

EXTENSION ACTIVITY
INTRODUCTION TO COLLEGE CHEMISTRY

ACID STRENGTH

Activity
Directions

i

This activity will serve as practice for the topics covered in the Acid Strength game. This activity is best used in conjunction with not only the tutorial levels, but also supplementary learning resources such as course lectures, textbook reading, etc. Questions labeled “Lock It In” are simply opportunities for you to solidify what you have accomplished in each task and help ensure you meet each objective.

1. Log into Collisions and navigate to the Acid Strength Game.
2. Play the Tutorial levels, if you haven't done so already.
3. Exit the levels and enter the Acid Strength sandbox.
4. Follow all instructions as written below. Be sure to reference your course's textbook, lecture notes, etc. as needed.



OBJECTIVE 1

Demonstrate a basic understanding of acid and base nomenclature.

Since all Brønsted-Lowry acids contain hydrogen as cations, acids are typically named for the anion that they contain.

In **binary acids**—acids that contain only two elements—nomenclature is rather simple. The prefix *hydro-* is added to the root name of the anion and the suffix *-ic* is added to the end along with the word “acid”. A classic example is HCl, a binary acid with the name hydrochloric acid. Notice the prefix *hydro-*, the root name of the chloride ion *-chlor-*, and the suffix *-ic*.

In **oxyacids**—acids that contain hydrogen, oxygen, and another element—the nomenclature also makes use of the anion name. In these acids, anions that end with the suffix *-ate* will have *-ic* at the end of the corresponding acid’s name. Anions that end with *-ite* will have *-ous* at the end of the corresponding acid’s name. If we consider the chlorate ion (ClO_3^-), its corresponding acid (HClO_3) is chloric acid whereas the acid that corresponds to chlorite (ClO_2^-) is chlorous acid. However, the nomenclature gets more complex. If the anion contains more oxygen atoms than the *-ate* ion, it receives the prefix *per-*. This naming convention gives us the *perchlorate ion* (ClO_4^-) and *perchloric acid* (HClO_4). If the anion contains one less oxygen than the *-ite* anion, then it receives the prefix *hypo-*. From this naming convention we get the *hypochlorous anion* (ClO^-) and *hypochlorous acid* (HClO).

Organic acids are simply organic compounds that have acidic properties. Although they are an important class of acids, some of which appear in this extension activity, the organic naming conventions will not be covered here.

Base nomenclature is less defined than acid nomenclature. That is because many bases are simply ionic compounds that are named using ionic compound nomenclature conventions. The classic examples are the alkali and alkaline earth metal hydroxides. These bases are named like any other ionic compounds (e.g. calcium hydroxide). Other bases typically follow the nomenclature rules of molecular and/or organic compounds.



OBJECTIVE 1

Demonstrate a basic understanding of acid and base nomenclature.

TASK 1: Determine and name the sandbox acids based on the associated anion listed in the table below. The last three are not available in the sandbox, but are good practice.

Anion	Anion Name	Chemical Formula of Acid	Acid Name
F^-	fluoride		
Br^-	bromide		
I^-	iodide		
NO_3^-	nitrate		
SO_4^{2-}	sulfate		
CO_3^{2-}	carbonate		
SO_3^{2-}	sulfite		
NO_2^-	nitrite		
SO_2^{2-}	hyposulfite		

LOCK IT IN:

Most of the bases available in the sandbox are ionic compounds and thus follow the relevant nomenclature rules. What is the name of the anion in those compounds? Give the name of one of the ionic bases.





OBJECTIVE 2

Classify acids as monoprotic or polyprotic based on their chemical and structural formulas.

One way that acids are classified is by the number of protons that are considered 'acidic' or capable of ionizing in solution. Different acids have different numbers of ionizable hydrogens (protons) and thus are deemed **monoprotic** (if only one proton can be produced in solution), **diprotic** (two protons), or triprotic (three protons). Acids with more than one ionizable proton are often just referred to as **polyprotic**.

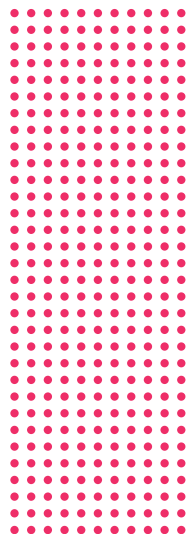
The method often used to write the chemical formulas of acids not only helps indicate that the substance is an acid, but also the number of protons that can be released by the substance in solution. Since the chemical formula of an acid is often written exactly like an ionic compound, we can simply look at the total number of hydrogen atoms listed first in the name to determine how many ionizable protons an acid will have. The chemical formula of sodium chloride is NaCl where the cation is written first and the anion second such that the overall charge of the formula unit is neutral. We can determine that each formula unit of NaCl will produce one sodium ion and one chloride ion when dissolved in water. Using this same logic, an acid like hydrazoic acid with a chemical formula of HN_3 produces one hydrogen ion (H^+) in solution. It is thus monoprotic.



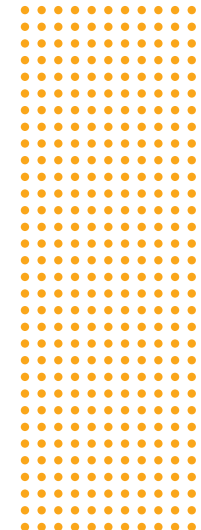
OBJECTIVE 2

Classify acids as monoprotic or polyprotic based on their chemical and structural formulas.

TASK 2: Determine if the acids in the table are monoprotic, diprotic, triprotic based on their chemical formulas. Almost all of them are available to you in the sandbox.



Chemical Formula	Monoprotic, Diprotic, or Triprotic
H_3PO_4	
HCl	
H_2CO_3	
HBr	
HCN	
HNO_3	



LOCK IT IN:

The chemical formula for acetic acid can be written in a few different ways, two of which are $\text{C}_2\text{H}_4\text{O}_2$ and $\text{HC}_2\text{H}_3\text{O}_2$. What is the advantage of writing it the second way compared to the first?



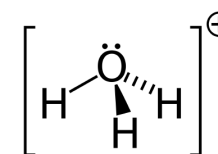
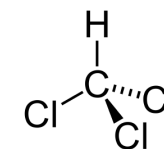
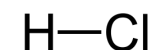


OBJECTIVE 2

Classify acids as monoprotic or polyprotic based on their chemical and structural formulas.

Determining whether a Brønsted–Lowry acid is monoprotic, diprotic, or triprotic is often possible using the structures of the molecules. The procedures for doing so can be complex and are more suited for higher level chemistry courses. However, there are a few basic patterns that can be used to identify **acidic protons**. In order to do so, it is important to remember that an acidic proton is simply a partial positive hydrogen atom that has a reasonable potential to become a hydrogen ion (H^+) in solution. Accordingly, one of the first things to look for in a structure is the presence of hydrogen atoms. However, not all hydrogen atoms are readily ionizable in solution, so we must be careful to identify those which have certain characteristics. A key concept in acid chemistry is that **a proton is more ionizable if the conjugate base that it leaves behind is more stable**. Here are a few guidelines that can help us identify acidic protons based on the stability of the resulting conjugate base:

1. Hydrogen atoms bonded to very electronegative atoms are generally more ionizable due to the partial positive character given to the hydrogen. Examples include hydrogen atoms bonded directly to halogens (fluorine, chlorine, bromine, and iodine), oxygen, and nitrogen.
2. Hydrogen atoms attached to carbon atoms and other atoms of similar or lower electronegativity than hydrogen are generally not very acidic. However, highly electronegative atoms attached to carbon (or the other atoms) adjacent to hydrogen will destabilize the bond with hydrogen and stabilize the conjugate base. The result is a more ionizable hydrogen atom. Although chloroform is not typically thought of as an acid, the hydrogen atom in chloroform below is more ionizable than it would be if the electronegative chlorine atoms were not part of the molecule.
3. Hydrogens bonded to electronegative atoms with a positive formal charge (*valence electrons - nonbonding electrons - $\frac{1}{2}$ bonding electrons*) are acidic. Take the hydronium ion in the image below. The oxygen atom has a positive formal charge (*6 valence electrons - 2 nonbonding electrons - $\frac{1}{2}$ x 6 bonding electrons = +1*). Hydronium will release one proton as a result.
4. There are several other guidelines regarding resonance, orbital hybridization, and other factors. However, these are generally discussed in higher courses and will not be addressed in this activity.

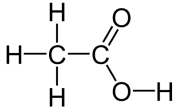
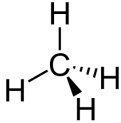
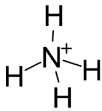
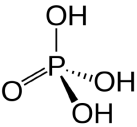
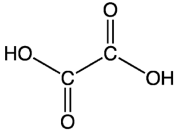




OBJECTIVE 2

Classify acids as monoprotic or polyprotic based on their chemical and structural formulas.

TASK 3: Determine if the substances in the table are acids and then determine if they are monoprotic, diprotic, or polyprotic based on their structures. In the case the substance is not acidic, simply write "N/A" in the third column.

Substance	At Least One Acidic Proton? (Yes or No)	Monoprotic, Diprotic, Triprotic, or N/A
		
		
		
		
		



LOCK IT IN:

Take a look at the acids available in the sandbox. Find one acid with a hydrogen that is ionizable according to what you learned in the second concept explained for Task 3. Identify the acid and explain why the hydrogen on this acid is less ionizable than the one in HF?



OBJECTIVE 3

Determine the relative strengths of acids based on their molecular structures.

There are many concepts that underlie the comparison of acid strength, which is defined by how well the acid is able to release hydrogen ions into solution. Much of the basics of these concepts were addressed as part of Task 3. For the purpose of Task 4 and Task 5, we will focus on comparing the strengths of binary acids and oxyacids/oxoacids, both of which can be found in the sandbox.

Binary Acids

Two concepts are central to the strength of binary acids—bond polarity and bond strength. Binary acids have ionizable protons partially because differences in electronegativity between hydrogen and the element to which it is bonded creates a partial positive hydrogen that is more likely to be released as a proton. You will thus notice that binary acids occur when hydrogen is attached to a more electronegative atom. Electronegativity differences alone, however, are not enough to compare the relative strengths of binary acids. **In fact, ranking binary acid strengths by electronegativity differences alone would give you an incorrect ranking.** The relationship between electronegativity and binary acid strength is more nuanced than that.

Bond strength, however, allows us to more accurately rank the strength of binary acids. While the electronegativity difference in a binary acid creates a hydrogen atom that is prepared to ionize, the bond strength will determine just how readily it does so. Release of a hydrogen ion in solution requires the breaking of a bond. A really strong bond requires more energy to break and thus won't happen as readily. In the case of a binary acid, a strong bond will mean that at any one point, only a fraction of ionizable hydrogen atoms will actually be released into the solution. These acids will be less strong. The opposite is true of a weaker bond. Such an acid would more readily release its hydrogen and act as a stronger acid. **Bond strength in binary acids generally decreases with increasing size of the non-hydrogen atom.**

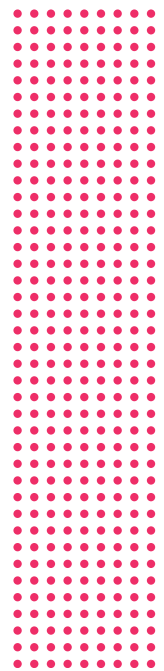
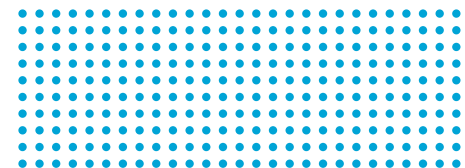


OBJECTIVE 3

Determine the relative strengths of acids based on their molecular structures.

TASK 4: Determine the difference in electronegativity between elements in the binary acids below. Use the electronegativity differences and bond strengths to rank the binary acids in the first table by their strength. Explain your reasoning in the “Justification” column of the table. Check your ranking using the sandbox.

Acid	Electronegativity of Hydrogen	Electronegativity of Second Element	Electronegativity Difference	Bond Strength (kJ/mol)
HI	2.20	2.66		299
HF	2.20	3.98		569
H ₂ S	2.20	2.58		381
HBr	2.20	2.96		366
HCl	2.20	3.16		432



	Justification
Strongest Acid	
Weakest Acid	



OBJECTIVE 3

Determine the relative strengths of acids based on their molecular structures.

LOCK IT IN:

Use a periodic table to summarize the trend that occurs in the strength of the binary acids formed as you go down the halogen group.



LOCK IT IN:

The hydrogen atoms in HF are more acidic than those in H₂O, which are more acidic than those in NH₃. Use a periodic table to identify the trend that occurs in acid strength for hydrides moving from left to right across a period. What explains this trend?



LOCK IT IN:

Check your rankings in the sandbox if you have not already done so. It is quite likely that you put hydrogen sulfide (H₂S) in the incorrect position. Explain how electronegativity can be used to explain the actual positioning of H₂S in the rankings.





OBJECTIVE 3

Determine the relative strengths of acids based on their molecular structures.

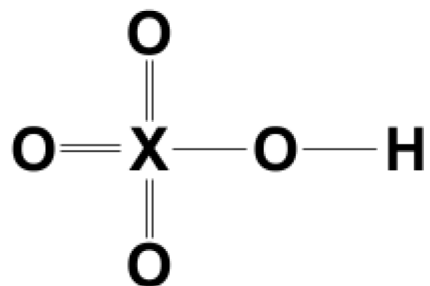
Oxyacids/Oxoacids

Remember that oxyacids are those that contain a hydrogen atom bonded to an oxygen atom that also contains a third element. A basic structure for an oxyacid is shown in the image below where X represents a third element.



Comparing the relative strengths of oxyacids relies on considering the electronegativity of the third element (X) and the number of oxygen atoms that are bonded to X. As the electronegativity of X increases, the more it helps to pull electrons away from the hydrogen atom and destabilize the oxygen-hydrogen bond. This means that as the electronegativity of X increases, the strength of the acid increases.

As the number of oxygens bonded to X increases, so does the strength of the acid. This is because oxygen is a very electronegative element that is capable of enhancing the pull of electrons away from the hydrogen atom so that it is released more easily. The acid in the image below has three additional oxygen atoms attached to X compared to our first oxyacid. As a result, the acid below is significantly stronger. Each additional oxygen atom strengthens the acid in a cumulative manner. In the case that X is a very electronegative atom, the acid would be very strong. In cases where X is not very electronegative, even the additional oxygen atoms might not be enough to make the acid strong.

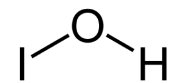
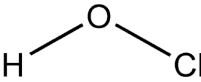
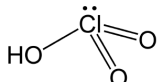
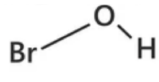
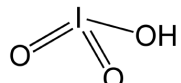
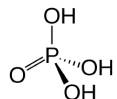


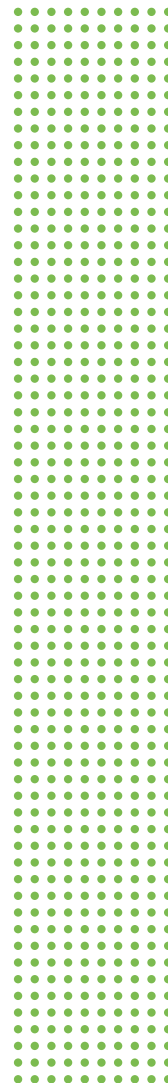


OBJECTIVE 3

Determine the relative strengths of acids based on their molecular structures.

TASK 5: Rank the oxyacids below by their strength. Explain your reasoning in the “Justification” column of the table.

Acid Name and Structure	Chemical Formula	Electronegativity of Non-Hydrogen Element Attached to Oxygen
 Hypiodous Acid	HIO	Iodine — 2.66
 Hypochlorous Acid	HClO	Chlorine — 3.16
 Chloric Acid	HClO ₃	Chlorine — 3.16
 Hypobromous Acid	HBrO	Bromine — 2.96
 Iodic Acid	HIO ₃	Iodine — 2.66
 Phosphoric Acid	H ₃ PO ₄	Phosphorus — 2.19





OBJECTIVE 3

Determine the relative strengths of acids based on their molecular structures.

	Justification
Strongest Acid	
Weakest Acid	

LOCK IT IN:

There are three oxyacids in the sandbox. What are they? Which two would you identify as strong and which one as weak? Explain why that is.

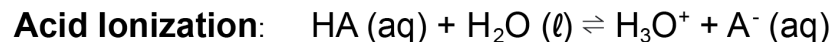




OBJECTIVE 4

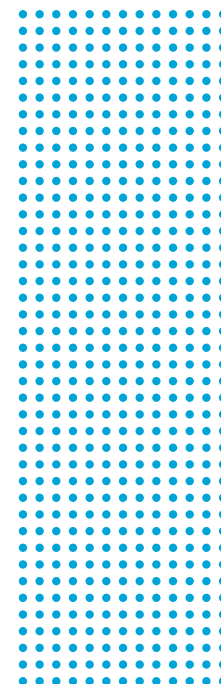
Demonstrate an understanding of the acid ionization constant (K_a) and pH.

At this point we have seen some of the ways in which the hydrogen atoms become acidic and how the strengths of acids can be compared structurally. However, one of the most important concepts in acid-base chemistry is a quantitative expression of the strength of an acid known as the **acid ionization constant (K_a)**. As you might remember from the LeChâtelier Game, K is the equilibrium constant—a ratio used to quantify the relationship between the concentrations or partial pressures of reactants and products at equilibrium. The acid ionization constant is simply the equilibrium constant for the ionization reaction of an acid. As such, the same principles of the equilibrium constant (e.g. an equilibrium constant is for a certain temperature) still apply and the expression is formatted the same way. Remember that the hydrogen ion given off by an acid in solution is transferred to a water molecule and creates hydronium (H_3O^+). As a result, $[\text{H}^+] = [\text{H}_3\text{O}^+]$.



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

Just like you have likely already learned about equilibrium constants for other reactions, the value of K_a can be quite small or quite large. A very large K_a tells us that the forward reaction is favored and thus more hydrogen ions will be produced in solution. A small K_a tells us that the reverse reaction (the one forming the acid) is more favored. Such an acid would not produce as many hydrogen ions in solution. What is often used to discuss the extent to which an acid ionizes is the $\text{p}K_a$ ($-\log_{10} K_a$). Very small and increasingly negative $\text{p}K_a$ values indicate strong acids. Very large $\text{p}K_a$ values indicate very weak acids from which hydrogen ions infrequently appear in solution. Although there is no formal cutoff for weak and strong acids, strong acids typically have $\text{p}K_a$ values of less than 1.

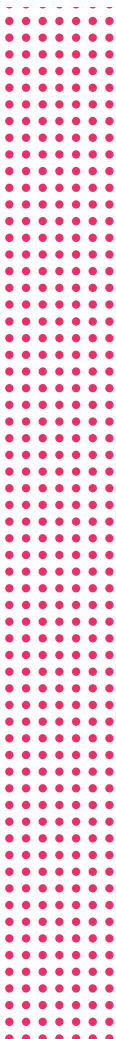




OBJECTIVE 4

Demonstrate an understanding of the acid ionization constant (K_a) and pH.

TASK 6: For each sandbox acid listed in the table, write out the expression necessary to calculate the acid ionization constant. For any polyprotic acid, simply write the expressions for **EACH** acidic hydrogen.



Acid and pK_a	Acid Ionization Constant Expression
H_2SO_4 1st $pK_a = -2.8$ 2nd $pK_a = 1.99$	
HCl $pK_a = -5.9$	
HNO_3 $pK_a = -1.4$	
HCN $pK_a = 9.21$	
H_2S 1st $pK_a = 7.0$ 2nd $pK_a \approx 17$	



LOCK IT IN:

What does the difference between the first and second pK_a of the diprotic acids tell us about the relative acidity of the first and second ionizable hydrogens?

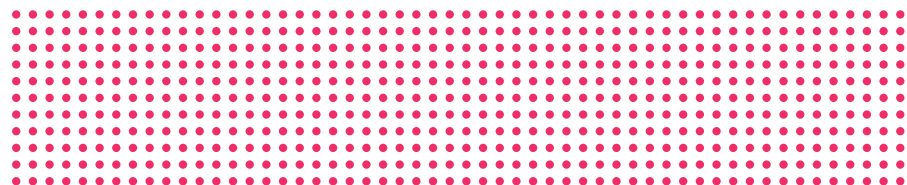


OBJECTIVE 4

Demonstrate an understanding of the acid ionization constant (K_a) and pH.

LOCK IT IN:

Use the pK_a to rank each acid in the table by its strength.



Strongest Acid

Weakest Acid

As you should know from your textbook reading or lecture notes, **pH** is a method of determining the acidity of a solution by taking the $-\log_{10} [H_3O^+]$ of a solution. In the case of a strong acid, $[H_3O^+]$ is equivalent to the concentration of the acid itself since in most circumstances, 100% of the acid molecules ionize in solution. However, since weak acids only partially ionize, a more involved process is required for determining the pH of a solution containing them. The following example shows you how to use ICE tables to determine the pH and percent ionization of a monoprotic weak acid solution available in the sandbox. Reference your textbook, notes, or the LeChâtelier Game extension activity if you are not familiar with ICE tables. Also, please note that the contribution of H_3O^+ by the autoionization of water is negligible except in extremely dilute acid solutions. As such, this process has been ignored in the example.



OBJECTIVE 4

Demonstrate an understanding of the acid ionization constant (K_a) and pH.

Example 1: Find the pH and percent ionization of a 0.500 M HF solution.

Use the balanced ionization equation of the acid to set up an ICE table. Notice that the initial $[H_3O^+]$ has been simplified to 0.00.	$HF(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + F^-(aq)$			
		[HF]	[H ₃ O ⁺]	[F ⁻]
	Initial	0.500	0.00	0.00
	Change			
	Equilibrium			
Use x to represent the stoichiometric changes in the concentrations of all reactants and products. Then sum all columns to complete the equilibrium concentration row.	$HF(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + F^-(aq)$			
		[HF]	[H ₃ O ⁺]	[F ⁻]
	Initial	0.500	0.00	0.00
	Change	-x	+x	+x
	Equilibrium	0.500-x	0.00 +x	0.00 +x



OBJECTIVE 4

Demonstrate an understanding of the acid ionization constant (K_a) and pH.

Substitute the values from the equilibrium row of the table into the acid ionization constant expression. K_a for HF at 25°C is 6.6×10^{-4} .

Solve the quadratic equation for x. Only the positive root can be valid!

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

$$6.6 \times 10^{-4} = \frac{x^2}{0.500 - x}$$

$$x = -\cancel{0.018} \quad x = 0.018$$

Use the determined value of x to determine the equilibrium concentration of $[\text{H}_3\text{O}^+]$.

	[HF]	$[\text{H}_3\text{O}^+]$	$[\text{F}^-]$
Initial	0.500	0.00	0.00
Change	-0.018	+0.018	+0.018
Equilibrium	$0.500 - 0.018 = 0.482$	$0.00 + 0.018 = 0.018$	$0.00 + 0.018 = 0.018$

Use

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

to determine the pH of the solution.

$$\text{pH} = -\log_{10} (0.018) = 1.74$$

Calculate the percent ionization using the following formula:

$$\% \text{ ionization} = \frac{[\text{H}_3\text{O}^+]_{\text{equil}}}{[\text{HA}]_{\text{equil}}} \times 100\%$$

$$\% \text{ ionization} = \frac{0.018 \text{ M}}{0.482 \text{ M}} \times 100\% = 3.73\%$$



OBJECTIVE 4

Demonstrate an understanding of the acid ionization constant (K_a) and pH.

TASK 7: Use your understanding of acid dissociation to determine the missing values in the table for the acids from the sandbox. Use the sandbox to determine if each is a strong or weak acid, and use the space beneath the table for any math and/or ICE tables.

Acid	Strong or Weak?	K_a	pK_a	Acid Concentration (M)	$[H_3O^+]$	pH	% Ionization
HI		3.2×10^9	-9.5	0.500			
HCN		6.2×10^{-10}	9.2	0.05			
HCl		1.3×10^6	-6.1	0.10			
HF		6.6×10^{-4}	3.2	1.2			

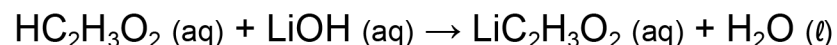
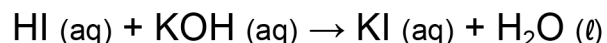


OBJECTIVE 5

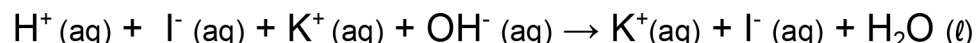
Demonstrate an ability to write a net ionic equation for a neutralization reaction.

Reactions that proceed with at least some components being in an ionic phase can be written in several different ways. Since ions are a very important part of reactions involving acids and bases, their reactions too can be written in multiple ways. An important type of reaction that you completed multiple times during the course of the Acid Strength Game is called a neutralization reaction where an acid and a base react with one another. The usual products of a **neutralization reaction** are water and a soluble salt, but there are occasions where other products are formed.

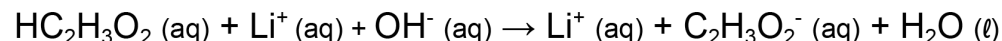
- **Molecular equations** include all substances written in either their molecular or formula unit form followed by the state of matter of that substance in the reaction. Substances that are liquids or gases receive the designation (*ℓ*) or (*g*). Substances that are solid will receive an (*s*) This designation includes substances that are insoluble in the reaction medium, yet are still present. Soluble compounds receive (*aq*) after them to indicate that they are dissolved in the solution. Let's use the neutralization reaction between hydroiodic acid (HI) and potassium hydroxide (KOH) and the reaction between acetic acid (HC₂H₃O₂) and lithium hydroxide (LiOH) as examples.



- **Complete ionic equations** separate any substances that fully ionize in solution into their constituent ions, each of which are followed by "(aq)". For example, **if you have a strong acid, the hydrogen ions and anions should be separated.** Notice in the example below that the hydrogen and iodide ions of HI are fully separated. A strong acid like HI fully dissociates in solution.



However, any substances that do not fully ionize should maintain the same form as in the molecular equation. This means that **weak acids should not be separated in the complete ionic equation** since most of the acid molecules will not be ionized in solution at any one point in time. Notice in the example below that HC₂H₃O₂ (acetic acid) in the reactants has not been separated into its constituent ions. A weak acid like HC₂H₃O₂ only partially dissociates in solution.



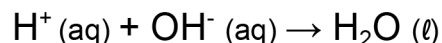


OBJECTIVE 5

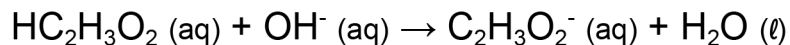
Demonstrate an ability to write a net ionic equation for a neutralization reaction.

- Net ionic equations** are complete ionic equations from which **spectator ions** have been removed. Spectator ions are those which remain in the same aqueous state both before and after the reaction. They do not participate in the reaction and can be identified as appearing the same on both the reactant and product sides of the complete ionic equation. In the example reaction, notice that K^+ and I^- remain in the same state as both reactants and products. They are spectator ions and are thus removed when creating the net ionic equation.

The net ionic equation for the reaction between hydroiodic acid and potassium hydroxide is simply the formation of water from hydrogen and hydroxide ions. **This exact equation will be the net ionic equation for any neutralization reaction between a strong acid and strong base.**



The net ionic equation for the reaction between acetic acid and lithium hydroxide still maintains the acetate ion ($C_2H_3O_2^-$) since acetic acid was only partially ionized in solution. This will be the case when a weak acid reacts with a strong base.



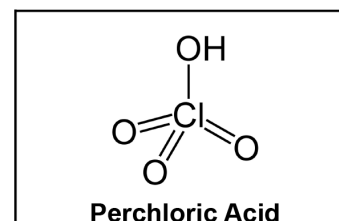
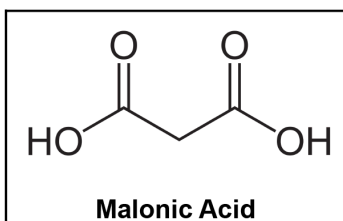
TASK 8: Perform each of the reactions listed below in the sandbox. Afterwards, write the complete ionic and net ionic equation for each in the relevant columns.

Molecular Equation	Complete Ionic Equation	Net Ionic Equation
$HCl (aq) + LiOH (aq) \rightarrow LiCl(aq) + H_2O (\ell)$		
$HCN (aq) + NaOH (aq) \rightarrow NaCN (aq) + H_2O(\ell)$		
$2 HCl (aq) + Mg(OH)_2 (s) \rightarrow MgCl_2(aq) + 2 H_2O (\ell)$		



CLOSURE


CLOSURE: Below are two molecules that are not found in the sandbox. For each characteristic, determine which value belongs to each molecule using your knowledge of acids and bases. Simply write the correct option in the column underneath the picture of the molecule. Justify your choices in the column to the far right of the table.



Property		Options		Justification
Acid Type		Monoprotic or Diprotic		
Acid Type		Strong Acid or Weak Acid		



CLOSURE



First (or Only) pK_a		2.83 or < 1		
pH of 0.5 M Solution		pH > 1 or pH < 1		

