Study Guide for Module 15A—Acids & Bases III

Reading Assignment: Sections 4.8, 14.7, 15.1, 15.2, 15.3, 15.4, 15.5 and 15.8 in *Chemistry, 6th Edition* by Zumdahl.

Guide for Your Lecturer:

1. *Review of Acids and Bases from Previous Modules*
✔ 2. *Calculation of the pH or pOH of a Solution of a Weak Acid or Base AGAIN*
3. *An Overview of Buffers*
✔ 4. *Calculation of the pH of a Buffer Solution*
5. *A Review of Acid-Base Titration*
6. *Titration Curves*
✔ 7. *Calculation of the pH or pOH at a Point During a Titration—AGAIN*
✔ 8. *Amphoterism*
✔ 9. *Polyprotic Acids*
✔ 10. *An Introduction to Formation and Dissociation Expressions*

Homework

Note: ✔ indicates problems to be stressed on drill quizzes and hour exams.

Review of Acids and Bases from Previous Modules

1a) Which of the following is the stronger acid? Explain your answer.

S. hydrofluoric acid or benzoic acid
K_a for HF = $7.0*10^{-4}$; K_a for benzoic acid = $6.6*10^{-5}$
$7.0*10^{-4} > 6.6*10^{-5}$ so HF is a stronger acid

A. acetic acid or benzoic acid

B. hydrocyanic acid or hydrofluoric acid

C. formic acid or acetic acid

D. benzoic acid or formic acid

E. nitrous acid or formic acid

F. benzoic acid or hypochlorous acid

■***Review of Acids and Bases from Previous Modules (continued)***

1b) For each of the following substances, write a balanced equation showing how the substance dissociates when placed in water. Then use the magnitude of the equilibrium expression to indicate the relative amounts of each of the species in the balanced equation.

S.	acetic acid	-Balanced equation for dissociation in water:	$CH_3COOH(aq) + H_2O \rightleftharpoons CH_3COO^-(aq) + H_3O^+(aq)$
		-Relative amounts each species:	$K_a = 1.8*10^{-5} << 1$ Therefore, much more CH_3COOH than CH_3COO^- or H_3O^+ in the solution at equilibrium.
A.	hydrofluoric acid	-Balanced equation for dissociation in water:	
		-Relative amounts each species:	
B.	nitric acid	-Balanced equation for dissociation in water:	
		-Relative amounts each species:	
C.	ammonia	-Balanced equation for dissociation in water:	
		-Relative amounts each species:	
D.	hydrocyanic acid	-Balanced equation for dissociation in water:	
		-Relative amounts each species:	
E.	CH_3NH_2	-Balanced equation for dissociation in water:	
		-Relative amounts each species:	
F.	propionic acid	-Balanced equation for dissociation in water:	
		-Relative amounts each species:	
G.	hydrochloric acid	-Balanced equation for dissociation in water:	
		-Relative amounts each species:	

✔✔✔■ *Calculation of the pH or pOH of a Solution of a Weak Acid or Base AGAIN*

2a) Work the indicated problem using and INITIAL/CHANGE/FINAL chart. (This is a review from Module 14B.)

S. What is the pH of a 0.52 M solution of acetic acid?

•Formula: CH_3COOH •Type cmpd: acid •Strength: weak

••

Prediction of pH: pH<7 Reason for prediction: CH_3COOH is an acid.

	CH_3COOH + H_2O ⇌	CH_3COO^-	+ H_3O^+
initial	0.52	0	0
Δ	-x	+x	+x
final	0.52 - x	+x	+x

K_a for acetic acid = $1.8*10^{-5}$

$$K_a = \frac{[CH_3COO^-][H_3O^+]}{[CH_3COOH]} = 1.8*10^{-5} = \frac{x*x}{0.52 - x}$$

Assume 0.52 >> x so $0.52 - x \approx 0.52$

Therefore, equation reduces to $1.8*10^{-5} = \frac{x*x}{0.52}$

$x^2 = 0.52*(1.8*10^{-5}) = 9.36*10^{-6}$

$x = 3.06*10^{-3}$

Check: $\frac{x}{0.52} = \frac{3.06*10^{-3}}{0.52} = 0.0059$

< 0.05 so ok

Therefore, $[H^+] = 3.06*10^{-3}$ M

$pH = -\log[H^+] = -\log(3.06*10^{-3}) = 2.51$

Agree with prediction: pH<7 as predicted

A. What is the pOH of a 0.19 M solution of benzoic acid?

•Formula: •Type cmpd: •Strength:

••

Prediction of pOH: Reason for prediction:

Agree with prediction:

B. What is the pH of a 0.26 M solution of hydrocyanic acid?

•Formula: •Type cmpd: •Strength:

••

Prediction of pH: Reason for prediction:

Agree with prediction:

✔✔✔■Calculation of the pH or pOH of a Solution of a Weak Acid or Base AGAIN (continued)

2a) Work the indicated problem using and INITIAL/CHANGE/FINAL chart.

C. What is the pOH of a 0.53 M solution of formic acid?

•Formula: •Type cmpd: •Strength:

Prediction of pOH: Reason for prediction:

Agree with prediction:

D. What is the pH of a 0.34 M solution of nitrous acid?

•Formula: •Type cmpd: •Strength:

Prediction of pH: Reason for prediction:

Agree with prediction:

E. What is the pH of a 0.45 M solution of hydrofluoric acid?

•Formula: •Type cmpd: •Strength:

Prediction of pH: Reason for prediction:

Agree with prediction:

✔✔✔■***Calculation of the pH or pOH of a Solution of a Weak Acid or Base AGAIN (cont'd)***

2b) S. What is the pH of a 0.26 M solution of ammonia?

•Formula: NH_3 •Type cmpd: base •Strength: weak

Prediction of pH: pH>7 Reason for prediction: NH_3 is a base.

	$NH_3 + H_2O \rightleftharpoons$	$NH_4^+ +$	OH^-
initial	0.26	0	0
Δ	-x	+x	+x
final	0.26 - x	+x	+x

K_b for $NH_3 = \frac{10^{-14}}{K_a} = \frac{10^{-14}}{5.6*10^{-10}} = 1.79*10^{-5}$

$K_b = \frac{[NH_4^+][OH^-]}{[NH_3]} = 1.79*10^{-5} = \frac{x*x}{0.26 - x}$

Assume 0.26 >> x so 0.26 - x ≈ 0.26

Therefore, eqn. reduces to $1.79*10^{-5} = \frac{x*x}{0.26}$

$x^2 = 0.26*(1.79*10^{-5}) = 4.64*10^{-6}$

$x = 2.15*10^{-3}$

Check: $\frac{x}{0.23} = \frac{2.15*10^{-3}}{0.26} = 0.0083$ < 0.05 so ok

Therefore, $[OH^-] = 2.15*10^{-3}$ M

$pOH = -\log[OH^-] = -\log(2.15*10^{-3}) = 2.667$

pH = 14 - pOH = 14 - 2.667 = 11.33 rounded

Agree with prediction: pH>7 as predicted

A. What is the pOH of a 0.53 M solution of ethylamine, $CH_3CH_2NH_2$?

•Formula: •Type cmpd: •Strength:

Prediction of pOH: Reason for prediction:

Agree with prediction:

B. What is the pH of a 0.34 M solution of methylamine, CH_3NH_2?

•Formula: •Type cmpd: •Strength:

Prediction of pH: Reason for prediction:

Agree with prediction:

✔✔✔■Calculation of the pH or pOH of a Solution of a Weak Acid or Base AGAIN (cont'd)

2b) C. What is the pOH of a 0.53 M solution of dimethylamine, $(CH_3)_2NH$?

•Formula: •Type cmpd: •Strength:

Prediction of pOH: Reason for prediction:

Agree with prediction:

D. What is the pH of a 0.34 M solution of ammonia?

•Formula: •Type cmpd: •Strength:

Prediction of pH: Reason for prediction:

Agree with prediction:

E. What is the pH of a 0.37 M solution of ammonia?

•Formula: •Type cmpd: •Strength:

Prediction of pH: Reason for prediction:

Agree with prediction:

■*An Overview of Buffers*

3a) Define buffer solution. (p. 716)

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b) A solution that contains approximately one mole of acetic acid and one mole of acetate ion can absorb either H^+ or OH^- (i.e. act like a buffer). Use LeChatelier's Principle to explain why in the chart below using arrows as in similar charts in Module 13.

Stress ↓	*Shift* ↓	$CH_3COOH(aq)$	+	H_2O	⇌	$CH_3COO^-(aq)$	+	$H_3O^+(aq)$
Add H_3O^+								
Add OH^-								

c) What must be present for a solution to function as an buffer? (Approximately equal amounts of a weak acid and its conjugate base. Note: For our purposes, "approximately equal" means that the concentration of the one of the substances is not more than 10 times greater than the other.)

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d) Briefly describe four ways to make a buffer solution. (1: Add approximately equal amounts of a weak acid and its salt to water. 2: Add enough strong base to a weak acid to neutralize about half of the acid. 3: Add approximately equal amounts of a weak base and its salt to water. 4: Add enough strong acid to a weak base to neutralize about half of the base)

-1)

-2)

-3)

-4)

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e) The following is an initial/change/final chart for the reaction of 0.20 moles of NaOH with 0.40 moles of acetic acid. Explain why the resulting solution would like a buffer. Note: This is an example of the 2nd way to make a buffer above.

	$NaOH$ +	CH_3COOH →	$NaCH_3COO$ +	H_2O
initial	0.20	0.40	0	
Δ	-0.20	-0.20	+ 0.20	
final	0	0.20	0.20	

---

f) The following is an initial/change/final chart for the reaction of 0.20 moles of HCl with 0.40 moles of ammonia. Explain why the resulting solution would like a buffer. Note: This is an example of the 4th way to make a buffer above.

	HCl +	NH_3 →	NH_4Cl +	H_2O
initial	0.20	0.40	0	
Δ	-0.20	-0.20	+ 0.20	
final	0	0.20	0.20	

■***An Overview of Buffers (continued)***

3g) Construct initial/Δ/final charts indicating the reaction which would occur if the following were mixed.

•Solution prepared adding 0.20 mole of acetic acid with 0.10 moles of sodium hydroxide.	•Solution prepared adding 0.20 mole of acetic acid with 0.20 moles of sodium hydroxide.

Which of the two solutions above would act like a buffer and why?

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h) Why won't a solution of a strong acid and one of its salts have buffer properties?

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i) Indicate whether or not the given solution would have buffer properties. Briefly explain your answer.

S. A solution which is 0.2 M in acetic acid and 0.3 M in sodium acetate.

	substance 1	substance 2
•Formula:	CH_3COOH	$NaCH_3COO$
•Type cmpd:	acid	salt
•Strength:	weak	strong

There are approximately equal concentrations of a weak acid and its salt. Therefore, the solution will act as a buffer.

A. A solution which is 0.1 M in hydrofluoric acid and 0.2 sodium fluoride.

	substance 1	substance 2
•Formula:		
•Type cmpd:		
•Strength:		

B. A solution which is 0.2 M in hydrochloric acid and 0.2 M in sodium chloride.

	substance 1	substance 2
•Formula:		
•Type cmpd:		
•Strength:		

■***An Overview of Buffers (continued)***

3i) C. A solution which is 0.3 M in aqueous ammonia and 0.4 M in ammonium chloride.

	substance 1	substance 2
•Formula:		
•Type cmpd:		
•Strength:		

D. A solution which is 0.2 M in hydrocyanic acid and 0.3 M sodium cyanide.

	substance 1	substance 2
•Formula:		
•Type cmpd:		
•Strength:		

E. A solution prepared by adding 0.5 moles of ammonia and 0.25 moles of hydrochloric acid.

	substance 1	substance 2
•Formula:		
•Type cmpd:		
•Strength:		

F. A solution prepared by adding 0.25 moles of acetic acid and 0.12 moles of sodium hydroxide.

	substance 1	substance 2
•Formula:		
•Type cmpd:		
•Strength:		

G. A solution prepared by adding 0.5 moles of nitric acid and 0.25 moles of ammonia.

	substance 1	substance 2
•Formula:		
•Type cmpd:		
•Strength:		

H. A solution prepared by adding 0.4 moles of hydrofluoric acid and 0.4 moles of potassium hydroxide.

	substance 1	substance 2
•Formula:		
•Type cmpd:		
•Strength:		

■***An Overview of Buffers (continued)***

3j) Define buffer capacity. (p. 726)

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k) In each of the following pairs, indicate which solution has the higher buffer capacity.

S. 50 mL of a solution which is 0.20 M in acetic acid and 0.20 M in sodium acetate or 20 mL of one which is 0.40 M in acetic acid and 0.40 M in sodium acetate?

In solution 1, mol CH_3COOH = mol $NaCH_3COO$ = M*L = (0.20 M)(0.050 L) = .01 mol

In solution 2, mol CH_3COOH = mol $NaCH_3COO$ = M*L = (0.40 M)(0.020 L) = .008 mol

Solution 1 has the greater buffering capacity since it has the larger amounts of acid/salt.

A. 70 mL of a solution which is 0.50 M in benzoic acid and 0.50 M in sodium benzoate or 60 mL of one which is 0.30 M in benzoic acid and 0.30 M in sodium benzoate?

B. 50 mL of a solution which is 0.50 M in acetic acid and 0.50 M in sodium acetate or 30 mL of one which is 0.40 M in acetic acid and 0.40 M in sodium acetate?

C. 100 mL of a solution which is 0.40 M in HF and 0.40 M in NaF or 50 mL of one which is 0.50 M in HF and 0.50 M in NaF?

D. 150 mL of a solution which is 0.40 M in HF and 0.40 M in KF or 100 mL of one which is 0.10 M in HF and 0.10 M in KF?

E. 75 mL of a solution which is 0.30 M in acetic acid and 0.30 M in potassium acetate or 100 mL of one which is 0.25 M in acetic acid and 0.25 M in potassium acetate?

✔✔✔■*Calculation of the pH of a Buffer Solution*

4. Determine the pH of the solution indicated using INITIAL/CHANGE/FINAL charts as needed.

S. A solution which 0.30 M in aqueous ammonia and 0.20 M in ammonium chloride.

•Formula: NH_3, NH_4Cl •Type cmpd: base, salt •Strength: base weak, salt strong

••

Do i/Δ/f chart for total dissociation of NH_4Cl.

	NH_4Cl →	NH_4^+ +	Cl^-
initial	0.20	0	0
Δ	-.20	+.20	+.20
final	0	+.20	+.20

Do i/Δ/f for dissociation of NH_3 .*

	NH_3 + H_2O ⇌	NH_4^+ +	OH^-
initial	0.30	0.20	0
Δ	-x	+x	+x
final	0.30 - x	0.20+x	+x

K_b for $NH_3 = \frac{10^{-14}}{K_a} = \frac{10^{-14}}{5.6*10^{-10}} = 1.79*10^{-5}$

$K_b = \frac{[NH_4^+][OH^-]}{[NH_3]} = 1.79*10^{-5} = \frac{(0.20 + x)*x}{0.30 - x}$

Assume 0.20 >> x so $0.20 + x \approx 0.20$ AND $0.30 - x \approx 0.30$. Therefore, get

$1.79*10^{-5} = \frac{0.20*x_1}{0.30}$

$x = 0.30*(1.79*10^{-5})/0.20$

$x = 2.68*10^{-5}$

Check: $\frac{x}{0.20} = \frac{2.68*10^{-5}}{0.20} = 0.000134$ < 0.05 so ok

Therefore, $[OH^-] = 2.68*10^{-5}$ M

$pOH = -\log[OH^-] = -\log(2.68*10^{-5}) = 4.572$

$pH = 14 - pOH = 14 - 4.572 = 9.43$ rounded

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*After the salt dissociates the solution contains two substances which react somewhat with water. They are NH_3 and NH_4^+. Since the two are related (they are a conjugate acid/base pair), we only have to consider one of them (the other is automatically taken into account). Thus, in this problem, you could take into account the "weak" nature of NH_3/NH_4^+ by either

a) considering the dissociation which occurs when NH_3 is placed in water, i.e. $NH_3 + H_2O = NH_4^+ + OH^-$

or b) the hydrolysis of the NH_4^+ from the salt, i.e. $NH_4^+ + H_2O = NH_3 + H_3O^+$.

A. A solution which is 0.15 M in acetic acid and 0.10 M in sodium acetate.

•Formula: •Type cmpd: •Strength:

••

✔✔✔■***Calculation of the pH of a Buffer Solution (continued)***

4. Determine the pH of the solution indicated using INITIAL/CHANGE/FINAL charts as needed.
   B. A solution which is 0.25 M in hydrofluoric acid and 0.15 M in sodium fluoride.
      •Formula: •Type cmpd: •Strength:

   C. A solution which is 0.40 M in aqueous ammonia and 0.10 M in ammonium chloride.
      •Formula: •Type cmpd: •Strength:

✔✔✔■Calculation of the pH of a Buffer Solution (continued)

4. Determine the pH of the solution indicated using INITIAL/CHANGE/FINAL charts as needed.

D. A solution which is 0.30 M in benzoic acid and 0.20 M in sodium benzoate.

•Formula: •Type cmpd: •Strength:

E. A solution which is 0.25 M in propionic acid and 0.87 M in sodium propionate.

•Formula: •Type cmpd: •Strength:

✔✔✔■Calculation of the pH of a Buffer Solution (continued)

4. Determine the pH of the solution indicated using INITIAL/CHANGE/FINAL charts as needed.
   F. A solution which is 0.67 M in butylammine and 0.93 M in butylammonium chloride.
      •Formula: •Type cmpd: •Strength:

■A Review of Acid-Base Titration

5a) Define titration. (pp. 161-64)

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b) Define equivalence point. (pp. 161, 732)

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c) Define indicator. (pp. 161, 745)

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d) Define endpoint. (The point where the indicator changes color during a titiration.)

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e) The most common indicator is litmus. What color does litmus turn...
   •in acidic solution? •in basic solution?

■***An Review of Acid-Base Titration***

5f) Use the following table of common acid-base indicators to determine the color of the given indicator in the specified solution. Explain how you got your answer. (p. 749)

Indicator	pH interval for color change	Acid Color	Base Color
Methyl Violet	0-2	Yellow	Violet
Methyl Yellow	1.2-2.3	Red	Yellow
Methyl Orange	2.9-4.0	Red	Yellow
Methyl Red	4.2-6.3	Red	Yellow
Bromthymol Blue	6.0-7.6	Yellow	Blue
Thymol Blue	8.0-9.6	Yellow	Blue
Phenolphthalein	8.3-10	Colorless	Pink
Alizarin Yellow G	10.1-12.0	Yellow	Red

S. What is the color of bromothymol blue in a solution with a pH of 11?
The pH interval over which bromothymol blue changes color is 6.0-7.6. Therefore, the indicator would be blue at pH 11 since it is above the point where is totally changed to the base color (7.6).

A. What is the color of phenolphthalein in a solution with a pH of 2?

B. What is the color of thymol blue in a solution with a pH of 10?

C. What is the color of methyl orange in a solution with a pH of 6?

D. What is the color of bromothymol blue in a solution with a pH of 8?

E. What is the color of alizarin yellow G in a solution with a pH of 4?

F. What is the color of methyl red in a solution with a pH of 7?

■***An Review of Acid-Base Titration (continued)***

5g) Recommend an indicator from the list on the previous page to detect the equivalence point of the following reactions and explain your answer.

S. A titration with an equivalence point at a pH of 4.5.
Methyl red would be a good one for this titration since the equivalence point of the reaction 4.5 lies within the pH interval of change. Methyl red is red when pH<4.2 and yellow when pH>6.3 .

A. A titration with an equivalence point at a pH of 9.2

B. A titration with an equivalence point at a pH of 10.2.

C. A titration with an equivalence point at a pH of 1.7.

D. A titration with an equivalence point at a pH of 7.3.

E. A titration with an equivalence point at a pH of 5.6.

F. A titration with an equivalence point at a pH of 3.1.

■***Titration Curves***

6a) Define titration curve. (736)

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b) Briefly explain how buffering can affect the shape of a titration curve. (p. 739)

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c) If a strong acid reacts with a strong base, at what pH would you expect the equivalence point to occur?

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d) If a strong acid reacts with a weak base, at what pH would you expect the equivalence point to occur? Use chemical equations to explain your answer.

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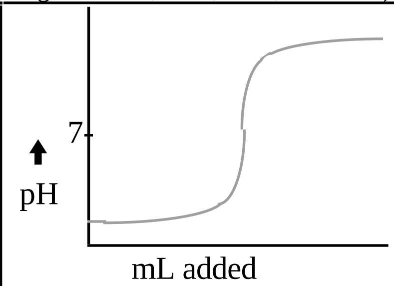
e) If a strong base reacts with a weak acid, at what pH would you expect the equivalence point to occur? Use chemical equations to explain your answer.

■*Titration Curves (continued)*

6f) Below are four general types of titration curves. Indentify the type of substance being titrated, the type of substance doing the titrating, the equivalence point, and any areas where buffering is occurring in each. (See Figures 15.1, 15.2, 15.3, and 15.5)

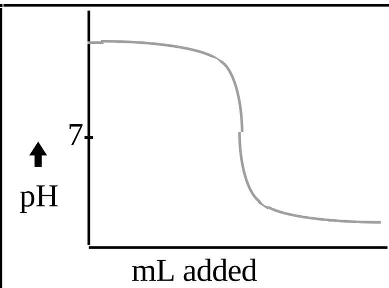


Substance in beaker:

Substance being added:

Substance being titrated:

Substance doing titration:

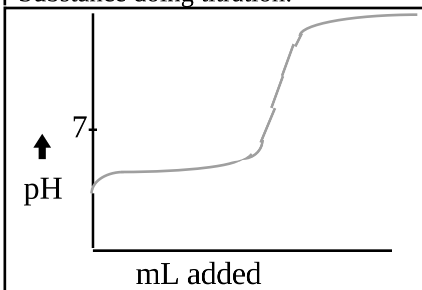


Substance in beaker:

Substance being added:

Substance being titrated:

Substance doing titration:

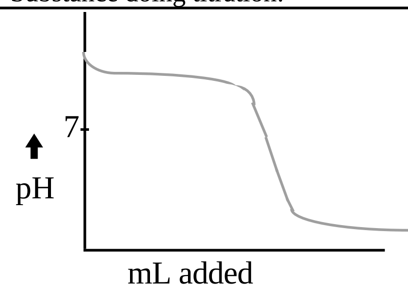


Substance in beaker:

Substance being added:

Substance being titrated:

Substance doing titration:



Substance in beaker:

Substance being added:

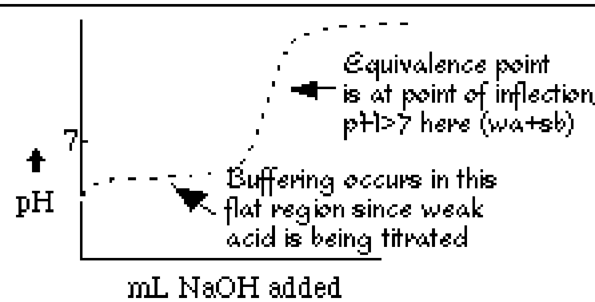
Substance being titrated:

Substance doing titration:

g) Sketch the titration curve for the indicated titration using the samples in *6f* above. Label your axes, the equivalence point, and any region in which buffering is occurring. (Figures 15.1, 15.2, 15.3, 15.3, and 15.5)

S. Titration of 0.2 M acetic acid with sodium hydroxide.

	substance 1	substance 2
•Formula:	CH_3COOH	NaOH
•Type cmpd:	acid	base
•Strength:	weak	strong



A. Titration of 0.1 M hydrochloric acid by sodium hydroxide.

	substance 1	substance 2
•Formula:		
•Type cmpd:		
•Strength:		

■***Titration Curves (continued)***

6g) Sketch the titration curve for the indicated titration. Label your axes, the equivalence point, and any region in which buffering is occurring. (Figures 15.1, 15.2, 15.3, and 15.5)

B. Titration of 0.1 M acetic acid by potassium hydroxide.

	substance 1	substance 2
•Formula:		
•Type cmpd:		
•Strength:		

C. Titration of 0.1 M sodium hydroxide by nitric acid.

	substance 1	substance 2
•Formula:		
•Type cmpd:		
•Strength:		

D. Titration of 0.1 M ammonia by hydrochloric acid.

	substance 1	substance 2
•Formula:		
•Type cmpd:		
•Strength:		

E. Titration of 0.1 M ammonia by nitric acid.

	substance 1	substance 2
•Formula:		
•Type cmpd:		
•Strength:		

F. Titration of potassium hydroxide by 0.1 M perchloric acid.

	substance 1	substance 2
•Formula:		
•Type cmpd:		
•Strength:		

✔✔✔■Calculation of the pH or pOH at a Point During a Titration—(Partial Neutralization AGAIN)

7. S. What is the pH of a solution prepared by adding 45 milliliters of 0.32 M sodium hydroxide and 32 milliliters of 0.12 M sulfuric acid? You will need two INITIAL/CHANGE/FINAL charts.
•Formula: H_2SO_4 , NaOH •Type cmpd: acid, base •Strength: both strong

••

Initial amounts are:
mol NaOH = (0.32 M)(0.045 L) = 0.0144 mol NaOH
mol H_2SO_4 = (0.12 M)(0.032 L) = 0.00384 mol H_2SO_4

Assume H_2SO_4 is used up & set up i/Δ/f chart:

	2NaOH	+ H_2SO_4	→ Na_2SO_4	+ $2H_2O$
initial	0.0144	0.00384	0	m
Δ	-2(0.00384)	-0.00384	+.00384	+.00384
final	0.00672	0	.00384	m+.00384

Since final NaOH > 0, assumption was ok.

Take into account dilution:

$$\text{Conc. NaOH} = \frac{\text{mol NaOH}}{\text{total liters soln}} = \frac{0.00672 \text{ mol NaOH}}{0.045+0.032 \text{ L}} = 8.73*10^{-2} \text{ M}$$

Now i/Δ/f for dissociation of NaOH:

	NaOH	→ Na^+	+ OH^-
initial	.0873	0	0
Δ	-.0873	+.0873	+.0873
final	0	+.0873	+.0873

Therefore, $[OH^-] = 8.73*10^{-2}$ M

$pOH=-\log[OH^-]= -\log(0.0873) = 1.059$

pH=14-pOH=14-1.049= 12.94 rounded

A. What is the pH of a solution prepared by adding 35 milliliters of 0.41 M hydrochloric acid and 14 milliliters of 0.23 M barium hydroxide? You will need two INITIAL/CHANGE/FINAL charts.
•Formula: •Type cmpd: •Strength:

••

B. What is the pH of a solution prepared by adding 23 milliliters of 0.15 M sulfuric acid and 16 milliliters of 0.75 M sodium hydroxide? You will need two INITIAL/CHANGE/FINAL charts.
•Formula: •Type cmpd: •Strength:

••

✔✔✔■Calculation of the pH or pOH at a Point During a Titration—(Partial Neutralization AGAIN)

7. C. What is the pH of a solution prepared by adding 14 milliliters of 0.27 M nitric acid to 19 milliliters of 0.61 M barium hydroxide? You will need two INITIAL/CHANGE/FINAL charts.
•Formula: •Type cmpd: •Strength:
••

D. What is the pH of a solution prepared by adding 87 milliliters of 0.42 M hydrochloric acid to 41 milliliters of 0.17 M barium hydroxide? You will need two INITIAL/CHANGE/FINAL charts.
•Formula: •Type cmpd: •Strength:
••

E. What is the pH of a solution prepared by adding 29 milliliters of 0.32 M hydrochloric acid to 35 milliliters of 0.87 M barium hydroxide? You will need two INITIAL/CHANGE/FINAL charts.
•Formula: •Type cmpd: •Strength:
••

✔✔✔■Calculation of the pH or pOH at a Point During a Titration—(Partial Neutralization AGAIN)

7. F. What is the pH of a solution prepared by adding 14 milliliters of 0.42 M hydrochloric acid to 25 milliliters of 0.32 M barium hydroxide? You will need two INITIAL/CHANGE/FINAL charts.
•Formula: •Type cmpd: •Strength:

✔✔✔■Amphoterism

8a) Define amphoteric. (p. 660)

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b) Write a chemical equation showing the following substance acting like an acid (i.e reacting with OH^-) and like a base (i.e reacting with H^+).

S. $Sn(OH)_2(H_2O)_2$

-Acting like an acid: $Sn(OH)_2(H_2O)_2 + OH^- \rightleftharpoons [Sn(OH)_3(H_2O)]^- + H_2O$

-Acting like a base: $Sn(OH)_2(H_2O)_2 + H_3O^+ \rightleftharpoons [Sn(OH)(H_2O)_3]^+ + H_2O$

A. $Al(OH)_3(H_2O)_3$
-Acting like an acid:

-Acting like a base:

B. $Zn(OH)_2(H_2O)_2$
-Acting like an acid:

-Acting like a base:

C. $Cr(OH)_3(H_2O)_3$
-Acting like an acid:

-Acting like a base:

✔✔✔■*Amphoterism (continued)*

8b) Write a chemical equation showing the following substance acting like an acid (i.e reacting with OH^-) and like a base (i.e reacting with H^+).

D. $Cu(OH)_2(H_2O)_4$

-Acting like an acid:

-Acting like a base:

E. $Sn(OH)_4(H_2O)_2$

-Acting like an acid:

-Acting like a base:

✔✔✔■*Polyprotic Acids*

9a) Define polyprotic acid. (p. 682)

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b) Write reactions showing the step-wise dissociation of the given polyprotic acid, the equilibrium expressions for each step, the overall dissociation equation, the equilibrium expression for the overall reaction, and the relationship between the step-wise and the overall dissociation constants.

S. Substance: H_2S 1) Step-wise dissociation reactions

$$H_2S + H_2O \rightleftharpoons HS^- + H_3O^+$$

$$HS^- + H_2O \rightleftharpoons S^{2-} + H_3O^+$$

2) Step-wise equil. expressions

$$K_{a1} = \frac{[HS^-][H_3O^+]}{[H_2S]}$$

$$K_{a2} = \frac{[S^{2-}][H_3O^+]}{[HS^-]}$$

3) Overall dissociation reaction:

$$H_2S + 2\,H_2O \rightleftharpoons S^{2-} + 2\,H_3O^+$$

4) Equilibrium expression for overall reaction

$$K_{overall} = \frac{[S^{2-}][H_3O^+]^2}{[H_2S]}$$

5) Relationship between the answers in *2)* and *4)*:

$K_{overall} = K_{a1} * K_{a2}$

A. Substance: H_2CO_3 1) Step-wise dissociation reactions

2) Step-wise equil. expressions

3) Overall dissociation reaction:

4) Equilibrium expression for overall reaction

5) Relationship between the answers in *2)* and *4)*:

✔✔✔■Polyprotic Acids (continued)

9b) Write reactions showing the step-wise dissociation of the given polyprotic acid, the equilibrium expressions for each step, the overall dissociation equation, the equilibrium expression for the overall reaction, and the relationship between the step-wise and the overall dissociation constants.

B. Substance: $H_2C_2O_4$ 1) Step-wise dissociation reactions 2) Step-wise equil. expressions

3) Overall dissociation reaction: 4) Equilibrium expression for overall reaction

5) Relationship between the answers in *2)* and *4)*:

C. Substance: H_2SO_3 1) Step-wise dissociation reactions 2) Step-wise equil. expressions

3) Overall dissociation reaction: 4) Equilibrium expression for overall reaction

5) Relationship between the answers in *2)* and *4)*:

D. Substance: H_3PO_4 1) Step-wise dissociation reactions 2) Step-wise equil. expressions

3) Overall dissociation reaction: 4) Equilibrium expression for overall reaction

5) Relationship between the answers in *2)* and *4)*:

E. Substance: H_3PO_3 Note: One of the H's in this compound is bonded to P and does not dissociate in water.

1) Step-wise dissociation reactions 2) Step-wise equil. expressions

3) Overall dissociation reaction: 4) Equilibrium expression for overall reaction

5) Relationship between the answers in *2)* and *4)*:

✔✔✔■Polyprotic Acids (continued)

9c) The table below contains two diprotic acids. List K_{a1} and K_{a2} for each.

•H_2S: K_{a1} = _____ K_{a2} = _____

•H_2CO_3: K_{a1} = _____ K_{a2} = _____

---

d) What assumption is usually made when one calculates the pH of a solution of a diprotic acid such as H_2S or H_2CO_3? (p. 683)

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e) What would be the predominant species present in a 0.2 M solution of H_2CO_3?

✔✔✔■An Introduction to Formation and Dissociation Expressions

10a) Define complex ion. (p. 766)

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b) Define formation constant. (The equilibrium constant for the step-wise formation of a complex ion.)

---

c) Define dissociation constant. (The equilibrium constant for the step-wise dissociation of a complex ion.)

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d) Write balanced step-wise reactions for either the formation or dissociation (as indicated) of the given metal ion complex. *Also* write equilibrium expressions for each of the equations.

S. Overall dissociation of $Co(CN)_6^{3-}$

-Step-wise dissociation of substance:			-Equilibrium expressions for each step:
$Co(CN)_6^{3-}$	=	$Co(CN)_5^{2-} + CN^-$	$K_1 = [Co(CN)_5^{2-}][CN^-]/[Co(CN)_6^{3-}]$
$Co(CN)_5^{2-}$	=	$Co(CN)_4^- + CN^-$	$K_2 = [Co(CN)_4^-][CN^-]/[Co(CN)_5^{2-}]$
$Co(CN)_4^-$	=	$Co(CN)_3 + CN^-$	$K_3 = [Co(CN)_3][CN^-]/[Co(CN)_4^-]$
$Co(CN)_3$	=	$Co(CN)_2^+ + CN^-$	$K_4 = [Co(CN)_2^+][CN^-]/[Co(CN)_3]$
$Co(CN)_2^+$	=	$Co(CN)^{2+} + CN^-$	$K_5 = [Co(CN)^{2+}][CN^-]/[Co(CN)_2^+]$
$Co(CN)^{2+}$	=	$Co^{3+} + CN^-$	$K_6 = [Co^{3+}][CN^-]/[Co(CN)^{2+}]$

-Overall dissociation of the substance: -Equilibrium expression for the overall reaction:

$Co(CN)_6^{3-} = Co^{3+} + 6\ CN^-$ $K_{diss} = \dfrac{[Co^{3+}][CN^-]^6}{[Co(CN)_6^{3-}]}$

A. Formation of $Cu(NH_3)_4^{2+}$

-Step-wise formation of substance: -Equilibrium expressions for each step:

-Overall formation of the substance: -Equilibrium expression for the overall reaction:

✔✔✔■An Introduction to Formation and Dissociation Expressions (continued)

10d) Write balanced step-wise reactions for either the formation or dissociation (as indicated) of the given metal ion complex. *Also* write equilibrium expressions for each of the equations.

B. Dissociation of $CuBr_4^{2-}$

-Step-wise dissociation of substance: -Equilibrium expressions for each step:

-Overall dissociation of the substance: -Equilibrium expression for the overall reaction:

C. Formation of $NiCl_4^{2-}$

-Step-wise formation of substance: -Equilibrium expressions for each step:

-Overall formation of the substance: -Equilibrium expression for the overall reaction:

D. Dissociation of $Pt(NH_3)_4^{2+}$

-Step-wise dissociation of substance: -Equilibrium expressions for each step:

-Overall dissociation of the substance: -Equilibrium expression for the overall reaction:

E. Formation of HgI_4^{2-}

-Step-wise formation of substance: -Equilibrium expressions for each step:

-Overall formation of the substance: -Equilibrium expression for the overall reaction:

✔✔✔■An Introduction to Formation and Dissociation Expressions (continued)

10e) S. The formation constant for $[Cu(NH_3)_4]^{2+}(aq)$ is $6.8*10^{12}$. If you begin with similar concentrations of Cu^{2+} and NH_3, what are the relative concentrations of $Cu^{2+}(aq)$, $NH_3(aq)$, and $[Cu(NH_3)_4]^{2+}(aq)$ at equilibrium?

$Cu^{2+}(aq) + 4\ NH_3(aq) \rightleftharpoons [Cu(NH_3)_4]^{2+}(aq)$

$K_{form} = [Cu(NH_3)_4]^{2+}/[Cu^{2+}][NH_3]^4 = 6.8*10^{12}$

$K_{form} >> 1$, therefore $[Cu(NH_3)_4]^{2+}$ is high, $[Cu^{2+}]$ and $[NH_3]$ are low

---

A. The dissociation constant for $[Fe(CN)_6]^{3-}$ is $1.3*10^{-37}$. If you begin with similar concentrations of Fe^{3+} and CN^-, what are the relative concentrations of $Fe^{3+}(aq)$, $CN^-(aq)$, and $[Fe(CN)_6]^{3-}(aq)$ at equilibrium?

B. The formation constant for $[Al(OH)_4]^-$ is $7.7*10^{33}$. If you begin with similar concentrations of Al^{3+} and OH^-, what are the relative concentrations of $Al^{3+}(aq)$, $OH^-(aq)$, and $[Al(OH)_4]^-(aq)$ at equilibrium?

C. The dissociation constant for $[Cd(CN)_4]^{2-}$ is $7.7*10^{-18}$. If you begin with similar concentrations of Cd^{2+} and CN^-, what are the relative concentrations of $Cd^{2+}(aq)$, $CN^-(aq)$, and $[Cd(CN)_4]^{2-}(aq)$ at equilibrium?

✔✔✔■An Introduction to Formation and Dissociation Expressions (continued)

10e) D. The formation constant for $[Ag(NH_3)_2]^+$ is $1.6*10^7$. If you begin with similar concentrations of Ag^+ and NH_3, what are the relative concentrations of $Ag^+(aq)$, $NH_3(aq)$, and $[Ag(NH_3)_2]^+(aq)$ at equilibrium?

E. The dissociation constant for $[HgCl_4]^{2-}$ is $8.3*10^{-16}$. If you begin with similar concentrations of Hg^{2+} and Cl^-, what are the relative concentrations of $Hg^{2+}(aq)$, $Cl^-(aq)$, and $[HgCl_4]^{2-}(aq)$ at equilibrium?

✔✔✔■Calculating the pH or pOH of Solutions--More practice on acid/base problems.

11) A. What is the pH of a 0.28 M solution of acetic acid?

•Formula: •Type cmpd: •Strength:

Prediction of pH: Reason for prediction:

Agree with prediction:

B. What is the pH of a 0.67 M solution of sodium fluoride?

•Formula: •Type cmpd: •Strength:

Prediction of pH: Reason for prediction:

Agree with prediction:

✔✔✔■Calculating the pH or pOH of Solutions--More practice on acid/base problems (cont'd)

11. C. What is the pOH of a 0.21 M solution of hydrochloric acid?

•Formula: •Type cmpd: •Strength:

••

Prediction of pOH: Reason for prediction:

Agree with prediction:

D. What is the pH of a 0.49 M solution of ammonium nitrate?

•Formula: •Type cmpd: •Strength:

••

Prediction of pH: Reason for prediction:

Agree with prediction:

✔✔✔■Calculating the pH or pOH of Solutions--More practice on acid/base problems (cont'd)

11. E. What is the pH of a solution which is 0.23 M in formic acid and 0.17 M in sodium formate?
•Formula: •Type cmpd: •Strength:

F. What is the pOH of a 0.37 M solution of sodium iodide?
•Formula: •Type cmpd: •Strength:

Prediction of pOH: Reason for prediction:

Agree with prediction:

✔✔✔■Calculating the pH or pOH of Solutions--More practice on acid/base problems (cont'd)

11. G. What is the pH of a 0.27 M solution of methylammonium chloride?

•Formula: •Type cmpd: •Strength:

••

Prediction of pH: Reason for prediction:

Agree with prediction:

H. What is the pOH of a solution which is 0.37 M in ammonia and 0.29 M in ammonium chloride?

•Formula: •Type cmpd: •Strength:

••

✔✔✔■Calculating the pH or pOH of Solutions--More practice on acid/base problems (cont'd)

11. I. What is the pH of a solution which is 0.28 M in nitric acid and 0.42 M in sodium nitrate?
•Formula: •Type cmpd: •Strength:

J. What is the pH of a solution which is 0.12 M in potassium acetate and 0.32 M in acetic acid?
•Formula: •Type cmpd: •Strength:

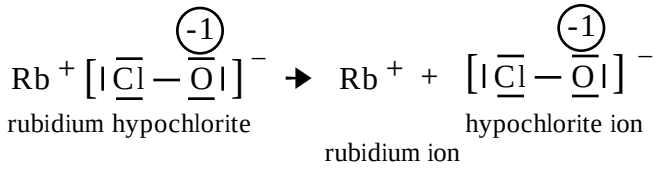
■***Bonding/Model Activity to Improve Ability to Visualize in 3-D***

S. a) Write balanced equations if rubidium hypochlorite dissociates and then undergoes hydrolysis.

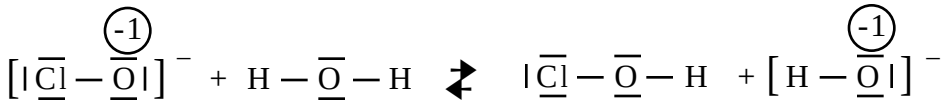
$RbClO \rightarrow Rb^+ + ClO^-$

$ClO^- + H_2O = HClO + OH^-$ (ClO^- undergoes hydrolysis because it is an anion of a weak acid. Rb^+ does not because it is a cation of a strong base.)

b) Draw the Lewis structure of all of the species in the above two reactions.



rubidium hypochlorite → rubidium ion + hypochlorite ion



hypochlorite ion + water ⇄ hypochlorous acid + hydroxide ion

c) Name all species in the equations above.

A. a) Write balanced equations if sodium cyanide dissociates and then undergoes hydrolysis.

b) Draw the Lewis structure of all of the species in the above two reactions.

c) Name all species in the equations above.

B. a) Write balanced equations if potassium acetate dissociates and then undergoes hydrolysis.

b) Draw the Lewis structure of all of the species in the above two reactions.

c) Name all species in the equations above.

■***Bonding/Model Activity to Improve Ability to Visualize in 3-D***

C. a) Write balanced equations if ammonium chloride dissociates and then undergoes hydrolysis.

b) Draw the Lewis structure of all of the species in the above two reactions.

c) Name all species in the equations above.

D. a) Write balanced equations if potassium propionate dissociates and then undergoes hydrolysis.

b) Draw the Lewis structure of all of the species in the above two reactions.

c) Name all species in the equations above.

A-Dd) When you go to drill be prepared to assemble models of each of the reactants in the equations above and then use those models to demonstrate to your instructor what happens as the reactions occur.

■***Challenge Questions***

A. What is the pH of a solution prepared by adding 25 ml of 0.10 M NaOH and 50 ml of 0.10 M acetic acid?

B. What is the pH of a solution prepared by adding 15 ml of 0.10 M HCl to 50 ml of 0.10 M aqueous ammonia?

C. If the step-wise acid dissociation constants for the diprotic acid H_2Y are $K_{a1} = 2.8*10^{-3}$ and $K_{a2} = 5.7*10^{-8}$, what would the relative pH or a solution prepared by dissolving KHY in water. That is, would HY^- be more likely to give up a hydrogen ion or to accept one? Explain your reasoning.

D. If the step-wise acid dissociation constants for the diprotic acid H_2X are $K_{a1} = 1.4*10^{-5}$ and $K_{a2} = 2.5*10^{-9}$, what would the relative pH or a solution prepared by dissolving NaHX in water. That is, would HX^- be more likely to give up a hydrogen ion or to accept one? Explain your reasoning.

E. What is the percent ionization (dissociation) in a 1.00 M solution of hydrofluoric acid? Show all steps.

F. What is the percent ionization (dissociation) in a 0.86 M solution of ammonia? Show all steps.

Revised by JW Carmichael Spring, 2000; SJB 5/8/2001; SJB 5/7/2002; MA 5/5/2003