IB · HL · Chemistry

7 hours 50 questions

Structured Questions

Proton Transfer Reactions

Brønsted–Lowry Acids & Bases / Conjugate Acids & Bases / Amphiprotic Species / The pH Scale / The Ion Product of Water / Strong & Weak Acids / Neutralisation Reactions / pH Curves / Interpreting pH Curves (HL) / The pOH Scale (HL) / Acid & Base Dissociation Constants (HL) / Solving Acid-Base Dissociation Problems (HL) / Salt Hydrolysis (HL) / Acid-Base Indicators (HL) / Choosing an Acid-Base Indicator...

Easy (17 questions)	/115
Medium (19 questions)	/188
Hard (14 questions)	/122
Total Marks	**/425**

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Easy Questions

1 (a) Define a *Brønsted–Lowry acid*.

.....

(1 mark)

(b) Which species in the following reaction acts as a Brønsted-Lowry base.

$$HSO_4^-(aq) + H_3O^+(aq) \rightleftharpoons H_2SO_4(aq) + H_2O(l)]$$

.....

(1 mark)

(c) Which species in the following equation is acting as a Brønsted-Lowry acid.

$$CO_3^{2-}(aq) + H^+(aq) \rightleftharpoons HCO_3^-(aq)$$

.....

(1 mark)

(d) Explain, using the Brønsted-Lowry theory, how water can act either as an acid or a base.

.....

.....

(2 marks)

2 (a) Describe the difference between an amphiprotic and amphoteric species.

.....

(1 mark)

(b) Write an equation to show ammonia, NH_3, acting as both a Brønsted–Lowry base and a Brønsted–Lowry acid.

Brønsted–Lowry base: .....

Brønsted–Lowry acid: .....

.....

.....

(2 marks)

(c) The equations for two acid-base reactions are given below.

$$HCO_3^-\ (aq) + H_2O\ (l) \rightleftharpoons H_2CO_3\ (aq) + OH^-\ (aq)$$
$$HCO_3^-\ (aq) + H_2O\ (l) \rightleftharpoons CO_3^{2-}\ (aq) + H_3O^+\ (aq)$$

Identify two different amphiprotic species in the above reactions.

.....

(1 mark)

(d) i) State what is meant by the term conjugate base.

[1]

ii) State the conjugate base of the hydroxide ion, OH^-

[1]

.....

.....

(2 marks)

3 (a) State an equation for the reaction of magnesium carbonate with dilute hydrochloric acid.

.....

(1 mark)

(b) State an equation for the reaction of lithium oxide with dilute nitric acid.

.....

(1 mark)

(c) Which acid and base would be required to produce ammonium sulfate, $(NH_4)_2SO_4$

.....

.....

(2 marks)

(d) Nitric acid and calcium hydroxide react together.

i) State the type of reaction that takes place.

[1]

ii) State the formula of the products of the reaction.

[1]

iii) State the sign of the enthalpy change for this reaction.

[1]

.....

.....

.....

(3 marks)

4 (a) Identify one conjugate acid-base pair in the reaction.

$$OCl^-(aq) + H_2O(l) \rightleftharpoons OH^-(aq) + HOCl(aq)$$

.....

(1 mark)

(b) State an equation for the reaction of aluminium hydroxide with dilute sulfuric acid.

.....

(1 mark)

(c) State an equation for the reaction of calcium hydrogencarbonate with dilute phosphoric acid, H_3PO_4.

.....

(1 mark)

(d) Write the formulae for the following:

i) Carbonic acid.

[1]

ii) Ammonium sulfate.

[1]

iii) Magnesium ethanoate.

[1]

.....

.....

.....

(3 marks)

5 (a) Using section 18 of the data booklet, identify an indicator that would show a yellow colour in ammonia solution?

.....

(1 mark)

(b) Suggest **two** characteristics that make a good indicator for a titration.

.....

.....

(2 marks)

(c) A typical set of acid-base titration results in shown in the table.

	Rough	Run 1	Run 2
Initial burette reading /±0.05 mL	0.00	0.30	0.60
Final burette reading/ ±0.05 mL	24.15	22.55	22.95

Determine the mean volume from these results.

.....

(1 mark)

(d) What is the recorded uncertainty on the mean volume calculated in part c)?

.....

(1 mark)

6 (a) State the relationship between pH and hydrogen ion concentration.

.....

(1 mark)

(b) Determine the pH of 0.200 mol dm^{-3} hydrochloric acid.

.....

(1 mark)

(c) Determine the hydrogen ion concentration in a sample of lake water of pH 5.60.

.....

(1 mark)

(d) The table below shows the hydrogen ion concentration in three solutions:

	P	Q	R
$[H^+]$	0.001	1×10^{-5}	1.00

List the three solutions in order from low pH to high pH

.....

(1 mark)

7 (a) State what is meant by the ionic product of water.

.....

(1 mark)

(b) Calculate the concentration of $[H^+]$ in a solution of sodium hydroxide, NaOH, whose concentration is 0.001 mol dm^{-3}.

.....

(1 mark)

(c) Calculate the pH of 0.001 mol dm^{-3} NaOH solution.

.....

(1 mark)

(d) The ionic product of water is 2.916×10^{-14} mol^2 dm^{-6} at 313 K. What is the pH of water at this temperature?

.....

(1 mark)

8 (a) State one **advantage** and one **disadvantage** of using a pH meter instead of universal indicator to measure pH.

.....

.....

(2 marks)

(b) State the name and formula of a strong alkali and a weak alkali.

.....

.....

(2 marks)

(c) State the meaning of the term *dissociation* as applied to acids and bases

.....

(1 mark)

(d) Write equations for the dissociation of:

Nitric acid, HNO_3: .....

Methanoic acid, HCOOH: .....

.....

.....

(2 marks)

(e) Identify the formula of the weakest conjugate base produced in the two acids in part d).

.....

(1 mark)

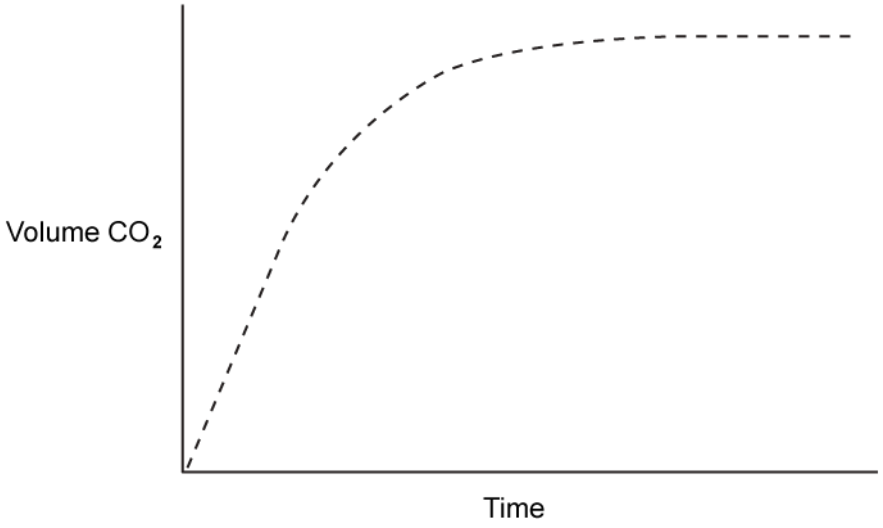
9 (a) Explain the difference between the terms *strong* acid and *weak* acid.

(2 marks)

(b) Other than measuring the pH, describe how you could distinguish between dilute solutions of the same concentration of hydrochloric acid and ethanoic acid.

(2 marks)

(c) A solution of 2.00 mol dm^{-3} hydrochloric acid was added to marble chips and the volume of carbon dioxide recorded. A graph of the result is shown below:



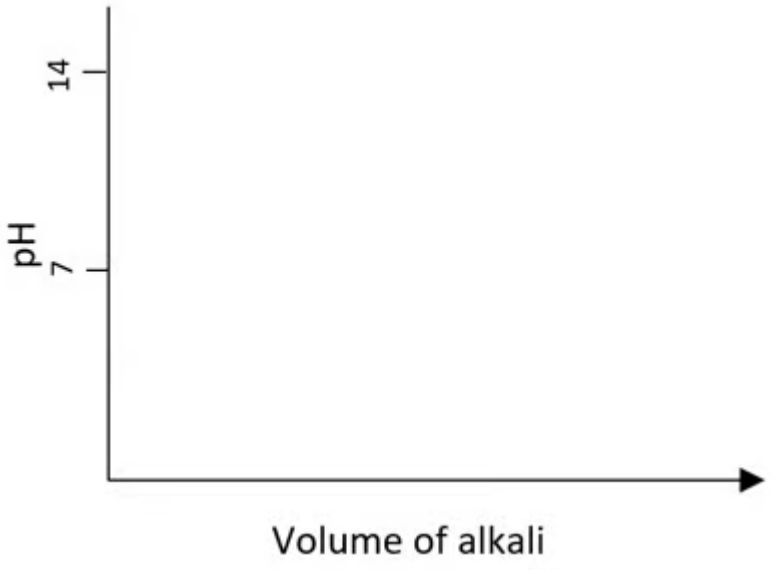
On the same graph, sketch the result of repeating the experiment with 2.00 mol dm^{-3} ethanoic acid.

(1 mark)

(d) The same experiment in part c) can be carried out by measuring how the mass of the reaction flask changes with time.
Sketch a graph of the expected result.

(1 mark)

10 (a) On the axes below, draw a sketch graph to show the neutralisation of ethanoic acid by sodium hydroxide:

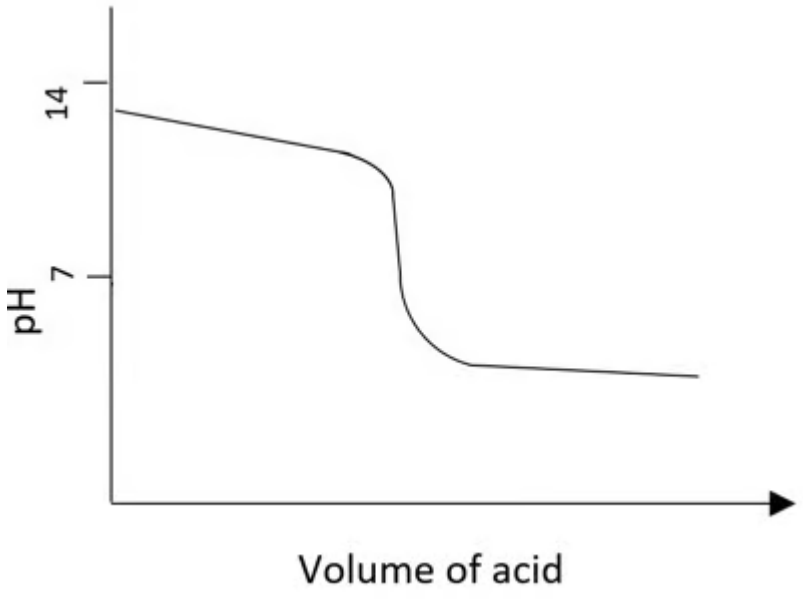


(2 marks)

(b) Write an equation for the reaction between ethanoic acid and sodium hydroxide and identify the species acting as a Lewis base in the reaction.

(2 marks)

(c) Identify the type of titration taking place from the curve and indicate where the buffer region is found on this curve.



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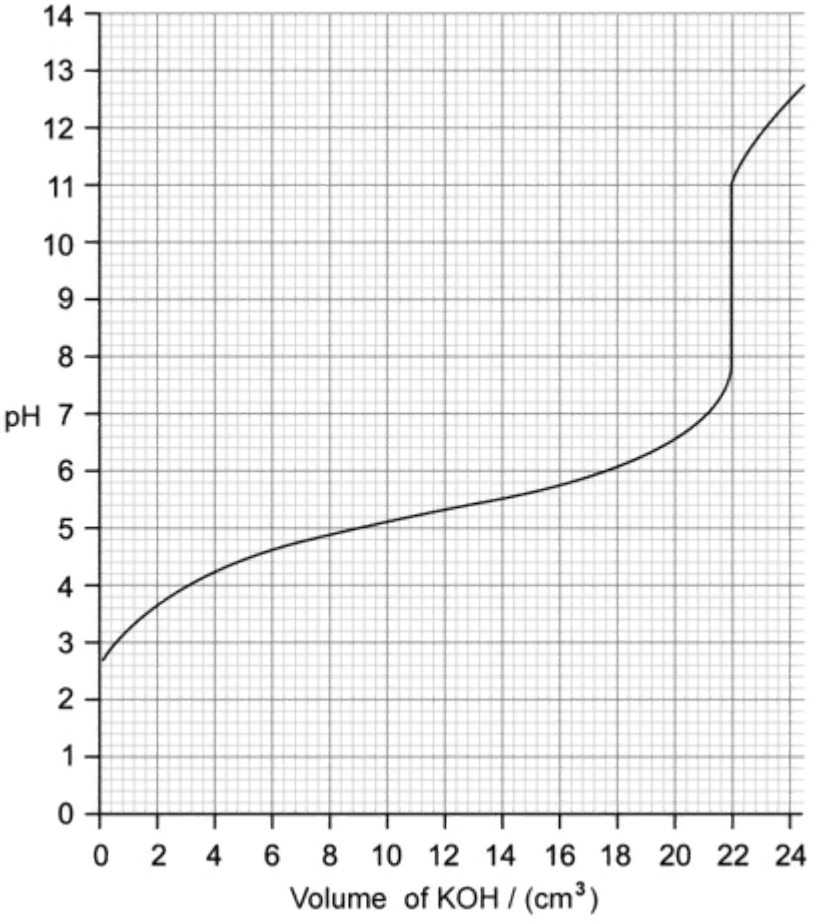
(2 marks)

(d) Identity on the graph the point at which pK_a= pH and find the pK_a of the acid.



(2 marks)

11 (a) Explain how an acid-base indicator works.

(3 marks)

(b) Phenolphthalein, $C_{20}H_{14}O_4$, is an acid-base indicator. State the formula and colour of the conjugate base of phenolphthalein.

(2 marks)

(c) Explain how suitable indicators are chosen for titrations.

(3 marks)

12 (a) Outline what is meant by a buffer solution.

(1 mark)

(b) Outline how a buffer solution can be made starting from 1.0 mol dm^{-3} ethanoic acid and 1.0 mol dm^{-3} sodium hydroxide.

(2 marks)

(c) Use suitable equations to explain how the buffer in b) functions when a small quantity of acid is added.

(4 marks)

(d) State the composition of a basic buffer

(1 mark)

13 (a) Explain what is meant by the term *hydrolysis* in acids and bases.

(1 mark)

(b) Salts can be acidic, basic or neutral. Explain how you can predict whether a salt is likely to be acidic. Include an equation in your answer.

(3 marks)

(c) Deduce which of the following salts are acidic, basic or neutral:

CH_3COONa NH_4Cl KCl

(3 marks)

14 (a) Hydrocyanic acid, HCN, is used in the synthesis of polymers and pharmaceuticals. It is a weak acid.

Write an equation to show the dissociation of hydrocyanic acid.

(1 mark)

(b) Pyridine is an organic compound with the chemical formula C_5H_5N. It is a weak base.

Write an equation to show how pyridine acts as a base.

(1 mark)

(c) Write an equation to show the reaction between hydrocyanic acid and pyridine and identify two conjugate acid-base pairs.

(2 marks)

(d) Using **Table 1**, deduce which of the two acids, ethanoic, CH_3COOH, or hydrocyanic is the stronger acid.

Acid	pK_a
ethanoic acid	4.76
hydrocyanic acid	9.20

(2 marks)

15 (a) Using **Table 1**, determine which of chloroethanoic acid, dichloroethanoic acid and trichloroethanoic acid is the stronger acid.

Table 1

Name of Acid	Formula	pK_a
chloroethanoic acid	$CH_2ClCOOH$	2.87
dichloroethanoic acid	$CHCl_2COOH$	1.35
trichloroethanoic acid	$CHCl_3COOH$	0.66

(4 marks)

(b) Write the K_a expression for dichloroethanoic acid, $CHCl_2COOH$.

(1 mark)

(c) Methylamine, CH_3NH_2, is a substance used to synthesise many commercially available compounds. State the K_b expression for methylamine.

(1 mark)

(d) State the relationship between K_a and K_b for an acid and its conjugate base.

(1 mark)

16 (a) A solution of 0.01 mol dm^{-3} ethanoic acid has a pH of 3.37 at 298 K. Determine the K_a of ethanoic acid.

(4 marks)

(b) A solution of 0.10 mol dm^{-3} methylamine, CH_3NH_2, has a pH of 11.80 at 298 K. Determine the K_b at this temperature.

(5 marks)

(c) Determine the $[H^+]$ in a 0.10 mol dm^{-3} solution whose $K_a = 1.00 \times 10^{-8}$ at 298 K.

(2 marks)

(d) Determine the pOH of the solution in part c).

(2 marks)

17 (a) The pK_a of methanoic acid is 3.75 at 298 K.

i) Write the formula of the conjugate base of methanoic acid.

[1]

ii) Determine the pK_b of the conjugate base

[2]

.....

.....

.....

(3 marks)

(b) The pK_a of ethanoic acid is 4.76. Determine whether the conjugate base of methanoic acid is weaker or stronger than the conjugate base of ethanoic acid.

.....

(1 mark)

(c) At 283 K the pK_w of pure water is 14.54. Determine the pH at this temperature.

.....

(1 mark)

(d) Comment on the acid-base nature of water at 283 K in part c).

.....

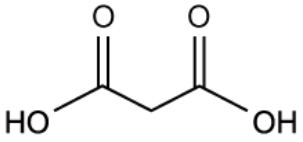
.....

(2 marks)

Medium Questions

1 (a) Malonic acid is a naturally occurring acid found in fruits and vegetables and is shown in **Figure 1.**

Figure 1



The first dissociation of malonic acid is:

$$C_3H_4O_4\,(aq) + H_2O\,(l) \rightleftharpoons C_3H_3O_4^-\,(aq) + H_3O^+\,(aq)$$

Identify one conjugate acid-base pair from the equation.

.....

(1 mark)

(b) The equilibrium constant for the first dissociation of malonic acid is 1.48×10^{-3}.

State, with a reason, the strength of malonic acid.

.....

.....

.....

(3 marks)

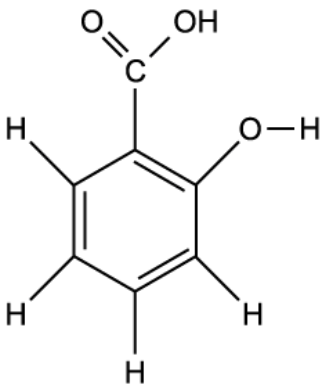
(c) The anion $C_3H_3O_4^-$ may be classified as *amphiprotic*. Explain the meaning of *amphiprotic* and write equations, using $C_3H_3O_4^-$, to illustrate your answer.

.....

(1 mark)

2 (a) Salicylic acid has the structure shown below in **Figure 1**.

Figure 1



Draw the structure of the conjugate base of salicylic acid, showing **all** the atoms and **all** the bonds.

(1 mark)

(b) Predict what would be seen if a small amount of copper (II) oxide was added to an aqueous solution of salicylic acid, HOC_6H_4COOH, and warmed.

Write a balanced equation for the reaction.

(2 marks)

(c) Suggest, with a reason, whether salicylic acid is likely to be soluble in water.

(1 mark)

(d) Determine the relative molecular mass, M_r, of salicylic acid using Table 6 from the Data book.

(1 mark)

3 (a) Write balanced equations to show the separate reactions between ethanoic acid and calcium carbonate, $CaCO_3$, magnesium oxide, MgO, and aluminium hydroxide, $Al(OH)_3$.

(3 marks)

(b) In **Table 1** below, suggest the names and formulae of the acids and bases needed to make the specified salts.

Table 1

Acid	Base	Salt
		Copper nitrate, $Cu(NO_3)_2$
		Calcium phosphate, $Ca_3(PO_4)_2$

(2 marks)

(c) The ethanoate ion, CH_3COO^-, carbon dioxide, CO_2, and the ethoxide ion, $CH_3CH_2O^-$, all contain carbon oxygen bonds.

Deduce the order in carbon to oxygen bond length from shortest to longest and explain your answer.

(3 marks)

(d) Ethanoic acid, CH_3COOH, shows two absorptions in an infrared spectrum that are not present in the spectrum of ethanol.

Using Section 20 of the Data book, state the wavenumber range of these absorptions and the bonds that cause them.

.....

.....

(2 marks)

4 (a) Glycolic acid, $C_2H_4O_3$, is a colourless, odourless crystalline solid that is highly soluble in water and behaves as a Brønsted–Lowry acid.

i) Define the term Brønsted–Lowry acid.

[1]

ii) State one difference between Brønsted–Lowry acids and the traditional theory of acids as substances that dissociate in water to form hydrogen ions.

[1]

.....

.....

(2 marks)

(b) The systematic IUPAC name for glycolic acid is 2-hydoxyethanoic acid.

Draw the structural formula for its conjugate base, showing **all** the atoms and bonds.

.....

(1 mark)

(c) Write an equation for the reaction between glycolic acid, $C_2H_4O_3$, and limescale, $CaCO_3$. State and explain one observation you would make.

.....

.....

(2 marks)

(d) State one reason why you would use glycolic acid to remove the limescale in a kettle at home, but not hydrochloric acid.

.....

(1 mark)

5 (a) An alkaline solution is formed when sodium hydrogencarbonate is dissolved in water.

Write an equation for the reaction and explain why the solution is alkaline.

.....

.....

(2 marks)

(b) State whether the HCO_3^- ion is behaving as a Brønsted–Lowry acid or as a base and give a reason for your answer.

.....

.....

(2 marks)

(c) Carbon dioxide gas dissolves in rainwater to form carbonic acid. State the formula of the conjugate base of carbonic acid.

.....

(1 mark)

(d) Carbonic acid and sulfuric acid can be described as *diprotic* acids. Explain the meaning of *diprotic.*

.....

(1 mark)

6 (a) The equilibrium constant for the first dissociation of formic acid is 1.8×10^{-4} mol dm^{-3}.

State, with a reason, the strength of formic acid.

.....

.....

(2 marks)

(b) Outline **one** laboratory method used to distinguish between equimolar solutions of formic acid and hydrochloric acid, giving the expected observations.

.....

(1 mark)

(c) Formic acid has the chemical formula HCOOH. Identify the conjugate base of formic acid and state whether it is a weak or strong conjugate base.

.....

.....

(2 marks)

(d) Draw the structure of formic acid and give its systematic IUPAC name.

.....

.....

(2 marks)

7 (a) The pH of an aqueous solution of salicylic acid at 298 K is 3.85. Determine the concentration of hydroxide ions in the solution, using Section 2 of the Data booklet.

.....

.....

(2 marks)

(b) **A** and **B** are two solutions of the same concentrations that have pH values of 3 and 6 respectively.

i) Identify which is the stronger acid and calculate the concentration of hydrogen ions in each solution.

[2]

ii) Calculate the ratio of the hydrogen ion concentrations in both **A** and **B**.

[1]

.....

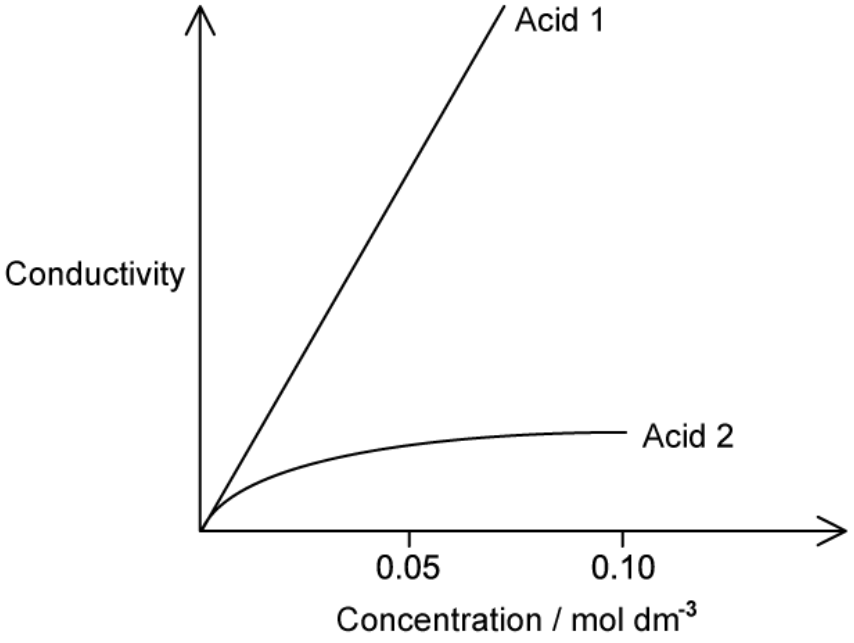
.....

.....

(3 marks)

(c) The variation of conductivity and concentration of a strong and weak monoprotic acid are shown in **Figure 1**.

Identify the strong and weak acid from the information given and justify your choices.



(3 marks)

(d) For acid 1 and acid 2 in part (c) compare the volume of 0.2 mol dm^{-3} NaOH required to neutralise 20 cm^3 of 0.1 mol dm^{-3} solutions of the acids.

(1 mark)

8 (a) The concentrations of solutions of weak acids can be determined by titration against standard solutions of alkalis, such as sodium hydroxide.

i) Explain what is meant by the term *standard solution*.

[1]

ii) State the name of the indicator which should be used for this titration and what would be observed at the equivalence point of the reaction if the sodium hydroxide is placed in the burette.

[2]

(3 marks)

(b) A solution of 25.0 cm^3 ethanoic acid was titrated against 0.150 mol dm^{-3} NaOH (aq) and it was found that 22.35 cm^3 of the NaOH was needed for complete neutralisation.

Write an equation for the reaction and determine the concentration of the ethanoic acid.

(3 marks)

(c) A solution of 0.1 mol dm^{-3} ammonia has a pH of approximately 11. Predict how the pH value of 0.1 mol dm^{-3} sodium hydroxide solution would compare and calculate its value.

(2 marks)

(d) Write an equation for the reaction between ammonia and water and use it to classify each product as a Brønsted–Lowry acid or base.

.....

.....

(2 marks)

9 (a) Glycolic acid, $C_2H_4O_3$, is an organic acid sometimes used to remove limescale, $CaCO_3$, from electric kettles and coffee machines.

Predict, with a reason, a difference in the reaction between the same concentration of sulfuric acid and glycolic acid with samples of calcium carbonate.

.....

.....

(2 marks)

(b) Another acid that is sometimes used to descale kettles is sulfamic acid, NH_2SO_3H. Sulfamic is classed as a *strong monoprotic* acid.

i) Explain the meaning of the term *strong monoprotic acid*.

[1]

ii) Calculate the pH of a 0.136 mol dm^{-3} solution of sulfamic acid and determine the concentration of hydroxide ions in the solution at 298 K.

[2]

.....

.....

.....

(3 marks)

(c) A solution of hydrochloric acid has a pH of 1 and a solution of carbonic acid has a pH of 5. Determine the ratio of hydrogen ion concentrations of hydrochloric acid to carbonic acid.

.....

.....

(2 marks)

(d) Outline two ways, apart from using pH, which could allow you to distinguish between two solutions of carbonic acid and hydrochloric acid that have the same concentration.

(4 marks)

10 (a) Four solutions of acids with identical concentrations are prepared. The equilibrium constants of these acids are given in **Table 1**.

Table 1

Acid	K_c mol dm^{-3} at 298 K
HCN	4.9×10^{-10}
HF	6.8×10^{-4}
CH_3COOH	1.7×10^{-5}
HCl	1.3×10^{6}

Write down the acid dissociation equation for HCN.

.....

(1 mark)

(b) Use the information in part (a) to complete this question.

i) Write down the list of acids in part (a) in order of **decreasing** pH.

[1]

ii) Write down the list of acids in order of **increasing** concentration of molecules of the acid present in the solution.

[1]

.....

.....

(2 marks)

(c) State the name and formula of all the chemical species present in the solution of CH_3COOH.

.....

.....

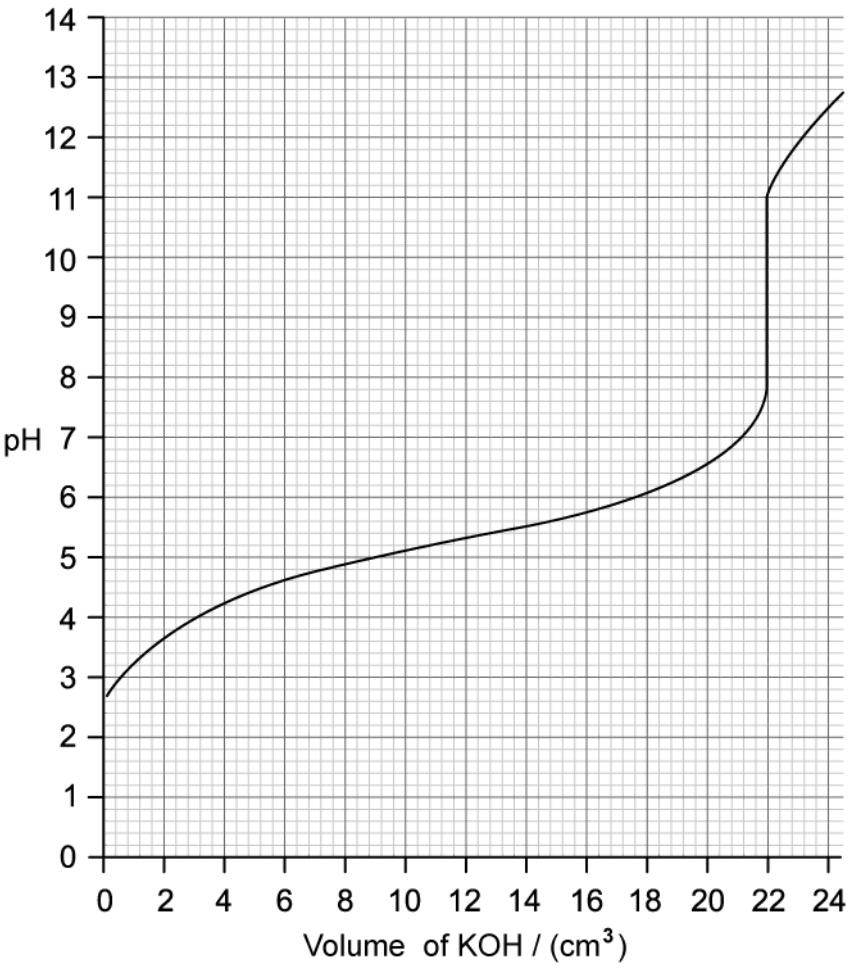
(2 marks)

(d) Write the name and formula of the conjugate base of HF.

.....

(1 mark)

11 (a) Ethanoic acid, CH_3COOH (aq) , is titrated with 0.16 mol dm^{-3} potassium hydroxide and the following graph is obtained.



Explain why the equivalence point is greater than pH 7 for this titration.

(3 marks)

(b) Explain what is meant by a buffer solution and describe where the 'buffer region' on the graph would occur.

(2 marks)

(c) Explain the shape of the pH curve up to the equivalence point.

(4 marks)

(d) Explain why potassium hydroxide can act as a Brønsted-Lowry base and Lewis base.

(3 marks)

12 (a) This question is about Brønsted-Lowry acids and bases.

i) Give the meaning of the term Brønsted-Lowry acid.

[1]

ii) Explain the term weak acid.

[2]

(3 marks)

(b) When an acid and a base react they produce a conjugate base and a conjugate acid.

$$\text{acid} + \text{base} \rightleftharpoons \text{conjugate base} + \text{conjugate acid}$$

Write an equation to show how hydrochloric acid behaves as a strong acid when it reacts with water, and state the role of water in this reaction.

(2 marks)

(c) Ethanoic acid is a weak acid. Hydrogen carbonate ions can also act as a weak acid if in an aqueous solution.

i) Write equations for each of these weak acids at equilibrium.

[2]

ii) A solution was made up containing sodium hydrogen carbonate and sodium carbonate. Explain how this solution would act as a buffer if a small amount of acid was added to it.

[2]

(4 marks)

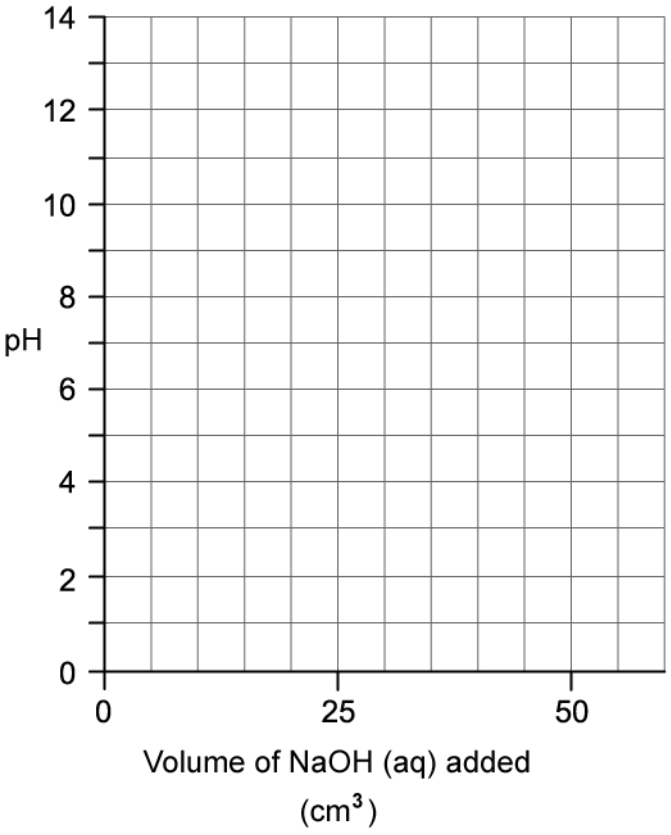
(d) Explain how a solution containing ethanoic acid and ethanoate ions can act as a buffer.

(4 marks)

13 (a) A student performed a titration of 25.0 cm^3 of 0.100 mol dm^{-3} hydrochloric acid, HCl (aq) , with 0.100 mol of sodium hydroxide, NaOH (aq).

i) Draw the expected pH curve on the graph and indicate the equivalence point for this.

[2]



ii) Explain why the salt produced in this reaction is neutral.

[3]

(5 marks)

(b) The student repeated the titration using two different chemicals, 25.0 cm^3 of 0.100 mol dm^{-3} nitric acid, HNO_3 (aq) , and 0.100 mol dm^{-3} ammonia, NH_3 (aq).

i) State the equation for this reaction.

[1]

ii) Explain why the salt produced in this reaction is acidic.

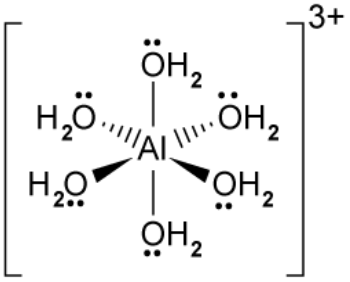
[4]

(5 marks)

(c) State the equation for reaction between nitric acid and water, this reaction and identify the conjugate acid formed in the reaction.

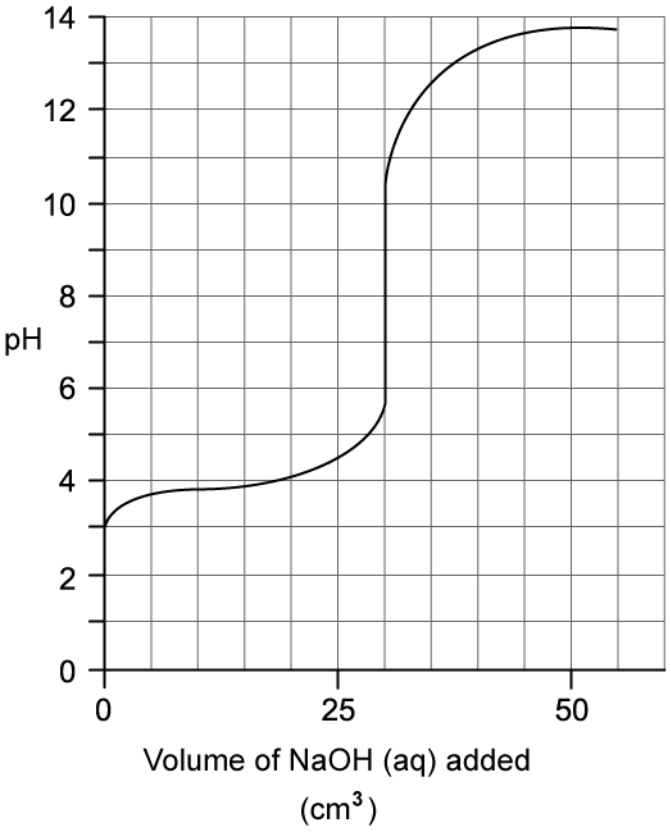
(2 marks)

(d) The image below shows the hexaaquaaluminium ion, $[Al(H_2O)_6]^{3+}$. Explain why this can behave as an acid.



(3 marks)

14 (a) 25.0 cm^3 of 0.100 mol dm^{-3} propanoic acid, CH_3CH_2COOH (aq) , is titrated with of 0.100 mol dm^{-3} sodium hydroxide. The pH curve for this titration is shown below.



i) Label the equivalence point and half equivalence point on the curve.

[2]

ii) Explain what is meant by the half equivalence point.

[1]

.....

.....

.....

(3 marks)

(b) The student used the pH range of the indicators to determine which was the best one to use for this titration.

i) Using Section 18 of the Data Booklet highlight on the graph the pH range of bromocresol green for this titration.

[1]

ii) Using Section 18 of the Data Booklet suggest a suitable choice of indicator for this titration and state the colour change you would expect to see.

[2]

(3 marks)

(c) The end point of an indicator depends on its pK_a

i) Explain the connection between the pH range of an indicator that is a weak acid and the value of pK_a for the indicator.

[3]

ii) Explain how the student can calculate the K_a of propanoic acid by using the pH curve.

[2]

(5 marks)

(d) A buffer solution contains a mixture of propanoic acid and its salt. A small amount of nitric acid is added to the buffer.

Write an equation, including state symbols, showing how this buffer can resist the change in pH.

.....

(1 mark)

15 (a) At 298K, water molecules dissociate into equal quantities of ions, and the pH is 7.

i) Write an equation to show the dissociation of water.

[1]

ii) At 313 K, the pH of water is 6.77. Explain why water is still neutral with a pH of 6.77.

[1]

(2 marks)

(b) The ionic product of water, K_w, can be used to find the pH of a strong base. Changing the temperature will affect the value for K_w.

i) Give the expression and units for the ionic product of water, K_w.

[2]

ii) As temperature increases, the value for K_w also increases. Explain why.

[3]

(5 marks)

(c) Determine the pH of pure water at 40 °.

K_w of pure water at 40 ° is 2.92×10^{-14} mol^2 dm^{-3}

(3 marks)

(d) Strong bases fully ionise in water, as shown by the equation of dissociation of sodium hydroxide:

$$NaOH\ (aq) \rightarrow Na^{+}\ (aq) + OH^{-}\ (aq)$$

At 298K, K_w is 1×10^{-14} mol^2 dm^{-6}.

Calculate the pH of a 0.05 mol dm^{-3} solution of NaOH at 298 K.

(3 marks)

16 (a) Weak acids do not fully ionise in solution. The acid dissociation constant, K_a is used to determine the hydrogen ion concentration.

Write an expression for the acid dissociation constant, K_a for the acid HA.

(1 mark)

(b) The pH of a 0.15 mol dm^{-3} solution of HCN is 5.08 at 298 K. Calculate the value of K_a for HCN at 298 K.

Give your answer to two decimal places.

(3 marks)

(c) A sample of 0.01 mol dm^{-3} butanoic acid has a K_a value of 1.51 x 10^{-5} mol dm^{-3}.

i) Write an expression for the acid dissociation constant, K_a, for butanoic acid.

[1]

ii) Calculate the pH of the 0.01 mol dm^{-3} butanoic acid. Give your answer to two decimal places.

[3]

(4 marks)

(d) 0.50 moles of ammonia was dissolved in water to make a 1.00 dm^3 solution. This solution has a hydroxide ion concentration of 6.40 x 10^{-3} mol dm^{-3}.

i) Write an expression for the base dissociation constant, K_b, of ammonia.

[1]

ii) Calculate a value for pK_b for ammonia.

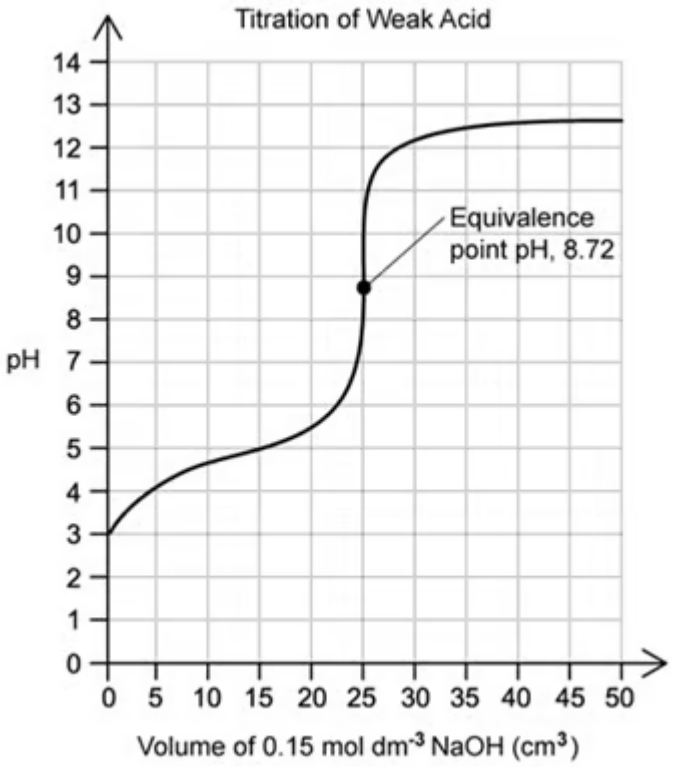
[3]

(4 marks)

17 (a) The pH curve shown below was obtained when a 0.150 mol dm^{-3} solution of sodium hydroxide was added to 25.0 cm^3 of an aqueous solution of ethanoic acid. The half equivalence point is where half of the volume of sodium hydroxide required for neutralisation has been added to the ethanoic acid.

i) Label the graph with an X to show the position of the half equivalence point.

[1]



ii) When half of the ethanoic acid solution has been neutralised, the remaining ethanoic acid concentration is equal to that of the sodium ethanoate that had formed. Calculate the pH at this point.

K_a of ethanoic acid = 1.75 x 10^{-5} mol dm^{-3}.

[2]

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(3 marks)

(b) A different titration was performed using 0.100 mol dm^{-3} ammonia solution, NH_3 (aq) (K_b = 4.75 at 298K) and 25.00 cm^3 of 0.100 nitric acid, HNO_3 (aq).

Calculate the pH of the ammonia solution before it was added to the nitric acid.

(6 marks)

(c) The titration is repeated using 0.200 mol dm^{-3} sodium hydroxide, NaOH (aq), instead of ammonia.

Determine whether the salt formed in this titration will be acidic, basic or neutral.

(2 marks)

(d) Determine the pH of the solution if 150 cm^3 of 0.30 mol dm^{-3} sodium hydroxide, NaOH (aq), is mixed with 200 cm^3 0.10 mol dm^{-3} of nitric acid, HNO_3 (aq).

(5 marks)

18 (a) Monochloroacetic acid, C/H_2COOH, is a skin irritant that is used in "chemical peels" intended to remove the top layer of dead skin from the face and ultimately improve the complexion.

Write an expression for the acid dissociation constant, K_a, of monochloroacetic acid.

(1 mark)

(b) Calculate the pH of a 0.05 M solution of monochloric acid.

The value of K_a for monochloroacetic acid is 1.35×10^{-3} mol dm^{-3}

(4 marks)

(c) Using Section 2 of the Data Booklet, calculate the value of $[OH^-]$ for the solution of monochloric acid.

(2 marks)

(d) Calculate the percentage dissociation for the solution of monochloric acid.

(2 marks)

19 (a) State the relationship between the following expressions for conjugate acid-base pair

i) K_a and K_b

[1]

ii) pKa and pK_b

[1]

.....

.....

(2 marks)

(b) Use Table 1 to calculate the following for the conjugate bases at 298 K.

Table 1

CH_3CH_2COOH	pK_a = 4.87
$CH(Cl_2)COOH$	pK_a = 1.35
$CH(CH_3)_2COOH$	pK_a = 4.84

i) pK_b of $CH_3CH_2COO^-$

[1]

ii) K_b of $CH(Cl_2)COO^-$

[2]

iii) K_a of $(CH_3)_2CHCOOH$

[1]

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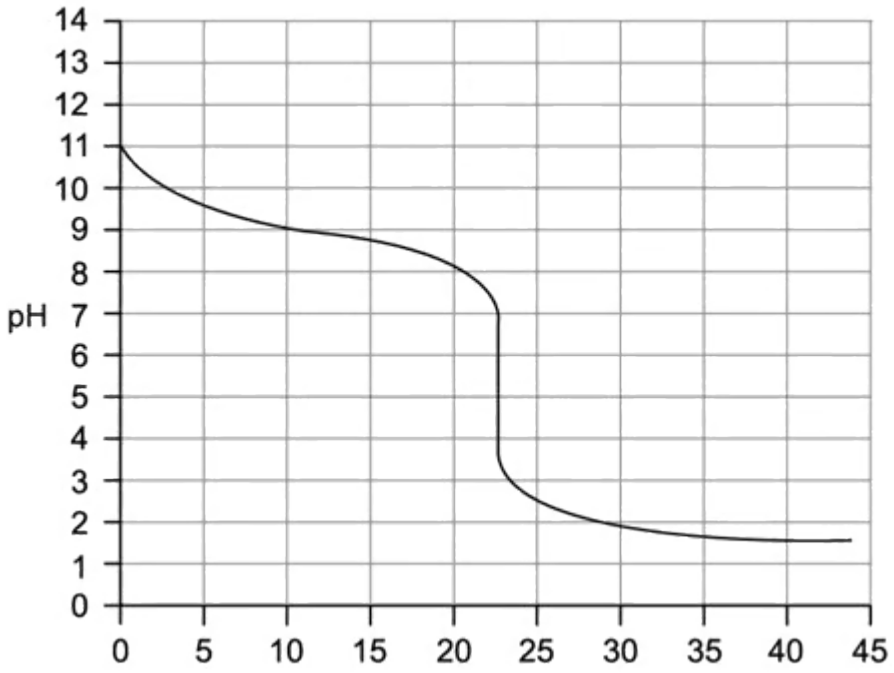
(4 marks)

(c) A student performs a titration using a 0.10 mol dm^{-3} ammonia, NH_3 (aq), and a hydrochloric acid and 0.10 hydrochloric acid, HCl (aq).



i) State the equation for the overall reaction that is occurring.

[1]

ii) Mark on the curve the point at which the pOH is equal to pK_b of the weak base and deduce the pK_b of the acid.

[3]

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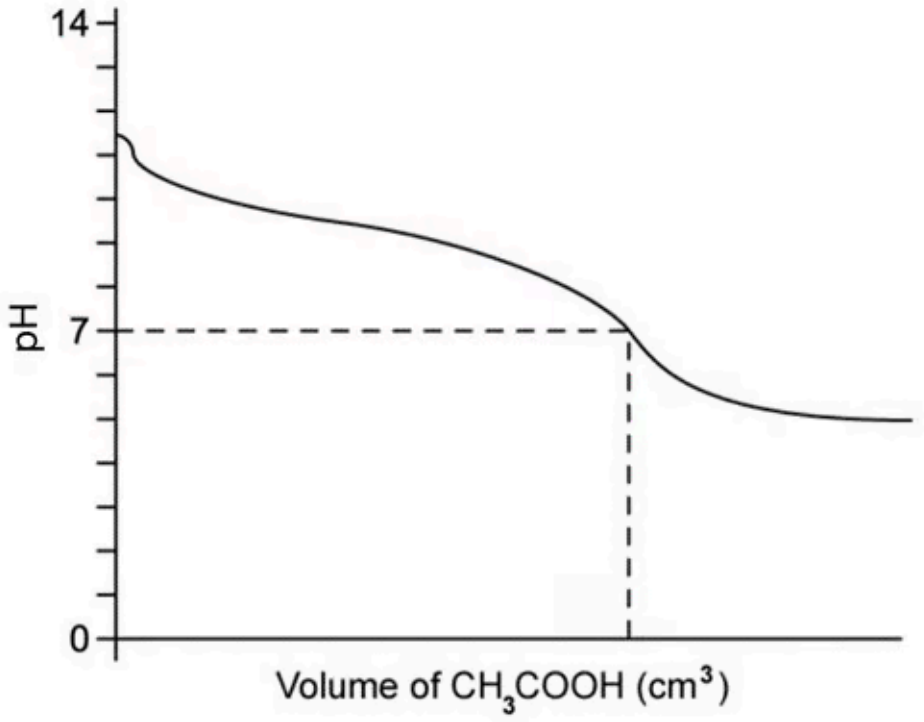
(4 marks)

(d) The student repeats the titration with 0.10 mol dm^{-3} ethanoic acid, CH_3COOH (aq) which has a pK_a value of 4.76. A sketch of the pH curve obtained is shown below.



Explain why it is difficult to determine the equivalence point for this reaction accurately.

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(1 mark)

Hard Questions

1 (a) Explain why an ammonium ion can not behave as a Brønsted-Lowry base.

.....

.....

(2 marks)

(b) State and explain the acid-base character of aqueous ammonia at 298 K.

.....

.....

(2 marks)

(c) Acids can be classed as monoprotic, diprotic and triprotic. Sulfuric acid is a diprotic acid.

i) State the equation for the first ionisation step of sulfuric acid, including state symbols.

[1]

ii) Label the conjugate acid and base pairs in your answer to part i).

[1]

.....

.....

(2 marks)

(d) The second ionisation step is for the ionisation of sulfuric acid is as follows.

$$HSO_4^-(aq) + H_2O(aq) \rightleftharpoons SO_4^{2-}(aq) + H_3O^+(aq)$$

Suggest why the second ionisation step reaches equilibrium.

.....

(1 mark)

2 (a) Sodium hydrogen carbonate solution, $NaHCO_3$ (aq) , can act as an amphiprotic species. State the equation for the reaction fo $NaHCO_3$ (aq) with the following compounds:

i) Sodium hydroxide solution.

[1]

ii) Hydrochloric acid.

[1]

(2 marks)

(b) Using your answer to part a) i) and ii), explain why $NaHCO_3$ is amphiprotic.

(3 marks)

(c) Phosphine is usually prepared by heating white phosphorus, one of the allotropes of phosphorus, with concentrated aqueous sodium hydroxide.

The equation for the reaction is.

$$P_4\,(s) + 3OH^-\,(aq) + 3H_2O\,(l) \rightarrow PH_3\,(g) + 3H_2PO_2^-\,(aq)$$

Identify the amphiprotic species in this reaction giving the formulas of both species it is converted to when it behaves in this manner.

(3 marks)

(d) 1.68 g of white phosphorus was used to make phosphine

i) Calculate the amount, in mol, of white phosphorus used.

[1]

ii) This phosphorus was reacted with 50.0 cm^3 of 3.00 mol dm^{-3} aqueous sodium hydroxide. Deduce, showing your working, which was the limiting reagent.

[1]

iii) Determine the excess amount, in mol, of the other reagent.

[1]

iv) Using section 2 of the data booklet. Determine the volume of phosphine, measured in cm^3 at standard temperature and pressure, that was produced.

[1]

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.....

(4 marks)

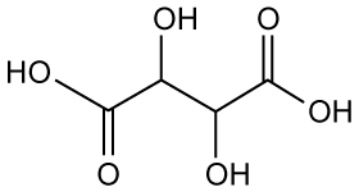
3 (a) Oxalic acid, $H_2C_2O_4$, is a weak diprotic acid and can be used in titrations. State the equation for the reaction of oxalic acid with sodium hydroxide.

(2 marks)

(b) The ionisation of oxalic acid occurs in two steps. State equations for both of these steps.

(2 marks)

(c) Tartaric acid shown below behaves as a Brønsted-Lowry acid when it reacts with calcium hydroxide, $Ca(OH)_2$. Sketch the structure of the salt formed from this reaction.



(3 marks)

4 (a) Using ionic equations state how HPO_4^{2-} can behave as an amphiprotic and amphoteric species.

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(4 marks)

(b) Gallium oxide behaves as an amphoteric oxide. State two equations to show how gallium oxide reacts with a strong monoprotic acid and strong base.

Reaction with strong monoprotic acid

.....

Reaction with strong base

.....

.....

.....

(2 marks)

(c) Identify the Brønsted-Lowry acids in the following reaction.

$$CH_3CH_2O^-(aq) + H_2O(l) \rightleftharpoons CH_3CH_2OH(aq) + OH^-(aq)$$

.....

(1 mark)

5 (a) A solution of hydrochloric acid of concentration 0.001 mol dm^{-3} has a pH value of 3. Suggest, giving a reason, the pH of the following solutions of acids:

i) 0.01 mol dm^{-3} hydrochloric acid

[2]

ii) 0.01 mol dm^{-3} ethanoic acid

[2]

(4 marks)

(b) A solution of 0.01 mol dm^{-3} ethanoic acid has a concentration of hydrogen ion of 1 x 10^{-4} mol dm^{-3}. Determine the percentage of ethanoic acid molecules that have dissociated.

(1 mark)

(c) Two separate titrations are carried out using 25.00 cm^3 of 0.01 mol dm^{-3} solutions of hydrochloric acid followed by ethanoic acid, against 0.01 mol dm^{-3} sodium hydroxide.

State what difference(s) would be observed in the two titrations.

(1 mark)

(d) Suggest a suitable indicator for the titration of hydrochloric acid and sodium hydroxide in part c), and state the colour changes observed.

(2 marks)

6 (a) Show how the ionic product for water is derived from the dissociation of water and give it units.

(3 marks)

(b) Determine the pH of 0.001 mol dm^{-3} sodium hydroxide.

(1 mark)

(c) Suggest, with a reason, how the magnitude of K_w changes with increasing temperature.

(4 marks)

7 (a) Malonic acid is a weak dibasic carboxylic acid with the formula $C_3H_4O_4$. Draw the displayed structure of malonic acid.

(1 mark)

(b) Suggest, with a reason, which of the two acids, ethanoic or malonic, has a higher pH?

(2 marks)

(c) Apart from testing the pH, suggest how equimolar solutions of malonic acid and ethanoic acid may be distinguished.

(1 mark)

(d) Write the formulas of two conjugate bases that can be formed from malonic acid.

(2 marks)

8 (a) Marble chips are added separately to solutions of the same concentration of ethanoic acid and hydrochloric acid. State **one** similarity and **one** difference you would expect to observe in the reactions.

(2 marks)

(b) Write an equation for the reaction between marble chips and ethanoic acid.

(1 mark)

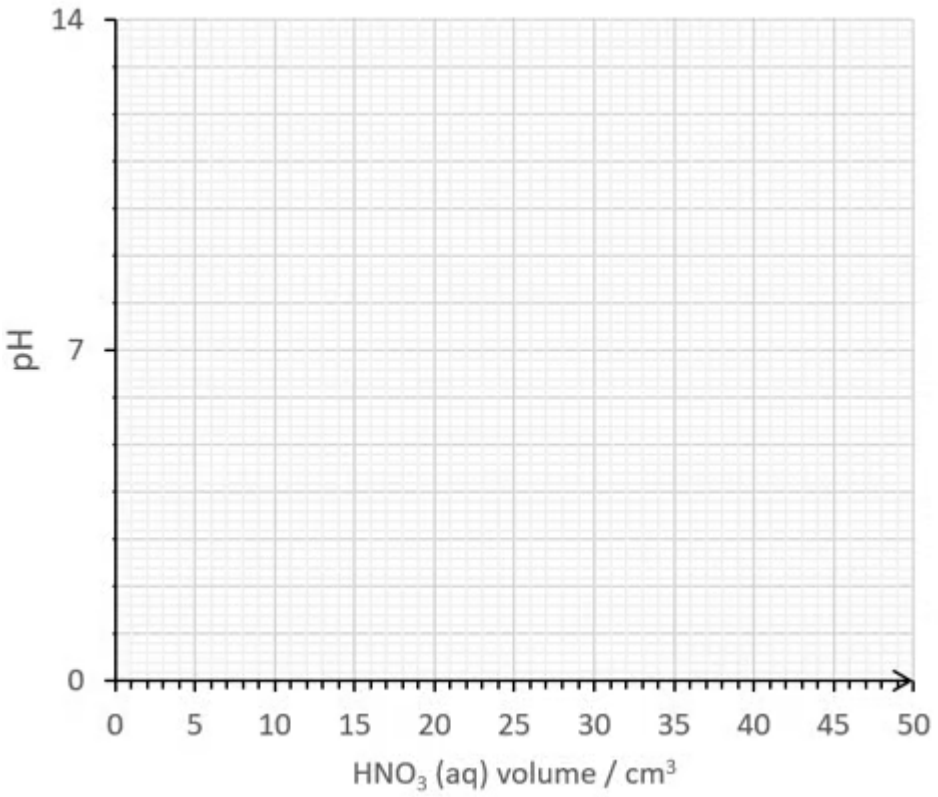
(c) Determine the volume, in cm^3, of 2.25 mol dm^{-3} ethanoic acid needed to completely react with 1.50 g of marble chips.

(3 marks)

(d) Determine the volume of CO_2, in cm^3, produced at 273 K and 101 kPa in part c).

(3 marks)

9 (a) Sketch the titration curve when 50 cm^3 of 0.1 mol dm^{-3} HNO_3 (aq) is titrated against 25 cm^3 of 0.1 mol dm^{-3} NH_3 (aq).



(4 marks)

(b) Select a suitable indicator for the titration from table 22 of the Data booklet.

(1 mark)

(c) Calculate the pH of 0.1 mol dm^{-3} ammonia.

pK_b of ammonia = 4.75

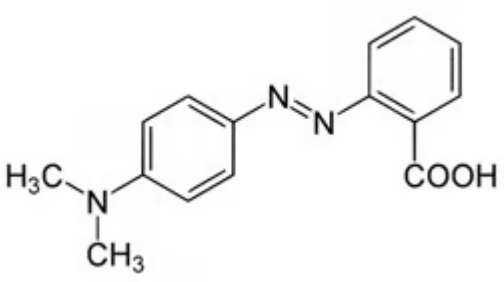
(5 marks)

(d) Deduce whether the pH of 0.1 mol dm^{-3} ethylamine would be higher or lower than 0.1 mol dm^{-3} ammonia solution.

(pK_b of ethylamine is 3.35)

(1 mark)

10 (a) Indicators are solutions of weak acids or bases. Methyl red has the molecular formula $C_{15}H_{15}N_2O_2$.



Draw the structure of the conjugate base of methyl red.

(1 mark)

(b) What will be seen if a few drops of methyl red are added during a titration of 50 cm^3 of 0.1 mol dm^{-3} HCl (aq) against 25 cm^3 of 0.1 mol dm^{-3} NaOH (aq).

(1 mark)

(c) The pK_a of methyl red is 5.1. Explain how this relates to the acid-base character of methyl red when added to water.

(3 marks)

11 (a) Using **Table 1**, discuss the relationship between the chemical structures and acidity of chloroethanoic acid, dichloroethanoic acid and trichloroethanoic acid.

Table 1

Name of Acid	Formula	pK_a
chloroethanoic acid	$CH_2ClCOOH$	2.87
dichloroethanoic acid	$CHCl_2COOH$	1.35
trichloroethanoic acid	$CHCl_3COOH$	0.66

(3 marks)

(b) This question is about acid buffers.

i) Explain how you could make a buffer given a supply of the following:
20 cm^3 of 0.10 mol dm^{-3} chloroethanoic acid
20 cm^3 of 0.10 mol dm^{-3} potassium hydroxide

[3]

ii) Determine the new concentration of each reactant in the buffer.

[1]

(4 marks)

(c) 20 cm^3 of 0.05 mol dm^{-3} dichloroethanoic acid was reacted with 10 cm^3 of 0.10 mol dm^{-3} sodium hydroxide. Suggest, with a reason, a pH value for the resulting solution.

(3 marks)

12 (a) Determine the K_a of benzoic acid

pK_a at 298 K = 4.2

(1 mark)

(b) Using the K_a value for benzoic acid, state and explain its acidic character.

(1 mark)

(c) Benzoic acid has a solubility of 0.344 g / 100 g water at 293 K. Determine the hydrogen ion concentration and pH of saturated benzoic acid solution at this temperature.

(5 marks)

(d) What assumption is made in the calculation in part c)?

(1 mark)

13 (a) Nitric acid, HNO_3, and hydrocyanic acid, HCN, can be made from ammonia. Hydrocyanic acid has a pK_a of 9.21.

Formulate equations for the dissociation of each acid and distinguish between the terms strong and weak in this context.

(3 marks)

(b) Write an expression for the acid dissociation constant, K_a, of hydrocyanic acid and calculate the K_a at 298 K.

(2 marks)

(c) Determine the hydrogen ion concentration and pH of 0.15 mol dm^{-3} hydrocyanic acid.

(2 marks)

(d) Write an expression to show the ionisation of the conjugate base of hydrocyanic acid and calculate it K_b value.

(2 marks)

14 (a) Calculate the pH of a solution made by mixing 50.0 cm^3 of 0.200 mol dm^{-3} HCl (aq) with 50.0 cm^3 of 0.100 mol dm^{-3} NH_3 (aq)

(3 marks)

(b) A 0.100 mol dm^{-3} solution of NH_3 (aq) contains 1.28 x 10^{-3} mol dm^{-3} in hydroxide ion.

i) Determine the pH of the solution.

[3]

ii) Comment on the relative base strength of 0.100 mol dm^{-3} NaOH (aq) compared to 0.100 mol dm^{-3} NH_3 (aq)

[2]

(5 marks)

(c) Determine the base dissociation constant, K_b for ammonia using the information in part b).

(3 marks)

(d) The pH of pure water is 6.92 at 328 K and K_b for NH_3 (aq) at this temperature is 1.80×10^{-5}.

Determine the pK_a of [NH_4^+] at this temperature.

(4 marks)