ACID-BASE TITRATIONS

PAST EXAM QUESTIONS

Syllabus:

- volumetric analysis methods involving acid-base reactions rely on the identification of an equivalence point by measuring the associated change in pH, using appropriate acid-base indicators or pH meters, to reveal an observable end point

- data obtained from acid-base titrations can be used to calculate the masses of substances and concentrations and volumes of solutions involved

- identify and distinguish between random and systematic errors, and estimate their effect on measured results

WACE 2016 Sample Exam Q9:

Bromophenol blue is an acid-base indicator that has a colour change from yellow to blue between pH 3.0 and 4.6. A sodium hydroxide solution (in a conical flask) is titrated with an acetic (ethanoic) acid solution (in a burette), using bromophenol blue indicator.

Which one of the following statements about this titration is true?

    (a) The end point and the equivalence point occur at the same time
    (b) The end point occurs after the equivalence point
    (c) The end point occurs before the equivalence point
    (d) The indicator will be yellow at the equivalence point of the titration

WACE 2016 Sample Exam Q11:

20 mL of 0.10 mol L^{-1} hydrochloric acid is mixed with 20.0 mL of 0.10 mol L^{-1} sodium hydroxide in a glass beaker. The volumes are measured using a 50.0 mL measuring cylinder. The temperature rise that occurred is measured and used to calculate the enthalpy change for the reaction. Which one of the following statements is correct?

    (a) Systematic error will be reduced by repeating the experiment several times and averaging the results
    (b) Random error will be reduced by using a 20.0 mL graduated pipette instead of the 50.0 mL measuring cylinder
    (c) Random error will be reduced by insulating the beaker
    (d) Systematic error will be increased by doubling the volume of the solution

WACE 2015 Q21:

Five trials resulting in the following titres were obtained using a burette in an acid-base titration.

Trial	1	2	3	4	5
Titre volume (mL)	37.52	36.98	36.95	36.76	37.03

Which of the trials should be used to calculate the average titre?

    (a) 2, 3 only
    (b) 2, 3, 4 only
    (c) 2, 3, 5 only
    (d) 1, 2, 3, 4, 5

WACE 2013 Q19:

The pH ranges for the colour change of four indicators are given below.

Alizarin yellow	10.1 – 12.0
Crystal violet	6.4 – 8.2
Bromocresol green	3.8 – 5.4
Malachite green	0.2 – 1.8

Which one of the indicators in the table is **most** suitable for the titration of hydrochloric acid with potassium carbonate solution?

(a) Alizarin yellow
(b) Crystal violet
(c) Bromocresol green
(d) Malachite green

TEE 2009 Q19:

A 20.0 mL aliquot of 0.100 mol L^{-1} sodium carbonate solution is titrated with hydrochloric acid with an approximate concentration of 0.1 mol L^{-1} in the presence of methyl orange indicator. The colour for methyl orange over a range of pH values is given below.

pH	1 – 3.3	3.3 – 4.4	4.4 – 14
Colour	Red	Orange	Yellow

Which one of the following describes what will be observed?

(a) The colour changes from yellow to orange after about 40 mL of the acid has been added
(b) The colour changes from yellow to orange after about 20 mL of the acid has been added
(c) The colour changes from yellow to red after about 20 mL of the acid has been added
(d) The colour changes from red to yellow after about 40 mL of the acid has been added

TEE 2000 Q15:

Which of the following best describes the equivalence point in an acid-base titration?

(a) The point at which chemical equilibrium is reached and no further reaction will occur
(b) The point at which equal moles of reactants have been mixed
(c) The point at which the indicator changes colour
(d) The point at which the stoichiometric amount of reactant has been added

TEE 2009 Q12:

A group of students conducted a series of titrations using the following steps:

 I.   Washed burette with distilled water and a small quantity of acid before filling with acid
 II.   Washed the pipette with distilled water before filing with base
 III.   Washed the conical flasks with distilled water and a small quantity of base before adding the base from the pipette
 IV.   Rinsed the sides of the conical flasks with distilled water during the titrations
 V.   Added two drops of indicator to each conical flask

The students found they could not obtain consistent results. Which of the above steps could have been responsible for the errors?

 (a) I and V only
 (b) II and III only
 (c) II, III and IV only
 (d) I, II and IV only

TEE 2006 Q13:

A student obtained the following results when titrating hydrochloric acid solution with 20.00 mL of sodium hydroxide solution.

	Trial 1	**Trial 2**	**Trial 3**	**Trial 4**
Vol of HCl (mL)	21.3	22.4	20.5	20.9

Which one of the following could lead to such a set of results?

 (a) Using only a few drops of indicator
 (b) Washing the conical flasks with distilled water and then rinsing with a small amount of sodium hydroxide solution
 (c) Always reading from the bottom of the meniscus in the burette
 (d) Washing the burette with water and then rinsing with hydrochloric acid solution

TEE 2002 Q23:

Which one of the following is **true** of a standard solution?

 (e) It must contain a primary standard substance
 (f) It must contain hydrochloric acid
 (g) It must have an accurately known concentration
 (h) It must have a concentration of 0.100 mol L^{-1}

TEE 2003 Q27:

Consider the following three statements about neutralisation reactions.

      I.   A neutralisation reaction is a reaction between an acid and a base
      II.   At the equivalence point of a neutralisation reaction the pH of the resulting solution will be 7
      III.   Salts are obtained from neutralisation reactions.

Which statement or combination of statements is always correct?

    (a) Only I
    (b) Only I and II
    (c) Only I and III
    (d) I, II and III

VCE 2015 Q1:

Which one of the following graphs represents the pH change when a weak acid is added to a strong base?
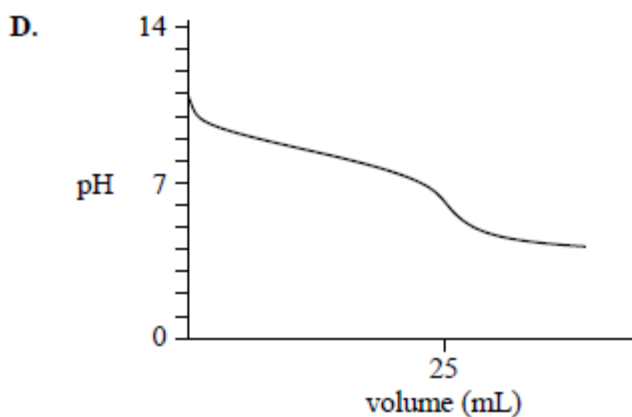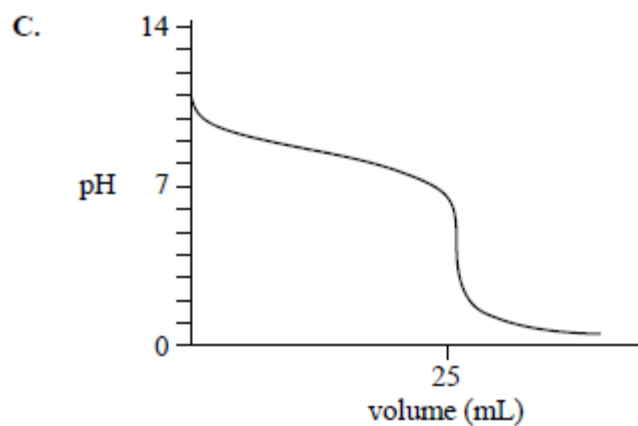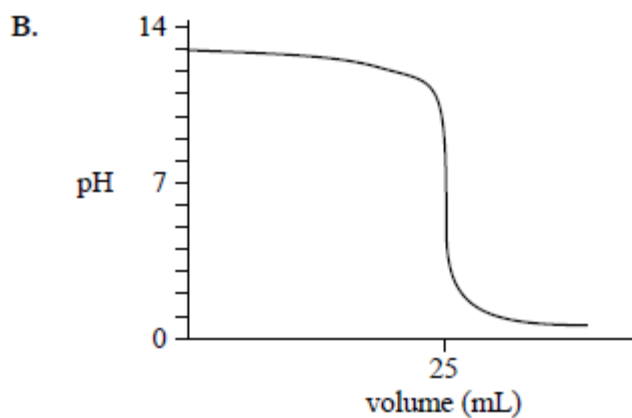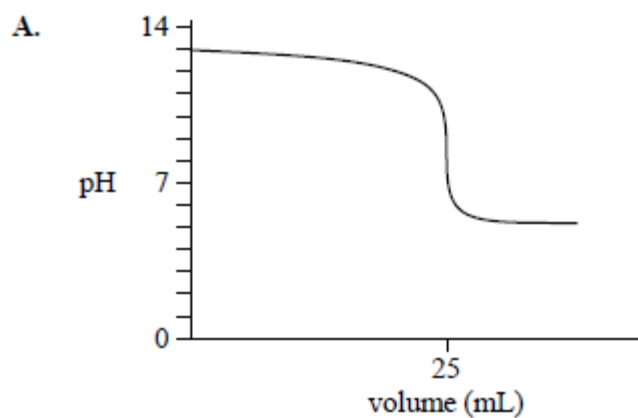
HSC 2015 Q14:

The graph shows the changes in pH during a titration.
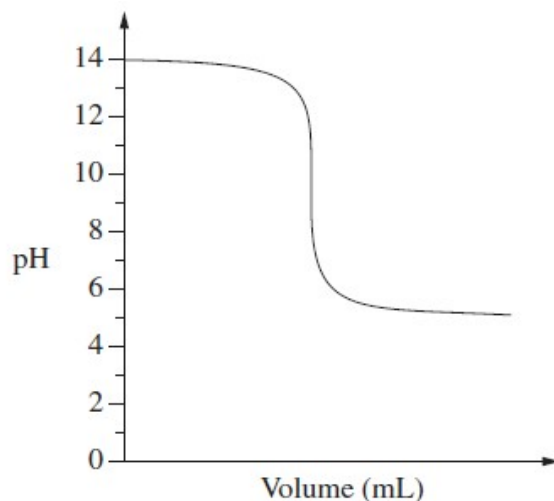
Which pH range should an indicator have to be used in this titration?

   (a) 3.1–4.4
   (b) 5.0–8.0
   (c) 6.0–7.6
   (d) 8.3–10.0

VCE 2014 Q6:

The diagram below represents the titration curve for the reaction between a particular acid and a particular base.
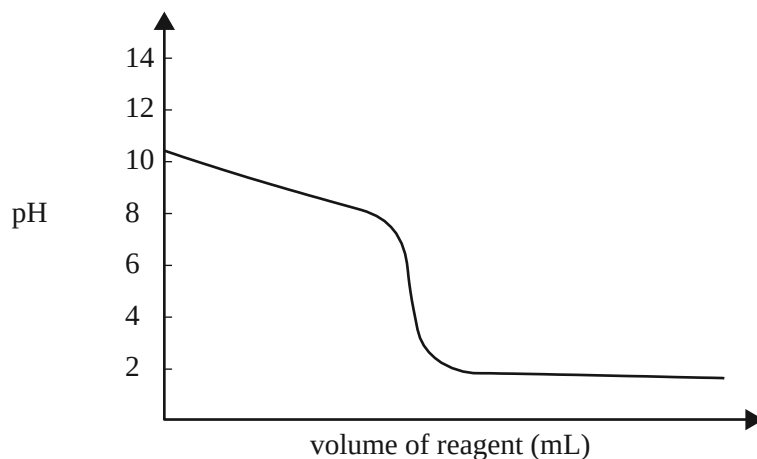
The equation that best represents the reaction described by the titration curve is:

   (a) $HCl(aq) + NH_3(aq) \rightarrow NH_4Cl(aq)$
   (b) $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$
   (c) $CH_3COOH(aq) + NH_3(aq) \rightarrow CH_3COONH_4(aq)$
   (d) $CH_3COOH(aq) + NaOH(aq) \rightarrow CH_3COONa(aq) + H_2O(l)$

VCE 2011 Q11:

Two titrations were performed as shown below.
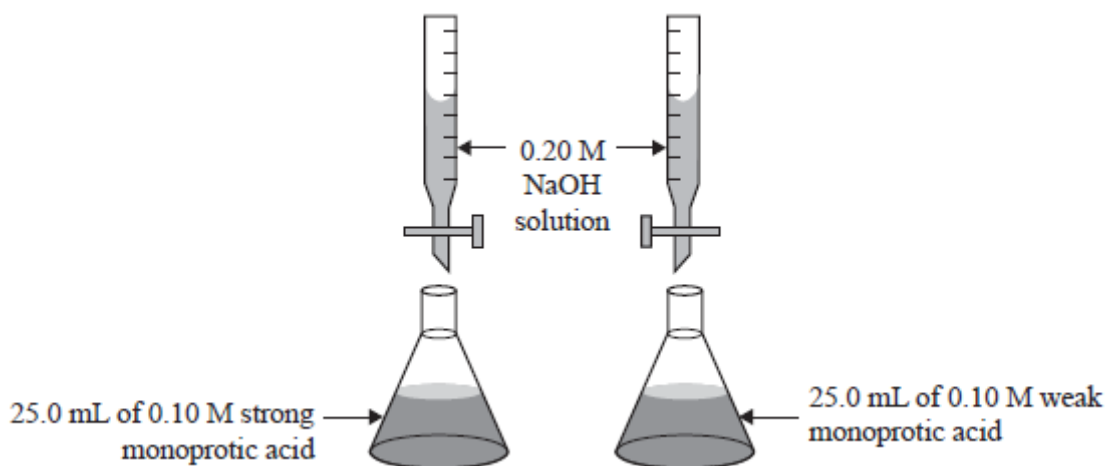
Which of the following statements is true?

- (a) The weak acid will require a greater volume of NaOH solution than the strong acid to reach the equivalence point
- (b) The weak acid will require a smaller volume of NaOH solution than the strong acid to reach the equivalence point
- (c) The weak acid will require the same amount of NaOH solution as the strong acid to reach the equivalence point
- (d) The equivalence point in a titration of a weak monoprotic acid with NaOH solution cannot be determined

VCE 2008 Q1:

The diagram shows a section of a 50.00 mL burette containing a colourless solution.

The reading indicated on the burette is closest to:

- (a) 14.50
- (b) 14.58
- (c) 15.42
- (d) 15.50

WACE 2012 Q37:

Oxalic acid dihydrate ($H_2C_2O_4.2H_2O$) is substance which can be used to create primary standards for acid-base titrations.

(a) List **two** properties of oxalic acid that make it a good primary standard. (2 marks)

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(b) A student was asked to prepare a standard solution of oxalic acid of approximate concentration 0.05 mol L^{-1}. The equipment listed below was available.

Electronic balance   Distilled water (20 L)
Beakers (20 mL, 50 mL, 100 mL, 250 mL)   Stirring rod
Volumetric flasks (250 mL, 500 mL)   Wash bottle
Oxalic acid ($H_2C_2O_4.2H_2O$) (5 g)   Weighing boats

Give a step-by-step, detailed description of a procedure for preparing the standard oxalic acid solution. Perform and include any necessary calculations. (7 marks)

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TEE 2009 Q6:

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Section 2: Short Answer

A student titrated an approximate 0.1 mol L^{-1} solution of hydrochloric acid against a standard solution of 0.200 mol L^{-1} sodium carbonate in order to determine the exact concentration of the acid.

The reaction occurring in the titration is shown below:

$$Na_2CO_3 \ + \ 2\,HC\ell \ \rightarrow \ 2\,NaC\ell \ + \ CO_2 \ + \ H_2O$$
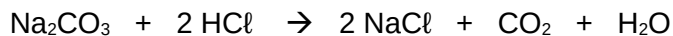
The student rinsed a 50 mL burette with distilled water and filled it with hydrochloric acid. He also rinsed a conical flask with distilled water and pipetted 25.0 mL of the sodium carbonate solution into the conical flask. A few drops of phenolphthalein were then added to the conical flask. He added the hydrochloric acid from the burette into the conical flask until there was a permanent colour change.

The student made two mistakes in his method. Complete the table below by stating:

- each mistake
- the effect the mistake had on the volume of HCℓ delivered from the burette
- why the volume of HCℓ was affected in the way stated
- the correct technique   (8 marks)

	Mistake 1	Mistake 2
Description of mistake		
Effect on volume of HCℓ		
Reason HCℓ volume is affected as stated above		
Correct technique		

TEE 2006 Q12:

Briefly explain why methyl orange is an inappropriate indicator to use in a titration between sodium hydroxide and acetic acid. (3 marks)

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TEE 2004 Q9:

Sodium carbonate is used as a primary standard in acid-base titrations, while sodium hydroxide is not. Explain why this is so. (4 marks)

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TEE 2000 Q5:

Answer the following questions about primary standards used in volumetric analysis.   (3 marks)

What are two characteristics of a primary standard?

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Why is a primary standard often required for use in volumetric analysis?

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VCE 2013 Q5:

A 20.00 mL aliquot of 0.200 mol L^{-1} CH_3COOH (ethanoic acid) is titrated with 0.150 mol L^{-1} NaOH. The equation for the reaction between ethanoic acid and NaOH solution is represented as:

$$OH^-(aq) + CH_3COOH(aq) \rightarrow H_2O(\ell) + CH_3COO^-(aq)$$
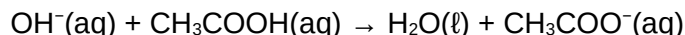
(a) What volume of the NaOH solution is required to completely react with the ethanoic acid?   (2 marks)

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(b) Define the terms 'equivalence point' and 'end point'.   (2 marks)

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Section 2: Short Answer

VCE 2008 Q8:

0.415 g of a pure acid, $H_2X(s)$, is added to exactly 100 mL of 0.105 mol L^{-1} NaOH(aq).

A reaction occurs according to the equation:

$$H_2X(s) \; + \; 2\,NaOH(aq) \; \rightarrow \; Na_2X(aq) \; + \; 2\,H_2O(\ell)$$
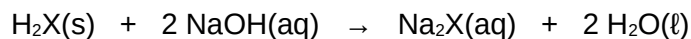
The NaOH is in excess. This excess NaOH requires 25.21 mL of 0.197 mol L^{-1} HCℓ(aq) for neutralisation.

(a) Calculate the amount, in mol, of NaOH that is added to the acid H_2X initially. (1 mark)

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(b) Calculate the amount, in mol, of NaOH that reacts with the acid H_2X. (2 marks)

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(c) Calculate the molar mass, in g mol^{-1}, of the acid H_2X. (2 marks)

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HSC 2015 Q26:

A sodium hydroxide solution was titrated against citric acid ($C_6H_8O_7$) which is triprotic.

(c) The sodium hydroxide solution was titrated against 25.0 mL aliquots of 0.100 mol L^{-1} citric acid. The average volume of sodium hydroxide used was 41.50 mL.

Calculate the concentration of the sodium hydroxide solution.   (4 marks)

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WACE 2016 Sample Exam Q38:

A student set out to compare the effectiveness of a given quantity of two antacid preparations, one containing $Mg(OH)_2$ and the other $A\ell(OH)_3$, purchased from his local pharmacy.

He titrated each preparation against a hydrochloric acid solution to determine how much acid each could neutralize and to determine the concentration of the active ingredient in each preparation. He first standardised the hydrochloric acid solution available in the laboratory against a primary standard, and he chose anhydrous sodium carbonate as the primary standard.

(a) Give **two** reasons why anhydrous sodium carbonate is an appropriate standard.   (2 marks)

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The student prepared 1.00 L of a 0.0248 mol L^{-1} Na_2CO_3 solution. He titrated three 25.0 mL aliquots of this solution against the $HC\ell$ and found an average titre of 24.35 mL

(b) Calculate the concentration of the standardised $HC\ell$ solution.   (4 marks)

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Section 3: Extended Answer

(c) Below is a list of common errors that can occur in titrations. From this list select **one** source of random error and **one** source of systematic error and explain your choice in the tables below.

- Reading of burette
- Bubbles in the pipette
- Not drying Na_2CO_3 in an oven prior to its use as a primary standard
- Rinsing all glassware with distilled water
- Incorrect indicator
- Perception of colour change at the end point

(4 marks)

Random error	Why error is classified as random

Systematic error	Why error is classified as systematic

The antacid suspensions were thoroughly shaken and 20.0 mL of each transferred to separate 250.0 mL volumetric flasks. Both were made up to the mark with distilled water and shaken vigorously. 10.0 mL aliquots of the diluted suspensions were transferred to conical flasks for titration and an appropriate indicator added.

The titre values obtained for the $Al(OH)_3$ suspension are shown in the table below:

Titre volume HCℓ (mL)				Average titre volume (mL)
Trials				
1	2	3	4	
22.62	21.98	21.94	21.90	21.94

(d) Account for the need for four trials in the titration. (1 mark)

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(e) i. Calculate the concentration, in moles per litre (mol L^{-1}), of $Al(OH)_3$, in the original $Al(OH)_3$ suspension. (5 marks)

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ii. From his titration of the Mg(OH)$_2$ diluted suspension, the student found the mass of Mg(OH)$_2$ in the 250 mL **diluted** suspension to be 1.13 g. Determine the concentration of Mg(OH)$_2$ in the original **undiluted** suspension and express your answer in moles per litre (mol L^{-1}). (2 marks)

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(f) Which of the preparations would be more effective (neutralize more HCℓ) for a given volume? Show your workings. (4 marks)

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WACE 2015 Q36:

Aspirin (chemical name: acetylsalicylic acid) is one of the most popular and readily available pain-relieving drugs. The chemical formula is aspirin is $C_9H_8O_4$.

(b) In one commercial brand of aspirin, each '300 mg tablet' is claimed to contain 100% aspirin. To determine the actual percentage by mass of aspirin in an aspirin tablet, the following procedure, involving a back titration, was used.

Step 1: Three aspirin tablets, each with a mass of 300.0 mg, were crushed and dissolved in excess sodium hydroxide solution. Exactly 100.0 mL of 0.204 mol L^{-1} solution of sodium hydroxide was used. The mixture was boiled to ensure complete reaction.

Step 2: The excess sodium hydroxide solution was titrated with hydrochloric acid as follows: 20.0 mL of the solution from step 1 was pipetted into a conical flask and 0.125 mol L^{-1} hydrochloric acid was placed in the burette. The indicator, phenolphthalein, was used and an average titre of 17.89 mL of hydrochloric acid was required to reach the end-point.

Notes:
  * Assume that any other chemicals present in an aspirin tablet are inert and will not react with either NaOH(aq) or HCℓ(aq).
  * Phenolphthalein is colourless at pH less than 8.3 and pink at pH greater than 10.0.

(i) This is a titration between a strong acid and a strong base. Strong acid-strong base titrations typically result in an equivalence point with a pH close to 7. Phenolphthalein was chosen as the indicator for this titration. Considering all of the species present in the solution at the equivalence point, explain why phenolphthalein is a suitable indicator to show the end-point. Support you answer with a suitable equation. (3 marks)

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Section 3: Extended Answer

(ii)   Calculate how many moles of hydroxide ions reacted with the aspirin.   (5 marks)

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(iii) Each aspirin molecule requires two hydroxide ions for complete reaction. Calculate the
       percentage by mass of aspirin in one aspirin tablet. (The molar mass of aspirin is
       180.154 g mol^{-1}).   (4 marks)

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An important procedure in volumetric analysis is the washing of equipment with the appropriate solution
prior to the titration in order to minimize experimental error.

(b) Before performing the experiment, the glassware was washed with the solutions given in the table.
    Complete the table below by stating the effect of the washing.   (4 marks)

Washing procedure	Effect on the volume of hydrochloric acid used	Effect on the % of aspirin calculated
The conical flask was washed with distilled water		

The burette was washed with distilled water		

WACE 2014 Question 40:

Citric acid is the active ingredient in some bathroom and kitchen cleaning solutions. A student determined the content of citric acid in a cleaner by titration with sodium hydroxide solution.

The sodium hydroxide solution first needed to be standardised. To do this, the student dissolved approximately 4 g of sodium hydroxide pellets in water, to give an approximately 0.1 mol L^{-1} solution. This solution was standardised by titrating 20.00 mL of the NaOH solution with a 0.105 mol L^{-1} standard hydrochloric acid solution. The average titration volume was 17.45 mL.

(a) Explain why sodium hydroxide is not suitable as a primary standard.   (2 marks)

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(b) Show that the concentration of the sodium hydroxide solution is 0.0916 mol L^{-1}. Show sufficient workings to justify your answer.   (3 marks)

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The student then weighed a 10.00 mL aliquot of the cleaner and found it weighed 10.4 g. This 10.00 mL aliquot was next diluted to 100.0 mL in a volumetric flask. Against the standardized sodium hydroxide solution, 20.00 mL aliquots of the diluted cleaner were titrated. The table below shows the results of the titrations.

Titre	1	2	3	4
Final reading (mL)	25.30	23.55	22.40	22.25
Initial reading (mL)	3.50	2.70	1.50	1.30
Titre volume (mL)				

(c) Calculate the average titre volume to be used in the calculation of the citric acid content.   (2 marks)

Section 3: Extended Answer

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(d) Given that citric acid ($C_6H_8O_7$) is a weak triprotic acid, determine the percentage composition by mass of citric acid in the cleaner. The molar mass of citric acid is 192.124 g mol^{-1}. (6 marks)

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(e) Select a suitable indicator for this titration from the table below. Explain your choice. (2 marks)

Indicator	Colour change (low pH – high pH)	pH range
Methyl yellow	red-yellow	2.4 – 4.0
Litmus	red-blue	5.0 – 8.0
Bromothymol blue	yellow-blue	6.0 – 7.6
Thymol blue	yellow-blue	8.0 – 9.6

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Section 3: Extended Answer

TEE 2008 Calculation Q3:

A bottle of anhydrous oxalic acid ($H_2C_2O_4$) was found to be contaminated with potassium chloride. 2.05 g of the mixture was dissolved in distilled water and the volume made up to 250.0 mL in a volumetric flask. 20.0 mL aliquots of the solution were titrated against 0.115 mol L^{-1} sodium hydroxide solution and the following results were obtained:

	TITRATION			
	1	2	3	4
Final volume (mL)	32.05	32.10	31.11	33.25
Initial volume (mL)	0.50	2.45	1.40	3.65
Titre (mL)				

(a) Write an equation for the reaction between oxalic acid and sodium hydroxide. (1 mark)

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(b) Complete the table. (1 mark)

(c) Calculate the average titre. (1 mark)

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(d) Calculate the concentration of the oxalic acid solution. (3 marks)

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(e) Calculate the percentage purity of the oxalic acid mixture.   (2 marks)

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(f)   What would be an appropriate indicator for this titration? Justify your answer.   (2 marks)

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TEE 2005 Calculation Q5:

(a) A hydrochloric acid solution was standardised by titrating 10.00 mL of it against a 0.106 mol L^{-1} sodium hydroxide solution. The following results were obtained.

	Volume of NaOH solution			
	1	2	3	4
Final volume (mL)	37.56	37.18	38.53	37.27
Initial volume (mL)	0.50	1.22	2.55	1.33
Titre (mL)				

Calculate the concentration of the hydrochloric acid solution. (3 marks)

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(b) A sample of magnesium oxide was found to be contaminated with sodium chloride. Magnesium oxide is not very soluble in water by can be dissolved in an excess of the standardised hydrochloric acid.

In order to determine the purity of the magnesium oxide, 3.86 g of the sample was dissolved in 500.0 mL of hydrochloric acid solution and then 50.0 mL of the resulting solution was titrated against the sodium hydroxide solution of known concentration. The average titre was found to be 10.4 mL.

Calculate the percentage of magnesium oxide in the contaminated sample. (8 marks)

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TEE 1998 Calculation Q4:

The Kjeldahl method is used to analyse for nitrogen in an organic substance.

The substance is treated with concentrated H_2SO_4, using anhydrous $CuSO_4$ as a catalyst; all nitrogen is converted into NH_4^+ ion.

The mixture is then treated with excess OH^- to convert the NH_4^+ ion into NH_3. The NH_3 is boiled off and absorbed in an excess of dilute $HC\ell$.

In a Kjeldahl determination 1.2540 g of dried pet food was heated for an hour with concentrated H_2SO_4 and $CuSO_4$ (together with K_2SO_4 to raise the boiling point of the mixture).

On cooling the reaction mixture, Zn pieces and an excess of concentrated NaOH solution were added and the flask quickly attached to a distillation apparatus as shown below. The mixture was gently boiled to drive the NH_3 into the receiving flask. (The Zn dissolves to give $Zn(OH)_4^{2-}$ and H_2 gas; the H_2 gas helps sweep out all the NH_3.)

The NH_3 was distilled into 50.00 mL of 0.01970 mol L^{-1} $HC\ell$.

Condenser

Kjeldahl flask
(decomposed
sample + NaOH
+ Zn)

Receiving flask
(NH_3 passes
into 50.00 mL of
0.01970 mol L^{-1}
$HC\ell$)
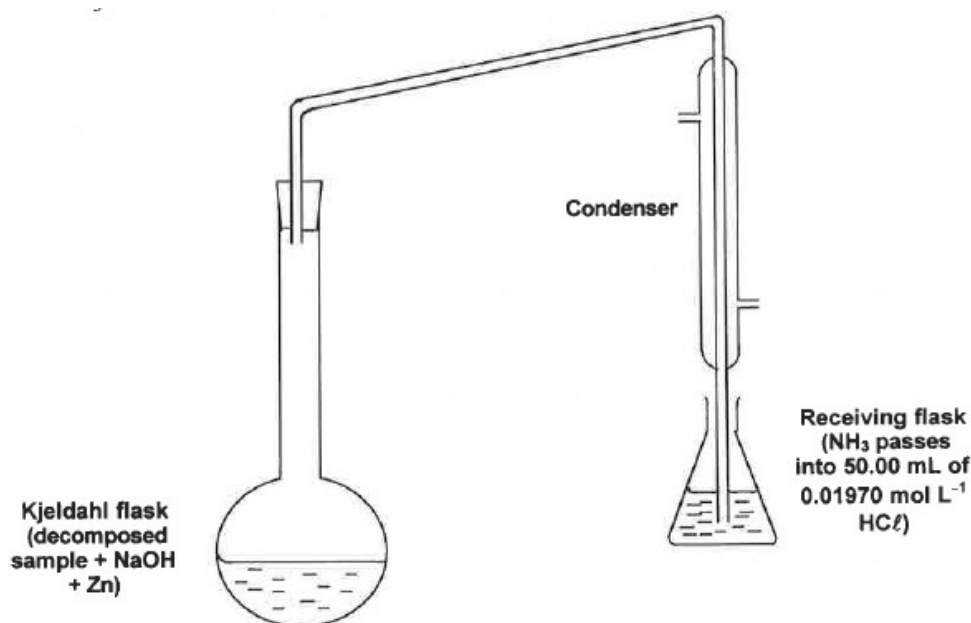
(a) Calculate the original number of moles of H^+ in the solution in the receiving flask before any NH_3 was absorbed. Show your working. (1 mark)

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(b) After the NH_3 had been absorbed by the HCℓ solution, the excess HCℓ was titrated with 0.1000 mol L^{-1} NaOH (in the burette). Methyl orange was used as the indicator; 5.62 mL of NaOH solution was needed for the colour change. Calculate the number of moles of H^+ in this solution after the absorption of the NH_3. Show your working. (2 marks)

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(c) Calculate the number of moles of NH_3 absorbed by the HCℓ solution, and hence the percentage by mass of nitrogen in the 1.2540 g of dried pet food. Show your working. (5 marks)

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(d) During the decomposition of the pet food (with H_2SO_4, $CuSO_4$ and K_2SO_4) there is no stopper on the flask. Why is nitrogen not lost? (5 marks)

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TEE 2004 Calculation Q2:

Borax, $Na_2B_4O_7 \cdot 10H_2O$, can be used as a primary standard in acid-base titrations. It reacts according to the following equation:

$$B_4O_7^{2-} + 2\,H^+ + 5\,H_2O \rightarrow 4\,H_3BO_3$$
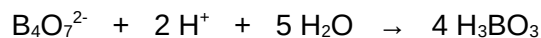
2.334 g of borax was dissolved in a 250.0 mL volumetric flask and the flask filled to the mark with distilled water. 20.00 mL aliquots of the borax solution were titrated against a hydrochloric acid solution and the following results were obtained.

	1	2	3	4
Final reading (mL)	20.20	36.80	21.07	37.70
Initial reading (mL)	2.55	20.20	4.35	21.07
Titration volume (mL)				

Calculate the concentration of the hydrochloric acid solution.   (9 marks)

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