Principles of Reactivity: The Chemistry of Acids and Bases

****a lot of calculations in this chapter will be done on the chalkboard Do not rely on these notes for all the material****

Acids, Bases and Arrhenius

<u>Acid</u> – sour like vinegar
<u>Base</u> (alkali) – soapy and tastes bitter

Add these together, you get a salt

$$2\,HCl(aq) + CaCO_3(s) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$$

Acid ***Base*** ***Salt***

Well, we are not going to throw chemicals in our mouth just to determine if it tastes sour or bitter

There has to be another way to determine what an acid or base is..

Arrhenius defined it for us:

An acid is a substance that contains hydrogen and releases a hydrogen ion (H^+)

A base is a substance that produces hydroxide ions (OH^-)

Again, the addition of the acid and base produce a salt

$HCl\,(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$

This is also an example of a neutralization reaction

What are the products of the mixing of nitric acid and sodium hydroxide?

The BrØnsted Concept of Acid and Bases

An acid is a substance that donates a proton

A base is a substances that accepts a proton

$HNO_3(aq) + H_2O(l) \rightarrow NO_3^-(aq) + H_3O^+(aq)$

Lewis Acid and Bases

A Lewis acid is a substance that accepts a pair of electrons

A Lewis base is a substance that donates a pair of electrons

Acids that donate one proton are called monoprotic acids

Some acids can donate more than one proton

↓

These are called polyprotic acids

Gives two protons – diprotic acid

Gives three protons – triprotic acid

What are some examples of these?

The Hydronium Ion and Water Ionization

When we have an H^+ ion in water, we often write it as the hydronium ion, H_3O^+.

You don't have to have a strong acid in solution to have the hydronium ion. Just add two waters together.

$$2H_2O(l) \leftrightarrow H_3O^+(aq) + OH^-(aq)$$

autoionization of water

$\therefore$ H_2O acts as an acid and a base

How did they figure this out? Pure water conducts electricity to a small extent.

What is an amphoteric substance?

A molecule or ion that can act as either an acid or a base

Name some examples of these

Conjugate Acid-Base Pairs

A conjugate acid-base pair are an acid and a base that are only different by a proton

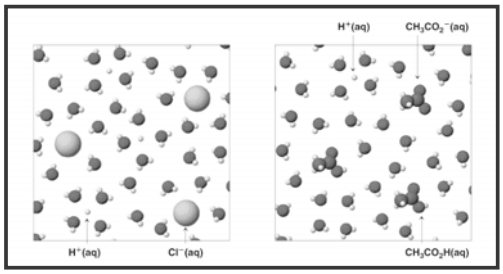
Conjugate pairs:

CH_3COOH and CH_3COO^-
NH_4^+ and NH_3
$HCOOH$ and $HCOO^-$

<u>Not</u> conjugate pairs:

CH_3COOH and $HCOO^-$
NH_4^+ and HNO_3

Acids and bases vary according to their strengths



Strong Acid and Bases

When an acid or base is strong, it dissociates completely in solution

$$HCl(aq) + H_2O(l) \xrightarrow{100\%} H_3O^+(aq) + Cl^-(aq)$$

Strong acid

There are six strong acid that you MUST learn!!!!

Hydrochloric acid – HCl	**Hydrobromic acid – HBr**
Nitric Acid – HNO_3	**Hydroiodic acid – HI**
Sulfuric Acid – H_2SO_4	**Perchloric acid – $HClO_4$**

What about strong bases?

Strong bases are the soluble compounds that produce the hydroxide ion when dissolved in water

The most common strong bases are group IA and IIA oxides and hydroxides

Examples: $NaOH$
$Ba(OH)_2$
Li_2O

Again, if an acid or base is strong, then it <u>100% dissociates</u>

Since a strong acid or base 100% dissociates, there are no reactants left. Therefore we do not need to know the relationship of products to reactants…which is what???

$$HNO_3(aq) + H_2O(l) \rightarrow NO_3^-(aq) + H_3O^+(aq)$$

<u>Therefore, you will not have an equilibrium constant for strong acids or bases and you will not ever do an ice table.</u>

But, what about weak acids and weak bases?

First of all, what does weak mean?

DOES NOT 100% dissociate

$$CH_3COOH(aq) + H_2O(l) \rightleftharpoons CH_3COO^-(aq) + H_3O^+(aq)$$

There are still some reactants left!!

So, how would you write the equilibrium expression?

$CH_3COOH(aq) + H_2O(l) \rightleftharpoons CH_3COO^-(aq) + H_3O^+(aq)$

$$K_a = \frac{[CH_3COO^-][H_3O^+]}{[CH_3COOH]}$$

Is the first compound in the equation an acid or a base?

The Ka gives you the strength of the acid

The larger the Ka, the stronger the acid

If the first compound was a base, you would solve for Kb

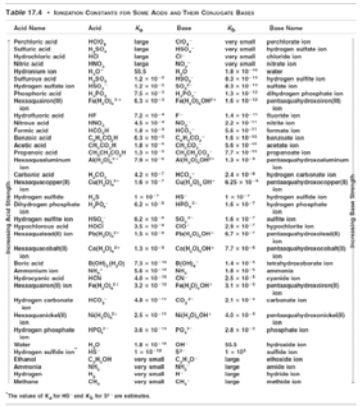


Table 17.4 • Ionization Constants for Some Acids and Their Conjugate Bases

Acid Name	Acid	K_a	Base	K_b	Base Name
Perchloric acid	$HClO_4$	large	ClO_4^-	very small	perchlorate ion
Sulfuric acid	H_2SO_4	large	HSO_4^-	very small	hydrogen sulfate ion
Hydrochloric acid	HCl	large	Cl^-	very small	chloride ion
Nitric acid	HNO_3	large	NO_3^-	very small	nitrate ion
Hydronium ion	H_3O^+	55.5	H_2O	1.8×10^{-16}	water
Sulfurous acid	H_2SO_3	1.2×10^{-2}	HSO_3^-	8.3×10^{-13}	hydrogen sulfite ion
Hydrogen sulfate ion	HSO_4^-	1.2×10^{-2}	SO_4^{2-}	8.3×10^{-13}	sulfate ion
Phosphoric acid	H_3PO_4	7.5×10^{-3}	$H_2PO_4^-$	1.3×10^{-12}	dihydrogen phosphate ion
Hexaquoiron(III) ion	$Fe(H_2O)_6^{3+}$	6.3×10^{-3}	$Fe(H_2O)_5OH^{2+}$	1.6×10^{-12}	pentaaquahydroxoiron(III) ion
Hydrofluoric acid	HF	7.2×10^{-4}	F^-	1.4×10^{-11}	fluoride ion
Nitrous acid	HNO_2	4.5×10^{-4}	NO_2^-	2.2×10^{-11}	nitrite ion
Formic acid	HCO_2H	1.8×10^{-4}	HCO_2^-	5.6×10^{-11}	formate ion
Benzoic acid	$C_6H_5CO_2H$	6.3×10^{-5}	$C_6H_5CO_2^-$	1.6×10^{-10}	benzoate ion
Acetic acid	CH_3CO_2H	1.8×10^{-5}	$CH_3CO_2^-$	5.6×10^{-10}	acetate ion
Propanoic acid	$CH_3CH_2CO_2H$	1.3×10^{-5}	$CH_3CH_2CO_2^-$	7.7×10^{-10}	propanoate ion
Hexaaquoaluminum ion	$Al(H_2O)_6^{3+}$	7.9×10^{-6}	$Al(H_2O)_5OH^{2+}$	1.3×10^{-9}	pentaaquahydroxoaluminum ion
Carbonic acid	H_2CO_3	4.2×10^{-7}	HCO_3^-	2.4×10^{-8}	hydrogen carbonate ion
Hexaaquacopper(II) ion	$Cu(H_2O)_6^{2+}$	1.6×10^{-7}	$Cu(H_2O)_5OH^+$	6.25×10^{-8}	pentaaquahydroxocopper(II) ion
Hydrogen sulfide	H_2S	1×10^{-7}	HS^-	1×10^{-7}	hydrogen sulfide ion
Dihydrogen phosphate ion	$H_2PO_4^-$	6.2×10^{-8}	HPO_4^{2-}	1.6×10^{-7}	hydrogen phosphate ion
Hydrogen sulfite ion	HSO_3^-	6.2×10^{-8}	SO_3^{2-}	1.6×10^{-7}	sulfite ion
Hypochlorous acid	HOCl	3.5×10^{-8}	OCl^-	2.9×10^{-7}	hypochlorite ion
Hexaaquatetol(II) ion	$Pb(H_2O)_6^{2+}$	1.5×10^{-8}	$Pb(H_2O)_5OH^+$	6.7×10^{-7}	pentaaquahydroxolead(II) ion
Hexaaquacobalt(II) ion	$Co(H_2O)_6^{2+}$	1.3×10^{-9}	$Co(H_2O)_5OH^+$	7.7×10^{-6}	pentaaquahydroxocobalt(II) ion
Boric acid	$B(OH)_3(H_2O)$	7.3×10^{-10}	$B(OH)_4^-$	1.4×10^{-5}	tetrahydroxoborate ion
Ammonium ion	NH_4^+	5.6×10^{-10}	NH_3	1.8×10^{-5}	ammonia
Hydrocyanic acid	HCN	4.0×10^{-10}	CN^-	2.5×10^{-5}	cyanide ion
Hexaaquanon(II) ion	$Fe(H_2O)_6^{2+}$	3.2×10^{-10}	$Fe(H_2O)_5OH^+$	3.1×10^{-5}	pentaaquahydroxoiron(II) ion
Hydrogen carbonate ion	HCO_3^-	4.8×10^{-11}	CO_3^{2-}	2.1×10^{-4}	carbonate ion
Hexaaquanickel(II) ion	$Ni(H_2O)_6^{2+}$	2.5×10^{-11}	$Ni(H_2O)_5OH^+$	4.0×10^{-4}	pentaaquahydroxonickel(II) ion
Hydrogen phosphate ion	HPO_4^{2-}	3.6×10^{-13}	PO_4^{3-}	2.8×10^{-2}	phosphate ion
Water	H_2O	1.8×10^{-16}	OH^-	55.5	hydroxide ion
Hydrogen sulfide ion*	HS^-	1×10^{-19}	S^{2-}	1×10^{5}	sulfide ion
Ethanol	C_2H_5OH	very small	$C_2H_5O^-$	large	ethoxide ion
Ammonia	NH_3	very small	NH_2^-	large	amide ion
Hydrogen	H_2	very small	H^-	large	hydride ion
Methane	CH_4	very small	CH_3^-	large	methide ion

Increasing Acid Strength

Increasing Base Strength

*The values of K_a for HS^- and K_b for S^{2-} are estimates.

Let's practice writing these equations and expressions

Water and the pH Scale

$$2H_2O(l) \leftrightarrow H_3O^+(aq) + OH^-(aq)$$

$$K = \frac{[H_3O^+][OH^-]}{[H_2O]^2}$$

Assume water concentration is constant

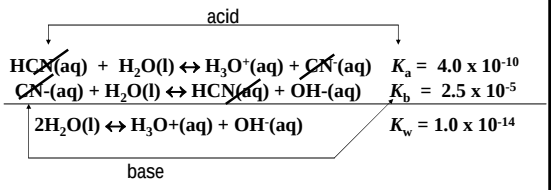
$$\therefore \quad K_w = [H_3O^+][OH^-]$$

Electrical conductivity measurements of pure water show that $[H_3O^+] = [OH^-] = 1.0 \times 10^{-7}\ M$

$$K_w = 1.0 \times 10^{-14}$$

The Connection Between the Ionization Constants for an Acid and Its Conjugate Base

$$K_w = K_a \bullet K_b$$



Recap

When do you <u>not</u> write an equilibrium expression and solve the equilibrium expression?

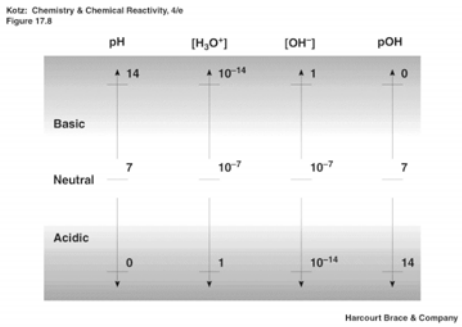
Strong acid and bases

When <u>do</u> you write an equilibrium expression and solve the equilibrium expression

Weak acid and bases

*****Therefore, you must learn your strong acid and bases. Everything else is weak.*****

The pH Scale



What is the equation that relates hydrogen ion concentration to pH?

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

If this is really high, the pH will be low

In pure water, the H_3O^+ concentration is 1.0×10^{-7}

$pH = -\log [1.0 \times 10^{-7}]$

$pH = 7.00$

There is a similar equation for pOH

$$pOH = -\log [OH^-]$$

If this is really high, the pOH will be low

In pure water, the OH^- concentration is 1.0×10^{-7}

$pOH = -\log [1.0 \times 10^{-7}]$

$pOH = 7.00$

How are pH and pOH related?

Recall….

$K_w = [H_3O^+][OH^-] = 1.0 \times 10^{-14}$

Take the log of both sides

$-\log([H_3O^+][OH^-]) = -\log (1.0 \times 10^{-14})$

$(-\log [H_3O^+] + (-\log [OH^-] = 14.00$

$pH + pOH = 14.00$

Learn this equation:

$pH + pOH = 14.00$

Acid-Base Properties of Salts

- **if you have a cation from a strong base and an anion from a strong acid, the salt solution is neutral.**

  example: NaCl, KCl or $NaNO_3$

- **if you have a cation from a strong base and an anion from a weak acid, the salt solution will be basic**

  example: NaCN, KF or NaHCOO

- **if you have a cation from a weak base and an anion from a strong acid, the salt solution is acidic**

  example: NH_4Cl

Table 17.5 • Acid–Base Properties of Typical Ions in Aqueous Solution

	Neutral		Basic			Acidic
Anions	Cl^- Br^- I^-	NO_3^- ClO_4^-	$CH_3CO_2^-$ HCO_3^- CO_3^{2-} S^{2-} F^-	CN^- PO_4^{3-} HCO_3^- HS^- NO_2^-	SO_3^{2-} HPO_4^{2-} SO_3^{2-} OCl^-	HSO_4^- $H_2PO_4^-$ HSO_3^-
Cations	Li^+ Na^+ K^+	Mg^{2+} Ca^{2+} Ba^{2+}	None			Al^{3+} NH_4^+ Transition metal ions

Calculating the pH of the Solution of a Polyprotic Base