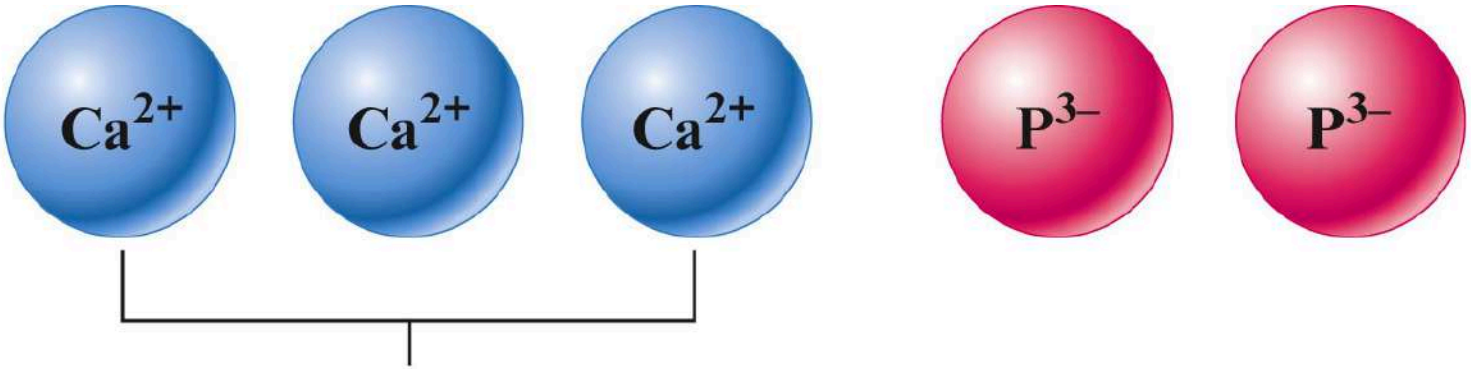


where $2(1+) + 2- = 0$

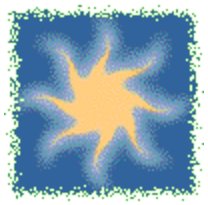


where $2(2+) + 3- = 11$

Ions and Their Compounds



where $3(2+) + 2(3-) = 0$



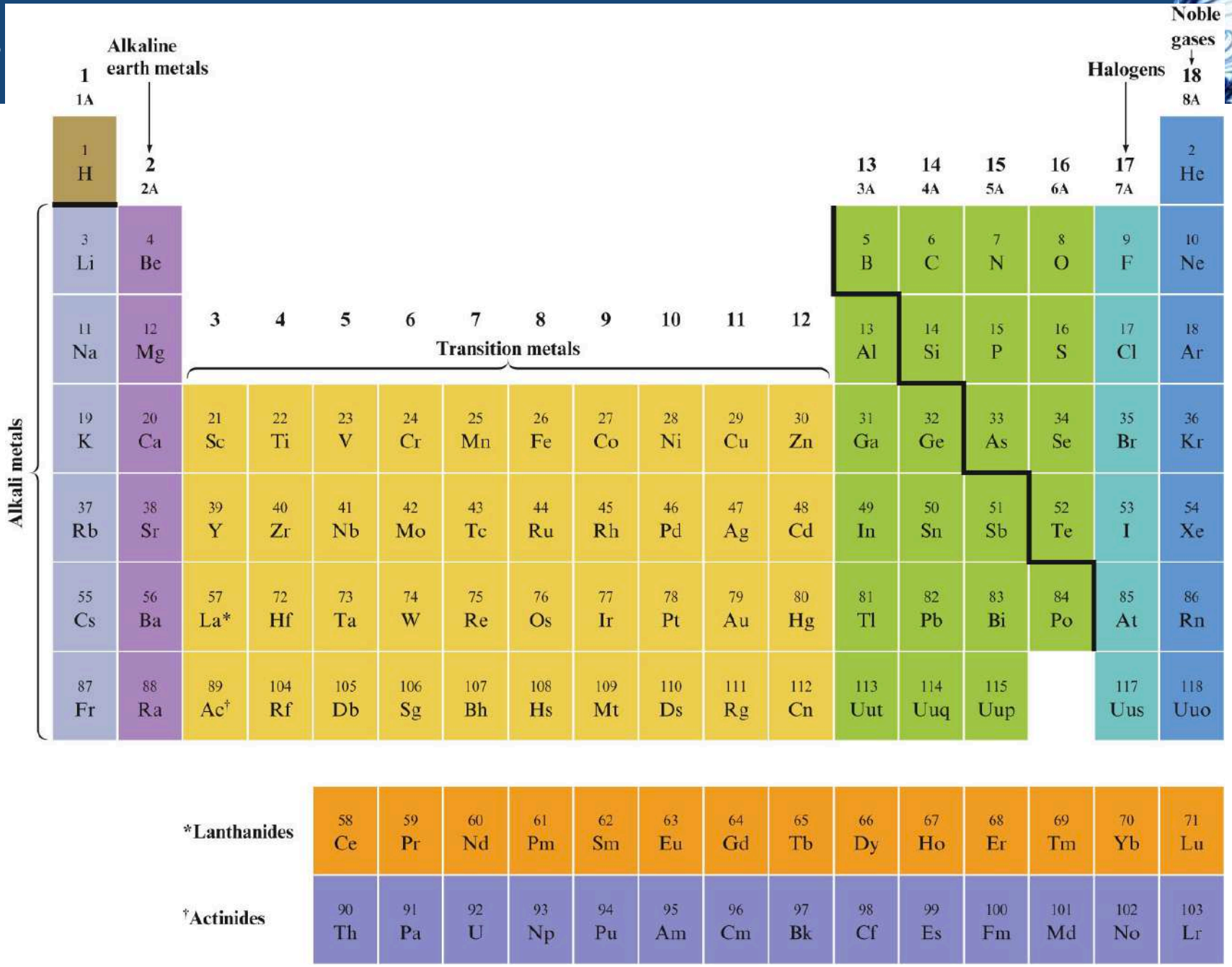
Exercise

A pair of ions is listed below. What is the formula for the ionic compound it forms?

K^+ and O^{2-}

K_2O

Ions


Alkaline earth metals
Noble gases
Halogens
Alkali metals
Transition metals
1 1A
2 2A
13 3A
14 4A
15 5A
16 6A
17 7A
18 8A
3 4 5 6 7 8 9 10 11 12
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
57 La*
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
89 Ac†
104 Rf
105 Db
106 Sg
107 Bh
108 Hs
109 Mt
110 Ds
111 Rg
112 Cn
113 Uut
114 Uuq
115 Uup
117 Uus
118 Uuo
*Lanthanides
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
71 Lu
†Actinides
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
103 Lr