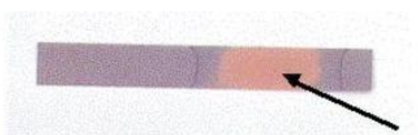
Acids & Bases

Acids form "Sour"; bases from alkali (wood ashes)

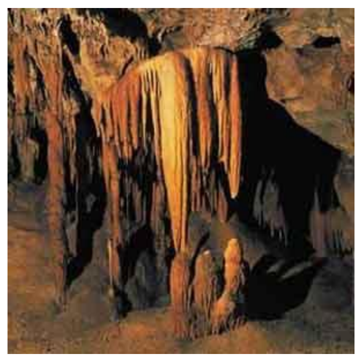
Traditional Properties

	Acid	**Base**
Taste	Sour	Bitter
Feel	None	Slippery
Litmus	B ➔ R	R ➔ B
Phenolphthalein	Colorless	Magenta
With Carbonate	CO_2 evolution	None
With "active" Metals	H_2 evolution	None
With most metals	None	Water Insoluble

Acids React With Blue Litmus ("litmus test" Blue ➔ Red in Acid (BRA))



Blue litmus paper with a drop of acid here



Acids react with carbonate ions:

$2\,H^+(aq) + CO_3^-(aq) \rightarrow H_2O(l) + CO_2(g)$

Atmospheric $CO_2 + H_2O \rightarrow H_2CO_3$

Dissolves Carbonates
A major erosion process

Activity Series

Acids react with "active" metals:

$2\,H^+ (aq) + Zn \rightarrow Zn^{++} + H_2(g)$

K, Ca, Na react with water:
$2\,Na + 2\,H_2O \rightarrow 2\,NaOH + H_2$

Mg, Al, Zn, Fe, Ni, Sn, Pb react with acids
$Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2$

Metals	Metal Ion	Reactivity
K	K^+	reacts with water
Ca	Ca^{2+}	
Na	Na^+	
Mg	Mg^{2+}	reacts with acids
Al	Al^{3+}	
Zn	Zn^{2+}	
Fe	Fe^{2+}	
Ni	Ni^{2+}	
Sn	Sn^{2+}	
Pb	Pb^{2+}	
H_2	H^+	
Cu	Cu^{2+}	highly unreactive
Hg	Hg^{2+}	
Ag	Ag^+	
Pt	Pt^+	
Au	Au^{3+}	

pH Scale

measurement of relative acidity
determined by hydrogen ion concentration
values range between 0 – 14

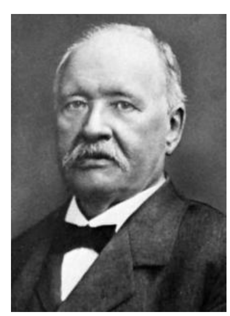
$pH < 7$ ➔ acidic
$pH = 7$ ➔ neutral
$pH > 7$ ➔ basic (alkaline)

measured using

indicators (pH papers or solutions)

pH: a measure of $[H^+]$ ➔ $[H_3O^+] = 1 \times 10^{-pH}$

Arrhenius Theory: Acids



1887 – Svante Arrhenius, Swedish Chemist
Doctoral Thesis on Electrolytes
Lowest possible grade
1903 – thesis earned Noble Prize in Chemistry

Neither water, acids, nor salts conduct
Current only flows by ionization

Acids, special case of ionization

HA ➔ $H^+ + A^-$

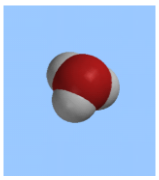
Acid = substance that forms hydrogen ions in water solution

$HA(aq) \rightarrow H^+(aq) + A^-(aq)$

H^+ = proton

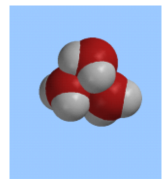
But, individual protons do NOT exist in water:

$H^+ + H_2O \rightarrow H_3O^+$ (Hydronium Ion)



$\downarrow$ + 2 H_20

$H_7O_3{}^+$



Arrhenius Acids form *hydronium ions* in solution

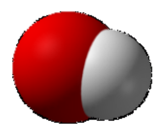
Arrhenius Theory: Bases

Base = substance that forms hydroxide ions (OH^-) in water

$MOH(aq) \rightarrow M^+(aq) + OH^-(aq)$

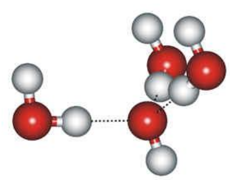
$NaOH(aq) \rightarrow Na^+(aq) + OH^-(aq)$

$Ca(OH)_2(aq) \rightarrow Ca^{+2}(aq) + 2\ OH^-(aq)$

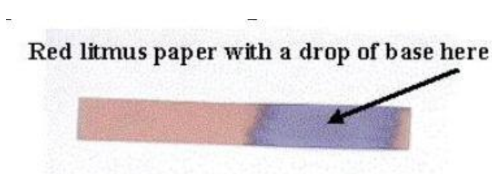


Arrhenius Bases form *hydroxide ions* in solution

Hydroxide also hydrated ($H_7O_4^-$)



Bases turn Red Litmus $\rightarrow$ Blue



Bases turn phenolphthalein magenta

Bases react with most metal ions:
$2\ OH^-(aq) + M^{2+} \rightarrow M(OH)_2(s)$

Most metal hydroxides insoluble in water
(Common Pollutant)

Arrhenius Neutralization Reaction

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

Problems With Arrhenius

Acidic properties depend upon dissociation in aqueous solutions
Fails to predict behavior in non-polar solvents

Problems with Arrhenius Solved in 1923
Johanes Bronsted – Danish Chemist

Martin Lowry – English Chemist

Published simultaneously, so, name of both on the theory
Allows acids & bases in non-aqueous solutions

Allows bases other than hydroxide

Compound can be either an acid or base dependent on conditions

Bronsted-Lowry Theory of Acids & Bases

$$AH + B \rightarrow BH^+ + A^-$$

Acid = proton donor
Base = proton acceptor (Prime departure from Arrhenius)

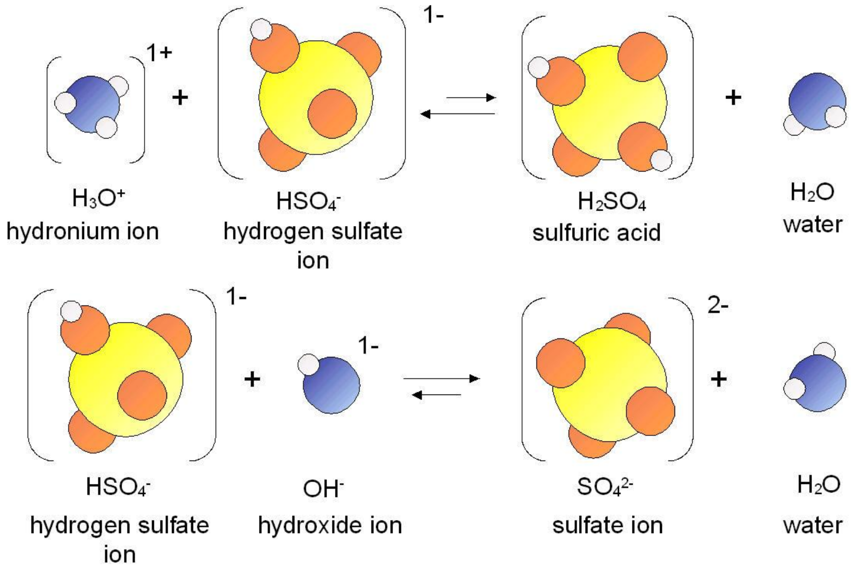
Acid-Base reaction = proton transfer

Solvent can be non-aqueous
Bases do not have to have OH^-

water can act as an acid or a base
$HCl + H_2O \rightarrow H_3O^+ + Cl^-$ (water a base)
$NH_3 + H_2O \rightarrow NH_4^+ + OH^-$ (water an acid)

amphoteric = substance that can act as an acid or as a base

An Amphoteric Ion



Bronsted-Lowry Neutralization Reactions

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

$NH_3 + HCl \rightarrow NH_4^+ + Cl^-$

Arrhenius reactions are also Bronsted-Lowry Acid Base Reactions
But, non-aqueous Bronsted reactions cannot be Arrhenius

Acid-Base: Conjugate Pairs

For “reversible” reaction

$AH + B \leftarrow \rightarrow BH^+ + A^-$
($\leftarrow \rightarrow$ is MS Word representation for a reversible reaction)

A = Acid (H donor) in forward reaction
B = Base (H acceptor) in forward reaction
BH^+ = Conjugate Acid (H donor in reverse reaction)
A^- = Conjugate Base (H acceptor in reverse reaction)

"Follow the Protons"

Conjugate Pairs (Differ by ONLY a proton)

conjugates: base (H_2O) – acid (H_3O^+)

$$\underset{\text{acid}}{HCl} + \underset{\text{base}}{H_2O} \rightleftharpoons \underset{\text{acid}}{H_3O^+} + \underset{\text{base}}{Cl^-}$$

conjugates: acid (HCl) – base (Cl^-)

$$\underset{\text{acid}}{HCl} + \underset{\text{base}}{H_2O} \rightleftharpoons \underset{\text{CA}}{H_3O^+} + \underset{\text{CB}}{Cl^-}$$

What are the conjugate acid-base pairs:

A = Acid (H donor) in forward reaction
B = Base (H acceptor) in forward reaction
BH^+ = Conjugate Acid (H donor in reverse reaction)
A^- = Conjugate Base (H acceptor in reverse reaction)

$$\mathbf{HC_4H_5O_3 + PO_4^{3-} \text{ « } HPO_4^{2-} + C_4H_5O_3^-}$$

A = Acid = $HC_4H_5O_3$

B = Base = PO_4^{3-}

BH^+ = Conjugate Acid = HPO_4^{2-}

A^- = Conjugate Base = $C_4H_5O_3^-$

$$\mathbf{HSO_4^- + HC_2O_4^- \leftarrow\rightarrow SO_4^{2-} + H_2C_2O_4}$$

A = Acid = HSO_4^-

B = Base = $HC_2O_4^-$

BH^+ = Conjugate Acid = $H_2C_2O_4$

A^- = Conjugate Base = SO_4^{2-}

$$\mathbf{HNO_2 + CN^- \leftarrow\rightarrow NO_2^- + HCN}$$

A = Acid = HNO_2
B = Base = CN^-
BH^+ = Conjugate Acid = HCN
A^- = Conjugate Base = NO_2^-

"Follow the Protons"

$$AH + B \leftarrow\rightarrow BH^+ + A^-$$

Removal of a proton from an acid forms its conjugate base

Addition of a proton to a base forms its conjugate acid.

Conjugate pair formulas differ only by a proton.

Completed Table

Acid	**Conjugate Base**
HNO_3	**NO_3^-**
HBr	Br^-
H_2O	**OH^-**
H_3O^+	H_2O
$H_2PO_4^-$	HPO_4^{2-}
HPO_4^{2-}	**PO_4^{3-}**
$C_2H_4O_2$	$C_2H_3O_2^-$

Relative Strengths of Acids & Bases

"strong" acid or base: 100 % completely ionized

$HCl \rightarrow H^+ + Cl^-$

$HNO_3 \rightarrow H^+ + NO_3^-$

"weak" acid or base: < 100 % ionized, partially ionized

$HC_2H_3O_2 \leftarrow\rightarrow H^+ + C_2H_3O_2^-$

$HF \leftarrow\rightarrow H^+ + F^-$

Bronsted-Lowry Theory:

strong acid = excellent proton donor (readily loses H^+)
weak acid = poor proton donor (does not lose H^+ easily)

strong base = very good proton acceptor (readily gains H^+)
weak base = poor proton acceptor (does not gain H^+ easily)

The stronger the attraction for H^+, the stronger the base

"Weak" or "Strong"
is about "H^+ attraction"

HCl	+	H_2O	$\leftarrow\rightarrow$	H_3O^+	+	Cl^-
stronger acid		stronger base		weaker acid		weaker base

stronger acid forms the weaker base
stronger base forms the weaker acid

Relative Acid and Base Strengths

	Acid	K_a (at 25°C)	Conjugate Base	
Strongest Acid	HI	10^{11}	I^-	Weakest Base
	HBr	10^{9}	Br^-	
	$HClO_4$	10^{7}	ClO_4^-	
	HCl	10^{7}	Cl^-	
	H_2SO_4	10^{2}	HSO_4^-	
	HNO_3	20	NO_3^-	
	H_3O^+	1	H_2O	
	H_2SO_3	1.5×10^{-2}	HSO_3^-	
	HSO_4^-	1.2×10^{-2}	SO_4^{2-}	
	H_3PO_4	7.5×10^{-3}	$H_2PO_4^-$	
	HF	7.2×10^{-4}	F^-	
	HNO_2	4.0×10^{-4}	NO_2^-	
	HCO_2H	1.8×10^{-4}	CO_2H^-	
	$HC_2H_3O_2$	1.8×10^{-5}	$C_2H_3O_2^-$	
	H_2CO_3	4.3×10^{-7}	HCO_3^-	
	HSO_3^-	1.0×10^{-7}	SO_3^{2-}	
	H_2S	9.1×10^{-8}	HS^-	
	HClO	3.5×10^{-8}	ClO^-	
	HBrO	2.0×10^{-9}	BrO^-	
	HCN	6.2×10^{-10}	CN^-	
	NH_4^+	5.6×10^{-10}	NH_3	
	HCO_3^-	4.8×10^{-11}	CO_3^{2-}	
	H_2O_2	2.4×10^{-12}	HO_2^-	
Weakest Acid	H_2O	1.0×10^{-14}	OH^-	Strongest Base

Assignment

Continue Taking Unit 10 Practice Test

The Practice Quiz is very similar to the Unit Exam

Success on Unit exam is directly related to practice exam experience