

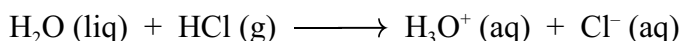
## Acid / Base Reactions (Method II):

All acid/base reactions involve a transfer of an  $\text{H}^+$  from either the solute or solvent to the other component. The direction of the transfer can then be used as a means of classifying the solute and solvent. They are classified as either a Brønsted/Lowry acid or a Brønsted/Lowry base (after to two scientists who first formulated the classification scheme). Under this system,

**An Acid:** an  $\text{H}^+$  donor

**A Base:** an  $\text{H}^+$  acceptor

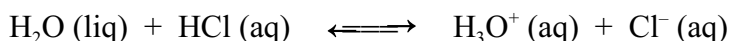
In the acid/base reaction previous described:



The HCl donates (or loses) an  $\text{H}^+$  to become  $\text{Cl}^-$  and thus HCl is classified as an acid in this reaction. The  $\text{H}_2\text{O}$  accepts an  $\text{H}^+$  to become  $\text{H}_3\text{O}^+$  and thus the  $\text{H}_2\text{O}$  is classified as a base in this reaction. Recall that in chemical equations, the reaction arrow,  $\longrightarrow$ , means that a chemical change took place but does not convey any indication of the “extent” of the reaction. That is, it provides no information on whether the reaction stops after 1%, 10%, 90% or 99.999%. All reactions eventually reach dynamic equilibrium.

As an analogy, think an outdoor tennis court which is surrounded by a fence and covered with 10,000 tennis balls. On one side of the net is Usain Bolt, the world’s fastest human, and you are on the other side with the objective of throwing all of the tennis ball onto the opposition’s side. As time passes, more and more tennis ball accumulate on your side because Usain is faster than you are. But, the rate at which he throws tennis balls over the net is dependent on TWO factors. Certainly, the rate depends on his speed but it is also a function of the distance he must travel to reach the next tennis ball. As Usain throws the balls onto your side the distance **he** must travel to the next ball gradually increases and thus the rate of tennis ball crossing the net from Usain’s side onto yours gradually decreases. Meanwhile, as the balls accumulate on you side, the distance **you** must travel to reach the next tennis ball decreases and thus your rate of tossing the ball onto Usain’s side increase. No matter how much faster Usain is than you, he will NEVER succeed in throwing all of the balls onto your side. Eventually, the rate of balls crossing the net from your side will match the rate of balls crossing the net towards your side. From that time on there will be a constant number of balls on each side (A dynamic equilibrium has been achieved). The side with the inherently faster player will end up with fewer balls on their court and the side with the inherently slower player will end up with more balls on their court at equilibrium.

So, like Usain Bolt, no matter how “good” HCl is as an acid, its reaction with water will never reach 100% and thus a dynamic equilibrium must ultimately be achieved.

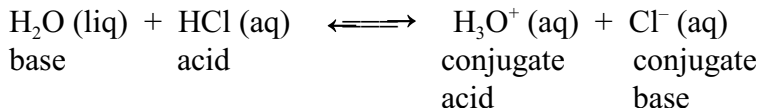


In the reverse direction, the  $\text{H}_3\text{O}^+$  donates an  $\text{H}^+$  to the  $\text{Cl}^-$  and therefore  $\text{H}_3\text{O}^+$  is an acid and  $\text{Cl}^-$  is a base. The product acid ( $\text{H}_3\text{O}^+$  is derived from the reactant base,  $\text{H}_2\text{O}$ ) and the product base ( $\text{Cl}^-$  is derived from the reactant acid,  $\text{HCl}$ ). This relationship is called a conjugate relationship.

Conjugate Acid: An acid **created** when a base accepts an  $\text{H}^+$ .

Conjugate Base: A base **created** when an acid donates an  $\text{H}^+$ .

Thus, the reactants and products can be labeled as:



### Classifications of Acids and Bases:

Acids and bases can be classified based on their abilities to react with a standard acid or a standard base. Since the solvent  $\text{H}_2\text{O}$  can function of both an acid or base, it is used as the reference acid and reference base.

**Strong Acid:** An acid that reacts with  $\text{H}_2\text{O}$  to form  $\text{H}_3\text{O}^+$  and the conjugate base to a large extent (which is approximated as  $\sim 100\%$ ).

There are only 6 common strong acids:  $\text{HNO}_3$ ,  $\text{HCl}$ ,  $\text{HBr}$ ,  $\text{HI}$ ,  $\text{H}_2\text{SO}_4$ , and  $\text{HClO}_4$ .  
*These should be committed to memory!*

**Weak acid:** An acid that reacts with  $\text{H}_2\text{O}$  to form  $\text{H}_3\text{O}^+$  and the conjugate base to a small extent (which is approximated as  $\sim 0\%$ ).

Weak acids are any acid that isn't a strong acid. E.g.,  $\text{HF}$ ,  $\text{HC}_2\text{H}_3\text{O}_2$ ,  $\text{HSO}_4^-$ ,  $\text{NH}_4^+$ ,  $\text{H}_2\text{CO}_3$ ,  $\text{HCN}$ , amino acids, and nucleic acids.

**Strong Base:** A base that reacts with  $\text{H}_2\text{O}$  to form  $\text{OH}^-$  and the conjugate acid to a large extent (which is approximated as  $\sim 100\%$ ).

There are only 10 common strong bases:  $\text{H}^-$ ,  $\text{N}^{3-}$ ,  $\text{P}^{3-}$ ,  $\text{As}^{3-}$ ,  $\text{O}^{2-}$ ,  $\text{S}^{2-}$ ,  $\text{Se}^{2-}$ ,  $\text{Te}^{2-}$ ,  $\text{NH}^{2-}$ , and  $\text{NH}_2^-$ . *These should be committed to memory!*

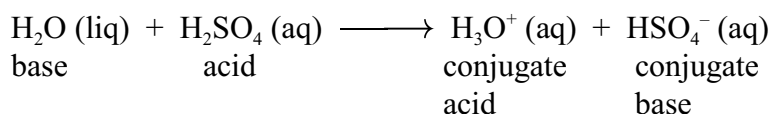
**Weak Base:** A base that reacts with  $\text{H}_2\text{O}$  to form  $\text{OH}^-$  and the conjugate acid to a small extent (which is approximated as  $\sim 0\%$ ).

Weak bases are all bases that aren't strong bases. E.g.,  $\text{F}^-$ ,  $\text{C}_2\text{H}_3\text{O}_2^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{NH}_3$ ,  $\text{HCO}_3^-$ ,  $\text{CN}^-$ , and all conjugate bases of weak acids.

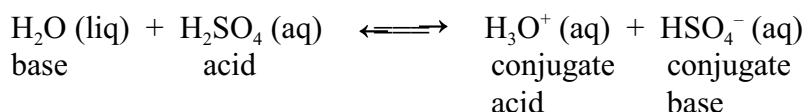
## Relative Strengths of Acids and Bases:

The classification of acids (or bases) as “strong” or “weak” is based on an arbitrary standard (the extent of their reactions with water). A better and more useful classification is achieved by allowing the acids (and bases) to “compete” against one another which results in an absolute ranking of the acids (and bases). Let’s look at several examples of such “competitions”.

First, consider the following acid/base reaction.



Even though  $\text{H}_2\text{SO}_4$  is classified as a “strong” acid, its reaction with water will never reach 100% and thus a dynamic equilibrium will ultimately be reached.



In this equilibrium there are two different competitions taking place. The two acids,  $\text{H}_2\text{SO}_4$  and  $\text{H}_3\text{O}^+$  are each trying to donate a proton ( $\text{H}^+$ ) while the two bases,  $\text{H}_2\text{O}$  and  $\text{HSO}_4^-$  are each trying to accept a proton.

Knowledge of the position of the equilibrium (and thus the extent of the original reaction) allows one to deduce which of the two acids is the stronger and which of the two bases is stronger.



IF at equilibrium, there are many  $\text{H}_3\text{O}^+$  and  $\text{HSO}_4^-$  ions and few  $\text{H}_2\text{SO}_4$  molecules, THEN, the original reaction:  $\text{H}_2\text{O (liq)} + \text{H}_2\text{SO}_4 \text{ (aq)} \longrightarrow \text{H}_3\text{O}^+ \text{ (aq)} + \text{HSO}_4^- \text{ (aq)}$ , must have gone to a LARGE EXTENT (>50%) to produce many aqueous ions.

If the reaction went to >50%, it follows then, that  $\text{H}_2\text{SO}_4$  must have donated more protons ( $\text{H}^+$ 's) than  $\text{H}_3\text{O}^+$  donated and thus  $\text{H}_2\text{SO}_4$  must be a **stronger** acid than  $\text{H}_3\text{O}^+$ . Likewise, If the reaction went to >50% it follows then, that  $\text{H}_2\text{O}$  must have accepted more protons than did  $\text{HSO}_4^-$  and thus  $\text{H}_2\text{O}$  must be a **stronger** base than  $\text{HSO}_4^-$ .

Conversely, IF at equilibrium, there are few  $\text{H}_3\text{O}^+$  and  $\text{HSO}_4^-$  ions and many  $\text{H}_2\text{SO}_4$  molecules, THEN, the original reaction:  $\text{H}_2\text{O (liq)} + \text{H}_2\text{SO}_4 \text{ (aq)} \longrightarrow \text{H}_3\text{O}^+ \text{ (aq)} + \text{HSO}_4^- \text{ (aq)}$ , must have gone to a SMALL EXTENT (<50%) to produce so few aqueous ions.

If the reaction went to <50%, it follows then, that  $\text{H}_3\text{O}^+$  must have donated more protons ( $\text{H}^+$ 's) than  $\text{H}_2\text{SO}_4$  donated and thus  $\text{H}_3\text{O}^+$  must be a **stronger** acid than  $\text{H}_2\text{SO}_4$ . Likewise, If the reaction went to <50% it follows then, that  $\text{HSO}_4^-$  must have accepted more protons than did  $\text{H}_2\text{O}$  and thus  $\text{HSO}_4^-$  must be a **stronger** base than  $\text{H}_2\text{O}$ .

How can one determine the extent of reaction between  $\text{H}_2\text{SO}_4$  and water,  
 $\text{H}_2\text{O}(\text{liq}) + \text{H}_2\text{SO}_4(\text{aq}) \longrightarrow \text{H}_3\text{O}^+(\text{aq}) + \text{HSO}_4^-(\text{aq})$  ?

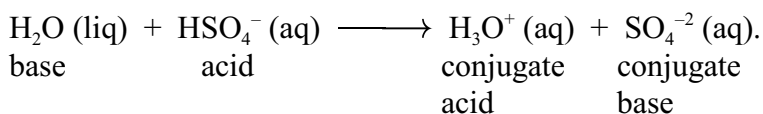
Conductivity! In this reaction, there are mobile charge carriers (ions) on the right side of the equation but none on the left side. Thus, the greater the conductivity of the solution the greater the number of ions that must be present (and thus the greater the extent of the reaction).

Actual conductivity measurements on  $\text{H}_2\text{SO}_4$  solutions clearly demonstrate that the solutions are excellent conductors of electricity after equilibrium is reached.

Thus, the original reaction,  $\text{H}_2\text{O}(\text{liq}) + \text{H}_2\text{SO}_4(\text{aq}) \longrightarrow \text{H}_3\text{O}^+(\text{aq}) + \text{HSO}_4^-(\text{aq})$ , must, then, gone to a large extent (experiments show  $\sim 100\%$ ).

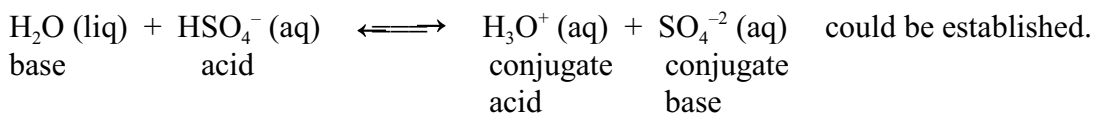
Finally, we can now definitively state that on an absolute basis (not by an arbitrary definition), that  $\text{H}_2\text{SO}_4$  is a stronger acid than  $\text{H}_3\text{O}^+$  and  $\text{H}_2\text{O}$  is a stronger base than  $\text{HSO}_4^-$ .

Let's consider another reaction with another pair of acids and bases.



The extent of this reaction needs to be determined so that the relative strengths of the two acids and the two bases can be unambiguously established. What solute can be used?  $\text{H}_2\text{SO}_4$  is unacceptable as the aqueous solution already contains one of the products,  $\text{H}_3\text{O}^+$ , from the first reaction. Is it possible to find a solute that contains only  $\text{HSO}_4^-$  ions which we can add to water to produce the above reaction? No, a collection of  $\text{HSO}_4^-$  ions only would have a tremendously large amount of repulsions which would prevent them from ever being confined to a bottle by themselves. Cations are needed to create attraction to the anions which would counterbalance the repulsions between the  $\text{HSO}_4^-$  ions. Thus an ionic solid containing  $\text{HSO}_4^-$  is needed. A sample of  $\text{NaHSO}_4$  would work. Upon dissolution the  $\text{Na}^+$  and  $\text{HSO}_4^-$  dissociate into the solution. After dissociation, the  $\text{HSO}_4^-$  ions would then react with the water to generate the above reaction for study.

The extent of reaction could be determined **if** the position of the equilibrium,

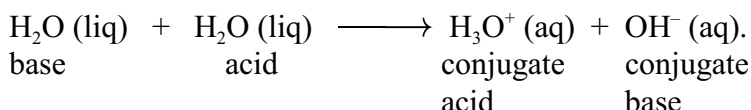


Unfortunately, the conductivity measurements used previously cannot be used in this example to establish the position of the equilibrium. IF the position of equilibrium lied far to the left (i.e., the reaction went to a small extent) there would be many ions present ( $\text{Na}^+$  and  $\text{HSO}_4^-$ ) and the solution would be highly conductive. IF the position of equilibrium lied far to the right (i.e., the reaction went to a large extent) there would also be many ions present ( $\text{Na}^+$ ,  $\text{H}_3\text{O}^+$  and  $\text{SO}_4^{2-}$ ) and the solution would again be highly conductive. Thus, simple conductivity measurements cannot establish the position of the equilibrium.

Alternatively, a pH meter can be used. A pH meter measures the concentration of  $\text{H}_3\text{O}^+$  in a solution. The  $\text{H}_3\text{O}^+$  concentrations in  $\text{NaHSO}_4$  solutions are found to be relatively small. Thus, the position of the equilibrium lies to the left which means that the original reaction goes to a small extent (<50%). As described earlier, for reactions that go <50%, the acid and base on the product side are stronger than the acid and base on the reactant side.

Therefore, we can now definitively state that on an absolute basis that  $\text{H}_3\text{O}^+$  is a stronger acid than  $\text{HSO}_4^-$  .....and  $\text{SO}_4^{2-}$  is a stronger base than  $\text{H}_2\text{O}$ .

The next reaction is an interesting one.



Common sense tells us this reaction goes to a very small extent. If it went to a large extent then water would exist as a collection of ions (without the solvent as the solvent water would also be consumed in the reaction). Thus, water would be an ionic solid at room temperature!!

Since the reaction clearly goes to a small extent (<50%), the acid and base on the right are stronger than the acid and base on the left side. Therefore, we can now definitively state that on an absolute basis that  $\text{H}_3\text{O}^+$  is a stronger acid than  $\text{H}_2\text{O}$  .....and  $\text{OH}^-$  is a stronger base than  $\text{H}_2\text{O}$ .

### Relative Strengths of Acids and Bases Rankings:

In the previous three examples, a total of four acids ( $\text{H}_2\text{SO}_4$ ,  $\text{HSO}_4^-$ ,  $\text{H}_2\text{O}$ , and  $\text{H}_3\text{O}^+$ ) and a total of four bases ( $\text{HSO}_4^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{H}_2\text{O}$ , and  $\text{OH}^-$ ) were compared in terms of their relative strengths. From the first reaction we found that  $\text{H}_2\text{SO}_4$  is a stronger acid than  $\text{H}_3\text{O}^+$  and  $\text{H}_2\text{O}$  is a stronger base than  $\text{HSO}_4^-$ . From the second reaction we found that  $\text{H}_3\text{O}^+$  is a stronger acid than  $\text{HSO}_4^-$  and  $\text{SO}_4^{2-}$  is a stronger base than  $\text{H}_2\text{O}$ . The third reaction demonstrated that  $\text{H}_3\text{O}^+$  is a stronger acid than  $\text{H}_2\text{O}$  and  $\text{OH}^-$  is a stronger base than  $\text{H}_2\text{O}$ .

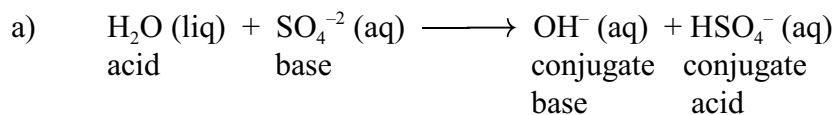
Combining these acid comparisons gives:  $\text{H}_2\text{SO}_4 > \text{H}_3\text{O}^+ > \text{HSO}_4^-$   
and:  $\text{H}_2\text{SO}_4 > \text{H}_3\text{O}^+ > \text{H}_2\text{O}$ .

There is **not** enough information to determine the relative strengths of  $\text{HSO}_4^-$  and  $\text{H}_2\text{O}$ .

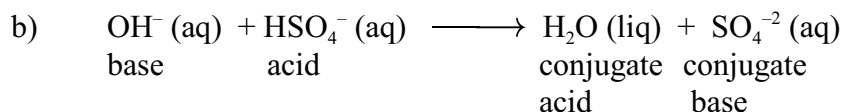
For bases, the comparisons also gives:  $\text{SO}_4^{2-} > \text{H}_2\text{O} > \text{HSO}_4^-$   
and:  $\text{OH}^- > \text{H}_2\text{O} > \text{HSO}_4^-$

Again, there is **not** enough information to determine the relative strengths of  $\text{SO}_4^{2-}$  and  $\text{OH}^-$ .

To eliminate the remaining uncertainties in strengths, another reaction is needed; one that compares  $\text{HSO}_4^-$  and  $\text{H}_2\text{O}$  as acids and  $\text{SO}_4^{2-}$  and  $\text{OH}^-$  as bases. To compare to acids they must appear on opposite side of the reaction. This provides two options,



or



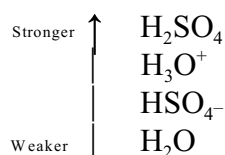
These two reactions are merely reverses of each other. If reaction a) goes to a large extent then b) must go to a small extent. If reaction a) goes to a small extent then reaction b) must go to a large extent. Therefore, only one is needed and it doesn't matter which one is used.

Reaction a) is actually easier to perform as it only requires  $\text{Na}_2\text{SO}_4$  (s). When  $\text{Na}_2\text{SO}_4$  is added to water, the ions will dissociate upon dissolution. Then the  $\text{SO}_4^{2-}$  ion can react with the water.

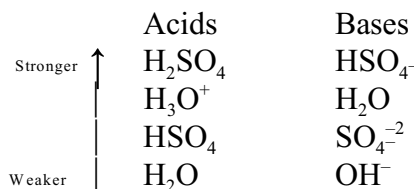
Reaction b) requires both  $\text{NaHSO}_4$  (s) and  $\text{NaOH}$  (s). When these two salts are added to water, both will dissociate upon dissolution into  $\text{Na}^+$  and  $\text{HSO}_4^-$  and  $\text{Na}^+$  and  $\text{OH}^-$  ions respectively. Then, the  $\text{HSO}_4^-$  and  $\text{OH}^-$  ion can react.

Since both reactions involve ionic compounds, conductivity cannot be used to determine the extent of reaction. A pOH meter however would work well. A pOH meter (which measures the concentration of  $\text{OH}^-$  ions) shows that there is very little  $\text{OH}^-$  in either solution once equilibrium is reached. Thus, reaction "a" goes to a small extent (and thus "b" goes to a large extent). Since "a" goes to a small extent, the product acid and product base are stronger than the reactant acid and reactant base ( $\text{OH}^- > \text{SO}_4^{2-}$  as bases and  $\text{HSO}_4^- > \text{H}_2\text{O}$  as acids).

With this final experiment we can rank the four acids in terms of decreasing strength.

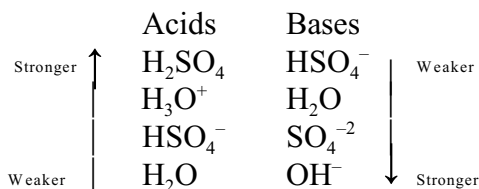


Placing the conjugate bases next to their respective acids give ,



The conjugate bases are already in the proper sequence of **increasing** relative strengths.

I.e.,



This table is referred to as an acid/base table.

## USING AN ACID/BASE TABLE:

Below is an expanded table with 8 acids and 8 conjugate bases.

|            | Acids                                         | Bases                                                     |            |
|------------|-----------------------------------------------|-----------------------------------------------------------|------------|
| Stronger ↑ | H <sub>2</sub> SO <sub>4</sub>                | HSO <sub>4</sub> <sup>-</sup>                             | ↓ Weaker   |
|            | HCl                                           | Cl <sup>-</sup>                                           |            |
|            | H <sub>3</sub> O <sup>+</sup>                 | H <sub>2</sub> O                                          |            |
|            | HSO <sub>4</sub> <sup>-</sup>                 | SO <sub>4</sub> <sup>-2</sup>                             |            |
|            | HC <sub>2</sub> H <sub>3</sub> O <sub>2</sub> | C <sub>2</sub> H <sub>3</sub> O <sub>2</sub> <sup>-</sup> |            |
|            | NH <sub>4</sub> <sup>+</sup>                  | NH <sub>3</sub>                                           |            |
|            | H <sub>2</sub> O                              | OH <sup>-</sup>                                           |            |
| Weaker ↓   | HX                                            | X <sup>-</sup>                                            | ↓ Stronger |

Consider a mixture of HCl and H<sub>2</sub>O. The expanded acid/base table shows that a reaction will occur between these two chemicals with HCl acting as the acid and H<sub>2</sub>O functioning as the base. It also shows that when these two react they will produce their respective conjugates, H<sub>3</sub>O<sup>+</sup> and Cl<sup>-</sup>. The extent of reaction can also be gleaned from the table by comparing the strengths of the two acids (or the strengths of the two bases). The table indicates that the reactant acid, HCl is a stronger acid than the product acid, H<sub>3</sub>O<sup>+</sup> and thus the reaction will go to a large extent (>50%) before equilibrium is reached. I.e., H<sub>2</sub>O (liq) + HCl (aq) → H<sub>3</sub>O<sup>+</sup> (aq) + Cl<sup>-</sup> (aq) Large Extent

Note that ANY acid that is **above** H<sub>3</sub>O<sup>+</sup> on the table (like H<sub>2</sub>SO<sub>4</sub> or HCl) is stronger than H<sub>3</sub>O<sup>+</sup>. These acids (which are stronger than H<sub>3</sub>O<sup>+</sup>) will therefore, react with H<sub>2</sub>O as a base to form H<sub>3</sub>O<sup>+</sup> and the conjugate base to a large extent. This is the definition mentioned earlier of a strong acid. Thus the six strong acids are listed in any expanded acid/base table above H<sub>3</sub>O<sup>+</sup>. As a reminder, a line can be drawn through the acid base table just above H<sub>3</sub>O<sup>+</sup> to separate the strong acids from the others.

|            | Acids                                         | Bases                                                     |            |
|------------|-----------------------------------------------|-----------------------------------------------------------|------------|
| Stronger ↑ | H <sub>2</sub> SO <sub>4</sub>                | HSO <sub>4</sub> <sup>-</sup>                             | ↓ Weaker   |
|            | HCl                                           | Cl <sup>-</sup>                                           |            |
|            | H <sub>3</sub> O <sup>+</sup>                 | H <sub>2</sub> O                                          |            |
|            | HSO <sub>4</sub> <sup>-</sup>                 | SO <sub>4</sub> <sup>-2</sup>                             |            |
|            | HC <sub>2</sub> H <sub>3</sub> O <sub>2</sub> | C <sub>2</sub> H <sub>3</sub> O <sub>2</sub> <sup>-</sup> |            |
|            | NH <sub>4</sub> <sup>+</sup>                  | NH <sub>3</sub>                                           |            |
|            | H <sub>2</sub> O                              | OH <sup>-</sup>                                           |            |
| Weaker ↓   | HX                                            | X <sup>-</sup>                                            | ↓ Stronger |

Consider a mixture of X<sup>-</sup> and H<sub>2</sub>O. The expanded acid/base table shows that a reaction will occur between these two chemicals with H<sub>2</sub>O acting as the acid and X<sup>-</sup> functioning as the base. It also shows that when these two react they will produce their respective conjugates, HX and OH<sup>-</sup>. The extent of reacting can also be gleaned from the table by comparing the strengths of the two acids (or the strengths of the two bases). The table indicates that the reactant acid, H<sub>2</sub>O is a stronger acid than the product acid, HX and thus the reaction will go to a large extent (>50%) before equilibrium is reached. I.e., H<sub>2</sub>O (liq) + X<sup>-</sup> (aq) → HX (aq) + OH<sup>-</sup> (aq) Large Extent

Note that ANY base that is **below**  $\text{OH}^-$  on the table is stronger than  $\text{OH}^-$ . These bases (which are stronger than  $\text{OH}^-$ ) will therefore, react with  $\text{H}_2\text{O}$  as an acid to form  $\text{OH}^-$  and the conjugate acid to a large extent. This is the definition mentioned earlier of a strong base. Thus the ten strong bases are listed in any expanded acid/base table below  $\text{OH}^-$ . As a reminder, a line can be drawn through the acid base table just below  $\text{OH}^-$  to separate the strong bases from the others.

|            | Acids                             |                   | Bases                              |            |
|------------|-----------------------------------|-------------------|------------------------------------|------------|
| Stronger ↑ | $\text{H}_2\text{SO}_4$           | } Strong<br>Acids | $\text{HSO}_4^-$                   | Weaker     |
|            | $\text{HCl}$                      |                   | $\text{Cl}^-$                      |            |
|            | $\text{H}_3\text{O}^+$            |                   | $\text{H}_2\text{O}$               |            |
|            | $\text{HSO}_4^-$                  |                   | $\text{SO}_4^{2-}$                 |            |
|            | $\text{HC}_2\text{H}_3\text{O}_2$ |                   | $\text{C}_2\text{H}_3\text{O}_2^-$ |            |
|            | $\text{NH}_4^+$                   |                   | $\text{NH}_3$                      |            |
|            | $\text{H}_2\text{O}$              |                   | $\text{OH}^-$                      |            |
| Weaker ↓   | $\text{HX}$                       |                   | $\text{X}^-$                       |            |
|            |                                   |                   | } Strong<br>Bases                  | Stronger ↓ |
|            |                                   |                   |                                    |            |

The acids which are weaker than  $\text{H}_3\text{O}^+$  are of course “weak acids” while the bases that are weaker than  $\text{OH}^-$  are “weak bases”. The labels can also be added to the table.

|            | Acids                             |                   | Bases                              |                 |
|------------|-----------------------------------|-------------------|------------------------------------|-----------------|
| Stronger ↑ | $\text{H}_2\text{SO}_4$           | } Strong<br>Acids | $\text{HSO}_4^-$                   | Weaker          |
|            | $\text{HCl}$                      |                   | $\text{Cl}^-$                      |                 |
|            | $\text{H}_3\text{O}^+$            | } Weak<br>Acids   | $\text{H}_2\text{O}$               | } Weak<br>Bases |
|            | $\text{HSO}_4^-$                  |                   | $\text{SO}_4^{2-}$                 |                 |
|            | $\text{HC}_2\text{H}_3\text{O}_2$ |                   | $\text{C}_2\text{H}_3\text{O}_2^-$ |                 |
|            | $\text{NH}_4^+$                   |                   | $\text{NH}_3$                      |                 |
|            | $\text{H}_2\text{O}$              |                   | $\text{OH}^-$                      |                 |
| Weaker ↓   | $\text{HX}$                       |                   | $\text{X}^-$                       |                 |
|            |                                   |                   | } Strong<br>Bases                  | Stronger ↓      |
|            |                                   |                   |                                    |                 |

How should bases such as  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$  be classified? Consider a reaction of an acid with a mixture of  $\text{H}_2\text{O}$  and  $\text{Cl}^-$ . In this mixture the acid will donate its  $\text{H}^+$  to the base that is the stronger. The table shows that  $\text{H}_2\text{O}$  is stronger than  $\text{Cl}^-$  and thus the  $\text{H}_2\text{O}$  will be the base that accepts the  $\text{H}^+$ . Thus, bases like  $\text{Cl}^-$  will never accept  $\text{H}^+$ 's as long as  $\text{H}_2\text{O}$  is present. They are simply too weak to act as bases in aqueous solutions.

How should acids such as  $\text{HX}$  be classified? Consider a reaction of a base with a mixture of  $\text{H}_2\text{O}$  and  $\text{HX}$ . In this mixture the base will accept an  $\text{H}^+$  from the acid that is the stronger. The table shows that  $\text{H}_2\text{O}$  is stronger than  $\text{HX}$  and thus the  $\text{H}_2\text{O}$  will be the acid that donates its  $\text{H}^+$ . Thus, acids like  $\text{HX}$  will donate  $\text{H}^+$ 's as long as  $\text{H}_2\text{O}$  is present. They are simply too weak to act as acids in aqueous solutions.



Thus, the completed table looks like:

| Acids      |                                                                                                                            |                                                       | Bases                                                                                                              |                                                       |            |
|------------|----------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|------------|
| Stronger ↑ | $\text{H}_2\text{SO}_4$<br>$\text{HCl}$                                                                                    | } Strong<br>Acids                                     | $\text{HSO}_4^-$<br>$\text{Cl}^-$                                                                                  | } Too weak to act<br>as bases in $\text{H}_2\text{O}$ | Weaker     |
|            | $\text{H}_3\text{O}^+$<br>$\text{HSO}_4^-$<br>$\text{HC}_2\text{H}_3\text{O}_2$<br>$\text{NH}_4^+$<br>$\text{H}_2\text{O}$ | } Weak<br>Acids                                       | $\text{H}_2\text{O}$<br>$\text{SO}_4^{2-}$<br>$\text{C}_2\text{H}_3\text{O}_2^-$<br>$\text{NH}_3$<br>$\text{OH}^-$ | } Weak<br>Bases                                       |            |
| Weaker ↓   | $\text{HX}$                                                                                                                | } Too weak to act<br>as acids in $\text{H}_2\text{O}$ | $\text{X}^-$                                                                                                       | } Strong<br>Bases                                     | Stronger ↓ |

We have seen that strong acid solutes such as  $\text{HCl}$  react with the solvent  $\text{H}_2\text{O}$  to create solutions which are strong electrolytes. But what about solutes such as  $\text{NH}_3$  and  $\text{HC}_2\text{H}_3\text{O}_2$ ?

Well, looking at the acid/base table above we see that the acid,  $\text{HC}_2\text{H}_3\text{O}_2$ , will react  $\text{H}_2\text{O}$  to form  $\text{H}_3\text{O}^+$  and  $\text{C}_2\text{H}_3\text{O}_2^-$  to a small extent. Thus the resulting solution of  $\text{HC}_2\text{H}_3\text{O}_2$  and  $\text{H}_2\text{O}$  will be a weak electrolyte (I.e., it conducts only slightly).

We can also see by looking at the acid/base table above we see that the base,  $\text{NH}_3$ , will react  $\text{H}_2\text{O}$  to form  $\text{NH}_4^+$  and  $\text{OH}^-$  to a small extent. Thus the resulting solution of  $\text{NH}_3$  and  $\text{H}_2\text{O}$  will be a weak electrolyte (I.e., it conducts only slightly).

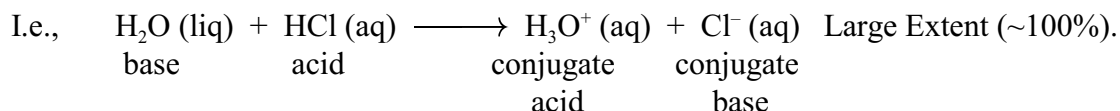
## INVENTORY:

In chemistry, an inventory is NOT an all inclusive list of everything that is present in the solution. It is simply a list of the MAJOR solute species (both molecules and ions) that are present in a solution in relatively high concentrations. Why is it necessary to take an inventory of a solution?

Chemists usually refer to solutions based on the components that were combined to make the solution and NOT to what is actually present in the solution. Recall, that there are several different possible results when a solute and solvent are mixed. The solute could: merely dissolve; it could undergo an acid/base reaction with the solvent; or it could undergo an oxidation/reduction reaction with the solvent. Some of these may even have occurred without the chemists knowing it! Thus, chemists prefer to list the original solution components and allow the user of the solution to deduce the actual solute species present. The process of deducing the current solution components is referred to as “inventorying.”

For example, 1M  $\text{HCl}$ . In this case, the 1M  $\text{HCl}$  “label” merely means that  $\text{HCl}$  was mixed with water and that there was originally 1 mole of  $\text{HCl}$  for every liter of final solution. It doesn’t mean that was only 1 mole of  $\text{HCl}$  or that there was only 1 liter of solution. It doesn’t even mean that there is **any**  $\text{HCl}$  left in the final solution!

Recall that HCl is one of the six strong acids (that you were told to have committed to memory). Thus, its reaction with water is known to go to a large extent.

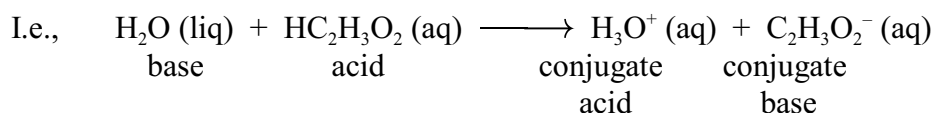


What, then, is the “inventory” for this solution? Clearly, the solute species existing in the final solution are  $\text{H}_3\text{O}^+$  (aq) and  $\text{Cl}^-$  (aq). The inventory of this solution is written as  $[\text{H}_3\text{O}^+] = 1\text{M}$  and  $[\text{Cl}^-] = 1\text{M}$  where [xxx] is read as “concentration of”.

Thus, the equation for **any** reaction involving this solution **should not** include HCl but rather  $\text{H}_3\text{O}^+$  and/or  $\text{Cl}^-$ .

Logically then, what should be the inventory of solutions of **any** strong acid? (As the conjugate base and  $\text{H}_3\text{O}^+$ !)

As a second example, let’s look at 1M  $\text{HC}_2\text{H}_3\text{O}_2$  (acetic acid). Again, the label indicates that originally 1 mole 1M  $\text{HC}_2\text{H}_3\text{O}_2$  was added for **each** liter of final solution. Looking at the acid/base table shows that 1M  $\text{HC}_2\text{H}_3\text{O}_2$  is indeed an acid and water can act as the base. Thus,  $\text{H}_3\text{O}^+$  and  $\text{C}_2\text{H}_3\text{O}_2^-$  would be the products.

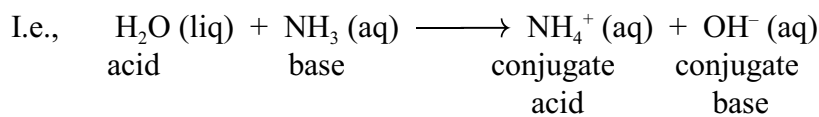


From the table it is clear that  $\text{H}_3\text{O}^+$  is a **stronger** acid than  $\text{HC}_2\text{H}_3\text{O}_2$  and that  $\text{C}_2\text{H}_3\text{O}_2^-$  is a **stronger** base than  $\text{H}_2\text{O}$  (ergo,  $\text{HC}_2\text{H}_3\text{O}_2$  is weak acid). We therefore conclude that this reaction will proceed to the right to a small extent before equilibrium is reached (which we approximate as zero %) . This solution should therefore be inventoried as  $[\text{HC}_2\text{H}_3\text{O}_2] = 1\text{M}$ .

Thus, the equation for **any** reaction involving this solution **should** include  $\text{HC}_2\text{H}_3\text{O}_2$  and **NOT** include  $\text{H}_3\text{O}^+$  and/or  $\text{C}_2\text{H}_3\text{O}_2^-$ .

Logically then, what should be the inventory of solutions of **any** weak acid? (As the weak acid itself!)

Consider a 1M  $\text{NH}_3$ . Again, the label indicates that there was originally 1 mole  $\text{NH}_3$  added for **each** liter of final solution. A glance at the acid/base table shows that  $\text{NH}_3$  is a base and water can act as the acid. Thus,  $\text{NH}_4^+$  and  $\text{OH}^-$  would be the products.



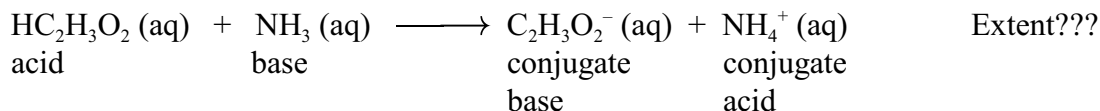
From the table it is clear that  $\text{OH}^-$  is a **stronger** base than  $\text{NH}_3$  and that  $\text{NH}_4^+$  is a **stronger** acid than  $\text{H}_2\text{O}$  (I.e.,  $\text{NH}_3$  is a weak base) . We therefore conclude that this reaction will proceed to the right to a small extent before equilibrium is reached (which we approximate as zero %) . This solution should therefore be inventoried as  $[\text{NH}_3] = 1\text{M}$ .

Thus, the equation for **any** reaction involving this solution **should** include  $\text{NH}_3$  and **NOT** include  $\text{NH}_4^+$  and/or  $\text{OH}^-$ .

Logically then, what should be the inventory of solutions of **any** weak base? (As the weak base itself!)

As a final example, what happens if equal volumes of 1M  $\text{HC}_2\text{H}_3\text{O}_2$  and 1M  $\text{NH}_3$  solutions are mixed?

We know that the acid,  $\text{HC}_2\text{H}_3\text{O}_2$ , and the base,  $\text{NH}_3$ , will react to form their respective conjugates,  $\text{C}_2\text{H}_3\text{O}_2^-$  and  $\text{NH}_4^+$  but to what extent?



By looking at the acid/base table, we see that both the reactant acid,  $\text{HC}_2\text{H}_3\text{O}_2$ , and reactant base,  $\text{NH}_3$ , are **stronger** than the product acid,  $\text{NH}_4^+$ , and the product base,  $\text{C}_2\text{H}_3\text{O}_2^-$ , respectively. Thus, we can tell that the reaction goes to a large extent. Since the products are ions which are created to a **large** extent the resulting solution is a strong electrolyte! The inventory of this final mixture should therefore be  $[\text{C}_2\text{H}_3\text{O}_2^-] = 0.5\text{M}$  and  $[\text{NH}_4^+] = 0.5\text{M}$ . (Do you see why 0.5 M and **not** 1M?)

This points out an important facet of acid/base reactions which is that a strong acid or strong base is **NOT** needed to create a reaction which goes to a large extent. A large extent reaction is generated when ever the reactant acid and base are **strongER** than the product acid and base.