SOLUTIONS - CHAPTER 5 Problems

1) Write Lewis dot symbols for the following atoms:
   a) Ca  b) Se  c) B  d) Cl  e) He

\[ \cdot\text{Ca} \quad \cdot\text{Se} \quad \cdot\text{B} \quad \cdot\text{Cl} \quad \cdot\text{He} \]

2) Write Lewis dot symbols for the following ions:
   a) Li\(^+\)  b) Cl\(^-\)  c) S\(^2-\)  d) Sr\(^2+\)  e) N\(^3-\)

\[
\begin{align*}
\boxed{\text{Li}^+} & \quad \boxed{\text{Cl}^-} & \quad \boxed{\text{S}^{2-}} \\
\boxed{\text{Sr}^{2+}} & \quad \boxed{\text{N}^{3-}}
\end{align*}
\]

3) (Burdge, 5.10) Explain what ionic bond is.

Ionic bonding is the bonding that occurs when electrons are transferred from one atom (or group of atoms) to another atom (or group of atoms). The bonding occurs due to the attractive force that exists between ions of opposite charge.

4) Specify which compound in each of the following pairs of ionic compounds should have a higher lattice energy. Explain your choice.

a) AlN or CaO
   AlN  The ions involved are 3+/3-, while those involved in CaO are 2+/2-.

b) NaF or CsF
   NaF  Both Na and Cs are + ions, but Na\(^+\) is smaller than Cs\(^+\) and so will have a stronger force of attraction for F\(^-\).

c) MgCl\(_2\) or MgF\(_2\)
   MgF\(_2\). Both F and Cl are - ions, but F\(^-\) is smaller than Cl\(^-\) and so will have a stronger force of attraction for Mg\(^2+\).

5) Give the empirical formula and name for the compounds formed from each of the pairs of ions

a) Rb\(^+\) and I\(^-\)
   RbI  rubidium iodide

b) Cs\(^+\) and SO\(_4^{2-}\)
   Cs\(_2\)SO\(_4\)  cesium sulfate

c) Sr\(^{2+}\) and N\(^3-\)
   Sr\(_3\)N\(_2\)  strontium nitride

d) Al\(^3+\) and S\(^2-\)
   Al\(_2\)S\(_3\)  aluminum sulfide
6) (Burdge, 5.98) Predict the formula and name of the binary compound formed from the following elements:

- a) Na and H \[\text{NaH}\] sodium hydride
- b) B and O \[\text{B}_2\text{O}_3\] diboron trioxide
- c) Na and S \[\text{Na}_2\text{S}\] sodium sulfide
- d) Al and F \[\text{AlF}_3\] aluminum fluoride
- e) F and O \[\text{OF}_2\] oxygen difluoride
- f) Sr and Cl \[\text{SrCl}_2\] strontium chloride

7) (Burdge, 5.33) Two different compounds, each containing only phosphorus and chlorine, were decomposed into their constituent elements. One produced 0.2912 g P for every gram of Cl; the other produced 0.1747 g P for every gram of Cl. Show that these results are consistent with the law of multiple proportions.

If we look at the ratio of the amount of phosphorus in each compound we get

\[
\frac{0.2912 \text{ g P}}{0.1747 \text{ g P}} = \frac{1.667}{\frac{3}{5}}
\]

which is the ratio of two small integers.

8) (Burdge, 5.38) Define molecular formula and empirical formula. What are the similarities and differences between the empirical formula and the molecular formula of a compound?

The molecular formula gives the number of atoms of each type of element per molecule of substance (for those substances that exist as individual molecules). The empirical formula gives the relative number of atoms of each type of element in the compound, reduced to the smallest set of whole numbers.

Both the molecular formula and the empirical formula contain the correct relative number of atoms of each element present in a pure chemical substance. For molecular compounds the molecular formula will be the empirical formula multiplied by some integer value.

9) (Burdge, 5.65) Explain the difference between the terms molecular mass and formula mass. To what type of compound does each refer?

The term molecular mass refers to the average mass of a single molecular of a substance, and so applies to substances that exist as molecules. The term formula mass refers to the average mass of one formula unit of a substance, and so applies to substances that do not exist as individual molecules, such as ionic compounds.
10) (Burdge, 5.48) Write the molecular formula of ethanol from the model shown. The color codes are black (carbon), red (oxygen), and white (hydrogen).

![Ethanol model]

The molecular formula is C₂H₆O. Note that an organic chemist would likely write the formula as CH₃CH₂OH to communicate information about the structure of the molecule.

11) (Burdge, 5.46) Write the empirical formulas of the following compounds:
   a) Al₂Br₆, b) Na₂S₂O₄, c) N₂O₅, d) K₂Cr₂O₇

   a) Al₂Br₆  empirical is AlBr₃
   b) Na₂S₂O₄  empirical is NaSO₂
   c) N₂O₅  empirical is N₂O₅
   d) K₂Cr₂O₇  empirical is K₂Cr₂O₇

12) Write the empirical formulas for the following organic compounds:
   a) C₆H₆, b) CH₃CH₂CH₃, c) CH₃COOH, d) CH₃CH₂C(CH₃)₃

   a) C₆H₆  empirical is CH
   b) CH₃CH₂CH₃  empirical is C₃H₈
   c) CH₃COOH  empirical is CH₂O
   d) CH₃CH₂C(CH₃)₃  empirical is C₃H₇

13) (Burdge, 5.68 a, b, e) Calculate the molecular mass or formula mass (in amu) for each of the following substances: a) Li₂CO₃,  b) C₂H₆, e) Fe(NO₃)₃

   a) Li₂CO₃
   
   \[
   \begin{align*}
   \text{Li} & \quad 2 \times 6.941 \text{ amu} = 13.882 \text{ amu} \\
   \text{C} & \quad 1 \times 12.0107 \text{ amu} = 12.0107 \text{ amu} \\
   \text{O} & \quad 3 \times 15.9994 \text{ amu} = 47.9982 \text{ amu} \\
   \end{align*}
   \]

   \[M = 73.891 \text{ amu}\]

   \[\approx 73.89 \text{ amu}\]

   b) C₂H₆
   
   \[
   \begin{align*}
   \text{C} & \quad 2 \times 12.0107 \text{ amu} = 24.0214 \text{ amu} \\
   \text{H} & \quad 6 \times 1.00794 \text{ amu} = 6.04764 \text{ amu} \\
   \end{align*}
   \]

   \[M = 30.0690 \text{ amu}\]

   \[\approx 30.07 \text{ amu}\]
e) Fe(NO$_3$)$_3$

Fe $\quad 1 \times 55.845$ amu $\quad = \quad 55.845$ amu
N $\quad 3 \times 14.0067$ amu $\quad = \quad 42.0201$ amu
O $\quad 9 \times 15.9994$ amu $\quad = \quad 143.9946$ amu

$M = 241.860$ amu
$\cong 241.86$ amu

Note that we often round off the molecular mass or formula mass to two digits to the right of the decimal place, as this is usually sufficient for calculations using $M$.

14) Find the percent composition for copper (II) nitrate (Cu(NO$_3$)$_2$).

Cu(NO$_3$)$_2$

Cu $\quad 1 \times 63.55$ amu $\quad = \quad 63.546$ amu
N $\quad 2 \times 14.0067$ amu $\quad = \quad 28.0134$ amu
O $\quad 6 \times 15.9994$ amu $\quad = \quad 95.9964$ amu

$M = 187.56$ amu

So
$\%$ Cu $= \left[\frac{63.546 \text{ amu}}{187.56 \text{ amu}}\right] \times 100 \% = 33.88 \%$ Cu
$\%$ N $= \left[\frac{28.0134 \text{ amu}}{187.56 \text{ amu}}\right] \times 100 \% = 14.94 \%$ N
$\%$ O $= \left[\frac{95.9964 \text{ amu}}{187.56 \text{ amu}}\right] \times 100 \% = 51.18 \%$ O

15) (Burdge, 5.74) For many years chloroform (CHCl$_3$) was used as an inhalation anesthetic in spite of the fact that it is also a toxic substance that may cause severe liver, kidney, and heart damage. Calculate the percent composition by mass of this compound.

CHCl$_3$

C $\quad 1 \times 12.0107$ amu $\quad = \quad 12.0107$ amu
H $\quad 1 \times 1.00794$ amu $\quad = \quad 1.00794$ amu
Cl $\quad 3 \times 35.453$ amu $\quad = \quad 106.36$ amu

$M = 119.38$ amu

So
$\%$ C $= \left[\frac{12.0107 \text{ amu}}{119.38 \text{ amu}}\right] \times 100 \% = 10.06 \%$ C
$\%$ H $= \left[\frac{1.00794 \text{ amu}}{119.38 \text{ amu}}\right] \times 100 \% = 0.84 \%$ H
$\%$ Cl $= \left[\frac{106.36 \text{ amu}}{119.38 \text{ amu}}\right] \times 100 \% = 89.10 \%$ Cl
16) If we know the empirical formula for a compound, what additional information do we need to determine its molecular formula?

You also need to know the molecular mass. Since

\[(\text{molecular formula}) = N \times (\text{empirical formula}) \quad N = 1, 2, 3\ldots\]

We can find \(N\) by using

\[N = \frac{M(\text{molecule})}{M(\text{empirical formula})}\]

17) Determine the empirical formulas for the compounds with the following compositions:

When you are given the percent composition for a compound it is easiest to proceed by assuming you have 100.00 g of the compound.

a) 2.1 % H; 65.3 % O; 32.6 % S

\[
\text{mol H} = \frac{(2.1 \text{ g H})}{(1.00794 \text{ g/mol})} = 2.1 \text{ mol H} \div 1.02 = 2.1
\]

\[
\text{mol O} = \frac{(65.3 \text{ g O})}{(15.9994 \text{ g/mol})} = 4.08 \text{ mol O} \div 1.02 = 4.00
\]

\[
\text{mol S} = \frac{(32.6 \text{ g S})}{(32.065 \text{ g/mol})} = 1.02 \text{ mol S} \div 1.02 = 1.00
\]

empirical formula is \(\text{H}_2\text{O}_4\text{S}\) (actual is likely \(\text{H}_2\text{SO}_4\))

b) 20.2 % Al; 79.8 % Cl

\[
\text{mol Al} = \frac{(20.2 \text{ g Al})}{(26.9815 \text{ g/mol})} = 0.749 \text{ mol Al} \div 0.749 = 1.00
\]

\[
\text{mol Cl} = \frac{(79.8 \text{ g Cl})}{(35.453 \text{ g/mol})} = 2.25 \text{ mol Cl} \div 0.749 = 3.00
\]

empirical formula is \(\text{AlCl}_3\)

18) The empirical formula of a compound is CH. If the molar mass of this compound is about 78 g, what is its molecular formula?

The mass of a CH unit is 13.02 g/mol

So the number of CH units per molecule is

\[N = \frac{(78. \text{ g/mol})}{(13.02 \text{ g/mol})} = 6.0\]

The formula is \(6 \cdot (\text{CH}) = \text{C}_6\text{H}_6\)
19) How many moles of substance are contained in 100.0 g of the following compounds:
   a) NaCl, b) CHCl$_3$

   a) NaCl \[ M = 1 \times (22.98976928 \text{ amu}) + 1 \times (35.453 \text{ amu}) = 58.44 \text{ amu} \]
   \[ = 58.44 \text{ g/mol} \]
   \[ \# \text{ moles} = \frac{100.0 \text{ g}}{58.44 \text{ g}} = 1.711 \text{ mol NaCl} \]

   b) CHCl$_3$ \[ M = 1 \times (12.0107 \text{ amu}) + 1 \times (1.00794 \text{ amu}) + 3 \times (35.453 \text{ amu}) \]
   \[ = 119.38 \text{ amu} = 119.38 \text{ g/mol} \]
   \[ \# \text{ moles} = \frac{100.0 \text{ g}}{119.38 \text{ g}} = 0.8377 \text{ mol CHCl}_3 \]

20) (Burdge, 5.84) How many molecules of ethane (C$_2$H$_6$) are present in 0.334 g of ethane?

   \[ M = 2 \times (12.0107 \text{ amu}) + 6 \times (1.00794 \text{ amu}) = 30.07 \text{ amu} = 30.07 \text{ g/mol} \]
   \[ \# \text{ molecules} = \frac{0.334 \text{ g}}{30.07 \text{ g}} \times \frac{6.022 \times 10^{23} \text{ molecule}}{1 \text{ mol}} = 6.69 \times 10^{21} \text{ molecules} \]

21) Ascorbic acid (vitamin C) contains C, H, and O. In one analysis, a sample of ascorbic acid was found to contain 2.145 g carbon, 0.239 g hydrogen, and 2.86 g oxygen. No other elements were present. Find the empirical formula and for ascorbic acid.

   Total mass of sample = grams C + grams H + grams O
   \[ = 2.145 \text{ g} + 0.239 \text{ g} + 2.86 \text{ g} = 5.24 \text{ g} \]

   We can now find the empirical formula

   \[ \text{mol C} = \frac{2.145 \text{ g C}}{12.0107 \text{ g/mol}} = 0.1786 \text{ mol C} \div 0.1786 = 1.000 \]

   \[ \text{mol H} = \frac{0.239 \text{ g H}}{1.00794 \text{ g/mol}} = 0.237 \text{ mol H} \div 0.1786 = 1.33 \]

   \[ \text{mol O} = \frac{2.86 \text{ g O}}{15.9994 \text{ g/mol}} = 0.179 \text{ mol O} \div 0.1786 = 1.00 \]

   Notice that the relative moles of H is not close to an integer value. However, if we multiply through by 3 we get values that are all close to integers.

   So the empirical formula is C$_3$H$_4$O$_3$ (M = 88.07 g/mol)
22) Monosodium glutamate (MSG), a food flavoring enhancer, has been blamed for “Chinese restaurant syndrome”, the symptoms of which are headache and chest pains. MSG has the following composition by mass: 35.51 percent C; 4.77 percent H; 37.85 percent O; 8.29 percent N; and 13.60 percent Na. What is its molecular formula if its mass is about 169 g?

We first need to find the empirical formula

\[
\begin{align*}
\text{mol C} &= \frac{(35.51 \text{ g C})}{(12.0107 \text{ g/mol})} = 2.957 \text{ mol C} \div 0.5916 = 4.998 \\
\text{mol H} &= \frac{(4.77 \text{ g H})}{(1.00794 \text{ g/mol})} = 4.73 \text{ mol H} \div 0.5916 = 8.00 \\
\text{mol O} &= \frac{(37.85 \text{ g O})}{(15.9994 \text{ g/mol})} = 2.366 \text{ mol O} \div 0.5916 = 3.999 \\
\text{mol N} &= \frac{(8.29 \text{ g N})}{(14.0067 \text{ g/mol})} = 0.592 \text{ mol N} \div 0.5916 = 1.00 \\
\text{mol Na} &= \frac{(13.60 \text{ g Na})}{(22.9898 \text{ g/mol})} = 0.5916 \text{ mol Na} \div 0.5916 = 1.000
\end{align*}
\]

The empirical formula has a mass of 169.11 g/mol

So \( N = \frac{(169. \text{ g/mol})}{(169.11 \text{ g/mol})} = 1.00 \)

So the molecular formula is also \( \text{C}_5\text{H}_8\text{O}_4\text{NNa} \) (likely \( \text{NaC}_5\text{H}_8\text{O}_4\text{N} \))

23) (Burdge, 5.55) Name the following binary molecular compounds:
   a) NCl\(_3\), b) IF\(_7\), c) P\(_4\)O\(_6\), d) S\(_2\)Cl\(_2\)

   a) NCl\(_3\) nitrogen trichloride  
   b) IF\(_7\) iodine heptafluoride  
   c) P\(_4\)O\(_6\) tetraphosphorus hexoxide  
   d) S\(_2\)Cl\(_2\) disulfur dichloride

24) (Burdge, 5.61) Name the following compounds: a) KClO, b) Ag\(_2\)CO\(_3\), c) HNO\(_2\), d) KMnO\(_4\), e) CsClO\(_3\), f) KNH\(_4\)SO\(_4\), g) Fe(BrO\(_4\))\(_2\), h) K\(_2\)HPO\(_4\)

   a) KClO potassium hypochlorite  
   b) Ag\(_2\)CO\(_3\) silver carbonate (I would also accept silver (I) carbonate)  
   c) HNO\(_2\) nitrous acid  
   d) KMnO\(_4\) potassium permanganate  
   e) CsClO\(_3\) cesium chlorate  
   f) KNH\(_4\)SO\(_4\) potassium ammonium sulfate  
   g) Fe(BrO\(_4\))\(_2\) iron (II) perbromate  
   h) K\(_2\)HPO\(_4\) potassium hydrogen phosphate
25) (Burdge, 5.63) Write formulas for the following compounds:

a) copper (I) cyanide \( \text{CuCN} \)
b) strontium chlorite \( \text{Sr(ClO}_2\text{)}_2 \)
c) perbromic acid \( \text{HBrO}_4 \)
d) hydroiodic acid \( \text{HI} \)
e) disodium ammonium phosphate \( \text{Na}_2\text{NH}_4\text{PO}_4 \)
f) lead (II) carbonate \( \text{PbCO}_3 \)
g) tin (II) sulfite \( \text{SnSO}_3 \)
h) cadmium thiocyanide \( \text{Cd(SCN)}_2 \)

26) What is wrong with the name for each of the following compounds:

a) \( \text{BaCl}_2 \) (barium dichloride) We know that barium is a \( \text{Ba}^{2+} \) ion (group 2A) and chlorine is a \( \text{Cl}^- \) ion (group 7A), so we do not have to use di- in the second part of the name. The correct name for the compound is barium chloride.

b) \( \text{Fe}_2\text{O}_3 \) (iron (II) oxide) Oxygen is a \( \text{O}^{2-} \) ion (group 6A). There are three of these, and so the total charge from the oxygens is \(-6\). For electrical neutrality, the total charge from the two irons must be \(+6\). Therefore the iron ion is the \( \text{Fe}^{3+} \) ion, and the correct name for the compound is iron (III) oxide.

c) \( \text{CsNO}_2 \) (cesium nitrate) The nitrate ion is \( \text{NO}_3^- \). So \( \text{NO}_2^- \) is the nitrite ion, and the correct name for the compound is cesium nitrite.

d) \( \text{Mg(HCO}_3\text{)}_2 \) (magnesium (II) bicarbonate) Since magnesium is in group 2A, we know it forms the \( \text{Mg}^{2+} \) ion, and so do not have to indicate the charge of the ion in the name. So the correct name for the compound is magnesium bicarbonate (or magnesium hydrogen carbonate).

27) Fill in the blanks in the table.

<table>
<thead>
<tr>
<th>Cation</th>
<th>Anion</th>
<th>Formula</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{Mg}^{2+} )</td>
<td>( \text{HCO}_3^- )</td>
<td>( \text{Mg(HCO}_3\text{)}_2 )</td>
<td>Magnesium hydrogen carbonate</td>
</tr>
<tr>
<td>( \text{Sr}^{2+} )</td>
<td>( \text{Cl}^- )</td>
<td>( \text{SrCl}_2 )</td>
<td>Strontium chloride</td>
</tr>
<tr>
<td>( \text{Fe}^{3+} )</td>
<td>( \text{NO}_3^- )</td>
<td>( \text{Fe(NO}_3\text{)}_3 )</td>
<td>Iron (III) nitrate</td>
</tr>
<tr>
<td>( \text{Mn}^{2+} )</td>
<td>( \text{ClO}_3^- )</td>
<td>( \text{Mn(ClO}_3\text{)}_2 )</td>
<td>Manganese (II) chlorate</td>
</tr>
<tr>
<td>( \text{Sn}^{4+} )</td>
<td>( \text{Br}^- )</td>
<td>( \text{SnBr}_4 )</td>
<td>Tin (IV) bromide</td>
</tr>
<tr>
<td>( \text{Co}^{2+} )</td>
<td>( \text{PO}_4^{3-} )</td>
<td>( \text{Co}_3(\text{PO}_4\text{)}_2 )</td>
<td>Cobalt (II) phosphate</td>
</tr>
<tr>
<td>( \text{Hg}_2^{2+} )</td>
<td>( \Gamma^- )</td>
<td>( \text{Hg}_2\text{I}_2 )</td>
<td>Mercury (I) iodide</td>
</tr>
<tr>
<td>( \text{Cu}^{+} )</td>
<td>( \text{CO}_3^{2-} )</td>
<td>( \text{Cu}_2\text{CO}_3 )</td>
<td>Copper (I) carbonate</td>
</tr>
<tr>
<td>( \text{Li}^+ )</td>
<td>( \text{N}^{3-} )</td>
<td>( \text{Li}_3\text{N} )</td>
<td>Lithium nitride</td>
</tr>
<tr>
<td>( \text{Al}^{3+} )</td>
<td>( \text{S}^{2-} )</td>
<td>( \text{Al}_2\text{S}_3 )</td>
<td>Aluminum sulfide</td>
</tr>
</tbody>
</table>

The first compound above can also be named magnesium bicarbonate.