

## Acids and Bases

Word	Definition
Acidity	The property of exhibiting the qualities of an acid.
Alkalinity	The property of exhibiting the qualities of a base
Amphiprotic	A species that can act either as a B/L acid or a B/L base, depending on what other species it is reacting with.
Amphoteric	A species that can act either as a B/L acid or a B/L base, depending on what other species it is reacting with.
Arrhenius Acid	An electrolyte that ionizes in aqueous solution to yield $H^+$ as the only positive ion in solution.
Arrhenius Base	An electrolyte that ionizes in aqueous solution to yield $OH^-$ as the only negative ion in solution.
Basicity	The property of exhibiting the qualities of a base
Bronsted/Lowry Acid	A species that donates $H^+$ to a B/L base in a chemical reaction.
Bronsted/Lowry Base	A species that accepts $H^+$ from a B/L acid in a chemical reaction.
Buret	A piece of laboratory equipment that precisely measures how much liquid has been let out of it by the valve on the bottom.
Caustic	A substance that will destroy or irreversibly damage any substance or surface it comes into contact with through a chemical change, usually used to describe bases.
Conjugate pair	An acid/base pair that differ only by one $H^+$ . Acids turn into conjugate bases, bases turn into conjugate acids.
Corrosive	A substance that will destroy or irreversibly damage any substance or surface it comes into contact with through a chemical change, usually used to describe acids.
Electrolyte	A compound that ionizes in water, allowing the solution to conduct electricity.
Hydrolysis	The process whereby a base reacts with a glycerol ester (fat) to produce soap.
Indicator	A substance whose color is sensitive to the pH of a solution to which it is added.
Neutralization	A double-replacement reaction where an acid and base react to form water and a salt.
Nonelectrolytes	A molecular compound that does not ionize in water, preventing the solution from conducting electricity.
pH	The negative log of the hydrogen ion concentration. A pH less than 7 indicates an acidic solution, a pH of greater than 7 indicates a basic solution and a pH of 7 indicates a neutral solution.
Protonation	The addition of an acid's $H^+$ ion (proton) to a water molecule to form hydronium ( $H_3O^+$ ).
Salt	An ionic compound formed when an acid and base neutralize each other. This compound consists of the anion of the acid and the cation of the base.
Titration	A process of controlled acid-base neutralization, carried out in burets.

# 1) Properties of Arrhenius Acids and Bases (HW: p. 19, 20)

**Essential Question:** Which is more dangerous; an acid or base?

“Oh my goodness! It’s acid! It’s gonna get you!!! It’s gonna eat you up, eat you up, eat you up!”

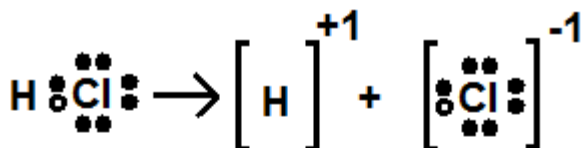
When I took chemistry in high school, my friend Tim was a bit of a prankster. He took an eyedropper with water in it and chased a friend of his around the lab room shouting what you see above. His friend ran in fear, mortal terror that he would be eaten away by an acid. Why didn’t Tim shout “it’s a base! It’s a base!” Would his friend have run in terror?

Acids and bases are a cornerstone of chemistry. These two substances have uses in industry, medicine, geology, cosmetics and in the home as well. Ammonia (NH<sub>4</sub>OH) is a base that is used to clean grease buildup on floors. Hydrochloric acid (HCl) is used to partially dissolve the surface of concrete flooring so that it roughens to hold floor paint better. Hydrofluoric acid (HF) is used to etch glass. Sulfuric acid (H<sub>2</sub>SO<sub>4</sub>) is used as a catalyst for certain reactions, and as a reactant in refining iron ore. Sodium hydroxide (NaOH) is reacted with animal fat or vegetable oil to form soap, and it is also used for drain cleaner.

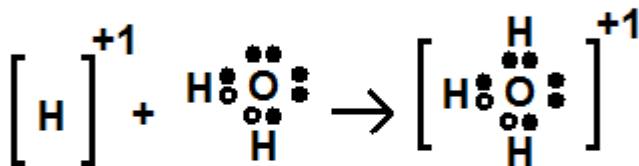
**Svante Arrhenius** (1859-1927) was the first to describe the conductivity of electrolyte solutions, and to hypothesize that solutions that conduct electricity contain dissolved ions. He also described acids and bases in terms of their properties. What follows is the **Arrhenius Definition** of acids and bases!

## **ACIDS: substances that contain H<sup>+</sup> ions that ionize when dissolved in water.**

Acids are the only molecules that ionize when dissolved in water. Acids are electrolytes, unlike other molecular substances like water (H<sub>2</sub>O) and sugar (C<sub>6</sub>H<sub>12</sub>O<sub>6</sub>). The H leaves the acid and bonds to the water molecule to form a hydronium ion (H<sub>3</sub>O<sup>+</sup>).

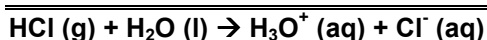


1) The acid ionizes to form a hydrogen ion and an anion. In this case, the anion is the chloride ion.

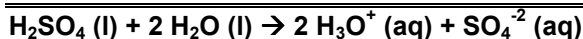


2) The hydrogen ion bonds to the water molecule by using a sneaky kind of bonding. H<sup>+</sup> doesn’t have any valence electrons of its own to share, and there are no unpaired electrons in the water molecule. The hydrogen mooches two electrons off of the oxygen. Notice how the other two bonds are represented as a circle and a dot? That shows one electron from each bonding atom pairing up. The hydrogen on top is bonded with two dots...both shared electrons originally belonged to just the oxygen atom. This is called a **COORDINATE COVALENT BOND**.

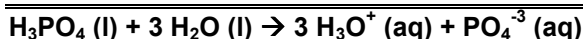
Examples:



The acid HCl contains 1 H<sup>+</sup> which combines with 1 H<sub>2</sub>O to form 1 H<sub>3</sub>O<sup>+</sup>



The acid H<sub>2</sub>SO<sub>4</sub> contains 2 H<sup>+</sup> which combines with 2 H<sub>2</sub>O to form 2 H<sub>3</sub>O<sup>+</sup>



The acid H<sub>3</sub>PO<sub>4</sub> contains 3 H<sup>+</sup> which combines with 3 H<sub>2</sub>O to form 3 H<sub>3</sub>O<sup>+</sup>

## Properties Of Acids:

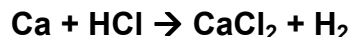
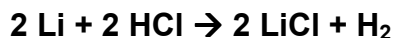
Table J  
Activity Series

Most	Metals	Nonmetals	Most
↓	Li	F <sub>2</sub>	↓
	Rb	Cl <sub>2</sub>	
	K	Br <sub>2</sub>	
	Cs	I <sub>2</sub>	
	Ba		
	Sr		
	Ca		
	Na		
	Mg		
	Al		
	Ti		
	Mn		
	Zn		
	Cr		
	Fe		
	Co		
	Ni		
	Sn		
	Pb		
**H <sub>2</sub>			
Cu			
Ag			
Au			
Least			Least

### a) Acids eat away (oxidize) active metals (above H<sub>2</sub> on Table J)

Metals like Li, Mg and Zn can be oxidized by an acid to produce hydrogen gas. They are listed above hydrogen (H<sub>2</sub>) on Table J. The three metals listed below hydrogen (Cu, Ag and Au) cannot be oxidized by an acid. There are some exceptions to this, but they will not be covered in this unit. The significance of this positioning will be explained in more detail in the next unit.

This is a single replacement reaction:



The active metal kicks out the hydrogen in the acid. This is one way to prepare a sample of hydrogen gas!

### b) Acids have a pH less than 7.

pH is a scale that measures the acidity or alkalinity of a solution. A pH of 7 is a neutral solution, and acids have a pH of less than 7. Each decrease of one in pH is a tenfold increase in acid strength. An acid with a pH of 3 is ten times more acidic than one with a pH of 4, and one hundred times more acidic than a solution with a pH of 5.

### c) Acidic solutions conduct electricity.

Acids are electrolytes, because they form ions in solution. The stronger the acid, the more it ionizes, and therefore the better it conducts electricity.

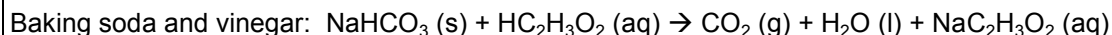
Strong acids (strong electrolytes) include HI, HCl, HNO<sub>3</sub> and H<sub>2</sub>SO<sub>4</sub>.

Weak acids (weak electrolytes) include H<sub>2</sub>CO<sub>3</sub> (found in soda) and HC<sub>2</sub>H<sub>3</sub>O<sub>2</sub> (found in vinegar).

### d) Dilute solutions of acids taste sour.

Citric acid is found in citrus fruits like lemons and grapefruits. It is also used in sour candies to give it that extra sour kick.

### e) Acids react with carbonates to form CO<sub>2</sub>, salt and water vapor



This is the "volcano" reaction...the CO<sub>2</sub> gas given off causes the solution to foam up and out.

### f) Acids can be formed by reaction of gaseous oxides with water

Burning fossil fuels releases nonmetallic oxides (CO<sub>2</sub>, NO<sub>2</sub>, SO<sub>2</sub> and similar molecules) into the atmosphere. When they combine with the water in the atmosphere, they form weak acids that can cause ecological problems. Plants and fish thrive in a narrow range of pH values. The acidification of rain has brought the pH of my lawn down so much that moss grows better than grass does, and the only way to reverse it is to place hundreds of pounds of lime (calcium carbonate, a weak base) on the lawn to bring the pH up so that the moss can't grow as well and the grass has a chance!

## Naming Acids (Reference Table K):

**Table K  
Common Acids**

Formula	Name
HCl(aq)	hydrochloric acid
HNO <sub>3</sub> (aq)	nitric acid
H <sub>2</sub> SO <sub>4</sub> (aq)	sulfuric acid
H <sub>3</sub> PO <sub>4</sub> (aq)	phosphoric acid
H <sub>2</sub> CO <sub>3</sub> (aq) or CO <sub>2</sub> (aq)	carbonic acid
CH <sub>3</sub> COOH(aq) or HC <sub>2</sub> H <sub>3</sub> O <sub>2</sub> (aq)	ethanoic acid (acetic acid)

a) **Binary Acids:** hydro- prefix, followed by nonmetal ion name with last syllable replaced with -ic acid

Naming:

HCl (aq): hydro + (chloride – ide + ic acid) =  
**hydrochloric acid**

HBr (aq): hydro + (bromide – ide + ic acid) =  
**hydrobromic acid**

H<sub>2</sub>S (aq): hydro + (sulfide – ide + ic acid) =  
**hydrosulfic acid, also called hydrosulfuric acid**

H<sub>3</sub>N (aq): hydro + (nitride – ide + ic acid) =  
**hydronitric acid**

Writing: just as you would write the name of any ionic compound, putting the H<sup>+1</sup> first, and the negative ion second.

Hydrofluoric acid: H<sup>+1</sup> and fluoride (F<sup>-1</sup>) → **HF (aq)**

Hydrophosphoric acid: H<sup>+1</sup> and phosphide (P<sup>-3</sup>) → **H<sub>3</sub>P (aq)**

a) **Ternary Acids:** no hydro- prefix, polyatomic ion name followed by -ic acid if ion ends in -ide, -ate or followed by -ous acid if ion ends in -ite

**Table E  
Selected Polyatomic Ions**

H <sub>3</sub> O <sup>+</sup>	hydronium	CrO <sub>4</sub> <sup>2-</sup>	chromate
Hg <sub>2</sub> <sup>2+</sup>	dimercury (I)	Cr <sub>2</sub> O <sub>7</sub> <sup>2-</sup>	dichromate
NH <sub>4</sub> <sup>+</sup>	ammonium	MnO <sub>4</sub> <sup>-</sup>	permanganate
C <sub>2</sub> H <sub>3</sub> O <sub>2</sub> <sup>-</sup> CH <sub>3</sub> COO <sup>-</sup>	acetate	NO <sub>2</sub> <sup>-</sup>	nitrite
		NO <sub>3</sub> <sup>-</sup>	nitrate
CN <sup>-</sup>	cyanide	O <sub>2</sub> <sup>2-</sup>	peroxide
CO <sub>3</sub> <sup>2-</sup>	carbonate	OH <sup>-</sup>	hydroxide
HCO <sub>3</sub> <sup>-</sup>	hydrogen carbonate	PO <sub>4</sub> <sup>3-</sup>	phosphate
C <sub>2</sub> O <sub>4</sub> <sup>2-</sup>	oxalate	SCN <sup>-</sup>	thiocyanate
ClO <sup>-</sup>	hypochlorite	SO <sub>3</sub> <sup>2-</sup>	sulfite
ClO <sub>2</sub> <sup>-</sup>	chlorite	SO <sub>4</sub> <sup>2-</sup>	sulfate
ClO <sub>3</sub> <sup>-</sup>	chlorate	HSO <sub>4</sub> <sup>-</sup>	hydrogen sulfate
ClO <sub>4</sub> <sup>-</sup>	perchlorate	S <sub>2</sub> O <sub>3</sub> <sup>2-</sup>	thiosulfate

Naming:

HNO<sub>3</sub> (aq): nitrate – ate + ic acid = **nitric acid**

HNO<sub>2</sub> (aq): nitrite – ite + ous acid = **nitrous acid**

HClO<sub>3</sub> (aq): chlorate – ate + ic acid = **chloric acid**

HClO<sub>2</sub> (aq): chlorite – ite + ous acid = **chlorous acid**

HCN (aq): cyanide – ide + ic acid = **cyanic acid**

Writing:

Sulfuric acid: H<sup>+</sup> and sulfate (SO<sub>4</sub><sup>2-</sup>) → **H<sub>2</sub>SO<sub>4</sub> (aq)**

Sulfurous acid: H<sup>+</sup> and sulfite (SO<sub>3</sub><sup>2-</sup>) → **H<sub>2</sub>SO<sub>3</sub> (aq)**

**BASES: substances that contain hydroxide (OH<sup>-1</sup>) ions dissolved in aqueous solution.**

**Table L  
Common Bases**

Formula	Name	
NaOH(aq)	sodium hydroxide	$\text{NaOH (s)} \rightarrow \text{Na}^{+1} \text{ (aq)} + \text{OH}^{-1} \text{ (aq)}$ (sodium hydroxide)
KOH(aq)	potassium hydroxide	$\text{Ca(OH)}_2 \text{ (s)} \rightarrow \text{Ca}^{+2} \text{ (aq)} + 2 \text{OH}^{-1} \text{ (aq)}$ (calcium hydroxide)
$\text{Ca(OH)}_2 \text{ (aq)}$	calcium hydroxide	
$\text{NH}_3 \text{ (aq)}$	aqueous ammonia	$\text{Al(OH)}_3 \text{ (s)} \rightarrow \text{Al}^{+3} \text{ (aq)} + 3 \text{OH}^{-1} \text{ (aq)}$ (aluminum hydroxide)

**Properties Of Bases:**

**a) Bases have a pH greater than 7**

pH is a scale that measures the **acidity** or **alkalinity** (basicity) of a solution. A pH of 7 is a neutral solution, and bases have a pH of more than 7. Each increase of one in pH is a tenfold increase in base strength. A base with a pH of 10 is ten times more basic than one with a pH of 9, and one hundred times more basic than a solution with a pH of 8.

**b) Basic solutions conduct electricity.**

Bases are electrolytes, because they form ions in solution. The stronger the base (the more alkaline the solution, in other words), the more it ionizes, and therefore the better it conducts electricity.

Strong bases (strong electrolytes) include Group 1 metal hydroxides (LiOH, NaOH, RbOH and CsOH).

Weak bases (weak electrolytes) include  $\text{Ca(OH)}_2$ ,  $\text{Mg(OH)}_2$  and  $\text{Al(OH)}_3$ , which can all be found in antacids. Antacids neutralize excess stomach acid that causes heartburn.

**c) Bases taste bitter**

Alkaloids, which are often found in medicines, have a bitter taste. So does coffee!

**d) Bases can be formed when Group 1 and 2 metals react with water, hydrogen is released too.**

$2 \text{Na (s)} + \text{H}_2\text{O (l)} \rightarrow 2 \text{NaOH (aq)} + \text{H}_2 \text{ (g)}$  ← sodium is reacting with water to form sodium hydroxide

$\text{Mg (s)} + 2 \text{H}_2\text{O (l)} \rightarrow \text{Mg(OH)}_2 \text{ (aq)} + \text{H}_2 \text{ (g)}$  ← magnesium is reacting with water to form magnesium hydroxide

What metal has to be reacted with water to form lithium hydroxide? Lithium!

**e) Bases hydrolyze fats (turns them into soap, also called “saponification”)**

Drain cleaner usually contains sodium hydroxide, which reacts with grease (nonpolar, so it can't dissolve in water) that is clogging the drain and turns it into soap (which is a sodium salt of a fatty acid and therefore ionic, which is soluble in water), which washes down the drain.

The manufacture of soap involves heating up animal fat or vegetable oil, (for example, glyceryl stearate) dissolving it in alcohol and adding NaOH or KOH to it slowly. This forms a soap (for example, sodium stearate), which can now be used for cleaning!

Ammonium hydroxide ( $\text{NH}_3 \text{ (aq)}$  or  $\text{NH}_4\text{OH}$ ) is a solution used to clean floors and countertops of greasy buildup or residue. NEVER mix ammonia with bleach or products containing bleach, as this can cause a serious health risk.

## HOW DO WE KNOW IF A SOLUTION IS ACIDIC OR BASIC?

### 1) pH probes

pH probes contain an electrode that detects electrical conductivity. Before using this electronic device, it has to be calibrated by giving it a taste of two different solutions with different pH's. These come in pocket devices that run on batteries or in computer interface probe form.

**Table M**  
**Common Acid–Base Indicators**

Indicator	Approximate pH Range for Color Change	Color Change
methyl orange	3.2–4.4	red to yellow
bromthymol blue	6.0–7.6	yellow to blue
phenolphthalein	8.2–10	colorless to pink
litmus	5.5–8.2	red to blue
bromcresol green	3.8–5.4	yellow to blue
thymol blue	8.0–9.6	yellow to blue

### 2) Acid-Base Indicators and narrowing down pH using multiple indicators (mixture of indicators gives great range of colors, pH paper)

Indicators are chemicals that have a certain characteristic color, depending on the pH. They can be used to determine if a solution is acidic or basic, or even to narrow the range of pH of a solution down. pH paper is paper soaked with a mixture of indicators that give a specific color at a specific pH, which is found on a chart on the pH paper bottle so you can compare the results to the chart. Litmus paper is paper soaked with litmus solution that has been allowed to dry.

**Methyl orange is RED from a pH of 3.2 or lower, and YELLOW from a pH of 4.4 or more. The middle of the range is an intermediate color (in this case, ORANGE).**

A solution yields the following results when tested with various indicators:

Methyl Orange = yellow  
Phenolphthalein = colorless  
Bromcresol Green = blue  
Thymol Blue = yellow

Can the pH be:

a) 2.8   b) 6.5   c) 8.5   d) 4.8

Well, let's use the reference table to figure out at what pH the above indicators will be the specified colors.

1) Methyl Orange = yellow at pH's above 4.4 (it's red at pH's below 3.2 and changes from red to yellow between 3.2 and 4.4)

**Since the pH must be above 4.4, we can eliminate choice A.**

2) Phenolphthalein = colorless at pH's below 8.2 (it's pink at pH's above 10 and changes from colorless to pink between 8.2 and 10)

**Since the pH must be below 8.2, choice C can be eliminated. Only choices B and D are left.**

3) Bromcresol Green = blue at pH's above 5.4 (it's yellow at pH's below 3.8 and changes from yellow to green between 3.8 and 5.4)

**Since the pH must be above 5.4, choice D can be eliminated.**

The answer must be Choice B. Let's see if that holds up with the last indicator:

4) Thymol Blue = yellow at pH's below 8.0, which 6.5 certainly is.

**The answer is therefore choice B, pH = 6.5.**

## 2) Acid and Base Neutralization (HW: p. 21- 23)

**Essential Question:** How do antacids work?

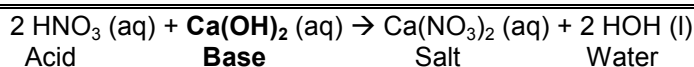
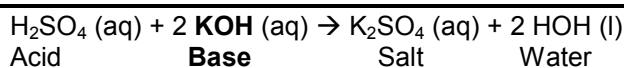
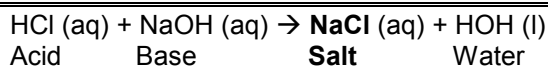
### Neutralization

When acidic and basic solutions are mixed, the  $H^+$  of the acid and the  $OH^-$  of the base combine to form water. The anion of the acid and the cation of the base come together to form a salt. A salt is defined as an ionic compound that can be formed by acid-base neutralization.

This is a simple double replacement reaction. The water formed is considered to be the precipitate. To make writing these reactions easier, water will be written as HOH.

One mole of  $H^+$  ions exactly neutralizes 1 mole of  $OH^-$  ions

**Completing Neutralization Reactions: it's exactly the same as you completed double replacement reactions!**



**Titration** - the controlled process of acid-base neutralization. It is used to determine the concentration of an acid or base.

Problem - You find a bottle labeled "NaOH", with no concentration written on it. You want to find out the concentration, because unless the concentration is known, this sample is totally useless in the lab. How can this be done?

- 1) Put a certain volume of the base in a buret
- 2) Place a certain volume of standardized solution acid with some phenolphthalein indicator into an Erlenmeyer flask.
- 3) Add the base to the acid drop-wise until the indicator just begins to turn color.
- 4) Record the volume of base necessary to neutralize the acid.

The point where the indicator turns color is called the "endpoint". Because the indicator might not turn color at exactly  $pH = 7$ , it might be a little off from the equivalence point, or the point where all of the acid  $H^+$  ions might have in fact reacted with all of the base  $OH^-$  ions. The best way to do a titration is to use a pH meter.

**ENDPOINT:** The pH at which an indicator that has been added to a titration setup turns color.

**Phenolphthalein turns from colorless to pink at a pH of 8.2, which is slightly on the base side of neutral. When base is added to acid with phenolphthalein in it, the solution will gradually take longer to get the pink color out of until one drop of base turns the solution permanently pink. This will be a pH of 8.2. This is the endpoint.**

**EQUIVALENCE POINT:** The point at which the titrated solution has a pH of 7. The concentration of hydronium is equivalent to the concentration of hydroxide. This can be determined by using a pH probe to determine when the solution is neutral rather than an indicator.

The best indicators give an endpoint close to the equivalence point. To determine if a solution has been neutralized, choose an indicator that changes color closest to a pH of 7. Phenolphthalein is the most commonly used indicator for titration, though bromthymol blue does a nice job as well. If you really have the big bucks, buy a pH probe...just stop titrating when the pH reaches 7!

## Solving Titration Problems

- 1) One mole of  $H^+$  neutralizes one mole of  $OH^-$ .
- 2) moles of  $H^+$  = moles of  $OH^-$
- 3) Since we are dealing with solutions and molarities, recall the formula  $M = \text{moles}/L$ . Rearrange this to **moles = M x L**. Liters are a unit of volume, so the formula now becomes moles = M x V. Therefore:

$$\text{moles of acid} = M_{\text{acid}} \times V_{\text{acid}} \quad \text{and moles of base} = M_{\text{base}} \times V_{\text{base}}$$

This gives the formula

$$M_{\text{acid}} \times V_{\text{acid}} = M_{\text{base}} \times V_{\text{base}}$$

Which can be abbreviated  $M_a V_a = M_b V_b$ . This can be remembered by saying out loud:

**MAH-VAH EQUALS MUB-VUB!**

Now, since acids may have more than one H and bases may have more than one OH, the equation has to be finalized as:

$$\# H M_a V_a = \# OH M_b V_b$$

If you are just trying to solve for moles instead of molarity, the formula can be simplified to

$$\# H \text{ Moles}_a = \# OH \text{ Moles}_b$$

**Here are a lot of sample problems for you!**

**How many moles of LiOH are needed to exactly neutralize 2.0 moles of  $H_2SO_4$ ?**

Since we are given moles of both acid and base, use the equation  $\# H \text{ Moles}_a = \# OH \text{ Moles}_b$ .

$$\# H \text{ Moles}_a = \# OH \text{ Moles}_b, \text{ rearranged to solve for moles of base is } \text{Moles}_b = \# H \text{ Moles}_a / \# OH$$

$$\text{Moles}_b = \# H \text{ Moles}_a / \# OH = (2 \times 2.0 \text{ moles}) / 1 = \mathbf{4.0 \text{ moles of LiOH}}$$

**How many moles of  $H_2SO_4$  are needed to exactly neutralize 5.0 moles of NaOH?**

Since we are given moles of both acid and base, use the equation  $\# H \text{ Moles}_a = \# OH \text{ Moles}_b$ .

$$\# H \text{ Moles}_a = \# OH \text{ Moles}_b, \text{ rearranged to solve for moles of acid is } \text{Moles}_a = \# OH \text{ Moles}_b / \# H$$

$$\# OH \text{ Moles}_b / \# H = (1 \times 5.0 \text{ moles}) / 2 = \mathbf{2.5 \text{ moles of } H_2SO_4}$$

**How many moles of HCl are needed to neutralize 0.10 L of 2.0 M NaOH?**

This requires a mixture of both equations. Since moles = M x V, one can easily be substituted for the other. We are given moles for the acid, so use  $\# H \text{ Moles}_a$  for that part. We are given molarity and volume for the base, so use  $\# OH M_b V_b$  for that part.

$$\# H \text{ Moles}_a = \# OH M_b V_b, \text{ rearranged to solve for moles of acid is } \text{Moles}_a = \# OH M_b V_b / \# H$$

$$\# OH M_b V_b / \# H = [(1) (2.0 \text{ M}) (0.10 \text{ L})] / 1 = \mathbf{0.20 \text{ moles of HCl}}$$

**How many moles of NaOH are needed to neutralize 0.010 L of 0.20 M H<sub>2</sub>SO<sub>4</sub>?**

This requires a mixture of both equations. Since moles = M x V, one can easily be substituted for the other. We are given moles for the base, so use # OH Moles<sub>b</sub> for that part. We are given molarity and volume for the acid, so use # H M<sub>a</sub>V<sub>a</sub> for that part.

# H M<sub>a</sub>V<sub>a</sub> = # OH Moles<sub>b</sub>, rearranged to solve for moles of base is Moles<sub>b</sub> = # H M<sub>a</sub>V<sub>a</sub> / # OH

# H M<sub>a</sub>V<sub>a</sub> / # OH = [(2) (0.20 M) (0.010 L)] / 1 = **0.0040 moles of HCl**

How many mL of 0.100 M HCl are needed to neutralize 40.0 mL of 0.500 M NaOH?

**If it takes 15.0 mL of 0.40 M NaOH to neutralize 5.0 mL of HCl, what is the molar concentration of the HCl solution?**

Since we are given molarity and volume for both acid and base, use the equation # H M<sub>a</sub>V<sub>a</sub> = # OH M<sub>b</sub>V<sub>b</sub>

# H M<sub>a</sub>V<sub>a</sub> = # OH M<sub>b</sub>V<sub>b</sub>, rearranged to solve for molarity of acid is M<sub>a</sub> = # OH M<sub>b</sub>V<sub>b</sub> / # H V<sub>a</sub>

M<sub>a</sub> = # OH M<sub>b</sub>V<sub>b</sub> / # H V<sub>a</sub> = [(1) (0.40 M) (15.0 mL)] / [(1) (5.0 mL)] = **1.2 M HCl**

**If it takes 10.0 mL of 2.0 M H<sub>2</sub>SO<sub>4</sub> to neutralize 30.0 mL of KOH, what is the molar concentration of the KOH?**

Since we are given molarity and volume for both acid and base, use the equation # H M<sub>a</sub>V<sub>a</sub> = # OH M<sub>b</sub>V<sub>b</sub>

# H M<sub>a</sub>V<sub>a</sub> = # OH M<sub>b</sub>V<sub>b</sub>, rearranged to solve for molarity of base is M<sub>b</sub> = # H M<sub>a</sub>V<sub>a</sub> / # OH V<sub>b</sub>

M<sub>b</sub> = # H M<sub>a</sub>V<sub>a</sub> / # OH V<sub>b</sub> = [(2) (2.0 M) (10.0 mL)] / [(1) (30.0 mL)] = **1.3 M KOH**

**How many mL of 2.0 M H<sub>2</sub>SO<sub>4</sub> are required to neutralize 30.0 mL of 1.0 M NaOH?**

Since we are given molarity and volume for both acid and base, use the equation # H M<sub>a</sub>V<sub>a</sub> = # OH M<sub>b</sub>V<sub>b</sub>

# H M<sub>a</sub>V<sub>a</sub> = # OH M<sub>b</sub>V<sub>b</sub>, rearranged to solve for volume of acid is V<sub>a</sub> = # OH M<sub>b</sub>V<sub>b</sub> / # H M<sub>a</sub>

V<sub>a</sub> = # OH M<sub>b</sub>V<sub>b</sub> / # H M<sub>a</sub> = [(1) (1.0 M) (30.0 mL)] / [(2) (2.0 M)] = **7.5 mL H<sub>2</sub>SO<sub>4</sub>**

**How many mL of 0.10 M Ca(OH)<sub>2</sub> are required to neutralize 25.0 mL of 0.50 M HNO<sub>3</sub>?**

Since we are given molarity and volume for both acid and base, use the equation # H M<sub>a</sub>V<sub>a</sub> = # OH M<sub>b</sub>V<sub>b</sub>

# H M<sub>a</sub>V<sub>a</sub> = # OH M<sub>b</sub>V<sub>b</sub>, rearranged to solve for volume of base is V<sub>b</sub> = # H M<sub>a</sub>V<sub>a</sub> / # OH M<sub>b</sub>

V<sub>b</sub> = # H M<sub>a</sub>V<sub>a</sub> / # OH M<sub>b</sub> = [(1) (0.50 M) (25.0 mL)] / [(2) (0.10 M)] = **63 mL Ca(OH)<sub>2</sub>**

### 3) Acid and Base Equilibrium (HW: p. 24, 25)

**Essential Question:** So what is this pH that we use to keep our fish alive and our bodies stink-free?

#### **K<sub>a</sub>, Ionization Constant for Acids at Equilibrium**

Acids dissociate to different degrees. Strong acids ionize 100% (go to completion without reaching equilibrium). In some cases, only a small amount of acid dissociates before solution equilibrium is established. These acids are weak acids, and one can compare acid strength from the acid dissociation constant, K<sub>a</sub>



$$K_a = \frac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}]}$$

H<sub>2</sub>O is left out because when weak acids dissolve, the concentration of the acid does not significantly change. It is left out of the equation like the concentration of undissolved solid is left out of the K<sub>sp</sub> equation.

**K<sub>a</sub> is the product of the dissolved ion concentrations divided by the undissolved acid concentration, and the higher the K<sub>a</sub>, the stronger the acid.**

**K<sub>a</sub> values are given on AE Reference Table C.**

#### **pH, Power of Hydronium Ion In A Solution**

Ah, pH. It's the easiest method to use for comparing the strengths of acids and bases. We test our fishtanks (fish pee out ammonia, which is a base, and brings the pH up), our lawns (acid rain brings the pH of the soil down) and even food is pH tested as it is being made to make sure that it falls within the right range. You wouldn't want your super-sour candy to have too little bite, would you? So just what is this pH, what does it mean, and how is it measured?

**Ionization of water** - water is a very weak electrolyte which actually dissolves in itself in the following manner:



Equilibrium is established after the concentration of H<sub>3</sub>O<sup>+</sup> and OH<sup>-</sup> are both 1 X 10<sup>-7</sup> M. This is insignificant compared to the concentration of H<sub>2</sub>O in a liter: 55.6 M. Therefore, an ionization constant must be derived in the same manner as K<sub>a</sub>, where the concentration of the water is ignored:

$$K_w = [\text{H}_3\text{O}^+][\text{OH}^-], \quad \text{and the } [\text{H}_3\text{O}^+] = [\text{OH}^-] = 1.0 \times 10^{-7} \text{ M}$$

$$K_w = [1.0 \times 10^{-7} \text{ M}] [1.0 \times 10^{-7} \text{ M}]$$

$$K_w = 1 \times 10^{-14}$$

**This means that the (concentration of H<sup>+</sup>) X (the concentration of OH<sup>-</sup>) in any aqueous solution at 298 K must be 1 X 10<sup>-14</sup>.**

**ADDING ACIDS TO WATER**- adding an acid to water increases the  $\text{H}_3\text{O}^+$  concentration. The  $\text{OH}^-$  concentration decreases by such an amount as to keep the product of the two equal to  $K_w$ .

**ADDING BASES TO WATER**- adding a base to water increases the  $\text{OH}^-$  concentration. The  $\text{H}_3\text{O}^+$  concentration decreases by such an amount as to keep the product of the two equal to  $K_w$ .

If  $[\text{OH}^-] = 1 \times 10^{-4} \text{ M}$ , what is the  $[\text{H}_3\text{O}^+]$ ?

$K_w = [\text{H}_3\text{O}^+][\text{OH}^-]$  rearranged to solve for  $[\text{H}_3\text{O}^+]$  is  $[\text{H}_3\text{O}^+] = K_w / [\text{OH}^-]$

$[\text{H}_3\text{O}^+] = K_w / [\text{OH}^-] = (1 \times 10^{-14}) / (1 \times 10^{-4}) = 1 \times 10^{-10} \text{ M}$

**Simply speaking, if  $[\text{OH}^-] = 1 \times 10^{-4}$ ,  $[\text{H}_3\text{O}^+]$  must equal  $1 \times 10^{-10}$ , because exponents add.  
 $(-4) + (-10) = (-14)$ , the exponent of  $K_w$ !**

If  $[\text{H}_3\text{O}^+] = 1 \times 10^{-5} \text{ M}$ , what is the  $[\text{OH}^-]$ ?

$K_w = [\text{H}_3\text{O}^+][\text{OH}^-]$  rearranged to solve for  $[\text{OH}^-]$  is  $[\text{OH}^-] = K_w / [\text{H}_3\text{O}^+]$

$[\text{OH}^-] = K_w / [\text{H}_3\text{O}^+] = (1 \times 10^{-14}) / (1 \times 10^{-5}) = 1 \times 10^{-9} \text{ M}$

**Simply speaking, if  $[\text{H}_3\text{O}^+] = 1 \times 10^{-5}$ ,  $[\text{OH}^-]$  must equal  $1 \times 10^{-9}$ , because exponents add.  
 $(-5) + (-9) = (-14)$ , the exponent of  $K_w$ !**

What is the  $\text{H}_3\text{O}^+$  ion concentration in a 0.0100 M solution of NaOH?

0.0100 M in scientific notation is  $1.00 \times 10^{-2} \text{ M}$ . NaOH is a base, so this is the concentration of the  $\text{OH}^-$  ion.

$K_w = [\text{H}_3\text{O}^+][\text{OH}^-]$  rearranged to solve for  $[\text{H}_3\text{O}^+]$  is  $[\text{H}_3\text{O}^+] = K_w / [\text{OH}^-]$

$[\text{H}_3\text{O}^+] = K_w / [\text{OH}^-] = (1 \times 10^{-14}) / (1.00 \times 10^{-2}) = 1.00 \times 10^{-12} \text{ M}$

**Simply speaking, if  $[\text{OH}^-] = 1 \times 10^{-2}$ ,  $[\text{H}_3\text{O}^+]$  must equal  $1.00 \times 10^{-12}$ , because exponents add.  
 $(-2) + (-12) = (-14)$ , the exponent of  $K_w$ !**

What is the  $\text{OH}^-$  ion concentration in a 0.1 M solution of HCl?

0.1 M in scientific notation is  $1 \times 10^{-1} \text{ M}$ . HCl is an acid, so this is the concentration of the  $\text{H}_3\text{O}^+$  ion.

$K_w = [\text{H}_3\text{O}^+][\text{OH}^-]$  rearranged to solve for  $[\text{OH}^-]$  is  $[\text{OH}^-] = K_w / [\text{H}_3\text{O}^+]$

$[\text{OH}^-] = K_w / [\text{H}_3\text{O}^+] = (1 \times 10^{-14}) / (1 \times 10^{-1}) = 1 \times 10^{-13} \text{ M}$

**Simply speaking, if  $[\text{H}_3\text{O}^+] = 1 \times 10^{-1}$ ,  $[\text{OH}^-]$  must equal  $1 \times 10^{-13}$ , because exponents add.  
 $(-1) + (-13) = (-14)$ , the exponent of  $K_w$ !**

pH - a measure of the  $[H_3O^+]$  in a solution.

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

## What the heck is a LOG?

Simply speaking, it is a way of expressing a number as a power of ten. For example:

Regular Number	As Scientific Notation	As a Logarithm
1	$10^0$	0
10	$10^1$	1
100	$10^2$	2
1000	$10^3$	3
10000	$10^4$	4
100000	$10^5$	5
0.1	$10^{-1}$	-1
0.01	$10^{-2}$	-2
0.001	$10^{-3}$	-3
0.0001	$10^{-4}$	-4

So, as you can see, the logarithm of a number that is a whole power of ten is simply the exponent of that number expressed in scientific notation. One million (1 000 000) is  $10^6$ , so the log of a million is 6! One millionth (0.000001) is  $1 \times 10^{-6}$ , so the log of one millionth is -6!

Numbers between powers of ten will have a logarithm value somewhere between the two powers of ten that the number is between. Use your calculator to find the log. For example:

Number	Between which two powers of ten?	Logarithm is between	Actual logarithm	Number expressed as power of ten
7	$10^0$ and $10^1$	0 and 1	0.85	$10^{0.85}$
45	$10^1$ and $10^2$	1 and 2	1.65	$10^{1.65}$
215	$10^2$ and $10^3$	2 and 3	2.33	$10^{2.33}$
6774	$10^3$ and $10^4$	3 and 4	3.83	$10^{3.83}$
42989	$10^4$ and $10^5$	4 and 5	4.63	$10^{4.63}$

That is the quick and dirty course on the basics of base ten logarithms.

## OK, so what the heck is a NEGATIVE log???

Easy! Just take the value of the log and reverse its sign!

Number	Log	-log
100 ( $10^2$ )	2	-2
10000 ( $10^4$ )	4	-4
0.01 ( $10^{-2}$ )	-2	2
0.00001 ( $10^{-5}$ )	-5	5

Its...just...that...easy!

## OK, so how do you figure out the pH of different solutions if you know their concentrations?

Depends on whether you have an acid or a base.

**ACIDS:** Ionize to form  $\text{H}_3\text{O}^{+1}$ . Since  $\text{pH} = -\log [\text{H}_3\text{O}^{+1}]$ , just take the log of the acid's concentration and reverse the sign.

What is the pH of a  $1 \times 10^{-4}$  M solution of HCl?

$$\text{pH} = -\log [\text{H}_3\text{O}^{+1}] = -\log [1 \times 10^{-4}] = 4$$

What is the pH of a 0.10 M solution of HCl?

$$\text{pH} = -\log [\text{H}_3\text{O}^{+1}] = -\log [0.10] = 1.0$$

What is the pH of a 0.0010 M solution of HCl?

$$\text{pH} = -\log [\text{H}_3\text{O}^{+1}] = -\log [0.0010] = 3.0$$

What is the pH of a 2.5 M solution of HCl?

$$\text{pH} = -\log [\text{H}_3\text{O}^{+1}] = -\log [2.5] = -0.40$$

What is the pH of a 0.030 M solution of HCl?

$$\text{pH} = -\log [\text{H}_3\text{O}^{+1}] = -\log [0.030] = 1.5$$

**BASES:** Ionize to form  $\text{OH}^{-1}$ . Since  $\text{pH} = -\log [\text{H}_3\text{O}^{+1}]$ , we first have to use  $K_w$  to find out the  $[\text{H}_3\text{O}^{+1}]$ . Then just take the log of the acid's concentration and reverse the sign.

What is the pH of a  $1 \times 10^{-4}$  M solution of NaOH?

$$[\text{H}_3\text{O}^{+1}] = K_w / [\text{OH}^{-1}] = (1 \times 10^{-14}) / (1 \times 10^{-4}) = 1 \times 10^{-10}$$

$$\text{pH} = -\log [\text{H}_3\text{O}^{+1}] = -\log [1 \times 10^{-10}] = 10$$

What is the pH of a 0.10 M solution of NaOH?

$$[\text{H}_3\text{O}^{+1}] = K_w / [\text{OH}^{-1}] = (1 \times 10^{-14}) / (0.10) = 1.0 \times 10^{-13}$$

$$\text{pH} = -\log [\text{H}_3\text{O}^{+1}] = -\log [1.0 \times 10^{-13}] = 13$$

What is the pH of a 0.0010 M solution of NaOH?

$$[\text{H}_3\text{O}^{+1}] = K_w / [\text{OH}^{-1}] = (1 \times 10^{-14}) / (0.0010) = 1.0 \times 10^{-11}$$

$$\text{pH} = -\log [\text{H}_3\text{O}^{+1}] = -\log [1.0 \times 10^{-11}] = 11$$

What is the pH of a 2.50 M solution of NaOH?

$$[\text{H}_3\text{O}^{+1}] = K_w / [\text{OH}^{-1}] = (1 \times 10^{-14}) / (2.50) = 4.00 \times 10^{-15}$$

$$\text{pH} = -\log [\text{H}_3\text{O}^{+1}] = -\log [4.00 \times 10^{-15}] = 14.4$$

What is the pH of a 0.0300 M solution of NaOH?

$$[\text{H}_3\text{O}^{+1}] = K_w / [\text{OH}^{-1}] = (1 \times 10^{-14}) / (0.0300) = 3.33 \times 10^{-13}$$

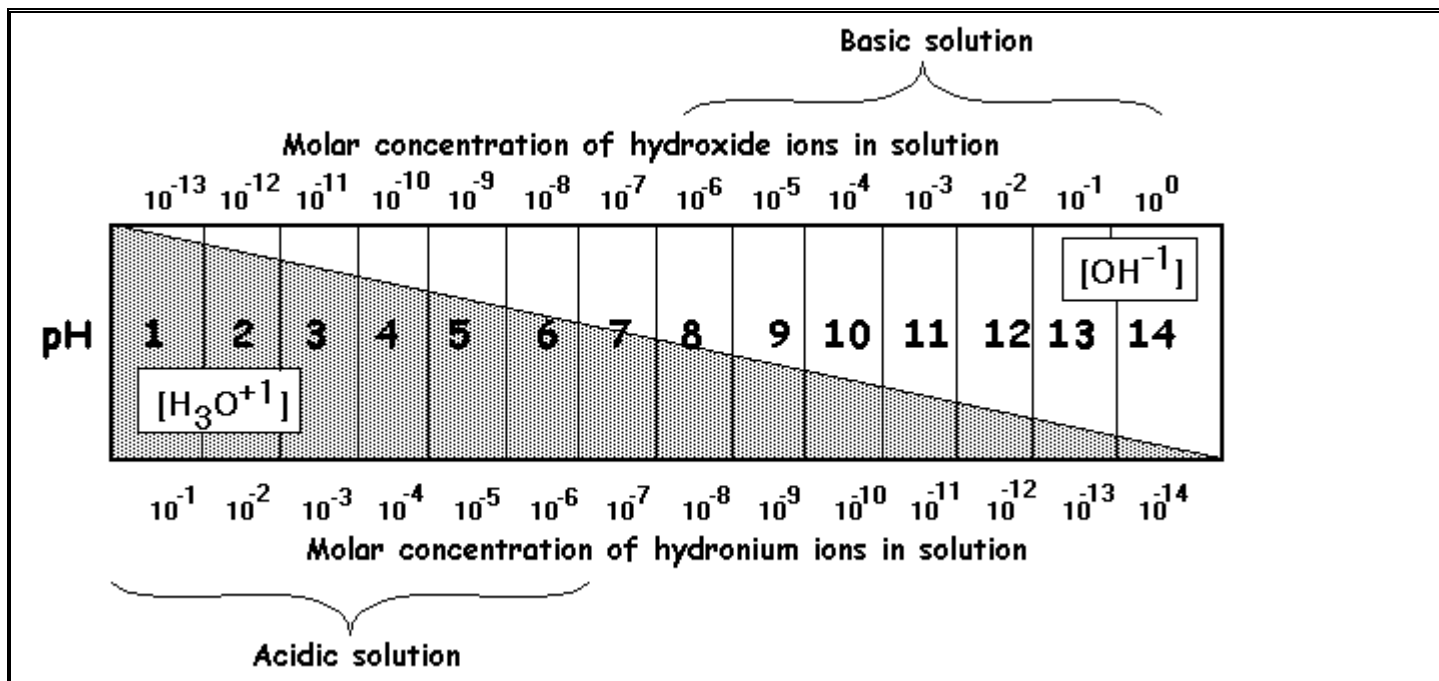
$$\text{pH} = -\log [\text{H}_3\text{O}^{+1}] = -\log [3.33 \times 10^{-13}] = 12.5$$

As you can see, acids have pH's less than 7 and bases have a pH of more than 7. What about water, which is neutral?

In water,  $[\text{H}_3\text{O}^{+1}] = [\text{OH}^{-1}] = 1.0 \times 10^{-7} \text{ M}$ .  $-\log [1.0 \times 10^{-7}] = 7.0$ ! **That's why a pH of 7 is considered neutral!**

If an acid is added to a basic solution, the pH will decrease (as  $\text{H}_3\text{O}^{+1}$  ions are added).

If a base is added to an acidic solution, the pH will increase (as  $\text{OH}^{-1}$  ions are added).



As you can see from the above diagram, an increase of one in pH is a tenfold increase in  $[\text{OH}^{-1}]$  ions.

A solution with a pH of 3 is ten times more acidic than a solution with a pH of 4.

A solution with a pH of 3 is a hundred times more acidic than a solution with a pH of 5.

A solution with a pH of 3 is a thousand times more acidic than a solution with a pH of 6.

A solution with a pH of 13 is ten times more basic than a solution with a pH of 12.

A solution with a pH of 13 is a hundred times more basic than a solution with a pH of 11.

A solution with a pH of 13 is a thousand times more basic than a solution with a pH of 10.

## AE Reference Table E

### Relative Strengths of Acids in Aqueous Solution at 1 atm and 298 K

Adapted from New York State Regents Chemistry Reference Table L, 1987 Revision

<b>Conjugate Pairs</b>		<b>K<sub>a</sub></b>
<b>Acid</b>	<b>Base</b>	
HI ⇌	H <sup>+1</sup> + I <sup>-1</sup>	Very large
HBr ⇌	H <sup>+1</sup> + Br <sup>-1</sup>	Very large
HCl ⇌	H <sup>+1</sup> + Cl <sup>-1</sup>	Very large
HNO <sub>3</sub> ⇌	H <sup>+1</sup> + NO <sub>3</sub> <sup>-1</sup>	Very large
H <sub>2</sub> SO <sub>4</sub> ⇌	H <sup>+1</sup> + HSO <sub>4</sub> <sup>-1</sup>	Large
H <sub>2</sub> O + SO <sub>2</sub> ⇌	H <sup>+1</sup> + HSO <sub>3</sub> <sup>-1</sup>	1.5 X10 <sup>-2</sup>
HSO <sub>4</sub> <sup>-1</sup> ⇌	H <sup>+1</sup> + SO <sub>4</sub> <sup>-2</sup>	1.2 X10 <sup>-2</sup>
H <sub>3</sub> PO <sub>4</sub> ⇌	H <sup>+1</sup> + H <sub>2</sub> PO <sub>4</sub> <sup>-1</sup>	7.5 X10 <sup>-3</sup>
HNO <sub>2</sub> ⇌	H <sup>+1</sup> + NO <sub>2</sub> <sup>-1</sup>	4.6 X10 <sup>-4</sup>
HF ⇌	H <sup>+1</sup> + F <sup>-1</sup>	3.5 X10 <sup>-4</sup>
HC <sub>2</sub> H <sub>3</sub> O <sub>2</sub> ⇌	H <sup>+1</sup> + C <sub>2</sub> H <sub>3</sub> O <sub>2</sub> <sup>-1</sup>	1.8 X10 <sup>-5</sup>
H <sub>2</sub> O + CO <sub>2</sub> ⇌	H <sup>+1</sup> + HCO <sub>3</sub> <sup>-1</sup>	4.3 X10 <sup>-7</sup>
HSO <sub>3</sub> <sup>-1</sup> ⇌	H <sup>+1</sup> + SO <sub>3</sub> <sup>-2</sup>	1.1 X10 <sup>-7</sup>
H <sub>2</sub> S ⇌	H <sup>+1</sup> + HS <sup>-1</sup>	9.5 X10 <sup>-8</sup>
H <sub>2</sub> PO <sub>4</sub> <sup>-1</sup> ⇌	H <sup>+1</sup> + HPO <sub>4</sub> <sup>-2</sup>	6.2 X10 <sup>-8</sup>
NH <sub>4</sub> <sup>+1</sup> ⇌	H <sup>+1</sup> + NH <sub>3</sub>	5.7 X10 <sup>-10</sup>
HCO <sub>3</sub> <sup>-1</sup> ⇌	H <sup>+1</sup> + CO <sub>3</sub> <sup>-2</sup>	5.6 X10 <sup>-11</sup>
HPO <sub>4</sub> <sup>-2</sup> ⇌	H <sup>+1</sup> + PO <sub>4</sub> <sup>-3</sup>	2.2 X10 <sup>-13</sup>
HS <sup>-1</sup> ⇌	H <sup>+1</sup> + S <sup>-2</sup>	1.3 X10 <sup>-14</sup>
H <sub>2</sub> O ⇌	H <sup>+1</sup> + OH <sup>-1</sup>	1.0 X10 <sup>-14</sup>
OH <sup>-1</sup> ⇌	H <sup>+1</sup> + O <sup>-2</sup>	<10 <sup>-36</sup>
NH <sub>3</sub> ⇌	H <sup>+1</sup> + NH <sub>2</sub> <sup>-1</sup>	Very small

## 4) Bronsted-Lowry Definition of Acids and Bases (HW: p. 26, 27)

**Essential Question:** If all poodles are dogs, are all dogs poodles?

Over the course of the last few topics, we have focused on acids and bases as discovered by Svante Arrhenius. There are other theories on what acids and bases are. This theory, developed by Johannes Brønsted and Thomas Lowry (published separately, but within months of each other, so they both got credit), is more general in nature. All poodles are dogs, but not all dogs are poodles. The Arrhenius theory is the “poodle” theory, and the alternate theory is the “dog” theory.

**According to Svante Arrhenius:**

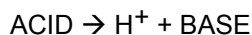
**Acid** – a compound that dissolves in water to produce  $H^{+1}$  as the only positively charged ion in solution

**Base** – a compound that dissolves in water to produce  $OH^{-1}$  as the only negatively charged ion in solution

The hydrogen atom is made of one proton and one electron. When hydrogen loses its electron to form  $H^{+}$ , all that's left is the proton. Therefore,  $H^{+}$  is just a proton!

**BRONSTED-LOWRY DEFINITION – based on what the species actually does in a chemical reaction.**

**ACID: Proton ( $H^{+}$ ) donor. BASE: Proton ( $H^{+}$ ) acceptor. Acids give up  $H^{+}$  to bases.**



Acid    Base

The HCl gives its  $H^{+}$  to the  $H_2O$  in the forward reaction.



Base    Acid

The  $H_2O$  gives its  $H^{+}$  to the  $NH_3$  in the forward reaction.



Acid                  Base

The  $HC_2H_3O_2$  gives its  $H^{+}$  to the  $H_2O$  in the forward reaction.

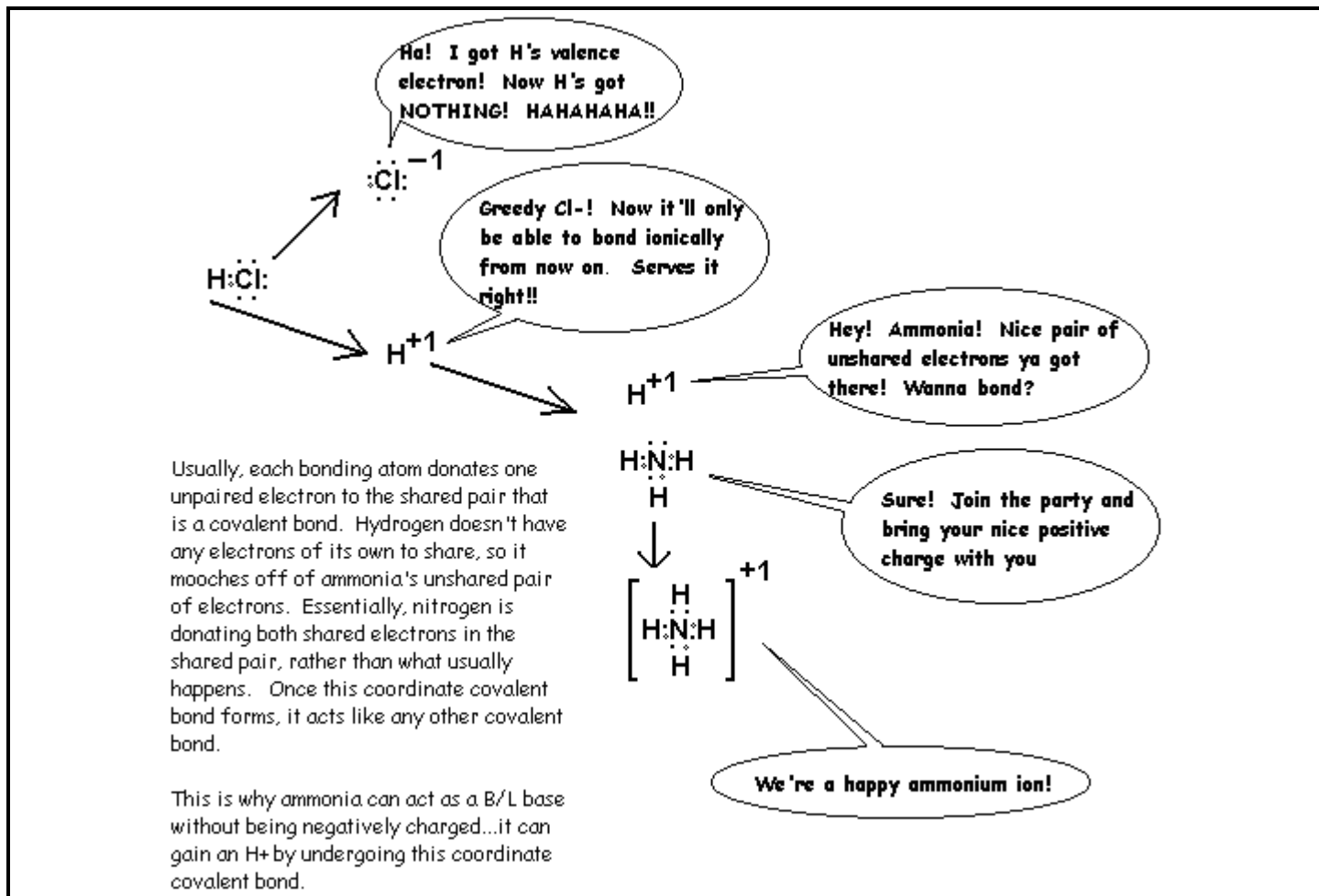
**Acids must contain at least one H. Bases do not necessarily need  $OH^{-}$ . Any negative ion will do.**



Water can be either an acid or a base. Substances that can either give up or take on a proton are called amphiprotic or amphoteric.

Species	Acid/Base/Amphiprotic	Why?
HCl	Acid	Contains an $H^{+}$ which it can give away
$Cl^{-}$	Base	Has a negative charge, which can attract $H^{+}$
$H_2SO_4$	Acid	Contains an $H^{+}$ which it can give away
$SO_4^{-2}$	Base	Has a negative charge, which can attract $H^{+}$
$HSO_4^{-1}$	Amphiprotic	Contains $H^{+}$ AND has a negative charge
$H_2S$	Acid	Contains an $H^{+}$ which it can give away
$S^{-2}$	Base	Has a negative charge, which can attract $H^{+}$
$HS^{-1}$	Amphiprotic	Contains $H^{+}$ AND has a negative charge

A species does not necessarily have to be charged negatively to be a base.  $\text{H}_2\text{O}$  and  $\text{NH}_3$  can act like bases because of COORDINATE COVALENT BONDING. This differs from a normal covalent bond only in the way it is formed.



## Conjugate acid/base pairs

When an acid loses an  $\text{H}^+$ , it forms its **conjugate base**. If the reaction were reversed, the conjugate base would pick up an  $\text{H}^+$  and turn back into the original acid. The strength of the conjugate is the opposite of the original...strong acids form weak conjugate bases. Strengths can be found on AE Ref. Table E.

What is the conjugate base of  $\text{HNO}_3$ ? The conjugate base forms when the acid loses  $\text{H}^+$ , so the conjugate base is  $\text{NO}_3^-$ . Not only do you have to get rid of the H, you also lose +1 in charge.

$\text{HNO}_3$  has a  $K_a$  of very large, meaning it is a strong acid. Therefore,  $\text{NO}_3^-$  is a weak base.

When a base gains an  $\text{H}^+$ , it forms its **conjugate acid**. If the reaction were reversed, the conjugate acid would lose an  $\text{H}^+$  and turn back into the original base. The strength of the conjugate is the opposite of the original...strong bases form weak conjugate acids. Strengths can be found on AE Ref. Table E.

What is the conjugate acid of  $\text{Cl}^-$ ? The conjugate acid forms when the base gains  $\text{H}^+$ , so the conjugate acid is  $\text{HCl}$ . Not only do you have to add the H, you also gain +1 in charge.

$\text{HCl}$  has a  $K_a$  of **very large**, meaning it is a strong acid. Therefore,  $\text{Cl}^-$  is a weak base.

## What about the conjugates for amphiprotic species?

Good question. Thank you! I thought so, too. ☺

Amphiprotic species can act as acids or bases, depending on the reaction they are involved in. Therefore, amphiprotic species have a conjugate acid and a conjugate base.

Amphiprotic Species	Conjugate Acid (by gaining H <sup>+</sup> )	Conjugate Base (by losing H <sup>+</sup> )
HSO <sub>4</sub> <sup>-1</sup>	H <sub>2</sub> SO <sub>4</sub>	SO <sub>4</sub> <sup>-2</sup>
H <sub>2</sub> PO <sub>4</sub> <sup>-1</sup>	H <sub>3</sub> PO <sub>4</sub>	HPO <sub>4</sub> <sup>-2</sup>
HPO <sub>4</sub> <sup>-2</sup>	H <sub>2</sub> PO <sub>4</sub> <sup>-1</sup>	PO <sub>4</sub> <sup>-3</sup>

So, to sum up the whole conjugate thing, here's a nice little chart:

Species	Acid/Base/Amphiprotic	Conj. Acid	Conj. Base
H <sub>2</sub> S	(weak) Acid		(strong) HS <sup>-1</sup>
HS <sup>-1</sup>	Amphiprotic	H <sub>2</sub> S	S <sup>-2</sup>
S <sup>-2</sup>	(strong) Base	(weak) HS <sup>-1</sup>	
H <sub>2</sub> SO <sub>3</sub>	(weak) Acid		(strong) HSO <sub>3</sub> <sup>-1</sup>
HSO <sub>3</sub> <sup>-1</sup>	Amphiprotic	H <sub>2</sub> SO <sub>3</sub>	SO <sub>3</sub> <sup>-2</sup>
SO <sub>3</sub> <sup>-2</sup>	(strong) Base	(weak) HSO <sub>3</sub> <sup>-1</sup>	
HNO <sub>3</sub>	(strong) Acid		(weak) NO <sub>3</sub> <sup>-1</sup>
NO <sub>3</sub> <sup>-1</sup>	(weak) Base	(strong) HNO <sub>3</sub>	

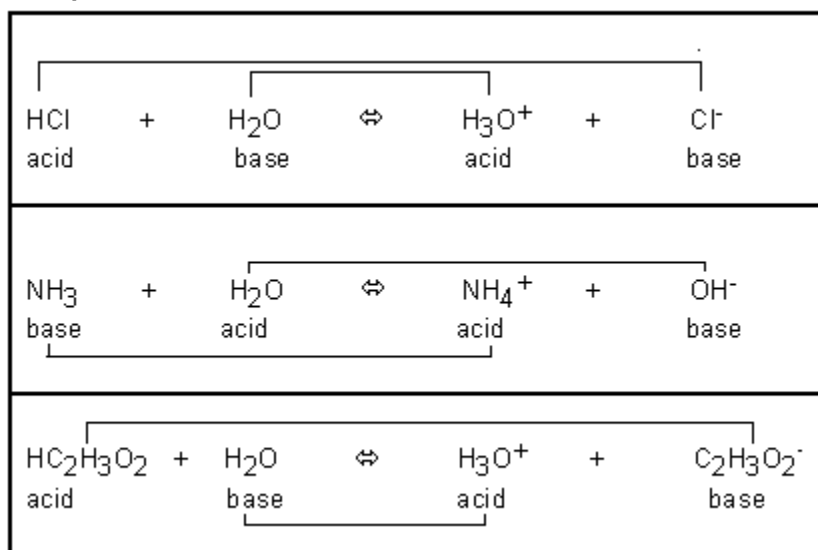
HS<sup>-1</sup> is amphiprotic. It can act as an ACID when reacted with a stronger base than it is (listed lower down on the base side of Table E). **Examples of species that can make HS<sup>-1</sup> act as an acid include CO<sub>3</sub><sup>-2</sup>, S<sup>-2</sup> and OH<sup>-1</sup>.**

It can act as a BASE when reacted with a stronger acid than it is (listed higher up on the acid side of Table E). **Examples of species that can make HS<sup>-1</sup> act as a base include HCl, HNO<sub>3</sub> and HSO<sub>3</sub><sup>-1</sup>.**

Now, how do you determine conjugates in an equation? The things to remember are:

- 1) There will be only one acid and one base on either side
- 2) The conjugates will look like each other, just differ by one H<sup>+</sup>.

### Examples:



Student Name: \_\_\_\_\_ Grades: \_\_\_\_\_, \_\_\_\_\_, \_\_\_\_\_, \_\_\_\_\_  
A & B Titration pH B/L A/B

## 1) ACIDS AND BASES HOMEWORK

### A) Short-Answer

- 1) Name a metal that can react with an acid: \_\_\_\_\_
- 2) Give a pH value that indicates an alkaline solution: \_\_\_\_\_
- 3) Why does HCl (aq) conduct electricity while  $C_6H_{12}O_6$  (aq) cannot? Explain in terms of *ionization*.

### B) Identify each as an acid or base based on their formulas and properties.

Property	Acid or Base?	Property	Acid or Base?
Turns litmus red		Turns bromthymol blue yellow	
Tastes sour		Tastes bitter	
Hydrolyzes fats into soap		Reacts with active metals to form $H_2$	
HCl (aq)		KOH (aq)	
pH of 12		Forms $H_3O^+$ in water	

### C) Name the following acids:

- 1) HCl (aq) \_\_\_\_\_
- 2)  $HClO_3$  (aq) \_\_\_\_\_
- 3)  $HClO_2$  (aq) \_\_\_\_\_
- 4)  $HNO_3$  (aq) \_\_\_\_\_
- 5)  $HNO_2$  (aq) \_\_\_\_\_
- 6)  $H_2SO_4$  (aq) \_\_\_\_\_
- 7) HBr (aq) \_\_\_\_\_
- 8)  $HC_2H_3O_2$  (aq) \_\_\_\_\_

**D) Write the formulas of the following acids:**

- 1) Hydrosulfuric acid \_\_\_\_\_
- 2) Perchloric acid \_\_\_\_\_
- 3) Sulfurous acid \_\_\_\_\_
- 4) Hypochlorous acid \_\_\_\_\_
- 5) Phosphoric acid \_\_\_\_\_
- 6) Chromic acid \_\_\_\_\_
- 7) Hydrobromic acid \_\_\_\_\_
- 8) Nitrous acid \_\_\_\_\_

**E) Name the following bases:**

- 1) KOH (aq) \_\_\_\_\_
- 2) Ca(OH)<sub>2</sub> (aq) \_\_\_\_\_
- 3) LiOH (aq) \_\_\_\_\_

**F) Write the formulas for the following bases:**

- 1) aluminum hydroxide \_\_\_\_\_
- 2) barium hydroxide \_\_\_\_\_
- 3) sodium hydroxide \_\_\_\_\_

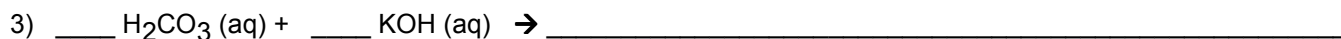
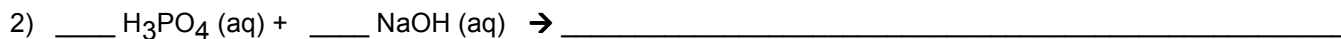
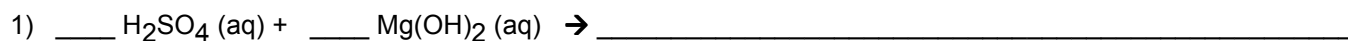
**G) What is the pH of a solution that turns methyl orange to yellow, phenolphthalein to colorless, bromcresol green to blue and thymol blue to yellow?**

- a) 2.7      b) 5.6      c) 9.0      d) 10.2

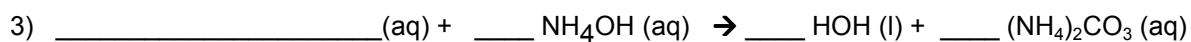
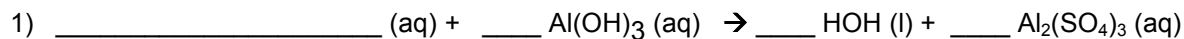
Explain how you arrived at your answer, using the process of elimination to show how you used Reference Table M to eliminate each choice.

## 2) Acid and Base Neutralization Homework

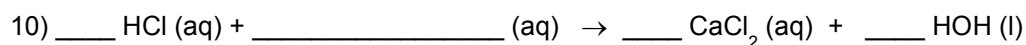
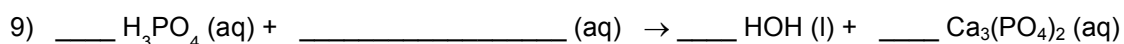
**A) Write the formulas of the products formed in each reaction and then balance the reaction:**



**B) Write the formula of the acid used in each reaction and then balance the reaction:**



**C) Write the formula of each base used in each reaction and then balance the reaction:**



**D) Solve the following titration problems:**

- 1) How many moles of KOH are needed to neutralize 1.5 moles of  $\text{H}_2\text{SO}_4$ ?
- 2) How many moles of NaOH are needed to neutralize 3.0 moles of HCl?
- 3) What volume of 0.80 M HCl will exactly neutralize 100. mL of 0.40 M KOH?
- 4) If exactly 5.0 mL of  $\text{HNO}_3$  will neutralize 15 mL of 2.0 M NaOH, what is the molarity of the  $\text{HNO}_3$  solution?
- 5) What volume of 0.25M HCl is needed to neutralize 1.5 L of 4.0 M NaOH?
- 6) What volume of 5.0 M NaOH is needed to neutralize 40. mL of 2.0 M HCl?
- 7) What is the molarity of an  $\text{H}_2\text{CO}_3$  solution if it takes 50. mL of  $\text{H}_2\text{CO}_3$  to exactly neutralize 100. mL of 0.50 M NaOH?
- 8) What is the molarity of a NaOH solution if it takes 100. mL of NaOH to neutralize 50. mL of 0.10 M  $\text{H}_2\text{SO}_4$ ?

9) What is the molarity of a 2.0 L sample of HCl that exactly neutralizes 1.0 L of a 2.00 M sample of NaOH?

10) 50. mL of  $\text{H}_2\text{SO}_4$  of unknown concentration is titrated with 25 mL of 5.0 M NaOH. What is the molarity of the  $\text{H}_2\text{SO}_4$ ?

11) How many mL of 1.0 M  $\text{H}_3\text{PO}_4$  are required to neutralize 50. mL of 3.0 M NaOH?

12) 200. mL of KOH are required to neutralize 100. mL of 0.10 M  $\text{H}_2\text{SO}_4$ . What is the molarity of the KOH?

13) How many moles of HCl can be neutralized by 0.50 L of 0.10 M NaOH?

14) How many moles of  $\text{H}_2\text{SO}_4$  can be neutralized by 0.10 L of 0.50 M NaOH?

SAFETY NOTE - It used to be standard practice that if a base was swallowed, the victim should drink acid to neutralize it, and vice versa. The chemistry is correct, but the damage to the tissues of the mouth, throat and stomach would be severe. Never induce vomiting in someone who has consumed acid or base, but rather dilute it and send for medical help immediately.

### 3) Acid and Base Equilibrium

**A) What is the  $\text{OH}^-$  concentration if the  $\text{H}^+$  concentration is (and state if the solution is acidic, basic or neutral)**

If the concentration of $\text{H}^+$ is...	...then the concentration of $\text{OH}^-$ is...	Acid, Base or Neutral?
$1 \times 10^{-7}\text{M}$		
$1 \times 10^{-2}\text{M}$		
$1 \times 10^{-10}\text{M}$		

**B) What is the  $\text{H}^+$  concentration if the  $\text{OH}^-$  concentration is (and state if the solution is acidic, basic or neutral)**

If the concentration of $\text{OH}^-$ is...	...then the concentration of $\text{H}^+$ is...	Acid, Base or Neutral?
$1 \times 10^{-13}\text{M}$		
$1 \times 10^{-3}\text{M}$		
$1 \times 10^{-9}\text{M}$		

**C) What is the pH of the following strong acids (100% ionization)?**

Concentration of Acid	Show Work	pH of Acid
0.17 M HCl		
0.024 M HCl		
0.003 M $\text{HNO}_3$		
0.0000887 M HBr		

**D) What is the pH of the following strong bases (100 % ionization)?**

Concentration of Base	Show Work	pH of Base
0.15 M NaOH		
0.0051 M KOH		
0.078 M NaOH		
0.0000045 M LiOH		

**E) Multiple Choice Questions: Place your answer in the space in front of each question.**

\_\_\_\_\_ 1) Which of the following solution pH values is the most acidic?  
a) 5                                      b) 7                                      c) 9                                      d) 11

\_\_\_\_\_ 2) Which of the following solutions can have a pH of 5?  
a) a  $10^{-5}$  M solution of HCl                                      b) a  $10^{-5}$  M solution of NaOH  
c) a  $10^{-5}$  M solution of NaCl                                      d) a  $10^{-5}$  M solution of CH<sub>4</sub>

\_\_\_\_\_ 3) What is the pH of a solution formed when equal volumes of 0.1 M HCl and 0.1 M NaOH are added to a beaker?  
a) less than 7                                      b) more than 7                                      c) exactly 7

Explain your answer: \_\_\_\_\_

\_\_\_\_\_ 4) Strong acids and bases have more dissolved ions per liter than weak acids and bases. Which pH value indicates the solution that is an acid that conducts electricity the best?  
a) 3                                      b) 5                                      c) 9                                      d) 12

Explain your answer: \_\_\_\_\_

\_\_\_\_\_ 5) Which pH value indicates the solution that is a base that conducts electricity the poorest?  
a) 3                                      b) 5                                      c) 9                                      d) 12

Explain your answer: \_\_\_\_\_

**F) Short-Answer: please place your answers in the provided spaces.**

1) A pH of 4 is how many times more acidic than a pH of 6? \_\_\_\_\_

2) A pH of 11 is how many times more basic than a pH of 8? \_\_\_\_\_

3) Complete the following chart:

Indicator used	pH of solution	Color of indicator in solution	Is the solution an acid or is it a base?
Methyl orange	9		
Litmus	10		
Bromcresol green	2		
Thymol blue	13		

4) What is the color of bromcresol green in a solution of 0.01 M HCl?

5) What is the color of thymol blue in a solution of 0.1 M NaOH?

#### 4) Bronsted-Lowry Definition of Acids and Bases

A) For each of the following systems, identify the conjugate acid/base pairs by connecting the conjugate pairs with a line and writing A for the acids and B for the bases:

1.	$\text{HBr} + \text{H}_2\text{O} \rightleftharpoons \text{H}_3\text{O}^+ + \text{Br}^-$
2.	$\text{H}_2\text{O} + \text{H}_2\text{O} \rightleftharpoons \text{H}_3\text{O}^+ + \text{OH}^-$
3.	$\text{NH}_3 + \text{OH}^- \rightleftharpoons \text{NH}_2^- + \text{H}_2\text{O}$
4.	$\text{H}_2\text{O} + \text{HPO}_4^{2-} \rightleftharpoons \text{PO}_4^{3-} + \text{H}_3\text{O}^+$
5.	$\text{H}_3\text{PO}_4 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{PO}_4^- + \text{H}_3\text{O}^+$
6.	$\text{CH}_3\text{COO}^- + \text{H}_3\text{O}^+ \rightleftharpoons \text{HCH}_3\text{COO} + \text{H}_2\text{O}$
7.	$\text{H}_2\text{PO}_4^- + \text{CH}_3\text{COO}^- \rightleftharpoons \text{HCH}_3\text{COO} + \text{HPO}_4^{2-}$
8.	$\text{H}_2\text{O} + \text{S}^{2-} \rightleftharpoons \text{HS}^- + \text{OH}^-$
9.	$\text{CN}^- + \text{HCH}_3\text{COO} \rightleftharpoons \text{HCN} + \text{CH}_3\text{COO}^-$
10.	$\text{OH}^- + \text{NH}_4^+ \rightleftharpoons \text{H}_2\text{O} + \text{NH}_3$

Continued...

**B) Complete the following chart. If the species is an acid, identify its conjugate base. If a base, identify its conjugate acid. If amphiprotic, identify both the conjugate acid and conjugate base:**

Species	Acid/Base/ Amphiprotic	Conj. Acid	Conj. Base
HI			
$\text{HSO}_4^{-1}$			
HF			
$\text{SO}_3^{-2}$			
$\text{O}^{-2}$			
$\text{PO}_4^{-3}$			
$\text{HSO}_3^{-1}$			
$\text{HNO}_2$			
$\text{C}_2\text{H}_3\text{O}_2^{-1}$			
$\text{NH}_3$			

**C) Based on the  $K_a$  values on AE Reference Table C, is the hydroxide ion a strong or weak base? Explain your reasoning in complete sentences.**

**D)  $\text{HSO}_3^-$  is an amphiprotic species.**

1) Write the formula of an acid that would make  $\text{HSO}_3^-$  act as a B/L base in a reaction: \_\_\_\_\_

2) Write the formula of a base that would make  $\text{HSO}_3^-$  act as a B/L acid in a reaction: \_\_\_\_\_

**E) Complete the following reaction, basing your answer on the relative positions of the amphiprotic species on the acid and base side of A/E Table E:**



## Chem Quiz: Neutralization

Name \_\_\_\_\_



Here's a quick quiz for you! Sneed just swallowed 430.0 mL of 4.000 M HCl. How many mL of 2.000 M NaOH will be necessary to neutralize his excess stomach acid?

**WAIT A MINUTE!** I think the acid was  $\text{H}_2\text{SO}_4$ . What's the answer now?

(Note: assume that this is the good old days when people used to do this kind of thing!!!!)