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Module 6: Acid/Base Reactions | Topic 4.4: Titrations

Foundation

1. In dot-point form and using the sub-headings provided below, describe the sequence of steps required to carry out an acid-base titration where an unknown HCl solution is in the conical flask and a standardised NaOH solution is in the burette.

   (a) Preparing and filling the burette

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   (b) Preparing and filling the conical flask

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   (c) Performing the acid-base titration

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2. In an experiment, 25.00 mL of acetic acid was titrated with a standardised 0.1200 mol L^{-1} potassium hydroxide solution. 27.50 mL of potassium hydroxide was required to reach the end point.

   (a) Write a chemical equation for the reaction between acetic acid and potassium hydroxide.

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   (b) Calculate the concentration of the unknown acetic acid solution.

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   ★ 0.1320 mol L^{-1} ★

3. Write a chemical equation for the following reactions:

   (a) An unknown diprotic acid (H_2X) completely reacting with sodium hydroxide solution.

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   (b) An unknown triprotic acid (H_3X) completely reacting with sodium hydroxide solution.

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Development

1. A household cleaning agent contains a weak base with the formula NaX. 1.00 g of this compound was dissolved in water to give 100.0 mL of solution. A 20.0 mL sample of the solution was titrated with 0.100 mol L^{-1} hydrochloric acid, and required 24.4 mL of the acid for neutralisation.

   What is the molar mass of the weak base?

   (a) 82.0 g mol^{-1}

   (b) 84.0 g mol^{-1}

   (c) 122 g mol^{-1}

   (d) 410 g mol^{-1}

2. To determine the concentration of a hydrochloric acid solution, the acid was titrated with a sodium carbonate standard solution. In this titration, the acid was in the conical flask while the base was in the burette.

   If the student rinsed the pipette used to deliver the hydrochloric acid solution with only water before using it, what effect will this have the calculated concentration of hydrochloric acid?

   (a) The calculated concentration will be unaffected

   (b) The calculated concentration will be too high

   (c) The calculated concentration will be too low

   (d) More information is required to determine the effect on the calculated concentration

3. In a titration between an unknown strong base and a standardised strong acid, the following procedure was used:

   - A burette was rinsed with water and then filled with the standard acid solution.
   - A pipette was rinsed with some water and then with the unknown base solution.
   - A conical flask was rinsed with some unknown base solution.
   - The rinsed pipette was used to transfer 25.00 mL of the unknown base solution into the conical flask.
   - An appropriate indicator was added to the base sample and it was titrated to the end point with the acid.

   Which of the following statements is correct?

   (a) The calculated base concentration will be correct

   (b) The calculated base concentration will be too low

   (c) The calculated base concentration will be too high

   (d) No definite conclusion can be reached about the base concentration

4. A bottle contained an unknown triprotic acid with a molar mass of 192.12 $g\,mol^{-1}$. 25.00 mL of this acid was titrated with 0.550 $molL^{-1}$ NaOH and the average titre was found to be 14.75 mL.

   What is the concentration of the unknown acid?

   (A) 0.520 $g\,L^{-1}$

   (B) 20.8 $g\,L^{-1}$

   (C) 62.5 $g\,L^{-1}$

   (D) 187 $g\,L^{-1}$

5. A student performed a titration to determine the concentration of a phosphoric acid solution. 10.0 mL of the acid solution was diluted to 200.0 mL in a volumetric flask. A 20.0 mL aliquot of this diluted acid was then titrated against a standardised 0.930 $mol\,L^{-1}$ NaOH solution to the phenolphthalein end point. The results are shown in the table below.

Titration	**Volume of NaOH used (mL)**
1	22.4
2	21.4
3	21.2
4	21.3

   (a) Briefly outline a suitable method that could have been used to standardise the NaOH solution. **2**

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   (b) Calculate the concentration of the phosphoric acid solution. **3**

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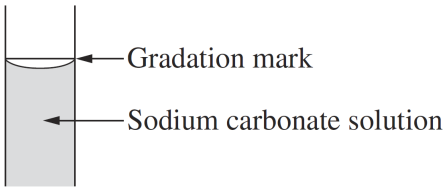
   ★ 6.60 $mol\,L^{-1}$ ★

6. A student determined the concentration of a HCl solution by using the following method.

   1. A conical flask was rinsed with distilled water.
   2. A 25.0 mL pipette was rinsed with distilled water.
   3. The student filled the pipette with a standard Na_2CO_3 solution to the level shown in the diagram.



   4. The standard Na_2CO_3 solution in the pipette was transferred to the conical flask. The student ensured that all of the Na_2CO_3 solution was transferred to the conical flask by blowing through the pipette.
   5. A few drops of methyl orange indicator was added to the conical flask.
   6. A burette was rinsed with distilled water and then with the unknown HCl solution. The student then carried out a titration to determine the concentration of the HCl solution.

During this experiment, the student made several mistakes.

(a) Identify the mistake the student made in Step 4 and propose a change to this step that would improve the validity of his method. **2**

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(b) Explain how the mistakes made in both Steps 2 and 3 will affect the calculation of the concentration of the HCl solution. **3**

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7. The concentration of hydrochloric acid in a solution was determined by an acid-base titration using a standard solution of sodium carbonate.

A 25.00 mL sample of 0.1050 mol L^{-1} sodium carbonate solution was added to a conical flask and three drops of methyl orange indicator added. The mixture was titrated with the hydrochloric acid and the following readings were recorded.

Titration	**Titre (mL)**
1	22.00
2	21.65
3	21.70
4	21.60

(a) Calculate the concentration of the hydrochloric acid. **3**

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(b) Explain the effect on the calculated concentration of hydrochloric acid if phenolphthalein is used as the indicator instead of methyl orange. **2**

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★ 0.2425 mol L^{-1} ★

8. A manufacturer makes lemon cordial by mixing flavouring, sugar syrup and citric acid. The concentration of the citric acid is determined by titration with NaOH.

The sodium hydroxide solution is prepared by dissolving 4.000 g of NaOH pellets in water to give 1.000 L of solution. This solution is standardised by titrating 25.00 mL with a 0.1011 mol L^{-1} standardised solution of HCl. The average titration volume is found to be 24.10 mL.

To analyse the lemon cordial 50.00 mL of the cordial is diluted to 500.0 mL. Then 25.00 mL of the diluted solution is titrated with the NaOH solution to the phenolphthalein endpoint.

The following data were collected during one of the analysis runs of the lemon cordial.

Titration #1 volume	26.55 mL
Titration #2 volume	27.25 mL
Titration #3 volume	27.30 mL
Titration #4 volume	27.20 mL

(a) Calculate the expected concentration of the NaOH solution using the mass data. **1**

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(b) Calculate the concentration of the standardised NaOH solution by using the appropriate titration data and account for any discrepancies between this value and the value calculated in part (a). **2**

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(c) Calculate the concentration of citric acid in the lemon cordial. **3**

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★ 0.1000 mol L^{-1}, 0.09746 mol L^{-1}, 0.3541 mol L^{-1} ★

9. A 0.2845 g sample of impure Na_2CO_3 was titrated against a previously standardised solution of HCl. 24.65 mL of HCl solution was required to reach the end point. When a 0.2204 g sample of pure Na_2CO_3 was titrated against the same HCl solution, 20.06 mL of HCl was required to reach the end point. **4**

Calculate the percentage by mass of sodium carbonate in the impure sample.

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★ 95.20% ★

10. The nitrogen content of bread was determined using the following procedure:

- A sample of bread weighing 2.80 g was analysed.
- The nitrogen in the sample was converted into ammonia.
- The ammonia was collected in 50.0 mL of 0.125 mol L^{-1} hydrochloric acid. All of the ammonia was neutralised, leaving an excess of hydrochloric acid.
- The excess hydrochloric acid was titrated with 23.30 mL of 0.116 mol L^{-1} NaOH solution.

(a) Write chemical equations for the TWO reactions involving hydrochloric acid. **2**

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(b) Calculate the number of moles of excess hydrochloric acid. **1**

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(c) Calculate the number of moles of ammonia. **2**

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(d) Calculate the percentage by mass of nitrogen in the bread. **2**

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★ 2.70×10^{-3} mol, 3.55×10^{-3} mol, 1.77% ★

11. A solution of hydrochloric acid was standardised by titration against a sodium carbonate solution using the following procedure.

- All glassware was rinsed correctly to remove possible contaminants.
- Hydrochloric acid was placed in the burette.
- 25.0 mL of sodium carbonate solution was pipetted into the conical flask.

The titration was performed and the hydrochloric acid was found to be 0.200 mol L^{-1}.

(a) Identify the substance used to rinse the conical flask and justify your answer. **2**

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(b) Seashells contain a mixture of carbonate compounds. The standardised hydrochloric acid was used to determine the percentage by mass of carbonate in a seashell using the following procedure. **4**

- A 0.145 g sample of the seashell was placed in a conical flask.
- 50.0 mL of the standardised hydrochloric acid was added to the conical flask.
- At the completion of the reaction, the mixture in the conical flask was titrated with 0.250 mol L^{-1} sodium hydroxide.

The volume of sodium hydroxide used in the titration was 29.5 mL.

Calculate the percentage by mass of carbonate in the sample of the seashell.

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★ 54.3% ★

12. A student was asked to deduce the identity of an unknown precipitate that has a chemical formula of $Fe(OH)_n$ where n is a positive integer. The method used by the student used is outlined below. **4**

- 1.010 g of pure solid $Fe(OH)_n$ was mixed with 20.00 mL of 2.000 mol L^{-1} HCl. All of the $Fe(OH)_n$ was neutralised, leaving behind an excess of HCl.
- The excess HCl was transferred into a 200.0 mL volumetric flask and then distilled water was added until the base of the meniscus was on the engraved mark.
- A 25.00 mL aliquot of the solution from the volumetric flask was then titrated with a previously standardised 0.1000 mol L^{-1} KOH solution. The average titre was 14.56 mL.

Calculate the value of n.

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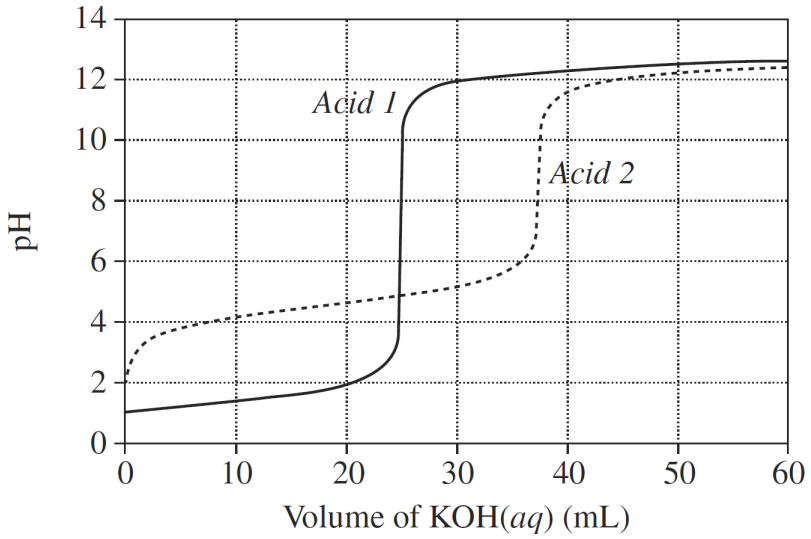
★ 3 ★

13. The graph shows changes in pH for the titrations of equal volumes of solutions of two monoprotic acids, *Acid 1* and *Acid 2*.



(a) Explain the differences between *Acid 1* and *Acid 2* in terms of their relative strengths and concentrations. **3**

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(b) Name the salt produced by the reaction of an acid of the same type as *Acid 2* with KOH. **1**

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(c) Calculate the concentration of hydrogen ions in the titrating mixture when 20 mL of KOH has been added to *Acid 1*. **1**

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(d) Why would phenolphthalein be a suitable indicator for both titrations? **1**

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★ 0.01 mol L^{-1} ★

Extension (Optional)

1. A student is attempting to work out the identity of an unknown acid with a chemical formula of H_nXO_3 where n is a positive integer and X is a non-metallic element which can either be phosphorous (P), sulfur (S), carbon (C) or nitrogen (N). To determine the identity of the acid, the student performs a series of titrations. **7**

   The student first prepares a secondary standard solution of NaOH by titrating 25.00 mL of NaOH against a 0.09756 mol L^{-1} solution of potassium hydrogen phthalate. The average titre was 27.25 mL. Note that potassium hydrogen phthalate is a monoprotic acid.

   The student then dissolves 2.569 g of H_nXO_3 in sufficient water to make a 250.0 mL solution. This solution of H_nXO_3 was titrated with 25.00 mL of the standardised NaOH solution and the average titre was found to be 16.31 mL.

   Using relevant calculations, deduce the identity of the unknown acid.

★ HNO_3 ★

2. Amino acids are named so because they contain a basic amine group ($-NH_2$) and an acidic carboxyl group ($-COOH$).

Glycine is the simplest amino acid with chemical formula NH_2CH_2COOH. At different pH levels, glycine exists in different forms and these are summarised in the points below.

- In a solution with a low pH, both the amine and the carboxyl group of glycine are protonated so glycine exists as a cation ($^+NH_3CH_2COOH$).
- In a solution with an intermediate pH, the amine group is protonated and the carboxyl group is deprotonated so glycine exists in a zwitterionic form ($^+NH_3CH_2COO^-$).
- In a solution with a high pH, both the amine and the carboxyl group are deprotonated so glycine exists as an anion ($NH_2CH_2COO^-$).

During a university lab, a student titrated a solution of glycine with a NaOH solution, starting from a low pH.

(a) Write TWO net ionic equations to represent the stepwise neutralisation reactions which occur during the titration. **2**

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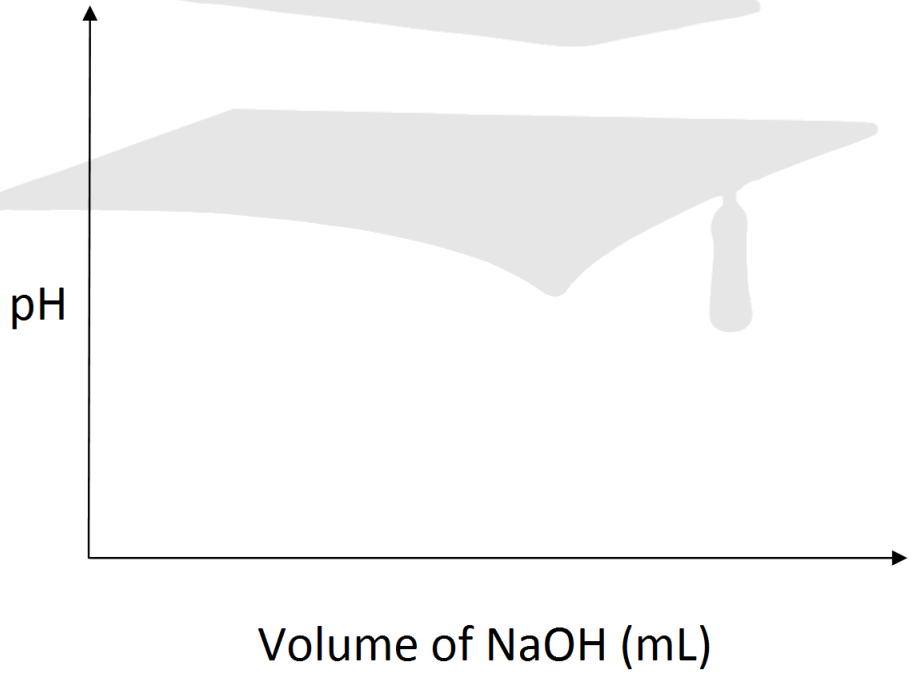
(b) Sketch a titration curve for a solution of glycine being titrated against a NaOH solution, starting from a low pH. Label the equivalence points on the titration curve. **2**



Note that no specific calculations are necessary for this part.