Objective 8. Apply equilibrium principles to acids and bases

1. You have solutions of 0.01 M acetic acid and HCl.
a. Which solution, acetic acid and HCl, has a higher concentration of H^+? Draw a picture of this solution to support your answer.
b. Which solution is drinkable? Do these solutions have the same or different pH? Calculate the pH of each solution.
Why does a weak acid have a higher pH than the same concentration of strong acid?
c. Every acid has a conjugate base. The conjugate base of a strong acid is weak. The conjugate base of a weak acid is strong.
(i) Consider the reaction:

$HCl + H_2O$ -->	Cl^-	+	H_3O^+	
Acid base	conjugate base of HCl		conjugate acid of H_2O	

This reaction is the acid dissociation reaction. A shortcut for this reaction is:

HCl (aq) -->	Cl^-	+	H^+ (aq)

The acid dissociation equilibrium constant, K_a, is: $K_a = [Cl^-]\,[H^+]/[HCl]$
HCl is a strong acid. Is K_a for HCl large or small?
Draw a picture of HCl (aq).
Use your picture of HCl to explain why conjugate base of HCl is weak. In other words, why doesn't the above reaction go in the reverse direction?
(ii) H_2O can behave like an acid or a base:

H_2O + H_2O -->	OH^-	+	H_3O^+ (aq)	

This reaction is the water dissociation reaction. A shortcut for this reaction is:

H_2O -->	OH^-	+	H^+ (aq)

The water dissociation equilibrium constant, K_w, is: $K_w = [OH^-]\,[H^+] = 1 \times 10^{-14}$.
Draw a picture of H_2O.
Use your picture of H_2O to explain why the conjugate acid of H_2O is strong.
Use your picture of H_2O to explain why the conjugate base of H_2O is strong.
(iii) Consider the reaction:

CH_3COOH +	H_2O -->	CH_3COO^-	+	H_3O^+
Acid	base	conjugate base of CH_3COOH		conjugate acid of H_2O

This reaction is the acid dissociation reaction. A shortcut for this reaction is:

CH_3COOH (aq) -->	CH_3COO^-	+	H^+ (aq)

Write the acid dissociation equilibrium constant, K_a, for acetic acid.
CH_3COOH is a weak acid. Is K_a for CH_3COOH large or small? Look up the K_a of CH_3COOH. You can find a table of K_a's for weak acids in the textbook or on the internet.
(iv) When a base is dissolved in water, it reacts with water to form its conjugate acid and OH^-. For example, sodium acetate ($NaCH_3COO$) is a base. The CH_3COO^- part is the basic part of this compound.

CH_3COO^-	+ H_2O -->	CH_3COOH	+	OH^-
Base	acid	conjugate acid of CH_3COO^-		conjugate base of H_2O

This reaction is the base hydrolysis reaction.
The base hydrolysis equilibrium constant, K_b, is: $K_b = [CH_3COOH]\,[OH^-]/[CH_3COO^-]$.
A table of K_b's for weak bases are not as easily found as for K_a's. But you can calculate K_b as long as you know the K_a of the conjugate acid using the formula: $K_aK_b = K_w$.
What is the numerical value of K_b for CH_3COO^-?

2. pH calculations for a weak acid – use K_a.
a. Aspirin has a pK_a of 3.5; salicylic acid has a pK_a of 2.98. Is aspirin a stronger or weaker acid than salicylic acid? To confirm your answer, write the acid dissociation reaction for each acid, calculate the equilibrium constant, K_a, for each acid, and briefly discuss what the value of K means.
b. Acetic acid is the acid in vinegar. Write the acid dissociation reaction for this acid. Look up the K_a of acetic acid. Calculate the pH of a 0.1 M acetic acid solution.
To calculate pH, do an equilibrium calculation:

	CH_3COOH -->	CH_3COO^- (aq) +	H^+ (aq)	$K_a = 1.8 \times 10^{-5} = [CH_3COO^-]\,[H^+]/[CH_3COOH]$
initial	0.1	0	0	

reacts	x	x	x	
equilibrium	0.1-x	x	x	$K_a = 1.8 \times 10^{-5} = [x]\,[x]/[\,0.1\text{-}x] \approx [x]\,[x]/[\,0.1]$

Note: K_a is very small so x is very small so assume 0.1 -x ≈ 0.1

Solve for x = $[H^+] = 1.34 \times 10^{-3}$ M
pH = - log $[H^+]$ = - log (1.34×10^{-3}) = 2.9
The pH of a 0.1 M acetic acid solution is 2.9.
Vinegar is 0.9 M acetic acid. Does vinegar have a higher or lower pH than 0.1 M acetic acid? Calculate the pH of vinegar to confirm your answer.
b. Carbonic acid is found in soda. Write the acid dissociation reaction for this acid. Look up the K_a of carbonic acid. Calculate the pH of a 0.1 M carbonic acid solution. (Answer: pH between 3 and 4)
c. Benzoic acid is found in food preservatives. Write the acid dissociation reaction for this acid. Look up the K_a of benzoic acid. Calculate the pH of a 0.1 M benzoic acid solution. (Answer: pH between 2 and 3)
d. Vinegar contains acetic acid and has a pH of 2.4. Calculate the concentration of acetic acid in vinegar. (Answer: between 0.8 and 1 M)

3. pH calculations for a weak base – use K_b.
a. You have 0.1 M solutions of NaOH (strong base) and $NaHCO_3$ (weak base). Explain why the strong base has a higher pH than the weak base. Draw a picture of each solution to support your answer.
b. Baking soda is sodium bicarbonate. What is the conjugate acid of baking soda? Write the base hydrolysis reaction for this base. Calculate K_b. Calculate pOH. Calculate pH. (Answers: pOH between 4 and 5. pH between 9 and 10.)
c. Sodium salicylate is the conjugate base of salicylic acid. Write the base hydrolysis reaction for this base. Calculate K_b. Calculate pOH. Calculate pH. (Answer: pH between 7.5 and 8.5)

4. Concentrated sulfuric acid (18 M) is used as the electrolyte in car batteries.
a. Calculate the pH of battery acid. (pH will be negative.)
b. Sulfuric acid is a diprotic acid. However, H^+ and HSO_4^- are the two ions predominantly present. Explain why the concentration of SO_4^{2-} is very low in sulfuric acid.
c. At what pH will HSO_4^- and SO_4^{2-} be observed? Give reasons.