IB · SL · Chemistry

4 hours 36 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

Easy (10 questions)	/53
Medium (13 questions)	/94
Hard (13 questions)	/84
Total Marks	**/231**

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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)

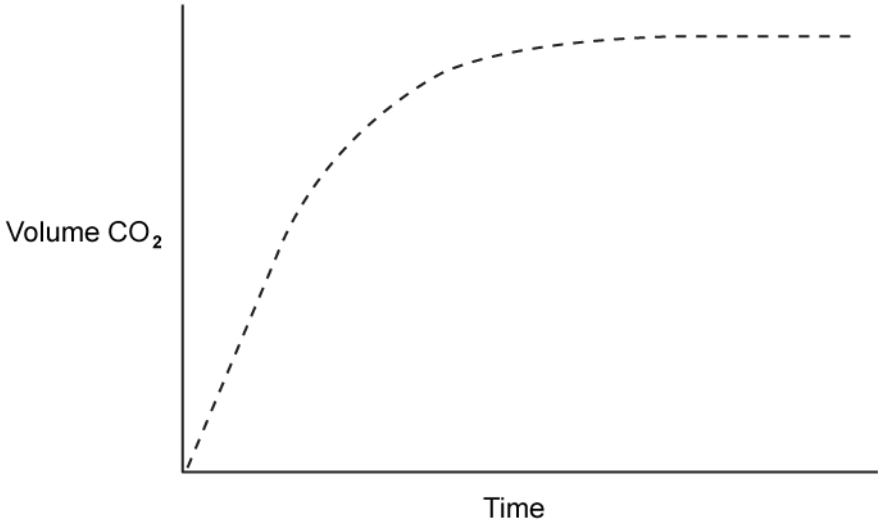
(b) Other than measuring the pH, describe how you could distinguish between dilute solutions of the same concentration of hydrochloric acid and ethanoic acid.

.....

.....

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

.....

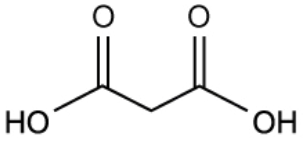
.....

(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)

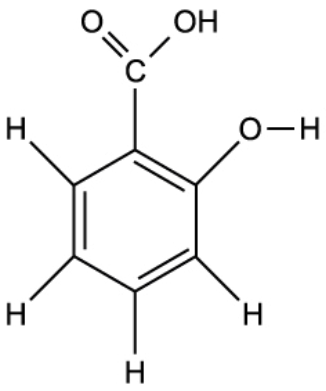
(c) The anion $C_3H_3O_4^-$ may be classified as *amphiprotic*. Explain the meaning of *amphiprotic* and write equations, using $C_3H_3O_4^-$, to illustrate your answer.

.....

(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)

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]

.....

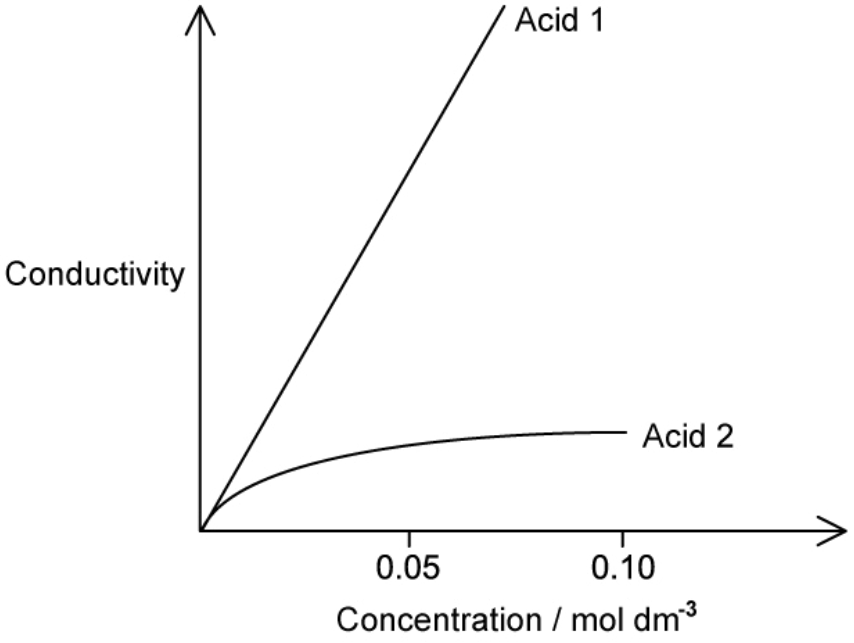
.....

.....

(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.



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(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) 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.

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

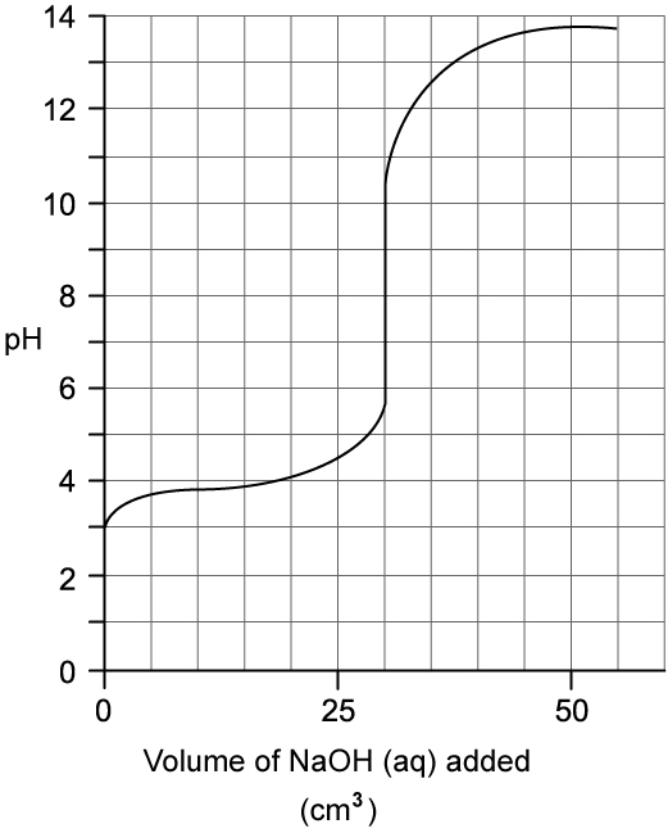
Write an equation to show how hydrochloric acid behaves as a strong acid when it reacts with water, and state the role of water in this reaction.

.....

.....

(2 marks)

12 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)

13 (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 x 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)

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]

.....

.....

.....

.....

(4 marks)

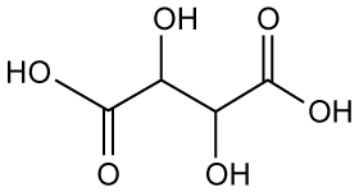
3 (a) Oxalic acid, $H_2C_2O_4$, is a weak diprotic acid and can be used in titrations. State the equation for the reaction of oxalic acid with sodium hydroxide.

(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) 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)

(c) 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).

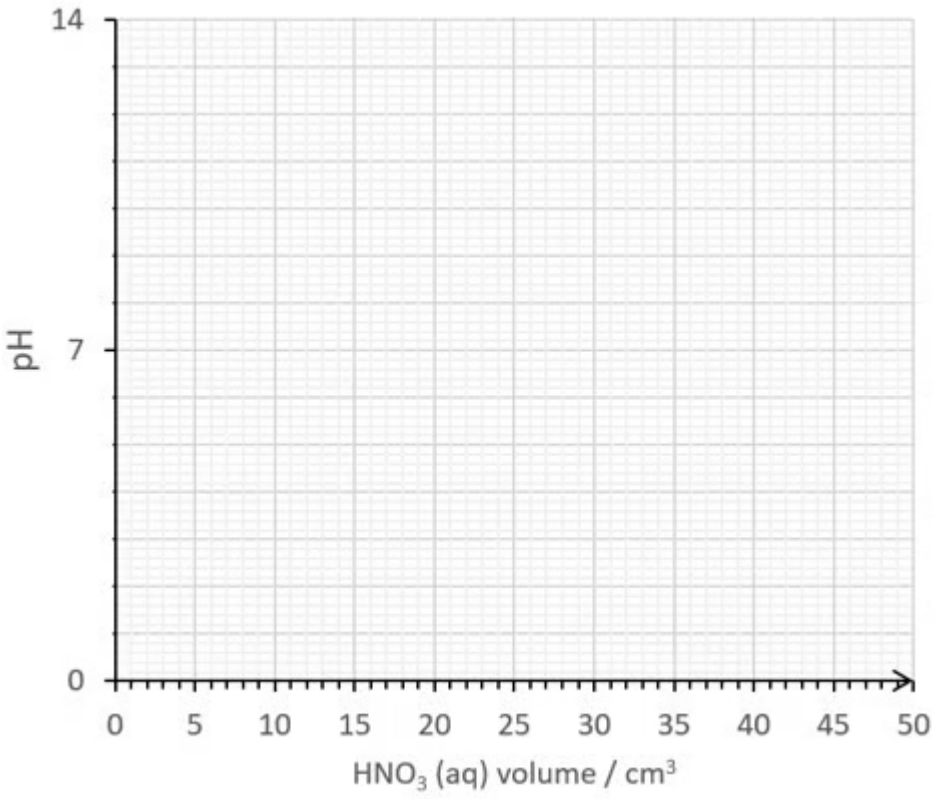
.....

.....

.....

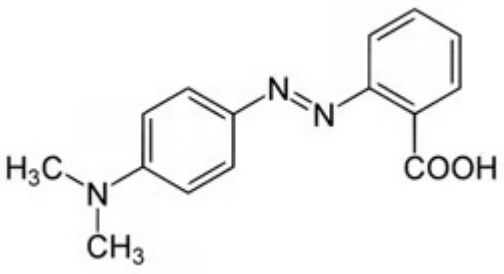
(3 marks)

9 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)

10 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)

11 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)

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.

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(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.

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(5 marks)

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

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(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.

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(3 marks)

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

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(2 marks)