Determination of pH 1

Mr Cole Chemistry

Q1.

Which change causes the pH of 10 cm^3 of 1.0 mol dm^{-3} NaOH to be halved at 298 K?

$K_w = 1.0 \times 10^{-14}$ at 298 K

A adding 10 cm^3 of water ○

B adding 10 dm^3 of water ○

C adding 5 cm^3 of 1.0 mol dm^{-3} HCl ○

D adding 10 cm^3 of 1.0 mol dm^{-3} HCl ○

(Total 1 mark)

Q2.

A strong acid H_2X dissociates in aqueous solution.

$$H_2X(aq) \rightarrow 2\,H^+(aq) + X^{2-}(aq)$$

What is the pH of a 0.020 mol dm^{-3} solution of this acid?

A 1.00 ○

B 1.40 ○

C 1.70 ○

D 2.00 ○

(Total 1 mark)

Q3.

Equal volumes of two solutions, each with the same concentration, are mixed together at 298 K

Which two solutions, when mixed, form a solution with a pH >7?

A HCOOH and HCOOK ○

B KOH and CH_3COOH ○

C NH_3 and HCl ○

D NH_4Cl and KCl ○

(Total 1 mark)

Q4.

Which statement about pH is correct?

A	The pH of a weak base is independent of temperature.	○
B	At temperatures above 298 K, the pH of pure water is less than 7.	○
C	The pH of 2.0 mol dm^{-3} nitric acid is approximately 0.30	○
D	The pH of 0.10 mol dm^{-3} sulfuric acid is greater than that of 0.10 mol dm^{-3} hydrochloric acid.	○

(Total 1 mark)

Q5.

This question is about sulfuric acid and its salts.

(a) Draw the displayed formula of a molecule of H_2SO_4

(1)

(b) In aqueous solution, sulfuric acid acts as a strong acid. The H_2SO_4 dissociates to form HSO_4^- ions and H^+ ions.

The HSO_4^- ions act as a weak acid and dissociate to form SO_4^{2-} ions and H^+ ions.

Give an equation to show each stage in the dissociation of sulfuric acid in aqueous solution.

Include appropriate arrows in your equations.

Equation 1 ____

Equation 2 ____

(2)

(c) A student is required to make 250 cm^3 of an aqueous solution that contains an accurately measured mass of sodium hydrogensulfate ($NaHSO_4$).

Describe the method that the student should use to make this solution.

(4)

(d) A solution that contains 605 mg of $NaHSO_4$ in 100 cm^3 of solution has a pH of 1.72

Calculate the value of K_a for the hydrogensulfate ion (HSO_4^-) that is behaving as a weak acid.
Give your answer to three significant figures.

State the units of K_a

K ______________________________ Units ______________________________

(6)

(e) Some sodium sulfate is dissolved in a sample of the solution from part **(d)**.

Explain why this increases the pH of the solution.

____

____

____

____

____

(2)

(Total 15 marks)

Q6.

The ionic product of water, $K_w = 2.93 \times 10^{-15}$ mol^2 dm^{-6} at 10 °C

(a) Which is the correct expression for K_w?

Tick (✓) **one** box.

A $K_w = \dfrac{[H_2O]}{[H^+][OH^-]}$ ☐

B $K_w = [H^+][H_2O]$ ☐

C $K_w = [H^+][OH^-]$ ☐

D $K_w = \dfrac{[H^+][OH^-]}{[H_2O]}$ ☐

(1)

(b) Calculate the pH of pure water at 10 °C

Give your answer to two decimal places.

pH of water ______________________

(2)

(c) Suggest why this pure water at 10 °C is **not** alkaline.

____

____

____

(1)

(d) Calculate the pH of a 0.0131 mol dm^{-3} solution of calcium hydroxide at 10 °C

Give your answer to two decimal places.

pH of solution ____

(3)

(e) The 0.0131 mol dm^{-3} calcium hydroxide solution at 10 °C was a saturated solution.

A student added 0.0131 mol of magnesium hydroxide to 1.00 dm^{3} of water at 10 °C and stirred the mixture until no more solid dissolved.

Predict whether the pH of the magnesium hydroxide solution formed at 10 °C is larger than, smaller than or the same as the pH of the calcium hydroxide solution at 10 °C

Explain your answer.

pH of magnesium hydroxide compared to calcium hydroxide

____

Explanation ____

____

____

(2)

(Total 9 marks)

Q7.

This question is about compounds containing ethanedioate ions.

(a) A white solid is a mixture of sodium ethanedioate ($Na_2C_2O_4$), ethanedioic acid dihydrate ($H_2C_2O_4.2H_2O$) and an inert solid. A volumetric flask contained 1.90 g of this solid mixture in 250 cm^3 of aqueous solution.

Two different titrations were carried out using this solution.

In the first titration 25.0 cm^3 of the solution were added to an excess of sulfuric acid in a conical flask. The flask and contents were heated to 60 °C and then titrated with a 0.0200 mol dm^{-3} solution of potassium manganate(VII). When 26.50 cm^3 of potassium manganate(VII) had been added the solution changed colour.

The equation for this reaction is

$$2MnO_4^- + 5C_2O_4^{2-} + 16H^+ \rightarrow 2Mn^{2+} + 8H_2O + 10CO_2$$

In the second titration 25.0 cm^3 of the solution were titrated with a 0.100 mol dm^{-3} solution of sodium hydroxide using phenolphthalein as an indicator. The indicator changed colour after the addition of 10.45 cm^3 of sodium hydroxide solution.

The equation for this reaction is

$$H_2C_2O_4 + 2OH^- \rightarrow C_2O_4^{2-} + 2H_2O$$

Calculate the percentage by mass of sodium ethanedioate in the white solid.

Give your answer to the appropriate number of significant figures.

Show your working.

Percentage by mass of sodium ethanedioate ____________________ %

(8)

(b) Ethanedioate ions react with aqueous iron(III) ions in a ligand substitution reaction.

Write an equation for this reaction.

Suggest why the value of the enthalpy change for this reaction is close to zero.

____

____

____

____

(2)

(c) Draw the displayed formula of the iron complex produced in the reaction in part (b)

Indicate the value of the O—Fe—O bond angle.

State the type of isomerism shown by the iron complex.

Bond angle ____

Type of isomerism ____________________________________

(3)

(d) Ethanedioate ions are poisonous because they react with iron ions in the body.
Ethanedioate ions are present in foods such as broccoli and spinach.

Suggest one reason why people who eat these foods do not suffer from poisoning.

____

____

(1)

(Total 14 marks)

Q8.

The rate equation for the acid-catalysed reaction between iodine and propanone is:

$$\text{rate} = k\,[H^+]\,[C_3H_6O]$$

The rate of reaction was measured for a mixture of iodine, propanone and sulfuric acid at pH = 0.70

In a second mixture the concentration of the sulfuric acid was different but the concentrations of iodine and propanone were unchanged. The new rate of reaction was a quarter of the original rate.

What was the pH of the second mixture?

A 1.00 ○

B 1.30 ○

C 1.40 ○

D 2.80 ○

(Total 1 mark)

Q9.

This question is about Brønsted–Lowry acids.

(a) Give the meaning of the term Brønsted–Lowry acid.

____

____

(1)

(b) What is meant by the term strong when describing an acid?

____

____

(1)

(c) At 298 K, 25.0 cm^3 of a solution of a strong monoprotic acid contained 1.45×10^{-3} mol of hydrogen ions.

Calculate a value for the pH of this solution.
Give your answer to 2 decimal places.

pH ____________________

(2)

(d) Calculate the pH of the solution formed after the addition of 35.0 cm^3 of 0.150 mol dm^{-3} NaOH to the original 25.0 cm^3 of monoprotic acid.

The ionic product of water K_w = 1.00 × 10^{-14} mol^2 dm^{-6} at 298 K.
Give your answer to two decimal places.

pH ____________________

(5)

(e) A buffer solution is made when 1.50 g of sodium hydroxide are added to 1.00 dm^3 of a 0.150 mol dm^{-3} solution of a weak acid HA.

For HA, the acid dissociation constant, K_a = 1.79 × 10^{-5} mol dm^{-3}.

Calculate the pH of this buffer solution.

pH ____________________

(6)

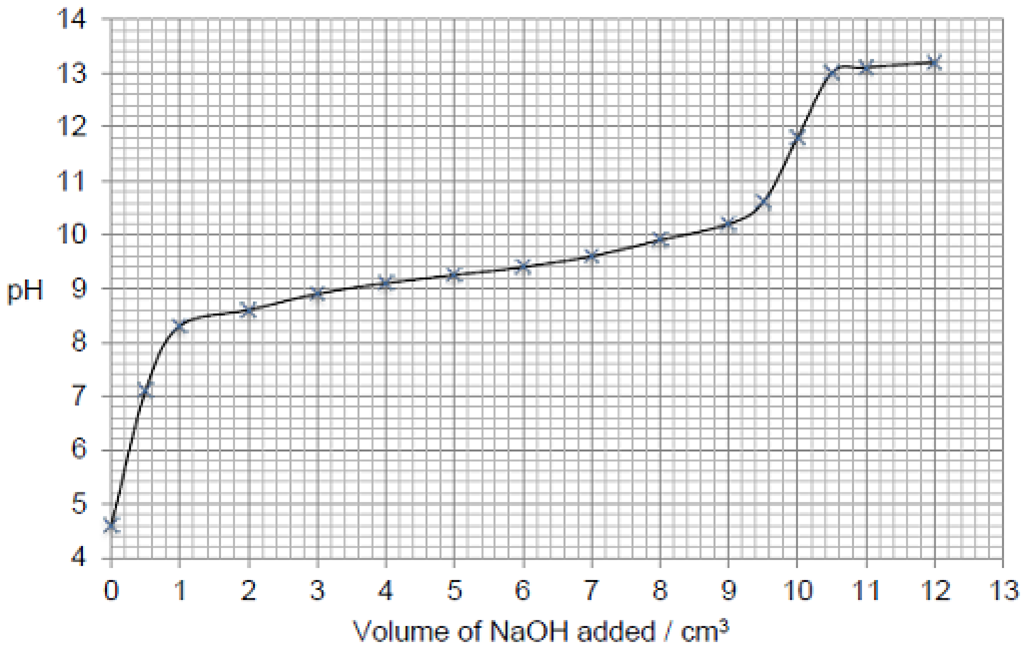
(Total 15 marks)

Q10.

Ammonium chloride, when dissolved in water, can act as a weak acid as shown by the following equation.

$$NH_4^+(aq) \rightleftharpoons NH_3(aq) + H^+(aq)$$

The following figure shows a graph of data obtained by a student when a solution of sodium hydroxide was added to a solution of ammonium chloride. The pH of the reaction mixture was measured initially and after each addition of the sodium hydroxide solution.



(a) Suggest a suitable piece of apparatus that could be used to measure out the sodium hydroxide solution.
Explain why this apparatus is more suitable than a pipette for this purpose.

Apparatus____

Explanation ____

____

____

(2)

(b) Use information from the curve in the figure above to explain why the end point of this reaction would be difficult to judge accurately using an indicator.

____

____

____

____

____

(2)

(c) The pH at the end point of this reaction is 11.8.

Use this pH value and the ionic product of water, $K_w = 1.0 \times 10^{-14}$ mol^2 dm^{-6}, to calculate the concentration of hydroxide ions at the end point of the reaction.

Concentration = ________________ mol dm^{-3}

(3)

(d) The expression for the acid dissociation constant for aqueous ammonium ions is

$$K_a = \frac{[NH_3][H^+]}{[NH_4^+]}$$

The initial concentration of the ammonium chloride solution was 2.00 mol dm^{-3}.

Use the pH of this solution, before any sodium hydroxide had been added, to calculate a value for K_a

K_a = _______________ mol dm^{-3}

(3)

(e) A solution contains equal concentrations of ammonia and ammonium ions.

Use your value of K_a from part **(d)** to calculate the pH of this solution. Explain your working.

(If you were unable to calculate a value for K_a you may assume that it has the value 4.75×10^{-9} mol dm^{-3}. This is **not** the correct value.)

pH = _______________

(2)

(Total 12 marks)

Mark schemes

Q1.

D

adding 10 cm^3 of 1.0 mol dm^{-3} HCl

[1]

Q2.

B

1.40

[1]

Q3.

B

KOH and CH_3COOH

[1]

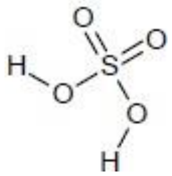
Q4.

B

[1]

Q5.

(a)



Ignore shape / bond angles
Ignore lone pair(s) on O atoms
NOT lone pair(s) on S atom

1

(b) Equation 1: $H_2SO_4 \rightarrow HSO_4^- + H^+$ / $H_2SO_4 + H_2O \rightarrow HSO_4^- + H_3O^+$

Equation 1: NOT $\rightleftharpoons$

1

Equation 2: $HSO_4^- \rightleftharpoons SO_4^{2-} + H^+$ / $HSO_4^- + H_2O \rightleftharpoons SO_4^{2-} + H_3O^+$

Equation 2: NOT $\rightarrow$ *or* $\leftrightarrow$

Allow $\leftrightharpoons$ *or* $\rightleftarrows$ *or* $\leftrightarrows$

1

Ignore state symbols in both equations
Allow multiples in both equations

(c) **M1** weigh solid and transfer using a method that Allows exact mass to be known (there should be two weighings, one of which could be zeroing, and method could be by difference or with washings or directly weighed into container)

M1 Ignore any mass quoted

NOT if any other solid added

1

M2 dissolve in water in suitable container (NOT in 250 cm^3 of water)

***M2** NOT if any other solution added*

1

M3 transfer with washings into 250 cm^3 volumetric/graduated flask

***M3** Reference to 250 cm^3 can appear anywhere*

1

M4 make up to mark / 250 cm^3 AND THEN shake / invert / mix

***M4** Allow if conical flask used*

NOT if beaker used

1

Alternative method (M2-4)

***M2** in 250 cm^3 volumetric/graduated flask*

***M3** dissolve (NOT in 250 cm^3 of water)*

***M4** make up to mark / 250 cm^3 AND THEN shake/invert/mix*

(d) **M1** $[H^+] = 10^{-1.72}$ (= 0.0191 (mol dm^{-3}))

1

M2 amount $NaHSO_4$ = 0.605/120.1 (= 5.04 x 10^{-3} (mol))

1

M3 initial $[NaHSO_4] = [HSO_4^-]$ = **M2** x 10 (= 5.04 x 10^{-2} (mol dm^{-3}))

$$K_a = \frac{[H^+][SO_4^{2-}]}{[HSO_4^-]} \quad \text{or} \quad K_a = \frac{[H^+]^2}{[HSO_4^-]}$$

1

M4 $K_a = \dfrac{0.0191^2}{0.0504 - 0.0191}$

1

M5 K_a = 1.17 x 10^{-2} (1.15 – 1.18 x 10^{-2}) must be 3sf

1

M6 mol dm^{-3}

1

*Correct answer scores **M1-5** (must be 3sf)*

***Alternative method** that does not subtract 0.0191:*

*7.21 x 10^{-3} (7.15 – 7.26 x 10^{-3}) scores **M1-5***

(where **M4** $K_a = \dfrac{0.0191^2}{0.0504}$)

If not correct answer:

*For **M1-3**, if answer is shown, it must be correct (Ignore sf)*

*Allow ECF from **M1/2/3** to **M4**/5 (but not from **M3** to **M5** if omission of **M3** gives negative **M5**)*

*NOT ECF from incorrect K_a expression in **M4** to **M5***

__M6__ If not mol dm^{-3}, Allow ECF for units from incorrect K_a expression in __M4__

7.21 x 10^{-2} (7.15 – 7.26 x 10^{-2}) gives __M1,2,4,5__ (by alternative method omitting __M3__)

(e) **M1** ($HSO_4^- \rightleftharpoons SO_4^{2-} + H^+$) equilibrium moves/shifts left (to counteract / remove increased [SO_4^{2-}])

__M1__ Allow H^+ reacts with SO_4^{2-}/sulfate

Ignore favours the reverse / left / backwards reaction

NOT base / A^- / sodium sulfate in place of SO_4^{2-}/sulfate

M2 so [H^+] decreases

1

__M2__ Allow fewer H^+ (ions) or amount of H^+ lower or removes H^+

__M2__ independent of __M1__

1

[15]

Q6.

(a) Ans = C

1

(b) [H^+] = $\sqrt{K_w} = \sqrt{2.93 \times 10^{-15}}$ (= 5.41×10^{-8})

1

pH = (− log (5.41×10^{-8}) = <u>7.27</u>

Must be 2dp

7.27 scores 2 marks

1

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

allow description in words

equal moles / quantities / numbers / ratio of H^+ and OH^-

1

(d) [OH^-] = 0.0131 <u>× 2</u> = 0.0262

pH = 12.95 scores 3 marks

pH = 12.42 scores 2 marks ($K_w = 1 \times 10^{-14}$)

pH = 12.65 scores 1 mark (not multiplied by 2)

pH = 12.35 scores 1 mark (divided by 2)

pH = 12.12 scores 0 marks (no × 2 and wrong K_w)

1

[H^+] = (K_w / [OH^-]) = 2.93×10^{-15} / 0.0262 (= 1.118×10^{-13})

1

pH = (− log (1.118×10^{-13}) = 12.9514 = 12.95
Or
[OH^-] = 0.0131 × 2 = 0.0262
pOH = (−log 0.0262) = 1.5817
pH =(−log K_w− pOH = −log 2.93×10^{-15}−1.58 = 14.53 − 1.58) = 12.95

allow to 2dp or more

1

(e) smaller / lower pH / less alkaline / more acidic

If not smaller CE = 0/2

Allow pH number between 8 and 12

1

(magnesium hydroxide) is less soluble / sparingly soluble/ solubility of hydroxide increases down group II

M2 dependent on M1 but if blank mark on

Ignore concentration and dissociation

Ignore incorrect formula

Do not allow $Mg(OH)_2$ is insoluble

1

[9]

Q7.

(a) Moles MnO_4^- $\frac{26.50 \times 0.02}{1000}$ = 5.30×10^{-4}

1

Moles in 25cm³ sample / pipette $C_2O_4^{2-}$ (from acid and salt)
= 5.30×10^{-4} **<u>× 5/2</u> = (1.325 × 10⁻³)**

1

Moles NaOH = $\frac{10.45 \times 0.1}{1000}$ (= 1.045×10^{-3})

1

So moles $C_2O_4^{2-}$ from acid in 25cm³ sample / pipette
= 1.045×10^{-3} **<u>÷ 2</u>** = 5.225×10^{-4}

1

Hence moles $C_2O_4^{2-}$ in sodium ethanedioate in 25 cm³

= $1.325 \times 10^{-3} - 5.225 \times 10^{-4}$ (= 8.025×10^{-4})

1

So moles $C_2O_4^{2-}$ in sodium ethanedioate in original sample
= 8.025×10^{-4} **<u>× 10</u>** **(= 8.025×10^{-3})**

1

Mass $Na_2C_2O_4$ = 8.025×10^{-3} **<u>× 134(.0)</u> = 1.075(35) g**
So % sodium ethanedioate in original sample

$\frac{1.075(35)}{1.90}$ × 100 = 56.6 % to 3 sig fig

1

The first CE is penalised by 2 marks; further errors are penalised by one mark each

M2 = M1 × 5/2

M4 = M3 ÷ 2

M5 = M2 – M4 (do not allow if negative and do not allow = M4-M2)

If no subtraction, max = 5 (M1, M2, M3, M4 and M6)

If incorrect subtraction, max = 6 (M1, M2, M3, M4, M6 and M7)

M6 = M5 × 10

(M6 can be scored by multiplying M2 and M4 by 10 before subtraction (giving $1.325 \times 10^{-2} - 5.225 \times 10^{-3} = 8.025 \times 10^{-3}$)

M7 = M6 × 134

M8 = (M7/1.90) × 100   Allow 56.5 – 56.8%

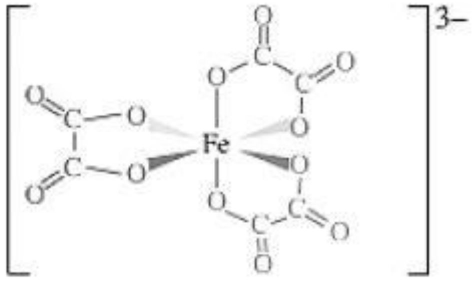
(b) $[Fe(H_2O)_6]^{3+} + 3C_2O_4^{2-} \longrightarrow [Fe(C_2O_4)_3]^{3-} + 6H_2O$

1

There are 6 Fe–O bonds broken and then made / same number and type of bond being broken and made.

1

(c)



Ignore all charges even if wrong

Ignore absence of square brackets

Candidates do not need to show 3D shape

1

90° or 180°

1

optical

1

(d) The ethanedioic acid is only present in small quantities/low concentration in these foods.

1

[14]

Q8.

B

[1]

Q9.

(a) Proton donor

1

(b) Completely ionises to give H^+ ions in water

1

(c) 0.058 mol dm^{-3}

1

1.24

1

(d) Amount of NaOH = 5.25×10^{-3}

1

Since 1:1 reaction amount of OH^- ions in excess

$= 5.25 \times 10^{-3} - 1.45 \times 10^{-3}$ mol

$= 3.80 \times 10^{-3}$ moles OH^-

1

$[OH^-] = 3.80 \times 10^{-3} \times 1000/60 = 0.0633$

1

$K_w = [H^+][OH^-$ so $H^+ = \frac{10^{-14}}{0.0633} = 1.58 \times 10^{-13}$

1

pH = 12.80

1

(e) Amount of OH^- added 1.5 / 40 = 0.0375 mol

1

Use of 1:1 ratio to calculate amount of A^- formed = 0.0375 mol

1

Amount of weak acid initially = 1 × 0.15 = 0.150 mol so amount of weak acid after addition of NaOH = 0.150 − 0.0375 = 0.1125

If M3 incorrect can only score max of 3 marks

1

$[H^+] = K_a [HA]/[A^-]$ or $[H^+] = 1.79 \times 10^{-5} \times 0.1125/0.0375$

1

$= 5.37 \times 10^{-5}$

1

pH = 4.27

1

[15]

Q10.

(a) Burette

1

Because it can deliver variable volumes

1

(b) The change in pH is gradual / not rapid at the end point

1

An indicator would change colour over a range of volumes of sodium hydroxide

Allow indicator would not change colour rapidly / with a few drops of NaOH

1

(c) $[H^+] = 10^{-pH} = 1.58 \times 10^{-12}$

1

$K_w = [H^+][OH^-]$ therefore $[OH^-] = K_w / [H^+]$

1

Therefore, $[OH^-] = 1 \times 10^{-14} / 1.58 \times 10^{-12} = 6.33 \times 10^{-3}$ (mol dm^{-3})

Allow 6.31–6.33 × 10^{-3} (mol dm^{-3})

1

(d) At this point, $[NH_3] = [H^+]$

Therefore $K_a = \frac{[H^+]^2}{[NH_4^+]}$

1

$[H^+] = 10^{-4.6} = 2.51 \times 10^{-5}$

1

$K_a = (2.51 \times 10^{-5})^2 / 2 = 3.15 \times 10^{-10}$ (mol dm^{-3})

Allow 3.15 – 3.16 × 10^{-10} (mol dm^{-3})

1

(e) When $[NH_3] = [NH_4^+]$, $K_a = [H^+]$ therefore $-\log K_a = -\log [H^+]$

Answer using alternative value

1

Therefore pH $= -\log_{10}(3.15 \times 10^{-10}) = 9.50$

M2 pH = $-\log_{10}(4.75 \times 10^{-9}) = 8.32$

Allow consequential marking based on answer from part (d)

1

[12]