IB · DP · Chemistry

2 hours 12 questions

Structured Questions: Paper 2

18.2 Calculations Involving Acids & Bases

Easy (4 questions)	/33
Medium (5 questions)	/61
Hard (3 questions)	/32
Total Marks	**/126**

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Easy Questions

1 (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.

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(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.

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(1 mark)

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

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(2 marks)

(d) The pK_a of hydrocyanic acid, HCN, is 9.2 at 298 K. Using section 21 of the Data booklet, deduce which of the two acids, ethanoic, CH_3COOH, or hydrocyanic is the stronger acid.

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(2 marks)

2 (a) Using section 21 of the Data booklet, determine the K_a of chloroethanoic acid, dichloroethanoic acid and trichloroethanoic acid and state which is the stronger acid.

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(4 marks)

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

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(1 mark)

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

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(1 mark)

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

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(1 mark)

3 (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)

4 (a) Use section 21 of the Data booklet to answer this question.

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

[1]

ii) Determine the pK_b of the conjugate base

[2]

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(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.

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(1 mark)

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

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(1 mark)

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

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(2 marks)

Medium Questions

1 (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.

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

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(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

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

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(5 marks)

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

K_w of pure water at 40 °C 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)

2 (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.

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(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.

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(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.

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

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(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.

ii) Calculate a value for pK_b for ammonia.

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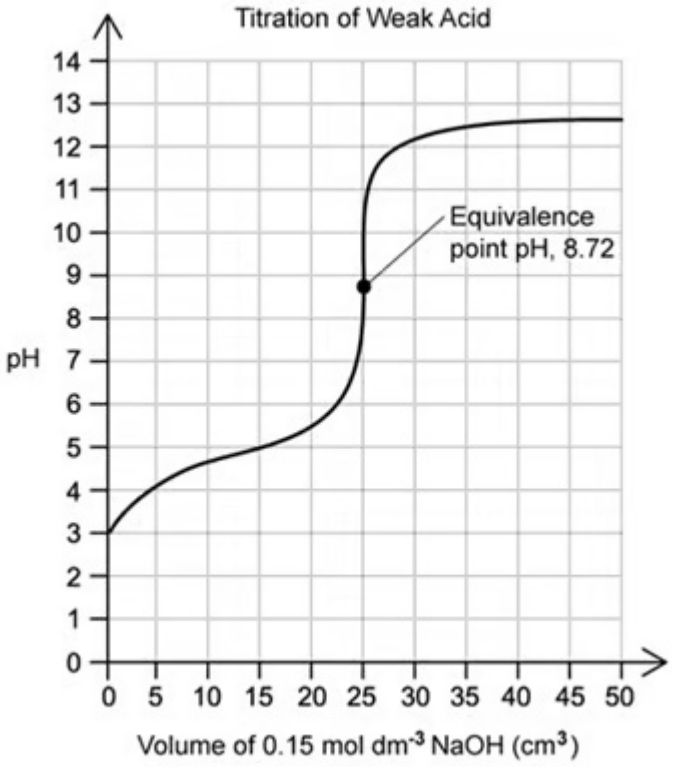
(4 marks)

3 (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.



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}.

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(3 marks)

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

Using Section 21 of the Data Booklet, 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)

4 (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)

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

i) K_a and K_b

ii) pKa and pK_b

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(2 marks)

(b) Using Section 21 of the Data Booklet, calculate the following for the conjugate bases at 298 K.

i) pK_b of $CH_3CH_2COO^-$

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

iii) K_a of $(CH_3)_2CHCOOH$

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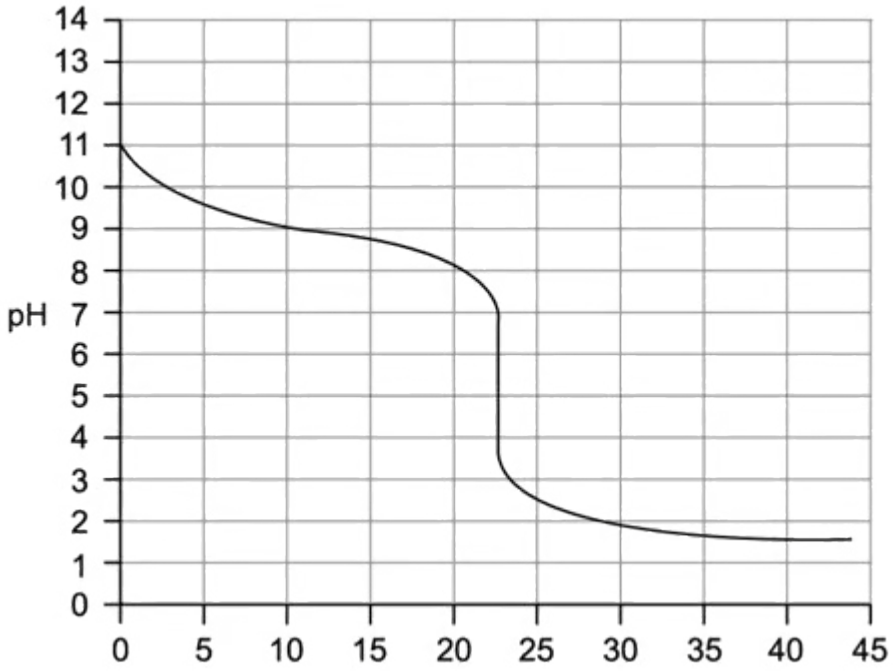
(4 marks)

(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.

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.

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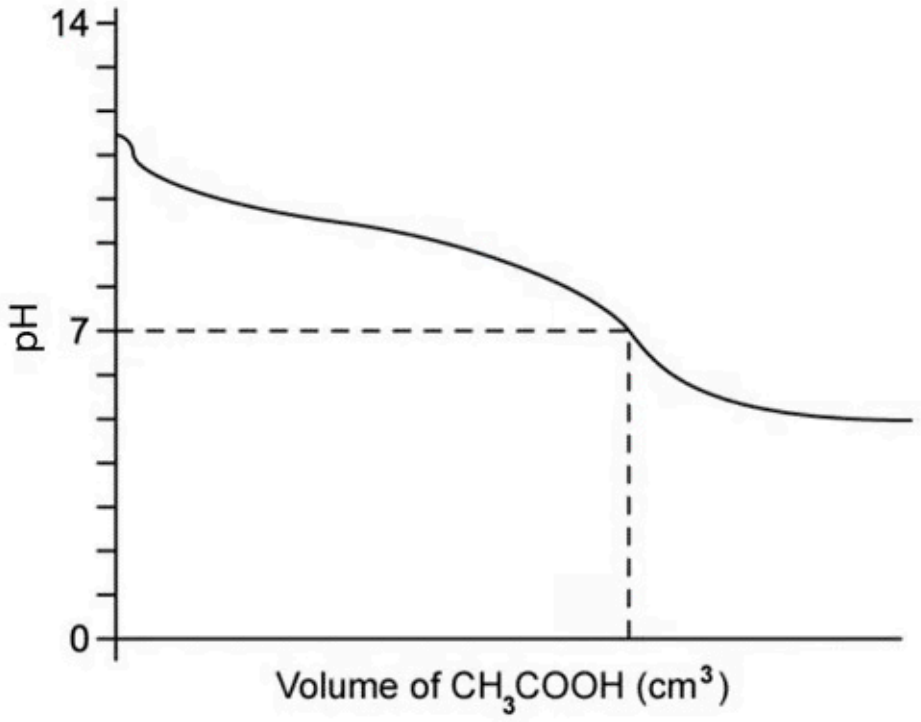
(4 marks)

(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) Determine the K_a of benzoic acid using section 21 of the Data booklet.

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(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)

2 (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)

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

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(2 marks)

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

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(2 marks)

3 (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)