Essay Questions

1972

Given a solution of ammonium chloride, what additional reagent or reagents are needed to prepare a buffer from the ammonium chloride solution?

Explain how this buffer solution resists a change in pH when:

(a) Moderate amounts of strong acid are added.
(b) Moderate amounts of strong base are added.
(c) A portion of the buffer solution is diluted with an equal volume of water.

1983

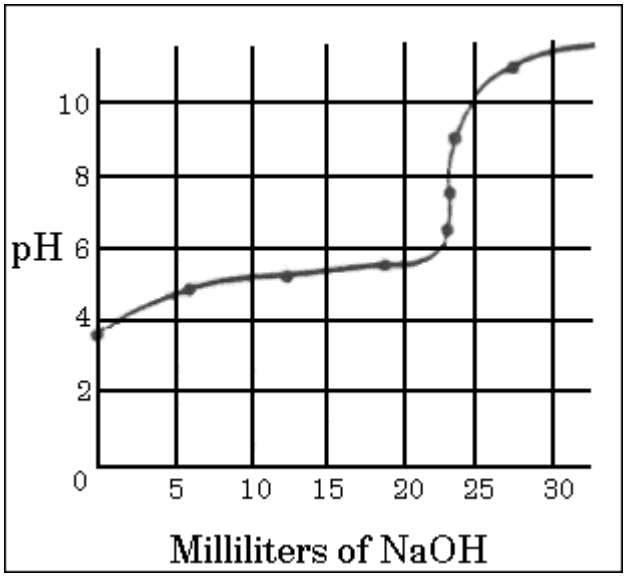
(a) Specify the properties of a buffer solution. Describe the components and the composition of effective buffer solutions.

(b) An employer is interviewing four applicants for a job as a laboratory technician and asks each how to prepare a buffer solution with a pH close to 9.

Archie A.	says he would mix acetic acid and sodium acetate solutions.
Beula B.	says she would mix NH_4Cl and HCl solutions.
Carla C.	says she would mix NH_4Cl and NH_3 solutions.
Dexter D.	says he would mix NH_3 and NaOH solutions.

Which of these applicants has given an appropriate procedure? Explain your answer, referring to your discussion in part (a). Explain what is wrong with the erroneous procedures.
(No calculations are necessary, but the following acidity constants may be helpful: acetic acid, $K_a = 1.8 \times 10^{-5}$ NH_4^+, $K_a = 5.6 \times 10^{-10}$)

1988



A 30.00 milliliter sample of a weak monoprotic acid was titrated with a standardized solution of NaOH. A pH meter was used to measure the pH after each increment of NaOH was added, and the curve above was constructed.

(a) Explain how this curve could be used to determine the molarity of the acid.

(b) Explain how this curve could be used to determine the dissociation constant K_a of the weak monoprotic acid.

(c) If you were to repeat the titration using a indicator in the acid to signal the endpoint, which of the following indicators should you select? Give the reason for your choice.

Methyl red	$K_a = 1 \times 10^{-5}$
Cresol red	$K_a = 1 \times 10^{-8}$
Alizarin yellow	$K_a = 1 \times 10^{-11}$

(d) Sketch the titration curve that would result if the weak monoprotic acid were replaced by a strong monoprotic acid, such as HCl of the same molarity. Identify differences between this titration curve and the curve shown above.

1992

The equations and constants for the dissociation of three different acids are given below.

$HCO_3^- \leftrightarrows H^+ + CO_3^{2-}$ $K_a = 4.2 \times 10^{-7}$

$H_2PO_4^- \leftrightarrows H^+ + HPO_4^{2-}$ $K_a = 6.2 \times 10^{-8}$

$HSO_4^- \leftrightarrows H^+ + SO_4^{2-}$ $K_a = 1.3 \times 10^{-2}$

(a) From the systems above, identify the conjugate pair that is best for preparing a buffer with a pH of 7.2. Explain your choice.

(b) Explain briefly how you would prepare the buffer solution described in (a) with the conjugate pair you have chosen.

(c) If the concentrations of both the acid and the conjugate base you have chosen were doubled, how would the pH be affected? Explain how the capacity of the buffer is affected by this change in concentrations of acid and base.

(d) Explain briefly how you could prepare the buffer solution in (a) if you had available the solid salt of the only one member of the conjugate pair and solution of a strong acid and a strong base.

1998

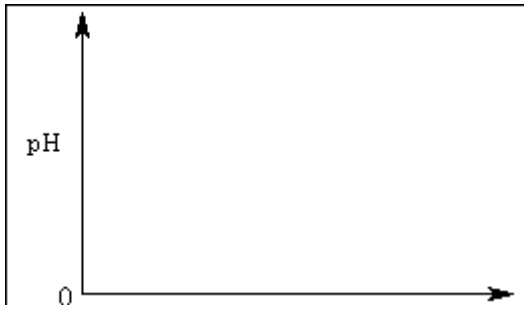
An approximately 0.1-molar solution of NaOH is to be standardized by titration. Assume that the following materials are available.

Clean, dry 50 mL buret	Analytical balance
250 mL Erlenmeyer flask	Phenolphthalein indicator solution
Wash bottle filled with distilled water	Potassium hydrogen phthalate, KHP, a pure solid monoprotic acid (to be used as the primary standard)

(a) Briefly describe the steps you would take, using materials listed above, to standardize the NaOH solution.

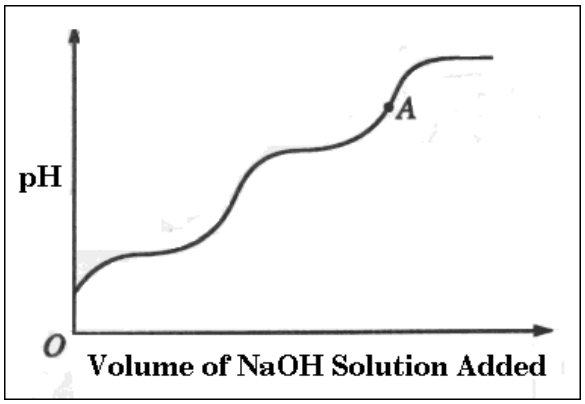
(b) Describe (i.e., set up) the calculations necessary to determine the concentration of the NaOH solution.

(c) After the NaOH solution has been standardized, it is used to titrate a weak monoprotic acid, HX. The equivalence point is reached when 25.0 mL of NaOH solution has been added. In the space provided at the right, sketch the titration curve, showing the pH changes that occur as the volume of NaOH solution added increases from 0 to 35.0 mL. Clearly label the equivalence point on the curve.



(d) Describe how the value of the acid-dissociation constant, K_a, for the weak acid HX could be determined from the titration curve in part (c).

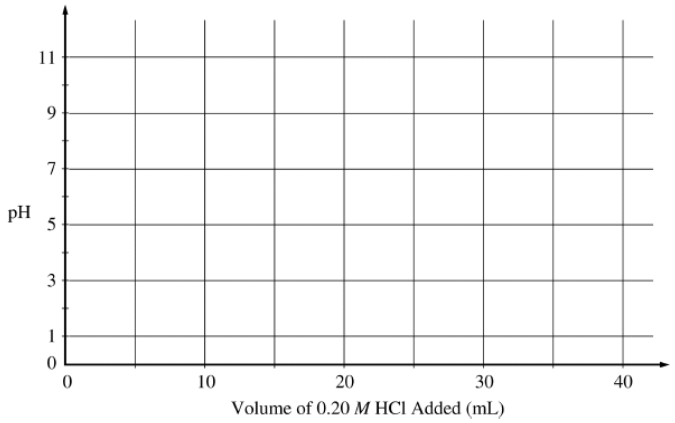
(e) The graph below shows the results obtained by titrating a different weak acid, H_2Y, with the standardized NaOH solution. Identify the negative ion that is present in the highest concentration at the point in the titration represented by the letter A on the curve.



2000

A volume of 30.0 mL of 0.10 *M* $NH_3(aq)$ is titrated with 0.20 *M* $HCl(aq)$. The value of the base-dissociation constant, K_b, for NH_3 in water is 1.8×10^{-5} at 25°C.

(a) Write the net-ionic equation for the reaction of $NH_3(aq)$ with $HCl(aq)$.
(b) Using the axes provided below, sketch the titration curve that results when a total of 40.0 mL of 0.20 *M* $HCl(aq)$ is added dropwise to the 30.0 mL volume of 0.10 *M* $NH_3(aq)$.



(c) From the table below, select the most appropriate indicator for the titration. Justify your choice.

Indicator	pK_a
Methyl Red	5.5
Bromothymol Blue	7.1
Phenolphthalein	8.7

(d) If equal volumes of 0.10 *M* $NH_3(aq)$and 0.10 *M* $NH_4Cl(aq)$ are mixed, is the resulting solution acidic, neutral, or basic? Explain.

Problems

1970

(a) What is the pH of a 2.0 molar solution of acetic acid. K_a acetic acid = 1.8×10^{-5}?
(b) A buffer solution is prepared by adding 0.10 liter of 2.0 molar acetic acid solution to 0.1 liter of a 1.0 molar sodium hydroxide solution. Compute the hydrogen ion concentration of the buffer solution.
(c) Suppose that 0.10 liter of 0.50 molar hydrochloric acid is added to 0.040 liter of the buffer prepared in (b). Compute the hydrogen ion concentration of the resulting solution.

1977

The value of the ionization constant, *Ka*, for hypochlorous acid, HOCl, is 3.1×10^{-8}.
(a) Calculate the hydronium ion concentration of a 0.050 molar solution of HOCl.
(b) Calculate the concentration of hydronium ion in a solution prepared by mixing equal volumes of 0.050 molar HOCl and 0.020 molar sodium hypochlorite, NaOCl.
(c) A solution is prepared by the disproportionation reaction below. $Cl_2 + H_2O \leftrightarrows HCl + HOCl$

Calculate the pH of the solution if enough chlorine is added to water to make the concentration of HOCl equal to 0.0040 molar.

1982

A buffer solution contains 0.40 mole of formic acid, HCOOH, and 0.60 mole of sodium formate, HCOONa, in 1.00 liter of solution. The ionization constant, K_a, of formic acid is 1.8×10^{-4}.

(a) Calculate the pH of this solution.
(b) If 100. milliliters of this buffer solution is diluted to a volume of 1.00 liter with pure water, the pH does not change. Discuss why the pH remains constant on dilution.
(c) A 5.00 milliliter sample of 1.00 molar HCl is added to 100. milliliters of the original buffer solution. Calculate the $[H_3O^+]$ of the resulting solution.
(d) A 800. milliliter sample of 2.00 molar formic acid is mixed with 200. milliliters of 4.80 molar NaOH. Calculate the $[H_3O^+]$ of the resulting solution.

1984

Sodium benzoate, C_6H_5COONa, is the salt of the weak acid, benzoic acid, C_6H_5COOH. A 0.10 molar solution of sodium benzoate has a pH of 8.60 at room temperature.

(a) Calculate the $[OH^-]$ in the sodium benzoate solution described above.
(b) Calculate the value for the equilibrium constant for the reaction:

$$C_6H_5COO^- + H_2O \leftrightarrows C_6H_5COOH + OH^-$$

(c) Calculate the value of K_a, the acid dissociation constant for benzoic acid.
(d) A saturated solution of benzoic acid is prepared by adding excess solid benzoic acid to pure water at room temperature. Since this saturated solution has a pH of 2.88, calculate the molar solubility of benzoic acid at room temperature.

1991

The acid ionization constant, K_a, for propanoic acid, C_2H_5COOH, is 1.3×10^{-5}.

(a) Calculate the hydrogen ion concentration, $[H^+]$, in a 0.20 molar solution of propanoic acid.
(b) Calculate the percentage of propanoic acid molecules that are ionized in the solution in (a).
(c) What is the ratio of the concentration of propanoate ion, $C_2H_5COO^-$, to that of propanoic acid in a buffer solution with a pH of 5.20?
(d) In a 100. milliliter sample of a different buffer solution, the propanoic acid concentration is 0.35 molar and the sodium propanoate concentration is 0.50 molar. To this buffer solution, 0.0040 mole of solid NaOH is added. Calculate the pH of the resulting solution.

1993

$$CH_3NH_2 + H_2O \leftrightarrows CH_3NH_3^+ + OH^-$$

Methylamine, CH_3NH_2, is a weak base that reacts according to the equation above. The value of the ionization constant, K_b, is 5.25×10^{-4}. Methylamine forms salts such as methylamonium nitrate, $(CH_3NH_3^+)(NO_3^-)$.

(a) Calculate the hydroxide ion concentration, $[OH^-]$, of a 0.225 molar aqueous solution of methylamine.
(b) Calculate the pH of a solution made by adding 0.0100 mole of solid methylamonium nitrate to 120.0 milliliters of a 0.225 molar solution of methylamine. Assume no volume change occurs.
(c) How many moles of either NaOH or HCl (state clearly which you choose) should be added to the solution in (b) to produce a solution that has a pH of 11.00? Assume that no volume change occurs.
(d) A volume of 100. milliliters of distilled water is added to the solution in (c). How is the pH of the solution affected? Explain.

1996

$$HOCl \leftrightarrows OCl^- + H^+$$

Hypochlorous acid, HOCl, is a weak acid commonly used as a bleaching agent. The acid-dissociation constant, K_a, for the reaction represented above is 3.2×10^{-8}.

(a) Calculate the $[H^+]$ of a 0.14-molar solution of HOCl.

(b) Write the correctly balanced net ionic equation for the reaction that occurs NaOCl is dissolved in water and calculate the numerical value of the equilibrium constant for the reaction.

(c) Calculate the pH of a solution made by combining 40.0 milliliters of 0.14-molar HOCl and 10.0 milliliters of 0.56-molar NaOH.

(d) How many millimoles of solid NaOH must be added to 50.0 milliliters of 0.20-molar HOCl to obtain a buffer solution that has a pH of 7.49? Assume that the addition of the solid NaOH results in a negligible change in volume.

(e) Household bleach is made by dissolving chlorine gas in water, as represented below.

$$Cl_2(g) + H_2O \leftrightarrows H^+ + Cl^- + HOCl(aq)$$

Calculate the pH of such a solution if the concentration of HOCl in the solution is 0.065 molar.

2001

Answer the following questions about acetylsalicylic acid, the active ingredient in aspirin.

(a) The amount of acetylsalicylic acid in a single aspirin tablet is 325 mg, yet the tablet has a mass of 2.00 g. Calculate the mass percent of acetylsalicylic acid in the tablet.

(b) The elements contained in acetylsalicylic acid are hydrogen, carbon, and oxygen. The combustion of 3.000 g of the pure compound yields 1.200 g of water and 3.72 L of dry carbon dioxide, measured at 750. mm Hg and 25°C. Calculate the mass, in g, of each element in the 3.000 g sample.

(c) A student dissolved 1.625 g of pure acetylsalicylic acid in distilled water and titrated the resulting solution to the equivalence point using 88.43 mL of 0.102 *M* NaOH(*aq*). Assuming that acetylsalicylic acid has only one ionizable hydrogen, calculate the molar mass of the acid.

(d) A 2.00×10^{-3} mole sample of pure acetylsalicylic acid was dissolved in 15.00 mL of water and then titrated with 0.100 *M* NaOH(*aq*). The equivalence point was reached after 20.00 mL of the NaOH solution had been added. Using the data from the titration, shown in the table below, determine

(i) the value of the acid dissociation constant, K_a , for acetylsalicylic acid and
(ii) the pH of the solution after a total volume of 25.00 mL of the NaOH solution had been added (assume that volumes are additive).

Volume of 0.100 *M* NaOH Added (mL)	pH
0.00	2.22
5.00	2.97
10.00	3.44
15.00	3.92
20.00	8.13
25.00	?

2002B

$$HC_3H_5O_3(aq) \leftrightarrows H^+(aq) + C_3H_5O_3^-(aq)$$

Lactic acid, $HC_3H_5O_3$, is a monoprotic acid that dissociates in aqueous solution, as represented by the equation above. Lactic acid is 1.66 percent dissociated in 0.50 *M* $HC_3H_5O_3$ (*aq*) at 298 K. For parts (a) through (d) below, assume the temperature remains at 298 K.

(a) Write the expression for the acid-dissociation constant, K_a , for lactic acid and calculate its value.

(b) Calculate the pH of 0.50 *M* $HC_3H_5O_3$.

(c) Calculate the pH of a solution formed by dissolving 0.045 mole of solid sodium lactate, $NaC_3H_5O_3$, in 250. mL of 0.50 M $HC_3H_5O_3$. Assume that volume change is negligible.

(d) A 100. mL sample of 0.10 M HCl is added to 100. mL of 0.50 *M* $HC_3H_5O_3$. Calculate the molar concentration of lactate ion, $C_3H_5O_3^-$, in the resulting solution.

2003

$$C_6H_5NH_2(aq) + H_2O(l) \leftrightarrows C_6H_5NH_3^+(aq) + OH^-(aq)$$

Aniline, a weak base, reacts with water according to the reaction represented above.

(a) Write the equilibrium constant expression, K_b , for the reaction represented above.

(b) A sample of aniline is dissolved in water to produce 25.0 mL of a 0.10 *M* solution. The pH of the solution is 8.82. Calculate the equilibrium constant, K_b , for this reaction.

(c) The solution prepared in part (b) is titrated with 0.10 *M* HCl. Calculate the pH of the solution when 5.0 mL of the acid has been added.

(d) Calculate the pH at the equivalence point of the titration in part (c).

(e) The pK_a values for several indicators are given below. Which of the indicators listed is most suitable for this titration? Justify your answer.

Indicator	pK_a
Erythrosine	3
Litmus	7
Thymolphthalein	10

2005

$$HC_3H_5O_2(aq) \leftrightarrows C_3H_5O_2^-(aq) + H^+(aq) \qquad K_a = 1.34 \times 10^{-5}$$

Propanoic acid, $HC_3H_5O_2$, ionizes in water according to the equation above.

(a) Write the equilibrium-constant expression for the reaction.

(b) Calculate the pH of a 0.265 *M* solution of propanoic acid.

(c) A 0.496 g sample of sodium propanoate, $NaC_3H_5O_2$, is added to a 50.0 mL sample of a 0.265 *M* solution of propanoic acid. Assuming that no change in the volume of the solution occurs, calculate each of the following.

(i) The concentration of the propanoate ion, $C_3H_5O_2^-(aq)$, in the solution
(ii) The concentration of the $H^+(aq)$ ion in the solution

The methanoate ion, $HCO_2^-(aq)$, reacts with water to form methanoic acid and hydroxide ion, as shown in the following equation.

$$HCO_2^-(aq) + H_2O(l) \leftrightarrows HCO_2H(aq) + OH^-(aq)$$

(d) Given that $[OH^-]$ is 4.18×10^{-6} *M* in a 0.309 *M* solution of sodium methanoate, calculate each of the following.

(i) The value of K_b for the methanoate ion, $HCO_2^-(aq)$

(ii) The value of K_a for methanoic acid, HCO_2H

(e) Which acid is stronger, propanoic acid or methanoic acid? Justify your answer.

2006B

$$C_6H_5COOH(s) \leftrightarrows C_6H_5COO^-(aq) + H^+(aq) \qquad K_a = 6.46 \times 10^{-5}$$

Benzoic acid, C_6H_5COOH, dissociates in water as shown in the equation above. A 25.0 mL sample of an aqueous solution of pure benzoic acid is titrated using standardized 0.150 *M* NaOH.

(a) After addition of 15.0 mL of the 0.150 *M* NaOH, the pH of the resulting solution is 4.37. Calculate each of the following.

(i) $[H^+]$ in the solution
(ii) $[OH^-]$ in the solution
(iii) The number of moles of NaOH added
(iv) The number of moles of $C_6H_5COO^-(aq)$ in the solution
(v) The number of moles of C_6H_5COOH in the solution

(b) State whether the solution at the equivalence point of the titration is acidic, basic, or neutral. Explain your reasoning.

In a different titration, a 0.7529 g sample of a mixture of solid C_6H_5COOH and solid NaCl is dissolved in water and titrated with 0.150 *M* NaOH. The equivalence point is reached when 24.78 mL of the base solution is added.

(c) Calculate each of the following.

(i) The mass, in grams, of benzoic acid in the solid sample
(ii) The mass percentage of benzoic acid in the solid sample