Tutorial 2: Strong & Weak Acids & Bases

***Strong Acid*- An acid which is 100% ionized in a water solution**.

E.g.) $HCl_{(g)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + Cl^-_{(aq)}$

Single arrow (goes to completion)
=Strong acid

Question: What is the $[HCl_{(g)}]$ in 1 M HCl?
Answer:

Question: What is $[H_3O^+]$ in 0.20 M HCl
Answer:

Important:

In a **Strong Acid** $[H_3O^+]$ = [Acid] (to Start with)

E.g.) What is $[H_3O^+]$ in 0.60 M HNO_3

Answer:

***Weak Acid*: An Acid which is <u>less than</u> 100% ionized in solution**.

(In Chem 12 WA's are usually significantly less than 100% ionized.)
(Usually < 5% ionized)

- In a solution of a ***weak acid***, most of the molecules *don't* ionize.

E.g.) $HF_{(g)} + H_2O_{(l)} \leftrightarrows H_3O^+_{(aq)} + F^-_{(aq)}$ ← ions
(Molecules) (Double arrow)

$[H_3O^+]$ is only a small fraction of [HF]

HF HF
HF HF
HF H_3O^+
HF HF
F^- HF
HF HF
HF HF

←H_2O is omitted in diagram

A beaker containing aqueous HF

NOTE: WA's can be molecules but they might also be + or – ions.
E.g.) $NH_4^+ + H_2O \leftrightarrows H_3O^+ + NH_3$
$HSO_4^- + H_2O \leftrightarrows H_3O^+ + SO_4^{2-}$

- (weak or strong) could have high or low *concentration*.

Weak* & *Strong → refers to <u>% ionization.</u>
Concentration → the <u>moles</u> of acid dissolved <u>per litre.</u>

Eg.) 10.0 M HCl → conc. and strong $[H_3O^+] = 10.0$ M
0.001 M HCl → dilute and strong $[H_3O^+] = 0.001$ M
10.0 M HF → conc. and weak $[H_3O^+]$ = low
0.001 M HF → dilute and weak $[H_3O^+]$ = very low

Concentration of ions would determine conductivity

The Acid Table

Notice single arrows for all SA's

Strong Acids

$HClO_4 \rightarrow H^+ + ClO_4^-$
$HI \rightarrow H^+ + I^-$
$HBr \rightarrow H^+ + Br^-$
$HCl \rightarrow H^+ + Cl^-$
$HNO_3 \rightarrow H^+ + NO_3^-$
$H_2SO_4 \rightarrow H^+ + HSO_4^-$

*Note H_2SO_4 is a SA but diprotic

- The first ionization is 100% = $H_2SO_4 + H_2O \rightarrow H_3O^+ + HSO_4^-$
- The second ionization is <100% $HSO_4^- + H_2O \leftrightarrows H_3O^+ + SO_4^{2}$

Double arrow

Weak Acids

$H_3O^+ \leftrightarrows H^+ + H_2O$
$HIO_3 \leftrightarrows H^+ + IO_3^-$
.
.
.
$H_2O \leftrightarrows H^+ + OH^-$

Most act as weak acids in water

$OH^- \leftarrow H^+ + O^{2-}$
$NH_3 \leftarrow H^+ + NH_2^-$

Bottom 2 on left NEVER act as acids in water (too weak as acids)

↑
Single arrows going backwards
(O^{2-} and H^+ can form OH^- but OH^- cannot form H^+ and O^{2-} in water solution.)

Strong Base

A substance (base) which (ionizes) or dissociates 100% in solution

Forms ions from molecules or atoms

Ions in an ionic solid separate and dissolve in water

Weak Base

A base which is less than 100% ionized in solution.

E.g.) $NH_{3(aq)} + H_2O_{(l)} \leftrightarrows NH_4^+{}_{(aq)} + OH^-{}_{(aq)}$

A neutral molecule

- Consists of mostly H_2O and NH_3 molecules with a few NH_4^+ and OH^- ions.

Using Acid Table & Periodic Table

Bases on Right Side

Strong Bases

$$\left.\begin{array}{l} \rightarrow OH^- \\ \rightarrow O^{2-} \\ \rightarrow NH_2^- \end{array}\right\} \text{Strong bases (bottom 3 on right side)}$$

- Any substance which dissociates completely to produce OH^-, O^{2-} or NH_2^- is a Strong Base

Alkali Metal Hydroxides (Group 1)

LiOH, NaOH, KOH, RbOH, CsOH are all highly (100%) soluble and form OH^-, so they are all ***strong bases***.

(Alkaline Earth) Hydroxides (Group 2)

$Mg(OH)_2$, $Ba(OH)_2$, $Sr(OH)_2$ are designated as Strong Bases (even though $Sr(OH)_2$ is the only one called "Soluble" on the Solubility Table. They dissociate to form 2 OH^- s each:

$Ba(OH)_{2(s)} \rightarrow Ba^{2+}{}_{(aq)} + 2OH^-{}_{(aq)}$

What is the $[OH^-]$ in 0.10 M NaOH?

$$\underset{0.10\ M}{NaOH_{(s)}} \rightarrow \underset{0.10\ M}{Na^+{}_{(aq)}} + \underset{0.10\ M}{OH^-{}_{(aq)}} \qquad [OH^-] = 0.10\ M$$

What is the $[OH^-]$ in 0.10 M $Ba(OH)_2$?

$$\underset{0.10\ M}{Ba(OH)_2} \rightarrow \underset{\_\_\_\_M}{Ba^{2+}} + \underset{\_\_\_\_\_M}{2OH^-}$$

For A ***Strong Base***

$$\boxed{\mathbf{[OH^-] = [Base] \times \#\ of\ OH's\ in\ formula}}$$

Salts which produce O^{2-} and NH_2^- are **definitely strong bases**.

E.g.) Quicklime in water: $CaO_{(s)} \rightarrow Ca^{2+}{}_{(aq)} + O^{2-}{}_{(aq)}$

$O^{2-} + H_2O \rightarrow OH^- + OH^-$ or $\mathbf{O^{2-} + H_2O \rightarrow 2OH^-}$

(Oxide ion) (100%)

This is a VERY important equation. Remember it!

Find $[OH^-]$ in 0.10 M CaO

$[O^{2-}] = 0.10$ M

$$\underset{O^{2-}}{(0.10M)} + H_2O \rightarrow \underset{2OH^-}{\_\_\_\_\_M} \qquad [OH^-] = \_\_\_\_\_\_M$$

Weak Bases

Found above OH^- on *right* side of Table.

H_2O
IO_3^-
.
.
.
PO_4^{3-}

Most form ***weak bases*** in water
Why do I say "most"?

OH^-
O^{2-}
NH_2^-

Strong bases

Very Weak (non-hydrolyzing Bases) or Spectators

These are the ***top*** **5** (not 6) "bases" on the ***right***.

ClO_4^-
I^-
Br^-
Cl^-
NO_3^-

They are so weak that they cannot react with H_2O to form OH^-
(They do ***not*** contribute any OH^- to a solution)

For this reason, these top 5 on the right are ***not*** usually referred to as "bases" in aqueous solution. They are called **Spectators**!

Conj. Bases of strong acids---- In acid-base reactions they are **SPECTATORS**

In a SA, the bond to H^+ is weak

Weak Bond

$$H—Cl + H_2O \rightarrow H_3O^+_{(aq)} + Cl^-_{(aq)}$$

Easily broken by water

So weak , it cannot take an H^+ from H_2O or even H_3O^+

SA's have non-hydrolyzing (**spectator**) ions for conj. Bases.

Amphiprotic Species (ions or molecules)

- are found on **both** sides of the table e.g.) HSO_4^-
- can act as acids (donate H^+'s) or as bases (accept H^+'s)
- to look at an amphiprotic species as an **acid**, you must find it on the **left** side:

Acid Strength Increases

e.g.) $C_6H_5OH \leftrightarrows$
→ $HCO_3^- \leftrightarrows$
$H_2O_2 \leftrightarrows$

HCO_3^- is a __________er acid than C_6H_5OH
HCO_3^- is a __________er acid than H_2O_2

- to look at an amphiprotic species as a **base**, you must find it on the **right** side:
for HCO_3^- as a **base**:

e.g.) $\leftrightarrows H^+ + Al(H_2O)_5(OH)^{2+}$
$\leftrightarrows H^+ + HCO_3^-$ ←
$\leftrightarrows H^+ + C_6H_5O_7^{3-}$

Base Strength Increases

HCO_3^- is a __________er base than $C_6H_5O_7^{3-}$
HCO_3^- is a __________er base than $Al(H_2O)_5(OH)^{2+}$

HSO_4^- in shaded region on top right will **not** act as a base in water (Too weak of a base)
- However, it is **not** a spectator! (like NO_3^- is) Why not?

(HSO_4^- is also found on the left side quite a way up, it is a relatively "strong" weak *acid*.)

The Leveling Effect for Acids

What is $[H_3O^+]$ in 1.0 M H_3O^+ ? ______

What is $[H_3O^+]$ in 1.0 M HNO_3? ______

What is $[H_3O^+]$ in 1.0 M HCl ? ______

Acids from $HClO_4$ to H_2SO_4 are 100% ionized in water

only solvent used in Chem 12 (and most Chemistry)

- so even though $HClO_4$ is above HCl on the chart, it is no more acidic in a water solution.

H_3O^+ is the strongest acid that can exist in an undissociated form in water solution.
- ***all stronger acids ionize to form H_3O^+***

(NOTE: although H_2SO_4 is diprotic, the H_3O^+ produced from the second ionization is very little compared to that from the first)

1st ionization: $H_2SO_4 + H_2O \rightarrow H_3O^+ + HSO_4^-$

$\uparrow$ 1M(SA) $\uparrow$ 1M

A very small amount of H_3O^+

2nd ionization: $HSO_4^- + H_2O \leftrightarrows H_3O^+ + SO_4^{2-}$

~1M (WA)

The only way you can tell which strong acid is "stronger" is to react them in a non-aqueous (not H_2O) solvent.

Eg) $HClO_4 + H_2SO_4 \leftrightarrows H_3SO_4^+ + ClO_4^-$

(it is found that $HClO_4$ donates a proton to H_2SO_4, not the other way around, so $HClO_4$ is a stronger acid than H_2SO_4) ***This is not important in Chemistry 12.***

This would not happen in a water solution.
(In H_2O, they would ***both*** form H_3O^+)

Leveling Affects of Bases

The strongest base which can exist in high concentrations in water solution is OH^-
The two stronger bases below it will react with water completely to form OH^-.

Eg) $O^{2-} + H_2O \rightarrow OH^- + OH^-$

SB

Single Arrow

Or

$O^{2-} + H_2O \rightarrow 2OH^-$

What is the final $[O^{2-}]$ in 1.0 M Na_2O ? Answer: 0 M

- **All** the O^{2-} will react with water to form OH^-

$1.0M \xrightarrow{2/1} 2.0\ M$

$O^{2-} + H_2O \rightarrow 2OH^-$ so $[OH^-] = 2.0\ M$

Write an equation for NH_2^- reacting with H_2O.

Answer: ____

Acid-Base Equilibria & Relative Strengths of Acids & Bases

- Take out your acid table
- Mix some $H_2PO_4^-$ and some CO_3^{2-}

Amphiprotic can donate or accept an H^+

Can only act as a base (accept an H^+) (doesn't have an H^+ to give

So, in this case CO_3^{2-} will play the role of base (take H^+) and $H_2PO_4^-$ will play the role of acid (donate an H^+).

$H_2PO_4^- + CO_3^{2-} \leftrightharpoons HCO_3^- + HPO_4^{2-}$
(A) (B) (A) (B)

Consider the 2 acids $H_2PO_4^-$ and HCO_3^-

Question: At equilibrium, which will be favoured, reactants or products?
They both "want" to donate protons.
- look them both up on the left side

Strength as acid

$H_2PO_4^-$ is ***above*** HCO_3^- on LEFT, so $H_2PO_4^-$ is a ***stronger*** acid than HCO_3^-.

Strong "push" to donate a proton

$H_2PO_4^- \rightarrow H^+ + HPO_4^{2}$

$H^+ + CO_3^{2-} \leftarrow HCO_3^-$

Weaker "push" to donate a proton

So the reaction:

$$H_2PO_4^- + CO_3^{2-} \leftrightharpoons HCO_3^- + HPO_4^{2-}$$

Will have a greater tendency to go right than left and products will be favoured.
- so find acid on each side. ***Equilibrium favors the side with the weaker acid***.

"*Only the weak survive*" or "*Survival of the weakest*"

"stronger" means a greater tendency to react and change to something else.

$H_2PO_4^- + CO_3^{2-} \leftrightarrows HCO_3^- + HPO_4^{2-}$
SrA WrA

Stronger acid

Weaker acid

Don't use terms "strong" and "weak", they have other specific meanings.

Question: Will

$$HSO_3^- + HCO_3^- \leftrightarrows H_2CO_3 + SO_3^{2-}$$

Favor reactants or products?

<u>Mixing 2 amphrotic ions</u> (products not given)
-complete rx. and tell which is favoured (r or p)

eg.) $HSO_4^- + H_2PO_4^- \rightarrow$?

Which will play role of acid?
(both are capable of being acids or bases)

- First, compare <u>these two</u> on <u>LEFT</u> side

HSO_4^- is higher than $H_2PO_4^-$ on LEFT side so has a greater tendency to act as an acid.

HA! HA! I win. I get to give you my proton. You have to act as the base!

I always knew you were a bigger loser than I am!

- Complete the equation: (making HSO_4^- act as the acid.)

$$HSO_4^- + H_2PO_4^- \leftrightarrows H_3PO_4 + SO_4^{2-}$$

A B A B

Identify A & B on this side

Now compare the 2 conjugate acids (Look fo them <u>both</u> on the LEFT side of chart.)
HSO_4^- is slightly <u>ABOVE</u> H_3PO_4 on the left side so HSO_4^- is the SrA and H_3PO_4 is the WrA.

$HSO_4^- + H_2PO_4^- \leftrightarrows H_3PO_4 + SO_4^{2-}$ so the products (with WrA,) are favoured!
SrA WrA

-Comparing realtive stengths of <u>bases.</u>

E.g.) $HSO_4^- + H_2PO_4^- \leftrightarrows H_3PO_4 + SO_4^{2-}$
Base Base

Compare these on the RIGHT side of table

$H_2PO_4^-$ is lower on the right side(stronger base) than SO_4^{2-}

So see:

$HSO_4^- + H_2PO_4^- \leftrightarrows H_3PO_4 + SO_4^{2-}$
SrA SrB WrA WrB

-Since this equilm favoured products (H_3PO_4 is WrA), we can say that equilm favours the side with the <u>weaker conjugate base.</u>

NOTICE: The SrA is on the same side as the SrB. [the SrA has the weaker conj. Base]
The WrA is on the same side as the WrB

(Birds of a feather flock together)
or
(The weakies hang out together and survive better than the "strongies".)

- So we could compare conj. Acids or conj. Bases. ***Equil^{m} favors the side with the weaker conj. Acid and the weaker conj. Base.***

<u>Starting with "Salts"</u>

The amphiprotic ions are often products of the *dissociation* of salts.
- Spectator ions must be discarded.

NOTE: All alkali ions Na^+, K^+, Li^+ …etc….. are ***spectators*** in Acid-Base reactions. Also top five ions right side of acid chart (ClO_4^-, I^-, Br^-, Cl^-, NO_3^-) are ***spectators*** in Acid-Base reactions.

E.g.) complete the net ionic reaction between and state whether equilm favors reactants or products

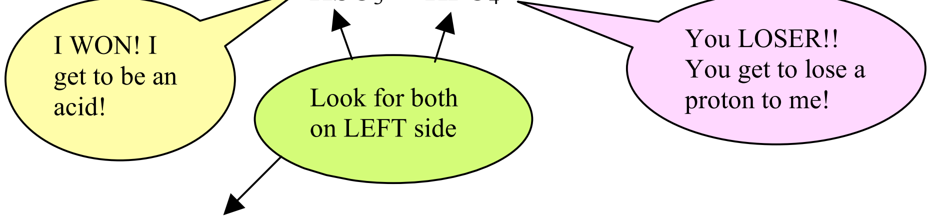
$NaHSO_3$ and K_2HPO_4
Dissociate

(Na^+) HSO_3^- (K^+) HPO_4^{2-}

NOTICE THIS
Had 2 K's, so
charge is 2-
<u>NOT</u> -

Spectator ions
DISCARD!

$HSO_3^- + HPO_4^{2-}$



HSO_3^- is higher, so it will play the role of the **acid**.

$HSO_3^- + HPO_4^{2-} \leftrightarrows H_2PO_4^- + SO_3^{2-}$
SrA B WrA B

HSO_3^- is a stronger acid than $H_2PO_4^-$, so equilm favors the side with the ***weaker*** acid ($H_2PO_4^-$) so ***products*** are favored!

Relating The Keq to A-B equilibria

If products are favored Keq is large (>1)
If reactants are favored Keq is small (<1)

Eg.) Given:

$HA + B^- \leftrightarrows HB + A^-$ Keq = 0.003
Which acid is stronger, HA or HB?

Keq is ***small*** so ***reactant*** side is favored.
Since equilm favors side with WrA, HA must be the weaker acid, so HB would be the stronger acid.
- Which is the stronger base? Ans. _______
(the SrB is on the same side as the SrA)
or
(the weaker acid (HA) has the stronger conj. Base (A^-))