3

SAMPLE PAPER

NZQA

NEW ZEALAND QUALIFICATIONS AUTHORITY
MANA TOHU MĀTAURANGA O AOTEAROA

Level 3 Chemistry

3.6: Demonstrate understanding of equilibrium principles in aqueous systems

Credits: Five

Check that you have completed ALL parts of the box at the top of this page.

Check that you have been supplied with the resource sheet for Chemistry 3.6.

You should answer ALL parts of ALL questions in this booklet.

If you need more room for any answer, use the space provided at the back of this booklet.

Check that this booklet has pages 2–11 in the correct order and that none of these pages is blank.

YOU MUST HAND THIS BOOKLET TO YOUR TEACHER AT THE END OF THE ALLOTTED TIME.

EXEMPLAR FOR LOW MERIT

NOTE: These exemplars do not fully show Grade Score Marking (GSM) because of the small sample of student scripts involved, and the absence of a cut score meeting to determine grade boundaries. GSM can be seen in the level 1 and level 2 exemplars from the 2012 examinations, which will be published on the NZQA website when the assessment schedules are published.

You are advised to spend 60 minutes answering the questions in this booklet.

Assessor's use only

QUESTION ONE

(a) Methanoic acid, HCOOH, is a weak acid. A dilute aqueous solution of this acid has a pH of 2.78.

$$pK_a\,(HCOOH) = 3.74$$

(i) Write an equation for the reaction of methanoic acid with water.

$HCOOH + H_2O \rightleftharpoons HCOO^- + H_3O^+$

$2H_2O \rightleftharpoons H_3O^+ + OH^-$

Correct equation.

(ii) List all the species in the aqueous solution of methanoic acid in order of decreasing concentration.

$H_2O > HCOOH > H_3O^+ > HCOO^- > OH^-$

Correct list.

Give reasons for you answer.

(iii) Calculate the concentration of the methanoic acid solution with a pH of 2.78.

$K_a = \dfrac{[HCOO^-][H_3O^+]}{[HCOOH]}$ (assume) $K_a = \dfrac{[H_3O^+]^2}{[HCOOH]}$

$pK_a = 3.74$

$K_a = 1.82 \times 10^{-4}$

$pH = 2.78$

$[H_3O^+] = 1.66 \times 10^{-3}$

$1.82 \times 10^{-4} = \dfrac{[1.66 \times 10^{-3}]^2}{[HCOOH]}$

$[HCOOH] = \dfrac{(1.66 \times 10^{-3})^2}{1.82 \times 10^{-4}}$

$= 1.51 \times 10^{-2}$

Correct numerical answer (no units).

(b) Justify the variation in the properties (pH and conductivity) for the four dilute aqueous solutions described in the table below.

Assessor's use only

	pH	Conductivity
HCl	1.0	high
NH_4Cl	5.1	high
NH_3	11.1	low
NaOH	13.0	high

$HCl + H_2O \rightarrow H_3O^+ + Cl^-$

- Has a very low pH as it is a strong acid meaning it completley dissocides in water. the conductivity is high as there are charged ions floating around in the solution.

$NH_4Cl + H_2O \rightleftharpoons NH_3 + H_3O^+ + Cl^-$

- NH_4^+ is the conjugate acid to NH_3, it is a weak acid this is way the pH isn't far below 7. Its conductivity is high as again there are ions in the solution.

$NH_3 + H_2O \rightarrow NH_4^+ + OH^-$

- NH_3 is a strong base, it completly dissocides in water.

$NaOH \rightarrow Na^+ + OH$

- NaOH is another strong base and because there are ions in the soln it is a good conductor.

[H_3O^+] not related to pH.

Correctly identifies HC1 as a strong acid, NH_4^+ as a weak acid, NaOH as a strong base.

Some connection between conductivity and ions in solution.

One correct Merit statement.

M5

QUESTION TWO

Assessor's use only

(a) Iron(II) sulfide, FeS, is dissolved in water to make a saturated solution.

(i) Write the equation for the equilibrium present in a saturated solution of FeS.

$FeS \rightleftharpoons Fe^{2+} + S^{2-}$

(ii) Write the expression for K_s(FeS)

Correct equation and correct K_s expression.

$K_s = [Fe^{2+}][S^{2-}]$

(iii) Calculate the solubility of FeS in a saturated solution, in mol L^{-1}.

$K_s(FeS) = 4.90 \times 10^{-18}$

$K_s = S \times S$

$K_s = S^2$

$4.90 \times 10^{-8} = S^2$

$S = \sqrt{4.90 \times 10^{-8}}$

$= 2.21 \times 10^{-4}$

(b) Some sulfides have very low solubility products. When hydrogen sulfide gas is bubbled through solutions of these ions, these ions separate from a mixture of ions.

(i) In a saturated solution of hydrogen sulfide $[H_3O^+]^2[S^{2-}] = 1.10 \times 10^{-23}$

Calculate the sulfide ion concentration when the pH of the solution is 4.20.

$[H_3O^+] = 10^{-4.20}$

$= 6.31 \times 10^{-5}$

Correct $[H_3O^+]$ concentration.

Assessor's use only

(ii) Calculate the solubility of FeS in this solution, in mol L^{-1}.

(c) A solution contains a mixture of the two metal ions Cu^{2+} and Zn^{2+}, both of the same concentration. The solution is saturated with hydrogen sulfide and adding hydrochloric acid lowers the pH of the solution.

$K_s(CuS) = 6.30 \times 10^{-36}$ $K_s(ZnS) = 1.6 \times 10^{-24}$

Account for the fact that at a pH close to 7 all the metal sulfides will precipitate whereas only the most insoluble sulfides precipitate out at a lower pH.

In your answer, you should use equilibrium principles and both Cu^{2+} and Zn^{2+} as examples.
(No calculations are required.)

$CuS \rightleftharpoons Cu^{2+} + S^{2-}$ | $ZnS \rightleftharpoons Zn^{2+} + S^{2-}$

Two correct statements.

A3

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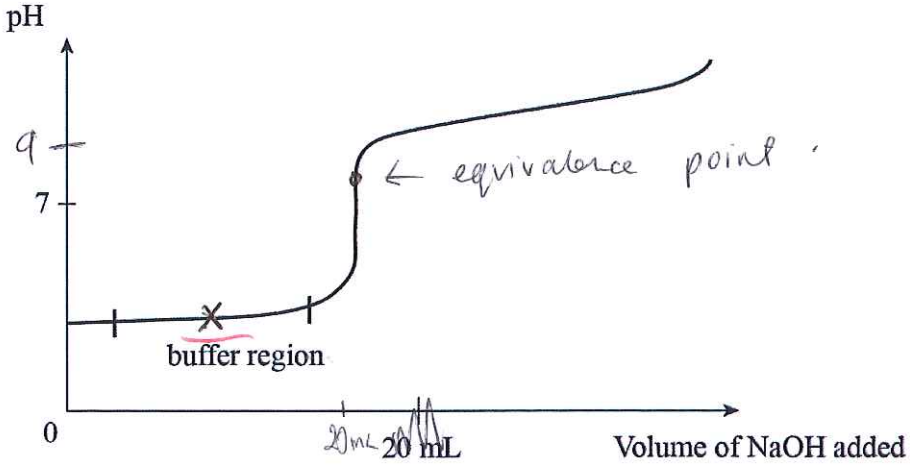
QUESTION THREE

Assessor's use only

20.00 mL of 0.125 mol L^{-1} ethanoic acid is titrated with 0.125 mol L^{-1} sodium hydroxide solution. The equation for this reaction is:

$$CH_3COOH(aq) + NaOH(aq) \rightarrow CH_3COONa(aq) + H_2O\ (l)$$

The titration curve for the reaction is given below and the buffer region is marked on the graph.



(a) (i) Explain why the solution in the titration flask can act as a buffer in this marked region. Use an equation in your answer.

(ii) Put an **X** on the graph to show at which point the buffering action is the most efficient. Give reasons for your answer.

(b) (i) Show that the pH at the equivalence point for this titration is 8.78.

Assessor's use only

$pK_a(CH_3COOH) = 9.24$ 4.76

$CH_3COOH + H_2O \rightleftharpoons CH_3COO^- + H_3O^+$

$K_a = \frac{[CH_3COO^-][H_3O^+]}{[CH_3COOH]}$ Assume: $[CH_3COO^-] = [H_3O^+]$: CH_3COOH @ equm = initial conc.

$pK_a = 4.76$

$K_a = 1.74 \times 10^{-5}$

$1.74 \times 10^{-5} = [H_3O^+]^2$

0.125

$K_a = \frac{[H_3O^+]^2}{[CH_3COOH]}$

$H_3O^+ = \sqrt{(1.74 \times 10^{-5} \times 0.125}$

$= 5.21 \times 10^{-4}$

$pH = -\log[H_3O^+]$

$= -\log(5.21 \times 10^{-4}) = 3.28$

(ii) Explain why methyl orange is not a suitable indicator for this titration and why phenolphthalein is a suitable indicator for this titration.

Indicator	pK_a
Methyl orange	3.70
Phenolphthalein	9.30

pH = pKa at equivlence point. pH at equivlence point = 8.75 Therefore phenolphthalein with a pH range of 8.30 - 10.30 would show a colour change with this reaction. Methyl orange however has a pKa which is too low and does not match the pH at the equivlence point.

Matches colour change of phenolphthalein to equivalence point of titration and that methyl orange will not change colour near the equivalence point.

Assessor's use only

(iii) Phenolphthalein is an acid-base indicator. It is a weak acid and its formula can be represented as HIn. Phenolphthalein is colourless in acidic solutions and purple in basic solutions.

$$pK_a\ (HIn) = 9.60 \quad \begin{matrix} 8.60 \\ \updownarrow \\ 10.60 \end{matrix}$$ pH rangge

Discuss the effect of adding ethanoic acid and sodium hydroxide in turn to a solution containing phenolphthalein. In your answer, you should refer to:

- equilibrium principles
- the species responsible for the colours seen
- the pH range within which this indicator is effective.

• $NaOH \rightarrow Na^+ + OH$ (strong base)

• $CH_3COOH + H_2O \rightleftharpoons CH_3COO^- + H_3O^+$ (weak acid)

phenolpthalein is effective as an indicator between a pH of 8.60 and 10.60.

Phenolpthalein would be colourless in the ethanoic acid (CH_3COOH) solution as it has pH to low to show a colour change if you were to then add NaOH (basic) solution the colour would begin to change to purple as the pH level got within the indicative range of phenolpthalein (pH 8.60 ↔ 10.60)

States the range over which phenolpthalein changes colour.

One correct Merit statement.

M5

3

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EXEMPLAR FOR HIGH MERIT

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$$pK_a\,(HCOOH) = 3.74$$

(i) Write an equation for the reaction of methanoic acid with water.

$HCOOH + H_2O_{(l)} \rightleftharpoons HCOO^-_{(aq)} + H_3O^+_{(aq)}$

Correct equation.

(ii) List all the species in the aqueous solution of methanoic acid in order of decreasing concentration.

$H_2O > HCOOH > H_3O^+ \geq HCOO^- > OH^-$

Correct order of species.

Give reasons for you answer.

Because it is a weak acid, the methanoic acid only partially dissociates so there is still a reasonable amount of HCOOH present. Equal amounts of $HCOO^-$ and H_3O^+ are produced from the dissociation of HCOOH but there is slightly more H_3O^+ due to the dissociation of water (also producing some OH^-)

Identifies HCOOH as a weak acid.

Justifies order for all species.

(iii) Calculate the concentration of the methanoic acid solution with a pH of 2.78.

$pH = 2.78 \qquad [H_3O^+] = 10^{-2.78}$

$= 1.66 \times 10^{-3}\ mol\,L^{-1}$

$K_a = \dfrac{[HCOO^-][H_3O^+]}{[HCOOH]}$ assuming $[HCOO^-] = [H_3O^+]$

$10^{-3.74} = \dfrac{(1.66 \times 10^{-3})^2}{[HCOOH]}$

$[HCOOH] = 0.0151\ mol\,L^{-1}$ (3sf)

Correct calculation.

(b) Justify the variation in the properties (pH and conductivity) for the four dilute aqueous solutions described in the table below.

Assessor's use only

	pH	Conductivity
HCl	1.0	high
NH_4Cl	5.1	high
NH_3	11.1	low
NaOH	13.0	high

HCl is a strong acid so will fully dissociate in water meaning there is a high concentration of ions in the solution and so has a high conductivity.

NaOH is a strong base, will will also fully dissociate in water thus freeing ions and able to conduct electricity well.

Identifies number of ions in solution as contributing to conductivity.

Correctly describes reasons for conductivity of HC1 and NaOH.

Two or more statements at Merit.

M6

QUESTION TWO

Assessor's use only

(a) Iron(II) sulfide, FeS, is dissolved in water to make a saturated solution.

(i) Write the equation for the equilibrium present in a saturated solution of FeS.

$FeS_{(s)} + aq \rightarrow Fe^{2+}_{(aq)} + S^{2-}_{(aq)}$

(ii) Write the expression for K_s(FeS). **Correct equation and correct K_s expression.**

$K_{s(FeS)} = [Fe^{2+}][S^{2-}]$

(iii) Calculate the solubility of FeS in a saturated solution, in mol L^{-1}.

$K_s(FeS) = 4.90 \times 10^{-18}$

$[Fe^{2+}] = [S^{2-}]$ substituting Fe^{2+} for 'S'

$K_s = S^2$

$4.90 \times 10^{-18} = S^2$

$S = 2.21 \times 10^{-9}$ (3sf)

Correct calculation.

(b) Some sulfides have very low solubility products. When hydrogen sulfide gas is bubbled through solutions of these ions, these ions separate from a mixture of ions.

(i) In a saturated solution of hydrogen sulfide $[H_3O^+]^2[S^{2-}] = 1.10 \times 10^{-23}$

Calculate the sulfide ion concentration when the pH of the solution is 4.20.

$pH = 4.20$ $[H_3O^+] = 10^{-4.20}$

$1.10 \times 10^{-23} = [10^{-4.2}]^2 [S^{2-}]$

$[S^{2-}] = 2.76 \times 10^{-15}$ mol L^{-1} (3sf)

Correct calculation.

(ii) Calculate the solubility of FeS in this solution, in mol L^{-1}.

Assessor's use only

$K_s = 4s^3$

$4.90 \times 10^{-18} = 4s^3$

$s = 1.07 \times 10^{-6}$ (3sf)

(c) A solution contains a mixture of the two metal ions Cu^{2+} and Zn^{2+}, both of the same concentration. The solution is saturated with hydrogen sulfide and adding hydrochloric acid lowers the pH of the solution.

$K_s(CuS) = 6.30 \times 10^{-36}$ $K_s(ZnS) = 1.6 \times 10^{-24}$

Account for the fact that at a pH close to 7 all the metal sulfides will precipitate whereas only the most insoluble sulfides precipitate out at a lower pH.

In your answer, you should use equilibrium principles and both Cu^{2+} and Zn^{2+} as examples. **(No calculations are required.)**

One correct statement at Merit.

M5

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QUESTION THREE

Assessor's use only

20.00 mL of 0.125 mol L^{-1} ethanoic acid is titrated with 0.125 mol L^{-1} sodium hydroxide solution. The equation for this reaction is:

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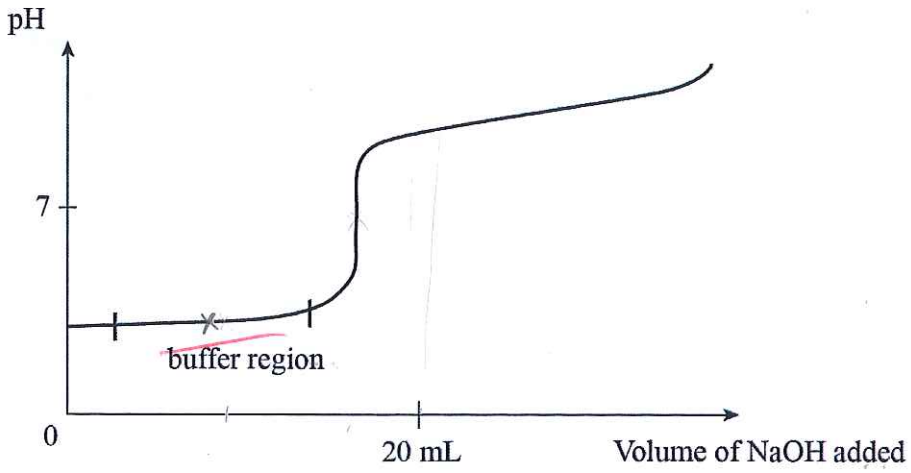

Identifies CH_3COOH and CH_3COO^- as acid conjugate base pair.

(a) (i) Explain why the solution in the titration flask can act as a buffer in this marked region. Use an equation in your answer.

Buffer regions resist changes in the pH when small amounts of acid or base is added. This is due to the presence of the weak acid $CH_3COOH_{(aq)}$ and its conjugate base $CH_3COO^-_{(aq)}$ in the solution.

When acid is added, the base will react with it

$H_3O^+ + CH_3COO^- \rightarrow H_2O + CH_3COOH$

and when a base is added, the acid will react with it

$OH^- + CH_3COOH \rightarrow H_2O + CH_3COO^-$ In this marked region, there are an equal/similar amount of acid and base in the solution.

Equations given for action of buffer with H_3O^+ and OH^-.

(ii) Put an **X** on the graph to show at which point the buffering action is the most efficient. Give reasons for your answer.

, the [acid] will be equal to the [base] making this point the most efficient buffering action occurs.

Correctly identifies most efficient buffer and correct reason.

(b) (i) Show that the pH at the equivalence point for this titration is 8.78.

Assessor's use only

$pK_a(CH_3COOH) = 9.24$

Correct calculation for calculation of [CH_3COOH^-] at equivalence point.

Identifies CH_3COOH^- as a weak base.

20 mL

at equivalence point $CH_3COOH + NaOH \rightarrow CH_3COONa + H_2O$

weak base.

$CH_3COO^- + H_2O \rightarrow OH^- + CH_3COOH$

$K_a = \frac{[OH^-][CH_3COOH]}{[CH_3COO^-]}$ 8.78

$10^{-9.24} = \frac{[OH^-]^2}{0.0625}$

$[OH^-] = 8.997 \times 10^{-6}$ mol L^{-1}

$pOH = 5.2221$

$pH = 14 - pOH = 8.7779$

$pH = 8.78.$

20 mL 0.125 mol L^{-1} CH_3COOH

$[CH_3COO^-] = 0.0625$ mol L^{-1} because if u now 40mL)

$[NaOH] = 0.125$ mol L^{-1}

Uses pK_b = 9.24 to find OH^- and then pH.

(ii) Explain why methyl orange is not a suitable indicator for this titration and why phenolphthalein is a suitable indicator for this titration.

Indicator	pK_a
Methyl orange	3.70
Phenolphthalein	9.30

The range of pH at which methyl orange changes is about 2.7 - 4.7 which is much less than the pH of the equivalence point thus would change colour much earlier on whereas phenolphthalein has a pH range much closer to the equivalence point (8.3 - 9.3) which would provide a much more suitable indication to when the solution has reached equivalence point.

Describes range of colour change for both methyl orange and phenolphthalein.

Recognises only phenolphthalein will change colour at or near equivalence point.

(iii) Phenolphthalein is an acid-base indicator. It is a weak acid and its formula can be represented as HIn. Phenolphthalein is colourless in acidic solutions and purple in basic solutions.

Assessor's use only

$$pK_a\ (HIn) = 9.60$$

Discuss the effect of adding ethanoic acid and sodium hydroxide in turn to a solution containing phenolphthalein. In your answer, you should refer to:

- equilibrium principles
- the species responsible for the colours seen
- the pH range within which this indicator is effective.

One correct answer at Excellence.

E7