EXPERIMENT 3

Determining K_a

Introduction

In the previous lab, acid and base solutions were evaluated to determine their general levels of acidity using pH. In this experiment, the pH of a solution will be used to determine the degree of dissociation of the hydrogen ion from the original acid. To briefly review the **Bronsted-Lowry theory**, an acid is defined a compound that donates a hydrogen ion and a base accepts a hydrogen ion. When an acid is added to water, the liquid water acts as a base according to the following chemical reaction:

$$HCl + H_2O \rightarrow H_3O^+ + Cl^-$$

In this example, the HCl dissociates completely and donates a hydrogen ion, H^+, to a water molecule which acts as a base by receiving the H^+. The resulting product is a hydronium ion, H_3O^+, that changes the pH of the water and a Cl^- that acts as a spectator ion. There is 100% dissociation of the HCl, so the concentration of the original HCl solution is the same as the concentration of the hydronium ion.

Strong acids and bases are acidic or basic compounds that completely dissociate as in the equation above. As a result, the concentration of the hydronium ion can be calculated directly from the initial concentration of the HCl. For example, in water 1M HCl would produce 1M $H_3O^+(aq)$ and 1M $Cl^-(aq)$. There would be no HCl left in solution at the end of the reaction. All of the reactant has been used up to form product. The pH of the solution can then be directly calculated from the initial concentration of the strong acid and base using the equation; pH = -log(H_3O^+).

However, the determination of pH in a weak acid or base solution is much more complicated. In these solutions, the pH is a function of both the initial concentration of the weak acid or base and the degree of dissociation of the H^+. To determine the degree of dissociation of the acid, HA, we need to know the equilibrium constant that governs the ratio between the reactants and products in the weak acid equilibrium. When the equilibrium involves a weak acid, we refer to the equilibrium constant as an "**<u>acid dissociation constant</u>**" and give it the symbol, $\mathbf{K_a}$.

$$HA + H_2O \leftrightarrow H_3O^+ + A^- \qquad K_a = \frac{[H_3O^+][A^-]}{[HA]}$$

The Acid Dissociation Constant, K_a

Acid dissociation constants have been determined for many different weak acids at approximately room temperature. Tables of these dissociation constants permit a researcher to determine the pH of a solution without performing experiments and to calculate the concentration of a weak acid needed to produce the desired pH of a final solution. You used a given K_a in the last experiment to do your pH calculations, but the K_a for each acid had to be determined experimentally before being tabulated. You will repeat the procedures used to determine the Ka for an unknown acid in a similar manner to the researchers who first developed the K_a tables.

In the previous experiment, you used an ICE table to determine the pH of a solution using the tabulated K_a. In this lab, the pH of a known acid solution will be used to determine equilibrium concentration of the H_3O^+ using the following equation.

$$pH = -\log[H_3O^+] \text{ and with a quick rearrangement, } [H_3O^+] = 10^{-pH}$$

Once you know the concentration of the H_3O^+, you can use an ICE table to determine the concentrations of the A- and the HA. Once you have all 3 of these values, you can then determine the K_a of the acid.

Using an ICE Table for Weak Acid Equilibria

The ICE table set up for a weak acid equilibrium follows the same format as in the previous lab. First, you write the balanced chemical reaction and record the initial concentrations of your reactants and products. Then you use the balanced equation to determine the changes that will take place based on the stoichiometry. Reactants will always decrease in concentration, so you use a negative coefficient before the variable, x. Products increase, so use a positive value of x. The value of the coefficient in front of the x is the value of the coefficient in the chemical equation.

Finally, add the values or formulas on the initial and change lines together to find the final formula for the equilibrium concentrations. Note that water is not used at all in the equilibrium as it is a pure liquid and pure liquids and solids cannot change their concentrations and thus will not affect the equilibrium. For the example below, we start with a 2.0M solution of HA in water.

	HA(aq)	+	**H_2O** (l)	⇆	H_3O^+ (aq) +	A^-(aq)
Initial	2.0				0	0
Change	-1x				+1x	+1x
Equilibrium	(2.0-1x)				(0+1x)	(0+1x)

If you know the pH of the solution, then solve for the H_3O^+ (aq) and solve for K_a using the equilibrium constant expression shown below.

$$K_a = \frac{[H_3O^+][A^-]}{[HA]} = \frac{[x][x]}{[2.0 - x]}$$

Relationship between pH, H_3O^+ and the Initial Acid Concentration

K_a is constant for a particular weak acid at a particular temperature and is independent of the initial acid concentration. Therefore, if you vary the initial concentration of the acid, [HA], the pH will change to compensate and maintain the equilibrium between the reactants and products.

$$HA(aq) + H_2O\ (l) \leftrightharpoons H_3O^+\ (aq) + A^-(aq)$$

For example, if you increase the concentration of HA, you will get more H_3O^+ produced in the solution. An increase in H_3O^+ means the solution is more acidic and a lower pH will be recorded. A lower pH would be expected because logically, if you add more acid to water, the solution should become more acidic.

In Your Lab….

For your experiment, you will measure the pH of several different concentrations of the same acid and calculate the K_a for each to demonstrate that K_a is independent of the solution concentration. You will prepare these solutions by starting with a stock acid solution and use NaOH, a strong base to react with some of the acid according to the following equation.

$$NaOH + HA \rightarrow H_2O + Na^+ + A^-$$

If you add NaOH to the solution in the previous example, you end up changing the initial concentrations of both the HA and A-. This is because for every mole of NaOH you add; you remove 1 mole of HA, thus decreasing the initial concentration of HA. A- is formed as a result of this reaction and thus increases the initial amount of A- in the ICE table. The additional Na^+ that is added to the solution does not affect the pH of the solution.

	HA(aq) +	**H_2O** (l) ⇆	H_3O^+ (aq) +	A^-(aq)
Initial	(2.0-1.0M = 1.0M)		0M	1.0M
Change	-1x		+1x	+1x
Equilibrium	(1.0-1x)		(0+1x)	(1.0+1x)

After preparing the solutions, you will record the pH and calculate the H_3O^+ in each one. Then you will use an ICE table to determine the equilibrium concentrations of the A- and HA. Once you have established the concentrations of all of the reactants and products at equilibrium, you can calculate K_a for the acid.

Once you have determined the K_a for the acid, you will compare it to a list of common weak acids (Table 1) to determine the identity of the weak acid based on its calculated K_a.

Table 1

Substance	**Formula (HA)**	**K_a at 25°C**
Iodic acid	HIO_3	2.0×10^{-1}
Chlorous acid	$HClO_2$	1.0×10^{-2}
Nitrous acid	HNO_2	1.0×10^{-3}
Formic acid	$HCHO_2$	2.0×10^{-4}
Acetic acid	$HC_2H_3O_2$	2.0×10^{-5}
Hypochlorous acid	HOCl	5.0×10^{-8}
Hypobromous acid	HOBr	2.0×10^{-9}
Hydrocyanic acid	HCN	5.0×10^{-10}
Hypoiodous acid	HOI	2.0×10^{-11}

Chemical Hazards

1.0M Weak Acid Solution

NFPA RATING: HEALTH: 1 FLAMMABILITY: 0 REACTIVITY: 0

INHALATION:
Move person into fresh air immediately. Contact TA immediately.
DERMAL EXPOSURE:
Wash off with soap and plenty of water.
EYE EXPOSURE:
Flush with copious amounts of water for at least 15 minutes. Assure adequate flushing by separating the eyelids with fingers. Contact your TA immediately.

pH 7 Buffer Solution

NFPA RATING: HEALTH: 0 FLAMMABILITY: 0 REACTIVITY: 0

DERMAL EXPOSURE:
Wash off with soap and plenty of water.
EYE EXPOSURE:
Flush with copious amounts of water. Assure adequate flushing by separating the eyelids with fingers. Contact your TA immediately.

0.50M Sodium Hydroxide Solution

NFPA RATING: HEALTH: 1 FLAMMABILITY: 0 REACTIVITY: 1

ORAL EXPOSURE
Caustic. If swallowed, wash out mouth with water provided person is conscious. Do not induce vomiting. Contact your TA immediately.
DERMAL EXPOSURE
Caustic. In case of extensive skin contact, flush with copious amounts of water for at least 15 minutes. Remove contaminated clothing and shoes. Contact your TA immediately.
EYE EXPOSURE
Caustic. In case of contact with eyes, flush with copious amounts of water for at least 15 minutes. Assure adequate flushing by separating the eyelids with fingers. Contact your TA immediately.

Experiment 3: Prelab Worksheet

(Submit through Brightspace before coming to lab)

Name: ________________________________ Date: ________ Section: ________ Grade: ________

Record all values with the correct number of significant figures and units.
Place all answers on the line next to the question.
Show calculations for any numerical answers.
See any 114 TA in the help office before your prelab is due if you have any questions.
Your answer must be completely correct to get any credit for the answer, no partial credit.

You make a solution of a weak acid with a pH of 3.75 and the pK_a is 5.42

1. Is the solution acidic or basic? ________________

2. Calculate the $[H_3O^+]$. ________________

3. Calculate the pOH ________________

4. Calculate the $[OH^-]$ ________________

5. Calculate the pK_b ________________

6. Calculate the K_b. ________________

For a solution of an aqueous hypochlorous acid solution, the K_a is 5.0×10^{-8} and [HOCl] is 0.050M.

7. Calculate the pH of this solution.

____

8. You add 2.0mL of 1.0M NaOH to the 1.0L acid solution, what is the new concentration of [HOCl]?

____

You make 50.00mL of a 0.045M solution of NaOH from a 2.5M stock solution.

9. How many milliliters of the concentrated stock solution will you need?

____

10. What is the pH of the diluted solution?

____

Experiment 3: Experimental Procedures and Data Sheet

Submit as part of your informal report

Name: ____ Date: ________ Section: ________

TA Signature: ______________________________________

All data must be written in pen at the time it is collected. **Pencil is not allowed!!**
Record all measurements with the correct number of significant figures and units.
TA signature and TA initials on any changes made to the data must be present or your data is invalid

1. Record the exact concentrations of the sodium hydroxide and the weak acid solutions.

   NaOH Concentration: ____________ Weak Acid Concentration: ___________

2. Use your 10.0mL graduated cylinder to transfer exactly 8.00 mL of acid to a clean dry 25 mL volumetric flask.

3. Use your 10.0mL graduated cylinder to transfer exactly 2.50 mL of NaOH to the flask containing the 8.00 mL of acid. Fill the 25 mL volumetric to the line with distilled water and swirl to mix.

4. Pour the mixed solution into a scintillation vial. Label the vial “Solution 1”.

5. Repeat this procedure for the remaining 3 solutions given in the table below.

Solution number	Volume of 1.00M weak acid mL	Volume of 0.50M NaOH mL
1	8.00	2.50
2	8.00	5.00
3	8.00	7.50
4	8.00	10.00

6. Calibrate your pH meter with the pH 7 buffer. (See experiment 4 lab procedures if necessary)

7. Once calibrated, rinse off the bulb of the pH meter with distilled water and then insert the pH meter into Solution 1.

8. Gently stir the solution with the pH meter and watch the reading. When the reading has stabilized on the pH meter, record the pH value on your data sheet. Repeat for the other 3 solutions.

   Solution 1 pH: _____________________ Solution 3 pH: _____________________

   Solution 2 pH: _____________________ Solution 4 pH: _____________________

Cleanup

1. Rinse the pH meter with distilled water and return it to the buffer solution.
2. Empty your solution into the waste container and rinse your volumetric flask out well with distilled water.
3. Dispose of solutions in the waste container provided.
4. Rinse all glassware with distilled water and remove markings with acetone if necessary.

Calculations

Do all calculations in the **Calculations** section and complete the results table before leaving lab. Use more paper if necessary. These calculations MUST be done **IN THE LAB** and checked by your TA before leaving. You will be expected to do these calculations WITHOUT the instructions during next week's Concept Review.

Grading

Points

Neatness and Clarity of Data	5pts	___________pts
Significant figures and units	5pts	___________pts
All data is present	10pts	___________pts

Deductions (sliding based on TA discretion)

Lab area left unclean	20pts	___________pts
Improper waste disposal	20pts	___________pts
Disruptive behavior	20pts	___________pts
Other: ____		___________pts

Plagiarism!!! Data are identical to another student 100pts __________pts

Grade for Experimental Procedures and Data ________pts

Experiment 3: Results Table

Submit as part of your informal report

Name: ____ Date: ________ Section: ________

TA Signature: ______________________________________ (after calculations are done during lab)

Record all results with the correct number of significant figures and units

K_a Calculations	Solution 1	Solution 2	Solution 3	Solution 4
$[H_3O^+]$				
$M_{dil.\ acid}$				
$M_{dil.\ NaOH}$				
HA				
A^-				
H_3O^+				
HA				
A^-				
K_a				
Average K_a				
Identity of acid				
Accepted K_a of acid				

Grading

Points

Significant figures and units	5pts	__________pts
Table is neat and legible	5pts	__________pts
All results are present	10pts	__________pts

Deductions (sliding based on TA discretion)

Results do not make sense	20pts	__________pts
Results do not match data	20pts	__________pts
Other: ____		__________pts

Plagiarism!!! Results are identical to another student 100pts **__________pts**

Grade on results table **__________pts**

Experiment 3: Calculations

Submit as part of your informal report

You must do these calculations out with your TA before you leave the lab.

Concentration of $[H_3O^+]$ for the ICE Table, x

Use the pH value that you recorded from your data to find the hydronium ion concentration of the solution using the equation below. Repeat for all of your solutions.

$$x = [H_3O^+] = 10^{-pH}$$

Solution 1: ______________________ Solution 3: ______________________

Solution 2: ______________________ Solution 4: ______________________

Concentration of Diluted Weak Acid before the Addition of NaOH, $M_{dil.\ acid}$

Multiply the concentration of the weak acid recorded on the bottle in the hood by the number of milliliters of acid dispensed into the volumetric flask. Divide this number by 25.00mL, the total volume of the dilute acid.

$$M_{dil.acid} = \frac{M_{conc.acid} V_{conc.acid}}{V_{dil.acid}}$$

Solution 1: ______________________ Solution 3: ______________________

Solution 2: ______________________ Solution 4: ______________________

Concentration of Diluted NaOH, $M_{dil.\ NaOH}$

Multiply the concentration of the sodium hydroxide, NaOH, recorded on the bottle in the hood by the number of milliliters of NaOH dispensed into the volumetric flask. Divide this number by 25.00mL, the total volume of the dilute NaOH.

$$M_{dil.NaOH} = \frac{M_{conc.NaOH} V_{conc.NaOH}}{V_{NaOH}}$$

Solution 1: ______________________ Solution 3: ______________________

Solution 2: ______________________ Solution 4: ______________________

Concentration of Diluted Weak Acid After the Addition of NaOH, HA

Each mole of NaOH added to the acid solution uses up 1 mole of the acid. To calculate the concentration of the weak acid to be used in the ICE table, subtract the concentration of the diluted NaOH from the concentration of the diluted weak acid.

$$1NaOH + 1HA \rightarrow 1H_2O + 1Na^+ + 1A^-$$

$$M_{\text{acid in ICE table}} = M_{\text{dil. Acid}} - M_{\text{dil. NaOH}}$$

Solution 1: ____________________ Solution 3: ____________________

Solution 2: ____________________ Solution 4: ____________________

Concentration of Weak Base, A^-

ince each mole of NaOH removes the H^+ from an acid molecule, HA, the number of moles of A- produced will equal the moles of NaOH added. Therefore, the molarity of the A- will be equal to the molarity of the diluted NaOH. Use this in the ICE table for the initial value of $A^-(aq)$.

Solution 1: ____________________ Solution 3: ____________________

Solution 2: ____________________ Solution 4: ____________________

Equilibrium Concentrations, H_3O^+, HA, and A^-

Use an ICE table for each concentration of the weak acid and NaOH. Use the values calculated in the previous sections. You will need 1 ICE table for each set of acid/NaOH concentrations.

	HA(aq)	+	**H_2O** (l)	⇆	H_3O^+ (aq) +	A^-(aq)
Initial	HA				0M	A^-
Change	x				x	x
Equilibrium	HA -x				x	A^- + x

H_3O^+ is the concentration of H_3O^+ found from the pH and is equal to x.
HA is the HA concentration initially calculated for the ICE table minus the H_3O^+ concentration.
A^- is the A^- concentration initially calculated for the ICE table plus the H_3O^+ concentration.

Find 1 set of each of these values for each pair of weak acid/NaOH concentrations.

Note: H_3O^+ is often negligible compared to HA, so HA at equilibrium is often equal to the initial concentration of HA. Don't be surprised if this happens. Use the rules for significant figures to decide if x is negligible relative to an initial concentration. The same rules apply to A^- in the ICE table as well.

Solution 1: H_3O^+ ______________ HA ______________ A^- _______________

Solution 2: H_3O^+ ______________ HA ______________ A^- _______________

Solution 3: H_3O^+ ______________ HA ______________ A^- _______________

Solution 4: H_3O^+ ______________ HA ______________ A^- _______________

Calculation of K_a

Use the values found for the ICE table variables in the equilibrium constant expression, Ka. Repeat for each ICE table.

$$K_a = \frac{[H_3O^+][A^- + x]}{[HA - x]}$$

Solution 1: _____________________ Solution 3: _____________________

Solution 2: _____________________ Solution 4: _____________________

Identification of the Weak Acid

Find the average value for the K_a of the weak acid from the K_a values determined from each ICE table. Compare them to the values given in Table 1 and record the identity of the weak acid.

Average K_a _______________________ Identity of weak acid _______________________