Chapter 8:

Solutions, Acids, and Bases

Bases are solutions with a pH greater than 7. Les Claypool, however, brings the bass no matter what the pH.

8.1: Introduction to Solutions

I could give you a great big explanation about the importance of solutions and whatnot, but I think I'll skip past all that nonsense and get right to business: **Solutions** are mixtures in which something dissolves something else.

- In a solution, the **solvent** is the thing that does the dissolving. In **aqueous solutions**, the solvent is water.
- The **solute** is the thing that gets dissolved. Solutes can consist of anything, as long as it's possible to dissolve them.

Example: In the case of salt water, the solvent is water and the solute is salt.

Fancy Solutions

*Some solutions are a little less obvious than the sort mentioned above. Metallic alloys are solid solutions in which a metal has dissolved something else. Air is a solution because it is completely homogeneous mixture of gases. Rubbing alcohol and water form a solution in which the two liquids are said to be **miscible** (i.e. they dissolve in one another). For some reason, nobody ever talks about these in middle school science texts, which is kind of a bummer.*

The air being crammed into this hot air balloon is a solution containing a bunch of different gases.

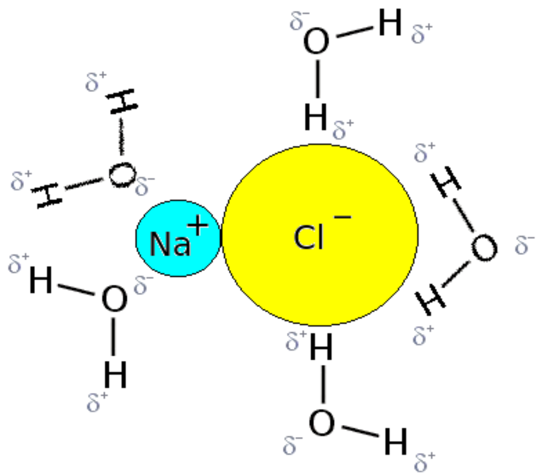
How To Make Solutions

There are lots and lots of different solutions out there in the world, and two main ways in which these solutions are made:

- **Mixing**: When gases form a solution or when liquids form solutions with each other, the main mechanism by which they're formed is plain ol' mechanical mixing. For example, air doesn't really have a lot of solvent/solute stuff going on. Instead, it's just a bunch of gas molecules zipping around and ignoring each other.[1]

1 *See Chapter 3 for information about how the molecules in a gas behave, if you haven't already.*

- **Dissolving**: When things dissolve, solvent particles are attracted to the particles in the solute and yank them apart.[2] When water molecules dissolve sodium chloride, NaCl, the partial positive charges on the hydrogen atoms and partial negative charges on oxygen are attracted to the Na^{+} and Cl^{-} ions, pulling them apart:[3]



The δ terms represent the partial positive and negative charges in the hydrogen and oxygen atoms in water. As you can see, partially-positive hydrogen atoms are attracted to negatively-charged chloride ions and partially-negative oxygen atoms are attracted to partially-positive sodium ions.

In a general sense, we can sum up the ability of a solvent to dissolve a solute using the phrase **like dissolves like**, which means that polar solvents will be good at dissolving polar solutes and nonpolar solvents will be good at dissolving nonpolar solutes. It is for this reason that water (which is polar) is good at dissolving sugar (which is also polar), while gasoline (which is nonpolar) is bad at dissolving sugar.

Sugar in a Gas Tank!

For those of you who want to destroy somebody's car by putting sugar in the gas tank, the concept of like dissolves like ensures that you won't succeed. Because sugar is polar and gasoline is not, the sugar will not dissolve, instead sinking to the bottom of the tank.[4] Not that we recommend destroying somebody's car, but a better way to do so would be to crush it or something.

The proper way to destroy a car.

2 *Why this happens is an interesting and complex question, and probably not one we should address now. As is nearly always the case, it has to do with thermodynamics.*

3 *Chapter 6 discusses where these partial charges come from in polar molecules like water.*

4 *Snopes.com discusses this urban legend in great detail: http://www.snopes.com/autos/grace/sugar.asp*

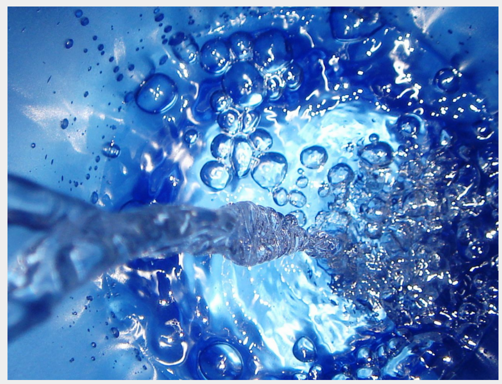
What Factors Affect Solubility?

The following things affect how well a solute will dissolve in a solvent:

- **"Like Dissolves Like"**: I just mentioned that on the last page, so if you don't remember, just look over there. Suffice to say that solvents tend to dissolve solutes with similar polarity.
- **Temperature**: Solids are usually more soluble at high temperatures, while gases are less soluble as solvent temperature increases.
- **Pressure of gas solutes**: If you're trying to dissolve a gas into a liquid, you can get more of it to dissolve by putting the liquid into a pressurized container full of this gas. For example, soda is made by exposing the uncarbonated beverage mixture to high-pressure carbon dioxide gas, forcing the bubbles into solution.

Why Does Boiled Water Taste Flat?

While cold water tastes good, water that has been boiled tastes flat. The reason for this is that cold water has a lot of nitrogen and oxygen dissolved in it, which makes our tongues happy. However, heating water to boiling decreases the amount of dissolved gases because the solubility of these gases decreases as solvent temperature rises. When the water cools, the lack of these dissolved gases makes the water taste yukky. Not to worry: If you stir the water for a few minutes, it'll taste better again![5]



This picture makes me have to pee.

Properties of Solutions

Let's say you've got a glass of water. Now, imagine drinking it. It probably tastes like water. Now, throw some Kool Aid™ powder into another glass of water. I imagine it tastes a little different. To end the experiment, throw the rest of your Kool Aid™ powder into the glass. It probably tastes terrible.[6]

5 *The next question in my mind is "If boiled water tastes flat, why do we like to drink coffee so much?" Answer: the flatness of the water is overpowered by the much stronger flavor of the coffee.*

6 *Because there's too much powder, not because Kool Aid™ tastes bad. Kraft Foods lawyers, please don't sue me.*

This experiment tells us two important things about solutions:

1. When you dissolve something, the solution has different properties than the pure solvent. That's why Kool Aid™ doesn't taste like water.

2. As you increase the concentration of a solution, some of its properties will continue to change. **Colligative properties** are any property of a solution that changes when the concentration of the solute changes.

Let's take a look at some of the wondrous things that happen when you add a solute into a solvent.

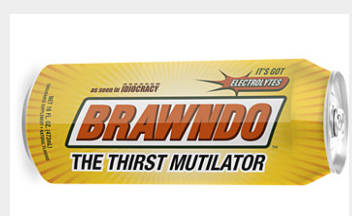
Looks like the Kool Aid man has really let himself go.

Electrical Conductivity

By itself, water does a terrible job of conducting electricity. However, when you dissolve an ionic compound in water, the ions that are formed allow the resulting solution to conduct electricity very well. Such solutions are called **electrolytes**. On the other hand, solutions that dissolved covalent compounds are poor conductors because covalent compounds don't form ions when they dissolve.

It's Got Electrolytes!

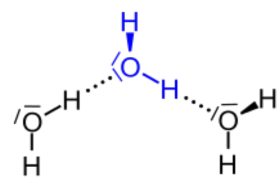
Popular sports drinks advertise the fact that they contain electrolytes. All this means is that they contain dissolved salt. If you want to save some money you can make your own sports drink by adding ½ tsp (5 mL) of salt to a bottle of Kool Aid.



Freezing and Boiling Point

Solutions generally have lower freezing/melting points[7] and higher boiling points than the pure solvent.[8] Here's why:

- **The freezing point of a solution decreases**: This occurs because the solute particles get in the way of the attractive intermolecular forces between solvent molecules. When liquids freeze, the liquid molecules which were bouncing around all over the place now need to arrange themselves in a stable pattern that allows them to become a solid. By adding a solute, this arrangement is disrupted. You can still freeze a solution, but you'll need to suck more energy out of it than you would the pure solvent.



The hydrogen bonds that hold water molecules together in ice are shown by dotted lines. When a solute is added to water, it gets in the way of these hydrogen bonds, making it necessary to pull more energy out of the water to make it freeze.

- **The boiling point of a solution increases**: This occurs because the solute particles cover up the top of the solution so that fewer molecules of solvent can wander away into the gas phase (i.e. boil).

- **How it interacts with light**: Solutions with high concentrations will absorb more light than solutions with low concentrations. As a result, the amount of light absorbed by a solution can be used to figure out its concentration.[9]

How to quickly make solutions:

Remember back in Chapter 7 where we talked about kinetics? Well, it turns out that in order to make stuff dissolve quickly, you've got to do pretty much the same things that you have to do in order to make chemical reactions occur quickly. These include:

- **Grinding the solute**: Powders have larger surface areas than large crystals, which allows more solvent to attach themselves to the surface at once.

- **Heating it**: Heating a solvent causes the molecules to hit the solute with more energy and frequency than a cold solvent. This causes dissolving to be much quicker.

- **Stirring it**: When fresh solvent is placed into contact with the solute, the solute dissolves more quickly. Stirring the solvent allows this to happen.

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7 *The temperature at which a liquid freezes is the same temperature at which it will melt, because they are just the same process in reverse.*

8 *This is true for solid solutes in liquid solvents, less so for other solutions.*

9 *This concept is described by Beer's law. In the US, you need to be 21 before you can use it.*

8.2: Concentration

The **concentration** of a solution is a way of describing the amount of solute that has been dissolved in the solvent. There are several different ways of describing the concentration of a solution because of course there are. It's chemistry, after all.

Qualitative Concentration: The Power of Words

One of the most common ways to describe the concentration of a solution is to simply describe it as being in one of three categories:

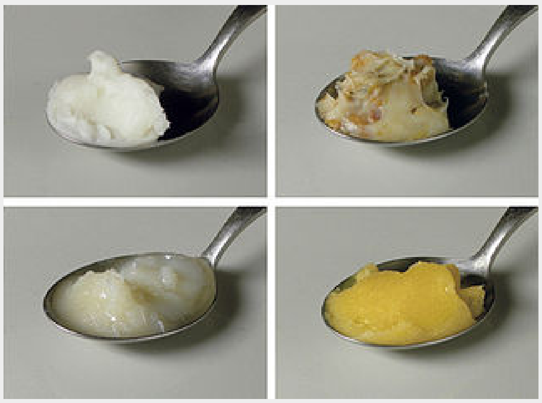
- **Unsaturated solutions** are solutions in which the maximum quantity of solute that *can* be dissolved hasn't yet been reached. If you were to place more solute into one of these solutions, it would also dissolve. Keep in mind that saying a solution is “unsaturated” doesn't necessarily tell you much. After all, if you drop a grain of sugar into a glass of iced tea or an entire spoonful, both glasses of tea would still have the capacity to dissolve more added sugar.

- **Saturated solutions** are solutions that have dissolved the maximum quantity of solute. Thinking back to a page and a half ago, you'll recall that solvent molecules pull apart the particles of solute. If you add enough solute, these molecules won't be able to pull anything else apart because they already have their hands full. In such a case, any added solute will just sink to the bottom. Saying that a solution is “saturated” is *sort of* quantitative, because there's only a very particular amount of solute that can dissolve in a liquid at any given temperature.

- **Supersaturated solutions** are solutions that have dissolved *more* than the usual amount that they can normally dissolve. These solutions aren't stable, so they're difficult to make and can spontaneously form crystals to generate a stable saturated solution.[10]

What's a Saturated Fat?

Saturated fats are fats in which there are no C=C double bonds. The term “saturated” in this case refers to the fact that these fats have the maximum possible amount of hydrogen in their structure – it has nothing at all to do with solutions.



Lard (pig fat) is a saturated fat. Gross.

10 *A nice explanation about how to make supersaturated solutions can be found here:* *http://preparatorychemistry.com/Bishop_supersaturated.htm*

Quantitative Concentration: Using Numbers

We scientists love to write numbers in our little lab notebooks. To satisfy this desire, we've come up with several ways to indicate precisely how much of a solute is present in a solution. Lucky you.

- **Percent by volume** is equal to the volume of one component divided by the overall volume of the solution. This is usually used in the case of liquid/liquid solutions, as in rubbing alcohol and water mixtures. A 91% rubbing alcohol/water solution contains 91 mL of rubbing alcohol for every 100 mL of rubbing alcohol solution.

- **Percent by mass** is equal to the mass of one component divided by the overall mass of the solution. This is usually used to describe the quantity of a solid solute in a solution. For example, if there is 1.0 grams of sodium chloride in 250 grams of a sodium chloride solution, the percent NaCl by mass is:

$$\frac{1.0\,grams\,NaCl}{250\,grams\,solution}\times 100\;percent = 0.40\;percent\;by\;mass$$

- **Molarity (M)** is equal to the number of moles of solute divided by the liters of solution. In chemistry, this is by far the most commonly-used way of expressing the concentration of a solution. Let's imagine that we have 50.0 grams of NaCl in 2.50 L of a solution. Converting 50.0 grams of NaCl to moles, we find that we have (50.0 g/58.44 g/mol) = 0.856 moles of NaCl. Using the equation M = mol / L, we get a final concentration of:

$$M = \frac{mol\;NaCl}{L\;solution} = \frac{0.856\,mol\;NaCl}{2.50\,L\;solution} = 0.342\,M$$

So, Are We Done Yet?

Yes and no. Yes, in that I'm not going to make you learn any more ways of calculating concentration. No in that there are a bunch more ways that you'll have to learn at some point in the future. Popular ways of measuring concentration include molality (used for colligative properties), normality (which is related to molarity), mole fraction[11] (useful for stuff you haven't learned yet), and parts per million/billion/trillion etc. This may seem like a big waste of time, but all of these units have been invented for their own specialized reasons. Which are mostly a big waste of time.

The game of aquatic old man chess requires great concentration. But that's another issue entirely.

11 *The National Institutes of Standards and Technology (NIST) calls this the "amount-of-substance fraction." Nobody else does, though.*

8.3: Acids and Bases

You've probably heard of acids and bases before, but you've also probably forgotten what they are. I mean, you know that lemon juice is an acid and baking soda is a base, but that's only because your teachers have been pounding those facts into your head for the past decade. Instead of giving you a bunch of random facts, let's actually learn about what these fascinating compounds are up to.

Acids: Our Little Sour Friends

Acids are chemical compounds that give off hydronium (written either as H^+ or H_3O^+) ions in water. This happens according to the following general equation:

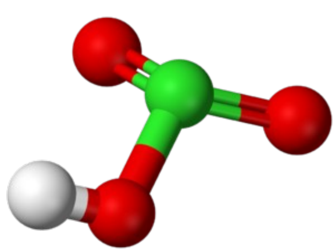
$$HA \rightarrow H^+ + A^-$$

Acids nearly always start with the letter H, which makes it easy to identify them from their formulas (HCl, HBr, H_2SO_4, and so forth). Just so you have another example of an acid breaking up to work from, we can see what happens when nitric acid dissociates in water:

$$HNO_3 \rightarrow H^+ + NO_3^{-1}$$

Some of the properties of acids include the following:

- **Acids taste sour**: Think "lemon" or "aspirin."[12]
- **Acids react with metals**: Acids are good at corroding metals, producing hydrogen gas in the process. For example, nitric acid does a fantastic (if dangerous) job of dissolving pennies, making hydrogen bubbles in the process.[13]



Though hypochlorous acid seems like a nice guy, he'll straight up melt your face off.

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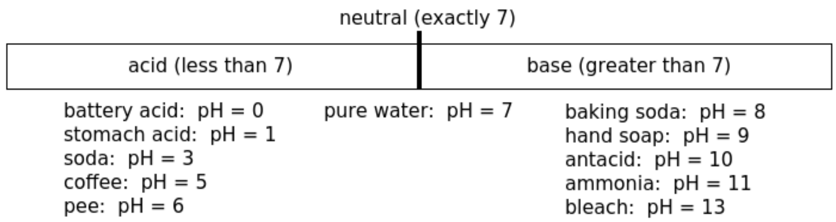
12 *The traditional way of describing the tastes of acids and bases is to say that acids are sour and bases are bitter. Nobody ever goes to the trouble of trying to explain the difference, which seems odd to me. "Sour" is like lemon juice or vinegar, whereas "bitter" is like baking soda or antacid. They both taste bad, but in different ways.*

13 *This is a very dangerous experiment, as the scar on my hand demonstrates.* However, you can dissolve the penny from the inside of a penny safely by scraping the side of a post-1982 penny against some concrete to expose the zinc and then put the penny in vinegar (acetic acid). The zinc on the inside of the penny will dissolve (forming H_2 gas in the process) while the thin coating of copper will remain intact.

- **Acids have a pH less than 7**: The pH scale is designed to indicate how acidic something is. If something has a pH less than 7, it's an acid. If something has a pH greater than 7, it's a base. If something has a pH of *exactly* 7, it's neutral. Acids, as I've mentioned twice, have a pH less than 7.



Fun Fact: *Even though most textbooks say that the pH scale runs from 0 – 14, that's totally not true. pH values can be below 0 or above 14. If anybody says otherwise, punch them in the nose.*

- **Acids turn litmus paper red and phenolphthalein colorless**: When you put these two compounds into acids, the color changes above are observed. This is because both litmus and phenolphthalein are **indicators**, chemical compounds that turn different colors in acids than in bases. Using either litmus or phenolphthalein, you can figure out whether a beaker contains an acid or a base. This is very handy, because the “taste it to see if it's sour” test is usually a bad idea.

Fun With Phenolphthalein

In addition to being a really nice acid-base indicator (it's colorless in acid and pink in base), phenolphthalein is also a powerful laxative. In fact, up until the 1990's, some over-the-counter laxatives contained phenolphthalein. The FDA banned the use of phenolphthalein as a laxative in 1999 because of fears it might cause cancer in heavy laxative users.[14] Which leads to an important question: Exactly who takes so many laxatives?[15]

Chocolate + laxative = the worst smoothie ever.

14 *Dunnick, J. K.; Hailey, J. R. (1996). "Phenolphthalein Exposure Causes Multiple Carcinogenic Effects in Experimental Model Systems." Cancer Research 56 (21): 4922–4926.*

15 *Answer: Old people. I've got a great story about my grandfather and laxatives, but it's not really appropriate to share here. Forget I said anything.*

Bases: So Very Bitter

Bases are chemical compounds that give off OH^- ions when you put them in water.[16] This happens according to the following general process:

$$BOH \rightarrow B^+ + OH^{-1}$$

As a result, a compound such as calcium hydroxide will undergo the following dissociation when placed in water:

$$Ca(OH)_2 \rightarrow Ca^{+2} + 2\ OH^{-1}$$

How About Ammonia?

Ammonia (NH_3) is a base even though it doesn't have any OH^- ions in it's formula. This is because, when placed in water, ammonia pulls an H^+ ion off of water, resulting in the formation of a hydroxide ion:

$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^{-1}$$

The double-headed arrow shown here indicates that this is an equilibrium process, characteristic of weak acids and bases. I mention this in a couple of pages, so check it out.

Ammonia is used in the manufacture of crystal meth. The guy above was arrested for methamphetamine possession, which should give you an idea of the kind of genius that does crystal meth.[17]

Some of the properties of bases include the following:

- **Bases taste bitter**: Like “baking soda” or “soap.”[18]
- **Bases react with oils and greases**: Because dirt frequently consists of oily and greasy stuff, basic soaps do a nice job of cleaning stuff up. Incidentally, one of the reasons that soaps feel slippery is that the dissolved oils and greases from your skin make your fingers slide together more than usual. Because you're being turned into soap. Seriously.
- **Bases have a pH greater than 7**: That table on the last page discusses this, so go back and have a look.
- **Bases turn litmus blue and phenolphthalein pink**: Yep.

16 *According to the Arrhenius definition, anyhow. More about this in high school chemistry.*
17 *If you're the guy in this picture, I assure you that I'm not making fun of you. Please don't murder my family.*
18 *I mention soap because I think it would be funny to make you eat soap.*

Neutral News!

From January 1, 2016 to January 1, 2017, Johann Schneider-Ammann was the President of the Swiss Federal Council. Because Switzerland is a famously neutral country, this, by definition, means that Mr. Schneider-Ammann is also neutral. I wouldn't go kick him in the shins or anything, though, because he once beat up a guy in a bar fight.[19]

You'd best step off.

Neutral Stuff

If acids give off H^+ ions and bases give off OH^- ions, what do we call everything else? Neutral compounds! Neutral compounds or solutions are those that have a pH of exactly 7 because the amount of H^+ and OH^- in the solution are the same.[20]

Properties of neutral compounds/solutions:

- **They can taste like almost anything.** Salt water is neutral, as is pure water and gasoline. This is one of the reasons that we don't use taste to figure out whether something is an acid, base, or neutral: We don't want you catching a mouthful of gasoline by accident.
- **They don't have any particular reactivity.** Again, since there are a lot of different neutral materials, you can't really make general statements about how they react.
- **They usually don't do anything to the color of an indicator.** If you start off with red litmus (i.e. litmus that's initially acidic) and put it into water, it'll stay the way it is. Likewise, if you start off with blue litmus (i.e. litmus that's initially basic), it'll also stay the same color. Since it's neutral, it doesn't do much to indicators.[21]

Strong and Weak!

Acids and bases are referred to as being "strong" or "weak" based on how well they break apart in water. Strong acids and bases (e.g. HCl and NaOH) break up almost completely, whereas weak ones (e.g. acetic acid and ammonia) break up incompletely. As a result a 1 M solution of HCl (a strong acid) will have a lower pH than a 1 M solution of acetic acid (a weak acid).[22]

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19 *I made that up. But wouldn't that be awesome?*

20 *From a technical standpoint, neutral compounds must have a pH of exactly 7 – no deviation at all. As a result of this, everything is technically either an acid or a base because there will always be some impurities that cause it to deviate from 7. However, if the pH of something is really close to 7, we usually refer to it as neutral, even though it's not technically correct.*

21 *There are about a billion indicators out there, and this generally holds true for the common acid-base indicators you'll run into. However, some indicators turn colors at different pH values, so they may not have the same result. Fortunately, you'll probably never need to worry about this.*

22 *"Strong" and "weak" refer only to acid strength and not to reactivity. Though HF is a weak acid, it is far more dangerous than the strong acid HCl.*

Neutralization Reactions

What happens when you put an acid together with a base? Well, given that acids product H^+ ions and bases product OH^- ions, you might guess that they combine according to the equation:

$$H^+ + OH^- \rightleftharpoons H_2O$$

And you'd be right. That's exactly what happens.

Because we start with two things that are not neutral and end with one thing that is neutral, this reaction is referred to as a **neutralization reaction**. You may vaguely remember this from chapter 7 where we referred to these as acid-base reactions. Not to worry – they're the same thing.

Science In Action!

Antacids are medicines that you can take to make your tummy hurt less after you ate an entire pizza. These compounds work by neutralizing your stomach acid (mostly HCl) with a base (milk of magnesia contains $Mg(OH)_2$).

Milk of magnesia, interestingly enough, is a laxative. Which, as you'll recall from this chapter, is something I've talked about a lot. I'm not a weirdo, though.

These antacids are Russian.
God only knows what's in them.

The Main Ideas in Chapter 8

- Solutions are formed when a solvent dissolves a solute. Aqueous solutions are those in which the solvent is water.
- Colligative properties are any properties of a solution that change with changing concentration. Examples are melting point, boiling point, and conductivity.
- The concentration of a solution is a measure of how much solute has been dissolved. Concentration can be expressed either qualitatively or quantitatively.
- Acids are solutions with a pH less than 7, neutral solutions have a pH of exactly 7 and basic solutions have a pH greater than 7.
- You can figure out whether something is an acid or base by tasting it, but it's usually a much better idea to use an indicator such as litmus or phenolphthalein.
- Neutralization reactions occur when an acid and base combine to make a neutral solution.

Images:

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