Normality

Normality is another way of expressing the concentration of a solution. It is based on an alternate chemical unit of mass called the equivalent weight. The normality of a solution is the concentration expressed as the number of equivalent weights (equivalents) of solute per liter of solution. A 1 normal (1 N) solution contains 1 equivalent weight of solute per liter of solution. Normality is widely used in analytical chemistry because it simplifies many of the calculations involving solution concentration.

Every substance may be assigned an equivalent weight. The equivalent weight may be equal to the formula weight (molecular weight, mole weight) of the substance or equal to an integral fraction of the formula weight (i.e., molecular weight divided by 2, 3, 4, and so on). To gain an understanding of the meaning of equivalent weight, consider the following two reactions:

\[
\text{HCl}_{(aq)} + \text{NaOH}_{(aq)} \rightarrow \text{NaCl}_{(aq)} + \text{H}_2\text{O}
\]

1 mole of hydrochloric acid (HCl) reacts with 1 mole of sodium hydroxide (NaOH) and 1 mole of sulfuric acid (H\(_2\)SO\(_4\)) reacts with 2 moles of NaOH. If you made 1 molar solutions of these substances, 1 liter of 1 M HCl will react with 1 liter of 1 M NaOH and 1 liter of 1 M H\(_2\)SO\(_4\) will react with 2 liters of 1 M NaOH. Therefore, H\(_2\)SO\(_4\) has twice the chemical capacity of HCl when reacting with NaOH. One can, however, adjust these acid solutions to be equal in reactivity by dissolving only 0.5 moles of H\(_2\)SO\(_4\) per liter of solution. By doing this, one is required to use 49.0 grams of H\(_2\)SO\(_4\) per liter (instead of 98.1 grams per liter) to make a solution that is equivalent to one made from 36.5 grams of HCl per liter. These weights, 49.0 grams of H\(_2\)SO\(_4\) and 36.5 grams of HCl, are chemically equivalent and are known as equivalent weights of these substances because each will react with the same amount of NaOH (40.0 grams). The equivalent weight of HCl is equal to its molecular weight, but that of H\(_2\)SO\(_4\) is \(\frac{1}{2}\) its molecular weight. The table below summarizes these relationships:

<table>
<thead>
<tr>
<th></th>
<th>Formula weight</th>
<th>Concentration</th>
<th>Volumes that react</th>
<th>Equivalent weight</th>
<th>Concentration</th>
<th>Volumes that react</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCl</td>
<td>36.5</td>
<td>1 M</td>
<td>1 L</td>
<td>36.5</td>
<td>1 N</td>
<td>1 L</td>
</tr>
<tr>
<td>NaOH</td>
<td>40.0</td>
<td>1 M</td>
<td>1 L</td>
<td>40.0</td>
<td>1 N</td>
<td>1 L</td>
</tr>
<tr>
<td>H(_2)SO(_4)</td>
<td>98.1</td>
<td>1 M</td>
<td>1 L</td>
<td>49.0</td>
<td>1 N</td>
<td>1 L</td>
</tr>
<tr>
<td>NaOH</td>
<td>40.0</td>
<td>1 M</td>
<td>2 L</td>
<td>40.0</td>
<td>1 N</td>
<td>1 L</td>
</tr>
</tbody>
</table>
Normality

Expressions for normality are shown below. Notice the similarity to molar solution definition.

\[
\text{normality} = N = \frac{\text{number of equivalents of solute}}{1 \text{ liter of solution}} = \frac{\text{equivalents}}{\text{liter}}
\]

where

\[
\text{number of equivalents of solute} = \frac{\text{grams of solute}}{\text{equivalent weight of solute}}
\]

then

\[
N = \frac{\text{grams of solute}}{\text{eq wt solute} \times \text{L solution}} = \frac{\text{grams}}{\text{eq wt} \times \text{L}}
\]

So, 1 liter of solution containing 36.5 grams of HCl would be 1 N, and 1 liter of solution containing 49.0 grams of H\(_2\)SO\(_4\) would also be 1 N. A solution containing 98.1 grams of H\(_2\)SO\(_4\) (1 mole) per liter would be 2 N when reacting with NaOH in the above equation.

Consider the following reactions in which an excess of HCl is present. Hydrogen actually exits as H\(_2\) molecules, but for convenience in considering the data, the hydrogen produced is shown as the number of atomic weights of hydrogen released per atomic weight of metal reacting.

\[
\begin{align*}
\text{Na} & (s) + \text{HCl}_{(aq)} \rightarrow \text{NaCl}_{(aq)} + \text{H}^+_{(g)} \\
\text{Ca} & (s) + 2 \text{HCl}_{(aq)} \rightarrow \text{CaCl}_2_{(aq)} + 2 \text{H}^+_{(g)} \\
\text{Al} & (s) + 3 \text{HCl}_{(aq)} \rightarrow \text{AlCl}_3_{(aq)} + 3 \text{H}^+_{(g)}
\end{align*}
\]

The table below summarizes the pertinent data for these reactions:

<table>
<thead>
<tr>
<th>Metal</th>
<th>Atomic Weight (amu)</th>
<th>Number of Atomic Weights of Hydrogen Liberated per Atomic Weight of Metal</th>
<th>Equivalent Weight of Metal (amu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>23.0</td>
<td>1</td>
<td>23.0/1 = 23.0</td>
</tr>
<tr>
<td>Ca</td>
<td>40.1</td>
<td>2</td>
<td>40.1/2 = 20.0</td>
</tr>
<tr>
<td>Al</td>
<td>27.0</td>
<td>3</td>
<td>27.0/3 = 9.0</td>
</tr>
</tbody>
</table>

In each of the reactions, the equivalent weight of the reacting metals is the weight that reacts with 1 equivalent weight of the acid, liberates 1 atomic weight of H atoms, or involves the transfer of 1 mole of electrons in the reaction. One atomic weight of Na metal lost 1 electron per atom going to NaCl; 1 atomic weight of Ca metal lost 2 electrons in going to CaCl\(_2\); 1 atomic weight of Al metal lost 3 electrons in going to AlCl\(_3\). In each reaction, 1 atomic weight of H\(^+\) gained 1 electron per atom in going to free hydrogen.
Two definitions of equivalent weight can now be stated:

1. The equivalent weight is the weight of a substance that will react with, combine with, contain, replace, or in any other way be equivalent to 1 gram-atomic weight of hydrogen.

2. In oxidation-reduction reactions the gram-equivalent weight is the weight of a substance that loses or gains 1 mole of electrons.

The equivalent weight of a substance may be variable; its value is dependent on the reaction that the substance is undergoing. Consider the following reactions:

\[
\begin{align*}
\text{NaOH} + \text{H}_2\text{SO}_4 & \rightarrow \text{NaHSO}_4 + \text{H}_2\text{O} \\
2\ \text{NaOH} + \text{H}_2\text{SO}_4 & \rightarrow \text{Na}_2\text{SO}_4 + 2\ \text{H}_2\text{O}
\end{align*}
\]

In the first reaction, 1 mole of sulfuric acid furnishes 1 gram-atomic weight of hydrogen. Therefore the equivalent weight of sulfuric acid is the formula weight (98.1 grams). In the second reaction, the equivalent weight of sulfuric acid is \(\frac{1}{2}\) the formula weight (49.0 grams).