3 The Periodic Table and Chemical Periodicity

3-1 Chemical Reactions
A chemical reaction occurs when you mix two materials together and they react together to form a new material. As we have mentioned in the previous chapters when this occurs no atoms are created or destroyed; instead the bonds that arrange the atoms into molecules are rearranged so the old molecules disappear and are replaced with new and different molecules.

Chemists have adopted a shorthand to make describing a chemical reaction quick and easy.

First, some terminology. The molecules that are reacting together are called the reactants. The new molecules that they are turned into are called the products.

Thus we have reactants → products

Next we give the chemical formula and physical form of all reactants and products:

\[ 2 \text{Na(s)} + \text{Cl}_2(g) \rightarrow \text{NaCl(s)} \] (Not balanced)

Note that if there is more than one product or reactant we write a plus sign between the products or reactants.

The above expression that identifies product and reactant molecules and their physical forms, and includes an arrow to help you identify which chemicals are the products and which are the reactants is called a chemical equation.

Notice we have said no atoms are created or destroyed in a chemical reaction, yet if you look at the above reaction it appears that a Cl atom has gone missing. That is why we say the above reaction is 'unbalanced' atoms are missing from one side or the other so the atoms aren't 'balanced' between the two sides. Learning a systematic way to balance a chemical equation is what we will do next.

3-2 Balancing Chemical Equations
To balance an equation we are trying to come up with a set of 'balancing coefficients'. These are numbers that sit in front of each chemical formula to tell you the relative amounts of each chemical you need to make all your atoms balance.

\[ \_\_\_\text{Na(s)} + \_\_\_\text{Cl}_2(g) \rightarrow \_\_\_\text{NaCl(s)} \]
Your book mentions one way to balance equations using algebra. This method works, but is both labor and math intensive, so both the book and I will use the method called **balancing by inspection**.

In this method you work back and forth, one element at a time, trying to come up with a consistent set of coefficients that will make the equation come into balance.

**The first rule is:** YOU CANNOT CHANGE A MOLECULAR FORMULA. YOU CAN ONLY CHANGE THE COEFFICIENTS IN FRONT OF A FORMULA. Why is that? Because if you change a formula, you change the chemical itself!

Let’s try to balance our equation. Let’s start by focusing on Cl, since it is the one that is out of balance:

\[
\begin{align*}
\text{total Cl} & \quad 2 \quad 1 \\
\text{Coefficients to balance} & \quad 1 \quad 2 \\
\text{Total Cl with coefficients} & \quad 1 \times 2 = 2 \quad 2 \times 1 = 2 \quad \text{Balanced!}
\end{align*}
\]

Now Na is out of balance so:

\[
\begin{align*}
\text{Na} & \quad 1 \quad 2 \times 1 = 2 \\
\text{Coefficients} & \quad 2 \quad \text{(set at 2)} \\
\text{Total Na with coefficients:} & \quad 2 \times 1 = 2 \quad 2 \times 1 = 2 \quad \text{Balanced!}
\end{align*}
\]

Once all atoms are balanced re-write the equation with the coefficients. Note, that you usually don’t write the coefficient of 1, so the above equation becomes:

\[
2\text{Na(s)} + \text{Cl}_2(g) \rightarrow 2\text{NaCl(s)}
\]

Which atoms do you start with? I usually start with atoms that occur only in one product or reactant. Once I lock in a couple of coefficients with that atom, then I look to other atoms in the same compound to try to lock in other coefficients:

Let’s try another

\[
\begin{align*}
\text{Ca(OH)}_2 & \quad \text{H}_3\text{PO}_4 & \quad \text{H}_2\text{O} & \quad \text{Ca}_3(\text{PO}_4)_2 \\
\text{Ca} & \quad 3 & \quad \text{P} & \quad 2 & \quad \text{O} & \quad 6 \quad 8 \quad 12 \quad 2 & \quad \text{H} & \quad 6 \quad 6 \quad 12 \\
\text{coefficients:} & \quad 3 \times 2 & \quad 2 & \quad 6 \times 2 & \quad 1 \times 2 \quad 3 \times 2 & \quad \text{Balanced!}
\end{align*}
\]

\[
3\text{Ca(OH)}_2(aq) + 2\text{H}_3\text{PO}_4(aq) \rightarrow 6\text{H}_2\text{O(l)} + \text{Ca}_3(\text{PO}_4)_2(s)
\]
When you have reactions with diatomic molecules you sometimes have to do a trick as in this example. Say we want to write the equation for the burning of butane, $C_4H_{10}$. We know we will need $O_2$ and our products will be water and $CO_2$. The largest molecule is the Butane $C_4H_{10}$. If this is going to balance, we will need 4 C on the right side.

Thus we will have:

$$C_4H_{10}(l) + O_2 (g) \rightarrow 4CO_2 (g) + 5H_2O(l)$$

We are at the point

$$C_4H_{10} + O_2 \rightarrow 4CO_2 + 5H_2O$$

Our $C_4H_{10}$ is balances out so we can now switch to the next compound on the left, $O_2$. We have 4(2) + 5 O on the right, for a total of 13 O. How can we get 13 O’s from $O_2$? The only way we can get 13 O from $O_2$ is to use 13/2 or (6-1/2) $O_2$ on the left.

$$C_4H_{10} + 13/2 O_2 \rightarrow 4CO_2 + 5H_2O$$

It is considered bad form to use ½ of a molecule in a chemical reaction, so you need to do one more step, multiply all the coefficients, on both sides of the equation by 2 to get rid of the ½ factor. Thus we get

$$2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$$

Once you think you are though you should always go back and check everything

<table>
<thead>
<tr>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>C 2x$4=8$</td>
<td>8</td>
</tr>
<tr>
<td>H 2x$10=20$</td>
<td>10x$2=20$</td>
</tr>
<tr>
<td>O 13x$2=26$</td>
<td>8(2) +10 = 26</td>
</tr>
</tbody>
</table>

Hooray, it all checks out.

Final touch - add the phases.

$$2C_4H_{10}(g) + O_2(g) \rightarrow 4CO_2(g) + 5H_2O(g)$$

Depending on which atoms you start with, balancing by inspection can sometimes get you in a bind, and you have to recognize that sometimes you simply have to start over. Look at this example:

$$NH_3(g) + O_2(g) \rightarrow NO(g) + H_2O(g)$$

$N 1(3)$ $1$ 3/2 (2)

But this I don’t want to multiply by 2 until the very last step so this leaves me in a bind.
Starting over, this time starting with the problem H!

\[ \frac{2}{3} \text{NH}_3(g) + \frac{3}{2} \text{O}_2(g) \rightarrow \frac{2}{3} \text{NO}(g) + \frac{3}{2} \text{H}_2\text{O}(g) \]

Multiplying by 2

\[ 4\text{NH}_3(g) + 3\text{O}_2(g) \rightarrow 4\text{NO}(g) + 6\text{H}_2\text{O}(g) \]

It should be mentioned that the coefficients you get are relative ratios of the amounts of each molecule you need in a given reaction. The actual amount of each chemical will be something we will worry about in a later chapter.

Clicker question: work through balancing an equation in a few steps

3-3 Group Properties

Now that we understand how to write an balance chemical reactions we will move on to the second major topic of this chapter, the periodic table.

About 50 years after Dalton had proposed the atomic theory that explained the differences between elements and compounds, chemists began to recognize that certain elements shared similar properties, like Li, Na, and K metals were all less dense than water, soft, and were highly reactive with water or O\textsubscript{2} or Cl\textsubscript{2}.

Common reactions

\[ 2\text{X}(s) + \text{Cl}_2(g) \rightarrow 2\text{XCl}(s) \]
\[ 4\text{X}(s) + \text{O}_2(g) \rightarrow 2\text{X}_2\text{O}(s) \]
\[ 2\text{X}(s) + 2\text{H}_2\text{O}(l) \rightarrow 2\text{XOH}(aq) + \text{H}_2(g) \]

Because of these common properties these metals, plus some others we will talk about in a minute, were placed into a group called the alkali metals.

Metals - because they were metals

Alkali - because the hydroxides of the metals made corrosive, basic solutions. (Alkali come from an arabic word meaning ash - Because the ash of certain plants is basic. That is how the pioneers made base to turn animal fat into soap, they mixed ash with water!)
Another group with similar properties are Magnesium, calcium, strontium and barium. These are called the **alkaline-earth metals** because they could be found in alkaline (basic) soil deposits.

Common reactions
\[
2X(s) + O_2(g) \rightarrow 2XO(s)
\]
\[
X(s) + 2H_2O(l) \rightarrow X(OH)_2(s) + H_2(g)
\]

Note: this reaction is slower than it was in the case of the alkali metals

Yet one more group of elements with similar properties are the nonmetal elements F₂, Cl₂, Br₂, and I₂.

As you can see their elemental form is diatomic. This diatomic form is a gas, and they are all very reactive, reacting with most metals and nonmetals.

This group is called the **halides** or **halogens**. Halogen is Greek word meaning salt former. (The product of the halide reacting with a metal is a salt!)

Reaction of alkali metal with a halide
\[
2X(s) + Y₂(g) \rightarrow 2XY(s)
\]

Reaction with an alkaline earth metal
\[
X(s) + Y₂(g) \rightarrow XY₂(s)
\]

Now let's imagine we are living about 1860 - 1870 and try to put our two key chemical concepts together.

1.) From Dalton we know that there are different elements that have different atomic masses
2.) Certain elements share the same common properties

### 3-4 Periodicity

So let's start arranging the element in order from smallest to largest

Li, Be, B, C, N, O, F, Ne, Na, Mg, Al, Si, P, S, Cl, Ar

But when we hit elements with common properties we fold our list back on top of itself so we can keep the elements with common properties together

Li, Be, B, C, N, O, F, Ne
Na, Mg, Al, Si, P, S, Cl, Ar

This was tried by two or three different chemists in the 1860's, but we now attribute the periodic table to the Russian Mendeleev because he was the one who used his table to predict the properties of elements that had not yet been discovered.

**Display Figure 3.10 periodic table,**

Here is the modern periodic table
then the periodic table we will use on a test.
Notice the Lanthanide series and the Actinide series that have been ‘popped’ out of the regular line up so we can get a more compact table

The horizontal rows are called periods
The elemental families with the same properties are in the vertical columns

Let’s examine those next

3-5 Groups of Elements
Look at the first column
Here are our original alkali metals, plus additional elements that weren’t known in the 1860’s
They are known as the alkali metals, or the Group 1 Metals
The next column over are the alkaline earth metals, or the Group 2 Metals
Groups 1-2 & 13-18 are known as the main group elements because the resemblance in the chemical properties is very strong.
The rightmost column (Group 18) contain the noble gases or inert gases which are very non-reactive
You should recognize our halogens in group 17

3-6 Classification of Elements
We have talked about metals and nonmetals. Where are they on the periodic table?

Figure 3.15
Metals on left (Blue-gray)
nonmetals on right (red) of zig-zag line
Green guys on either side
called metaloids or semimetals or semiconductors because properties are intermediate between metals and nonmetals

Have talked about main group elements (1&2, 13-18)
What about 3-12?
Properties are most metallic in lower left fo table
are most nonmetal in upper right
These are called Transition metals because they are metals, but located in
region where elements are making transition between metals and nonmetals

Properties
- High density
- High melting point
- Unlike Group 1 &2 compounds made with these metals are often colored

What about Lanthanide and actinide series?
These are called the **inner transition metals**
Lanthanide also called **rare-earth elements** because thought they were rare
Actinides are radioactive and don’t occur in nature but are produced in nuclear reactions

3-7 **Periodic Trends (And their exceptions)**
While the periodic table is a great general organizer, there are lots of exceptions to the periodic trends

For instance H is usually placed as a group 1 element
- but its elemental form is a diatomic gas, not a metal!
> Sometimes is placed in group 17
> sometimes just given its own special group

In general the top element in a group is a bit different than the main body of the group

I think I will leave it at that.

Summary clicker questions
- identify metal or nonmetal, main group for various atoms