Paper 4

1 (a) Correct headings and units
AND initial and final burette readings recorded [1]

All burette readings to 0.05 cm^3
AND correct calculation of all titre volumes [1]

1 (b) Consistent titres indicated with ticks or shown in the calculation of the average titre
AND correct calculation of average titre [1]

Accuracy marks:
Award [2] if 24.70 $cm^3 \leq$ average titre $\leq$ 25.10 cm^3
Award [1] if 24.60 $cm^3 \leq$ average titre < 24.70 cm^3
Award [1] if 25.10 cm^3 < average titre $\leq$ 25.20 cm^3
Otherwise, no marks awarded for accuracy

1 (c) (i) Amount of sodium hydroxide = (average titre) ÷ 1000 × 0.0400 = A mol [1]

1 (c) (ii) Amount of ethanedioic acid = A ÷ 2 = B mol [1]

1 (d) $2\ MnO_4^-(aq) + 16\ H^+(aq) + 5\ C_2O_4^{2-}(aq) \rightarrow 2\ Mn^{2+}(aq) + 10\ CO_2(g) + 8\ H_2O(l)$ [1]

1 (e) (i) Amount of manganate(VII) ions = 24.80 ÷ 1000 × 0.0200 = 4.96×10^{-4} mol [1]

1 (e) (ii) Amount of ethanedioate ions = 4.96×10^{-4} × 5 ÷ 2 = 0.00124 mol [1]

1 (f) Amount of sodium ethanedioate = 0.00124 – B = C mol [1]

1 (g) Mass of ethanedioic acid = B × 90 = D g
Mass of sodium ethanedioate = C × 134 = E g [1]

Percentage by mass of ethanedioic acid = D ÷ (D+E) × 100 % [1]

2 (a)

Mass of capped bottle and solid /g	6.65
Mass of empty bottle and cap /g	5.39
Mass of solid used /g	1.26

[1] headers and units and all readings to 2 d.p.

2 (b)

	FA 3	FA 4
NaOH	No ppt On warming (or heating), gas evolved (or gas produced) turned damp red litmus paper blue	White ppt insoluble in excess
NH_3	No ppt	White ppt insoluble in excess

5 correct observations ⇒ 3m
3-4 correct observations ⇒ 2m
1-2 correct observations ⇒ 1m

2 (c) reagents used: $AgNO_3(aq)$ followed by $NH_3(aq)$

unknown	observations
FA 3	cream/pale cream ppt partially soluble in NH_3 Accept: cream/pale cream ppt insoluble in NH_3 Accept: pale yellow ppt partially soluble in NH_3
FA 4	no ppt

[1] for reagents used
[1] for both sets of observations

2 (d)

unknown	observation
FA 5	purple $KMnO_4$ decolourised *or* turned colourless *or* purple solution decolourised *or* turned colourless

[1]

2 (e) **[1]** for each ion in the correct FA and explanation with reference to the observation in 2(b) and ppt formula stated i.e. AgBr, and $Mg(OH)_2$

FA 3 contains NH_4^+ and $Br^–$
Explanation: NH_4^+ gives NH_3 gas on warming/heating with NaOH(aq).
$Br^–$ gives cream AgBr ppt with $Ag^+(aq)$ and ppt partially soluble (accept: insoluble) in $NH_3(aq)$.

FA 4 contains Mg^{2+}
Explanation: White $Mg(OH)_2$ ppt produced with NaOH(aq) and with $NH_3(aq)$, and ppt insoluble in excess reagent.

FA 5 contains $SO_3^{2–}$

Explanation: FA 5 contains a sulfur-containing anion (pg19) which would be SO_4^{2-} or SO_3^{2-}. SO_3^{2-} can be oxidised (to SO_4^{2-}) so SO_3^{2-} can reduce and therefore decolourise $KMnO_4$ (in acid solution).

2 (f)

[1] for observation: White ppt dissolves

[1] for explanation and <u>balanced</u> equation:

The added NH_4^+, from NH_4Cl, reacts with the $Mg(OH)_2$ ppt, which hence dissolves. $Mg(OH)_2 + 2NH_4^+ \rightarrow Mg^{2+} + 2H_2O + 2NH_3$

or:

Mixture P contains the equilibrium, $Mg(OH)_2(s) \rightleftharpoons Mg^{2+}(aq) + 2OH^-(aq)$

The added NH_4^+ removes OH^-, $NH_4^+ + OH^- \rightarrow NH_3 + H_2O$

The position of the above equilibrium shifts to the right, therefore the white ppt $Mg(OH)_2(s)$ dissolves (or in terms of $[OH^-]$ decreases, ionic product for $Mg(OH)_2$ becomes less than its K_{sp})

2 (g)

[1] for each ion – the chosen reagent(s) and how to decide if the test result is positive (i.e. expected observation & conclusion of anion)

test 1: Add $H_2SO_4(aq)$ / $HCl(aq)$ / $HNO_3(aq)$

If effervescence is seen and the gas gives white ppt with limewater, the ion is CO_3^{2-}.

If a (pale) brown gas is seen, the ion is NO_2^-.

test 2: Add NaOH(aq) and A*l* foil and heat

If a gas is produced (NH_3 gas) that turns damp red litmus paper blue, the ion is NO_3^-.

NO_2^- also gives NH_3 gas in test 2 but it would already have given a positive result in test 1.

or

test 1: Add NaOH(aq) and A*l* foil and heat

If a gas is produced (NH_3 gas) that turns damp red litmus paper blue, the ion is NO_3^- or NO_2^-.

test 2: Add $H_2SO_4(aq)$ / $HCl(aq)$ / $HNO_3(aq)$

If effervescence is seen and the gas gives white ppt with limewater, the ion is CO_3^{2-}.

If a (pale) brown gas is seen, the ion is NO_2^-. So if the FA solution gives positive test in test 1 but negative test in test 2, the ion is NO_3^-.

3 (a) (i) (ii)

expt	*volume of **FA 5** / cm³*	*volume of **FA 6** / cm³*	*volume of water in solution 1 / cm³*	t / s	1/t / s^{-1}	lg(1/t)	lg($V_{FA\ 6}$)
1	*15.0*	*85.0*	*0.0*	*32*			
2	*15.0*	*25.0*	*60.0*	*10*			
3							
4							
5							

[1] Table with correct headers and units.

[1] Record all data with correct precision
- volumes to 0.5 cm^3
- t to nearest second
- calculated values to 3 sf.

[1] Complete set of volume of **FA 6** and time readings for 5 experiments and all values of t increase as volume of **FA 6** decreases. Data for experiments 1 and 2 must be included.

[1] Choose 3 other well-spaced values for the volume of **FA 6**. All volumes must differ by at least 10 cm^3.

[1] Correctly calculates 1/t, lg(1/t) and lg($V_{FA\ 6}$) values for all 5 experiments.

3 (b) (i) [1] Axes correct way round, with correct labels and appropriate scale. Scale must be chosen so that plotted points occupy at least half the graph grid in both x and y directions.

[1] All plotted points correct to within ± ½ small square.

[1] A best fit line is drawn with anomalous points excluded.

3 (b) (ii) [1] Correct calculation of gradient of the graph with working shown. The ***m*** value is equal to the gradient of the line.

3 (c)
- Correct calculation of lg(1/25) = –1.40
- Correct reading of lg($V_{FA\ 6}$) value from graph to within ±½ small square.
- Correct calculation of volume of **FA 6** using value for lg($V_{FA\ 6}$).

[2] for all 3 points correct.
[1] for 2 points correct.

3 (d) Selects Experiment 1 and explains that time, t, is smallest value and so has greatest % error. [1]
OR
Selects Experiment 2 and explains that volume of **FA 6** used (25 cm^3) is smallest and so has greatest % error [1]

3 (e) Calculates $n(H^+) = 0.1 \times 2 \times 85 \times 10^{-3} = 0.0170$ mol
$[H^+] = 0.0170 / (205/1000) = 0.0829$ mol dm^{-3}

[1]
Shows correct units in final answer in part **3(c)**
and
appropriate significant figures in all final answers: 3 s.f. in **3(b)(ii)**, 3 or 4 sf in **1(c), 1(e), 1(f), 1(g), 3(c), 3(e)**
and
2 d.p. in **1(b)**
and
attempting **1(b), 1(c), 1(e), 1(f), 1(g), 3(b)(ii), 3(c), 3(e)**

3 (f) (i) The value of t will be lower. This is because the $[H^+]$ is higher than expected, so rate of reaction is faster.

3 (f) (ii) Measuring volumes of **FA 5**, **FA 6** and water separately and mixing to make solution 1.

4 (a)

$$\frac{[H_2C_2O_4] \times \text{Volume } H_2C_2O_4}{[NaOH] \times \text{Volume NaOH}} = \frac{1}{2}$$

Given $[H_2C_2O_4] \approx [NaOH]$
$\Rightarrow$ Volume $H_2C_2O_4$: Volume NaOH = 1:2
Volume of $H_2C_2O_4 = 50 \times 1/3 = 17$ cm^3
Volume of NaOH = $50 \times 2/3 = 33$ cm^3

or use algebra:
Let volume $H_2C_2O_4$ = V cm^3, then volume NaOH = (50 – V) cm^3

$$\frac{[H_2C_2O_4] \times V}{[NaOH] \times (50 - V)} = \frac{1}{2}$$

Volume of $H_2C_2O_4$ = V = 17 cm^3
Volume of NaOH = 50 – V = 33 cm^3

[1] for both volumes, including working

4 (b) **M1**: A table showing all the chosen different volumes of the two solutions to be used. Total volume must be 50 cm^3. There should be at least three $H_2C_2O_4$ volumes < 17 cm^3 and at least three > 17 cm^3 so that there are at least three plotted points on each line.

- **M1** and **M5** are lost if the student adds extra water / uses same acid volumes throughout / same NaOH volumes throughout.
- **M1** is lost if there is no tabulation of all the chosen volumes – the question wanted this tabulation (table need not have lines).

- **M1** is lost if there is only one or two data points to draw either the left-line (left side of 17 cm^3 acid) or the right-line (right side of 17 cm^3 acid). We need at least three data points per line in this experiment.
- For this 'continuous variation method experiment' (2020 C2 Practical 23), it is more convenient to go in steps of 5 cm^3 when choosing the volumes. It is quite inconvenient to measure 8 cm^3 / 12 cm^2 / 17 cm^3 etc using the measuring cylinder.

M2: Same table showing measurement of initial temperature of $H_2C_2O_4$ (or NaOH) and the highest temperature reached after mixing. The question stated that we may 'assume that $H_2C_2O_4$ and NaOH solutions have the same temperature', so we only need to measure the initial temperature of one of them; hence there is no need to consider the 'weighted average initial temperature' which many students did.

M3: Use of thermometer, two measuring cylinders. Many students described about using a 10 cm^3 measuring cylinder to measure 5 cm^3 of one solution. However, this '10 cm^3 measuring cylinder' is no longer suitable for other larger volumes in your experiment. If you wish to specify the capacity of the measuring cylinder, you may just use two 50 cm^3 measuring cylinders.

M4: Took action to minimise heat loss e.g. using *two* styrofoam cups stacking one into the other / use a lid for the styrofoam cup / switch off the fans to ensure draft-free environment. **M4** is lost if student uses a beaker as the reaction container (instead of styrofoam cup / polystyrene cup). Using just *one* styrofoam cup is not good enough to score **M4**.

M5: Overall sequence of actions:

measure volume of one solution, add it into a styrofoam cup

↓

measure temperature of this solution in the cup

↓

measure volume of second solution, add it into the same cup

↓

stir and measure the highest temperature reached

M5 is lost if the student uses a burette to add the second solution to the first solution because it would take too long to run that in from a burette – we should mix the two solutions quickly (but carefully). If the student uses a burette to measure the volume of the second solution, the student should run this second solution into *another styrofoam cup* then add it to the first solution in the first cup.

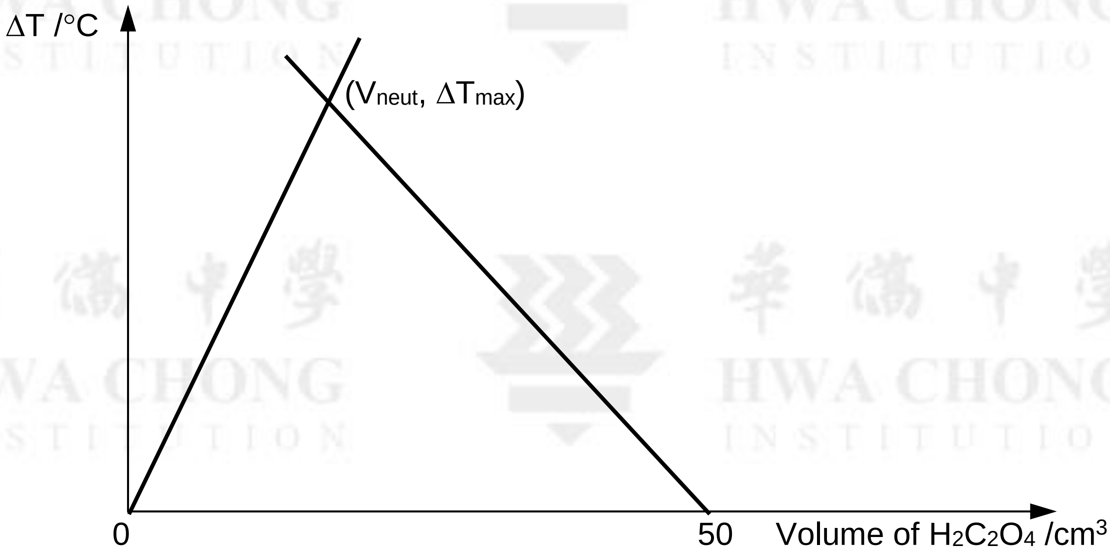
M5 is lost if the student designed a *temperature vs. time* graph experiment i.e. took temperature readings at 1 min, 2 min, 3 min, 4 min, 5 min etc.

Sample Answers:

Volume of $H_2C_2O_4$ /cm^3	Volume of NaOH /cm^3	Initial temperature of $H_2C_2O_4$ /°C	Highest temperature after mixing /°C	ΔT /°C
5 10 15	45 40 35			
20 30 40	30 20 10			

1. Use a measuring cylinder to measure 5 cm^3 of $H_2C_2O_4$ (or 45 cm^3 NaOH) and add it into a styrofoam cup. Place this styrofoam cup into a second styrofoam cup, which is then placed in a beaker for support. The two layers of styrofoam cups help to minimise heat loss to the surroundings (during the reaction).
2. Use a thermometer to measure and record the initial temperature of the solution in the cup.
3. Use a second measuring cylinder to measure 45 cm^3 of NaOH (or 5 cm^3 $H_2C_2O_4$). Add this second solution to the first solution in the cup. Cover the cup with a lid that has a hole for the thermometer. The lid also helps to minimise heat loss to the surroundings. Use the thermometer to stir the mixture and measure the highest temperature reached. Wash and dry the styrofoam cup and the thermometer.
4. Repeat the above steps using the volumes shown in the table.

4 (c)



[1]
- label y-axis ΔT /°C
- label x-axis volume $H_2C_2O_4$ /cm^3
- two straight lines that intersect, inverted V-shape

Students may label the intersection point because that helps in answering the next part, e.g. label it as (V_{neut}, ΔT_{max}).

[1] • intersection point must have volume $H_2C_2O_4$ more to the left because it is around 17 cm^3

4 (d) **[1]** for calculation steps to determine [$H_2C_2O_4$] in mol dm^{-3}
[1] for calculation steps to determine ΔH_{neut}

$$\frac{[H_2C_2O_4] \times V_{neut}}{2.00 \times (50 - V_{neut})} = \frac{1}{2}$$

$$[H_2C_2O_4] \times V_{neut} = \tfrac{1}{2} \times 2.00 \times (50 - V_{neut})$$

$$\therefore [H_2C_2O_4] = \frac{50 - V_{neut}}{V_{neut}}$$

Heat change q = $50 \times 4.18 \times \Delta T_{max}$
n(H_2O) produced = n(NaOH) reacted = $2.00 \times (50 - V_{neut})/1000$
$\Delta H_{neut} = - q \div n(H_2O)$