CHAPTER 4

Chemical Foundations: Elements, Atoms, and Ions

INTRODUCTION

In Chapter 4 you are introduced to the names and symbols of the common elements and ions. Make sure you learn the names and symbols now. Most of the chemistry covered in subsequent chapters depends upon knowledge of these names and symbols.

The remainder of the chapter covers the categories of elements that are organized into the periodic table and the formation of ions from atoms.

CHAPTER DISCUSSION

Models of the Atom

This chapter is the first of many chapters in which theories (models) play a big role. It is crucial to examine these models and understand their significance and limitations. You should develop questions and observations about what the models help us to understand and what the models do not answer. For example, in this chapter you should do this for both Dalton's model and for the more modern view of the structure of the atom.

The reason to make a model more complicated than Dalton's model arose from questions that Dalton's model could not answer.

Look at the following questions concerning Dalton's model. Can it explain the following?

1. When you pour water on a table, the water molecules seem to "stick" together as the water forms drops. How can the molecules "stick" together?
2. Compounds that consist solely of oxygen atoms include the oxygen we breathe (symbolized as O_2) and ozone (symbolized as O_3). How can oxygen atoms form diatomic (two-atom) or triatomic (three-atom) molecules? Why are other molecules with only oxygen unstable?
3. Chlorine naturally exists as a yellow-green gas. Nitrogen naturally exists as a colorless gas. Iron naturally exits as a solid. How can these different properties be explained?

Realize that Dalton's simple model cannot account for the observations made above. We know, then, that Dalton's model is incomplete. However, Dalton's model is still useful (for example, when we study gas laws in Chapter 13, we will use it almost exclusively). It is important to understand not only what the model tells us, but what it doesn't answer.

The next models of the atoms began incorporating the subatomic particles protons, neutrons, and electrons. But even this does not answer all of our questions. For example, in Section 4.6 you will find the question, "If all atoms are composed of these same components, why do different atoms have different chemical properties?" This requires a more modern view of the structure of the atom.

Even this modern view of the atom as presented in this chapter (and expanded upon in Chapter 11) brings about questions. Consider the following:

> Opposite charges are said to attract one another, and like charges are said to repel. If this is the case, why do the electrons not fall into the nucleus? What holds the protons together in the nucleus?

The simple models that are discussed in Chapter 4, while more complicated than Dalton's model (and while they can answer more questions than Dalton's model) cannot answer these questions.

And even though Dalton's model is quite simple and brings about many questions, we still use it frequently. Look back, for example, at the molecular level drawings in Chapter 3 (and these drawings throughout the text). They use Dalton's model because it conveys all the useful information. For example, consider chemical formulas in the next section. This emphasizes once again that all models are simplifications and will fail at some point. On the other hand, models are also extremely useful when properly applied.

Chemical Formulas

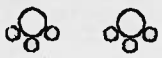
A chemical formula symbolizes the makeup of a molecule. For example, we can sketch a molecule of water as

However, it is much easier to write "H_2O," which conveys that there are two hydrogen atoms joined with one oxygen atom in a water molecule. Note, though, that the formula "H_2O" does not tell us that the order of atoms is HOH. In most cases, the formula just tells you which atoms, and how many of each, are in the molecule. So how do we know the structure? Sometimes formulas will be written to indicate the structure. Also, we will study how to determine the structure from a formula in more detail in Chapter 12.

To test your understanding of this idea, which of the following sketches do you think best represents "$2NH_3$"? Think about this before reading on.

a) 

b) 

c) 

The correct answer is "c." The ammonia molecule (NH_3) has one nitrogen atom and three hydrogen atoms bonded together. The "2" in front of the "NH_3" just means we have two of these molecules. We will see this idea again in Chapter 6–the "2" is called a coefficient, and the "3" is a subscript. We can examine this further by looking at Figure 4.15 in your text. Notice how a chemical equation (which we will study in more detail in Chapter 6) can be symbolized with a molecular perspective (that, incidentally, uses Dalton's model). You can symbolize the chemical reaction shown in Figure 4.15 as

$$2H_2O \rightarrow 2H_2 + O_2$$

Make sense of these symbols and how they relate to the molecular-level representation, and you are in good shape for understanding Chapter 6 (which is crucial for understanding the remaining chapters, especially Chapters 7, 8 and 9).

The Periodic Table

This chapter also introduces you to the periodic table that will be studied in more detail in Chapter 11. For now you should realize that the periodic table was constructed to minimize confusion and memorization and increase understanding and explanation, so use it this way. The elements in the table are not arranged alphabetically or chronologically according to discovery, but according to the number of protons. The elements in the same vertical column have chemical similarities that you will study later. But you should realize now that you can determine the most stable charge of many of the ions made from atoms.

For example, look at the example problems in Section 4.11 of your text. Notice that the most stable ionic charge for Na and Li is 1+, and both are in the same column of the periodic table. What is the most stable charge for Mg and Ca as ions? Each stable ion has a charge of 2+, each of these is in the same column, and they are one column from Li and Na. Find other examples of this, and realize that the periodic table is loaded with such patterns. Now is the time to begin your appreciation of this wonderful table, which provides many answers. Use the periodic table as the valuable resource that it is.

LEARNING REVIEW

1. This review question can help you determine your progress with the material in Chapter 4. You should be able to answer each of the questions below for the common elements listed in Table 4.3 of the textbook. Answer each question below for the element symbolized by Br.

   a. What is the name of the element?

   b. In which group of the periodic table is it found?

   c. What is its family name?

   d. When found in nature uncombined with other elements, what is its state?

   e. At room temperature, what is its physical state; solid, liquid, or gas?

   f. What is the name and charge of the ion it forms?

   g. How many neutrons are found in this isotope $^{80}_{35}\text{Br}$?

2. ~~Which of the ten most abundant elements (determined by mass percent) on earth are not~~ found in ~~large amounts in the human body?~~

3. ~~Match the elements below with the correct description.~~

oxygen	most abundant element on earth
silicon	most abundant element in the human body
carbon	trace element in human body
titanium	25.7% of mass on earth
hydrogen	these three elements make up 93% of mass in the human body
molybdenum	less than 1% of the mass on earth

4. Write symbols for the following elements.

   a. arsenic

   b. fluorine

   c. magnesium

   d. iron

e. neon

f. lead

g. potassium

h. chromium

i. nitrogen

j. calcium

5. Which of the common elements in Table 4.3 of your textbook have a one-letter symbol?

6. Some of the element symbols are not related to the modern name of the element. What are the elements represented by the following element symbols?

a. W

b. Hg

c. Cu

d. K

e. Fe

f. Pb

g. Sb

h. Na

7. Match the element name with the correct element symbol.

cadmium	Cl
carbon	Cr
calcium	C
chlorine	Co
cobalt	Cu
copper	Cd
chromium	Ca

8. Match the element symbol with the correct element name.

Na	silver
Sr	sulfur
S	sodium
Ag	silicon
Si	strontium

9. Describe the main parts of Dalton's atomic theory.

10. How does Dalton's atomic theory relate to the law of constant composition?

11. Dalton's model became more widely accepted when the existence of NO, NO_2, and N_2O became known. What aspect of Dalton's model allowed Dalton to predict the existence of these compounds?

12. Write chemical formulas for the following compounds.
    a. ethyl alcohol, which contains two carbon atoms, six hydrogen atoms, and one oxygen atom
    b. a compound that contains one atom of magnesium and two atoms of bromine
    c. a compound that contains four atoms of phosphorus and ten atoms of oxygen
    d. a compound that contains one atom of arsenic and three atoms of hydrogen

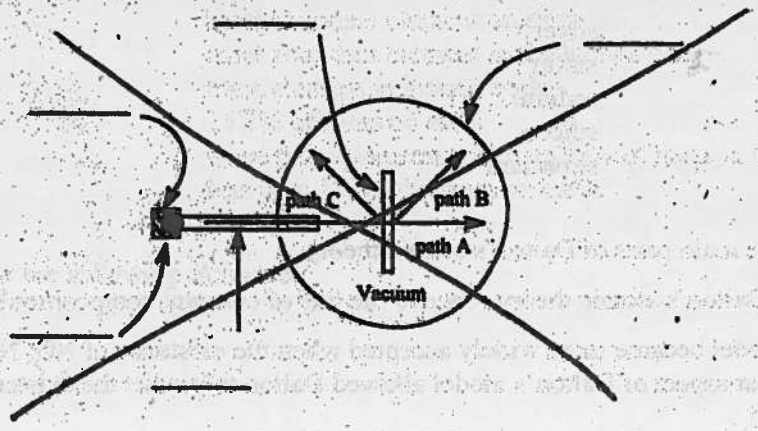
13. What is the *total* number of atoms found in each of the following compounds? What is the total number of elements found in each?
    a. KOH
    b. N_2O_3
    c. CCl_4
    d. H_2O_2
    e. Na_3PO_4

14. A physicist named J. J. Thomson showed that all atoms can be made to emit tiny particles that are repelled by the negative pole of an electric field. Which subatomic particle was this evidence for?
    a. proton
    b. neutron
    c. electron
    d. nucleus
    e. isotope

15. Match the scientist with the discovery.

Ernest Rutherford	demonstrated the existence of electrons
J. J. Thomson	demonstrated the existence of neutrons
Lord Kelvin	developed the plum pudding model of the atom
Rutherford & Chadwick	developed the nuclear-atom model from gold-foil experiments

16. Label the parts of the experimental apparatus used to develop the model of the nuclear atom.



17. In the gold-foil experiment, how did Rutherford interpret each of the following observations?
    a. Most of the α-particles traveled unimpeded through the foil.
    b. Some of the α-particles were deflected slightly from the straight path when they entered the foil.
    c. A few of the α-particles bounced back when they entered the foil.

18. Fill in the missing relative masses and relative charges for each of the subatomic particles.

		Relative Mass	Relative Charge
a.	Electron	_____	1 –
b.	Proton	_____	_____
c.	Neutron	1839	_____

19. Is the following statement true or false? An isotope of sodium could contain 12 protons, 12 neutrons and 11 electrons.

20. Label the parts of the symbol (X) below.

    _____ *A*

    X _____

    _____ *Z*

21. Write the symbols for the isotopes below in ${}^{A}_{Z}\mathrm{X}$ notation.
    a. An isotope of hydrogen has an atomic number of 1 and a mass number of 3.
    b. An isotope of chlorine has an atomic number of 17 and a mass number of 37.
    c. An isotope of oxygen has 8 protons and 10 neutrons.
    d. An isotope of uranium has 92 electrons and 143 neutrons.
    e. An isotope of sulfur has an atomic number of 16 and 16 neutrons.

22. An isotope of titanium contains 24 neutrons and has a mass number of 46.
    a. How many protons does it contain?
    b. How many electrons does it contain?

23. Aluminum-29 has an atomic number of 13.
    a. What is its mass number?
    b. How many neutrons does it have?

24. Match the group name on the left with an element found in that group.

halogen	Ca
transition metal	Ne
alkali metal	Fe
alkaline earth metal	K
noble gas	F

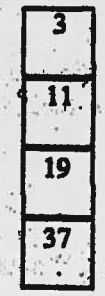
25. Fill in the boxes of the periodic table with element symbols for each of the families below. The number at the top of each box represents atomic number.

a. halogens

b. alkaline earth metals

c. noble gases

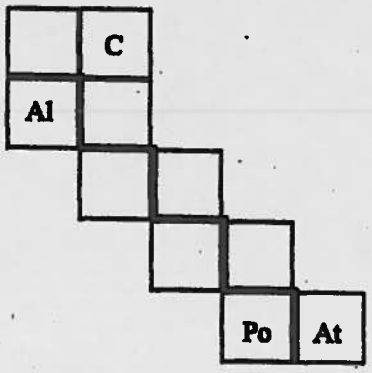
d. alkali metals



26. Which of the following elements are nonmetals?

a. Al
b. C
c. Cr
d. P
e. Br
f. I

27. Some of the elements along the jagged line on the right side of the periodic table have properties of both metals and nonmetals. Fill in the elemental symbols for these metalloids.



28. Some elements exist in nature as diatomic molecules. Which of the elements below will be found as diatomic molecules?

a. Ar
b. O
c. K
d. F
e. S
f. N
g. H
h. Cl

29. At room temperature, what is the physical state (solid, liquid, or gas) of each of the elements that naturally form diatomic molecules?

30. Which elements are always found in nature as individual atoms?

a. carbon
b. krypton
c. magnesium
d. chlorine
e. helium
f. neon
g. aluminum
h. sulfur

31. Fill in the name of the correct element next to its description at 25°C.

a. Liquid metal _____
b. Yellow green gas _____
c. Colorless gas _____
d. A 2-carat diamond _____
e. A reddish-brown liquid _____
f. Dark purple solid _____

32. Balance the equations for the formation of cations from neutral atoms.

a. $Ca \rightarrow$ _____ + _____
b. $K \rightarrow$ _____ + _____
c. $Sr \rightarrow$ _____ + _____
d. $Rb \rightarrow$ _____ + _____

33. Balance the equations for the reactions of cations with electrons.

a. Mg^{2+} + _____ $\rightarrow$ _____
b. Li^{+} + _____ $\rightarrow$ _____
c. $2H^{+}$ + _____ $\rightarrow$ _____
d. Na^{+} + _____ $\rightarrow$ _____

34. Fill in the correct number of protons for either the element or the ion in the table below.

Element	Protons	Electrons	Ion	Protons	Electrons
potassium	19	19			
oxygen				8	10
bromine	35				36
strontium		38		38	
aluminum	13				10

35. You wish to find out whether the compound MgF_2 is composed of ions. What test could you perform to help you make a decision?

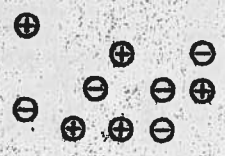
36.

a. Which diagram represents a solid NaCl crystal?

b. Which diagram represents NaCl dissolved in water?

c. Which form of NaCl, solid or aqueous solution, allows free movement of ions?

i.

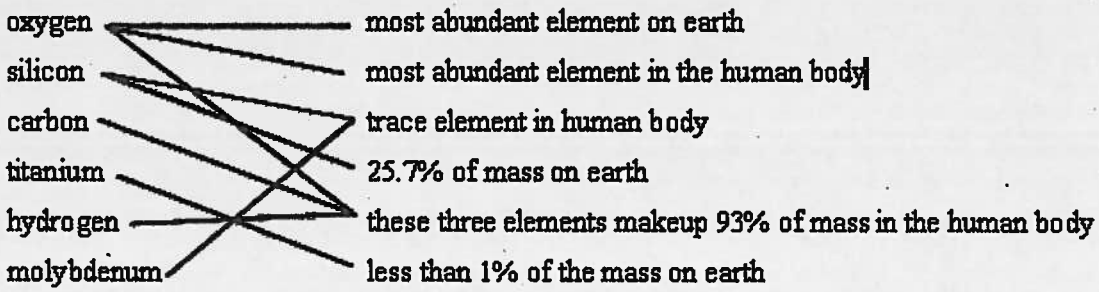


ii.

37. How many of each ion are needed to form a neutral compound?
    a. Ca^{2+} and F^-
    b. Mg^{2+} and O^{2-}
    c. Na^+ and S^{2-}
    d. Li^+ and I^-
    e. Sr^{2+} and Cl^-
    f. K^+ and P^{3-}
    g. Na^+ and N^{3-}
    h. Na^+ and N^{3-}
38. What is wrong with the formulas below? Write the correct formula for each.
    a. $AlCl_2$
    b. NaO
    c. Mg_2P
    d. CaI_3
    e. LiN_3
    f. KS

ANSWERS TO LEARNING REVIEW

1.
    a. bromine
    b. Group 7
    c. halogens
    d. Br_2
    e. liquid
    f. bromide ion, Br^-
    g. 45
2. Silicon, aluminum and iron are found in large amounts on earth, but in small amounts in the human body.
3. Note that some of the elements are found in more than one category.



4.

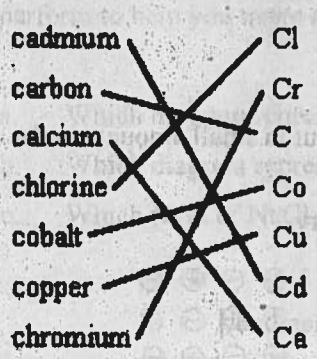
a. As
b. F
c. Mg
d. Fe
e. Ne
f. Pb
g. K
h. Cr
i. N
j. Ca

5. Boron, carbon, fluorine, iodine, nitrogen, oxygen, phosphorous, potassium, sulfur, tungsten and uranium all have one-letter symbols.

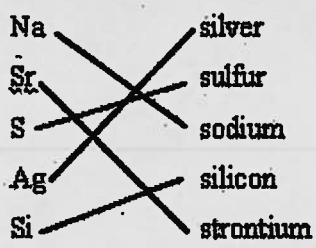
6.

a. tungsten
b. mercury
c. copper
d. potassium
e. iron
f. lead
g. antimony
h. sodium

7. There are quite a few elements whose symbols begin with the letter "c." The symbols for these elements are therefore similar to each other.



8.



9. Dalton's atomic theory states that all elements are made of atoms. For any one element, all the atoms are the same (Dalton didn't know about isotopes). Different elements are made from different kinds of atoms. Atoms from different elements can combine to make compounds. Each compound always has the same relative numbers and kinds of atoms. Chemical reactions do not cause new elements to form.

10. The law of constant composition states that compounds always have the same proportions of each element by mass. Dalton's model states that compounds always have the same relative numbers and kinds of atoms. If compounds always have the same relative number of atoms, they will also have a constant proportion by mass. For example, the compound carbon dioxide always has one carbon atom for two oxygen atoms. The ratio of the mass of a carbon atom to the mass of two oxygen atoms also stays constant for molecules of carbon dioxide. This relationship was predicted by Dalton's model.

11. Dalton's model states that atoms from different elements can combine to produce compounds, and each compound always has the same relative numbers and kinds of atoms. Dalton predicted that different compounds would be found that were made of the same kinds of atoms, but combined in different numbers. The discovery of NO, NO_2, and N_2O confirmed Dalton's prediction and supported his model.

12.

a. C_2H_6O

b. $MgBr_2$

c. P_4O_{10}

d. AsH_3

13. Remember that when an element symbol has no subscript, only one atom of that element is present. Subscript numbers always refer to the element to the *left* of the subscript number.

a. There are three atoms total and three different elements.

b. There are five atoms total and two different elements.

c. There are five atoms total and two different elements.

d. There are four atoms total and two different elements.

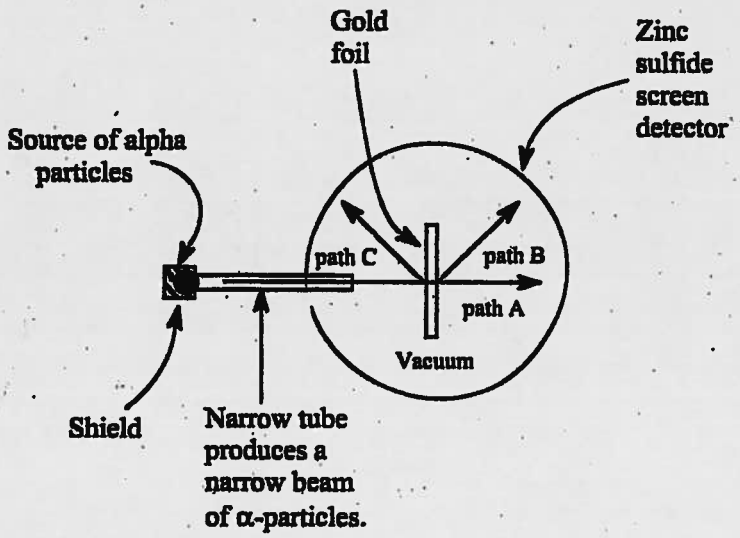
e. There are eight atoms total and three different elements.

14. Because the particles were repelled by the negative pole, it was believed that the particles were negatively charged because like charges repel each other. The electron is a subatomic particle with a negative charge, so the correct answer is c.

15.

Ernest Rutherford	demonstrated the existence of electrons
J. J. Thomson	demonstrated the existence of neutrons
Lord Kelvin	developed the plum pudding model of the atom
Rutherford & Chadwick	developed the nuclear atom model from gold foil experiments

16.



17.

a. An atom consists mostly of empty space.

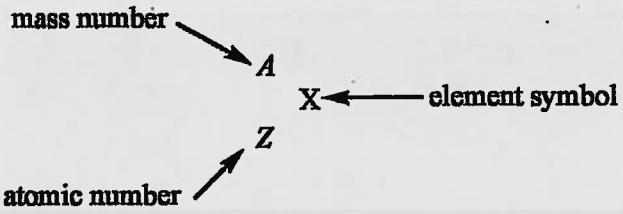
b. α-particles have a positive charge because they contain two protons. When a moving α-particle travels close to the nucleus of an atom that itself contains protons, the α-particle is deflected from its path because two areas of positive charge repel each other.

c. Some of the α-particles scored a direct hit and bounced straight back. The particle that the α-particle hit must be an area within the atom that is very massive for the heavy α-particle to bounce straight back.

18.

		Relative Mass	Relative Charge
a.	Electron	1	1 –
b.	Proton	1836	1 +
c.	Neutron	1839	0

19. Isotopes of all atoms have the same number of protons as they do electrons. All sodium isotopes have 11 protons and 11 electrons. So the answer is false.



20.

21.

a. $^{3}_{1}H$

b. $^{37}_{17}Cl$

c. $^{18}_{8}O$

d. $^{235}_{92}U$

e. $^{32}_{16}S$

22.

a. The mass number provides the number of protons plus the number of neutrons. If the number of neutrons is 24, then the number of protons is 46 minus 24, or 22 protons.

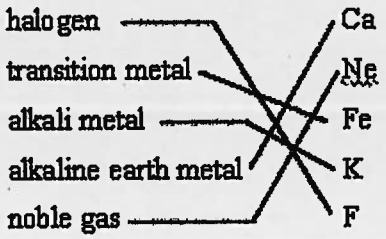
b. The number of protons always equals the number of electrons, so there are 22 electrons in this isotope.

23.

a. When isotopes are designated with the element name followed by a number, as in aluminum-29, the number is e

b. Aluminum-29 has 16 neutrons.

24.



25.

a. halogens

9 F
17 Cl
35 Br
53 I

b. alkaline earth metals

12 Mg
20 Ca
38 Sr
56 Ba

c. noble gases

2 He
10 Ne
18 Ar
36 Kr
54 Xe

d. alkali metals

3 Li
11 Na
19 K
37 Rb

26. C, P, Br, and I are nonmetals. The nonmetals are found to the right of the jagged line on the right side of the periodic table.

27.

B	C				
Al	Si				
		Ge	As		
			Sb	Te	
				Po	At

28.

a. Oxygen is found in nature as O_2 molecules.

d. Fluorine is found in nature as F_2 molecules.

f. Nitrogen is found in nature as N_2 molecules.

g. Hydrogen is found in nature as H_2 molecules.

h. Chlorine is found in nature as Cl_2 molecules.

29. Most of the diatomic molecules—H_2, N_2, O_2, F_2, Cl_2—are gases at room temperature. Br_2 is a reddish-brown liquid; I_2 is a dark purple solid.

30.

a. Carbon is usually found combined with other elements such as hydrogen.

b. Krypton is always found as individual krypton atoms.

c. Magnesium is usually found combined with other elements.

d. Chlorine is found as either Cl_2, or combined with other elements.

e. Helium is always found as individual helium atoms.

f. Neon is always found as individual neon atoms.

g. Aluminum is usually found combined with other elements.

h. Sulfur is usually found as S_8 molecules or combined with other elements.

31. Only a few of the elements have unique properties, but there are many elements that could be described as colorless gases or as shiny metals.

a.	Liquid metal	mercury
b.	Yellow green gas	chlorine
c.	Colorless gas	Many elements fit this description, such as oxygen, hydrogen, etc.
d.	A 2 carat diamond	carbon
e.	A reddish-brown liquid	bromine
f.	Dark purple solid	iodine

32. Cations have lost one or more electrons, and the number of electrons lost always equals the charge on the cation.

a. $Ca \rightarrow Ca^{2+} + 2e^-$

b. $K \rightarrow K^+ + e^-$

c. $Sr \rightarrow Sr^{2+} + 2e^-$

d. $Rb \rightarrow Rb^+ + e^-$

33. Cations will react with electrons to form neutral atoms.

a. $Mg^{2+} + 2e^- \rightarrow Mg$

b. $Li^+ + e^- \rightarrow Li$

c. $2H^+ + 2e^- \rightarrow H_2$

d. $Na^+ + e^- \rightarrow Na$

34. The number of protons does not change when neutral atoms form ions, but the number of electrons either increases or decreases.

Element	Protons	Electrons	Ion	Protons	Electrons
potassium	19	19	potassium	19	18
oxygen	8	8	oxide	8	10
bromine	35	35	bromide	35	36
strontium	38	38	strontium	38	36
aluminum	13	13	aluminum	13	10

35. You can place some solid MgF_2 in water. If the solid MgF_2 contains Mg^{2+} ions and F^- ions, when the compound dissolves in water an aqueous solution of Mg^{2+} and F^- ions will form. Test whether or not a solution of MgF_2 will conduct an electrical current by immersing electrodes in the solution. If the solution allows current to flow and a bulb to shine, there is evidence that ions are in solution, free to move around, and able to conduct an electrical current.

36.

a. A solid NaCl crystal is an ordered rigid structure, structure i.

b. Ions are pulled away from the orderly crystal by water molecules, as in structure ii.

c. Ions in water are free to move around and are not packed close together. Those in a solid are ordered and packed close together so that each anion is surrounded by cations.

37.

a.	one calcium and two fluoride ions	CaF_2
b.	one magnesium and one oxide ion	MgO
c.	two sodium and one sulfide ion	Na_2S
d.	one lithium and one iodide ion	LiI
e.	two strontium and two chloride ions	$SrCl_2$
f.	three potassium and one phosphide ion	K_3P
g.	three sodium and one nitride ion	Na_3N

38.

a. Aluminum forms ions with a 3+ charge, and chlorine forms ions with a 1– charge. Three chlorine ions will combine with one aluminum ion to form $AlCl_3$.

b. Sodium forms ions with a 1+ charge, and oxygen forms ions with a 2– charge. Two sodium ions will combine with one oxide to form Na_2O.

c. Magnesium forms ions with a 2+ charge, and phosphorus forms ions with a 3– charge. Three magnesium ions will combine with two phosphide ions to form Mg_3P_2.

d. Calcium forms ions with a 2+ charge, and iodine forms ions with a 1– charge. One calcium ion will combine with two iodide ions to form CaI_2.

e. Lithium forms ions with a 1+ charge, and nitrogen forms ions with a 3– charge. Three lithium ions will combine with one nitride ion to form Li_3N.

f. Potassium forms ions with a 1+ charge, and sulfur forms ions with a 2– charge. Two potassium ions will combine with one sulfide ion to form K_2S.