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

Section 1: Multiple choice

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. **Strong base + Weak acid. Equivalence point will be basic**

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

Section 1: Multiple choice

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? **Strong acid + Weak base. Equivalence point will be acidic.**

(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

Section 1: Multiple choice

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}

<u>Section 1: Multiple choice</u>

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.

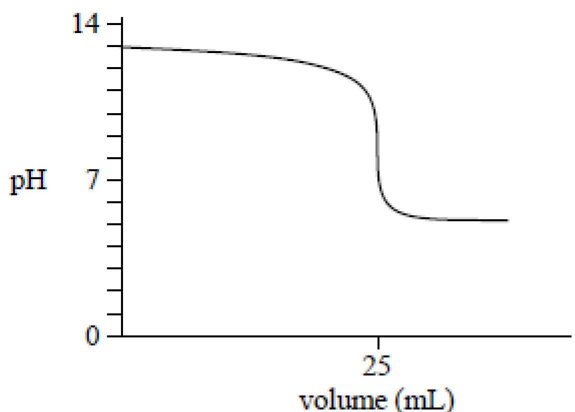
Which statement or combination of statements is always correct?

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

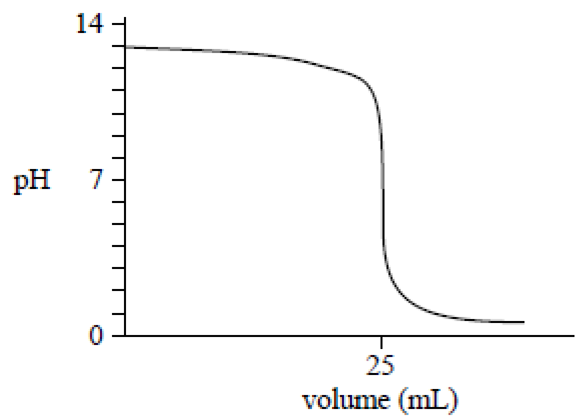
VCE 2015 Q1:

Which one of the following graphs represents the pH change when a weak acid is added to a strong base?
Equivalence point will be basic

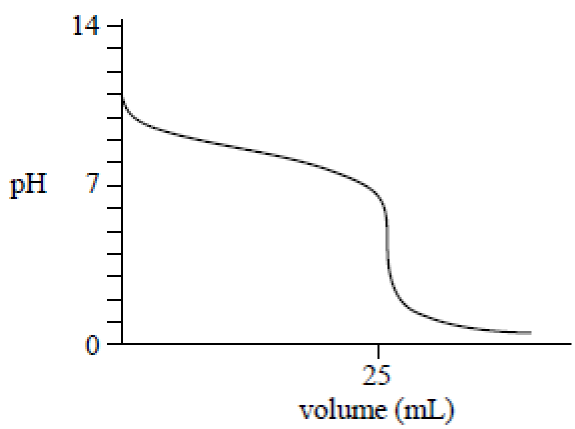
A.



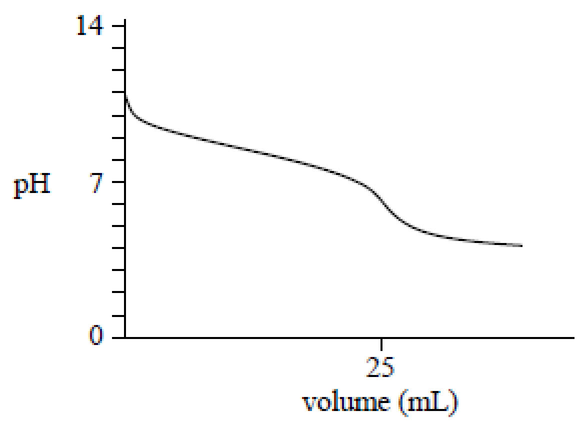
B.



C.



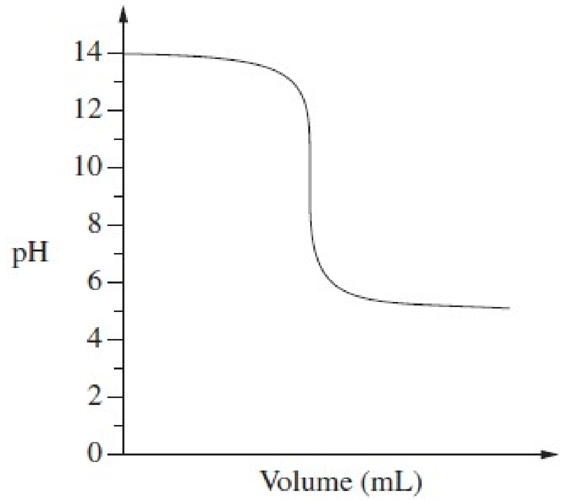
D.



Section 1: Multiple choice

HSC 2015 Q14:

The graph shows the changes in pH during a titration.

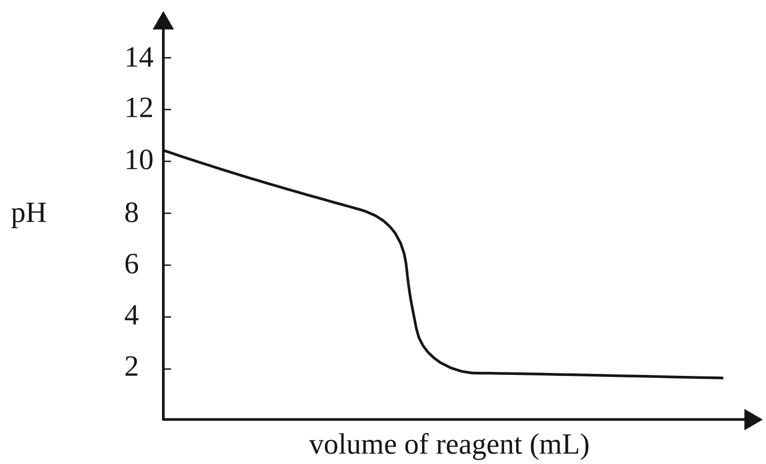


Which pH range should an indicator have to be used in this titration?

(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.



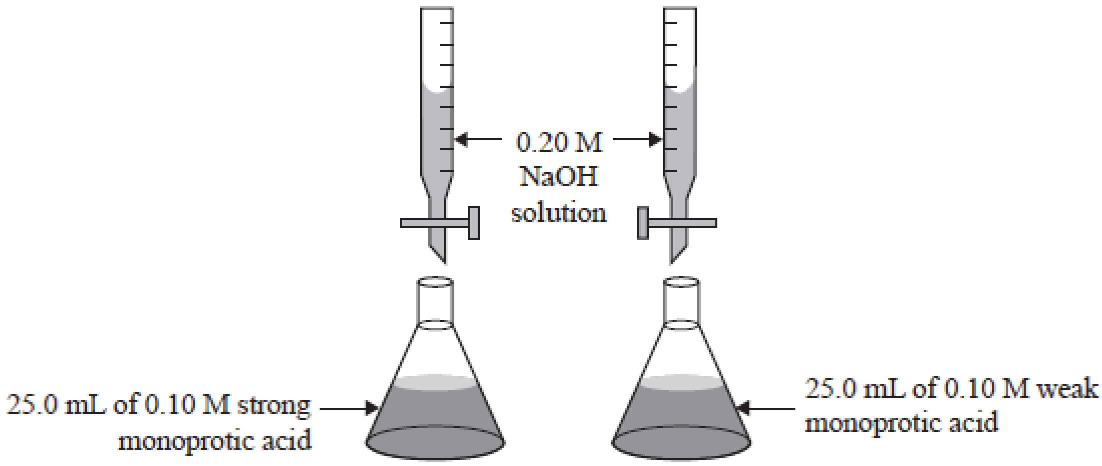
The equation that best represents the reaction described by the titration curve is:

(a) $HC\ell(aq) + NH_3(aq) \rightarrow NH_4C\ell(aq)$
(b) $HC\ell(aq) + NaOH(aq) \rightarrow NaC\ell(aq) + H_2O(\ell)$
(c) $CH_3COOH(aq) + NH_3(aq) \rightarrow CH_3COONH_4(aq)$
(d) $CH_3COOH(aq) + NaOH(aq) \rightarrow CH_3COONa(aq) + H_2O(\ell)$

Section 1: Multiple choice

VCE 2011 Q11:

Two titrations were performed as shown below.

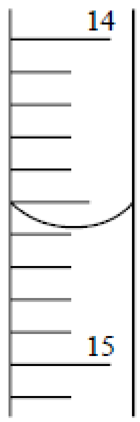


Which of the following statements is true?

(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

Section 2: Short Answer

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)

One mark each for any two of the following:

- **Available in solid form**
- **Available with high degree of purity**
- **Not deliquescent or hygroscopic (doesn't absorb water from the air)**
- **High molar mass**
- **High solubility in water**
- **Readily available**
- **Stable**
- **Known formula**

(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)

Procedure: (1 mark per dot point)

- **Weigh out required mass into beaker**
- **Dissolve in a small quantity of <u>DISTILLED WATER</u>** ***(no marks for just "water")***
- **Transfer solution from beaker to volumetric flask, with sufficient rinsing of the beaker with distilled water**
- **Fill volumetric flask to the mark with <u>DISTILLED WATER</u>** ***(no marks for just "water")***
- **Thoroughly mix solution by inverting flask multiple times**

Calculation of mass: (2 marks)

- **Note: Students may either use 250 mL OR 500 mL volumetric flask.**

- **For 250 mL volumetric flask…**
  n = cV = 0.05 x 0.250 = 0.0125 mol required
  m($H_2C_2O_4.2H_2O$) = n x M = 0.0125 x 126.068 = 1.57 g

- **OR, for 500 mL volumetric flask…**
  n = cV = 0.05 x 0.500 = 0.025 mol required
  m($H_2C_2O_4.2H_2O$) = n x M = 0.025 x 126.068 = 3.15 g

TEE 2009 Q6:

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 …

There are actually 4 mistakes in this method. Any two could be described. 1 mark per box.

	Mistake 1	Mistake 2	Mistake 3	Mistake 4
Description of mistake	**Burette rinsed with water**	**Phenolphthalein used as indicator**	**Na_2CO_3 is too concentrated**	**Pipette wasn't rinsed with Na_2CO_3**
Effect on volume of HCℓ	**Volume of HCl increased**	**Volume of HCl decrease**	**The volume of HCl needed is too large for the burette**	**If pipette had water in it then volume of HCl decreased**
Reason HCℓ volume is affected as stated above	**HCl is diluted by water so more required to neutralise Na_2CO_3**	**Colour change will occur at higher pH so less HCl is added to the Na_2CO_3**	**25 mL of Na_2CO_3 will require 100 mL of HCl solution**	**Water in pipette would dilute Na_2CO_3, so less moles of HCl is required to neutralise**
Correct technique	**Rinse burette with HCl**	**Use methyl orange**	**Dilute the Na_2CO_3 solution with a volumetric flask**	**Rinse the pipette with Na_2CO_3 solution before use**

Section 2: Short Answer

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)

- **CH_3COO^- is a weak base and produce OH^- in water**
- **As a result the equivalence point have a pH greater than 7**
- **Methyl orange changes colour at 4-5, which is not the equivalence point**

$CH_3COO^- + H_2O \rightleftharpoons CH_3COOH + OH^-$
(equation not required for full marks in this case but good to include)

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)

- **Sodium carbonate:**
  - **is available in pure state**
  - **does not absorb water from atmosphere**
  - **has a high molar mass**
  - **does not react with CO_2**

- **Sodium hydroxide:**
  - **absorbs water from the atmosphere**
  - **reacts with CO_2**
  - **has a low molar mass**

Two marks for Na_2CO_3 discussion, two marks for NaOH discussion.
1 mark per relevant property listed.

Section 2: Short Answer

TEE 2000 Q5:

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

What are two characteristics of a primary standard?

One mark each for any two of the following:

- **Available in solid form**
- **Available with high degree of purity**
- **Can be obtained dry (not hygroscopic or deliquescent)**
- **High molar mass**
- **High solubility in water**
- **Readily available**
- **Stable, doesn't decompose**
- **Known formula**

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

In general, most substances do <u>not</u> have the above properties. The primary standard provides a solution of <u>known</u> concentration and hence a starting point for analysing other solutions.

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)

$$n(CH_3COOH) = c \times V \text{¿} 0.200 \times 0.020 \text{¿} 0.004\,mol\, n(NaOH) = 0.004\,mol\, V(NaOH) = \frac{n}{c} \text{¿} \frac{0.004}{0.150}$$

$$\text{¿} 0.02666\,L \text{¿} 26.7\,mL$$

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

- **Equivalence point: When the reactants have combined in the exact stoichiometric ratio (mole ratio) indicated in the equation / The point in the reaction where no reactant is in excess**

- **End point: When the indicator used in the reaction changes colour**

Examiner's comments: This question was not well done. There is evidence that many students thought that the equivalence point in an acid-base titration is at pH 7. This suggests a disconnect with the use of indicators, given that commonly used indicators change colour at pH values other than 7. Phenolphthalein (8.3-10.0) is the indicator normally used in the reaction in this question because the pH at the equivalence point is 8.8. End point descriptions such as 'when a colour change occurs' were far too general; 'indicator colour change' was expected.

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:

$$H_2X(s) + 2\,NaOH(aq) \rightarrow Na_2X(aq) + 2\,H_2O(\ell)$$

Section 2: Short Answer

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)

$$n(NaOH\ initial)=c\times V\text{¿}0.105\times 0.100\text{¿}0.0105\,mol$$

(b) Calculate the amount, in mol, of NaOH that reacts with the acid H_2X. (2 marks) $n(HCl)=c\times V$

$$\text{¿}0.197\times 0.02521\text{¿}0.004966\,mol\; n(NaOH\ excess)=n(HCl)\text{¿}0.004966\,mol$$

$$n(NaOH\ reacted)=n(NaOH\ initial)-n(NaOH\ excess)\text{¿}0.0105-0.004966\text{¿}0.00553\,mol$$

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

$$n(H_2X)=\frac{1}{2}\times n(NaOH\ reacted)\text{¿}0.002767\,mol\; M(H_2X)=\frac{m}{n}\text{¿}\frac{0.415}{0.002767}\text{¿}150\,g\,mol^{-1}$$

Section 2: Short Answer

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)

$$n\left(C_6 H_8 O_7\right) = c \times V \text{¿} 0.100 \times 0.025 \text{¿} 0.0025\, mol\, n\left(NaOH\right) = 3 \times n\left(C_6 H_8 O_7\right) \text{¿} 0.0075\, mol\, c\left(NaOH\right) = \frac{n}{V}$$

$$\text{¿} \frac{0.0075}{0.04150} \text{¿} 0.181\, mol\, L^{-1}$$

Section 3: Extended Answer

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)

Any two of following:

- **It can be obtained with high degree of purity and has a known formula**
- **It undergoes reactions according to known chemical equations**
- **It is stable (to air)**
- **It has high formula mass**
- **Reacts rapidly with acids**
- **Dissolves readily to give standard solutions**

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)

$$Na_2CO_3 + 2\,HC\ell \rightarrow CO_2 + H_2O + 2\,NaC\ell$$

$$n(Na_2CO_3) = c \times V ¿ 0.0248 \times 0.025 ¿ 0.00062\,mol\; n(HCl) = 2 \times n(Na_2CO_3) ¿ 0.00124\,mol\; c(HCl) = \frac{n}{V}$$

$$¿ \frac{0.00124}{0.02435} ¿ 0.0509\,mol\,L^{-1}$$

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
Reading of the burette	**There is random uncertainty when reading the analogue scale on the burette**

Systematic error	Why error is classified as systematic
Bubbles in the pipette	**Bubbles will reduce the volume of solution in the pipette, resulting in less volume transferred to the conical flask and less titre volume**
Not drying Na_2CO_3	**Water in the Na_2CO_3 would contribute to the mass of Na_2CO_3 weighed. As a result there would be the wrong concentration of primary standard, consistently affecting titre volumes**
Rinsing all glassware with distilled water	**Would dilute solutions in the burette and pipette, lowering their concentration**
Incorrect indicator	**Endpoint will not coincide with the equivalence point, causing the user to consistently stop the titration too early or too late**
Perception of colour change at end point	**If the readings are taken beyond the point of colour change consistently it will increase the titre volume**

Section 3: Extended Answer

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 $A\ell(OH)_3$ 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)

To increase the precision (reliability) / To reduce the random error

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

$$A\ell(OH)_3 + 3\,HC\ell \rightarrow A\ell C\ell_3 + 3\,H_2O$$

$$n(HCl) = c \times V \text{¿} 0.05092 \times 0.02194 \text{¿} 0.0011173\,mol\; n(Al(OH)_3\,aliquot) = \frac{1}{3} \times n(HCl) \text{¿} 3.7242 \times 10^{-4}\,mol$$

$$n(Al(OH)_3\,250\,mL\,flask) = n(Al(OH)_3\,aliquot) \times \frac{250}{10} \text{¿} 0.0093106\,mol$$

$$\therefore 20\,mL\,of\,original\,Al(OH)_3\,contains\,0.0093106\,mol\; c(Al(OH)_3\,original) = \frac{n}{V} \text{¿} \frac{0.0093106}{0.020}$$

$$\text{¿} 0.466\,mol\,L^{-1}$$

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)

m($Mg(OH)_2$) in 20 mL undiluted suspension = 1.13 g

$$n(Mg(OH)_2) = \frac{m}{M} \text{¿} \frac{1.13}{58.326} \text{¿} 0.0193739\,mol\; c(Mg(OH)_2) = \frac{n}{V} \text{¿} \frac{0.0193739}{0.020} \text{¿} 0.969\,mol\,L^{-1}$$

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

Section 3: Extended Answer

1 L of $A\ell(OH)_3$ suspension contains 0.466 mol of $A\ell(OH)_3$

$$n(HCl)\,neutralised\,by\,Al(OH)_3 = 3 \times n(Al(OH)_3)\text{¿}\,3 \times 0.466\text{¿}\,1.40\,mol$$

1 L of $Mg(OH)_2$ suspension contains 0.969 mol of $Mg(OH)_2$

$$n(HCl)\,neutralised\,by\,Mg(OH)_2 = 2 \times n(Mg(OH)_2)\text{¿}\,2 \times 0.969\text{¿}\,1.94\,mol$$

Same volume of $Mg(OH)_2$ can neutralise more moles of $HC\ell$, therefore it is more effective than $A\ell(OH)_3$.

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)

Na^+ ions and $C\ell^-$ ions (from the reaction of NaOH and HCℓ) are neutral.

The reaction between $C_9H_8O_4$ (aspirin) and NaOH forms a basic salt, $C_9H_7O_4^-$(aq). It undergoes hydrolysis to produce hydroxide ions.

$C_9H_7O_4^-(aq) + H_2O(\ell) \rightarrow C_9H_8O_4(aq) + OH^-(aq)$

The hydrolysis of the ion makes the solution slightly basic at the equivalence point, which means it is necessary to use an indicator that changes colour on the basic side of pH 7.

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

$$n(NaOH\ initial) = c \times V ¿ 0.204 \times 0.100 ¿ 0.0204\, mol\ (¿ 100\, mL)\, n(HCl) = c \times V ¿ 0.125 \times 0.01789$$

$$¿ 0.002236\, mol\, n(NaOH\ excess \in 20\, mL) = n(HCl) ¿ 0.002236\, mol$$

$$n(NaOH\ excess \in 100\, mL) = n(NaOH\ excess \in 20\, mL) \times \frac{100}{20} ¿ 0.01118\, mol$$

$$n(NaOH\ reacted) = n(NaOH\ initial) - n(NaOH\ excess) ¿ 0.0204 - 0.01118 ¿ 0.009219\, mol$$

(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)

$$n(aspirin) = \frac{1}{2} \times n(NaOH\ reacted) ¿ \frac{1}{2} \times 0.009219 ¿ 0.004609\, mol\, m(aspirin) \in 3\, tablets = n \times M$$

$$¿ 0.004609 \times 180.154 ¿ 0.8304\, g\, m(aspirin) \in 1\, tablet = \frac{0.8304}{3} ¿ 0.2768\, g ¿ 277\, mg$$

$$\%aspirin = \frac{m(aspirin)}{m(tablet)} \times 100 ¿ \frac{277\, mg}{300\, mg} \times 100 ¿ 92.3\,\%$$

(b)

Washing procedure	Effect on the volume HCℓ	Effect on the % aspirin
conical flask was washed with distilled water	**no change**	**no change**
burette was washed with distilled water	**increased**	**decreased**

WACE 2014 Question 40:

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

Description	Marks
Any two of the following:	
• does not have high molar mass • absorbs moisture/is deliquescent/hygroscopic • reacts with CO_2 from the atmosphere • mass varies over time • cannot be obtained pure	1-2
Incorrect	0
Total	**2**

(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)

Section 3: Extended Answer

Description	Marks
n(HCℓ) = 0.01745 × 0.105 = 1.832 × 10^{-3} mol	1
n(NaOH) = n(HCℓ) = 1.832 × 10^{-3} mol	1
c(NaOH) = $\frac{n}{v} = \frac{1.832\times10^{-3}}{0.02} = 9.16\times10^{-2}$ molL^{-1}	1
Incorrect	0
Total	**3**

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)	3.50	2.70	1.50	1.30

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

Description	Marks
Differences in initial and final readings = 21.80, 20.85, 20.90, 20.95	1
Titre volume = $\frac{20.85 + 20.90 + 20.95}{3}$ = 20.90 mL	1
Incorrect	0
Total	**2**

(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)

Description	Marks
n(NaOH) = 0.02090 × 0.0916 = 1.914 × 10^{-3} mol	1
In 20 mL of dilute citric acid, n(citric) = $\frac{1.914 \times 10^{-3}}{3} = 6.381 \times 10^{-4}$ mol	1
n(citric) in 100 mL = 6.381 × 10^{-4} × 5 = 0.003191 mol	1
hence in 10 mL original = 0.003191 mol	1
m(citric) = n × M = 0.003191 × 192.124 = 0.613 g	1
Therefore % composition = $\frac{0.613}{10.4} \times 100 = 5.89\%$	1
Incorrect	0
Total	**6**

(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

Description	Marks
Thymol blue	1
The citrate ion hydrolyses to give hydroxide ions and so an equivalence point in the basic region or appropriate equation	1
Incorrect	0
Total	**2**

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 Results	Trials (mL)			
	1	2	3	4
Final Volume	32.05	32.10	31.11	33.25
Initial volume	0.50	2.45	1.40	3.65
Titre	31.55	29.65	29.71	29.60

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

$$H_2C_2O_4 + 2OH^- \rightarrow C_2O_4^{2-} + 2H_2O$$

(b) Complete the table. (1 mark)

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

$$V(OH^-) = \frac{29.65 + 29.71 + 29.60}{3} = 29.65 \text{ mL}$$

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

$$n(OH^-) = 0.115(0.02965) = 3.41 \times 10^{-3} \text{ mol}$$
$$n(H_2C_2O_4) = ½\,(3.41 \times 10^{-3}) = 1.71 \times 10^{-3} \text{ mol}$$
$$[H_2C_2O_4] = \frac{1.71 \times 10^{-3}}{0.0200} = 8.53 \times 10^{-2} \text{ mol L}^{-1}$$

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

$$n(H_2C_2O_4 \text{ in } 250.0 \text{ mL}) = 1.71 \times 10^{-3} \times \frac{250}{20} = 0.0213 \text{ mol}$$

$$m(H_2C_2O_4) = 0.0213(90.036) = 1.92 \text{ g}$$

$$\% \text{ purity} = \frac{1.92}{2.05} \times 100 = 93.6\ \%$$

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

Phenolphthalein (or equivalent) [1 mark]

The equivalence point of the reaction is basic due to the production of a slightly basic salt (the oxalic acid ion is slightly basic) and the indicator changes in the basic range. (or anything reasonable) [1 mark]

Section 3: Extended Answer

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)

V(NaOH) = 35.96 mL

n(OH^-) = 0.106 x 0.03596 = 3.81 x 10^{-3} mol

n(HCℓ) = 3.81 x 10^{-3} mol

[HCℓ] = n/V = 0.381 mol/L

(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)

$n(OH^-) = c \times V = 0.106 \times 0.0104 = 1.10 \times 10^{-3}$ moles

$n(H^+$ left over in 50 mL$) = n(OH^-) = 1.10 \times 10^{-3}$ moles

$n(H^+$ left over in 500 mL$) = 500/50 \times 1.10 \times 10^{-3} = 0.0110$ mol

$n(H^+$ initial$) = c \times V = 0.381 \times 0.500 = 0.1905$ mol/L

$n(H^+$ reacted with MgO$) = n(H^+$ initial$) - n(H^+$ left over$) = 0.1905 - 0.0110 = 0.1795$ mol

$MgO + 2 H^+ \rightarrow Mg^{2+} + H_2O$

$n(MgO) = 0.5 \times n(H^+$ reacted with MgO$) = 0.08975$ mol

$m(MgO) = n \times M = 3.62$ g

% MgO = $3.62/3.86 \times 100 = 93.7\%$

TEE 1998 Calculation Q4:

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

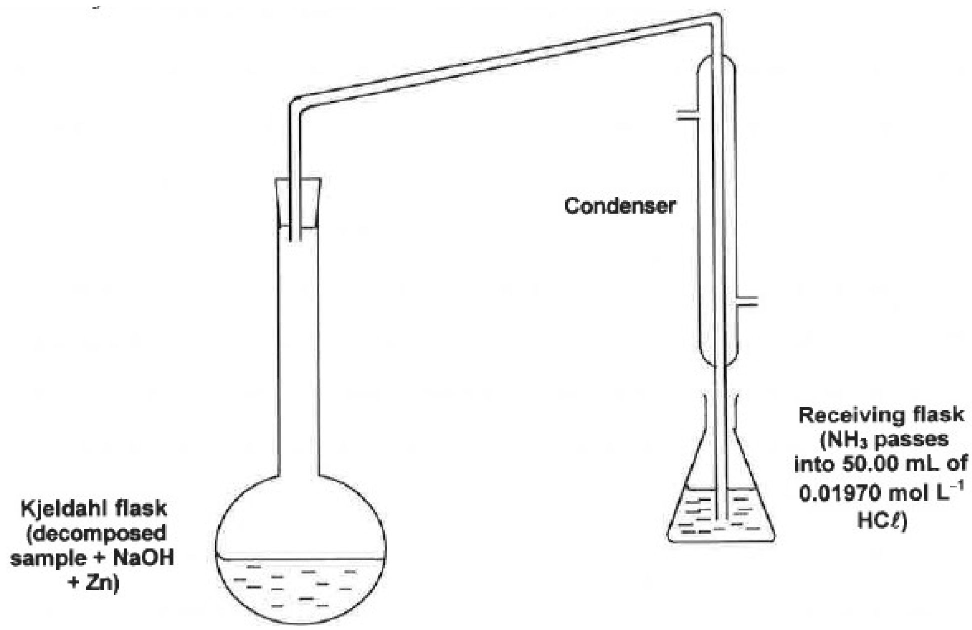
The substance is treated with concentrated H_2SO_4, using anhydrous $CuSO_4$ as a catalyst; all nitrogen is converted into NH_4^+ ion.

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 HCℓ.

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} HCℓ.



(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)

(a) $n(H+) = 50.00 \times 10^{-3} \times 0.0197$
$= 9.85 \times 10^{-4}$ mol

(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)

(b) $n(OH^-) = 5.62 \times 10^{-3} \times 0.100 = 5.62 \times 10^{-4}$ mol

$\therefore n(H^+) = 5.62 \times 10^{-4}$ mol

(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)

(c) $n(HCl)$ reacting with $NH_3 = 9.85 \times 10^{-4} - 5.62 \times 10^{-4}$

$\therefore n(NH_3) = 9.85 \times 10^{-4} - 5.62 \times 10^{-4}$ mol

$\therefore n(N) = 9.85 \times 10^{-4} - 5.62 \times 10^{-4} = 4.23 \times 10^{-4}$ mol

$\therefore m(N) = 4.23 \times 10^{-4} \times 14.01 = 5.926 \times 10^{-3}$ g

$\% N = (5.926 \times 10^{-3} \div 1.254) \times 100$

$= 0.473\%$

(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)

(d) Nitrogen is not lost because the acid keeps the N in as the NH_4^+ ion **or** the nitrogen is combined in a compound.

Section 3: Extended Answer

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)

Average Titration Volume = (16.60 + 16.72 + 16.63)/3
= 16.65 mL

$n(Na_2B_4O_7.10H_2O)$ $= {}^{2.334}/_{381.4}$
$= 6.120 \times 10^{-3}$ mol in 250 mL
$= ({}^{20}/_{250}) \times 6.120 \times 10^{-3}$ in 20 mL
$= 4.896 \times 10^{-4}$ mol in 20 mL

$n(H^+)$ $= 2n(B_4O_7^{2-})$
$= 2(4.896 \times 10^{-4})$
$= 9.792 \times 10^{-4}$ mol

$c(HCl)$ $= 9.792 \times 10^{-4}/0.01665$
$=$ **0.0588 molL^{-1}**