# CHEMISTRY CK-12 Tracy Paulsen 8.2: pH

## Introduction

It is frequently useful to compare how acidic or basic a solution is in comparison to other solutions. A couple of ways to do this is to compare [H+] to [OH-] or to find the pH of a solution.

## Relationship between [H+] and [OH-]

We have learned that acids and bases are related to hydrogen ions [H+] and hydroxide ions [OH-]. Both of these ions are present in both acids and bases. However, they are also present in pure water. Water self-ionizes according to the following reaction:

*H2O(l)*  *H+(aq) + OH-(aq)*

The equilibrium expression for this reaction would be:

*Kw = [H+][OH-]*

The equilibrium constant for this particular equilibrium is Kw, meaning the equilibrium constant for water. From experimentation, chemists have determined that in pure water, [H+]=1x10-7 M and [OH-]=1x10-7 M. If you substitute these values into the equilibrium expression, you find that Kw=1x10-14. **This is a very important point** - any solution which contains water, even if other things are added, will shift to establish this equilibrium. Therefore, for any solution, the following relationship will always be true:

Kw = 1x10-14 = [H+] x [OH-] (@ 25°C )

We can describe whether a solution is acidic, basic, or neutral according to the concentrations in this equilibrium.

* If [H+] = [OH-], **the solution is neutral** (such as in pure water)
* If [H+] > [OH-], **the solution is acidic.** This means that [H+] > 1x10-7 M (and the [OH-] < 1x10-7 M).
* If [H+] < [OH-], **the solution is basic.** This means that [OH-] > 1x10-7 M (and the [H+] < 1x10-7 M).

We can use this equation to calculate the concentrations of H+ and OH-. Consider the following example.

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| **Example:** Suppose acid is added to some water, and [H+] is measured to be 1x10-4 M. What would [OH-] be? |
| **Solution:** substitute what we know into the equilibrium expression:  Kw = 1x10-14 = [H+] [OH-]  1x10-14=[1x10-4][OH-]  **[OH-]=1x10-10 M**  Note that because [H+] > [OH-], the solution must be acidic. |

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| **Example:** If the final hydrogen ion concentration is 1x10-12 M, we can calculate the final hydroxide ion concentration. |
| **Solution:**  Kw = 1x10-14 = [H+] [OH-]  1x10-14 = [1x10-12] [OH-]  **[OH-] = 1x10-2 M**  Note that because [H+] < [OH-], the solution must be basic. |

Using the Kw expression, anytime we know either the [H+] or the [OH-]in a water solution, we can always calculate the other one.

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| **Example:** What would be the [H+] for a grapefruit found to have a [OH-] of 1.26x10-11? What is [H+] and is the solution acidic, basic, or neutral? |
| **Solution:**  Kw = 1x10-14 = [H+] [OH-]  1x10-14 = [H+] [1.26x10-11]  **[H+] = 7.94x10-4 M**  Also, the solution must be acidic because [H+] > [OH-] |

**pH Scale**

A few very concentrated acid and base solutions are used in industrial chemistry and inorganic laboratory situations. For the most part, however, acid and base solutions that occur in nature, those used in cleaning, and those used in organic or biochemistry applications are relatively dilute. Most of the acids and bases dealt with in laboratory situations have hydrogen ion concentrations between 1.0 M and 1.0x10-14 M. Expressing hydrogen ion concentrations in exponential numbers becomes tedious and is difficult for those not trained in chemistry. A Danish chemist named Søren Sørensen developed a shorter method for expressing acid strength or hydrogen ion concentration with a non-exponential number. He named his method **pH**. The p from pH comes from the German word *potenz* meaning “power or the exponent of”. Sørensen’s idea that the pH would be a simpler number to deal with in terms of discussing acidity level led him to a formula that relates pH and [H+]:

***pH = - log [H+]***

If the hydrogen ion concentration is between 1.0 M and 1.0x10-14, the value of the pH will be between 0 and 14.

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| **Example:** Calculate the pH of a solution given that [H+]=0.01 M. |
| **Solution:**  pH = - log (0.01)  **pH = 2** |

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| **Example:** Calculate the pH of saliva with [H+]=1.58x10-6 M. |
| **Solution:** pH = - log (1.58x10-6)  **pH = 5.8** |

If you are given [OH-] it is still possible to find the pH, but it requires one more step. You must first find [H+] and then use the pH equation.

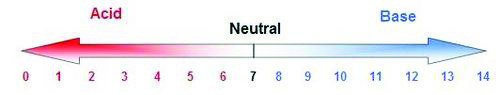
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| **Example:** Calculate the pH of a solution with [OH-]=7.2x10-4 M. |

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| **Solution:** In order to find pH, we need [H+].  Kw = 1x10-14 = [H+] [OH-]  1x10-14 = [H+] [7.2x10-4]  [H+] = 1.39x10-11 M  We can now find the pH  pH = - log (1.39x10-11)  **pH = 10.9** |

The pH scale developed by Sørensen is a logarithmic scale, which means that a difference of 1in pH units indicates a difference of a factor of 10 in the hydrogen ion concentrations. A difference of 2 in pH units indicates a difference of a factor of 100 in the hydrogen ion concentrations. Not only is the pH scale a logarithmic scale but by defining the pH as the *negative* log of the hydrogen ion concentration, the numbers on the scale get smaller as the hydrogen ion concentration gets larger. For example, pH=1 is a stronger acid than pH=2 and, it is stronger by a factor of 10 (the difference between the pH’s is 1).

The closer the pH is to 0 the greater the concentration of [H+] ions and therefore the more acidic the solution. The closer the pH is to 14, the higher the concentration of OH- ions and the stronger the base.

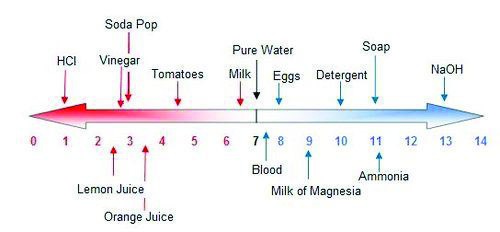
*The pH Scale.*



Have you ever cut an onion and had your eyes water up? This because of a compound with the formula C3H6OS that is found in onions. When you cut the onion, a variety of reactions occur that release a gas. This gas can diffuse into the air and mix with the water found in your eyes to produce a dilute solution of sulfuric acid. This is what irritates your eyes and causes them to water. There are many common examples of acids and bases in our everyday lives. Look at the pH scale to see how these common examples relate in terms of their pH.

*pH Scale for Common Substances*

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| **Example:** Compare lemon juice (pH=2.5) to milk (pH=6.5). Answer each of the following: a) Label each as acidic, basic, or neutral   1. Which has a higher concentration of H+ ions? 2. How many times more H+ does that solution have? |
| **Solution:**   1. Both lemon juice and milk are acidic, because their pH’s are less than 7. (\*Note: milk is only very slightly acidic as its pH is very close to 7) 2. The lower the pH, the higher the concentration of H+ ions. Therefore, lemon juice has more H+. 3. Each step down on the pH scale increases the H+ concentration by 10 times. It is 4 steps down on the pH scale to go from 6.5 to 2.5. Therefore, lemon juice has 10x10x10x10 or 10,000 times more H+ ions than milk. |

## 8.2: Review Questions

1) In saturated limewater, [H+]=3.98x10-13 M.

a) Find [OH]- b) What is the pH? c) Is the solution acidic, basic, or neutral?

2) In butter, [H+]=6.0x10-7 M.

a) Find [OH]- b) What is the pH? c) Is the solution acidic, basic, or neutral?

1. In peaches, [OH-]=3.16x10-11 M

a) Find [OH]- b) What is the pH? c) Is the solution acidic, basic, or neutral?

1. During the course of the day, human saliva varies between acidic and basic. If [OH-]=3.16x10-8 M,

a) Find [OH]- b) What is the pH? c) Is the solution acidic, basic, or neutral?

1. A solution contains 4.33x10-8M hydroxide ions. What is the pH of the solution?
2. A solution contains a hydrogen ion concentration of 6.43x10-9 M. What is the pH of the solution?
3. If the pH of one solution is 5 less than another solution, how does the amount of H+ in each solution compare? Which has more H+? How many times more?