

## Chapter 12

## AQUEOUS REACTIONS, Part 2

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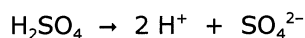
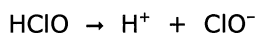
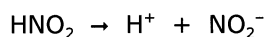
We have some unfinished business which we must now attend to. We need to cover names and formulas for acids. Back in Chapter 4, when we were doing names of compounds, I said that I would put off names of acids until later. Later is now. I also said that you could still pick this up while in Chapter 4 if that's where your instructor wanted to cover it. So, if you're really in Chapter 4 right now, this is the right place for acid names.

Although I mentioned in Chapter 11 that covalent oxides such as  $\text{CO}_2$ ,  $\text{SO}_2$  and  $\text{SO}_3$  are acids, those are not subject to acid names. Those keep the binary covalent name from Chapter 4. The system of acid names which is described here is for those with one or more H's in the formula.

By the way, there is no separate naming for bases. The names of bases are handled by the methods in Chapter 4.

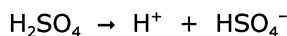
### 12.1 Names and formulas for acids

If you're coming to this section directly from Chapter 4, have no fear. I'll present this section strictly as a naming section without worrying about all the details so far of acids. All you have to know is that water can break up ("dissociate") an acid by pulling off  $\text{H}^+$ , thereby also forming an anion in the process. Here are some simple examples.

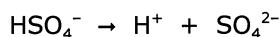


For naming acids, here's the catch: it's the anion part which gives identity and name to an acid. The name of an acid is derived from the name of the anion which is involved.

Notice in the third example that  $\text{H}_2\text{SO}_4$  can give 2  $\text{H}^+$ . This happens in two steps. In the first step, you get one  $\text{H}^+$  and a hydrogen anion, bisulfate.



The bisulfate anion can then dissociate again.



In fact, hydrogen anions have been called "acid anions" for this reason.

There are other acids which are also capable of multiple steps, but this section is about naming and not about multiple steps. The important thing for naming is the very last, final anion after all steps. Thus, for naming purposes, for acids with multiple steps, consider only the fully dissociated anion.

Let's look at the connection between an acid's name and the name of its anion. The connection is based on the suffix of the anion's name, and there are only three possibilities. In Chapter 4, we discussed anion names and the endings for those names: the three endings were "-ide", "-ate" and "-ite". Monatomics took the *-ide* ending, while polyatomics took any of the three. Now, we name acids according to those three endings.

- CATEGORY 1. ACIDS WHICH DISSOCIATE TO AN ANION WHOSE NAME ENDS IN "-ide".

For these, the name of the acid is derived by changing "-ide" to "-ic acid" and adding the prefix "hydro-".

HBr	The anion would be $\text{Br}^-$ , bromide. The acid name is hydrobromic acid.
HCN	The anion would be $\text{CN}^-$ , cyanide. The acid name is hydrocyanic acid.

I used hydrochloric acid, HCl, as an example in the prior Chapter. It falls in this Category. The anion is chloride.

- CATEGORY 2. ACIDS WHICH DISSOCIATE TO AN ANION WHOSE NAME ENDS IN "-ate".

The name of the acid is derived by changing "-ate" to "-ic acid". Although this is another "-ic acid" like above, this does not take the "hydro-" prefix.

$\text{HClO}_4$	The anion would be $\text{ClO}_4^-$ , perchlorate. The acid name is perchloric acid.
$\text{H}_2\text{C}_2\text{O}_4$	The anion would be $\text{C}_2\text{O}_4^{2-}$ , oxalate. The acid name is oxalic acid.

I used acetic acid,  $\text{CH}_3\text{CO}_2\text{H}$ , as an example in the prior Chapter. It falls in this Category. The anion is acetate.

• CATEGORY 3. ACIDS WHICH DISSOCIATE TO AN ANION WHOSE NAME ENDS IN "-ite".

The name of the acid is derived by changing "-ite" to "-ous acid".

$\text{HClO}$                       The anion would be  $\text{ClO}^-$ , hypochlorite. The acid name is hypochlorous acid.  
 $\text{HNO}_2$                       The anion would be  $\text{NO}_2^-$ , nitrite. The acid name is nitrous acid.

That's all there is to it. Except for several quirks. Two of the quirks are very common, so I need to point these out. These are sulfuric acid and phosphoric acid, both of which have an extra syllable inserted. Don't ask me why. I didn't do it.

$\text{H}_2\text{SO}_4$                       The anion would be  $\text{SO}_4^{2-}$ , sulfate. This falls under Category 2 and the name would be sulfic acid, but instead it is sulfuric acid.

$\text{H}_3\text{PO}_4$                       The anion would be  $\text{PO}_4^{3-}$ , phosphate. This falls under Category 2 and the name would be phosphic acid, but instead it is phosphoric acid.

You're best off to just memorize these quirks and any other quirks your instructor might have.

OK, that covers translating the formula into the name. Now let's go backwards: translate the name into formula. First, identify the anion involved using the three relationships above. This gets you the anion's formula. Note the charge for that anion: the value for the charge is the number of  $\text{H}^+$ 's to place into the formula for the neutral acid compound.

hydroiodic acid

There's the *hydro-* prefix and the *-ic acid* part. This tells you that this is Category 1 and that the anion ends in *-ide*. In between *hydro-* and *-ic*, you can see *-iod-*, so the anion which is involved is iodide,  $\text{I}^-$ . It has a negative one charge, so the neutral acid will have one  $\text{H}^+$ . The formula is  $\text{HI}$ . (By the way, with three consecutively pronounced vowels in the middle of the word, hydroiodic is often written hydriodic. Either way is fine.)

carbonic acid

There's *-ic acid* but no *hydro-*. That means this is Category 2, so the anion will end in *-ate*. The anion is carbonate,  $\text{CO}_3^{2-}$ . Two negatives on the anion will need two  $\text{H}^+$ 's for the neutral acid compound. The formula is  $\text{H}_2\text{CO}_3$ .

chlorous acid

The *-ous acid* part makes this Category 3, so the anion will end in *-ite*. It's chlorite,  $\text{ClO}_2^-$ . A negative one charge needs one  $\text{H}^+$ . The formula is  $\text{HClO}_2$ .

Notice that, in writing the formula, I put H first. This is the usual way, although it's not the law (unless your instructor makes it the law). In fact, I've been writing acetic acid as  $\text{CH}_3\text{CO}_2\text{H}$ , with the acid-H written last.

That's all there is for translating the name into a formula.

Time for you to do a few. Write the names for the following acids.

HF \_\_\_\_\_  $\text{H}_2\text{CrO}_4$  \_\_\_\_\_

Now write the formulas for the following.

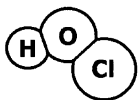
nitric acid \_\_\_\_\_ arsenic acid \_\_\_\_\_

Just like all the other naming from Chapter 4, this system takes practice. Do it.

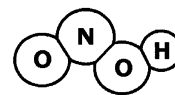
Before ending this part, let me point out a few more things.

A number of the above examples involve oxyanions. This leads to a new term, "oxyacid": an oxyacid is any acid whose anion is an oxyanion. We did the oxyanion name relationships in Chapter 4. All oxyanion names end in *-ate* or *-ite*, so all oxyacids will fall under Category 2 or 3 above.

Neutral acids, by themselves as pure compounds, are typically covalent; they are not ionic compounds. Remember this. Neutral molecules for hypochlorous acid and for nitrous acid are shown



at left and at right as examples. All of the bonds are covalent bonds. What makes them an acid is that they can give  $H^+$  and an anion when dissolved in water but, by themselves, they are neutral and covalent.



This covalent business is important to know for all three categories above, but it's most important for Category 1. That's because the actual names are different for the acid compared to the pure compound by itself. Pure HCl, by itself, is a gas and its name is hydrogen chloride. Pure HBr, by itself, is a gas and its name is hydrogen bromide. In water, however, HCl is hydrochloric acid and HBr is hydrobromic acid. This can lead to an ambiguity: for example, if you just write HCl, are you talking about the covalent compound (hydrogen chloride) or are you talking about the acid (hydrochloric acid)? We used HCl quite a bit in Chapter 7 and in that usage the reaction was described for gases; in that context, we knew it was the covalent compound, hydrogen chloride. When you're dealing with aqueous solutions, such as in this Chapter, then we know we are talking about the acid solution, hydrochloric acid. Phases can also tell you:  $HCl(g)$  means the gas phase molecule and that means it's hydrogen chloride, while  $HCl(aq)$  means the aqueous solution and that means it's hydrochloric acid. On the other hand, if the wording just says "HCl" with no other info, then it can refer to hydrogen chloride or to hydrochloric acid. Keep this distinction in mind. Typically, if the compound is dissolved in water, then the formula is assumed to represent the acid; otherwise, it is assumed to represent the neutral covalent compound. Fortunately, this distinction only applies for Category 1 acids. Acids in Categories 2 and 3 always take an acid name, regardless of whether they are by themselves as a pure compound or they are dissolved in water.

OK, that's enough about names and formulas for acids. You folks from Chapter 4 can go back now afore you get discombobulated. The rest of you need to continue.

## 12.2 Neutralizations

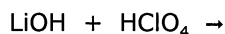
Let's resume our coverage now regarding neutralizations or acid-base reactions or whatever you want to call them. We can say that an acid neutralizes a base or a base neutralizes an acid. It doesn't matter; both ways say the same thing.

By definition, a neutralization involves an acid and a base as the reactants. What about the products? We get to that now. The products of neutralization include a salt and usually water. I said "usually" water since it's most of the time but not always. The most common situation for no water is when ammonia is the base.

The key part for now is "salt". While most people regard "salt" as table salt (mostly sodium chloride), the term "salt" in chemistry designates an entire family of compounds of which there are a huge number. Salts are sometimes defined as the product of an acid-base reaction, but it's more useful to be able to recognize a salt just by a formula. All salts are ionic compounds but not all ionic compounds are salts. For our aqueous purposes right now, the principal types of ionic compounds which would NOT be considered salts are hydroxides and oxides. Thus, we will define a salt as an ionic compound with an anion other than hydroxide or oxide. This includes  $NaCl$ ,  $K_2SO_4$ ,  $NH_4NO_3$ ,  $LiH_2PO_4$ ,  $Ba(ClO_4)_2$ , and many more. Here's an important point to note for the salt product of a neutralization reaction: the cation of the salt comes from the base and the anion of the salt comes from the acid. Remember this.

Let's do an example. Consider the reaction of lithium hydroxide and perchloric acid. What products are expected? Write balanced equations for this reaction, in the undissociated and the net ionic formats.

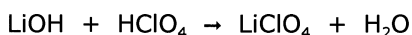
First, you need your reactant formulas. The formula of the base is  $LiOH$ . "Perchloric acid" is related to perchlorate anion,  $ClO_4^-$ , so the acid formula is  $HClO_4$ . We start with this much.



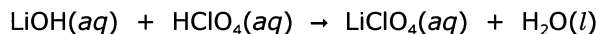
Now the products: a salt and usually water. What salt? The cation comes from the base, so it's  $Li^+$ . The anion comes from the acid, so it's  $ClO_4^-$ . Together, they're lithium perchlorate,  $LiClO_4$ . Put that into the equation.



What about "usually water"? In general, go ahead and put it into the equation unless the reaction involves ammonia. Being wrong or right with water will always show up when trying to balance, so you can always check at that time.

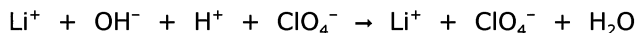


Well, you're in luck. This one balances readily. It's done. This is your final undissociated equation. How about phases?

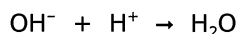


Many of the common acids and bases are soluble, so they'll get (*aq*). For a typical neutralization reaction, the salt product is usually soluble so it, too, will get (*aq*). Less commonly, a reactant may be insoluble or a salt may be insoluble, so be careful. In those cases the insoluble reagent gets the (*s*) designation. H<sub>2</sub>O gets its usual designation as (*l*).

Let's do the net ionic equation. Start with the above and bust up everybody who's dissociated.



Cancel out left and right as usual. That includes the lithium and perchlorate ions: they're spectators. What's left?

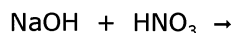


That's it. This is a common result. In fact, every neutralization between a strong acid and strong base will end up at this same net ionic equation.

Your turn.

.....  
**Example.** Write the undissociated equation and the net ionic equation for the reaction of sodium hydroxide and nitric acid.  
 .....

Follow the same steps as above. Start with the reactants.



The formula of the salt product is \_\_\_\_\_. (Cation from base, anion from acid.)

The undissociated equation is



Now go to net ionic. Bust up everyone that's dissociated.

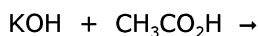


Get rid of the spectators. Put the final net ionic equation here:

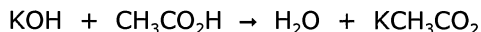


How does this compare to the net ionic equation for the prior LiOH/HClO<sub>4</sub> reaction?

The two reactions so far used strong acids and strong bases. When dealing with a weak acid or a weak base, the net ionic equation comes out differently. Let me show you how and why. We'll start with a weak acid example, the reaction of potassium hydroxide with acetic acid. Reactants, please.

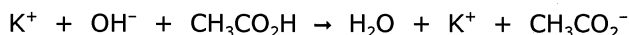


Add the salt, please. Which salt? What's the cation? It's K<sup>+</sup>. What's the anion? It's CH<sub>3</sub>CO<sub>2</sub><sup>-</sup>. Put them together, you get potassium acetate. You'll want some water with that salt.



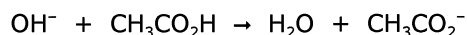
Notice that it works out to be balanced already, so this undissociated equation is done. Let's go to the net ionic.

We start with the undissociated equation and bust up everybody who's dissociated.



Notice that I kept acetic acid in undissociated form. Since it's a weak acid, very little acetic acid is actually dissociated. For this reason, it is entered into the equation in that manner. This is an important distinction from the strong acid cases. Remember this!

Continuing from here, we drop the spectating K<sup>+</sup> to reach the final net ionic equation.



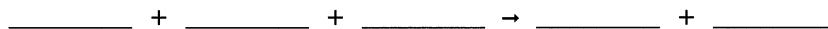
This outcome involving a weak acid is different compared to the net ionic equations for the strong acid cases. Notice that this is a good application for where you would need to know who is strong and who is weak.

Again and for emphasis: when constructing a net ionic equation, break up the strongs into their dissociated ions but write in the weaks as undissociated.

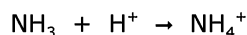
Let's go to weak bases. Consider ammonia. Here's the undissociated equation for the reaction of ammonia with hydrobromic acid.



Ammonium bromide is the salt product; notice that it also derives its cation from the base and its anion from the acid. That much is the same as earlier, but now there's no water. How about net ionic? No problem! You lead the way: put in ammonia as its neutral formula,  $\text{NH}_3$ , but bust up the strong acid into its dissociated ions. Ammonium bromide is also dissolved and dissociated.

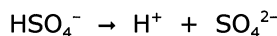
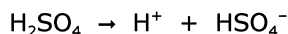


Drop the bromide. It's a spectator. The final net ionic equation is

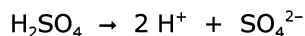


Hopefully you can see that these acid-base reactions are actually quite straightforward. Yes, they'll take lots of practice, but they do tend to be simpler than doing precipitation reactions.

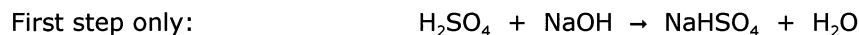
Before closing off this section, let me mention those acids which have more than one step. We talked in the beginning of this Chapter about sulfuric acid and how its dissociation can be broken into two steps.



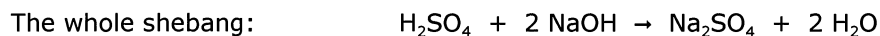
By the additivity of reactions, we can add these two together to get the overall equation.



In terms of neutralization reactions, the reaction can be written for the first step only or for all steps at once. I'll illustrate these two ways for sulfuric acid, using NaOH as base.



OR



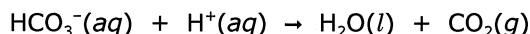
How do you know when to do which? It's not necessarily obvious, so some clue has to be provided. For example, if I ask for a balanced, undissociated equation for the reaction between sulfuric acid and sodium hydroxide, then both of the above are correct. If I ask for the equation for the reaction of equal mole amounts, then it's the first equation because it has the 1:1 rxn ratio. If I ask for the equation for the reaction with excess base, then it's the second one. This may seem a bit trickier, but think about it. As long as some base is in excess, then it will keep going and going and going until all steps are done. That gives you the whole shebang.

I think that's enough right now on acids and bases. Let's mosey on to gas-forming reactions.

### 12.3 It's a gas!

A gas-forming reaction is a reaction which forms a gas. There's not much to that definition.

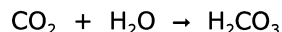
For starters, I'll tell you now that we've already looked at a gas-forming reaction but we didn't call it that at the time. It was the first reaction in Chapter 11: baking soda and acid. We chose hydrochloric acid at that time for that example.



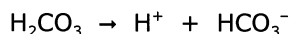
I also said you could use vinegar which, as we've seen, contains acetic acid. That equation would be similar but with a different salt product.



In either case,  $\text{CO}_2$  gas comes bubbling out. The reason that it bubbles out so freely is that  $\text{CO}_2$  has a lousy solubility in water. The first bits of  $\text{CO}_2$  formed in the reaction dissolve in the solution, but afterwards the solution can't hold anymore and the gas bubbles out. I mentioned this last Chapter with the acid rain connection. Remember? I said  $\text{CO}_2$  can dissolve to a small extent in water and that a small portion of dissolved  $\text{CO}_2$  can form carbonic acid

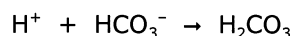


which can then do its acid thing.

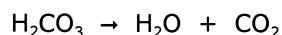


When you react sodium bicarbonate with an acid, you actually run these reactions backwards. Let's see how this works. To keep things somewhat easy, I'll use hydrochloric acid again. I'll stick with the net ionic format; the sodium and chloride ions are spectators, so I can leave them out.

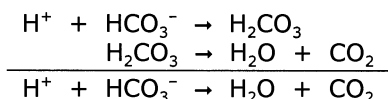
The first step is to react  $\text{H}^+$  (from the acid) with the bicarbonate anion.



Now right away, there are three things to note. First, this is backwards to the equation immediately prior. Second, carbonic acid is a weak acid, so it's written in undissociated form. Third, carbonic acid itself is quite reactive in water and it readily forms  $\text{CO}_2$ . That takes us to the next equation.

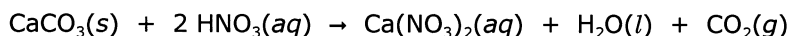


This equation is also backwards to one from above. Now, bring in the additivity of reactions and add these last two reactions together.

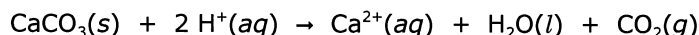


This gives you the overall, net ionic equation for the reaction between baking soda and hydrochloric acid, as first introduced in Chapter 11.

This reactivity with acids is very common for bicarbonate compounds in general. Furthermore, bicarbonate is the hydrogen anion of carbonate, and carbonate compounds react with acids in a similar manner. Calcium carbonate is a nice example. This stuff is actually very common geologically, biologically and even gastronomically: it's part of stalactites and stalagmites, marble, limestone, chalk, corals, shells, and some antacids. Like many carbonate compounds, it reacts with many acids to form carbon dioxide. I'll use nitric acid for this example.



The net ionic equation is



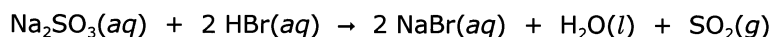
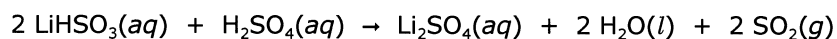
Notice that  $\text{CaCO}_3$ ,  $\text{H}_2\text{O}$  and  $\text{CO}_2$  are all written undissociated in the net ionic equation. All of this still relates to the points which you circled for net ionic equations in Chapter 11.

From these examples, we can summarize the characteristics of a  $\text{CO}_2$ -forming reaction as follows.

- The reactants are an acid and either a carbonate or a bicarbonate compound.
- The products are a salt, water and carbon dioxide.

For the salt, the anion comes from the acid and the cation comes from the other reactant.

Other types of gas-forming reactions are also known although not as common as the  $\text{CO}_2$ -formers. For example, there are  $\text{SO}_2$ -forming reactions. These start with a sulfite or bisulfite compound and that reacts with an acid. Here're a couple examples.



The characteristics for  $\text{SO}_2$ -formers closely parallel those above for  $\text{CO}_2$ -formers.

- The reactants are an acid and either a sulfite or a bisulfite compound.

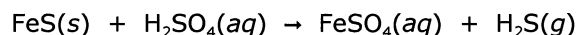
- The products are a salt, water and sulfur dioxide.

Once again, for the salt, the anion comes from the acid and the cation comes from the other reactant.

SO<sub>2</sub> is a lot more soluble in water than CO<sub>2</sub>, so you don't get the vigorous bubbling action here. Nevertheless, the smell of SO<sub>2</sub> is obvious in these reactions (but it can be harmful and must be avoided).

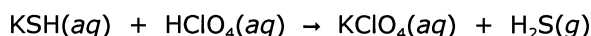
I mentioned sulfite compounds in Chapter 3 and their use as food preservatives. SO<sub>2</sub> is also used in some foods: they just gas your produce or whatever before shipping it out. Since sulfite, bisulfite and SO<sub>2</sub> are related chemically by the reactions above, each of these can work as a preservative. Read the labels. These things are part of your world. They are part of the food you eat. If you're one of the sulfite-sensitive people also mentioned in Chapter 3, then you must avoid all exposures to SO<sub>2</sub> and to sulfites because of this chemical connection.

Although there are several other kinds of gas-forming reactions, I'll just do one more example: hydrogen sulfide. This gas is readily formed in reactions between sulfide compounds and acids. Let me do one example.

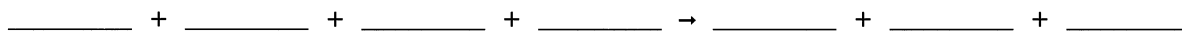


This one's a potent killer. I mentioned H<sub>2</sub>S in Chapter 4, when we were doing some examples for binary covalent names. At that time, I said it was wretched smelling. That's true, but it's also one of the most toxic gases on the planet. Nature produces it in a variety of ways, ranging from volcanos to deep-sea vents to simple bacterial action. Unfortunately, it is a killer in places which are not obvious: sewer systems and even drains in homes. Many bacteria metabolize sulfur compounds. Some bacteria grow in stagnant air and produce ionic sulfides, most of which are insoluble. This gives sulfide precipitates. Where can you find stagnant air? Sewers and drains, especially if plugged or not used often. If these sulfide compounds come into contact with acids, then H<sub>2</sub>S can form. Sewer workers know about this, since the gas can collect in pockets in large sewer lines and can be accidentally encountered. Many home plumbers know about this one, too. Why? These sulfide compounds can form in drain pipes, even in homes. Let's say your drain starts to plug. What do you do? Well, many people go to the store and buy drain cleaner, which is usually sodium hydroxide solution. Strong base, high concentration, powerful stuff. (I mentioned this in Chapter 11.) This stuff works many times, but not always. So if it doesn't work, then what? Well, there's another drain cleaner out there, usually in hardware or home improvement stores, which is sulfuric acid. Strong acid, high concentration, powerful stuff. You or your plumber can try to clear the drain with sulfuric acid. (Make sure you get the base out first with lots of water. If you don't, you can blow your drain system to smithereens. You could be burned in the process.) If the acid hits a pocket of sulfide deposits, you get H<sub>2</sub>S, like the reaction above. That means it's time to vamoose, quickly. Too many people, including sewer workers and plumbers, have died from this stuff. All because of bacteria doing their natural thing.

Like sulfides, the hydrogen anion of sulfide, HS<sup>-</sup>, will also react with acids to form H<sub>2</sub>S.



Here, you can do the net ionic equation for this one. First, bust up everybody that's dissolved and dissociated.



Potassium ion and perchlorate ion are spectators. Drop them. Write out the final result here.

\_\_\_\_\_

Let's now summarize the characteristics of the H<sub>2</sub>S-formers.

- The reactants are an acid and a compound with either S<sup>2-</sup> or HS<sup>-</sup> as the anion.
- The products are a salt and hydrogen sulfide gas.

Notice that water is not a product in this type of gas-forming reaction, although it was a product in CO<sub>2</sub>-formers and SO<sub>2</sub>-formers.

OK, this is enough for my purposes for gas-forming reactions. Your instructor may cover other types and that is their prerogative. Again, like I said from the very beginning in Chapter 1, I'm not going to cover everything.

Actually, right now, I'm going back to Chapter 1 anyway.

## 12.4 Back to balance

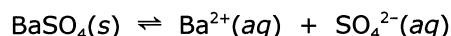
I'm going to tell it to you again. Not because I've run out of things to say (ha!), but because it is absolutely so important in all aspects of Nature, including chemistry, biology, physics, and just about everything that has to do with anything.

“ BALANCE. I cannot tell you in one paragraph the importance of balance in chemistry. So I will take time throughout the entire book to emphasize this. What we are dealing with in many cases is the balance of opposing processes. Different forces in combat with each other. Nature's tug-of-war. Again, this is not just chemistry. THERE IS STRUGGLE IN ALL OF NATURE. The expansion of the universe. The population dynamics of a simple ecosystem. So much of your world is the net outcome of different influences, different forces, different directions. Even your own personal finances: earn money, spend money. A lot of people think chemistry is just a fixed subject, black-or-white, yes-or-no. This is wrong. Very wrong. The majority of chemistry is dominated by balance. And in order for you to better understand the subject, you must come to appreciate these opposing influences, these opposing forces, these opposing directions.

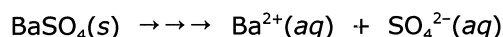
There is struggle in all of your world. Nature designed it that way. Keep this in mind. Forever. ”

I brought up balance again in Chapter 10 with solubility and dissociation. I will now extend it to acids and bases and to gas-formers. I'm also going to throw in a new term. As applied to chemical reactions, balance is called equilibrium. Very important. Underline it. The plural is equilibria, not equilibriums. (It's a Latin plural.) Chemical equilibrium will occur whenever opposing forces are operating within a chemical system. There will be a competition.

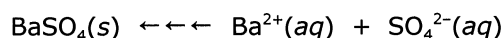
Let's apply this to our solubility discussion from Chapter 10. When you have an ionic solid in contact with water and part of that ionic solid is dissolved, even a tiny part, then you have an equilibrium. The opposing forces are the ionic bonds and water's hydration: the ionic bonds are trying to hold the solid together while the water is trying to pull the ions apart. We commonly designate an equilibrium process by a chemical equation which uses double-half-arrows instead of the usual single-full-arrow. I'll give an example, using barium sulfate again since we had talked about it so much previously.



Here's the important meaning of the double-half-arrows: BOTH directions of the reaction are possible. One direction is the forward, left-to-right direction

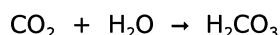


which tells us that some  $\text{BaSO}_4$  can dissolve (although it's a tiny amount). The other direction is the backwards or the reverse

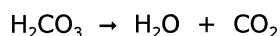


and it tells us that barium ions and sulfate ions can form solid barium sulfate (which is precipitation). I want to emphasize here that the double-half-arrows mean both directions are possible. They don't mean both directions are equally important. As a matter of fact, most equilibria are not equally important in both directions. For barium sulfate, we know dissolving is tiny.

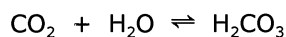
I discussed a second example of doing a reaction backwards when I talked about  $\text{CO}_2$  being an acid. In Chapter 11, I said it's because it can react with water to form carbonic acid.



Here in this Chapter, I said carbonic acid reacts readily to form carbon dioxide.



These are the opposite of each other and both directions are possible. So this is also equilibrium and we can use the double-half-arrows.



It is important that you understand the meaning here. The double-half-arrows mean that  $\text{CO}_2$  and  $\text{H}_2\text{O}$  can react to form  $\text{H}_2\text{CO}_3$  and that  $\text{H}_2\text{CO}_3$  can react to form  $\text{CO}_2$  and  $\text{H}_2\text{O}$ . If you had a bucket of this solution, then both things would indeed be going on at the same time! Yes, both directions at once! Why does this happen? It's part of balance. If the energies of products and reactants are close enough, then

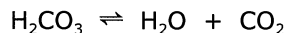


they are in competition with each other and both directions can occur. I'm not going into the energy business right now, so you'll have to wait for those aspects. Energy, along with entropy, will be connected to equilibrium in Chapter 47.

By the way, since equilibria go both ways, they can be written either way. I can write



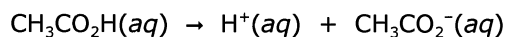
OR



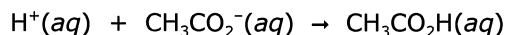
and it means the same thing.

A lot of reactions involve equilibria but many others do not, at least not to a significant extent. An excellent example of this difference is provided by the strong and weak acids and bases. In a nutshell and for practical purposes, weaks involve equilibria and strongs do not. THIS IS THE KEY DIFFERENCE BETWEEN ALL STRONG AND WEAK CASES OF ACIDS AND BASES. I'll show you how this works. We'll use acetic acid as our example for a weak acid again; we actually talked about its equilibrium in Chapter 11, but we didn't call it that at the time.

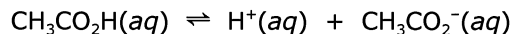
Acetic acid dissociates, but not a lot.



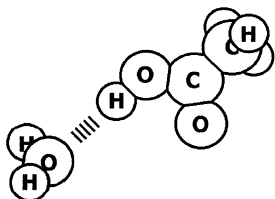
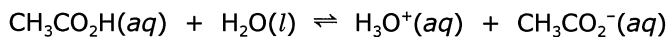
The reason is that the backwards reaction also occurs: acetate can react with  $\text{H}^+$  to re-form the acid.



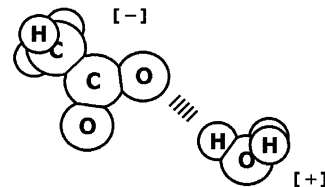
Both processes occur at the same time. Some molecules dissociate to ions and some ions recombine to form neutral molecules. This is an equilibrium. We can represent this as



Why is this an equilibrium and a strong acid such as hydrochloric acid is not? We have to go back to the whole story. Remember,  $\text{H}^+$  doesn't just form by itself.  $\text{CH}_3\text{CO}_2\text{H}$  doesn't just willingly break one of its bonds. NO ACID MOLECULE IN WATER WILL EVER BREAK ITS OWN BOND BY ITSELF. Something has to pull off the  $\text{H}^+$ , and it's really the  $\text{H}_2\text{O}$  molecules that do this. This is better seen in the  $\text{H}_3\text{O}^+$  version of the equation.

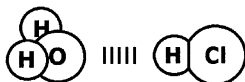


I've illustrated this notion of pulling in the diagram on the left. Water is trying to pull  $\text{H}^+$  off the molecule of acetic acid. If it wins, you get acetate and  $\text{H}_3\text{O}^+$  (and also  $\text{H}_5\text{O}_2^+$  as in any case of protonated water). Some waters do win, but acetate does not surrender willingly: it pulls back! I show this on the right. These are opposing



processes. They are in competition. These two processes will reach a balance, but that balance is nowhere near even. Depending on conditions, the amount dissociated could be 10% or 1% or 0.1% or etc. The exact numbers aren't important for us at this time, but we'll see their calculations later in Chapter 52.

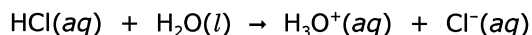
Now we compare this to a strong acid. How do strongs behave differently? I'll show this with hydrochloric acid. Water yanks on the neutral  $\text{HCl}$  molecule (shown at left), and breaks the bond to form



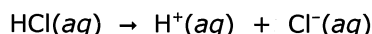
$\text{H}_3\text{O}^+$  and  $\text{Cl}^-$  (shown at right). Now here comes the important part: chloride does NOT pull back. Chloride is fairly content just being its old, hydrated self in water. It doesn't really care



about fighting over some  $\text{H}^+$ . That means there is no opposing process. There is no competition. THERE IS NO EQUILIBRIUM. We can represent this by using the standard single-full-arrow in the chemical equation.

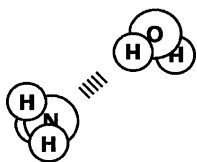


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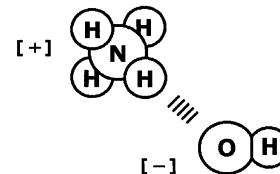
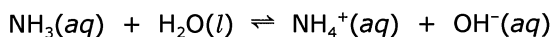


These aspects are critically important. Let me summarize the key differences between strong and weak acids.

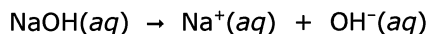
- When a strong acid dissolves in water, water pulls  $H^+$  off the acid molecule, leaving behind an anion. The anion does not pull back on  $H^+$  to a significant extent. There is no significant equilibrium.
- When a weak acid dissolves in water, water pulls  $H^+$  off the acid molecule, leaving behind an anion. The anion, however, pulls back on  $H^+$  and these two processes are in competition. This makes up an equilibrium.



The notion of competition is also important in distinguishing weak bases and strong bases. When ammonia dissolves in water, some ammonia molecules pull apart some water molecules to give  $NH_4^+$  and  $OH^-$ . Now, it's the hydroxide which competes, pulling back on the  $H^+$  in the ammonium cation. There's your competition. There's your equilibrium:



On the other hand, when sodium hydroxide dissolves in water, you get full dissociation into separate  $Na^+(aq)$  and  $OH^-(aq)$  ions. No competition. No equilibrium. That makes it a strong base.



Thus, the distinction between strong and weak bases has a parallel to the acids. Let's summarize this.

- Weak bases are characterized by an equilibrium competition between opposing processes.
- Strong bases lack an opposing process; there is no significant competition and there is no equilibrium.

Equilibria are incredibly important. There's a lot more to this stuff, and we'll come back to this in more detail in later Chapters. We'll do the math then, too, which is how you can calculate whether dissociation is 10% or 1% or 0.1% or etc. For now, this introduction will suffice. Even at this stage, it is important to realize how Nature can play the balance game in chemical reactions.

These things are part of your world. A very big part. Many of the biological processes in your cells are equilibria. In fact, many chemical components of your cells are weak acids or weak bases. Your health and your life depend on the proper balance between all of these. It's not just biology which depends on these aspects. Many of the reactions which help to shape this planet are also equilibrium reactions.

Unfortunately, it is not always easy to know at this stage if a given reaction involves equilibrium or not. Yes, the strong/weak acids and bases are clear cut, but other types of reactions are not obvious. We won't worry about everything at this time. Just be aware that I may choose to use the single-full-arrow ( $\rightarrow$ ) for reactions or I may choose to use the double-half-arrows ( $\rightleftharpoons$ ). It depends on what I want to emphasize at the time. Don't be surprised by this. We are still developing the Grand Puzzle.

This concludes our first three types of aqueous reactions. We are coming to our final aqueous reaction type: oxidation-reduction.

## Problems

1. True or false.
  - a. Hydrobromic acid is an oxyacid.
  - b.  $H^+$  is always a spectator ion in an acid/base reaction.
  - c. The dissociation of a weak acid in water represents an equilibrium system.
  - d. In the reaction of ammonium bicarbonate and sulfuric acid, ammonium is a spectator ion.
  - e. In an aqueous solution of chlorous acid,  $ClO_2^-$  and  $H_2O$  compete for  $H^+$  in an equilibrium process.

- f. The reaction of  $\text{K}_2\text{C}_2\text{O}_4$  with  $\text{HCl}(aq)$  produces  $\text{CO}_2(g)$ .
2. True or false.
- In the reaction of  $\text{HCl}$  with  $\text{LiOH}$ ,  $\text{Cl}^-$  is a spectator ion.
  - $(\text{NH}_4)_2\text{SO}_4$  is a salt.
  - An equilibrium is characterized as having opposing processes.
  - In a solution of ammonia in water,  $\text{NH}_3$  and  $\text{OH}^-$  compete for  $\text{H}^+$  in an equilibrium process.
  - When  $\text{HClO}_4$  dissolves in water, dissociation is complete and the reverse reaction (back to neutral molecules) does not occur.
  - Hydrochloric acid is a binary acid.
3. Give the formula for each of the following.
- hydrofluoric acid
  - oxalic acid
  - hypochlorous acid
  - carbonic acid
4. Give the name for each of the following acids.
- $\text{HBr}$
  - $\text{HNO}_2$
  - $\text{H}_3\text{AsO}_4$
  - $\text{HCN}$
5. For each of the following aqueous reactions, what is the formula of the salt which is produced?
- $\text{HNO}_3 + \text{LiOH}$
  - $\text{HCl} + \text{NH}_3$
  - acetic acid + sodium hydroxide
  - hydrochloric acid + calcium hydroxide
6. Write the undissociated equation and the net ionic equation for the aqueous reaction of  $\text{KOH}$  with  $\text{HBr}$ .
7. Write the undissociated equation and the net ionic equation for the aqueous reaction of  $\text{NaOH}$  with  $\text{HClO}_2$ .
8. Write the undissociated equation and the net ionic equation for the aqueous reaction of ammonia and hydrofluoric acid.
9. Write the undissociated equation for the aqueous reaction of  $\text{H}_3\text{PO}_4$  with  $\text{KOH}$  under the following conditions.
- The reactants are in a one-to-one mole ratio.
  - $\text{KOH}$  is in excess.
10. Write the undissociated equation and the net ionic equation for the reaction of  $\text{Na}_2\text{SO}_3(aq)$  with  $\text{HClO}_4(aq)$ .
11. Write the undissociated equation and the net ionic equation for the reaction of solid barium carbonate with hydrobromic acid.