2

Atoms, Molecules, and Ions

I. Atomic Theory

A. Postulates

1. _____

_____

2. _____

_____

3. _____

_____

B. Basic laws of chemistry explained by postulates of Atomic Theory

1. Law of conservation of mass

_____

_____

2. Law of constant composition

_____

_____

3. Law of multiple proportions

_____

_____

II. Components of the atom

A. Electron

1. Location: _____

2. Relative charge: _____

c. Groups with special names
(1) Alkali metals
(a) Group number: _____
(b) Example: _____
(c) Chemical property: _____
_____
(2) Alkaline earth metals
(a) Group number: _____
(b) Example: _____
(3) Halogens
(a) Group number: _____
(b) Example: _____
(4) Noble gases
(a) Group number: _____
(b) Example: _____
(c) Chemical property: _____
_____

3. Metals, nonmetals, and metalloids
a. Diagonal line or stairway that starts to the left of boron (B) separates the metals from the nonmetals.
b. Location of metals relative to the stairway:
_____
c. Location of nonmetals relative to the stairway:
_____
d. Metalloids
(1) Location relative to the stairway:
_____
(2) What is a metalloid?
_____
(3) Name the six elements classified as metalloids.
_____

IV. Molecules

A. Nature
1. Charge: _____
2. Type of atoms that make up a molecule: _____
3. Forces that hold atoms together are called _____ and consist of _____.

B. Representation

1. Structural formulas

Definition: _____

2. Condensed structural formulas

a. Definition: _____

b. Reactive group

_____ is the reactive group in alcohols.

_____ is the reactive group in amines.

3. Molecular formulas

a. Definition: _____

b. Exercises

(1) Write the molecular formula for the molecule made up of two atoms of hydrogen (H) and two atoms of oxygen (O).

Solution:

H_2O_2

The subscripts after the element's symbol show how many atoms of that element are in the molecule.

(2) Write the molecular formula for

(a) the molecule made up of one carbon (C) atom and four chlorine (Cl) atoms. **(E2)**

(b) the molecule made up of two carbon (C) atoms and four hydrogen (H) atoms and two oxygen (O) atoms. **(E3)**

V. Ions

A. Definition: _____

B. Types of Ions

1. Cations (definition): _____

_____

2. Anions (definition): _____

_____

3. Number of protons and electrons in an ion
   a. The number of protons (atomic number) remains unchanged (as compared to the atom).
   b. The number of electrons changes
      (1) For cations (positive charge), the number of electrons decreases by the size of the charge.
      (2) For anions (negative charge), the number of electrons increases by the size of the charge.

      A good mnemonic for remembering this is *a*nions *i*ncrease the number of their electrons (the vowels go together) and *c*ations *d*ecrease the number of their electrons (the consonants go together).
   c. ***Exercises***
      (1) Give the symbol for the ion that has 11 protons and 10 electrons.
      Solution: The atomic number (no. of protons) is 11, hence, the element is sodium (Na). The number of electrons decreases, therefore, the ion is a cation (positive charge) and the number of electrons is decreased by 1. Thus the charge must be +1. The symbol is therefore Na^+.
      (2) How many protons and electrons are there in the Al^{3+} ion? **(E4)**

      (3) How many protons and electrons are there in the S^{2-} ion? **(E5)**

VI. Formulas for Ionic Compounds

A. Nature of ionic compounds
   1. They are made up of two oppositely charged ions.
   2. The principle of electrical neutrality when applied to ioinic compounds requires that _____

   _____.
   3. The formula for an ionic compound shows the simplest ratio between cation and anion.

B. Ions with a noble-gas structure
   1. For main-group elements, the charges of the ions formed by the atoms can be predicted by applying this principle:

   _____

   _____

2. Charge of ions formed by the main-group elements
   a. Group 1: _____
   b. Group 2: _____
   c. Group 16: _____
   d. Group 17: _____
   e. Al in Group 13: _____
   f. N in Group 15: _____

C. Cations of the transition and post-transition metals
1. Transition metals are in groups 3 – 12.
2. Post-transition metals are those in periods 4 – 7 and in groups 13, 14, or 15.
3. These cations typically have charges of _____.
4. They ordinarily do not have a charge of _____.

D. Polyatomic Ions
1. Two common polyatomic cations are _____ and _____.
2. Polyatomic anions usually have one or more oxygen atoms. These are collectively called _____.
3. Memorize the name, formula and charge of the polyatomic ions listed in Table 2.2 of your text.

E. Forming ionic compounds
1. Rules
   a. Compounds have electrical neutrality. Na^+ and S^{2-} must be written as Na_2S, since you need two positive charges to balance the −2 charge on the S.
   b. The positive ion is always written before the negative ion.
   c. If two or more polyatomic ions are used in the formula, enclose the polyatomic ion in parentheses and put the number of ions you need outside the parentheses as a subscript.
   d. Do not write the charge of the ion in the formula. For example, sodium sulfide is Na_2S, not $Na^{2+}S^{2-}$; $2Na^+S^{2-}$; or $Na_2^+S^{2-}$.
2. *Exercises*

   Predict the formulas of the ionic compounds formed by a

   a. calcium ion and phosphate ion

   Solution: Calcium ion is Ca^{2+} and phosphate ion is PO_4^{3-}. To balance the charges, we need three ions of Ca to get a total positive charge of 6, and two ions of phosphate to obtain a total negative charge of 6. Thus we write $Ca_3(PO_4)_2$; not $Ca_3P_2O_8$ or $Ca_3^{2+}(PO_4)_2^{3-}$.

   b. manganese ion and bromine ion **(E6)**

c. sodium ion and nitrogen ion **(E7)**

d. aluminum ion and sulfate ion **(E8)**

VII. Names/Formulas of Compounds

A. Ionic compounds

1. Kinds

a. metal ion + nonmetal ion

Example: _____

b. metal ion + polyatomic ion

Example: _____

c. ammonium ion + nonmetal ion

Example: _____

d. ammonium ion + polyatomic ion

Example: _____

2. Rules

a. When a metal is involved, the name of the metal is used.

b. When the metal ion can have two different charges, the charge of the ion is indicated by writing it in Roman numerals in parentheses after the name of the metal.
Example: Cu^{+} is written as copper(I),
Cu^{2+} is written as copper(II).

c. When a nonmetal is involved, *ide* is added as a suffix to the root word of the nonmetal (usually the first syllable).
Example: bromine becomes bromide

d. Polyatomic ions retain their names.

e. ***Exercises:***
Name the following compounds:

(1) Li_3N **(E9)**

(2) $(NH_4)_2CO_3$ **(E10)**

(3) MgO **(E11)**

(4) FeO
Solution: Since oxygen always has a charge of 2-, in order to have electrical neutrality, iron has to have a charge of 2+. Thus, the compound's name is iron(II) oxide.

(5) CuS **(E12)**

(6) Fe_2S_3 **(E13)**

3. Most polyatomic ions contain one or more oxygen atoms. Collectively, these polyatomic ions are called oxoanions.

a. Rules for naming oxoanions

(1) The suffix *ate* is used _____

_____

(2) The suffix *ite* is used _____

_____

(3) The suffix *hypo* is used _____

_____

(4) The suffix *per* is used _____

_____

b. Memorize Table 2.3 in your text.

4. Writing the formula given the name of the compound
Exercises: Write the formulas of the following compounds:

a. sodium nitrite: **(E14)** _____

b. rubidium dichromate: **(E15)** _____

c. ammonium sulfate: **(E16)** _____

d. calcium perchlorate: **(E17)** _____

B. Binary Molecular Compounds

1. Rule: The first nonmetal gets its full name. The second nonmetal gets its root word + *ide*. Both nonmetals get a prefix denoting how many atoms are used to make the compound. However, when only one atom is used, the prefix mono is not attached.
Example: CO_2 – first nonmetal = carbon; second nonmetal = dioxide

2. Prefixes (Table 2.4)
   2 atoms - di
   3 atoms - _____
   4 atoms - _____
   5 atoms - _____
   6 atoms - _____
   7 atoms - _____

3. ***Exercises:***
   Name the following compounds:
   a. BrI **(E18)**

   b. PBr_3 **(E19)**

   c. SF_6 **(E20)**

4. Acids
   a. Definition: _____
   b. When the gaseous binary molecules form acidic aqueous solutions, the *ide* suffix is changed to *ic*.
   c. When a hydrogen ion combines with an oxoanion, an oxoacid is formed. The prefixes of the oxoanion, *per* and *hypo*, remain unchanged. The suffix *ate* is changed to *ic*, while the suffix *ite* is changed to *ous*.
   Example: $HClO_3$ is derived from H^+ and ClO_3^- (chlorate). The name of the acid is chloric acid.

SELF-TEST

Multiple Choice:

1. Fluorine has the nuclear symbol $^{19}_{9}F$. The total number of subatomic particles (neutrons + protons + electrons) in a fluorine atom is
   a. 9 **b.** 10 **c.** 18 **d.** 19 **e.** 28

2. The combination of numbers and symbols in $5\ N_2$ stands for
   a. 5 nitrogen atoms **b.** 10 separate nitrogen atoms
   c. 5 nitrogen molecules **d.** 10 nitrogen molecules
   e. none of those

3. The number of protons in a molecule of CO_2 is
   a. 3 **b.** 12 **c.** 16 **d.** 22 **e.** 32

4. The formulas of ammonium sulfide and aluminum fluoride are
   a. NH_4SO_3 , Al_3F **b.** NH_4SO_4 , AlF_3
   c. $(NH_3)_2SO_3$, AlF_2 **d.** $(NH_4)_2S$, AlF_3
   e. $(NH_4)_2SO_3$, AlF_3

5. The law of multiple proportions can be applied to
   a. $^{1}_{1}H$ and $^{2}_{1}H$ **b.** Cl and Cl_2
   c. CO_2 and SiO_2 **d.** CuO and Cu_2O

6. The formula of chromium(III) oxide is
   a. CrO **b.** Cr_3O **c.** CrO_3 **d.** Cr_3O_2 **e.** Cr_2O_3

7. To form Fe^{3+}
   a. an Fe atom must gain 3 protons.
   b. an Fe^{2+} ion must gain 1 proton.
   c. an Fe atom must gain 3 electrons.
   d. an Fe^{2+} ion must gain 1 electron.
   e. none of the above will work.

8. Consider the following statements
   — There are always more neutrons than protons in an atom's nucleus.
   — The nucleus of any atom is heavier than all its electrons.
   — In ions, the number of protons is always greater than the number of electrons.
   — An atom has always more subatomic particles than an ion.

   The number of true statements is
   a. 0 **b.** 1 **c.** 2 **d.** 3 **e.** 4

9. In a chemical reaction, if an atomic particle carries a positive charge, then the atom has
   a. lost electrons **b.** lost protons **c.** lost neutrons
   d. gained electrons **e.** gained protons

10. A nuclear symbol for the element simultaneously in group 5 and period 4 is
    a. $^{91}_{40}Zr$ b. $^{51}_{23}V$ c. $^{9}_{4}Be$ d. $^{11}_{5}B$

Problems:

Consider the element zinc (Zn).

1. Look it up in the Periodic Table. What is its atomic number?

2. One of zinc's isotopes has a mass number of 64. Write the nuclear symbol for this isotope. Its ion is Zn^{2+}. How many electrons does its ion have?

3. Describe zinc as a metal, nonmetal, or metalloid; main group, transition or post-transition element. Describe its place in the periodic table (group and period).

4. Write the formula for the ionic compound formed when zinc ions (Zn^{2+}) combine with iodide ions (I^-).

5. Write the formulas of the following compounds:
   carbon disulfide
   aluminum carbonate
   perchloric acid
   ammonium permanganate
   cobalt(II) sulfide
   calcium hydride
   ammonia
   dinitrogen tetraoxide
   hydriodic acid
   magnesium hypobromite

6. Write the names of the following compounds:
   $Na_2Cr_2O_7$
   P_4O_{10}
   $Fe_2(SO_4)_3$
   Na_2Se
   $Ca(HCO_3)_2$
   XeF_4
   ClI_3
   CH_4
   H_2SO_3
   $Al(IO_2)_3$

ANSWERS

Exercises:

(E1) 13 protons, 14 neutrons, 13 electrons
(E2) CCl_4
(E3) $C_2H_4O_2$
(E4) 13 protons, 10 electrons
(E5) 16 protons, 18 electrons
(E6) $MnBr_2$
(E7) Na_3N
(E8) $Al_2(SO_4)_3$
(E9) lithium nitride
(E10) ammonium carbonate
(E11) magnesium oxide
(E12) copper(II) sulfide
(E13) iron(III) sulfide
(E14) $NaNO_2$
(E15) $Rb_2Cr_2O_7$
(E16) $(NH_4)_2SO_4$
(E17) $Ca(ClO_4)_2$
(E18) bromine iodide
(E19) phosphorus tribromide
(E20) sulfur hexafluoride

Self-Test

Multiple Choice:

1. e **2.** c **3.** d **4.** d **5.** d **6.** e **7.** e **8.** b **9.** a **10.** b

Problems:

1. 30
2. $^{64}_{30}Zn$; 28
3. Zinc is a transition metal in group 12, period 4.
4. ZnI_2
5. CS_2 , $Al_2(CO_3)_3$, $HClO_4$, NH_4MnO_4 , CoS , CaH_2 , NH_3 , N_2O_4 , HI , $Mg(BrO)_2$
6. sodium dichromate, tetraphosphorus decaoxide, iron(III) sulfate, sodium selenide, calcium hydrogen carbonate, xenon tetrafluoride, chlorine triiodide, methane, sulfurous acid, aluminum iodite