

## Acids and Bases

### Acid-Base Properties of Salts

#### Acid-Base Properties of Salt Solutions Page [1 of 2]

This is table salt, sodium chloride, and we call it a salt, but why do we call it a salt? And the other thing that I'm going to tell you is that chemists define salts in a much broader sense than just the one thing that you want to put on your food to make it taste better. In particular, what a salt is to a chemist is the product of an acid-base neutralization reaction. And that holds for a lot of compounds, not just sodium chloride. And what I'd like to do in this tutorial is talk about the effect that a salt, a particular salt, and we're going to categorize the salts in a second, when you put it into water; it has effect on the pH typically. And the effect that it has on the pH can be predicted based on the properties of the acid-base reaction that would have led to the salt.

Okay, so the first category, and there are going to be four categories, so let me set those out first. There's the reaction of a strong acid with a strong base; that's one category. There's the reaction of a strong acid with a weak base; that's category two. There's the reaction of a weak acid with a strong base; that's category three. And then there's a weak acid and a weak base; that's category four. So again, we're talking about neutralization, acid-base neutralization reactions, and then there are just the 4 possible combinations of strong and weak.

So let's look at the first one, which is a strong acid and a strong base, and, interestingly enough, that's what leads to our sodium chloride. If we take hydrochloric acid, which is a strong acid, and sodium hydroxide, which is a strong base, and we add 1 equivalent of each one, then we're going to make water and sodium chloride. And how would we isolate the sodium chloride? Well, we could do this reaction, and the products are water and sodium chloride, and then we could just evaporate off the water and what's going to be left is sodium chloride. Now, typically we won't do that. What we'll do is we'll go to the Great Salt Lake in Utah and just scrape up some salt, but it has exactly the same composition. And again, it results in our laboratory from the reaction of a strong acid and a strong base.

Now, what happens when we take sodium chloride and we put it into water? Sodium chloride, being the product of a strong acid and a strong base, essentially has no effect on the pH. So, if we take salt and put it into water and measure the pH, it'll be really close to 7 still. What does that mean? Basically, what it says is that Cl minus, being the conjugate base of a strong acid, has no affinity for protons. We already knew that. If HCl is a really strong acid, then Cl minus, it's conjugate base, has to be a really weak base, meaning that it has no affinity for protons. But similarly, sodium cation is solvated, so it has water around it, but it doesn't hydrolyze, meaning it doesn't break any bonds. What we'll see is that there are some cations that do break bonds. For instance, when we look at aluminum 3 plus in water, bonds were broken after it was hydrated. So hexa aqua aluminum 3 plus, that was a Brønsted acid. But sodium cations, when you put them in water, they get a bunch of waters around them, but they don't increase the propensity for that water to donate a proton or anything like that. And what we say is that sodium cations are not hydrolyzed to any extent. So, as a result of these two facts, sodium chloride solutions are essentially neutral.

Now, let's look at a salt that results from the neutralization of a weak acid, such as hydrofluoric acid, with a strong base, such as sodium hydroxide. And what happens when we do this reaction is that we get water and sodium fluoride. Now, this is the weak acid, this is the strong base. And I write this going to completion, because the hydroxide, being strong a strong base, totally deprotonates the hydrofluoric acid. And then, when we remove the water, by evaporation, for instance, what we'd end up with is sodium fluoride. Now, sodium fluoride, being the salt of a weak base, this F minus actually does have some affinity for a proton. Remember, when this is chloride, that chloride had no affinity for a proton. But fluoride does have an affinity for a proton. How do we know that it should have an affinity for a proton? Because its conjugate acid is a weak acid, meaning that fluoride likes that proton. So, when we take sodium fluoride and we throw it into water, we do get a hydrolysis reaction. That is, the fluoride picks a proton off of the water to form HF and hydroxide. So an increase in the concentration of hydroxide, in the Arrhenius sense, means that F minus is a base. Now, can we calculate what quantitatively the effect of fluoride should be when we put it into water? In other words, we take sodium fluoride and we put it into water. What quantitatively should be the effect on pH? We can do that. Basically, what we need is we need an equilibrium expression for this reaction, F minus plus water going to HF plus hydroxide. And the equilibrium constant for this is a  $K_b$ , because this is a base. And remember that  $K_b$  is related to  $K_a$  and  $K_w$ .  $K_w$  is the water constant and  $K_a$  is the acid constant for the conjugate acid of fluoride. The conjugate acid of fluoride is hydrofluoric acid. And we've gone through this before, but you can convince yourself that this statement is true by looking at the expression for  $K_a$ , which is in purple here. And remember, the trick we did was we multiplied by the proton concentration in the numerator and the denominator to get an expression that looks like  $K_b = \frac{K_w}{K_a}$ . In any case, we can use  $K_b$ . We're going to calculate it based on knowing what  $K_a$  is, by looking it up on a table. So, if we wanted to calculate what is the pH of a 1.0 molar solution of sodium fluoride, we make an ICE diagram, where the initial concentration of fluoride is 1, and, of course, the change is minus x and plus x and plus x. And what are we going to calculate to be? Well, it's over  $K_a$ .  $K_a$  is the acid constant for hydrofluoric acid, which is 6.8

## Acids and Bases

### Acid-Base Properties of Salts

#### Acid-Base Properties of Salt Solutions Page [2 of 2]

times  $10^{-4}$ , so  $x$  is equal to 1.5 times  $10^{-11}$ . And then we're going to solve  $x$  squared over  $1.0 - x$  is equal to 1.5 times  $10^{-11}$ . And we get  $x$  is equal to 3.8 times  $10^{-6}$ . And this is the hydroxide ion concentration, because remember, in our ICE diagram,  $x$  is the hydroxide ion concentration. So what we have to do to get the pH is calculate the pOH. You know how to do that now, and then we can calculate the pH from the pOH. And it's a little bit higher than 7. That makes sense, because fluoride is a base, and so we expect that the solution should be alkaline or basic when we measure the pH.

Now, what about the third category, which is salts that come from the neutralization of weak bases with strong acids? Ammonia, for instance, reacting with hydrochloric acid, gives ammonium chloride. Again, we could take ammonia, take an equivalent of hydrochloric acid. We would get ammonium chloride, rip off all the water and we'd have a pile of ammonium chloride. It's a white crystalline solid. So ammonia as a gas or in solution, it would be an aqueous solution, but ammonium chloride is a white solid. And if we dump that into water, what's going to happen? Well, the HCl essentially force the ammonia to pick up a proton in this reaction. But ammonia is a weak base, so it doesn't really want that proton all that much. And so, what happens when we take ammonium chloride and we put it in water? Nothing happens to the chloride. Remember, the chloride doesn't experience hydrolysis to any extent. It doesn't attract a proton to itself. But the ammonium reacts with water in a hydrolysis reaction to form hydronium in solution, meaning that it's functioning as an acid. And we can calculate what the pH is, but we need a  $K_a$ , or an equilibrium constant, for this reaction that's written in red. Well, where are we going to get that? Once again, we're going to use the relationship between  $K_a$  and  $K_b$ .  $K_a$  is the  $K_a$  or the equilibrium constant for the reaction in red, and  $K_b$  is the base constant for ammonia. So this is ammonium, the  $K_b$  for ammonium, that's the thing that we're interested in. And this is the  $K_b$  for ammonia, something that we can look up. And you can, again, convince yourself that this equation is true. So we can find the  $K_a$  with equilibrium constant for the thing in red, knowing  $K_b$  for ammonia, the base constant for ammonia.

So we'll do that. Let's say what is the pH of a .20 molar solution of ammonium chloride? And again, ammonium chloride is an acid, because it is the salt that results from the neutralization of a weak base with a strong acid. So we have our equilibrium. We set-up our ICE diagram, as we always do. We're interested in  $K_a$  for this reaction, which is for ammonium cation, over  $K_b$ , where  $K_w$  is the water constant and  $K_b$  is the base constant for ammonia, the conjugate base of ammonium. So we plug that value in, we get that the equilibrium constant for this reaction in purple is 5.6 times  $10^{-10}$ . And then we plug in our equilibrium values from our ICE diagram, .20 minus  $x$ ,  $x$  and  $x$ , into this kind of expression and solve for  $x$ . And, when we solve for  $x$ , we get that  $x$  is equal to 1.1 times  $10^{-5}$ . Okay, fine. What was  $x$  again? We've got to bring the sheet back again.  $x$  is the proton concentration. So we're there. We have that the proton concentration is equal to 1.1 times  $10^{-5}$ , and this is molarity, so we should put an "M" there. And this is equal to the proton concentration. And now, we know how to take the pH, it's the negative log of the proton concentration, and so we get the pH is 4.96. That's again, slightly acidic, or, actually fairly profoundly acidic, about 100 times the proton concentration of neutral water.

Finally, what about salts that result from neutralization reactions between weak acids and weak bases, category number four? And it turns out that those are going to be acidic or basic, depending on the relative values of  $K_a$  for the cation and  $K_b$  for the anion. So, if we consider something like ammonium fluoride, both the cation, ammonium, and the anion, fluoride, are going to experience hydrolysis. And we have to consider both those equilibria. So ammonium will react with water to form hydronium and ammonia. And that has a  $K_a$  for ammonium and we've calculated that already. And then fluoride is going to experience hydrolysis. It'll react with water to form hydrofluoric acid and hydroxide, so it's a base, because it's increasing the concentration of hydroxide. And we calculated the  $K_b$  for fluoride already. So what we have to do is we have to compare the relative value of  $K_a$  for ammonium with the  $K_b$  for fluoride to determine whether we're going to have predominately protons or hydronium in solution, or predominately hydroxide in solution. In other words, whichever value of the equilibrium constant between  $K_a$  and  $K_b$  is larger will determine whether protons are going to dominate or whether hydroxide is going to dominate. So the values for those, for the ammonium is 5.6 times  $10^{-10}$ , and the  $K_b$  for fluoride is 1.4 times  $10^{-11}$ . So this is slightly larger. 5.6 times  $10^{-10}$  is larger than 1.4 times  $10^{-11}$ , so that means that this top reaction is going to dominate. There's going to be excess protons, or excess hydronium in solution. And what does that mean? Well, that means that the resulting solution from dissolving ammonium fluoride in water is going to be slightly acidic.

Okay, so in many ways what I've shown you here is that the equilibria involving acids and bases are very, very versatile. We can use them to calculate equilibrium constants for all different kinds of solutions, including these salts that result from acid-base neutralizations. And we can also use them when we do things like titrations and all kinds of other – buffers, for instance. They're all topics that are going to use these tools later on.