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ABSTRACT

Presented are the teacher's guide and student materials for one of a series of self-instructional, computer-based learning modules for an introductory, undergraduate chemistry course. The student manual for this acid-base equilibria unit includes objectives, prerequisites, pretest, a discussion of equilibrium constants, and 20 problem sets. Included in the teacher's guide are implementation instructions, answers to problem sets, software, a listing of the computer program in BASIC, and 10 unit tests. (BT)

ED182122

CHEMICAL EQUILIBRIUM

UNIT 4. EQUILIBRIA IN ACID-BASE SYSTEMS

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A COMPUTER-ENRICHED MODULE FOR INTRODUCTORY CHEMISTRY

$$HF + H_2O \rightleftharpoons H_3O^+ + F^-$$

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OBJECTIVES

A. **Weak acids, weak bases and their salts.**

Upon completion of this section you should be able to

1. use the appropriate equilibrium constant, K, to determine $[H_3O^+]$, $[OH^-]$, pH, and percentage dissociation of a <u>weak</u> acid or <u>weak</u> base.
2. use pH, percentage dissociation of H_3O^+ to determine the equilibrium constant, K, for a weak acid or weak base.
3. distinguish between
   a. weak acid and a strong acid
   b. weak base and a strong base.
4. test the validity of approximate solutions to the equation involving weak acids, weak bases and their salts.
5. classify various salt solutions as acidic, basic or neutral (determine the pH of the salt solutions given K for the reaction of salt ions with water).

B. Common ion and buffer solutions.

When you have finished this section you should be able to

1. apply Le Chatelier's principle to ionic equilibria.
2. use the equilibrium constant, K, and buffer concentrations of a partially dissociated acid and its salt to calculate the pH of a buffer solution before, during and after the addition of a strong acid or base.
3. compare the behavior of a buffered solution with that of an unbuffered solution upon the addition of a strong acid or a strong base.

PREREQUISITES

You should be able to do the following before attempting this unit:

1. define and illustrate
   a. pH
   b. pOH
   c. a strong acid
   d. a strong base
   e. a Brönsted-Lowry acid
   f. a Brönsted-Lowry base
2. calculate $[OH^-]$ given $[H_3O^+]$ and <u>vice versa</u>.
3. convert $[H_3O^+]$ to pH and <u>vice versa</u>.
4. write balanced <u>net</u> ionic equations for acid-base reactions.

PRE-TEST

1. Given a 0.001 mole/l aqueous solution of HCl, calculate:
   a. $[H_3O^+]$
   b. the pH
   c. the pOH
   d. the $[OH^-]$

2. Calculate the pH of an HCl solution with $[H_3O^+] = 3.5 \times 10^{-3}$ mole/l.
3. Calculate the $[OH^-]$ concentration of a KOH solution whose pH = 12.26.
4. Define and illustrate a Brönsted-Lowry acid and a Brönsted-Lowry base.
5. Write an <u>ionic</u> equation for the ionization of HCl in water.
6. Write an <u>ionic</u> equation for the ionization of KOH in water.
7. Which of the following would yield the larger number of H_3O^+ ions?
   a. 100 ml of 0.1 mole/l HCl.
   b. 100 ml of 0.1 mole/l CH_3COOH, acetic acid, (weak acid).

Answers to pre-test:

1. a. 0.001 mole/l since HCl is <u>strong</u> acid
   b. 3
   c. 11
   d. 1.0×10^{-11} mole/l
2. 2.46
3. 1.78×10^{-2} mole/l
4. Brönsted-Lowry acid is a proton donor;

   $$\underset{\text{acid}}{HCN} + H_2O \rightleftharpoons H_3O^+ + CN^-$$

   Brönsted-Lowry base is a proton acceptor;

   $$\underset{\text{base}}{CH_3NH_2} + H_2O \rightleftharpoons CH_3NH_3^+ + OH^-$$

5. $HCl + H_2O \longrightarrow H_3O^+ + Cl^-$
6. $KOH \xrightarrow{H_2O} K^+ + OH^-$
7. a. 100 ml 0.1 mole HCl yields 0.01 mole H_3O^+ ion -- strong acid completely ionized.
   b. 100 ml 0.1 mole CH_3COOH yields less than 0.01 mole H_3O^+ since it is a weak acid and <u>not</u> completely ionized.

INTRODUCTION.

Aqueous systems involving weak acids, weak bases, and their salts are important examples of chemical equilibria. The behavior of these systems is of particular interest to biologists and chemists. The general representation of these systems according to Brönsted-Lowry definitions follow:

1. Weak Acid, HA

   $$HA + H_2O \rightleftharpoons H_3O^+ + A^-$$

2. Weak Base, B

   $$B + H_2O \rightleftharpoons BH^+ + OH^-$$

3. Salt, NaA, of a weak acid (HA) and a strong base (NaOH). Initially NaA is considered to be totally ionized to Na^+ and A^-. The weak acid anion then comes to equilibrium with water as follows:

   $$A^- + H_2O \rightleftharpoons HA + OH^-$$

4. Salt BHCl of a weak base (B) and a strong acid (HCl). Again the salt is considered to ionize completely to BH^+ and Cl^- with the weak base cation forming an equilibrium with water:

$$BH^+ + H_2O \rightleftharpoons B + H_3O^+$$

These equilibrium systems have two common features:

1. Water is the solvent.
2. The values of the equilibrium constants are relatively small, less than 10^{-4} in most cases. Therefore the systems contain ions in equilibrium with molecules of undissociated acid or base, unlike strong acid and base solutions which contain no undissociated solute molecules.*

In these aqueous solutions the concentration of water is very large (55.5 mole/l) and is considered to be a constant when compared to the concentrations of species in dilute solutions. Hence for

$$HA + H_2O \rightleftharpoons H_3O^+ + A^-,$$

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

where $[H_2O]$ can be considered to be included in K.

Let's examine this type of equilibrium by looking at each of the above reactions, remembering that the mathematical treatment of each system is the same, only the values of K are different.

Problem 1. Examine the weak acid system involving hydrofluoric acid, HF

$$HF + H_2O \rightleftharpoons H_3O^+ + F^-$$

$$K = \frac{[H_3O^+][F^-]}{[HF]} = 6.7 \times 10^{-4}.$$

Given that initially 0.1 mole (2.0 grams) HF are dissolved in 1.0 liter of solution, calculate the $[H_3O^+]$ and pH of the solution.

Solution: Choose x = number of moles of H_3O^+ formed. Note that x would also be equal to number of moles F^- ion formed and moles of HF reacting.

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*WARNING -- In solutions of weak acids there are actually two sources of H_3O^+ ions:

1. $HA + H_2O \rightleftharpoons \underset{x}{H_3O^+} + A^-$

2. $2\,H_2O \rightleftharpoons \underset{y}{H_3O^+} + OH^-$

In most problems, y, the concentration of H_3O^+ due to self-ionization of water is small compared to x, the concentration of H_3O^+ from weak acid ionization, i.e., $x + y \approx x$.

If $x < 10^{-6}$ mole/l the assumption that $x + y \approx x$ no longer holds.

A similar warning is given for solution of weak bases with $[OH^-] < 10^{-6}$ mole/l.

In view of the small value of K, what relative magnitude do you expect for x?

________________________(answer)

A detailed analysis of the situation can be obtained by filling out a reaction scorecard as follows.
Remember x = number of moles H_3O^+ formed.

	H_2O + HF	⇌ H_3O^+	+ F^-
initial number moles from data	0.1 mole	0 mole	0 mole
change in moles	-x mole	+x mole	+x mole
moles at equilibrium	(0.1 - x) mole	x mole	x mole
equilibrium concentrations	$\frac{(0.1 - x)\text{ mole}}{1\text{ liter}}$	$\frac{x\text{ mole}}{1\text{ liter}}$	$\frac{x\text{ mole}}{1\text{ liter}}$

Using the equilibrium concentrations in the equilibrium expression

$$K = 6.7 \times 10^{-4} = \frac{(x)(x)}{(0.1 - x)} .$$

This yields the quadratic equation

$$x^2 + (6.7 \times 10^{-4})x - (6.7 \times 10^{-5}) = 0 .$$

EFFECT OF CONCENTRATION

In order to further examine this system use the ACID program. You will use this program to help solve Problems 2 through 5.

First choose a concentration of weak acid HF ($K = 6.7 \times 10^{-4}$) of 0.10 mole HF dissolved in 1.0 liter of solution. The computer will solve the quadratic equation choosing the correct root. Answer NO when the computer asks "DONE?".

Problem 2. What effect would decreasing the number of moles HF initially present to 0.05 (holding the solution volume at 1.0 liters), have on:

	prediction increase, decrease, no effect	check with computer, correct?
1. $[H_3O^+]$	________	________
2. pH	________	________
3. % dissociation*	________	________

Problem 3. Check your predictions by answering YES to the question, "would you like to try another concentration of HF?" Enter 0.05 moles and 1.0 liter.

Problem 4. Compare the results of this HF solution with the 0.1 mole/liter solution. Were your predictions correct?

*% dissociation = $\frac{\text{moles HF dissociated}}{\text{initial moles HF}} \times 100$

Run as many concentrations of HF as you like (limit of 10) observing the effect initial concentration has on each of the parameters. When you have finished, answer NO to the "concentration of HF?" question.

EFFECT OF THE VALUE OF EQUILIBRIUM CONSTANT, K

Problem 5. Choose another weak acid whose equilibrium constant appears below:

Acid	K
HNO_2	4.6×10^{-4}
HCN	4.93×10^{-10}
CH_3COOH	1.76×10^{-5}

Answer "YES" to the question "Would you like to try another acid?". Run the program as before using 0.10 moles of acid and 1.00 liters of solution for the first concentration of your acid. Run as many different concentrations of your acid as you like (limit: ten different concentrations).

Does a decrease in initial acid concentration have the same effect on $[H_3O^+]$, pH and % dissociation as it did in the case of HF?

Answer "YES" to the question "DONE?". The computer will summarize your data in tabular form. Log off the terminal and carefully remove and save your printout. You will need this information to solve Problems 6 to 10.

Problem 6. Complete the reaction scorecard below for the acid you chose and fill in the reaction scorecard for you acid. Let x = $[H_3O^+]$ equilibrium concentration.

	H_2O + ______	= H_3O^+	+ ______
initial number moles from data			
changes in moles at equilibrium			
equilibrium concentration			

Using the reaction scorecard, set up the quadratic equation which the computer solved.

K =

quadratic equation:

Problem 7. After comparing the effect of initial acid concentration in both cases, describe the effect of decreasing initial acid concentration on:

$[H_3O^+]$:

pH:

% dissociation:

Problem 8. Compare the two acids when the initial concentrations are the same.
Which has the larger value of $[H_3O^+]$?
Which has the larger value of pH?
Which is more highly dissociated (ionized)?
Which is the stronger acid? Explain.

APPLICATION OF A SIMPLIFYING APPROXIMATION

Many times scientists apply approximations in the solution of problems. In systems where K is less than 10^{-4} an approximation avoiding the solution of quadratic equations may be used*.

Problem 9. Check the values of $[HA]_{initial}$ and $[H_3O^+]_{equilibrium}$ listed in your output summary.

Is $[HA]_{initial} - [H_3O^+] \approx [HA]_{initial}$ in each case? If so, the number moles of undissociated acid at equilibrium can be approximated by the initial number of moles undissociated acid.

e.g. initial $[HA] = 0.100$ mole/l

$[H_3O^+] = 0.00001$ mole/l

then equilibrium $[HA] = 0.100 - 0.00001 = 0.09999 \approx 0.1000$

error in assumption $= \dfrac{0.00001}{0.100} \times 100 = 0.01\%$

With this assumption the equilibrium expression becomes

$$K = \frac{[H_3O^+][A^-]}{[HA]} = \frac{x^2/V^2}{0.1 - x} = \frac{x^2/V^2}{0.1}$$

where V is the volume of solution in liters.

More generally,

$$K = \frac{x^2/V^2}{[HA]_{initial}}$$

$$\text{and } \frac{x}{V} = \sqrt{K \cdot [HA]_{initial}} \qquad (1)$$

Problem 10. Select several initial acid concentrations and compare the results from equation (1) with the computer's more accurate quadratic solution. Make the comparison for both acids.

Acid	$[HA]_{initial}$	exact quadratic $[H_3O^+]$	approximated $[H_3O^+]$	% Error
HA				
HA				
____				
____				

In your judgment, is the approximation valid for both acids? Explain.

*A concentration expressed to two significant figures is usually sufficient. A pH reading of 7.35 indicates a concentration of two significant figures.

You may wish to try other acids including one with K greater than 10^{-3} by re-running the ACID program and then comparing with calculated results using the square root approximation (equation (1)). Is the approximation valid in cases where K is greater than 10^{-3}? Explain.

Problems 11 to 16 will give you practice in using the concepts covered in the preceding material.

Problem 11. What is the pH of 1.55 M benzoic acid whose ionization constant is 6.60×10^{-5}?

Problem 12. A 5.37 M solution of a weak acid, HX, has a pH of 2.25. What is the ionization constant of the acid?

Problem 13. If a weak acid, HX, is 78.15% ionized in 1.67 M solution, at what concentration is the acid 12.55% ionized?

Problem 14. What is the degree of ionization of a 1.39 M solution of HClO whose ionization constant is 3.20×10^{-8}?

Problem 15. CH_3COOH is 8.6×10^{-3} ionized in 4.146 M solution. What is the ionization constant for this acid?

Problem 16. A weak acid, HX, is 61.85% ionized in 0.12 M solution. What percent of HX is ionized in a 0.913 M solution?

WEAK BASES

Equilibrium systems involving aqueous solutions of weak bases are quite similar to those weak acid systems we have just examined. Both have values of K less than 10^{-4}. The major difference is that the OH^- ion appears in the equilibrium expression rather than H_3O^+. (This should not bother us for we can easily calculate H_3O^+ and pH from OH^- and $K = 10^{-14}$ for the ionization of pure water.) For a typical weak base, B

$$B + H_2O \rightleftharpoons BH^+ + OH^-$$

$$K = \frac{[BH^+][OH^-]}{[B]}$$

Problem 17. Let's fill out a scorecard for 0.10 moles of the weak base ammonia, NH_3, dissolved in 0.50 liter of solution.

$K = 1.8 \times 10^{-}$ for NH_3.

Choose x = moles of hydroxyl ion, OH^-, formed. Now you complete the scorecard.

H_2O +	NH_3 =	NH_4^+ +	OH^-
initial number of moles from data			
changes in moles			
moles at equilibrium			
equilibrium concentration			

Now write an expression for K:

K =

Finally the quadratic equation:

Now get the ACID program and run as before, this time using the ammonia (NH_3) system as an example.

Problem 18. Vary the initial concentration of NH_3 and observe the effect of decreasing NH_3 concentration on:

$[OH^-]$ ______

pH ______

pOH ______

% dissociation ______

Choose another weak base from the following list and run it in the ACID program using the same set of initial concentrations as those used with ammonia.

Base	K
methylamine CH_3-NH_2	2.7×10^{-11}
aniline C_6H_5-NH_2	2.34×10^{-5}
hydroxylamine H-O-NH_2	1.07×10^{-8}

Compare the following for the cases in which initial concentrations of both bases are equal:

$[OH^-]$ ______ ______

pH ______ ______

pOH ______ ______

% dissociation ______ ______

Which is the stronger base? NH_3 or the base you chose? Explain.

How can K's be used to compare the strengths of acids or bases? Explain.

Arrange the bases in the above list in order of increasing base strength (weakest first).

The same approximation that was used to calculate $[H_3O^+]$ in weak acid systems, may be used to calculate $[OH^-]$ in weak base systems.

Problem 19. Derive an expression for $[OH^-]$ in weak base solutions similar to that used for $[H_3O^+]$ in weak acids.

Problem 20. Use this expression to calculate the equilibrium $[OH^-]$ concentrations and pH's of the solutions on your printout.

Problem 21. Is the approximation valid for the base you chose? At what concentrations does the approximation give the best results?

Problems 22 to 25 illustrate solutions involving weak bases:

Problem 22. Calculate the pH of a 1.60 M methylamine (CH_3-NH_2) solution whose equilibrium dissociation constant is 1.8×10^{-5}.

Problem 23. At 25°C a 0.10 M ammonia solution is 4.3% ionized. Calculate the equilibrium constant of aqueous ammonia.

Problem 24. Calculate the $[OH^-]$ in a 0.010 M solution of aniline, $C_6H_5NH_2$. The equilibrium constant, K, for the dissociation of aniline is 4.2×10^{-10}.

Problem 25. What molarity of NH_3 provides a hydroxide ion solution whose pH = 11.18. ($K = 1.8 \times 10^{-5}$ for NH_3).

SALT SOLUTIONS INVOLVING WEAK ACIDS AND BASES

Now let's turn our attention to aqueous solutions containing salts. A salt is product of the reaction between an acid and a base. The acid and base may be thought of as the parents and the salt the child.

$$\text{Acid (parent)} + \text{Base (parent)} \longrightarrow \text{Salt (child)}$$

The child will have the properties of both parents. Thus the pH of these salt solutions may be considered to be generic in origin, depending on the equilibrium constants of the parent acid and parent base involved. Suppose we prepare three salt solutions each 0.10 M in the salt NaCl, NaF, NH_4Cl.

Problem 26. Predict the pH of each solution; pH < 7, pH = 7, pH > 7.

	pH
(A) 0.10 M NaCl	________
(B) 0.10 M NaF	________
(C) 0.10 M NH_4Cl	________

By examining these solutions carefully, we can check our answers.

The first solution:

$$Na^+ + Cl^- + H_2O \longrightarrow Na^+ + Cl^- + H_2O$$

The ions in this solution do not react with water since both the parent acid and the parent base are strong (i.e. K's are very large). The Na^+ and Cl^- ions are said to be unreacting spectator ions. Therefore the pH of this solution is the pH of pure water, pH = 7.

The second solution:

$$Na^+ + F^- + H_2O \longrightarrow Na^+ + HF + OH^-$$

The Na^+ ion does not react with water, it is again a spectator ion and may be cancelled on both sides of the equation.

$$\cancel{Na^+} + F^- + H_2O \longrightarrow \cancel{Na^+} + HF + OH^-$$

and the net ionic equation becomes

$$F^- + H_2O \longrightarrow HF + OH^-$$

Since the parent acid HF is a weak acid ($K = 6.7 \times 10^{-5}$) we expect the F^- ions will react with water to form HF and OH^- ions. Thus the solution has a pH > 7 due to the value of $[OH^-]$ being greater than $[OH^-]$ of water.

In the last equation the parent base involved is weak (NH_3, $K = 1.8 \times 10^{-5}$) while the parent acid, HCl, is strong. Thus the Cl^- ion is a spectator and the net ionic equation becomes

$$NH_4^+ + H_2O \longrightarrow NH_3 + H_3O^+$$

Ammonium ions, NH_4^+, react with water to form undissociated $NH_3 + H_3O^+$ ions. The solution therefore has a pH < 7 since the value of $[H_3O^+]$ is greater than that of pure water.

The following list provides a handy summary of the acid-base characteristics of salt solutions:

Salt (parents)	Example	pH
strong acid-strong base	KNO_3	~7
strong acid-weak base	$(CH_3NH_3)^+Cl^-$	<7
weak acid-strong base	$Li^+(CN)^-$	>7
weak acid-weak base	$(NH_4)^+F^-$	(depends on K's of reactions of ions with water)

Problem 27. With the aid of your text determine the relative pH's (pH < 7, pH ~ 7, pH > 7) for aqueous solutions of each of the following salts:

a. $(NH_4)^+(NO_3)^-$
b. $(CH_3NH_3)^+F^-$
c. KCl
d. $(CH_3COO)^-K^+$
e. $Na(CN)^-$

The above section has dealt with making a rough estimate of the pH of aqueous salt solutions. How do we determine the exact pH of a salt solution?

In order to solve this problem we must consider the concept of combining several equilibrium reactions into a single reaction. Consider the equations involved in the reaction of sodium fluoride, NaF, with water. The reaction

$$F^- + H_2O \rightleftharpoons HF + OH^- \qquad K = \frac{[HF][OH^-]}{[F^-]}$$

may be considered as a summation of

$$F^- + H_3O^+ \rightleftharpoons H_2O + HF \qquad K_1 = \frac{[HF]}{[F^-][H_3O^+]}$$

$$2\,H_2O \rightleftharpoons H_3O^+ + OH^- \qquad K_w = 10^{-14} = [H_3O^+][OH^-] .$$

Problem 28. Show that $K = K_1 \cdot K_w$.

In general if one reaction can be written as the sum of two or more other reactions, the equilibrium constant for the overall reaction will be the product of the equilibrium constants of the component reactions.

In our NaF problem K_1 may be shown to be the reciprocal of K_2 the equilibrium constant for the reaction

$$HF + H_2O \rightleftharpoons H_3O^+ + F^- \qquad K_2 = \frac{[H_3O^+][F^-]}{[HF]} .$$

Problem 29. Show that the relationship $K_1 = \frac{1}{K_2}$ is true.

The reason for using this reciprocal relationship is that K's for weak acid and base ionizations are easily accessible in reference books. The equilibrium constant for the reaction

$$F^- + H_2O \rightleftharpoons HF + OH^-$$

becomes

$$K = K_1 \cdot 10^{-14} = \frac{1 \times 10^{-14}}{K_2} .$$

Problem 30. Using tables of ionization constants in you text verify that $K = 1.5 \times 10^{-11}$ for the reaction of NaF with water.

A reaction scorecard with x = moles of F^- reacting looks like:

$$H_2O + F^- \rightleftharpoons HF + OH^-$$

	F^-	HF	OH^-
initial moles	0.1	0	0
change in moles	-x	+x	+x
number moles at equilibrium	0.1 - x	x	x
equilibrium concentration	$\frac{0.1 - x}{1}$	$\frac{x}{1}$	$\frac{x}{1}$

As before in the case of weak acids and bases we obtain a quadratic equation in x.

$$K = \frac{(x/1)(x/1)}{[(0.1 - x)/1]} = 1.5 \times 10^{-11}$$

and

$$x^2 + (1.5 \times 10^{-11})x - (1.5 \times 10^{-12}) = 0$$

Since K is small, our square root approximation should again be valid.

$$\frac{x^2}{[0.1]} = 1.5 \times 10^{-11}$$

$$x = \sqrt{1.5 \times 10^{-12}}$$

$$x = 1.2 \times 10^{-6} \text{ moles}$$

$$[OH^-] = 1.2 \times 10^{-6} \text{ moles/l}$$

$$pOH = 5.92$$

$$pH = 14.00 - 5.92 = 8.08.$$

Problem 31. What is the pH of 1.0 liter of a solution containing 0.2 moles NH_4Cl? $K = 1.8 \times 10^{-5}$ for the reaction

$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-.$$

a. Calculate K for the reaction

$$NH_4^+ + H_2O \rightleftharpoons H_3O^+ + NH_3.$$

b. Complete a reaction scorecard.

c. Set up the expression for K.

d. Solve for x, $[H_3O^+]$ and pH.

e. Do these results confirm our prediction in Problem 1?

COMMON IONS AND BUFFER SOLUTIONS

Up to this point we have considered solutions which contained a single substance dissolved in water, a weak acid, a weak base or a salt. Buffer solutions contain a mixture of a weak acid and one of its salts or a weak base and one of its salts. The function of a buffer solution is to maintain a relatively constant value of pH. Let's examine such a solution in order to see how it operates.

Problem 32. Consider the weak acid HCOOH, formic acid, in an aqueous solution:

$$HCOOH + H_2O \rightleftharpoons H_3O^+ + HCOO^- \qquad K = 2.1 \times 10^{-4}.$$

Calculate the $[H_3O^+]$ and pH of a solution which contains 0.10 M HCOOH.

Now suppose that sodium formate is added to this solution. What will happen to the equilibrium values of [HA] and $[H_3O^+]$? (Hint: Le Chatelier's principle)

Will the pH increase or decrease?

Problem 33. In order to obtain quantitative verification of your predictions consider a solution of 0.1 mole of HCOOH and 0.2 moles HCOONa dissolved in 1.0 liter of water.

Solution: A completed scorecard for the final solution appears below where x = moles of H_3O^+ formed.

H_2O +	HCOOH =	H_3O^+ +	$HCOO^-$
initial number of moles	0.1	0	0.2
change in moles	$-x$	$+x$	$+x$
equilibrium moles	$0.1 - x$	x	$0.2 + x$
equilibrium concentration	$\frac{0.1 - x}{1}$	$\frac{x}{1}$	$\frac{0.2 + x}{1}$

$$K = \frac{[H_3O^+][HCOO^-]}{[HCOOH]} = \frac{(x/1)(0.2 + x)/1}{(0.1 - x)/1} = 2.1 \times 10^{-4},$$

yielding with no approximations

$$x^2 + (0.2 + 2.1 \times 10^{-4})x - (2.1 \times 10^{-5}) = 0$$

$$x^2 + 0.2x - 2.1 \times 10^{-5} = 0 .$$

Since K is again small we can make the assumption x will be very small and

$$0.1 - x \approx 0.1$$

and

$$0.2 + x \approx 0.2$$

so that the expression for K becomes

$$K = \frac{(x/1)(0.2/1)}{(0.1/1)} = 2.1 \times 10^{-4}$$

$$0.2x = 2.1 \times 10^{-5}$$

$$x = 1.05 \times 10^{-4}$$

$$pH = -(0.02 - 4) = 3.98.$$

This solution of HCOOH and HCOONa is said to be buffered at a pH = 3.98. It will maintain this pH to within several hundredth's of a pH unit upon the addition of a strong acid or strong base. How does it work? Let us see what happens upon addition of small amounts of strong acid or strong base.

If a strong acid is added the additional H_3O^+ ions react with $HCOO^-$ ions to form undissociated HCOOH, i.e., the equilibrium position of HCOOH dissociation is shifted to increase the concentration of HCOOH:

$$HCOOH + H_2O \longleftarrow H_3O^+ + HCOO^-$$

Most of the added H_3O^+ ions are removed from the solution and the pH remains at approximately 4.0.

<u>Problem 34.</u> Prove this by adding 0.01 mole of H_3O^+ to 1.0 liter of the HCOOH-HCOONa buffer of Problem 33. Set up the reaction scorecard and calculate the new pH.

It is interesting to note that the addition of 0.01 moles of H_3O^+ to an unbuffered 1.0 liter of pure water changes the pH from 7.0 to 2.0.

The weak acid of the buffer reacts to addition of strong base OH^- by undergoing a neutralization reaction.

$$HCOOH + OH^- \longrightarrow H_2O + HCOO^-$$

Again the added ions are removed from the solution and pH remains approximately 4.0.

Problem 35. Prove this by adding 0.01 mole of OH^- to 1.0 liter buffer of pH 4.0. Calculate the new pH.

Note the addition of 0.01 mole OH^- to 1.0 liters of pure water changes the pH from 7.0 to 12.0.

Problem 36. Explain using net ionic equations how each of the following buffer systems would react to the addition of (1) a strong acid and (2) a strong base.

a. CH_3COOH, CH_3COONa

b. NH_3, NH_4Cl

Problem 37. Three parameters determine the initial pH of a buffer solution. Can you list them? (Hint: refer to data given in Problem 33).

(A)

(B)

(C)

Work Problems 38 to 41. (This set contains problems to review all the concepts we have developed in our study of weak acids, bases, salts, and buffers.)

Problem 38. What is the pH of a solution prepared by dissolving 0.300 moles of sodium acetate, CH_3COONa, in 100 ml of 0.20 M HCl?

($K = 1.8 \times 10^{-5}$ for $CH_3COOH + H_2O \rightleftharpoons CH_3COO^- + H_3O^+$)

Problem 39. Find the pH of a solution 0.25 M in $NaNO_2$ and 0.75 M HNO_2.

($K = 5.1 \times 10^{-4}$ for $H_2O + HNO_2 \rightleftharpoons H_3O^+ + NO_2^-$)

Problem 40. Calculate the pH of the buffer formed by mixing 100 ml of 0.60 M NH_4Cl with 100 ml of 0.40 M NaOH.

($K = 1.8 \times 10^{-5}$ for $NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$)

Problem 41. Calculate the concentration of $NaNO_2$ in 0.10 M HNO_2 necessary to obtain a solution whose pH = 4.3.

($K = 5.1 \times 10^{-4}$ for $H_2O + HNO_2 \rightleftharpoons H_3O^+ + NO_2^-$)

BUFFER SIMULATION

The BUFFER program will allow you to conduct experiments with buffer solutions You may choose the pH of the buffer by selecting a particular acid/salt system. The equilibrium constant of the acid will determine the general pH range of the buffer.

The pH of a buffer solution can be estimated by finding the pK of the acid equilibrium constant,

$$pK = -\log K = \log(1/K)$$

The effective pH range of the buffer can be estimated as pK ± 1, that is, from pK - 1.0 to pK + 1.0. The exact pH of the buffer may be adjusted by varying the initial concentrations of weak acid and salt.

Problem 42. Prove that pK (of the weak acid) = pH (of buffer solution) when $[HA^+] = [A^-]$.

In order to understand the BUFFER program, visualize two beakers with equal volumes of solution. One contains pure water and the other contains a buffer solution whose composition has been selected by you to obtain a desired pH. You may add drops (0.05 ml/drop) of strong acid or strong base to both solutions and observe the change in composition in buffer and reference. If the capacity of the buffer is exceeded by adding excessive amounts of strong acid or strong base, the pH of the buffer will show a large change from that of the previous pH.

Before you run the program select a weak-acid/salt system and obtain a value for the K of the acid.

Run the BUFFER program noting the effect of the concentration of the salt on the pH of the buffer. Adjust the pH of the buffer to a value you like. Choose a concentration of strong acid and begin adding it to the buffer and water reference solutions. Continue adding acid until the buffer capacity has been exceeded. (The program will let you know when you have exceeded this capacity.)

Repeat the experiment, preparing the buffer as before, choosing a concentration of strong base and adding it to both solutions until the buffer capacity has been exceeded.

Log off the terminal.

Problem 43. (A) State the effect of adding strong acid on:

(i) $[A^-]$ of buffer ______

(ii) $[H_3O^+]$ of buffer ______

(iii) pH of buffer ______

(iv) pH of water ______

(B) State the effect of adding strong base on:

(i) $[A^-]$ of buffer ______

(ii) $[H_3O^+]$ of buffer ______

(iii) pH of buffer ______

(iv) pH of water ______

(C) In a weak acid/salt buffer system, what is the relationship between the concentration of the salt in the buffer solution and the concentration of strong acid which may be added to the buffer? How does this relationship determine the buffer capacity?

SUMMARY OF EQUILIBRIUM CONSTANTS

In order to emphasize the general nature of equilibria we have made no distinction among the equilibrium constants associated with the various types of reactions in this unit. In practice chemists usually refer to these equilibrium constants by given names and attach subscripts to them. This information is summarized in TABLE 1.

TABLE 1: Aqueous Equilibrium Constants

Reaction Type	Symbol	Name
$HA + H_2O \rightleftharpoons H_3O^+ + A^-$	K_a	acid constant of HA ionization constant of HA
$B + H_2O \rightleftharpoons BH^+ + OH^-$	K_b	base constant of B ionization constant of B
$H_2O + H_2O \rightleftharpoons H_3O^+ + OH^-$	K_w	ionization constant of water
$A^- + H_2O \rightleftharpoons HA + OH^-$	K_h or K_b	hydrolysis constant of A^- base constant of A^-
$BH^+ + H_2O \rightleftharpoons H_3O^+ + B$	K_h or K_a	hydrolysis constant of BH^+ acid constant of BH^+

Problem Set 1

1. HOW MANY MOLES OF THE SODIUM SALT SHOULD BE ADDED TO 231 ML OF 0.616 M HNO_2 TO PREPARE A BUFFER WITH A pH OF 3.750 ? ASSUME THAT NO VOLUME CHANGE OCCURS WHEN THE SODIUM SALT IS ADDED TO THE SOLUTION. THE IONIZATION CONSTANT OF HNO_2 IS 4.50E-04 .

2. A SOLUTION PREPARED FROM 0.315 MOLE OF A WEAK ACID, HX, AND 0.698 MOLE OF NaX DILUTED TO 393 ML HAS A pH OF 3.000. WHAT IS THE IONIZATION CONSTANT OF HX ?

3. $NaHSO_3$ IS 5.21E-04 % IONIZED IN 4.842 M SOLUTION. WHAT IS THE IONIZATION CONSTANT FOR THIS ACID?

4. A 6.490 M SOLUTION OF A WEAK ACID, HX, HAS A pH OF 5.250 WHAT IS THE IONIZATION CONSTANT OF THE ACID ?

5. HOW MANY MOLES OF HClO MUST BE USED TO PREPARE 1.34 L OF SOLUTION THAT HAS A pH OF 6.645 ? THE IONIZATION CONSTANT OF HClO IS 3.20E-08 .

6. A BUFFER SOLUTION IS MADE UP BY ADDING 1.282 MOLES OF THE SODIUM SALT TO 1.922 LITERS OF A 0.882 M SOLUTION OF HAc WHOSE IONIZATION CONSTANT IS 1.800E-05. WHAT IS THE pH OF THIS SOLUTION?

7. A WEAK ACID, HX, IS 7.081 % IONIZED IN 1.704 M SOLUTION. WHAT PERCENT OF HX IS IONIZED IN A 0.348 M SOLUTION ?

8. WHAT IS THE pH OF 4.602 M Formic acid WHOSE IONIZATION CONSTANT IS 2.100E-04?

9. A SOLUTION PREPARED FROM 0.695 MOLE OF A WEAK ACID, HX, DILUTED TO 185 ML HAS A pH OF 6.539 . WHAT IS THE pH OF THE SOLUTION AFTER 0.348 MOLE OF SOLID NaX IS DISSOLVED IN IT? ASSUME THAT NO SIGNIFICANT VOLUME CHANGE OCCURS WHEN THE NaX IS DISSOLVED IN THE SOLUTION.

10. WHAT IS THE CONCENTRATION OF $NaHCO_3$ IN A SOLUTION PREPARED BY ADDING 28 ML OF 3.360 M OF THE SODIUM SALT TO 187 ML OF 4.360 M HCL ? ASSUME THAT THE TOTAL VOLUME OF THE SOLUTION IS 215 ML. THE IONIZATION CONSTANT OF NaHCO3 IS 4.80E-11

Problem Set 2

1. HOW MANY MOLES OF THE SODIUM SALT SHOULD BE ADDED TO 120 ML OF 0.525 M HNO_2 TO PREPARE A BUFFER WITH A pH OF 6.970 ? ASSUME THAT NO VOLUME CHANGE OCCURS WHEN THE SODIUM SALT IS ADDED TO THE SOLUTION. THE IONIZATION CONSTANT OF HNO_2 IS 4.50E-04 .

2. WHAT IS THE CONCENTRATION OF HClO IN A SOLUTION PREPARED BY ADDING 96 ML OF 2.425 M OF THE SODIUM SALT TO 122 ML OF 2.860 M HCL ? ASSUME THAT THE TOTAL VOLUME OF THE SOLUTION IS 218 ML. THE IONIZATION CONSTANT OF HClO IS 3.20E-08

3. WHAT IS THE pH OF 2.634 M Formic acid WHOSE IONIZATION CONSTANT IS 2.100E-04?

4. IF A WEAK ACID, HX, IS 10.381 % IONIZED IN 3.655 M SOLUTION, AT WHAT CONCENTRATION IS THE ACID 39.381 % IONIZED?

5. A SOLUTION PREPARED FROM 0.530 MOLE OF A WEAK ACID, HX, AND 0.058 MOLE OF NaX DILUTED TO 204 ML HAS A pH OF 3.920. WHAT IS THE IONIZATION CONSTANT OF HX ?

6. $NaHCO_3$ IS 1.59E-05 % IONIZED IN 5.262 M SOLUTION. WHAT IS THE IONIZATION CONSTANT FOR THIS ACID?

7. A 5.848 M SOLUTION OF A WEAK ACID, HX, HAS A pH OF 5.800 . WHAT IS THE IONIZATION CONSTANT OF THE ACID ?

8. A SOLUTION PREPARED FROM 0.548 MOLE OF A WEAK ACID, HX, DILUTED TO 235 ML HAS A pH OF 2.460 . WHAT IS THE pH OF THE SOLUTION AFTER 0.278 MOLE OF SOLID NaX IS DISSOLVED IN IT? ASSUME THAT NO SIGNIFICANT VOLUME CHANGE OCCURS WHEN THE NaX IS DISSOLVED IN THE SOLUTION.

9. A BUFFER SOLUTION IS MADE UP BY ADDING 0.942 MOLES OF THE SODIUM SALT TO 0.502 LITERS OF A 0.269 M SOLUTION OF Formic acid WHOSE IONIZATION CONSTANT IS 2.100E-04. WHAT IS THE pH OF THIS SOLUTION?

10. HOW MANY MOLES OF $NaHCO_3$ MUST BE USED TO PREPARE 1.52 L OF SOLUTION THAT HAS A pH OF 4.035 ? THE IONIZATION CONSTANT OF $NaHCO_3$ IS 4.80E-11 .

Problem Set 3

1. A BUFFER SOLUTION IS MADE UP BY ADDING 1.?22 MOLES OF THE SODIUM SALT TO 0.242 LITERS OF A 0.214 M SOLUTION OF $NaHCO_3$ WHOSE IONIZATION CONSTANT IS 4.800E-11. WHAT IS THE pH OF THIS SOLUTION?

2. A SOLUTION PREPARED FROM 0.407 MOLE OF A WEAK ACID, HX, DILUTED TO 218 ML HAS A pH OF 2.574 . WHAT IS THE pH OF THE SOLUTION AFTER 0.148 MOLE OF SOLID NaX IS DISSOLVED IN IT? ASSUME THAT NO SIGNIFICANT VOLUME CHANGE OCCURS WHEN THE NaX IS DISSOLVED IN THE SOLUTION.

3. WHAT IS THE CONCENTRATION OF Benzoic acid IN A SOLUTION PREPARED BY ADDING 87 ML OF 3.600 M OF THE SODIUM SALT TO 450 ML OF 3.535 M HCL ? ASSUME THAT THE TOTAL VOLUME OF THE SOLUTION IS 537 ML. THE IONIZATION CONSTANT OF Benzoic acid IS 6.60E-05

4. A SOLUTION PREPARED FROM 0.338 MOLE OF A WEAK ACID, HX, AND 0.348 MOLE OF NaX DILUTED TO 472 ML HAS A pH OF 4.185. WHAT IS THE IONIZATION CONSTANT OF HX ?

5. A 2.476 M SOLUTION OF A WEAK ACID, HX, HAS A pH OF 5.750 . WHAT IS THE IONIZATION CONSTANT OF THE ACID ?

6. WHAT IS THE DEGREE OF IONIZATION OF A 1.302 M SOLUTION OF HCN WHOSE IONIZATION CONSTANT IS 4.00E-10 ?

7. HOW MANY MOLES OF Benzoic acid MUST BE USED TO PREPARE 1.33 L OF SOLUTION THAT HAS A pH OF 6.190 ? THE IONIZATION CONSTANT OF Benzoic acid IS . 6.60E-05 .

8. A WEAK ACID, HX, IS 7.681 % IONIZED IN 0.402 M SOLUTION. WHAT PERCENT OF HX IS IONIZED IN A 3.273 M SOLUTION ?

9. CALCULATE THE pH OF 1.472 M NH3 WHOSE IONIZATION CONSTANT IS 1.8E-5.

10. HOW MANY MOLES OF THE SODIUM SALT SHOULD BE ADDED TO 389 ML OF 0.184 M $NaHSO_3$ TO PREPARE A BUFFER WITH A pH OF 5.774 ? ASSUME THAT NO VOLUME CHANGE OCCURS WHEN THE SODIUM SALT IS ADDED TO THE SOLUTION. THE IONIZATION CONSTANT OF $NaHSO_3$ IS 5.60E-08 .

Problem Set 4

1. A SOLUTION PREPARED FROM 0.373 MOLE OF A WEAK ACID, HX, DILUTED TO 492 ML HAS A pH OF 2.375 . WHAT IS THE pH OF THE SOLUTION AFTER 0.338 MOLE OF SOLID NaX IS DISSOLVED IN IT? ASSUME THAT NO SIGNIFICANT VOLUME CHANGE OCCURS WHEN THE NaX IS DISSOLVED IN THE SOLUTION.

2. A SOLUTION PREPARED FROM 0.948 MOLE OF A WEAK ACID, HX, AND 0.778 MOLE OF NaX DILUTED TO 155 ML HAS A pH OF 6.489. WHAT IS THE IONIZATION CONSTANT OF HX ?

3. WHAT IS THE DEGREE OF IONIZATION OF A 3.198 M SOLUTION OF $NaHSO_3$ WHOSE IONIZATION CONSTANT IS 5.60E-08 ?

4. HOW MANY MOLES OF HCN MUST BE USED TO PREPARE 0.13 L OF SOLUTION THAT HAS A pH OF 5.930 ? THE IONIZATION CONSTANT OF HCN IS 4.00E-10 .

5. IF A WEAK ACID, HX, IS 10.081 % IONIZED IN .1.370 M SOLUTION, AT WHAT CONCENTRATION IS THE ACID 25.481 % IONIZED?

6. HOW MANY MOLES OF THE SODIUM SALT SHOULD BE ADDED TO 200 ML OF 0.531 M HAc TO PREPARE A BUFFER WITH A pH OF 3.750 ? ASSUME THAT NO VOLUME CHANGE OCCURS WHEN THE SODIUM SALT IS ADDED TO THE SOLUTION. THE IONIZATION CONSTANT OF HAc IS 1.80E-05 .

7. A 4.684 M SOLUTION OF A WEAK ACID, HX, HAS A pH OF 6.600 . WHAT IS THE IONIZATION CONSTANT OF THE ACID ?

8. WHAT IS THE pH OF 1.866 M HCN WHOSE IONIZATION CONSTANT IS 4.000E-10 ?

9. A BUFFER SOLUTION IS MADE UP BY ADDING 0.382 MOLES OF THE SODIUM SALT TO 1.222 LITERS OF A 0.308 M SOLUTION OF $NaHCO_3$ WHOSE IONIZATION CONSTANT IS 4.800E-11. WHAT IS THE pH OF THIS SOLUTION?

10. WHAT IS THE CONCENTRATION OF Benzoic acid IN A SOLUTION PREPARED BY ADDING 63 ML OF 2.940 M OF THE SODIUM SALT TO 419 ML OF 1.640 M HCL ? ASSUME THAT THE TOTAL VOLUME OF THE SOLUTION IS 482 ML. THE IONIZATION CONSTANT OF Benzoic acid IS 6.60E-05

Problem Set 5

1. WHAT IS THE CONCENTRATION OF HNO_2 IN A SOLUTION PREPARED BY ADDING 15 ML OF 2.650 M OF THE SODIUM SALT TO 279 ML OF 3.060 M HCL ? ASSUME THAT THE TOTAL VOLUME OF THE SOLUTION IS 294 ML. THE IONIZATION CONSTANT OF HNO2 IS 4.50E-04

2. HOW MANY MOLES OF HF MUST BE USED TO PREPARE 0.18 L OF SOLUTION THAT HAS A pH OF 2.410 ? THE IONIZATION CONSTANT OF HF IS 7.00E-04 .

3. A SOLUTION PREPARED FROM 0.381 MOLE OF A WEAK ACID, HX, DILUTED TO 459 ML HAS A pH OF 3.085 . WHAT IS THE pH OF THE SOLUTION AFTER 0.458 MOLE OF SOLID NaX IS DISSOLVED IN IT? ASSUME THAT NO SIGNIFICANT VOLUME CHANGE OCCURS WHEN THE NaX IS DISSOLVED IN THE SOLUTION.

4. CALCULATE THE pH OF 1.782 M METHYLAMINE WHOSE IONIZATION CONSTANT IS 1.8E-5.

5. HAc IS 8.94E-03 % IONIZED IN 4.446 M SOLUTION. WHAT IS THE IONIZATION CONSTANT FOR THIS ACID?

6. A 4.564 M SOLUTION OF A WEAK ACID, HX, HAS A pH OF 3.200 . WHAT IS THE IONIZATION CONSTANT OF THE ACID ?

7. HOW MANY MOLES OF THE SODIUM SALT SHOULD BE ADDED TO 199 ML OF 0.779 M HNO_2 TO PREPARE A BUFFER WITH A pH OF 4.104 ? ASSUME THAT NO VOLUME CHANGE OCCURS WHEN THE SODIUM SALT IS ADDED TO THE SOLUTION. THE IONIZATION CONSTANT OF HNO_2 IS 4.50E-04 .

8. A SOLUTION PREPARED FROM 0.709 MOLE OF A WEAK ACID, HX, AND 0.028 MOLE OF NaX DILUTED TO 424 ML HAS A pH OF 3.590. WHAT IS THE IONIZATION CONSTANT OF HX ?

9. A BUFFER SOLUTION IS MADE UP BY ADDING 1.022 MOLES OF THE SODIUM SALT TO 2.042 LITERS OF A 0.521 M SOLUTION OF HAc WHOSE IONIZATION CONSTANT IS 1.800E-05. WHAT IS THE pH OF THIS SOLUTION?

10. A WEAK ACID, HX, IS 5.481 % IONIZED IN 0.864 M SOLUTION. WHAT PERCENT OF HX IS IONIZED IN A 1.758 M SOLUTION ?

Problem Set 6.

1. A BUFFER SOLUTION IS MADE UP BY ADDING 0.682 MOLES OF THE SODIUM SALT TO 1.122 LITERS OF A 0.442 M SOLUTION OF Formic acid WHOSE IONIZATION CONSTANT IS 2.100E-04. WHAT IS THE pH OF THIS SOLUTION?

2. A SOLUTION PREPARED FROM 0.727 MOLE OF A WEAK ACID, HX, DILUTED TO 248 ML HAS A pH OF 5.635 . WHAT IS THE pH OF THE SOLUTION AFTER 0.238 MOLE OF SOLID NaX IS DISSOLVED IN IT? ASSUME THAT NO SIGNIFICANT VOLUME CHANGE OCCURS WHEN THE NaX IS DISSOLVED IN THE SOLUTION.

3. WHAT IS THE CONCENTRATION OF Propionic acid IN A SOLUTION PREPARED BY ADDING 15 ML OF 4.850 M OF THE SODIUM SALT TO 409 ML OF 0.270 M HCL ? ASSUME THAT THE TOTAL VOLUME OF THE SOLUTION IS 424 ML. THE IONIZATION CONSTANT OF Propionic acid IS 1.40E-05

4. HOW MANY MOLES OF THE SODIUM SALT SHOULD BE ADDED TO 392 ML OF 0.936 M HClO TO PREPARE A BUFFER WITH A pH OF 6.664 ? ASSUME THAT NO VOLUME CHANGE OCCURS WHEN THE SODIUM SALT IS ADDED TO THE SOLUTION. THE IONIZATION CONSTANT OF HClO IS 3.20E-08 .

5. A 2.872 M SOLUTION OF A WEAK ACID, HX, HAS A pH OF 5.800 . WHAT IS THE IONIZATION CONSTANT OF THE ACID ?

6. IF A WEAK ACID, HX, IS 17.781 % IONIZED IN 3.840 M SOLUTION, AT WHAT CONCENTRATION IS THE ACID 38.881 % IONIZED?

7. WHAT IS THE DEGREE OF IONIZATION OF A 2.748 M SOLUTION OF Benzoic acid WHOSE IONIZATION CONSTANT IS 6.60E-05 ?

8. WHAT IS THE pH OF 3.294 M Formic acid WHOSE IONIZATION CONSTANT IS 2.100E-04?

9. HOW MANY MOLES OF HAc MUST BE USED TO PREPARE 0.66 L OF SOLUTION THAT HAS A pH OF 6.105 ? THE IONIZATION CONSTANT OF HAc IS 1.80E-05 .

10. A SOLUTION PREPARED FROM 0.469 MOLE OF A WEAK ACID, HX, AND 0.448 MOLE OF NaX DILUTED TO 313 ML HAS A pH OF 3.300. WHAT IS THE IONIZATION CONSTANT OF HX ?

Problem Set 7

1. A SOLUTION PREPARED FRCM 0.810 MOLE OF A WEAK ACID, HX, AND 0.978 MOLE OF NaX DILUTED TO 287 ML HAS A pH OF 6.335. WHAT IS THE IONIZATION CONSTANT OF HX ?

2. WHAT IS THE DEGREE OF IONIZATION OF A 5.064 M SOLUTION OF HF WHOSE IONIZATION CONSTANT IS 7.00E-04 ?

3. HOW MANY MOLES OF HAc MUST BE USED TO PREPARE 0.72 L OF SOLUTION THAT HAS A pH OF 4.505 ? THE IONIZATION CONSTANT OF HAc IS 1.80E-05 .

4. IF A WEAK ACID, HX, IS 17.081 % IONIZED IN 4.755 M SOLUTION, AT WHAT CONCENTRATION IS THE ACID 27.181 % IONIZED?

5. CALCULATE THE pH OF 1.744 M METHYLAMINE WHOSE IONIZATION CONSTANT IS 1.8E-5.

6. A 6.646 M SOLUTION OF A WEAK ACID, HX, HAS A pH OF 6.600 . WHAT IS THE IONIZATION CONSTANT OF THE ACID ?

7. A SOLUTION PREPARED FROM 0.536 MOLE OF A WEAK ACID, HX, DILUTED TO 325 ML HAS A pH OF 2.000 . WHAT IS THE pH OF THE SOLUTION AFTER 0.748 MOLE OF SOLID NaX IS DISSOLVED IN IT? ASSUME THAT NO SIGNIFICANT VOLUME CHANGE OCCURS WHEN THE NaX IS DISSOLVED IN THE SOLUTION.

8. HOW MANY MOLES OF THE SODIUM SALT SHOULD BE ADDED TO 203 ML OF 0.770 M Propionic acid TO PREPARE A BUFFER WITH A pH OF 4.289 ? ASSUME THAT NO VOLUME CHANGE OCCURS WHEN THE SODIUM SALT IS ADDED TO THE SOLUTION. THE IONIZATION CONSTANT OF Propionic acid IS 1.40E-05 .

9. A BUFFER SOLUTION IS MADE UP BY ADDING 0.122 MOLES OF THE SODIUM SALT TO 1.342 LITERS OF A 0.175 M SOLUTION OF HNO_2 WHOSE IONIZATION CONSTANT IS 4.500E-04. WHAT IS THE pH OF THIS SOLUTION?

10. WHAT IS THE CONCENTRATION OF Formic acid IN A SOLUTION PREPARED BY ADDING 61 ML OF 4.795 M OF THE SODIUM SALT TO 152 ML OF 1.405 M HCL ? ASSUME THAT THE TOTAL VOLUME OF THE SOLUTION IS 213 ML. THE IONIZATION CONSTANT OF Formic acid IS 2.10E-04

Problem Set 8

1. WHAT IS THE CONCENTRATION OF HF IN A SOLUTION PREPARED BY ADDING 25 ML OF 2.400 M OF THE SODIUM SALT TO 24 ML OF 5.070 M HCL ? ASSUME THAT THE TOTAL VOLUME OF THE SOLUTION IS 49 ML. THE IONIZATION CONSTANT OF HF IS 7.00E-04

2. HOW MANY MOLES OF THE SODIUM SALT SHOULD BE ADDED TO 441 ML OF 0.605 M HClO TO PREPARE A BUFFER WITH A pH OF 2.524 ? ASSUME THAT NO VOLUME CHANGE OCCURS WHEN THE SODIUM SALT IS ADDED TO THE SOLUTION. THE IONIZATION CONSTANT OF HClO IS 3.20E-08 .

3. HOW MANY MOLES OF Benzoic acid MUST BE USED TO PREPARE 1.18 L OF SOLUTION THAT HAS A pH OF 3.610 ? THE IONIZATION CONSTANT OF Benzoic acid IS 6.60E-05 .

4. A 2.068 M SOLUTION OF A WEAK ACID, HX, HAS A pH OF 4.550 . WHAT IS THE IONIZATION CONSTANT OF THE ACID ?

5. CALCULATE THE pH OF 0.928 M METHYLAMINE WHOSE IONIZATION CONSTANT IS 1.8E-5.

6. IF A WEAK ACID, HX, IS 19.981 % IONIZED IN 4.910 M SOLUTION, AT WHAT CONCENTRATION IS THE ACID 12.081 % IONIZED?

7. WHAT IS THE DEGREE OF IONIZATION OF A 5.568 M SOLUTION OF HClO WHOSE IONIZATION CONSTANT IS 3.20E-08 ?

8. A BUFFER SOLUTION IS MADE UP BY ADDING 0.682 MOLES OF THE SODIUM SALT TO 1.122 LITERS OF A 0.150 M SOLUTION OF $NaHCO_3$ WHOSE IONIZATION CONSTANT IS 4.800E-11. WHAT IS THE pH OF THIS SOLUTION?

9. A SOLUTION PREPARED FROM 0.588 MOLE OF A WEAK ACID, HX, AND 0.038 MOLE OF NaX DILUTED TO 208 ML HAS A pH OF 4.114. WHAT IS THE IONIZATION CONSTANT OF HX ?

10. A SOLUTION PREPARED FROM 0.555 MOLE OF A WEAK ACID, HX, DILUTED TO 243 ML HAS A pH OF 4.545 . WHAT IS THE pH OF THE SOLUTION AFTER 0.518 MOLE OF SOLID NaX IS DISSOLVED IN IT? ASSUME THAT NO SIGNIFICANT VOLUME CHANGE OCCURS WHEN THE NaX IS DISSOLVED IN THE SOLUTION.

Problem Set 9

1. IF A WEAK ACID, HX, IS 9.881 % IONIZED IN 2.635 M SOLUTION, AT WHAT CONCENTRATION IS THE ACID 24.781 % IONIZED?

2. WHAT IS THE CONCENTRATION OF HF IN A SOLUTION PREPARED BY ADDING 64 ML OF 3.660 M OF THE SODIUM SALT TO 148 ML OF 0.630 M HCL ? ASSUME THAT THE TOTAL VOLUME OF THE SOLUTION IS 212 ML. THE IONIZATION CONSTANT OF HF IS 7.00E-04

3. A SOLUTION PREPARED FROM 0.864 MOLE OF A WEAK ACID, HX, DILUTED TO 248 ML HAS A pH OF 6.194 . WHAT IS THE pH OF THE SOLUTION AFTER 0.668 MOLE OF SOLID NaX IS DISSOLVED IN IT? ASSUME THAT NO SIGNIFICANT VOLUME CHANGE OCCURS WHEN THE NaX IS DISSOLVED IN THE SOLUTION.

4. A SOLUTION PREPARED FROM 0.591 MOLE OF A WEAK ACID, HX, AND 0.938 MOLE OF NaX DILUTED TO 417 ML HAS A pH OF 5.475. WHAT IS THE IONIZATION CONSTANT OF HX ?

5. A BUFFER SOLUTION IS MADE UP BY ADDING 0.682 MOLES OF THE SODIUM SALT TO 0.622 LITERS OF A 0.854 M SOLUTION OF HF WHOSE IONIZATION CONSTANT IS 7.000E-04. WHAT IS THE pH OF THIS SOLUTION?

6. CALCULATE THE pH OF 1.704 M METHYLAMINE WHOSE IONIZATION CONSTANT IS 1.8E-5.

7. A 6.748 M SOLUTION OF A WEAK ACID, HX, HAS A pH OF 2.900 . WHAT IS THE IONIZATION CONSTANT OF THE ACID ?

8. HOW MANY MOLES OF HClO MUST BE USED TO PREPARE 1.89 L OF SOLUTION THAT HAS A pH OF 3.925 ? THE IONIZATION CONSTANT OF HClO IS 3.20E-08 .

9. HOW MANY MOLES OF THE SODIUM SALT SHOULD BE ADDED TO 454 ML OF 0.458 M HClO TO PREPARE A BUFFER WITH A pH OF 5.779 ? ASSUME THAT NO VOLUME CHANGE OCCURS WHEN THE SODIUM SALT IS ADDED TO THE SOLUTION. THE IONIZATION CONSTANT OF HClO IS 3.20E-08 .

10. WHAT IS THE DEGREE OF IONIZATION OF A 1.764 M SOLUTION OF $NaHSO_3$ WHOSE IONIZATION CONSTANT IS 5.60E-08 ?

Problem Set 10

1. WHAT IS THE CONCENTRATION OF HCN IN A SOLUTION PREPARED BY ADDING 73 ML OF 4.015 M OF THE SODIUM SALT TO 110 ML OF 1.130 M HCL ? ASSUME THAT THE TOTAL VOLUME OF THE SOLUTION IS 183 ML. THE IONIZATION CONSTANT OF HCN IS 4.00E-10

2. A 2.410 M SOLUTION OF A WEAK ACID, HX, HAS A pH OF 5.100 . WHAT IS THE IONIZATION CONSTANT OF THE ACID ?

3. A SOLUTION PREPARED FROM 0.867 MOLE OF A WEAK ACID, HX, AND 0.688 MOLE OF NaX DILUTED TO 442 ML HAS A pH OF 5.500. WHAT IS THE IONIZATION CONSTANT OF HX ?

4. A WEAK ACID, HX, IS 14.881 % IONIZED IN 1.482 M SOLUTION. WHAT PERCENT OF HX IS IONIZED IN A 3.888 M SOLUTION ?

5. HOW MANY MOLES OF HClO MUST BE USED TO PREPARE 0.54 L OF SOLUTION THAT HAS A pH OF 5.725 ? THE IONIZATION CONSTANT OF HClO IS 3.20E-08 .

6. CALCULATE THE pH OF 1.678 M NH3 WHOSE IONIZATION CONSTANT IS 1.8E-5.

7. A BUFFER SOLUTION IS MADE UP BY ADDING 1.142 MOLES OF THE SODIUM SALT TO 1.602 LITERS OF A 0.243 M SOLUTION OF Propionic acid WHOSE IONIZATION CONSTANT IS 1.400E-05. WHAT IS THE pH OF THIS SOLUTION?

8. HOW MANY MOLES OF THE SODIUM SALT SHOULD BE ADDED TO 475 ML OF 0.888 M Benzoic acid TO PREPARE A BUFFER WITH A pH OF 4.310 ? ASSUME THAT NO VOLUME CHANGE OCCURS WHEN THE SODIUM SALT IS ADDED TO THE SOLUTION. THE IONIZATION CONSTANT OF Benzoic acid IS 6.60E-05 .

9. A SOLUTION PREPARED FROM 0.998 MOLE OF A WEAK ACID, HX, DILUTED TO 425 ML HAS A pH OF 4.420 . WHAT IS THE pH OF THE SOLUTION AFTER 0.228 MOLE OF SOLID NaX IS DISSOLVED IN IT? ASSUME THAT NO SIGNIFICANT VOLUME CHANGE OCCURS WHEN THE NaX IS DISSOLVED IN THE SOLUTION.

10. $NaHSO_3$ IS 4.07E-04 % IONIZED IN 2.958 M SOLUTION. WHAT IS THE IONIZATION CONSTANT FOR THIS ACID?

Problem Set 11

1. A BUFFER SOLUTION IS MADE UP BY ADDING 0.662 MOLES OF THE SODIUM SALT TO 1.362 LITERS OF A 0.193 M SOLUTION OF HNO_2 WHOSE IONIZATION CONSTANT IS 4.500E-04. WHAT IS THE pH OF THIS SOLUTION?

2. CALCULATE THE pH OF 1.680 M METHYLAMINE WHOSE IONIZATION CONSTANT IS 1.8E-5.

3. A 4.834 M SOLUTION OF A WEAK ACID, HX, HAS A pH OF 3.200 . WHAT IS THE IONIZATION CONSTANT OF THE ACID ?

4. A SOLUTION PREPARED FROM 0.678 MOLE OF A WEAK ACID, HX, DILUTED TO 339 ML HAS A pH OF 4.819 . WHAT IS THE pH OF THE SOLUTION AFTER 0.648 MOLE OF SOLID NaX IS DISSOLVED IN IT? ASSUME THAT NO SIGNIFICANT VOLUME CHANGE OCCURS WHEN THE NaX IS DISSOLVED IN THE SOLUTION.

5. WHAT IS THE DEGREE OF IONIZATION OF A 5.568 M SOLUTION OF Benzoic acid WHOSE IONIZATION CONSTANT IS 6.60E-05 ?

6. IF A WEAK ACID, HX, IS 16.581 % IONIZED IN 2.260 M SOLUTION, AT WHAT CONCENTRATION IS THE ACID 16.081 % IONIZED?

7. WHAT IS THE CONCENTRATION OF HClO IN A SOLUTION PREPARED BY ADDING 69 ML OF 2.825 M OF THE SODIUM SALT TO 362 ML OF 2.965 M HCL ? ASSUME THAT THE TOTAL VOLUME OF THE SOLUTION IS 431 ML. THE IONIZATION CONSTANT OF HClO IS 3.20E-08

8. A SOLUTION PREPARED FROM 0.466 MOLE OF A WEAK ACID, HX, AND 0.218 MOLE OF NaX DILUTED TO 358 ML HAS A pH OF 6.994. WHAT IS THE IONIZATION CONSTANT OF HX ?

9. HOW MANY MOLES OF THE SODIUM SALT SHOULD BE ADDED TO 133 ML OF 0.482 M HF TO PREPARE A BUFFER WITH A pH OF 6.770 ? ASSUME THAT NO VOLUME CHANGE OCCURS WHEN THE SODIUM SALT IS ADDED TO THE SOLUTION. THE IONIZATION CONSTANT OF HF IS 7.00E-04 .

10. HOW MANY MOLES OF HNO_2 MUST BE USED TO PREPARE 1.37 L OF SOLUTION THAT HAS A pH OF 5.615 ? THE IONIZATION CONSTANT OF HNO_2 IS 4.50E-04 .

Problem Set 12

1. A SOLUTION PREPARED FROM 0.553 MOLE OF A WEAK ACID, HX, DILUTED TO 383 ML HAS A pH OF 6.159 . WHAT IS THE pH OF THE SOLUTION AFTER 0.078 MOLE OF SOLID NaX IS DISSOLVED IN IT? ASSUME THAT NO SIGNIFICANT VOLUME CHANGE OCCURS WHEN THE NaX IS DISSOLVED IN THE SOLUTION.

2. A SOLUTION PREPARED FROM 0.288 MOLE OF A WEAK ACID, HX, AND 0.438 MOLE OF NaX DILUTED TO 337 ML HAS A pH OF 6.425. WHAT IS THE IONIZATION CONSTANT OF HX ?

3. HNO_2 IS 5.07E-02 % IONIZED IN 5.766 M SOLUTION. WHAT IS THE IONIZATION CONSTANT FOR THIS ACID?

4. A BUFFER SOLUTION IS MADE UP BY ADDING 0.063 MOLES OF THE SODIUM SALT TO 1.563 LITERS OF A 0.607 M SOLUTION OF HAc WHOSE IONIZATION CONSTANT IS 1.800E-05. WHAT IS THE pH OF THIS SOLUTION?

5. HOW MANY MOLES OF THE SODIUM SALT SHOULD BE ADDED TO 246 ML OF 0.875 M HClO TO PREPARE A BUFFER WITH A pH OF 2.449 ? ASSUME THAT NO VOLUME CHANGE OCCURS WHEN THE SODIUM SALT IS ADDED TO THE SOLUTION. THE IONIZATION CONSTANT OF HClO IS 3.20E-08 .

6. A 5.134 M SOLUTION OF A WEAK ACID, HX, HAS A pH OF 4.600 . WHAT IS THE IONIZATION CONSTANT OF THE ACID ?

7. HOW MANY MOLES OF Benzoic acid MUST BE USED TO PREPARE 1.17 L OF SOLUTION THAT HAS A pH OF 3.540 ? THE IONIZATION CONSTANT OF Benzoic acid IS 6.60E-05 .

8. IF A WEAK ACID, HX, IS 1.981 % IONIZED IN 0.360 M SOLUTION, AT WHAT CONCENTRATION IS THE ACID 6.181 % IONIZED?

9. WHAT IS THE CONCENTRATION OF $NaHCO_3$ IN A SOLUTION PREPARED BY ADDING 18 ML OF 4.535 M OF THE SODIUM SALT TO 55 ML OF 4.525 M HCL ? ASSUME THAT THE TOTAL VOLUME OF THE SOLUTION IS 73 ML. THE IONIZATION CONSTANT OF NaHCO3 IS 4.80E-11

10. CALCULATE THE pH OF 0.826 M METHYLAMINE WHOSE IONIZATION CONSTANT IS 1.8E-5.

Problem Set 13

1. HOW MANY MOLES OF THE SODIUM SALT SHOULD BE ADDED TO 246 ML OF 0.508 M Benzoic acid TO PREPARE A BUFFER WITH A pH OF 3.675 ? ASSUME THAT NO VOLUME CHANGE OCCURS WHEN THE SODIUM SALT IS ADDED TO THE SOLUTION. THE IONIZATION CONSTANT OF Benzoic acid IS 6.60E-05 .

2. A BUFFER SOLUTION IS MADE UP BY ADDING 0.152 MOLES OF THE SODIUM SALT TO 1.732 LITERS OF A 0.843 M SOLUTION OF HNO_2 WHOSE IONIZATION CONSTANT IS 4.500E-04. WHAT IS THE pH OF THIS SOLUTION?

3. A SOLUTION PREPARED FROM 0.393 MOLE OF A WEAK ACID, HX, AND 0.138 MOLE OF NaX DILUTED TO 256 ML HAS A pH OF 2.484. WHAT IS THE IONIZATION CONSTANT OF HX ?

4. A 6.442 M SOLUTION OF A WEAK ACID, HX, HAS A pH OF 2.500 . WHAT IS THE IONIZATION CONSTANT OF THE ACID ?

5. CALCULATE THE pH OF 0.328 M METHYLAMINE WHOSE IONIZATION CONSTANT IS 1.8E-5.

6. A WEAK ACID, HX, IS 25.881 % IONIZED IN 1.304 M SOLUTION. WHAT PERCENT OF HX IS IONIZED IN A 4.838 M SOLUTION ?

7. WHAT IS THE CONCENTRATION OF Formic acid IN A SOLUTION PREPARED BY ADDING 88 ML OF 5.090 M OF THE SODIUM SALT TO 118 ML OF 1.285 M HCL ? ASSUME THAT THE TOTAL VOLUME OF THE SOLUTION IS 206 ML. THE IONIZATION CONSTANT OF Formic acid IS 2.10E-04

8. WHAT IS THE DEGREE OF IONIZATION OF A 5.622 M SOLUTION OF $NaHCO_3$ WHOSE IONIZATION CONSTANT IS 4.80E-11 ?

9. A SOLUTION PREPARED FROM 0.716 MOLE OF A WEAK ACID, HX, DILUTED TO 152 ML HAS A pH OF 4.755 . WHAT IS THE pH OF THE SOLUTION AFTER 0.398 MOLE OF SOLID NaX IS DISSOLVED IN IT? ASSUME THAT NO SIGNIFICANT VOLUME CHANGE OCCURS WHEN THE NaX IS DISSOLVED IN THE SOLUTION.

10. HOW MANY MOLES OF HClO MUST BE USED TO PREPARE 0.65 L OF SOLUTION THAT HAS A pH OF 2.925 ? THE IONIZATION CONSTANT OF HClO IS 3.20E-08 .

Problem Set 14

1. A SOLUTION PREPARED FROM 0.798 MOLE OF A WEAK ACID, HX, AND 0.448 MOLE OF NaX DILUTED TO 181 ML HAS A pH OF 3.569. WHAT IS THE IONIZATION CONSTANT OF HX ?

2. HOW MANY MOLES OF Benzoic acid MUST BE USED TO PREPARE 2.03 L OF SOLUTION THAT HAS A pH OF 4.320 ? THE IONIZATION CONSTANT OF Benzoic acid IS 6.60E-05 .

3. A BUFFER SOLUTION IS MADE UP BY ADDING 0.502 MOLES OF THE SODIUM SALT TO 0.282 LITERS OF A 0.777 M SOLUTION OF $NaHCO_3$ WHOSE IONIZATION CONSTANT IS 4.800E-11. WHAT IS THE pH OF THIS SOLUTION?

4. A 3.460 M SOLUTION OF A WEAK ACID, HX, HAS A pH OF 5.700 . WHAT IS THE IONIZATION CONSTANT OF THE ACID ?

5. CALCULATE THE pH OF 1.236 M METHYLAMINE WHOSE IONIZATION CONSTANT IS 1.8E-5

6. IF A WEAK ACID, HX, IS 7.281 % IONIZED IN 1.895 M SOLUTION, AT WHAT CONCENTRATION IS THE ACID 22.581 % IONIZED?

7. HOW MANY MOLES OF THE SODIUM SALT SHOULD BE ADDED TO 392 ML OF 0.244 M $NaHSO_3$ TO PREPARE A BUFFER WITH A pH OF 3.324 ? ASSUME THAT NO VOLUME CHANGE OCCURS WHEN THE SODIUM SALT IS ADDED TO THE SOLUTION. THE IONIZATION CONSTANT OF $NaHSO_3$ IS 5.60E-08 .

8. WHAT IS THE CONCENTRATION OF HF IN A SOLUTION PREPARED BY ADDING 1 ML OF 1.360 M OF THE SODIUM SALT TO 432 ML OF 2.075 M HCL ? ASSUME THAT THE TOTAL VOLUME OF THE SOLUTION IS 433 ML. THE IONIZATION CONSTANT OF HF IS 7.00E-04

9. A SOLUTION PREPARED FROM 0.175 MOLE OF A WEAK ACID, HX, DILUTED TO 407 ML HAS A pH OF 5.659 . WHAT IS THE pH OF THE SOLUTION AFTER 0.158 MOLE OF SOLID NaX IS DISSOLVED IN IT? ASSUME THAT NO SIGNIFICANT VOLUME CHANGE OCCURS WHEN THE NaX IS DISSOLVED IN THE SOLUTION.

10. WHAT IS THE DEGREE OF IONIZATION OF A 5.742 M SOLUTION OF $NaHCO_3$ WHOSE IONIZATION CONSTANT IS 4.80E-11 ?

Problem Set 15

1. A BUFFER SOLUTION IS MADE UP BY ADDING 0.672 MOLES OF THE SODIUM SALT TO 1.492 LITERS OF A 0.473 M SOLUTION OF Propionic acid WHOSE IONIZATION CONSTANT IS 1.400E-05. WHAT IS THE pH OF THIS SOLUTION?

2. A SOLUTION PREPARED FROM 0.964 MOLE OF A WEAK ACID, HX, AND 0.458 MOLE OF NaX DILUTED TO 330 ML HAS A pH OF 4.085, WHAT IS THE IONIZATION CONSTANT OF HX ?

3. WHAT IS THE CONCENTRATION OF HCN IN A SOLUTION PREPARED BY ADDING 28 ML OF 0.880 M OF THE SODIUM SALT TO 501 ML OF 1.000 M HCL ? ASSUME THAT THE TOTAL VOLUME OF THE SOLUTION IS 529 ML. THE IONIZATION CONSTANT OF HCN IS 4.00E-10

4. HOW MANY MOLES OF THE SODIUM SALT SHOULD BE ADDED TO 315 ML OF 0.809 M Formic acid TO PREPARE A BUFFER WITH A pH OF 4.670 ? ASSUME THAT NO VOLUME CHANGE OCCURS WHEN THE SODIUM SALT IS ADDED TO THE SOLUTION. THE IONIZATION CONSTANT OF Formic acid IS 2.10E-04 .

5. IF A WEAK ACID, HX, IS 2.881 % IONIZED IN 4.475 M SOLUTION, AT WHAT CONCENTRATION IS THE ACID 30.881 % IONIZED?

6. WHAT IS THE DEGREE OF IONIZATION OF A 5.772 M SOLUTION OF HF WHOSE IONIZATION CONSTANT IS 7.00E-04 ?

7. A 2.614 M SOLUTION OF A WEAK ACID, HX, HAS A pH OF 2.000 . WHAT IS THE IONIZATION CONSTANT OF THE ACID ?

8. HOW MANY MOLES OF Propionic acid MUST BE USED TO PREPARE 1.32 L OF SOLUTION THAT HAS A pH OF 5.410 ? THE IONIZATION CONSTANT OF Propionic acid IS 1.40E-05 .

9. WHAT IS THE pH OF 4.404 M $NaHSO_3$ WHOSE IONIZATION CONSTANT IS 5.600E-08?

10. A SOLUTION PREPARED FROM 0.844 MOLE OF A WEAK ACID, HX, DILUTED TO 272 ML HAS A pH OF 5.475 . WHAT IS THE pH OF THE SOLUTION AFTER 0.428 MOLE OF SOLID NaX IS DISSOLVED IN IT? ASSUME THAT NO SIGNIFICANT VOLUME CHANGE OCCURS WHEN THE NaX IS DISSOLVED IN THE SOLUTION.

Problem Set 16

1. A WEAK ACID, HX, IS 22.781 % IONIZED IN 0.862 M SOLUTION. WHAT PERCENT OF HX IS IONIZED IN A 3.598 M SOLUTION ?

2. WHAT IS THE pH OF 0.408 M Benzoic acid WHOSE IONIZATION CONSTANT IS 6.600E-05?

3. HOW MANY MOLES OF HClO MUST BE USED TO PREPARE 0.61 L OF SOLUTION THAT HAS A pH OF 2.725 ? THE IONIZATION CONSTANT OF HClO IS 3.20E-08 .

4. A SOLUTION PREPARED FROM 0.194 MOLE OF A WEAK ACID, HX, DILUTED TO 122 ML HAS A pH OF 2.779 . WHAT IS THE pH OF THE SOLUTION AFTER 0.488 MOLE OF SOLID NaX IS DISSOLVED IN IT? ASSUME THAT NO SIGNIFICANT VOLUME CHANGE OCCURS WHEN THE NaX IS DISSOLVED IN THE SOLUTION.

5. WHAT IS THE CONCENTRATION OF HF IN A SOLUTION PREPARED BY ADDING 23 ML OF 0.710 M OF THE SODIUM SALT TO 309 ML OF 1.815 M HCL ? ASSUME THAT THE TOTAL VOLUME OF THE SOLUTION IS 332 ML. THE IONIZATION CONSTANT OF HF IS 7.00E-04

6. WHAT IS THE DEGREE OF IONIZATION OF A 0.444 M SOLUTION OF HNO_2 WHOSE IONIZATION CONSTANT IS 4.50E-04 ?

7. HOW MANY MOLES OF THE SODIUM SALT SHOULD BE ADDED TO 363 ML OF 0.229 M Formic acid TO PREPARE A BUFFER WITH A pH OF 5.890 ? ASSUME THAT NO VOLUME CHANGE OCCURS WHEN THE SODIUM SALT IS ADDED TO THE SOLUTION. THE IONIZATION CONSTANT OF Formic acid IS 2.10E-04 .

8. A BUFFER SOLUTION IS MADE UP BY ADDING 1.313 MOLES OF THE SODIUM SALT TO 0.813 LITERS OF A 0.079 M SOLUTION OF Formic acid WHOSE IONIZATION CONSTANT IS 2.100E-04. WHAT IS THE pH OF THIS SOLUTION?

9. A SOLUTION PREPARED FROM 0.509 MOLE OF A WEAK ACID, HX, AND 0.128 MOLE OF NaX DILUTED TO 300 ML HAS A pH OF 3.185. WHAT IS THE IONIZATION CONSTANT OF HX ?

10. A 4.558 M SOLUTION OF A WEAK ACID, HX, HAS A pH OF 3.750 . WHAT IS THE IONIZATION CONSTANT OF THE ACID ?

Problem Set 17

1. A BUFFER SOLUTION IS MADE UP BY ADDING 0.112 MOLES OF THE SODIUM SALT TO 0.712 LITERS OF A 0.137 M SOLUTION OF HAc WHOSE IONIZATION CONSTANT IS 1.800E-05. WHAT IS THE pH OF THIS SOLUTION?

2. A SOLUTION PREPARED FROM 0.521 MOLE OF A WEAK ACID, HX, AND 0.658 MOLE OF NaX DILUTED TO 280 ML HAS A pH OF 3.265. WHAT IS THE IONIZATION CONSTANT OF HX ?

3. A WEAK ACID, HX, IS 8.981 % IONIZED IN 0.320 M SOLUTION. WHAT PERCENT OF HX IS IONIZED IN A 2.733 M SOLUTION ?

4. A SOLUTION PREPARED FROM 0.097 MOLE OF A WEAK ACID, HX, DILUTED TO 253 ML HAS A pH OF 5.694 . WHAT IS THE pH OF THE SOLUTION AFTER 0.808 MOLE OF SOLID NaX IS DISSOLVED IN IT? ASSUME THAT NO SIGNIFICANT VOLUME CHANGE OCCURS WHEN THE NaX IS DISSOLVED IN THE SOLUTION.

5. WHAT IS THE pH OF 1.200 M Benzoic acid WHOSE IONIZATION CONSTANT IS 6.600E-05?

6. HOW MANY MOLES OF THE SODIUM SALT SHOULD BE ADDED TO 480 ML OF 0.213 M HNO_2 TO PREPARE A BUFFER WITH A pH OF 4.789 ? ASSUME THAT NO VOLUME CHANGE OCCURS WHEN THE SODIUM SALT IS ADDED TO THE SOLUTION. THE IONIZATION CONSTANT OF HNO_2 IS 4.50E-04 .

7. HOW MANY MOLES OF $NaHSO_3$ MUST BE USED TO PREPARE 1.70 L OF SOLUTION THAT HAS A pH OF 3.125 ? THE IONIZATION CONSTANT OF $NaHSO_3$ IS 5.60E-08 .

8. WHAT IS THE DEGREE OF IONIZATION OF A 5.010 M SOLUTION OF Formic acid WHOSE IONIZATION CONSTANT IS 2.10E-04 ?

9. A 3.310 M SOLUTION OF A WEAK ACID, HX, HAS A pH OF 3.250 . WHAT IS THE IONIZATION CONSTANT OF THE ACID ?

10. WHAT IS THE CONCENTRATION OF Benzoic acid IN A SOLUTION PREPARED BY ADDING 26 ML OF 2.090 M OF THE SODIUM SALT TO 103 ML OF 4.900 M HCL ? ASSUME THAT THE TOTAL VOLUME OF THE SOLUTION IS 129 ML. THE IONIZATION CONSTANT OF Benzoic acid IS 6.60E-05

Problem Set 18

1. WHAT IS THE CONCENTRATION OF Propionic acid IN A SOLUTION PREPARED BY ADDING 42 ML OF 2.990 M OF THE SODIUM SALT TO 450 ML OF 2.130 M HCL ? ASSUME THAT THE TOTAL VOLUME OF THE SOLUTION IS 492 ML. THE IONIZATION CONSTANT OF Propionic acid IS 1.40E-05

2. A SOLUTION PREPARED FROM 0.471 MOLE OF A WEAK ACID, HX, AND 0.668 MOLE OF NaX DILUTED TO 236 ML HAS A pH OF 5.885. WHAT IS THE IONIZATION CONSTANT OF HX ?

3. A 2.848 M SOLUTION OF A WEAK ACID, HX, HAS A pH OF 6.500 . WHAT IS THE IONIZATION CONSTANT OF THE ACID ?

4. HOW MANY MOLES OF $NaHSO_3$ MUST BE USED TO PREPARE 0.39 L OF SOLUTION THAT HAS A pH OF 6.670 ? THE IONIZATION CONSTANT OF $NaHSO_3$ IS 5.60E-08 .

5. WHAT IS THE pH OF 3.792 M $NaHCO_3$ WHOSE IONIZATION CONSTANT IS 4.800E-11?

6. IF A WEAK ACID, HX, IS 18.981 % IONIZED IN 0.570 M SOLUTION, AT WHAT CONCENTRATION IS THE ACID 14.781 % IONIZED?

7. A BUFFER SOLUTION IS MADE UP BY ADDING 1.052 MOLES OF THE SODIUM SALT TO 1.432 LITERS OF A 0.946 M SOLUTION OF HCN WHOSE IONIZATION CONSTANT IS 4.000E-10. WHAT IS THE pH OF THIS SOLUTION?

8. HCN IS 3.81E-05 % IONIZED IN 3.630 M SOLUTION. WHAT IS THE IONIZATION CONSTANT FOR THIS ACID?

9. HOW MANY MOLES OF THE SODIUM SALT SHOULD BE ADDED TO 315 ML OF 0.570 M Propionic acid TO PREPARE A BUFFER WITH A pH OF 6.175 ? ASSUME THAT NO VOLUME CHANGE OCCURS WHEN THE SODIUM SALT IS ADDED TO THE SOLUTION. THE IONIZATION CONSTANT OF Propionic acid IS 1.40E-05 .

10. A SOLUTION PREPARED FROM 0.545 MOLE OF A WEAK ACID, HX, DILUTED TO 351 ML HAS A pH OF 2.784 . WHAT IS THE pH OF THE SOLUTION AFTER 0.928 MOLE OF SOLID NaX IS DISSOLVED IN IT? ASSUME THAT NO SIGNIFICANT VOLUME CHANGE OCCURS WHEN THE NaX IS DISSOLVED IN THE SOLUTION.

Problem Set 19

1. A SOLUTION PREPARED FROM 0.434 MOLE OF A WEAK ACID, HX, DILUTED TO 421 ML HAS A pH OF 6.270 . WHAT IS THE pH OF THE SOLUTION AFTER 0.038 MOLE OF SOLID NaX IS DISSOLVED IN IT? ASSUME THAT NO SIGNIFICANT VOLUME CHANGE OCCURS WHEN THE NaX IS DISSOLVED IN THE SOLUTION.

2. HOW MANY MOLES OF THE SODIUM SALT SHOULD BE ADDED TO 168 ML OF 0.177 M Propionic acid TO PREPARE A BUFFER WITH A pH OF 5.005 ? ASSUME THAT NO VOLUME CHANGE OCCURS WHEN THE SODIUM SALT IS ADDED TO THE SOLUTION. THE IONIZATION CONSTANT OF Propionic acid IS 1.40E-05 .

3. WHAT IS THE pH OF 1.080 M Formic acid WHOSE IONIZATION CONSTANT IS 2.100E-04?

4. A BUFFER SOLUTION IS MADE UP BY ADDING 0.252 MOLES OF THE SODIUM SALT TO 1.032 LITERS OF A 0.286 M SOLUTION OF HCN WHOSE IONIZATION CONSTANT IS 4.000E-10. WHAT IS THE pH OF THIS SOLUTION?

5. WHAT IS THE CONCENTRATION OF Propionic acid IN A SOLUTION PREPARED BY ADDING 49 ML OF 2.400 M OF THE SODIUM SALT TO 203 ML OF 3.630 M HCL ? ASSUME THAT THE TOTAL VOLUME OF THE SOLUTION IS 252 ML. THE IONIZATION CONSTANT OF Propionic acid IS 1.40E-05

6. HCN IS 3.12E-05 % IONIZED IN 2.430 M SOLUTION. WHAT IS THE IONIZATION CONSTANT FOR THIS ACID?

7. HOW MANY MOLES OF $NaHSO_3$ MUST BE USED TO PREPARE 2.04 L OF SOLUTION THAT HAS A pH OF 3.220 ? THE IONIZATION CONSTANT OF $NaHSO_3$ IS 5.60E-08 .

8. A SOLUTION PREPARED FROM 0.410 MOLE OF A WEAK ACID, HX, AND 0.448 MOLE OF NaX DILUTED TO 220 ML HAS A pH OF 4.944. WHAT IS THE IONIZATION CONSTANT OF HX ?

9. IF A WEAK ACID, HX, IS 5.881 % IONIZED IN 1.915 M SOLUTION, AT WHAT CONCENTRATION IS THE ACID 6.581 % IONIZED?

10. A 6.166 M SOLUTION OF A WEAK ACID, HX, HAS A pH OF 6.100 . WHAT IS THE IONIZATION CONSTANT OF THE ACID ?

Problem Set 20

1. A BUFFER SOLUTION IS MADE UP BY ADDING 0.922 MOLES OF THE SODIUM SALT TO 0.242 LITERS OF A 0.201 M SOLUTION OF HAc WHOSE IONIZATION CONSTANT IS 1.800E-05. WHAT IS THE pH OF THIS SOLUTION?

2. A SOLUTION PREPARED FROM 0.707 MOLE OF A WEAK ACID, HX, AND 0.018 MOLE OF NaX DILUTED TO 196 ML HAS A pH OF 5.345. WHAT IS THE IONIZATION CONSTANT OF HX ?

3. IF A WEAK ACID, HX, IS 5.681 % IONIZED IN 3.395 M SOLUTION, AT WHAT CONCENTRATION IS THE ACID 36.481 % IONIZED?

4. HOW MANY MOLES OF HNO_2 MUST BE USED TO PREPARE 0.58 L OF SOLUTION THAT HAS A pH OF 5.215 ? THE IONIZATION CONSTANT OF HNO_2 IS 4.50E-04 .

5. HOW MANY MOLES OF THE SODIUM SALT SHOULD BE ADDED TO 398 ML OF 0.703 M HNO_2 TO PREPARE A BUFFER WITH A pH OF 6.585 ? ASSUME THAT NO VOLUME CHANGE OCCURS WHEN THE SODIUM SALT IS ADDED TO THE SOLUTION. THE IONIZATION CONSTANT OF HNO_2 IS 4.50E-04 .

6. A 2.254 M SOLUTION OF A WEAK ACID, HX, HAS A pH OF 4.500 . WHAT IS THE IONIZATION CONSTANT OF THE ACID ?

7. CALCULATE THE pH OF 0.224 M NH3 WHOSE IONIZATION CONSTANT IS 1.8E-5.

8. A SOLUTION PREPARED FROM 0.794 MOLE OF A WEAK ACID, HX, DILUTED TO 296 ML HAS A pH OF 3.505 . WHAT IS THE pH OF THE SOLUTION AFTER 0.708 MOLE OF SOLID NaX IS DISSOLVED IN IT? ASSUME THAT NO SIGNIFICANT VOLUME CHANGE OCCURS WHEN THE NaX IS DISSOLVED IN THE SOLUTION.

9. WHAT IS THE CONCENTRATION OF HF IN A SOLUTION PREPARED BY ADDING 3 ML OF 2.035 M OF THE SODIUM SALT TO 193 ML OF 2.260 M HCL ? ASSUME THAT THE TOTAL VOLUME OF THE SOLUTION IS 196 ML. THE IONIZATION CONSTANT OF HF IS 7.00E-04

10. Formic acid IS 3.02E-02 % IONIZED IN 4.374 M SOLUTION. WHAT IS THE IONIZATION CONSTANT FOR THIS ACID?

The CM Project

The Computer-enriched Module (CM) project is a collaborative effort by 19 faculty members in the disciplines of chemistry, mathematics and physics, to produce self-instructional computer-based materials at the introductory college level in those disciplines. Each module is designed to be usable in an academic environment with minimal computational facilities, and by students and faculty who are not programming experts. It may be used as an adjunct to standard textual materials, or in many cases, as a replacement for them. The primary aim of each module is to use the computer in such a way that students may take a more active role in the development and discovery of concepts and phenomena.

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TEACHER'S GUIDE TO

A MODULE ON CHEMICAL EQUILIBRIUM

UNIT 4 EQUILIBRIA IN ACID-BASE SYSTEMS

FRANK A. SETTLE JR.

VIRGINIA MILITARY INSTITUTE

a computer-enriched module

for introductory chemistry

featuring the programs

ACID

BUFFER

Supported by grants from the
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TEACHER'S GUIDE TO UNIT ON EQUILIBRIA IN ACID-BASE SYSTEMS OF THE CHEMICAL EQUILIBRIUM MODULE

EDUCATIONAL OBJECTIVES

The primary educational objective is to enable the student to apply equilibrium concepts to chemical systems involving weak acids and bases. The student should be able to discover the relationships between initial concentration of weak acid or base, the magnitude of equilibrium constant for ionization, the pH and the percentage dissociation. These equilibrium concepts will be used to understand two additional systems involving weak acids and bases, hydrolysis of salts and buffer solutions.

The approach taken in this unit is to treat weak acid-base reactions as further examples of equilibrium systems. To emphasize this point, subscripts have been omitted from equilibrium constants. Table 1 of the student manual summarizes the types of equilibrium constants involved in this unit. The student uses ACID program to examine several weak acid-base systems observing the effect of magnitude of equilibrium constant and initial reactant concentration on the values of pH and percentage dissociation. The validity of a simplifying approximation is determined by comparing answers obtained from exact quadratic equations with those obtained by the approximation:

$$K = \frac{X^2}{C - X} \approx \frac{X^2}{C}$$

where

K = equilibrium constant

C = initial weak acid (or base) concentration

X = equilibrium H_3O^+ (or BH^+) concentration

An optional extention of this simple approximation is the use of a program which employs the method of successive approximations. An example of such an iterative program is found in reference [1] on page 176.

Polyprotic acid-base equilibria are not discussed in this unit. Many programs and problems involving student generated programs exist. Reference [2] page 176 contains examples of such programs and problems.

Hydrolysis of salts is presented as an example of another aqueous equilibrium system. The equilibrium constant for this reaction is derived from K_w and appropriate dissociation constants for the weak acid or base involved.

Finally, buffer action is examined using the BUFFER program to compare the behavior of buffered and unbuffered solutions towards the addition of strong acids or bases. These buffer and/or hydrolysis sections might well be made optional if time is a critical factor.

No attempt has been made to deal with the general features of titration curves of weak acids with a strong base or weak bases with strong acids. A number of interesting BASIC programs for these titrations exist in references [1] page 196 and [2] page 185. A logical extension to this module would be the use of such programs to simulate titration curves.

IMPLEMENTATION

It is desirable that the student be familiar with the concepts of unit 3 ("Equilibrium Calculations") of this module before attempting this unit. It may also be necessary for the student to read the unit on "pH, Strong Acids and Bases" or its equivalent chapter in a textbook.

ANSWERS TO PROBLEMS

1. Since the value of K is small x would be expected to be small.

2. | | |
   |---|---|
   | $[H_3O^+]$ | decrease |
   | pH | increase |
   | % dissociation | increase |

3. See computer printout from ACID

4. See computer printout from ACID

5. Should give same trends as HF

6. See computer printout from ACID

	H_2O + HNO_2	$\rightleftharpoons$ H_3O^+	+ NO_2^-
initial # moles from data	0.1 moles	0	0
changes in moles at equilibrium	(0.1-x) moles	X moles	X moles
equilibrium concentration	0.1 moles/l	X moles/l	X moles/l

$$K = \frac{X \cdot X}{0.1 - X} = 4.6 \times 10^{-4}$$

$$X^2 + (4.6 \times 10^{-4})X - (4.6 \times 10^{-5}) = 0$$

7. $[H_3O^+]$ decreases in both cases
pH increases
% dissociation increases

8. HF has larger value of $[H_3O^+]$
HNO_2 has larger pH value
HF is more highly dissociated
HF is stronger acid - more H_3O^+ from the same initial acid concentration than HNO_2

9. yes

10. See computer printout from ACID

11. 2.00

12. 5.96×10^{-6}

13. 1.07×10^{-2} moles/liter

14. 2.11×10^{-4}

15. 1.80×10^{-5}

16. 3.8%

17. $H_2O + NH_3 \rightleftharpoons NH_4^+ + OH^-$

	H_2O + NH_3	NH_4^+	OH^-
initial number of moles from data	0.1 mole	0	0
change in moles	-X	+X	+X
moles at equilibrium	(0.1-X) moles	X moles	X moles
equilibrium concentration	$\frac{(0.1-X)\text{ moles}}{0.5\ l}$	$\frac{X\text{ moles}}{0.5\ l}$	$\frac{X\text{ moles}}{0.5\ l}$

$$K = \frac{\frac{X}{0.5} \cdot \frac{X}{0.5}}{\frac{0.1 - X}{0.5}} = \frac{\frac{X^2}{0.5}}{0.1 - X} = 1.8 \times 10^{-5}$$

quadratic expression

$$X^2 + (9.0 \times 10^{-7})X + (9.0 \times 10^{-6}) = 0$$

18.

$[OH^-]$	decreases
pH	decreases
pOH	increases
% dissociation	increases

For methyl amine, $CH_3\text{-}NH_2$ and NH_3

$[OH^-]$	$NH_3 > CH_3\text{-}NH_2$
pH	$CH_3\text{-}NH_2 > NH_3$
pOH	$NH_3 > CH_3\text{-}NH_2$
% dissociation	$NH_3 > CH_3\text{-}NH_2$

The larger the value of K the stronger the acid or base

$$CH_3\text{-}NH_2 < HO\text{-}NH_2 < NH_3 < C_6H_5\text{-}NH_2$$

19. $B + H_2O \rightleftharpoons BH^+ + OH^-$

$$K = \frac{[BH^+][OH^-]}{[B]}$$

let $x = [OH^-] = [BH^+]$

$$K = \frac{x \cdot x}{[B]_{initial} - x} = \frac{x^2}{[B]_{initial}}$$

$$x^2 = K[B_{initial}]$$

22. 11.7

23. 1.8×10^{-5}

24. 2.0×10^{-6}

25. 0.12 mole/l

26. (A) pH = 7 (B) pH > 7 (C) pH < 7

27. a. pH ≈ 7 b. pH > 7 cannot say exactly
c. pH = 7 d. pH < 7 e. pH > 7

28. $$K = \frac{[HF][OH^-]}{[F^-]} = \frac{[HF]}{[F^-][H_3O^+]} \cdot \frac{[H_3O^+][OH^-]}{1} = K_1 \cdot K_W$$

$$K_1 \cdot K_W = \frac{[HF][OH^-]}{[F^-]}$$

29. $$K_1 = \frac{[HF][OH^-]}{[F^-]} \qquad K_2 = \frac{[F^-]}{[HF][OH^-]} \qquad K_1 = \frac{1}{K_2}$$

30. $$HF + H_2O \rightleftharpoons F^- + H_3O^+ \qquad K' = 6.7 \times 10^{-4}$$
$$F^- + H_2O \rightleftharpoons HF + OH^-$$
$$K = \frac{1 \times 10^{-14}}{K'} = \frac{1 \times 10^{-14}}{6.7 \times 10^{-4}} = 1.5 \times 10^{-11}$$

31. a. $$NH_4^+ + H_2O \rightleftharpoons NH_3 + H_3O^+$$
$$K = \frac{[NH_3][H_3O^+]}{[NH_4^+]} = \frac{K_W}{K_1}$$
where
$$K_1 = \frac{[NH_4^+][OH^-]}{[NH_3]}$$
$$K_W = [H_3O^+][OH^-] = 1.0 \times 10^{-14}$$
$$K = \frac{1.0 \times 10^{-14}}{1.8 \times 10^{-5}} = 5.5 \times 10^{-10}$$

b. let x = number moles NH_3 formed

$$H_2O + NH_4^+ \rightleftharpoons NH_3 + H_3O^+$$

initial no. moles	0.2 moles	0	0
change in moles	-x moles	+x moles	+x moles
no. moles at equilibrium	(0.2-x) moles	x moles	x moles
equilibrium concentration	$\frac{0.2-x}{1}\ \frac{\text{moles}}{1}$	$x\ \frac{\text{moles}}{1}$	$x\ \frac{\text{moles}}{1}$

c. $K = 5.6 \times 10^{-10} = \frac{x^2}{0.2 - x} = \frac{x^2}{0.2}$

d. $x^2 = 1.12 \times 10^{-10}$

$x = 1.06 \times 10^{-5}$ = moles NH_3 = moles OH^-

$[OH^-] = \frac{1.06 \times 10^{-5}}{1.0 \text{ liter}} = 1.06 \times 10^{-5}$ mole/l $= [NH_3]$

$[H_3O^+] = \frac{1.0 \times 10^{-14}}{1.06 \times 10^{-5}} = 9.4 \times 10^{-10}$ mole/l

pH $= -\log(9.4 \times 10^{-10}) = (-0.97 - 10)$

pH = 9.03

e. pH > 7 solution is basic thus confirming our prediction.

32. $2.1 \times 10^{-4} = \frac{X \cdot X}{0.1 - X} = \frac{X^2}{0.1}$

$X^2 = 2.1 \times 10^{-5} = 21. \times 10^{-6}$

$X = 4.6 \times 10^{-3}$

pH $= -(0.66 - 3) = 2.34$

Addition of $HCOO^-$ to the system

$$HCOOH + H_2O \rightleftharpoons HCOO^- + H_3O^+$$

will cause concentrations of reactant HCOOH to increase and concentration product H_3O^+ to decrease. Thus the pH of the solution will <u>increase</u>.

34. let X = moles of H_3O^+ in solution after addition of acid. When 0.01 mole H_3O^+ is added to the buffer solution it will react with

0.01 mole $HCOO^-$ to form 0.01 additional mole of HCOOH. Thus the scorecard would appear as follows:

$$H_2O + HCOOH \rightleftharpoons H_3O^+ + HCOO^-$$

	HCOOH	H_3O^+	$HCOO^-$
initial moles	0.10 moles	0.01 moles	0.20 moles
change in moles	+0.01 moles	-0.01 moles	-0.01 moles
no. moles at equilibrium	0.11 moles	X	0.19 moles
equilibrium concentrations	0.11 $\frac{\text{moles}}{1}$	X	0.19 $\frac{\text{moles}}{1}$

$$K = 2.1 \times 10^{-4} = \frac{(X)(0.19)}{0.11}$$

$$X = 2.1 \times 10^{-4}\left(\frac{0.11}{0.19}\right)$$

$$X = 1.2 \times 10^{-4}$$

$$pH = 3.91$$

35. let X = moles of H_3O^+ in solution after addition of base. When 0.01 mole OH^- is added to the buffer solution it will react with 0.01 moles of HCOOH to form an additional 0.01 mole of $HCOO^-$. Thus the scorecard:

$$H_2O + HCOOH \rightleftharpoons H_3O^+ + HCOO^-$$

	HCOOH	H_3O^+	$HCOO^-$
initial moles	0.10 moles	2.1×10^{-4}	0.20 moles
change in moles	-0.01 moles		+0.01 moles
no. moles at equilibrium	0.09 moles	X	0.21 moles
equilibrium concentrations	0.09 $\frac{\text{moles}}{1}$	$\frac{X}{1}$	0.21 $\frac{\text{moles}}{1}$

$$K = 2.1 \times 10^{-4} = \frac{(X)(0.21)}{(0.09)}$$

$$X = 9.0 \times 10^{-5}$$

$$pH = 4.04$$

36. (a) acid: $H_3O^+ + CH_3COO^- \longrightarrow H_2O + CH_3COOH$

base: $OH^- + CH_3COOH \longrightarrow CH_3COO^- + H_2O$

(b) acid: $H_3O^+ + NH_3 \longrightarrow NH_4^+ + H_2O$

base: $OH^- + NH_4^+ \longrightarrow NH_3 + H_2O$

37. (A) K_a of weak acid

(B) concentration of weak acid

(C) concentration of weak base

38. 4.44

39. 2.82

40. 9.56

41. 0.90 mole/l

42. $K = \frac{[H^+][A^-]}{[HA]} = [H^+]$

taking negative logarithm of both sides

$-\log K = -\log[H^+]$

$pK = pH$

43. (A) (i) decrease $[A^-]$

(ii) increase slightly

(iii) decrease slightly

(iv) decrease markedly

(B) (i) increase $[A^-]$

(ii) decrease slightly

(iii) increase slightly

(iv) increase markedly

(C) when moles of added H_3O^+ = moles of salt in solution buffer capacity exceeded.

ANSWERS TO PROBLEM SETS

TEST 1	TEST 2	TEST 3	TEST 4
1. 3.60E-01	1. 2.64E+02	1. 1.18E+01	1. 4.58E+00
2. 2.22E-03	2. 1.07E+00	2. 4.98E+00	2. 2.66E-07
3. 5.60E-08	3. 1.63E+00	3. 5.83E-01	3. 4.23E-04
4. 4.87E-12	4. 1.72E-01 M	4. 6.73E-05	4. 4.57E-04
5. 2.15E-06	5. 1.31E-05	5. 1.28E-12	5. 1.78E-01 M
6. 4.62E+00	6. 4.80E-11	6. 2.28E-05	6. 1.08E-02
7. 1.50E+01	7. 4.30E-13	7. 8.42E-09	7. 1.35E-14
8. 1.51E+00	8. 4.99E+00	8. 2.76E+00	8. 4.56E+00
9. 1.34E+01	9. 4.52E+00	9. 1.17E+01	9. 1.03E+01
10. 4.38E-01	10. 2.70E+02	10. 2.38E-03	10. 3.84E-01

	TEST 5	TEST 6	TEST 7	TEST 8
1.	1.35E-01	3.82E+00	5.58E-07	1.22E+00
2.	3.96E-03	1.13E+01	5.92E-02	1.32E-03
3.	6.17E+00	1.72E-01	3.92E-05	1.08E-03
4.	1.18E+01	5.42E-02	1.65E+00 M	3.84E-10
5.	1.80E-05	8.75E-13	1.17E+01	1.16E+01
6.	8.73E-08	5.97E-01 M	9.50E-15	1.48E+01 M
7.	8.87E-01	1.34E-02	4.36E+00	4.22E-04
8.	1.01E-05	1.58E+00	4.26E-02	1.09E+01
9.	4.73E+00	2.27E-08	3.06E+00	4.94E-06
10.	3.88E+00	4.79E-04	1.00E+00	9.42E+00

TEST 9	TEST 10	TEST 11	TEST 12
1. 3.50E-01 M	1. 6.79E-01	1. 3.75E+00	1. 1.16E+01
2. 4.39E-01	2. 2.62E-11	2. 1.17E+01	2. 5.72E-07
3. 1.28E+01	3. 2.51E-06	3. 8.24E-08	3. 4.50E-04
4. 5.32E-06	4. 9.48E+00	4. 9.92E+00	4. 3.56E+00
5. 3.26E+00	5. 6.02E-05	5. 1.91E-02	5. 8.76E-04
6. 1.17E+01	6. 1.17E+01	6. 2.42E+00 M	6. 1.23E-10
7. 2.35E-07	7. 5.32E+00	7. 4.52E-01	7. 1.48E-03
8. 8.36E-01	8. 5.68E-01	8. 4.74E-08	8. 3.54E-02 M
9. 4.00E-03	9. 8.57E+00	9. 2.64E+02	9. 1.12E+00
10. 3.14E-04	10. 5.60E-08	10. 1.80E-08	10. 1.16E+01

	TEST 13	TEST 14	TEST 15	TEST 16
1.	3.90E-02	1.51E-04	4.83E+[illegible]	1.19E+01
2.	2.37E+00	7.06E-05	3.91E-05	2.29E+00
3.	1.15E-03	1.07E+01	4.66E-02	6.81E+01
4.	1.56E-06	1.15E-12	2.50E+00	6.16E+00
5.	1.14E+01	1.17E+01	2.77E-02 M	4.92E-02
6.	1.44E+01	1.65E-01 M	6.32E-02	1.39E-02
7.	7.36E-01	1.97E-04	3.86E-05	1.35E+01
8.	1.64E-05	3.14E-03	1.43E-06	4.99E+00
9.	9.93E+00	1.09E+01	3.30E+00	1.64E-04
10.	2.88E+01	1.66E-05	1.11E+01	6.94E-09

	TEST 17	TEST 18	TEST 19	TEST 20
1.	4.81E+00	2.55E-01	1.15E+01	6.02E+00
2.	6.87E-04	1.85E-06	4.21E-02	1.14E-07
3.	3.17E+00	3.51E-14	1.83E+00	5.54E-02 M
4.	1.19E+01	3.20E-07	9.33E+00	4.81E-08
5.	2.05E+00	4.87E+00	4.67E-01	4.84E+02
6.	2.83E+00	9.89E-01 M	4.00E-10	4.44E-10
7.	1.71E+01	9.29E+00	1.33E+01	1.13E+01
8.	3.23E-02	4.00E-10	1.24E-05	7.39E+00
9.	9.56E-08	3.76E+00	1.52E+00 M	3.11E-02
10.	4.21E-01	5.99E+00	1.02E-13	2.10E-04

SOFTWARE

Program Descriptions

ACID

This is an interactive program which deals with the systems

$$HA + H_2O \rightleftharpoons H_3O^+ + A^-$$

$$B + H_2O \rightleftharpoons BH^+ + OH^-$$

where HA is a weak acid and B is a weak base.

The student chooses the system, acid or base, and enters the appropriate equilibrium constant, initial number of moles of acid or base, and the volume of the solution. The program calculates initial and equilibrium concentrations of reactant and product species, the pH of the equilibrium solution and the percentage dissociation of original acid or base. These calculations employ the quadratic formula to obtain exact solutions. After the student obtains answers from his initial input data he may (1) enter another initial concentration (2) change to a different acid (or base) reaction or (3) terminate the program. These choices are available to him after each set of calculations.

BUFFER

This is an interactive simulation program to allow the student to make up given volume of weak acid/salt buffer solution. The behavior of this solution is compared with an equal volume of a pure water solution upon the addition of small amount of strong acid or base. The student may adjust the initial pH of the buffer by adding weak acid or salt. He then chooses whether to add strong acid or strong base. Next he adds the reagent he has chosen dropwise to both solutions and observes the results. He may add as many increments of reagent as he desires. It is recommended that initially the student add increments of 1 or 2 drops in order to best maximize pH difference in buffered and water solutions. If the buffer capacity whould be exceeded, the program prints "BUFFER CAPACITY EXCEEDED" and terminates.

REFERENCES

Computer programming references for an instructor or his motivated students interested in writing their own programs to accompany these units are given below:

[1] "BASIC and Chemistry", L. Soltzberg, A. A. Shah, J. C. Saber, and E. T. Canty (Houghton Mifflin, Boston, 1975).

[2] "Introduction to Computer Programming for Chemists - BASIC Version", C. L. Wilkins, C. E. Klopfenstein, T. L. Isenhour, P. C. Jurs (Allyn and Bacon, Boston, 1974).

Sample run of ACID

```
ENTER THE TYPE OF EQUILIBRIUM YOU WISH TO STUDY.
'ACID' FOR WEAK ACID OR 'BASE' FOR WEAK BASE.?BASE

ENTER THE FORMULA OF YOUR BASE.
?NH3

ENTER THE VALUE OF THE EQUILIBRIUM CONSTANT?1.8E-05

ENTER THE # OF MOLES OF NH3 ORIGINALLY IN THE SOLUTION
?0.1
NTER THE VOLUME OF THE SOLUTION IN LITERS?1

INITIAL CONC BASE =  .1              MOLES/LITER
EQUIL   CONC BASE =  9.86673E-02     MOLES/LITER
OH-     CONC      =  1.33267E-03     MOLES/LITER
BH+     CONC      =  1.33267E-03     MOLES/LITER
PH =  11.1247           % DISSOCIATION =  1.33267

WOULD YOU LIKE TO CHOOSE ANOTHER CONC OF NH3?
ANSWER YES OR NO?YES
ENTER THE # OF MOLES OF NH3 ORIGINALLY IN THE SOLUTION
?1
ENTER THE VOLUME OF THE SOLUTION IN LITERS?100

INITIAL CONC BASE =  .01             MOLES/LITER
EQUIL   CONC BASE =  9.58464E-03     MOLES/LITER
OH-     CONC      =  4.15360E-04     MOLES/LITER
BH+     CONC      =  4.15360E-04     MOLES/LITER
PH =  10.6184           % DISSOCIATION =  4.15359

WOULD YOU LIKE TO CHOOSE ANOTHER CONC OF NH3?
ANSWER YES OR NO?YES
ENTER THE # OF MOLES OF NH3 ORIGINALLY IN THE SOLUTION
?.5
NTER THE VOLUME OF THE SOLUTION IN LITERS?10

INITIAL CONC BASE =  .05             MOLES/LITER
EQUIL   CONC BASE =  4.90603E-02     MOLES/LITER
OH-     CONC      =  9.39726E-04     MOLES/LITER
BH+     CONC      =  9.39726E-04     MOLES/LITER
PH =  10.973            % DISSOCIATION =  1.87945

WOULD YOU LIKE TO CHOOSE ANOTHER CONC OF NH3?
ANSWER YES OR NO?NO

     NH3     K =  .000018

INITIAL                      EQUILIBRIUM
  [HA]         [HA]          [H3O+]       [A-]       PH        DISSOCIATION
  .1000        .0987         .0013        .0013      11.1247     1.3327
  .0100        .0096         .0004        .0004      10.6184     4.1536
  .0500        .0491         .0009        .0009      10.9730     1.8795
```

```
WOULD YOU LIKE TO TRY A DIFFERENT ACID OR BASE?  YES OR NO ?YES
'ACID' FOR WEAK ACID OR 'BASE' FOR WEAK BASE.?ACID

ENTER THE FORMULA OF YOUR ACID.
?HF

ENTER THE VALUE OF THE EQUILIBRIUM CONSTANT?6.7E-04

ENTER THE # OF MOLES OF HF ORIGINALLY IN THE SOLUTION
?.3
NTER THE VOLUME OF THE SOLUTION IN LITERS?5

INITIAL CONC ACID =  .06           MOLES/LITER
EQUIL   CONC ACID =  5.39858E-02   MOLES/LITER
H3O+    CONC      =  6.01419E-03   MOLES/LITER
A-      CONC      =  6.01419E-03   MOLES/LITER
PH =  2.22083           % DISSOCIATION =  10.0237

WOULD YOU LIKE TO CHOOSE ANOTHER CONC OF HF?
ANSWER YES OR NO?YES
NTER THE # OF MOLES OF HF ORIGINALLY IN THE SOLUTION
?.03
NTER THE VOLUME OF THE SOLUTION IN LITERS?2

INITIAL CONC ACID =  .015          MOLES/LITER
EQUIL   CONC ACID =  1.21472E-02   MOLES/LITER
H3O+    CONC      =  2.85282E-03   MOLES/LITER
A-      CONC      =  2.85282E-03   MOLES/LITER
PH =  2.54473           % DISSOCIATION =  19.0188

WOULD YOU LIKE TO CHOOSE ANOTHER CONC OF HF?
ANSWER YES OR NO?NO

     HF      K =   .00067

INITIAL                     EQUILIBRIUM
  [HA]          [HA]        [H3O+]        [A-]        PH        DISSOCIATION
  .0600         .0540       .0060         .0060       2.2208     10.0237
  .0150         .0121       .0029         .0029       2.5447     19.0188

WOULD YOU LIKE TO TRY A DIFFERENT ACID OR BASE?  YES OR NO ?YES
ACID' FOR WEAK ACID OR 'BASE' FOR WEAK BASE.?ACID

ENTER THE FORMULA OF YOUR ACID.
?HCN

ENTER THE VALUE OF THE EQUILIBRIUM CONSTANT?8E-07

ENTER THE # OF MOLES OF HCN ORIGINALLY IN THE SOLUTION
?.001
ENTER THE VOLUME OF THE SOLUTION IN LITERS?10
```

```
INITIAL CONC ACID =   .0001          MOLES LITER
EQUIL   CONC ACID =   9.14468E-05      MOLES/LITER
H3O+    CONC      =   8.55321E-06      MOLES/LITER
A-      CONC      =   8.55321E-06      MOLES/LITER
PH =  5.06788             % DISSOCIATION =  8.55321

WOULD YOU LIKE TO CHOOSE ANOTHER CONC OF HCN?
ANSWER YES OR NO?YES
ENTER THE # OF MOLES OF HCN ORIGINALLY IN THE SOLUTION
?.0001
NTER THE VOLUME OF THE SOLUTION IN LITERS?10

INITIAL CONC ACID =   .00001         MOLES/LITER
EQUIL   CONC ACID =   7.54343E-06      MOLES/LITER
H3O+    CONC      =   2.45657E-06      MOLES/LITER
A-      CONC      =   2.45657E-06      MOLES/LITER
PH =  5.60968             % DISSOCIATION =  24.5657

WOULD YOU LIKE TO CHOOSE ANOTHER CONC OF HCN?
ANSWER YES OR NO?NO

     HCN       K =  8.00000E-07


INITIAL                      EQUILIBRIUM
   [HA]          [HA]          [H3O+]       [A-]        PH        DISSOCIATION
   .0001         .0001         .0000        .0000       5.0679      8.5532
   .0000         .0000         .0000        .0000       5.6097     24.5657

WOULD YOU LIKE TO TRY A DIFFERENT ACID OR BASE?  YES OR NO ?NO
```

Sample run of BUFFER

```
 ENTER FØRMULA ØF THE WEAK ACID BUFFER COMPØNENT
?CH3CØØH

 ENTER FØRMULA ØF THE SALT BUFFER CØMPØNENT
?CH3CØØNA

 ENTER THE EQUILIBRIUM CØNSTANT FØR WEAK ACID
?1.8E-05

 ENTER THE CØNCENTRATIØN ØFWEAK ACID (MØLES/LITER)
?.1

 CØNCENTRATIØN ØF SALT (MØLES/LITER) ?
?.15

THE PH ØF THE BUFFER IS  4.92083

 DØ YØU WISH TØ ADJUST THE PH ØF THE BUFFER ?
 ANSWER YES ØR NØ
?YES
 ENTER THE CØNCENTRATIØN ØF WEAK ACID (MØLES/LITER)
?.13

 CØNCENTRATIØN ØF SALT (MØLES/LITER) ?
?.15

THE PH ØF THE BUFFER IS  4.80689

 DØ YØU WISH TØ ADJUST THE PH ØF THE BUFFER ?
 ANSWER YES ØR NØ
?NØ

 ENTER TØTAL VØLUME ØF BUFFER IN MILLITERS
?250
 ADDING STRØNG ACID ØR STRØNG BASE TØ BUFFER ?
 ANSWER ACID ØR BASE
?BASE
 ENTER CØNCENTRATIØN ØF STRØNG BASE (MØLES/LITER)
?.1

 WE WILL NØW ADD THE SAME # ØF DRØPS ØF STRØNG BASE TØ
 250    ML ØF BUFFER SØLUTIØN AND  250    ML PURE WATER
 EACH DRØP IS CØNSIDERED TØ HAVE A VØLUME ØF 0.05 ML

 DRØPS ØF BASE
?1
 TØTAL ML STRØNG BASE ADDED  .05
 PH ØF WATER  9.30096
```

```
 PH ØF BUFFER  4.80701
 FINISHED ?
?NØ
 DRØPS ØF BASE
?1
 TØTAL ML STRØNG BASE ADDED  .1
 PH ØF WATER  9.60191
 PH ØF BUFFER  4.80714
 FINISHED ?
?NØ
 DRØPS ØF BASE
?5
 TØTAL ML STRØNG BASE ADDED  .35
 PH ØF WATER  10.1455
 PH ØF BUFFER  4.80776
 FINISHED ?
?NØ
 DRØPS ØF BASE
?20
 TØTAL ML STRØNG BASE ADDED  1.35
 PH ØF WATER  10.7301
 PH ØF BUFFER  4.81026
 FINISHED ?
?NØ
 DRØPS ØF BASE
?100
 TØTAL ML STRØNG BASE ADDED  6.35
 PH ØF WATER  11.394
 PH ØF BUFFER  4.82275
 FINISHED ?
?NØ
 DRØPS ØF BASE
?100
 TØTAL ML STRØNG BASE ADDED  11.35
 PH ØF WATER  11.6378
 PH ØF BUFFER  4.83527
 FINISHED ?
?NØ
 DRØPS ØF BASE
?500
 TØTAL ML STRØNG BASE ADDED  36.35
 PH ØF WATER  12.1036
 PH ØF BUFFER  4.89858
 FINISHED ?
?NØ
 DRØPS ØF BASE
?1000
 TØTAL ML STRØNG BASE ADDED  86.35
 PH ØF WATER  12.4095
 PH ØF BUFFER  5.03101
 FINISHED ?
?NØ
```

```
DRØPS ØF BASE
?4000
 TØTAL ML STRØNG BASE ADDED  286.35
 PH ØF WATER  12.7275
 PH ØF BUFFER  5.97802
 FINISHED ?
?NØ
 DRØPS ØF BASE
?4000
 BUFFER CAPACITY EXCEEDED !


 BUFFER SYSTEM CH3CØØH/CH3CØØNA
 ØRIGINAL BUFFER PH = 4.80689

DRØPS ØF BASE       PH WATER    PH BUFFER
 1                  9.30096      4.80701
 2                  9.60191      4.80714
 7                  10.1455      4.80776
 27                 10.7301      4.81026
 127                11.394       4.82275
 227                11.6378      4.83527
 727                12.1036      4.89858
 1727               12.4095      5.03101
 5727               12.7275      5.97802
```

ACID Program

```
100 REM ****************** P R O G R A M ******************************
110 REM STRING VARIABLES: LINES 160, 240, 300, 310, 370, 570,
120 REM 580, 590, 600, 730, 810, 820, 830, 950, 990, 1110.
130 REM PRINT USING/IMAGE PAIR AT LINES 1040,1050
140 REM ***************************************************************
150 REM
160 DIM A$[4],F$[20],Y$[1]
170 DIM C0[10],C1[10],I0[10],P4[10],D[10]
180 PRINT " CBACID  ACID-BASE EQUILIBRIUM DEMONSTRATION ";
190 PRINT "PROGRAM"
200 PRINT
210 PRINT "ENTER THE TYPE OF EQUILIBRIUM YOU WISH TO STUDY."
220 PRINT "'ACID' FOR WEAK ACID OR 'BASE' FOR WEAK BASE.";
230 INPUT A$
240 IF A$="ACID" OR A$="BASE" THEN 300
250 PRINT "PLEASE ENTER 'ACID' OR 'BASE' ";
260 GOTO 230
270 REM
280 REM@>@>INPUT OF PARAMETERS.
290 REM
300 PRINT LIN(2);"ENTER THE FORMULA OF YOUR ";A$[1;4];"."
310 INPUT F$
320 PRINT LIN(1);"ENTER THE VALUE OF THE EQUILIBRIUM CONSTANT";
330 INPUT K
340 PRINT
350 LET I=0
360 LET I=I+1
370 PRINT "ENTER THE # OF MOLES OF ";F$;" ORIGINALLY IN ";
380 PRINT "THE SOLUTION"
390 INPUT M
400 PRINT "ENTER THE VOLUME OF THE SOLUTION IN LITERS";
410 INPUT V
420 LET C0[I]=M/V
430 REM
440 REM@>@>QUADRATIC ROOTS DERIVED.
450 REM    FORMERLY SUBROUTINE IN ORIGINAL.
460 REM
470 FOR Z9=1 TO 1
480   LET A=1
```

```
490   LET B=K
500   LET C=-B*C0[I]
510   LET R0=B**2-4*A*C
520   IF R0<0 THEN 1260
530   LET R1=(-B+SQR(R0))/(2*A)
540   LET R2=(-B-SQR(R0))/(2*A)
550   IF (R1<0 OR (C0[I]-R1)<0) THEN 620
560   LET R=R1
570   IF (R<.000001 AND A$="ACID") THEN 1160
580   IF (R<.000001 AND A$="BASE") THEN 1180
590   IF (R>1 AND A$="ACID") THEN 1200
600   IF (R>1 AND A$="BASE") THEN 1230
610   GOTO 680
620   LET R=R2
630   IF R<.000001 THEN 570
640   REM
650   REM@>@>CALCULATION OF OUTPUT VALUES.
660   REM
670   FOR Z8=1 TO 1
680     C0[I]=M/V
690     C1[I]=C0[I]-R
700     I0[I]=R
710     P4[I]=(LOG(1/R))/2.30258
720     D[I]=(R/C0[I])*100
730     IF A$="ACID" THEN 800
740     LET P4[I]=14-P4[I]
750   NEXT Z8
760 NEXT Z9
770 REM
780 REM@>@>INDIVIDUAL DISPLAY.
790 REM
800 PRINT
810 PRINT "INITIAL CONC ";A$;" = ";C0[I];" MOLES/LITER"
820 PRINT "EQUIL   CONC ";A$;" = ";C1[I];" MOLES/LITER"
830 IF A$="BASE" THEN 870
840 PRINT "H3O+    CONC      = ";I0[I];" MOLES/LITER"
850 PRINT "A-      CONC      = ";I0[I];" MOLES/LITER"
860 GOTO 890
870 PRINT "OH-     CONC      = ";I0[I];" MOLES/LITER"
880 PRINT "BH+     CONC      = ";I0[I];" MOLES/LITER"
890 PRINT "PH = ";P4[I];"      % DISSOCIATION = ";D[I]
900 IF I=10 THEN 990
```

```
910 PRINT
920 PRINT "WOULD YOU LIKE TO CHOOSE ANOTHER CONC OF ";F$;"?"
930 PRINT "ANSWER YES OR NO";
940 INPUT Y$
950 IF Y$="Y" THEN 360
960 REM
970 REM@>@>TABULAR DISPLAY.
980 REM
990 PRINT LIN(1),TAB(5);F$;"      K = ";K
1000 PRINT LIN(2),"INITIAL                          EQUILIBRIUM"
1010 PRINT "    [HA]          [HA]          [H3O+]         [A-]    ";
1020 PRINT "      PH         DISSOCIATION"
1030 FOR J=1 TO I
1040   PRINT USING 1050;C0[J],C1[J],I0[J],I0[J],P4[J],D[J]
1050   IMAGE 6(DDD.DDDD,XXXX)
1060 NEXT J
1070 PRINT
1080 PRINT "WOULD YOU LIKE TO TRY A DIFFERENT ACID OR BASE?";
1090 PRINT "  YES OR NO ";
1100 INPUT Y$
1110 IF Y$="Y" THEN 220
1120 STOP
1130 REM
1140 REM@>@>ERROR WARNING MESSAGES.
1150 REM
1160 PRINT "WARNING - - THE H3O+ CONC IS LESS THAN 1.0E-6"
1170 GOTO 300
1180 PRINT "WARNING - - THE OH-  CONC IS LESS THAN 1.0E-6"
1190 GOTO 300
1200 PRINT "WARNING - - THE H3O+ CONC IS GREATER THAN 1.0";
1210 PRINT " - - VERY ACIDIC SOLUTION!"
1220 GOTO 300
1230 PRINT "WARNING - - THE OH-  CONC IS GREATER THAN 1.0";
1240 PRINT " - - VERY BASIC SOLUTION!"
1250 GOTO 300
1260 PRINT "ROOTS ARE IMAGINARY."
1270 PRINT "THE DATA GIVEN IS NOT POSSIBLE - - TRY AGAIN."
1280 GOTO 300
1290 END
>
```

BUFFER Program

```
10 DIM D[20],P[20],Z[20]
20 DIM A$[20],S$[20],Q$[5]
30 PRINT
40 PRINT
50 PRINT " ENTER FØRMULA ØF THE WEAK ACID BUFFER CØMPØNENT "
60 INPUT A$
70 PRINT
80 PRINT " ENTER FØRMULA ØF THE SALT BUFFER CØMPØNENT "
90 INPUT S$
100 PRINT
110 PRINT " ENTER THE EQUILIBRIUM CØNSTANT FØR WEAK ACID "
120 INPUT K
130 PRINT
140 PRINT " ENTER THE CØNCENTRATIØN ØF WEAK ACID (MØLES/LITER)"
150 INPUT C1
160 PRINT
170 PRINT " CØNCENTRATIØN ØF SALT (MØLES/LITER) ? "
180 INPUT C2
190 PRINT
200 LET H=K*C1/C2
210 LET P1=(LØG(1/H))/2.30258
220 PRINT "THE PH ØF THE BUFFER IS ";P1
230 PRINT
240 PRINT " DØ YØU WISH TØ ADJUST THE PH ØF THE BUFFER ?"
250 PRINT " ANSWER YES ØR NØ "
260 INPUT Q$
270 IF Q$="YES" THEN 140
280 PRINT
290 PRINT " ENTER TØTAL VØLUME ØF BUFFER IN MILLITERS "
300 INPUT V1
310 PRINT " ADDING STRØNG ACID ØR STRØNG BASE TØ BUFFER ?"
320 PRINT " ANSWER ACID ØR BASE "
330 INPUT Q$
340 IF Q$="BASE" THEN 750
350 PRINT " ENTER CØNCENTRATIØN ØF STRØNG ACID (MØLES/LITER) "
360 INPUT C3
370 PRINT "WE WILL NØW ADD THE SAME # ØF DRØPS STRØNG ACID TØ "
380 PRINT V1;" ML BUFFER SØLUTIØN AND ";V1;" ML ØF PURE WATER "
390 PRINT "EACH DRØP IS CØNSIDERED TØ HAVE A VØLUME ØF 0.05 ML "
400 PRINT
410 LET I=0
420 LET D2=0
430 LET I=I+1
440 PRINT " DRØPS ØF ACID "
450 INPUT D1
460 LET D2=D1+D2
470 LET D[I]=D2
480 LET V4=D[I]/20
```

```
490 LET H1=(V4*C3)/(V1+V4)
500 IF V4*C3>V1*C2 THEN 720
510 LET H2=(C1*V1+C3*V4)*K/(C2*V1-C3*V4)
520 LET P[I]=(LØG(1/H1))/2.30258
530 LET Z[I]=(LØG(1/H2))/2.30258
540 PRINT " TØTAL ML STRØNG ACID ADDED ";V4
550 PRINT " PH ØF WATER = ";P[I]
560 PRINT " PH ØF BUFFER = ";Z[I]
570 PRINT " FINISHED ?"
580 INPUT Q$
590 IF Q$="YES" THEN 610
600 GØTØ 430
610 LET J=I
620 PRINT
630 PRINT
640 PRINT " BUFFER SYSTEM ";A$;"/";S$
650 PRINT " ØRIGINAL BUFFER PH = ";P1
660 PRINT
670 PRINT "  DRØPS ØF ACID    PH WATER    PH BUFFER      "
680 FØR I=1 TØ J
690   PRINT D[I],P[I],Z[I]
700 NEXT I
710 END
720 PRINT " BUFFER CAPACITY EXCEEDED !"
730 LET J=I-1
740 GØTØ 620
750 PRINT " ENTER CØNCENTRATIØN ØF STRØNG BASE (MØLES/LITER)"
760 INPUT C4
770 PRINT
780 PRINT " WE WILL NØW ADD THE SAME # ØF DRØPS ØF STRØNG BASE TØ "
790 PRINT V1;" ML ØF BUFFER SØLUTIØN AND ";V1;" ML PURE WATER "
800 PRINT " EACH DRØP IS CØNSIDERED TØ HAVE A VØLUME ØF 0.05 ML "
810 PRINT
820 LET I=0
830 LET D2=0
840 LET I=I+1
850 PRINT " DRØPS ØF BASE "
860 INPUT D1
870 LET D2=D1+D2
880 LET D[I]=D2
890 LET V5=D[I]/20
900 IF V5*C4>V1*C1 THEN 1030
910 LET H1=(V5*C4)/(V1+V5)
920 LET H2=(1E-14)/H1
930 LET H3=(C1*V1-C4*V5)*K/(C2*V1+C4*V5)
940 LET P[I]=(LØG(1/H2))/2.30258
950 LET Z[I]=(LØG(1/H3))/2.30258
960 PRINT " TØTAL ML STRØNG BASE ADDED ";V5
970 PRINT " PH ØF WATER ";P[I]
980 PRINT " PH ØF BUFFER ";Z[I]
990 PRINT " FINISHED ?"
1000 INPUT Q$
1010 IF Q$="YES" THEN 1060
1020 GØTØ 840
```

```
1030 PRINT " BUFFER CAPACITY EXCEEDED ! "
1040 LET J=I-1
1050 GØTØ 1070
1060 LET J=I
1070 PRINT
1080 PRINT
1090 PRINT " BUFFER SYSTEM ";A$;"/";S$
1100 PRINT " ØRIGINAL BUFFER PH = ";P1
1110 PRINT
1120 PRINT "DRØPS";3" ØF BASE    PH WATER   PH BUFFER  "
1130 FØR I=1 TØ J
1140   PRINT D[I],P[I],Z[I]
1150 NEXT I
1160 END
```

Unit Test on Acid-Base Equilibria time = 20 min.

TEST 1

1. WHAT IS THE DEGREE OF IONIZATION OF A 2.082 M SOLUTION OF Formic acid WHOSE IONIZATION CONSTANT IS 2.10E-04 ?

2. A BUFFER SOLUTION IS MADE UP BY ADDING 1.542 MOLES OF THE SODIUM SALT TO 0.802 LITERS OF A 0.876 M SOLUTION OF HCN WHOSE IONIZATION CONSTANT IS 4.000E-10. WHAT IS THE pH OF THIS SOLUTION?

3. A SOLUTION PREPARED FROM 0.815 MOLE OF A WEAK ACID, HX, AND 0.518 MOLE OF NaX DILUTED TO 204 ML HAS A pH OF 5.289. WHAT IS THE IONIZATION CONSTANT OF HX ?

4. A 4.300 M SOLUTION OF A WEAK ACID, HX, HAS A pH OF 3.850 . WHAT IS THE IONIZATION CONSTANT OF THE ACID ?

5. CALCULATE THE pH OF 1.794 M METHYLAMINE WHOSE IONIZATION CONSTANT IS 1.8E-5.

TEST 1

1. 2.08E-02

2. 9.74E+00

3. 3.27E-06

4. 4.64E-09

5. 1.18E+01

Unit Test on Acid-Base Equilibria time = 20 min.

TEST 2

1. CALCULATE THE pH OF 1.482 M NH3 WHOSE IONIZATION CONSTANT IS 1.8E-5.

2. WHAT IS THE CONCENTRATION OF $NaHSO_3$ IN A SOLUTION PREPARED BY ADDING 35 ML OF 2.585 M OF THE SODIUM SALT TO 371 ML OF 2.725 M HCL ? ASSUME THAT THE TOTAL VOLUME OF THE SOLUTION IS 406 ML. THE IONIZATION CONSTANT OF NaHSO3 IS 5.60E-08

3. A BUFFER SOLUTION IS MADE UP BY ADDING 0.752 MOLES OF THE SODIUM SALT TO 0.532 LITERS OF A 0.106 M SOLUTION OF HCN WHOSE IONIZATION CONSTANT IS 4.000E-10. WHAT IS THE pH OF THIS SOLUTION?

4. WHAT IS THE DEGREE OF IONIZATION OF A 2.496 M SOLUTION OF HAc WHOSE IONIZATION CONSTANT IS 1.80E-05 ?

5. A 4.702 M SOLUTION OF A WEAK ACID, HX, HAS A pH OF 5.650 . WHAT IS THE IONIZATION CONSTANT OF THE ACID ?

TEST 2

1. 1.17E+01

2. 2.23E-01

3. 1.05E+01

4. 6.69E-03

5. 1.07E-12

Unit Test on Acid-Base Equilibria time = 20 min.

TEST 3

1. CALCULATE THE pH OF 1.230 M NH3 WHOSE IONIZATION CONSTANT IS 1.8E-5.

2. A WEAK ACID, HX, IS 33.781 % IONIZED IN 1.860 M SOLUTION. WHAT PERCENT OF HX IS ICNIZED IN A 4.478 M SOLUTION ?

3. A BUFFER SOLUTION IS MADE UP BY ADDING 1.052 MOLES OF THE SODIUM SALT TO 1.432 LITERS OF A 0.490 M SOLUTICN OF HCN WHOSE IONIZATION CONSTANT IS 4.000E-10. WHAT IS THE pH OF THIS SOLUTION?

4. A SOLUTION PREPARED FROM 0.261 MOLE OF A WEAK ACID, HX, DILUTED TO 301 ML HAS A pH OF 6.534. WHAT IS THE pH OF THE SOLUTION AFTER 0.358 MOLE OF SOLID NaX IS DISSOLVED IN IT? ASSUME THAT NO SIGNIFICANT VOLUME CHANGE OCCURS WHEN THE NaX IS DISSOLVED IN THE SOLUTION.

5. A 1.450 M SOLUTION OF A WEAK ACID, HX, HAS A pH OF 2.050. WHAT IS THE IONIZATION CONSTANT OF THE ACID ?

TEST 3

1. 1.17E+01

2. 2.34E+01

3. 9.57E+00

4. 1.31E+01

5. 5.53E-05

Unit Test on Acid-Base Equilibria   time = 20 min.

TEST   4

1. HOW MANY MOLES OF HCN MUST BE USED TO PREPARE 1.25 L OF SOLUTION THAT HAS A pH OF 4.895 ? THE IONIZATION CONSTANT OF HCN IS 4.00E-10 .

2. WHAT IS THE DEGREE OF IONIZATION OF A 3.654 M SOLUTION OF Formic acid WHOSE IONIZATION CONSTANT IS 2.10E-04 ?

3. WHAT IS THE CONCENTRATION OF Propionic acid IN A SOLUTION PREPARED BY ADDING 29 ML OF 4.400 M OF THE SODIUM SALT TO 16 ML OF 3.200 M HCL ? ASSUME THAT THE TOTAL VOLUME OF THE SOLUTION IS 45 ML. THE IONIZATION CONSTANT OF Propionic acid IS 1.40E-05

4. WHAT IS THE pH OF 1.272 M $NaHSO_3$ WHOSE IONIZATION CONSTANT IS 5.600E-08?

5. A SOLUTION PREPARED FROM 0.086 MOLE OF A WEAK ACID, HX, AND 0.698 MOLE OF NaX DILUTED TO 467 ML HAS A pH OF 3.694. WHAT IS THE IONIZATION CONSTANT OF HX ?

TEST   4

1. 5.08E-01

2. 2.76E-02

3. 1.14E+00

4. 3.57E+00

5. 1.64E-03

Unit Test on Acid-Base Equilibria time = 20 min.

TEST 5

1. A SOLUTION PREPARED FROM 0.142 MOLE OF A WEAK ACID, HX, AND 0.418 MOLE OF NaX DILUTED TO 234 ML HAS A pH OF 6.369. WHAT IS THE IONIZATION CONSTANT OF HX ?

2. WHAT IS THE DEGREE OF IONIZATION OF A 4.638 M SOLUTION OF Formic acid WHOSE IONIZATION CONSTANT IS 2.10E-04 ?

3. CALCULATE THE pH OF 0.920 M METHYLAMINE WHOSE IONIZATION CONSTANT IS 1.8E-5.

4. HOW MANY MOLES OF THE SODIUM SALT SHOULD BE ADDED TO 282 ML OF 0.816 M Propionic acid TO PREPARE A BUFFER WITH A pH OF 4.564 ? ASSUME THAT NO VOLUME CHANGE OCCURS WHEN THE SODIUM SALT IS ADDED TO THE SOLUTION. THE IONIZATION CONSTANT OF Propionic acid IS 1.40E-05 .

5. HOW MANY MOLES OF HCN MUST BE USED TO PREPARE 1.23 L OF SOLUTION THAT HAS A pH OF 4.420 ? THE IONIZATION CONSTANT OF HCN IS 4.00E-10 .

TEST 5

1. 1.26E-06

2. 3.11E-02

3. 1.16E+01

4. 1.18E-01

5. 4.46E+00

Unit Test on Acid-Base Equilibria time = 20 min.

TEST 6

1. IF A WEAK ACID, HX, IS 12.081 % IONIZED IN 4.310 M SOLUTION, AT WHAT CONCENTRATION IS THE ACID 16.381 % IONIZED?

2. CALCULATE THE pH OF 0.724 M NH3 WHOSE IONIZATION CONSTANT IS 1.8E-5.

3. WHAT IS THE CONCENTRATION OF Formic acid IN A SOLUTION PREPARED BY ADDING 26 ML OF 4.995 M OF THE SODIUM SALT TO 313 ML OF 2.010 M HCL ? ASSUME THAT THE TOTAL VOLUME OF THE SOLUTION IS 339 ML. THE IONIZATION CONSTANT OF Formic acid IS 2.10E-04

4. HOW MANY MOLES OF HF MUST BE USED TO PREPARE 1.65 L OF SOLUTION THAT HAS A pH OF 5.180 ? THE IONIZATION CONSTANT OF HF IS 7.00E-04 .

5. A SOLUTION PREPARED FROM 0.239 MOLE OF A WEAK ACID, HX, DILUTED TO 460 ML HAS A pH OF 6.664 . WHAT IS THE pH OF THE SOLUTION AFTER 0.378 MOLE OF SOLID NaX IS DISSOLVED IN IT? ASSUME THAT NO SIGNIFICANT VOLUME CHANGE OCCURS WHEN THE NaX IS DISSOLVED IN THE SOLUTION.

TEST 6

1. 2.23E+00 M

2. 1.16E+01

3. 3.83E-01

4. 1.03E-07

Unit Test on Acid-Base Equilibria   time = 20 min.

TEST 7

1. A SOLUTION PREPARED FROM 0.297 MOLE OF A WEAK ACID, HX, AND 0.728 MOLE OF NaX DILUTED TO 337 ML HAS A pH OF 5.119. WHAT IS THE IONIZATION CONSTANT OF HX ?

2. A 6.346 M SOLUTION OF A WEAK ACID, HX, HAS A pH OF 6.400 . WHAT IS THE IONIZATION CONSTANT OF THE ACID ?

3. A SOLUTION PREPARED FROM 0.232 MOLE OF A WEAK ACID, HX, DILUTED TO 468 ML HAS A pH OF 3.614 . WHAT IS THE pH OF THE SOLUTION AFTER 0.548 MOLE OF SOLID NaX IS DISSOLVED IN IT? ASSUME THAT NO SIGNIFICANT VOLUME CHANGE OCCURS WHEN THE NaX IS DISSOLVED IN THE SOLUTION.

4. IF A WEAK ACID, HX, IS 8.581 % IONIZED IN 4.015 M SOLUTION, AT WHAT CONCENTRATION IS THE ACID 4.181 % IONIZED?

5. WHAT IS THE pH OF 2.652 M HF WHOSE IONIZATION CONSTANT IS 7.000E-04?

TEST 7

1. 1.86E-05

2. 2.50E-14

3. 7.30E+00

4. 1.77E+01 M

5. 1.37E+00

Unit Test on Acid-Base Equilibria time = 20 min.

TEST 8

1. A 2.050 M SOLUTION OF A WEAK ACID, HX, HAS A pH OF 6.950 . WHAT IS THE IONIZATION CONSTANT OF THE ACID ?

2. WHAT IS THE DEGREE OF IONIZATION OF A 3.456 M SOLUTION OF Propionic aci WHOSE IONIZATION CONSTANT IS 1.40E-05 ?

3. A SOLUTION PREPARED FROM 0.452 MOLE OF A WEAK ACID, HX, DILUTED TO 126 ML HAS A pH OF 5.774 . WHAT IS THE pH OF THE SOLUTION AFTER 0.848 MOLE OF SOLID NaX IS DISSOLVED IN IT? ASSUME THAT NO SIGNIFICANT VOLUME CHANGE OCCURS WHEN THE NaX IS DISSOLVED IN THE SOLUTION.

4. A BUFFER SOLUTION IS MADE UP BY ADDING 1.313 MOLES OF THE SODIUM SALT TO 0.313 LITERS OF A 0.730 M SOLUTION OF Propionic acid WHOSE IONIZATION CONSTANT IS 1.400E-05. WHAT IS THE pH OF THIS SOLUTION?

5. WHAT IS THE pH OF 0.858 M $NaHCO_3$ WHOSE IONIZATION CONSTANT IS 4.800E-11?

TEST 8

1. 6.14E-15

2. 6.95E-03

3. 1.24E+01

4. 5.61E+00

5. 5.19E+00

Unit Test on Acid-Base Equilibria time = 20 min.

TEST 9

1. WHAT IS THE pH OF 1.884 M Propionic acid WHOSE IONIZATION CONSTANT IS 1.400E-05?

2. IF A WEAK ACID, HX, IS 13.481 % IONIZED IN 2.200 M SOLUTION, AT WHAT CONCENTRATION IS THE ACID 33.281 % IONIZED?

3. HOW MANY MOLES OF $NaHSO_3$ MUST BE USED TO PREPARE 1.59 L OF SOLUTION THAT HAS A pH OF 2.305 ? THE IONIZATION CONSTANT OF $NaHSO_3$ IS 5.60E-08 .

4. A BUFFER SOLUTION IS MADE UP BY ADDING 1.352 MOLES OF THE SODIUM SALT TO 0.832 LITERS OF A 0.664 M SOLUTION OF HClO WHOSE IONIZATION CONSTANT IS 3.200E-08. WHAT IS THE pH OF THIS SOLUTION?

5. WHAT IS THE CONCENTRATION OF Benzoic acid IN A SOLUTION PREPARED BY ADDING 67 ML OF 4.190 M OF THE SODIUM SALT TO 45 ML OF 4.880 M HCL ? ASSUME THAT THE TOTAL VOLUME OF THE SOLUTION IS 112 ML. THE IONIZATION CONSTANT OF Benzoic acid IS 6.60E-05

TEST 9

1. 2.29E+00

2. 2.78E-01 M

3. 7.02E+02

4. 7.88E+00

5. 1.96E+00

Unit Test on Acid-Base Equilibria time = 20 min.

TEST 10

1. A SOLUTION PREPARED FROM 0.311 MOLE OF A WEAK ACID, HX, AND 0.138 MOLE OF NaX DILUTED TO 291 ML HAS A pH OF 3.185. WHAT IS THE IONIZATION CONSTANT OF HX ?

2. A BUFFER SOLUTION IS MADE UP BY ADDING 0.563 MOLES OF THE SODIUM SALT TO 1.063 LITERS OF A 0.792 M SOLUTION OF $NaHCO_3$ WHOSE IONIZATION CONSTANT IS 4.800E-11. WHAT IS THE pH OF THIS SOLUTION?

3. A WEAK ACID, HX, IS 6.581 % IONIZED IN 1.480 M SOLUTION. WHAT PERCENT OF HX IS IONIZED IN A 1.128 M SOLUTION ?

4. A 2.056 M SOLUTION OF A WEAK ACID, HX, HAS A pH OF 6.150. WHAT IS THE IONIZATION CONSTANT OF THE ACID ?

5. WHAT IS THE pH OF 4.740 M HAC WHOSE IONIZATION CONSTANT IS 1.800E-05?

TEST 10

1. 2.90E-04

2. 1.01E+01

3. 7.50E+00

4. 2.44E-13

5. 2.03E+00