Q15.

This question is about the pH of some solutions containing potassium hydroxide and ethanoic acid.

Give all values of pH to 2 decimal places.

(a) (i) Write an expression for pH.

___

(1)

(ii) Write an expression for the ionic product of water, K_w

___

(1)

(iii) At 10 °C, a 0.154 mol dm^{-3} solution of potassium hydroxide has a pH of 13.72. Calculate the value of K_w at 10 °C.

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___

___

(2)

(b) At 25 °C, the acid dissociation constant K_a for ethanoic acid has the value 1.75×10^{-5} mol dm^{-3}.

(i) Write an expression for K_a for ethanoic acid.

___

___

(1)

(ii) Calculate the pH of a 0.154 mol dm^{-3} solution of ethanoic acid at 25 °C.

___

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(3)

(c) At 25 °C, the acid dissociation constant K_a for ethanoic acid has the value 1.75×10^{-5} mol dm^{-3}.

(i) Calculate the pH of the solution formed when 10.0 cm^3 of 0.154 mol dm^{-3} potassium hydroxide are added to 20.0 cm^3 of 0.154 mol dm^{-3} ethanoic acid at 25 °C.

(4)

(ii) Calculate the pH of the solution formed when 40.0 cm^3 of 0.154 mol dm^{-3} potassium hydroxide are added to 20.0 cm^3 of 0.154 mol dm^{-3} ethanoic acid at 25 °C.

At 25 °C, K_w has the value 1.00×10^{-14} mol^2 dm^{-6}.

(4)

(Total 16 marks)

Q16.

In this question, give all values of pH to two decimal places.

Calculating the pH of aqueous solutions can involve the use of equilibrium constants such as K_w and K_a

K_w is the ionic product of water. The value of K_w is 5.48×10^{-14} mol^2 dm^{-6} at 50 °C.

(a) (i) Write an expression for pH.

____

(1)

(ii) Write an expression for K_w

____

(1)

(b) (i) Calculate the pH of pure water at 50 °C.

____

____

____

(2)

(ii) Suggest why this pure water is **not** acidic.

____

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(1)

(iii) Calculate the pH of 0.140 mol dm^{-3} aqueous sodium hydroxide at 50 °C.

____

____

____

____

____

(3)

(c) Calculate the pH of the solution formed when 25.0 cm^3 of 0.150 mol dm^{-3} aqueous sulfuric acid are added to 30.0 cm^3 of 0.200 mol dm^{-3} aqueous potassium hydroxide at 25 °C. Assume that the sulfuric acid is fully dissociated.

(6)

(Total 14 marks)

Q17.

In this question, give all values of pH to 2 decimal places.

(a) (i) Write an expression for the term pH.

(1)

(ii) Calculate the concentration, in mol dm^{-3}, of an aqueous solution of sulfuric acid that has a pH of 0.25

(2)

(b) A student carried out a titration by adding an aqueous solution of sodium hydroxide from a burette to an aqueous solution of ethanoic acid. The end-point was reached when 22.60 cm^3 of the sodium hydroxide solution had been added to 25.00 cm^3 of 0.410 mol dm^{-3} ethanoic acid.

(i) Write an equation for the reaction between sodium hydroxide and ethanoic acid.

(1)

(ii) Calculate the concentration, in mol dm^{-3}, of the sodium hydroxide solution used.

(2)

(iii) A list of indicators is shown below.

Indicator	**pH range**
thymol blue	1.2–2.8
bromophenol blue	3.0–4.6
litmus	5.0–8.0
cresol purple	7.6–9.2

Select from the list the most suitable indicator for the end-point of this titration.

(1)

(iv) Suggest why the concentration of sodium hydroxide in a solution slowly decreases when left open to air.

(1)

(c) At 298 K, the value of the acid dissociation constant, K_a, for ethanoic acid in aqueous solution is 1.74×10^{-5} mol dm^{-3}

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

(1)

(ii) Calculate the pH of 0.410 mol dm^{-3} ethanoic acid at this temperature.

(3)

(iii) Calculate the pH of the buffer solution formed when 10.00 cm^3 of 0.100 mol dm^{-3} potassium hydroxide are added to 25.00 cm^3 of 0.410 mol dm^{-3} ethanoic acid.

(6)

(Total 18 marks)

Q18.

In this question, give all pH values to 2 decimal places.

(a) (i) Write expressions for the ionic product of water, K_w, and for pH.

K_W = ______________________________

pH = ______________________________

(ii) At 318 K, the value of K_w is 4.02×10^{-14} mol^2 dm^{-6} and hence the pH of pure water is 6.70
State why pure water is not acidic at 318 K.

____

____

(iii) Calculate the number of moles of sodium hydroxide in 2.00 cm^3 of 0.500 mol dm^{-3} aqueous sodium hydroxide.

____

____

(iv) Use the value of K_w given above and your answer to part (a)(iii) to calculate the pH of the solution formed when 2.00 cm^3 of 0.500 mol dm^{-3} aqueous sodium hydroxide are added to 998 cm^3 of pure water at 318 K.

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(6)

(b) At 298 K, the acid dissociation constant, K_a, for propanoic acid, CH_3CH_2COOH, has the value 1.35×10^{-5}mol dm^{-3}.

(i) Write an expression for K_a for propanoic acid.

____

____

(ii) Calculate the pH of 0.125 mol dm^{-3} aqueous propanoic acid at 298 K.

(4)

(c) Sodium hydroxide reacts with propanoic acid as shown in the following equation.

$$NaOH + CH_3CH_2COOH \rightarrow CH_3CH_2COONa + H_2O$$

A buffer solution is formed when sodium hydroxide is added to an excess of aqueous propanoic acid.

(i) Calculate the number of moles of propanoic acid in 50.0 cm^3 of 0.125 mol dm^{-3} aqueous propanoic acid.

(ii) Use your answers to part (a)(iii) and part (c)(i) to calculate the number of moles of propanoic acid in the buffer solution formed when 2.00 cm^3 of 0.500 mol dm^{-3} aqueous sodium hydroxide are added to 50.0 cm^3 of 0.125 mol dm^{-3} aqueous propanoic acid.

(iii) Hence calculate the pH of this buffer solution at 298 K.

(6)

(Total 16 marks)

Q19.

(a) By reference to the forces between molecules, explain why ammonia is very soluble in water.

____

____

(2)

(b) Aqueous solutions of ammonia have a pH greater than 7.

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

____

(ii) Explain why the pH of a solution containing 1.0 mol dm^{-3} of ammonia is less than 14 at 298 K.

____

____

(3)

(c) An ammonium ion in aqueous solution can behave as a Brønsted–Lowry acid. State what is meant by the term *Brønsted–Lowry acid*.

____

(1)

(d) State what is meant by the term *buffer solution*. Identify a reagent which could be added to a solution of ammonia in order to form a buffer solution.

Buffer solution ____

____

Reagent ____

(3)

(e) An acidic buffer solution is obtained when sodium ethanoate is dissolved in aqueous ethanoic acid.

(i) Calculate the pH of the buffer solution formed at 298 K when 0.125 mol of sodium ethanoate is dissolved in 250 cm^3 of a 1.00 mol dm^{-3} solution of ethanoic acid. The acid dissociation constant, K_a, for ethanoic acid is 1.70×10^{-5} mol dm^{-3} at 298 K.

____

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____

____

____

____

(ii) Write an ionic equation for the reaction which occurs when a small volume of dilute hydrochloric acid is added to this buffer solution.

____

(5)

(Total 14 marks)

Mark Scheme

Q15.

(a) (i) - log[H^+]

*penalise missing [ ] here **and not elsewhere***

1

(ii) [H^+][OH^-]

Allow ( ) brackets, but must have charges

1

(iii) Mark independently from a(ii)

[H^+] = $10^{-13.72}$ = 1.905×10^{-14}

If wrong no further mark

1

$K_w = 1.905 \times 10^{-14} \times 0.154 = = (2.93 - 2.94) \times 10^{-15}$

1

(b) (i) $Ka = \dfrac{[H^+][CH_3COO^-]}{[CH_3COOH]}$

Must have charges and all brackets, allow ( )

Acid/salt shown must be CH_3COOH not HA

and correct formulae needed

1

(ii) **In pH values penalise fewer than 3 sig figs each time but allow more than 2 dp**
For values above 10, allow 3sfs - do not insist on 2 dp

$K_a = \dfrac{[H^+]^2}{[CH_3COOH]}$

Allow HA

1

($[H^+]^2 = 1.75 \times 10^{-5} \times 0.154 = 2.695 \times 10^{-6} = 2.70 \times 10^{-6}$)

If √ shown but not done gets pH = 5.57 (scores 2)

[H^+] = 1.64×10^{-3}

*Allow mark for pH conseq to their [H+] **here only***

1

pH = 2.78 or 2.79

1

(c) (i) **In pH values penalise fewer than 3 sig figs each time but allow more than 2 dp**

For values above 10, allow 3sfs - do not insist on 2 dp

M1 Initially

mol OH^- = $(10 \times 10^{-3}) \times 0.154$ **and**

mol HA = $(20 \times 10^{-3}) \times 0.154$

or mol OH^- = 1.54×10^{-3} **and** mol HA = 3.08×10^{-3}

1

M2 $[H^+] = K_a \dfrac{[CH_3COOH]}{[CH_3COOH^-]}$

or with numbers

Allow Henderson Hasselbach

$pH = pK_a + \log \dfrac{[CH_3COO^-]}{[CH_3COOH]}$

M3 mol ethanoic acid left = (mol ethanoate ions) = 1.54×10^{-3}

$K_a = [H^+]$ **or** $pH = pK_a$ scores **M1**, **M2** and **M3**

1 If either mol acid in mixture or mol salt wrong

- max 2 for M1 and M2

Any mention of $[H^+]^2$ - max 2 for M1 and M3

1

M4 pH (= - log 1.75×10^{-5}) = 4.76 or 4.757

Not 4.75

1

If no subtraction (so mol ethanoic acid in buffer = original mol)
pH = 4.46 scores 2 for **M1** and **M2**
If $[H+]^2$ used, pH = 3.02 scores 2 for **M1** and **M3**

(ii) **In pH values penalise fewer than 3 sig figs each time but allow more than 2 dp**
For values above 10, allow 3sfs - do not insist on 2 dp

M1 XS mol KOH (= $(20 \times 10^{-3}) \times 0.154$) = 3.08×10^{-3}

If no subtraction: max 1 for correct use of volume

No subtraction and no use of volume scores zero

If wrong subtraction or wrong moles

*Can only score **M2** and **M3** for process*

1

M2 $[OH^-] = 3.08 \times 10^{-3} \times \dfrac{10^3}{60}$ = 0.0513(3)

*Mark for dividing their answer to **M1** by correct volume (method mark)*

*If no volume or wrong volume or multiplied by volume, max 2 for **M1** and **M3** process*

1

M3 $[H^+] = \frac{10^{-14}}{0.05133}$ (= 1.948×10^{-13} to 1.95×10^{-13})

or pOH = 1.29

Mark for K_w divided by their answer to ***M2***

If pOH route, give one mark for 14 – pOH

1

M4 pH = 12.7(1)

Allow 3sf but not 12.70

1

If no subtraction and no use of volume (pH = 11.79 scores zero)
If no subtraction, max 1 for correct use of volume, ($60cm^3$)
(pH = 13.01 scores 1)
If volume not used, pH = 11.49 (gets 2)
If multiplied by vol, pH = 10.27 (gets 2)

[16]

Q16.

(a) (i) –log[H^+]

Penalise missing [ ] here ***and not elsewhere***

1

(ii) [H^+][OH^-]

1

(b) (i) [H^+] = 2.34×10^{-7}

1

pH = 6.63

Penalise fewer than 3 sig figs but allow more than 2 dp

1

(ii) [H^+] = [OH^-]

1

(iii) **M1** [H^+] = K_w/[OH^-]

if upside down or CE, allow M3 only for correct use of their [H^+]

1

M2 (= 5.48×10^{-14}/0.140) = 3.91×10^{-13}

1

M3 pH = 12.4(1)

not 12.40 (AE from 12.407)

1

Penalise fewer than 3 sig figs but allow more than 3 sfs
For values above 10, allow 3sfs - do not insist on 2 dp.
For values below 1, allow 2dp – do not insist on 3 sig figs

Not allow pH = 14 – pOH but can award M3 only for pH = 13.1(46)
Can award all three marks if pK_w = 13.26 is used

(c) **M1** mol NaOH = mol OH^- = $(30 \times 10^{-3}) \times 0.20 = 6.0 \times 10^{-3}$

mark for answer

1

M2 mol H_2SO_4 = $(25 \times 10^{-3}) \times 0.15 = 3.75 \times 10^{-3}$

mark for answer

1

M3 mol H^+ = $(25 \times 10^{-3}) \times 0.15 \times 2 = 7.5 \times 10^{-3}$
OR XS mol H_2SO_4 = 0.75×10^{-3}

if factor of 2 missed or used wrongly, CE - lose M3 and next mark gained. In this case they must then use K_w to score any more.
see examples below

1

M4 XS mol H^+ = 1.5×10^{-3}

1

M5 $[H^+] = (1.5 \times 10^{-3}) \times (1000/55) = 0.0273$

if no use or wrong use of volume, lose M5 and M6 except if 1000 missed
AE –1 (pH = 4.56)

1

M6 pH = 1.56

Penalise fewer than 3 sig figs but allow more than 3 sfs
For values above 10, allow 3sfs - do not insist on 2 dp.
For values below 1, allow 2dp – do not insist on 3 sig figs

1

[14]

Q17.

(a) (i) $-\log[H^+]$

or $\log 1/[H^+]$
penalise ( )

1

(ii) $[H^+] = 0.56$

mark for the answer; allow 2dp or more

1

$[H_2SO_4] = \frac{1}{2} \times 0.56 = 0.28$

1

(b) (i) $CH_3COOH + NaOH \rightarrow CH_3COONa + H_2O$

OR

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

Allow CH_3CO_2H etc

1

(ii) mol acid = $(25.0 \times 10^{-3}) \times 0.41 = 1.025 \times 10^{-2}$ or 1.03×10^{-2}

1

$[NaOH] = 1.025 \times 10^{-2}/22.6 \times 10^{-3} = 0.45(4)$

mark for answer
if not 0.454 look back for error

1

OR

[NaOH] = 1.03 × 10^{-2}/22.6 × 10^{-3} = 0.456 or 0.46

(iii) cresol purple

1

(iv) NaOH reacts with <u>carbon dioxide</u> (in the air)

1

(c) (i) $K_a = \dfrac{[H^+][CH_3COO^-]}{[CH_3COOH]}$

allow molecular formulae or minor slip in formulae

penalise ( )
allow H_3O^+
not allow HA etc

1

(ii) $K_a = \dfrac{[H^+]^2}{[CH_3COOH]}$ or with numbers

1

allow HA etc here
This can be scored in part (c)(i) but doesn't score there.

$[H^+] = (\sqrt{(1.74 \times 10^{-5} \times 0.410)} = \sqrt{(7.13 \times 10^{-6})}) = 2.67 \times 10^{-3}$

1

mark for 2.67 × 10^{-3} or 2.7 × 10^{-3} either gives 2.57

pH = 2.57 can give three ticks here for (c)(ii)
penalise decimal places < 2 >

1

pH mark conseq on their [H^+]

so 5.15 gets 2 marks where square root not taken

(iii) **M1** mol OH^- = (10.0 × 10^{-3}) × 0.10 = 1.0 × 10^{-3}

If no subtraction or other wrong chemistry the max score is 3 for M1, M2 and M4

1

M2 orig mol HA = (25.0 × 10^{-3}) × 0.41 = 0.01025

1

or 1.025 × 10^{-2} or 1.03 × 10^{-2}

M3 mol <u>HA</u> in buffer = orig mol HA – mol OH^-

1

= 0.00925 or 0.0093

If A^- is wrong, max 3 for M1, M2 and M3 or use of
pH = pKa – log [HA]/[A^-]

M4 mol A^- in buffer = mol OH^- = 1.0×10^{-3}

Mark is for insertion of correct numbers in correct expression for $[H^+]$

1

M5 $[H^+] = \left(\frac{K_a \times [CH_3COOH]}{[CH_3COO^-]} = \right)$

1

$$\frac{(1.74 \times 10^{-5})(0.00925)}{0.0010} \text{ or } \frac{(1.74 \times 10^{-5})(0.00930)}{0.0010}$$

(= 1.61×10^{-4} or 1.62×10^{-4})

M6 pH = 3.79 can give six ticks for 3.79

if [HA]/[A^-] upside down lose M5 & M6

If wrong method e.g. $[H^+]^2$/[HA] max 3 for M1, M2 and M3

Some may calculate concentrations
[HA] = 0.264 and [A^-] = 0.0286 and rounding this to 0.029 gives pH = 3.80 (which is OK)

NB Unlike (c)(ii), this pH mark is NOT awarded conseq to their $[H^+]$ unless following AE

BEWARE: using 0.01025 wrongly instead of 0.00925 gives pH = 3.75
(this gets 3 for M1, M2 & M4)

1

[18]

Q18.

(a) (i) $[H^+][OH^-]$

1

$-\log [H^+]$

1

(ii) $[H^+] = [OH^-]$

1

(iii) $(2.0 \times 10^{-3}) \times 0.5 = 1.0 \times 10^{-3}$

1

(iv) $[H^+] = \frac{4.02 \times 10^{-14}}{1.0 \times 10^{-3}}$ (= 4.02×10^{-11})

1

pH = 10.40

1

(b) (i) $K_a = \frac{[H^+][CH_3CH_2COO^-]}{[CH_3CH_2COOH]}$

1

$$= \frac{[H^+]}{[CH_3CH_2COOH]}$$

1

$[H^+] = \sqrt{(1.35 \times 10^{-5}) \times 0.125}$ $(= 1.30 \times 10^{-3})$

1

pH = 2.89

1

(c) (i) $(50.0 \times 10^{-3}) \times 0.125 = 6.25 \times 10^{-3}$

1

(ii) $(6.25 \times 10^{-3}) - (1.0 \times 10{-}3) = 5.25 \times 10^{-3}$

1

(iii) mol salt formed = 1.0×10^{-3}

1

$$[H^+] = K_a \times \frac{[CH_3CH_2COOH]}{[CH_3CH_2COO{-})}$$

1

$$= (1.35 \times 10^{-5}) \times \frac{(5.25 \times 10^{-3})/V}{(1.0 \times 10^{-3})/V} \quad (= 7.088 \times 10^{-5})$$

1

pH = 4.15

1

[16]

Q19.

(a) Hydrogen bonding **(1)**
between H_2O and NH_3 **(1)**

2

(b) (i) $NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$ **(1)**

(ii) Ammonia is weak base **(1)**

NOT partially ionised

Equilibrium to left or incomplete reaction **(1)**

3

(c) A proton donor **(1)**

1

(d) *Buffer solution*: A solution which resists change in pH **(1)**
when small amounts of acid or base added or on dilution **(1)**

Reagent: NH_4Cl **(1)**

Allow a correct strong acid

3

(e) (i) $K_a = [H^+] [A^-] / [HA]$ **(1)**
$= [H^+] [0.125 \times 4]$ **(1)** / 1.00

$[H^+] = 1.70 \times 10^{-5} / 0.125 \times 4 = 3.40 \times 10^{-5}$ **(1)**

pH = $-\log_{10} [H^+] = 4.47$ **(1)**

Allow pH conseq to $[H^+]$ if 2 place decimals given

(ii) $H^+ + CH_3COO^- \rightarrow CH_3COOH$ **(1)**

5

[14]