Polyprotic Acids And Bases

The name "polyprotic" literally means many protons. Therefore, in this section we will be observing some specific acids and bases which either lose or accept more than one proton. Then, we will be talking about the equations used in finding the degree of dissociation. Finally, with given examples, we will be able to approach problems dealing with polyprotic acids and bases.

Introduction

Polyprotic acids are specific acids that are capable of losing more than a single proton per molecule in acid-base reactions. (In other words, acids that have more than one ionizable H⁺ atom per molecule). Protons are lost through several stages (one at each stage), with the first proton being the fastest and most easily lost. Contrast with monoprotic acids in section Monoprotic Versus Polyprotic Acids And Bases.

<table>
<thead>
<tr>
<th>Common Polyprotic Acids:</th>
<th>Formula:</th>
<th>Strong/Weak Acid:</th>
<th>Number of Ionizable Hydrogens:</th>
<th>$K_a1$:</th>
<th>$K_a2$:</th>
<th>$K_a3$:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfuric acid</td>
<td>H₂SO₄</td>
<td>Strong</td>
<td>2 (diprotic)</td>
<td>Very Large</td>
<td>1.1E-2</td>
<td></td>
</tr>
<tr>
<td>Sulfurous acid</td>
<td>H₂SO₃</td>
<td>Weak</td>
<td>2 (diprotic)</td>
<td>1.3E-2</td>
<td>6.2E-8</td>
<td></td>
</tr>
<tr>
<td>Phosphoric acid</td>
<td>H₃PO₄</td>
<td>Weak</td>
<td>3 (triprotic)</td>
<td>7.1E-3</td>
<td>6.3E-8</td>
<td>4.2E-13</td>
</tr>
<tr>
<td>Carbonic acid</td>
<td>H₂CO₃</td>
<td>Weak</td>
<td>2 (diprotic)</td>
<td>4.4E-7</td>
<td>4.7E-11</td>
<td></td>
</tr>
<tr>
<td>Hydrosulfuric acid or Hydrogen sulfide</td>
<td>H₂S</td>
<td>Weak</td>
<td>2 (diprotic)</td>
<td>1.0E-7</td>
<td>1E-19</td>
<td></td>
</tr>
<tr>
<td>Oxalic acid</td>
<td>H₂C₂O₄</td>
<td>Weak</td>
<td>2 (diprotic)</td>
<td>5.4E-2</td>
<td>5.3E-5</td>
<td></td>
</tr>
</tbody>
</table>
Malonic acid | \( \text{H}_2\text{C}_3\text{H}_2\text{O}_4 \) | Medium Strong | 2 (diprotic) | 1.5E-3 | 2.0E-6  

From the table above, we see that Sulfuric acid is the strongest. Since it is the strongest acid, it dissociates the fastest and easiest.

**Side Note:** On the pH scale, there are numbers ranging from 0-14. The closer the pH number is to 0, the more acidic that substance is. The closer the pH number is to 14, the more basic that substance is. Finding the pH can be used to see whether an acid will release an \( \text{H}^+ \) ion. The equation for \( \text{pH} = -\log\{\text{H}_3\text{O}^+\} \)

For more on pH, check out the section on How To Predict The Relative Strength Of Acids

**Ionization Constant**

It is important to know that \( K_1 > K_2 > K_3 \), where \( K \) stands for the acidity constant or **acid ionization constant** (first, second, and third, respectively). These constants are used to measure the degree of dissociation of hydrogens in the acid. For a more in depth discussion on this, go to Ionization Constants

**Example 1**

To find \( K_{a1} \) of Hydrosulfuric acid (\( \text{H}_2\text{S} \)), you must first write the reaction:

\[
\text{H}_2\text{S} \rightarrow \text{H}^+ + \text{HS}^-
\]

Dividing the products by the reactants, we then have:

\[
K_{a1} = [\text{H}^+] [\text{HS}^-] / [\text{HS}^-]
\]

To find \( K_{a2} \), we start with the reaction:

\[
\text{HS}^- \rightarrow \text{H}^+ + \text{S}_2^-
\]

Then, like when finding \( K_{a1} \), write the products over the reactants:

\[
K_{a2} = [\text{H}^+] [\text{S}_2^-] / [\text{HS}^-]
\]

From these reactions we can observe that it takes two steps to fully remove the \( \text{H}^+ \) ion. This also means that this reaction will produce two **equivalence points** or **stoichiometric points**. The equivalence point, by definition, is the point during an
acid-base titration in which there has been equal amounts of acid and base reacted. If we were to graph this, we would be able to see exactly just what two equivalence points looks like. Let's check it out:

NatalieTitration1.bmp

Note the multiple equivalence points and notice that they are almost straight lines at that point, indicating equal added quantities of acid and base.

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**Titrations**

- In strong acid + strong base titrations, the pH changes slowly at first, rapidly through the equivalence point of pH=7, and then slows down again. If it is being titrated in a strong acid, the pH will go up as the base is added to it. Conversely, if it is in a strong base, the pH will fall down as acid is added.

- In strong acid + weak base titrations, the pH changes slowly at the equivalence point and the pH equals the pKₐ of the acid. The pH is below 7.

- For the weak acid + strong base, the pH is above 7 at the equivalence point.

- If there is strong acid or strong base left over after the equivalence point, this can be used to find the pH of the solution.

Next, let's take a look at sulfuric acid. This unique polyprotic acid is the only one to be completely deprotonated after the first step:

\[ \text{H}_2\text{SO}_4(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{HSO}_4^-(aq) \]

Now let's try something a little harder. The ionization of phosphoric acid (three dissociation reactions this time) can be written like this:

Start with \( \text{H}_3\text{PO}_4 \):
\[ K_{a1} = \text{H}_3\text{PO}_4(aq) \leftrightarrow \text{H}^+(aq) + \text{H}_2\text{PO}_4^-(aq) \]

\[ K_{a2} = \text{H}_2\text{PO}_4^-(aq) \leftrightarrow \text{HPO}_4^2-(aq) + \text{H}^+(aq) \]

\[ K_{a3} = \text{HPO}_4^2-(aq) \leftrightarrow \text{H}^+(aq) + \text{PO}_4^{3-}(aq) \]

So from these above reactions we can see that it takes three steps to fully remove the H\(^+\) ion. This also means that this reaction will produce three equivalence points.

**Polyprotic Bases** are bases that can accept at least one H\(^+\) ion, or proton, in acid-base reactions.

<table>
<thead>
<tr>
<th>Common Polyprotic Bases:</th>
<th>Formula</th>
<th>Strong/Weak Base</th>
<th>Diprotic/Triprotic Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphate ion</td>
<td>PO(_4^{3-})</td>
<td>Weak</td>
<td>Triprotic</td>
</tr>
<tr>
<td>Sulfate ion</td>
<td>SO(_4^{2-})</td>
<td>Very Weak</td>
<td>Diprotic</td>
</tr>
<tr>
<td>Carbonate ion</td>
<td>CO(_3^{2-})</td>
<td>Strong</td>
<td>Diprotic</td>
</tr>
</tbody>
</table>

**Example 1: Some examples for calculating the constant, \(K_b\)**

First, start with the reaction \(\text{A}^{3-} + \text{H}_2\text{O} \leftrightarrow \text{HA}^{2-} + \text{OH}^-\)

\[ K_{b1} = [\text{OH}^-][\text{HA}^{2-}]/[\text{A}^{3-}] = \frac{K_W}{K_{a3}} \]

Then, we plug in the products over the reactants:

\[ \text{HA}^{2-} + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{A}^- + \text{OH}^- \]

\[ K_{b2} = [\text{OH}^-][\text{H}_2\text{A}^-]/[\text{HA}^{2-}] = \frac{K_W}{K_{a2}} \]

Finally, we are left with the third dissociation, or \(K_{b3}\):

\[ \text{H}_2\text{A}^- + \text{H}_2\text{O} \leftrightarrow \text{H}_3\text{A} + \text{OH}^- \]

\[ K_{b3} = [\text{OH}^-][\text{H}_3\text{A}]/[\text{H}_2\text{A}^-] = \frac{K_W}{K_{a1}} \]
References


Outside Links

- http://www.science.uwaterloo.ca/~cchieh/cact/c123/polyprot.html

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