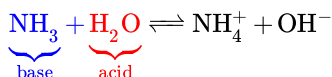


12.3.1: Water - Acid and Base in One

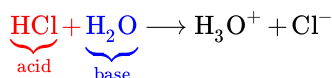
Learning Objectives

- Describe the autoionization of water.
- Calculate the concentrations of H_3O^+ and OH^- in aqueous solutions, knowing the other concentration.

We have already seen that H_2O can act as an acid or a base:



where H_2O acts as an **acid** (in red).



where H_2O acts as an **base** (in blue).

It may not surprise you to learn, then, that within any given sample of water, some H_2O molecules are acting as acids, and other H_2O molecules are acting as bases. The chemical equation is as follows:



This occurs only to a very small degree: only about 6 in 10^8 H_2O molecules are participating in this process, which is called the **autoionization of water**.

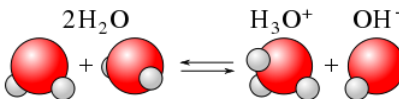


Figure 12.3.1.1: Autoionization of water, resulting in hydroxide and hydronium ions.

At this level, the concentration of both $\text{H}_3\text{O}^+(\text{aq})$ and $\text{OH}^-(\text{aq})$ in a sample of pure H_2O is about $1.0 \times 10^{-7} \text{ M}$ (at room temperature). If we use square brackets—[]—around a dissolved species to imply the molar concentration of that species, we have

$$[\text{H}_3\text{O}^+] = [\text{OH}^-] = 1.0 \times 10^{-7} \quad (12.3.1.2)$$

for *any* sample of pure water because H_2O can act as both an acid and a base. The product of these two concentrations is 1.0×10^{-14} :

$$[\text{H}_3\text{O}^+] \times [\text{OH}^-] = (1.0 \times 10^{-7})(1.0 \times 10^{-7}) = 1.0 \times 10^{-14}$$

- For acids, the concentration of $\text{H}_3\text{O}^+(\text{aq})$ (i.e., $[\text{H}_3\text{O}^+]$) is greater than $1.0 \times 10^{-7} \text{ M}$.
- For bases the concentration of $\text{OH}^-(\text{aq})$ (i.e., $[\text{OH}^-]$) is greater than $1.0 \times 10^{-7} \text{ M}$.

However, the *product* of the two concentrations— $[\text{H}_3\text{O}^+][\text{OH}^-]$ —is *always* equal to 1.0×10^{-14} , no matter whether the aqueous solution is an acid, a base, or neutral:

$$[\text{H}_3\text{O}^+][\text{OH}^-] = 1.0 \times 10^{-14}$$

This value of the product of concentrations is so important for aqueous solutions that it is called the **autoionization constant of water** and is denoted K_w :

$$K_w = [\text{H}_3\text{O}^+][\text{OH}^-] = 1.0 \times 10^{-14} \quad (12.3.1.3)$$

This means that if you know $[\text{H}_3\text{O}^+]$ for a solution, you can calculate what $[\text{OH}^-]$ has to be for the product to equal 1.0×10^{-14} ; or if you know $[\text{OH}^-]$, you can calculate $[\text{H}_3\text{O}^+]$. This also implies that as one concentration goes up, the other must go down to compensate so that their product always equals the value of K_w .

Warning: Temperature Matters

The degree of autoionization of water (Equation 12.3.1.1)—and hence the value of K_w —changes with temperature, so Equations 12.3.1.2- 12.3.1.3 are accurate only at room temperature.

✓ Example 12.3.1.1: Hydroxide Concentration

What is $[\text{OH}^-]$ of an aqueous solution if $[\text{H}_3\text{O}^+]$ is $1.0 \times 10^{-4} \text{ M}$?

Solution

Solutions to Example 14.7.1

Steps for Problem Solving	
Identify the "given" information and what the problem is asking you to "find."	Given: $[\text{H}_3\text{O}^+] = 1.0 \times 10^{-4} \text{ M}$ Find: $[\text{OH}^-] = ? \text{ M}$
List other known quantities.	none
Plan the problem.	Using the expression for K_w , (Equation 12.3.1.3), rearrange the equation algebraically to solve for $[\text{OH}^-]$. $[\text{OH}^-] = \frac{1.0 \times 10^{-14}}{[\text{H}_3\text{O}^+]}$
Calculate.	Now substitute the known quantities into the equation and solve. $[\text{OH}^-] = \frac{1.0 \times 10^{-14}}{1.0 \times 10^{-4}} = 1.0 \times 10^{-10} \text{ M}$ It is assumed that the concentration unit is molarity, so $[\text{OH}^-]$ is $1.0 \times 10^{-10} \text{ M}$.
Think about your result.	The concentration of the acid is high ($> 1 \times 10^{-7} \text{ M}$), so $[\text{OH}^-]$ should be low.

? Exercise 12.3.1.1

What is $[\text{OH}^-]$ in a 0.00032 M solution of H_2SO_4 ?

Hint

Assume **both** protons ionize from the molecule...although this is not the case.

Answer

$3.1 \times 10^{-11} \text{ M}$

When you have a solution of a particular acid or base, you need to look at the formula of the acid or base to determine the number of H_3O^+ or OH^- ions in the formula unit because $[\text{H}_3\text{O}^+]$ or $[\text{OH}^-]$ may not be the same as the concentration of the acid or base itself.

✓ Example 12.3.1.2: Hydronium Concentration

What is $[\text{H}_3\text{O}^+]$ in a 0.0044 M solution of $\text{Ca}(\text{OH})_2$?

Solution

Solutions to Example 14.7.2

Steps for Problem Solving	
Identify the "given" information and what the problem is asking you to "find."	Given: $[\text{Ca}(\text{OH})_2] = 0.0044 \text{ M}$ Find: $[\text{H}_3\text{O}^+] = ? \text{ M}$

Steps for Problem Solving	
List other known quantities.	<p>We begin by determining $[\text{OH}^-]$. The concentration of the solute is 0.0044 M, but because $\text{Ca}(\text{OH})_2$ is a strong base, there are two OH^- ions in solution for every formula unit dissolved, so the actual $[\text{OH}^-]$ is two times this:</p> $[\text{OH}^-] = 2 \times 0.0044 \text{ M} = 0.0088 \text{ M}$
Plan the problem.	<p>Use the expression for K_w (Equation 12.3.1.3) and rearrange the equation algebraically to solve for $[\text{H}_3\text{O}^+]$.</p> $[\text{H}_3\text{O}^+] = \frac{1.0 \times 10^{-14}}{[\text{OH}^-]}$
Calculate.	<p>Now substitute the known quantities into the equation and solve.</p> $[\text{H}_3\text{O}^+] = \frac{1.0 \times 10^{-14}}{(0.0088)} = 1.1 \times 10^{-12} \text{ M}$ <p>$[\text{H}_3\text{O}^+]$ has decreased significantly in this basic solution.</p>
Think about your result.	<p>The concentration of the base is high ($> 1 \times 10^{-7} \text{ M}$) so $[\text{H}_3\text{O}^+]$ should be low.</p>

? Exercise 12.3.1.2

What is $[\text{H}_3\text{O}^+]$ of an aqueous solution if $[\text{OH}^-]$ is $1.0 \times 10^{-9} \text{ M}$?

Answer

$$1.0 \times 10^{-5} \text{ M}$$

In any aqueous solution, the product of $[\text{H}_3\text{O}^+]$ and $[\text{OH}^-]$ equals 1.0×10^{-14} (at room temperature).

Contributions & Attributions

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