Chemistry 30 Unit 4 - Acid/Base Equilibrium

The Bronsted-Lowery Acid-Base Concept

Bronsted

Lowery

Let us think about our definition of acids and how it has progressed:

it started in Chem 20 with:
"acids are compounds with an H in them and are aqueous."

Then went to the first Arrhenius definition:
"acids ionize to form hydrogen ions in water"

Then we learned about hydronium and it changed to:
"acids ionize to form hydronium in water".

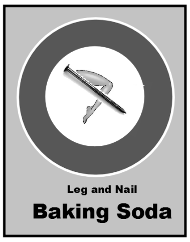
Then we applied the idea of equilibrium to acids and came up with the reaction equilibrium eqn and the $K_w = [H_3O^+][OH^-]$

Then we learned about a new way to express the concentrations of hydrogen and hydronium:

$pH = -\log[H_3O^+]$ $pOH = -\log[OH^-]$

But our theory is still not complete...there are still certain things which can not be explained by our current understanding.

One such thing is Leg and Nail Brand Baking Soda.



$NaHCO_{3(aq)}$

If dissolved in water, it has a pH > 7. So it is a base.

But...if placed in a strong base like lye, it will partially neutralize the base. So it is an acid.

So is baking soda an acid or a base? We need to refine our theory.

A new theory about acids and bases came in 1923 out of Denmark. Two scientists, Johannes Brønsted and Thomas Lowery, came up with a new way of thinking of acids and bases.

Consider the following:

Let's look at a typical acid reaction:

$$HCl_{(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + Cl^-_{(aq)}$$

Notice a hydrogen is transferred from the acid to the water.

Now a base reaction:

$$NH_{3(aq)} + H_2O_{(l)} \rightleftharpoons OH^-_{(aq)} + NH_4^+{}_{(aq)}$$

Here, a hydrogen is taken from the water and gained by the base.

By studying reactions like these, Bronsted and Lowery determined that hydrogen transfer or proton transfer must be the real key to acid-base chemistry.

According to the Bronsted-Lowery Concept:

1. An acid is something that donates protons.
2. A base is something that accepts protons.
3. An acid-base reaction involves the transfer of one or more protons.
4. The protons move from the strongest acid to the strongest base.
5. A substance (i.e. whole compound) can act as an acid or base (term: amphoteric).
6. An entity (i.e. an ion or molecule) can act as a proton donor or acceptor (term: amphiprotic).

So, according to this new theory, there is no substance that is "only an acid". Any acid can act as a base, given there is a stronger acid present to donate an electron.

This can explain the nature of baking soda.

Acting as a base in the presence of a strong acid...

proton transfer

$HCO_3^-{}_{(aq)} + H_3O^+{}_{(aq)} \rightleftharpoons H_2CO_{3(aq)} + HOH_{(l)}$

base acid

Acting as an acid in the presence of a stronger base...

acid base

$HCO_3^-{}_{(aq)} + OH^-{}_{(aq)} \rightleftharpoons CO_3^{2-}{}_{(aq)} + HOH_{(l)}$

proton transfer

We say that baking soda is <u>amphoteric</u> because it can act as an acid or a base and also <u>amphiprotic</u> because it can gain or donate protons.

So this new theory can define acids and bases in terms of the movement of protons in reactions.

It can't, however, explain <u>why</u> the protons move...

ex) Classify each reactant as either a Bronsted-Lowery Acid or Base.

a) $HF_{(aq)} + SO_3^{2-}{}_{(aq)} \rightleftharpoons F^-{}_{(aq)} + HSO_3^-{}_{(aq)}$
A B

b) $CO_3^{2-}{}_{(aq)} + CH_3COOH_{(aq)} \rightleftharpoons CH_3COO^-{}_{(aq)} + HCO_3^-{}_{(aq)}$
B A

c) $H_3PO_{4(aq)} + OCl^-{}_{(aq)} \rightleftharpoons H_2PO_4^-{}_{(aq)} + HOCl_{(aq)}$
A B

d) $HCO_3^-{}_{(aq)} + HSO_4^-{}_{(aq)} \rightleftharpoons SO_4^{2-}{}_{(aq)} + H_2CO_{3(aq)}$
B A B A

Conjugate Acid-Base Pairs

An Bronsted-Lowery Acid-Base rxn goes to equilibrium.
The reaction can proceed forwards or backwards.
Note also there is always two acids, one on the products and one on the reactants, as well as two bases.

Forwards

acid base

ex) $CH_3COOH_{(aq)} + H_2O_{(l)} \rightleftharpoons CH_3COO^-{}_{(aq)} + H_3O^+{}_{(aq)}$

proton

Reverse

proton

$CH_3COO^-{}_{(aq)} + H_3O^+{}_{(aq)} \rightleftharpoons CH_3COOH_{(aq)} + H_2O_{(l)}$

base acid

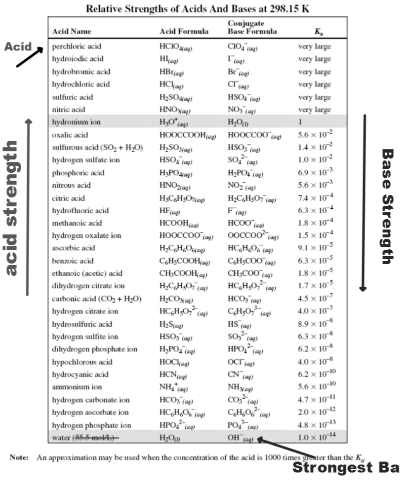
Also, the acids and base are essentially the same; their formulas only vary by one proton.

acids		bases
$CH_3COOH_{(aq)}$	←	$CH_3COO^-{}_{(aq)}$
$H_3O^-{}_{(aq)}$	←	$H_2O_{(l)}$

Compounds which vary by only one proton are called <u>conjugate acid-base pairs</u>. A Bronsted-Lowery acid-base reaction always involves two conjugate pairs.

A list of conjugate pairs is given on page 8-9 of your data booklet.

Strongest Acid
SA


Relative Strengths of Acids And Bases at 298.15 K

Acid Name	Acid Formula	Conjugate Base Formula	K_a
perchloric acid	$HClO_{4(aq)}$	$ClO_4^-{}_{(aq)}$	very large
hydroiodic acid	$HI_{(aq)}$	$I^-{}_{(aq)}$	very large
hydrobromic acid	$HBr_{(aq)}$	$Br^-{}_{(aq)}$	very large
hydrochloric acid	$HCl_{(aq)}$	$Cl^-{}_{(aq)}$	very large
sulfuric acid	$H_2SO_{4(aq)}$	$HSO_4^-{}_{(aq)}$	very large
nitric acid	$HNO_{3(aq)}$	$NO_3^-{}_{(aq)}$	very large
hydronium ion	$H_3O^+{}_{(aq)}$	$H_2O_{(l)}$	1
oxalic acid	$HOOCCOOH_{(aq)}$	$HOOCCOO^-{}_{(aq)}$	5.6×10^{-2}
sulfurous acid ($SO_2 + H_2O$)	$H_2SO_{3(aq)}$	$HSO_3^-{}_{(aq)}$	1.4×10^{-2}
hydrogen sulfate ion	$HSO_4^-{}_{(aq)}$	$SO_4^{2-}{}_{(aq)}$	1.0×10^{-2}
phosphoric acid	$H_3PO_{4(aq)}$	$H_2PO_4^-{}_{(aq)}$	6.9×10^{-3}
nitrous acid	$HNO_{2(aq)}$	$NO_2^-{}_{(aq)}$	5.6×10^{-3}
citric acid	$H_3C_6H_5O_{7(aq)}$	$H_2C_6H_5O_7^-{}_{(aq)}$	7.4×10^{-4}
hydrofluoric acid	$HF_{(aq)}$	$F^-{}_{(aq)}$	6.3×10^{-4}
methanoic acid	$HCOOH_{(aq)}$	$HCOO^-{}_{(aq)}$	1.8×10^{-4}
hydrogen oxalate ion	$HOOCCOO^-{}_{(aq)}$	$OOCCOO^{2-}{}_{(aq)}$	1.5×10^{-4}
ascorbic acid	$H_2C_6H_6O_{6(aq)}$	$HC_6H_6O_6^-{}_{(aq)}$	9.1×10^{-5}
benzoic acid	$C_6H_5COOH_{(aq)}$	$C_6H_5COO^-{}_{(aq)}$	6.3×10^{-5}
ethanoic (acetic) acid	$CH_3COOH_{(aq)}$	$CH_3COO^-{}_{(aq)}$	1.8×10^{-5}
dihydrogen citrate ion	$H_2C_6H_5O_7^-{}_{(aq)}$	$HC_6H_5O_7^{2-}{}_{(aq)}$	1.7×10^{-5}
carbonic acid ($CO_2 + H_2O$)	$H_2CO_{3(aq)}$	$HCO_3^-{}_{(aq)}$	4.5×10^{-7}
hydrogen citrate ion	$HC_6H_5O_7^{2-}{}_{(aq)}$	$C_6H_5O_7^{3-}{}_{(aq)}$	4.0×10^{-7}
hydrosulfuric acid	$H_2S_{(aq)}$	$HS^-{}_{(aq)}$	8.9×10^{-8}
hydrogen sulfite ion	$HSO_3^-{}_{(aq)}$	$SO_3^{2-}{}_{(aq)}$	6.3×10^{-8}
dihydrogen phosphate ion	$H_2PO_4^-{}_{(aq)}$	$HPO_4^{2-}{}_{(aq)}$	6.2×10^{-8}
hypochlorous acid	$HOCl_{(aq)}$	$OCl^-{}_{(aq)}$	4.0×10^{-8}
hydrocyanic acid	$HCN_{(aq)}$	$CN^-{}_{(aq)}$	6.2×10^{-10}
ammonium ion	$NH_4^+{}_{(aq)}$	$NH_{3(aq)}$	5.6×10^{-10}
hydrogen carbonate ion	$HCO_3^-{}_{(aq)}$	$CO_3^{2-}{}_{(aq)}$	4.7×10^{-11}
hydrogen ascorbate ion	$HC_6H_6O_6^-{}_{(aq)}$	$C_6H_6O_6^{2-}{}_{(aq)}$	2.0×10^{-12}
hydrogen phosphate ion	$HPO_4^{2-}{}_{(aq)}$	$PO_4^{3-}{}_{(aq)}$	4.8×10^{-13}
water ~~(55.5 mol/L)~~	$H_2O_{(l)}$	$OH^-{}_{(aq)}$	1.0×10^{-14}

Note: An approximation may be used when the concentration of the acid is 1000 times greater than the K_a.

acid strength

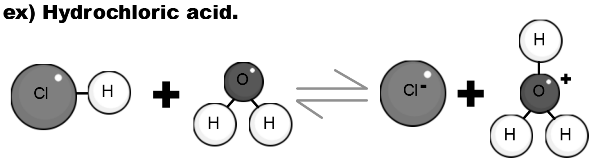
Base Strength

Strongest Base
SB

Notice the trends:
- the stronger the acid, the weaker the conjugate base.
- the stronger the base, the weaker the conjugate acid.

According to this new theory, strong acids are compounds which easily donate their proton.

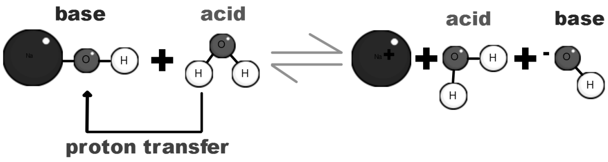
ex) Hydrochloric acid.



In this reaction, the water molecule has a stronger attraction for protons than the chlorine. Bases have strong attraction for protons, acids have a weak attraction for protons (even strong acids).

So, in reality, strong acids have weak attractions for protons.

A strong base is a compound which has a strong attraction for protons and is a good proton acceptor.



Why are some acids good proton donors and some not good donors?

Bronsted-Lowery theory does not explain why some species are good proton donors. The table of acid strength was built purely by experiment.

In fact, no current acid-base theory can predict which acids will be strong acids and which would be weak acids.

HW: Page 687 #1-4, 688 #5-7, 690 #8-10