Introduction to Acids and Bases

If you're anything like me, you enjoy spicy ramen. If not, maybe you have a penchant for chocolate... or if you're reading this during the holidays, you're craving peppermint. These seemingly random foods have something in common: they're known to cause heartburn.

If you've ever had heartburn, you know that the name is accurate. It feels like your chest is literally burning. But why is this the case? Heartburn is really just a result of your stomach acid having too much hydrochloric acid, which causes it to back up into your esophagus. This causes the "burn in your chest" that we described earlier.

So, naturally, to relieve your spicy ramen-induced heartburn, you reach for an antacid and take one. This antacid is actually a base, and after about 20 minutes, your heartburn ends because the antacid has neutralized all of the backed-up hydrochloric acid. This demonstrates today's lesson: acids and bases.

Overview

- In this lesson, we'll cover the introduction of what an **acid** and a **base** are, and how it relates to **pH.**
- After, we'll list some acids and bases you might be familiar with and distinguish between **strong** and **weak** acids and bases.
- Then, we'll learn different rules on how acids and bases **react with each other.**
- Finally, we'll briefly talk about different experiments that can be done with acids and bases, such as **litmus tests** and **titrations**.

Acids, Bases, and the pH Scale

The concept of acids and bases has been around for centuries, and scientists of their time typically characterized the two based on physical properties. For example, we know that acids taste sour (think lemon juice) and that bases taste bitter. We also know that bases feel somewhat soapy, while acids do not. While these characterizations are interesting, we aren't particularly interested in physical properties. We want to determine a chemistry-based definition for acids and bases. To do that, we first have to understand the concept of the pH scale.

Imagine a scale like the one below. On the left, we have the quality of "acidic," and on the right, we have "basic." We'll get into what these traits mean in a bit, but for now, imagine that every molecule falls somewhere on this scale. We'll label the scale from 0 to 14, where 0 is extremely acidic, 14 is extremely basic, and 7 is in the middle, representing a neutral molecule.

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Drawn scale of the acid-base characteristic.

This hypothetical scale that we've described is the pH scale: a tool that chemists use to measure the tendency of molecules to be acidic or basic. So, for example, if we know that water has a pH of 7, we know it's neutral. If I were to tell you that black coffee had a pH of 5, it would mean it's a weak acid. Baking soda, with a pH of 9, would be considered a weak base.

Now that we have a rudimentary understanding of how acids and bases are organized, what *are* acids and bases, chemically?

> Definition
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> **Acids** are molecules with hydrogen atoms (also known as a proton) that tend to be donated.

Looking back at our ramen example at the beginning of the lesson, hydrochloric acid (with a formula HCl) is an acid because it has a hydrogen atom H^+ that it is willing to give to a base.

$$HCl \rightarrow H^+ + Cl^-$$

Now, let's consider our antacid. We know that antacids are basic, meaning somehow, a molecule has to neutralize the hydrochloric acid that was just ionized. As it turns out, bases do this by acting as a complementary molecule to acids.

> Definition
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> Converse to acids, **bases** are molecules that tend to accept hydrogen atoms (also known as a proton).

Antacids typically are made up of magnesium hydroxide (with a formula $Mg(OH)_2$. After magnesium and hydroxide dissociate, hydroxide is prime for accepting the free proton from HCl.

$$Mg(OH)_2 \rightarrow Mg^{2+} + 2OH^-$$

After both HCl and $Mg(OH)_2$ have dissociated, the hydrogen from HCl reacts with the free hydroxide from the $Mg(OH)_2$, leading to a reaction that neutralizes the acid and makes your stomach feel better. The overall balanced reaction looks like this:

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$$2HCl + Mg(OH)_2 \rightarrow MgCl_2 + 2H_2O$$

As you can see, a clear transfer of a proton occurs from the acid, HCl, to the base, $Mg(OH)_2$. What role these molecules play in the transfer of a proton defines whether they are an acid or a base.

Hydrogen atoms are called protons in acid-base reactions because they only consist of one proton once ionized. Be sure you understand this concept, as hydrogen atoms will be called protons from here on out.

Acid and base reactions, however, typically play out similarly despite what molecules are involved. This is where the concept of acid and base strength comes into play.

Acid and Base Strength

Before, we talked about the concept of how acids and bases are defined based on whether they accept or donate a proton. But what do strong or weak acids and bases mean?

> Definition
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> **Acid and Base Strength** is based on how readily acids and bases perform their respective roles.

This means that a strong acid would more readily give up a proton than a weak acid, and a strong base more readily accepts a proton than a weak base. If you recall the pH scale, this means that a strong acid is closer to 0, and a strong base is closer to 14.

Now let's shift our thinking for a moment. Think about what would happen once a strong acid performs its role and donates a proton. Remember that a strong acid really wants to get rid of its proton. It most certainly wouldn't want it back!

So what happens to the strong acid *after* it's given up its proton? Because it doesn't want to accept the proton back, it becomes a weak base. This is a trend that is seen in all strong acids and bases: they form a weak variant of the opposite once they have reacted in an acid-base reaction. We call these variants conjugates.

> Definition
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> Strong acids form weak **conjugate bases** because they don't want to accept back the proton they so readily gave up. Strong bases form weak **conjugate acids** because they don't want to give up the proton they so readily accepted. The opposite is true as well: weak acids/bases form strong conjugate bases/acids respectively.

To make sure you understand this concept, let's show an example of this formation of conjugates.

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$$HCl + H_2O \rightarrow Cl^- + H_3O^+$$

Strong Acid + Weak Base → Weak Conjugate Base + Strong Conjugate Acid

In this example, all acids are in red and all bases are in blue. Strong Acid HCl forms the Weak Conjugate Base Cl^-. Weak Base H_2O forms the Strong Conjugate Acid H_3O^+. We call these reactant-conjugate acid and base groups **conjugate pairs**. To reiterate this, the two conjugate pairs are displayed below.

$$HCl + H_2O \rightarrow Cl^- + H_3O^+$$

The reaction has these two conjugate pairs because two distinct conjugate transformations are occurring: 1. a Strong Acid is turning into a Weak Conjugate Base *(in green)*, and 2. a Weak Base is turning into a Strong Conjugate Acid *(in dark blue)*.

For AP Chemistry, you should familiarize yourself with the following Strong Acids and Bases.

Name (s)	Formula (s)	Strong Acid or Base?
Hydrochloric acid	HCl	Strong Acid
Hydrobromic acid	HBr	Strong Acid
Hydroiodic acid	HI	Strong Acid
Chloric acid	$HClO_3$	Strong Acid
Perchloric acid	$HClO_4$	Strong Acid
Nitric acid	HNO_3	Strong Acid
Sulfuric acid	H_2SO_4	Strong Acid
Group 1 Metal Hydroxides	LiOH, NaOH, KOH, RbOH, CsOH	Strong Bases
Group 2 Metal Hydroxides	$Ca(OH)_2$, $Sr(OH)_2$, $Ba(OH)_2$	Strong Bases

Now that we understand the concept of strong and weak acids and bases and conjugate pairs, let's try to generalize what happens during different acid-base reactions.

Acid-Base Reactions and Neutralization

Insofar, we've established what acids and bases are, and how every molecule falls on the pH scale (the "acid-base" character scale) that determines what role it will play: a proton donor or acceptor. We've learned also that strength dictates how readily these molecules perform their roles. Let's try to apply these principles to make some generalizations about reactions.

What happens when we react a strong acid and a weak base?

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If we react a strong acid and a weak base, we yield a weakly acidic solution. This is because the strong acid forms a weak conjugate base, and the weak base forms a strong conjugate acid. An example of this is shown below.

$$HBr + NH_3 \rightarrow Br^- + NH_4^+$$

$$\text{Strong Acid} + \text{Weak Base} \rightarrow \text{Weak Conjugate Base} + \text{Stronger Conjugate Acid}$$

In this example, HBr and Br^-, as well as NH3 and NH_4^+ are conjugate pairs.

What happens when we react a weak acid and a strong base?

If we react a weak acid and a strong base, we yield a weakly basic solution. This is because the weak acid forms a strong conjugate base, and the strong base forms a weak conjugate acid. An example of this is shown below.

$$HNO_2 + NaOH \rightarrow NaNO_2 + H_2O$$

$$\text{Weak Acid} + \text{Strong Base} \rightarrow \text{Stronger Conjugate Base} + \text{Weak Conjugate Acid}$$

In this example, HNO_2 and $NaNO_2$, as well as NaOH and H_2O are conjugate pairs.

What happens when we react a weak acid and a weak base?

This is certainly the most tricky scenario. If we react a weak acid and a weak base, both will form a conjugate base and acid, respectively, that are stronger. However, rather than having a regular reaction, this reaction would end up in a state of equilibrium, where a certain percentage of weak base/weak acid and stronger conjugate acid/stronger conjugate base would be maintained. To try and demonstrate this, an example is shown below.

$$HNO_2 + NH_4OH \rightleftharpoons H_2O + NH_4NO_2$$

$$\text{Weak Acid} + \text{Weak Base} \rightarrow \text{Stronger Conjugate Base} + \text{Stronger Conjugate Acid}$$

In this example, HNO_2 and H_2O, as well as NH_4OH and NH_4NO_2 are conjugate pairs. **Weak acid-base reactions, although in equilibrium, will favor the side with weaker acids and bases more**. Therefore, in this equilibrium, there would be more of the weak acid and base than the stronger conjugate base and acid.

What happens when we react a strong acid and a strong base?

Lastly, if we react a strong acid and a strong base, we get two products: water and a neutral salt. This means that our overall product will be neutral as opposed to being acidic or basic. An example of this is demonstrated below.

$$HCl + NaOH \rightarrow H_2O + NaCl$$

$$\text{Strong Acid} + \text{Strong Base} \rightarrow \text{Water} + \text{Neutral Salt}$$

Recall that water is neutral. This means that combining a strong acid and strong base neutralizes the acidity and basicity of both substances and leaves us with a neutral mixture. This is called a **neutralization reaction**.

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Now that we understand this concept, how would chemists experiment with acids and bases in practice?

Experiments with Acids and Bases

There are two basic acid-base experiments that you should familiarize yourself with: the litmus test and titrations. You've probably heard of a litmus test before. The term "litmus test" was popularized in modern-day culture as a term that could help to deduce something quickly. In chemistry, however, it is used to determine pH, which will, in turn, determine if a sample is acidic, neutral, or basic.

> Definition
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> **Litmus Tests** measure a sample's acidity or basicity by using litmus, a mix of dyes that turns blue when exposed to a base and red when exposed to an acid.

Naturally, the more red the litmus paper is, the more acidic, and the bluer, the more basic. If the litmus paper turns up somewhere in between the two, so is the sample's pH. But what if we wanted to figure out the exact concentration of an acid or base? This is where acid-base titration comes into play.

> Definition
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> **Acid-Base Titration** involves using an acid or base with a known concentration to neutralize an unknown concentration base or acid. If done exactly, the concentration can be determined.

This means that if we wanted to figure out an acid's concentration, we would use a base with a known concentration, and slowly add some until the mixture is neutralized. If we know the exact amount of base that we added, as well as its concentration, we can deduce the acid's concentration. Some calculations are tested on the AP Chemistry course, but we will have a separate lesson on titration and its calculations releasing soon.

We hope this introduction helps you to grasp the basics behind acids and bases! Acids and bases are classically known as one of the more difficult topics in AP Chemistry, so be sure to review places of confusion. If you understand the concepts discussed in this lesson, you'll have an incredibly strong foundation that will help you during the AP test and in higher-level chemistry courses.

Introduction to Acids and Bases - Key takeaways

- In this lesson, we covered the introduction of what an acid and a base are, and how it relates to pH.
- After, we provided examples of acids and bases and described whether they were strong or weak.

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- Then, we learned different rules on how acids and bases react together.
- Finally, we briefly discussed different experiments that can be done with acids and bases, such as litmus tests and titrations.