2020 RI H2 Chemistry Prelim Paper 4 – Suggested Solutions

1(a)(i)

Table 1.1

final burette reading / cm^3	25.40	35.40
initial burette reading / cm^3	0.00	10.00
volume of **FA 2** used / cm^3	25.40	25.40

Note: *(also applies to Table 1.2)*
- Record burette readings to **2 d.p.**
- Get **consistent results** (i.e. at least two titre values which are within 0.10 cm^3 of each other).

Comments:
- Generally well done.

1(a)(ii)

$$V_1 = \frac{25.40 + 25.40}{2}$$

$$= \underline{25.40\ cm^3}$$

Note:
- Average volume, V_1, should be calculated **using consistent titres** (within 0.10 cm^3 of each other) obtained in Table 1.1.
- **Working** must be shown.
- Average volume to **2 d.p.**

Comments:
- Generally well done.

1(b)(i)

Amount of $KMnO_4$ used = $\frac{25.40}{1000} \times 0.0200 = 0.000508$ mol

From equation 2, mole ratio of MnO_4^- : Fe^{2+} = 1 : 5

Amount of Fe^{2+} = $0.000508 \times 5 = 0.00254$ mol

$[Fe^{2+}] = \frac{0.00254}{10} \times 1000 = \underline{0.254\ mol\ dm^{-3}}$

Note:
For all questions involving calculations,
- statements and working should be clearly shown.
- all final answers to **3 s.f.**

Comments:
- Generally well done.

1(b)(ii)

Concentration of hydrated halotrichite in **FA 1** = $\frac{22.26}{100} \times 1000 = 222.6\ g\ dm^{-3}$

Since each formula unit of the hydrated halotrichite contains only one Fe^{2+}, from **(b)(i)**, concentration of hydrated halotrichite in **FA 1**
= concentration of Fe^{2+}
= $0.254\ mol\ dm^{-3}$

Relative formula mass of hydrated halotrichite = $\frac{222.6}{0.254} = \underline{876}$

Comments:
- Some students did not read the question carefully – FA 1 is prepared by dissolving <u>22.26 g</u> of hydrated halotrichite in only <u>100 cm^3</u> of water.
- A few students incorrectly gave units for the M_r of the hydrated halotrichite. Note that
  - Relative formula mass (M_r) and relative atomic mass (A_r) have no units
  - Units for molar mass is $g\ mol^{-1}$

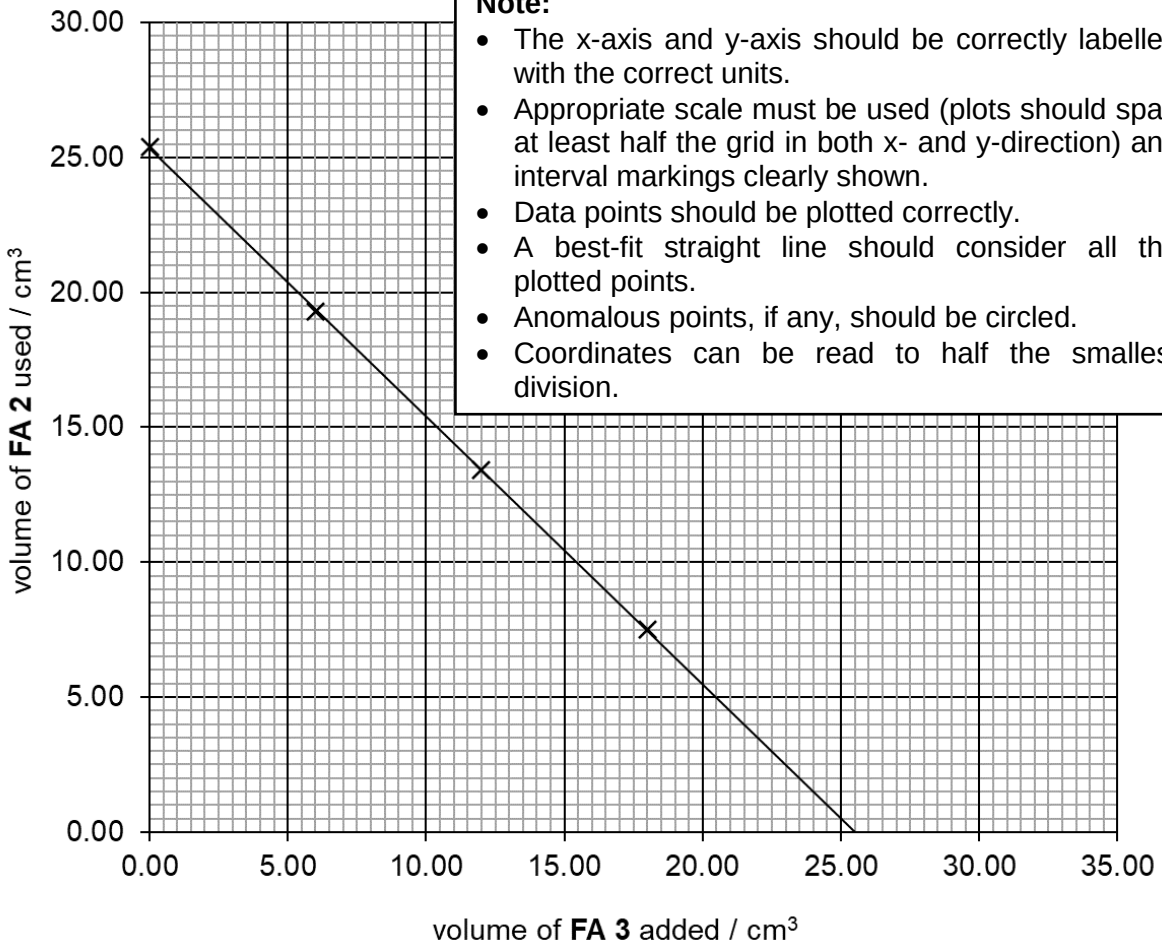
1(c)

Table 1.2

Volume of **FA 3** added / cm^3	0.00	6.00	12.00	18.00
final burette reading for **FA 2** / cm^3		19.30	33.40	42.50
initial burette reading for **FA 2** / cm^3		0.00	20.00	35.00
volume of **FA 2** used / cm^3	25.40	19.30	13.40	7.50

Comments:
- Generally well done.
- Some students did not follow the question and failed to select volumes of FA 3 which differ by at least 6.00 cm^3.

1(d)



Note:
- The x-axis and y-axis should be correctly labelled with the correct units.
- Appropriate scale must be used (plots should span at least half the grid in both x- and y-direction) and interval markings clearly shown.
- Data points should be plotted correctly.
- A best-fit straight line should consider all the plotted points.
- Anomalous points, if any, should be circled.
- Coordinates can be read to half the smallest division.

Comments:
- Generally well done.
- The scale chosen for x-axis should allow room for extrapolation to obtain V_2.
- Avoid odd scales, e.g. one large square for 4 cm^3 or 6 cm^3. Such odd scales will be penalised as it makes the plotting and/or reading of coordinates difficult.

1(e)(i) From graph, V_2 = 25.50 cm^3

Comments:
- Generally well done.
- To obtain V_2 (volume of FA 3 required to react completely with 10.0 cm^3 of FA 1 with no FA 2 added), the extrapolation of graph to obtain the x-intercept must be clearly shown.

1(e)(ii) From **(b)(i)**, Amount of Fe^{2+} = 0.000508 × 5 = 0.00254 mol

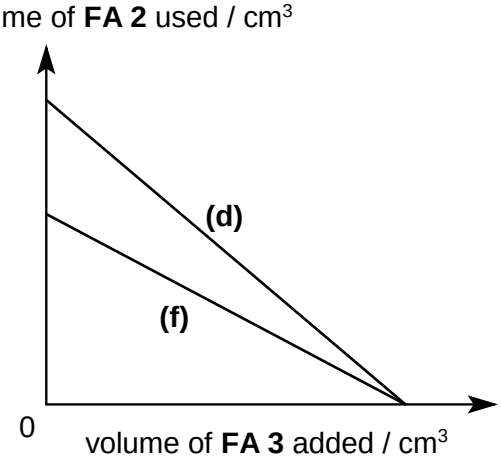
From equation 2, mole ratio of H_2O_2 : Fe^{2+} = 1 : 2

Amount of $H_2O_2 = \frac{0.00254}{2}$ = 0.00127 mol

$[H_2O_2] = \frac{0.00127}{25.50} \times 1000$ = <u>0.0498 mol dm^{-3}</u>

Comments:
- Generally well done.
- The calculation should make use of the V_2 obtained in (e)(i), instead of using a specific point on the graph, e.g. at 6 cm^3 of FA 3 added.

1(f)



With a higher concentration of $KMnO_4$ in **FA 2**, a <u>smaller volume of **FA 2**</u> will contain the <u>same amount of $KMnO_4$ required to react with the Fe^{2+} present in 10.0 cm^3 of **FA 1** if no **FA 3** is added</u> (i.e. smaller V_1).

Since the <u>volume and concentration of Fe^{2+} in **FA 1** is the same</u>, the <u>volume of **FA 3**</u> required to react completely with the Fe^{2+} <u>if no **FA 2** was added</u> remains <u>unchanged</u> (i.e. V_2 is unchanged).

Comments:
- Most students showed understanding that with a higher [$KMnO_4$], volume of FA 2 required to completely react with the (remaining) Fe^{2+} would be lower than that in (d). However, a number of students did not realise that V_2 (x-intercept) will remain unchanged as this is the volume of FA 3 required to react with Fe^{2+} <u>with no FA 2 added</u>. Since the amount of Fe^{2+} (volume and concentration of FA 1) and concentration of FA 3 remains unchanged, V_2 will be the same for both (d) and (f).

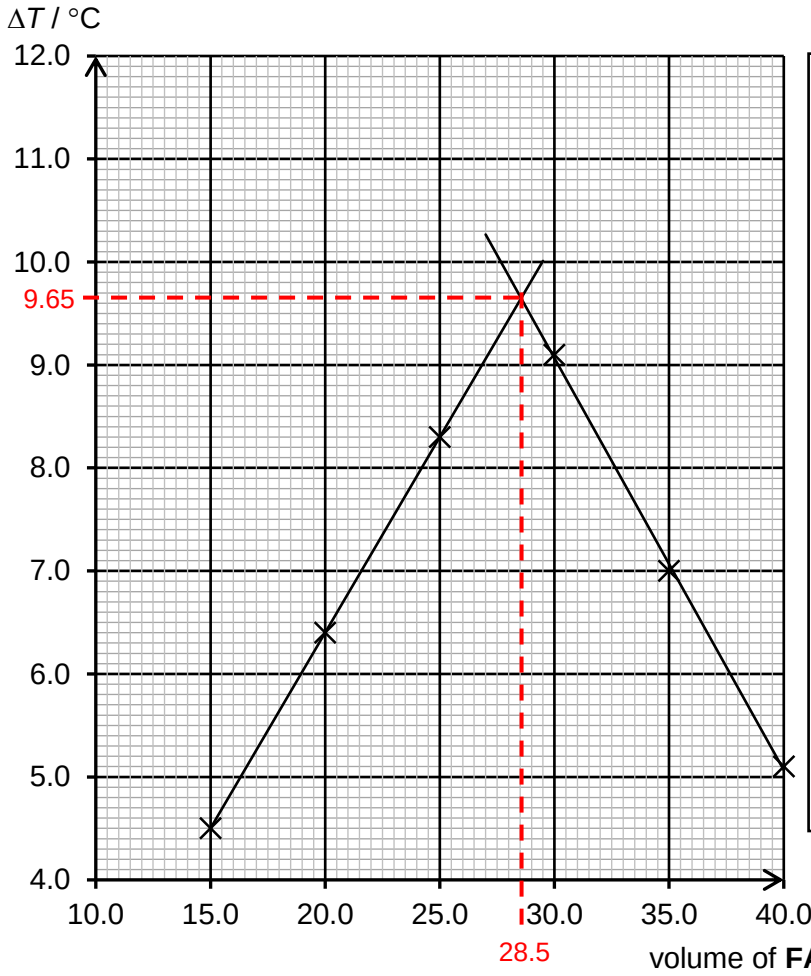
2(a)

volume of **FA 4** / cm^3	10.0	15.0	20.0	25.0	30.0	35.0
volume of **FA 5** / cm^3	40.0	35.0	30.0	25.0	20.0	15.0
T_2 / °C	34.1	36.0	38.1	37.3	35.4	33.5
T_1 / °C	29.0	29.0	29.0	29.0	29.0	29.0
ΔT / °C	+5.1	+7.0	+9.1	+8.3	+6.4	+4.5

Comments:
- Generally well done.
- Some students did not read, understand or follow the instructions stated in the question. For this question, students are required to:
  - construct an appropriate table with proper headings and units.
  - record all measurements of volume, temperature and temperature change. Hence, volume of FA 5 needs to be included.
  - use an appropriate volume of FA 5 so that the total volume of each mixture is 50.0 cm^3.
  - record all data to the appropriate number of decimal places, typically to half the smallest division or according to the question. It is stated in the question that temperature readings are to be recorded to 0.1 °C. Volumes of reagents should also be recorded to 1 d.p.
  - calculate all ΔT correctly.

2(b)

Plot a graph of ΔT vs volume of **FA 5**.



Note:
- The x-axis and y-axis should be correctly labelled with the correct units.
- Appropriate scale must be used (plots should span at least half the grid in both x- and y-direction) and interval markings clearly shown.
- Data points should be plotted correctly.
- 2 best-fit, intersecting, straight lines drawn using data points.
- Anomalous points, if any, should be circled.
- Coordinates can be read to half the smallest division.

ΔT_{max} = +9.65 °C
Volume of **FA 5** = 28.5 cm^3
Volume of **FA 4** = 50 – 28.5 = 21.5 cm^3

Comments:
- Students are required to plot the points and draw the best-fit lines on the grid provided.
- The scale chosen for y-axis should allow
  - room for extrapolation for the two best-fit lines to intersect
  - the plots to span at least half the grid in the y-direction
- Students are required to know that a best-fit line is one with equal distribution of data points above and below the line. Poor experimental technique would affect the experimental results and hence the quality of the best-fit lines.
- Some students tried to manipulate their data points to obtain a straight line. As a result, their plotted points do not match their experimental data in Q2(a).
- The determination of ΔT and volumes of FA 4 and FA 5 were generally well done.

2(c) Amount of H_2SO_4 in **FA 4** = 0.800 (21.5/1000) = 0.0172 mol
Amount of $M(OH)_x$ in **FA 5** = 1.20 (28.5/1000) = 0.0342 mol

Comments:
- Generally well done.

2(d) Ratio of $M(OH)_x$ to H_2SO_4 = 1.988:1 ≈ 2:1 $\Rightarrow$ x = 1

Comments:
- Some students forgot that H_2SO_4 is a dibasic acid and did not include that in the determination of x.
- Note that x must be a whole number.

2(e) $[M(OH)_x]$ = 16.8 x (1000/250) = 67.2 g dm^{-3}
M_r of $M(OH)_x$ = 67.2 / 1.2 = 56.0
A_r of M = 56.0 – 16.0 – 1.0 = 39.0

Comments:
- Generally well done .

2(f) $q = mc\Delta T$ = 50(4.18)(+9.65) = +2016.8 J
ΔH_{neut} = –2016.8 / 0.0342 = –58970 J mol^{-1} = –59.0 kJ mol^{-1}

Comments:
- Enthalpy change of neutralisation is the energy change when an acid and a base react to form one mole of water. A common mistake was to divide the heat evolved by the amount of H_2SO_4 used (H_2SO_4 is a dibasic acid – 1 mol of H_2SO_4 forms 2 mol of H_2O).
- For all Energetics questions, students need to include the sign and units for ΔH (as well as ΔS and ΔG).
- Some students forgot to include the negative sign in ΔH = –q/n or incorrectly thought that $\Delta H = mc\Delta T$.
- Note that "m" in $mc\Delta T$ is the total mass of the solution, which is 50.0 g in this question.

2(g) The magnitude of ΔT_{max} decrease. Ethanedioic acid is a weak acid and does not dissociate completely in aqueous solution. Energy will be required to further ionise the unionised ethanoic acid. Hence, for the same mass of solution and same amount of H_2O formed, the amount of heat change will be smaller.

Comments:
- When stoichiometric amount of an acid (whether weak or strong) is reacted with a strong base, the same amount of H_2O will be formed.
- A common misconception is that ethanedioic acid, being a weak acid, undergoes partial ionisation to form less H^+ and hence less H_2O is formed upon reaction with a strong base. Note that as more base is added, more ethanedioic acid will dissociate to release more H^+ until all the acid is consumed. Hence, the amount of base required to neutralise the acid and the amount of H_2O formed will remain the same.

3(a)(i)

test	Observations
1. Using a measuring cylinder, transfer 10 cm^3 of **FA 1** to a clean boiling tube. 2. Using another measuring cylinder, measure out 10 cm^3 of aqueous sodium carbonate. 3. Use a dropping pipette to transfer 1.0 cm^3 of aqueous sodium carbonate from the measuring cylinder to the boiling tube. 4. Mix the contents of the boiling tube thoroughly. 5. Repeat points 3 and 4 until the measuring cylinder is empty.	Effervescence observed. CO_2 gas evolved gave a white ppt. with limewater. White ppt formed. Then green ppt formed. Initial ppt turned darker green/brown upon mixing thoroughly.

Comments:

- A number of students did not identify that the gas given out is CO_2. Students should note that test and identity of gas must be given for any gas evolved, as specified by the question.
- While most students are able to record the observation of two precipitates, many students did not record that the white ppt was first observed before the green ppt started to be observed.
- As the question already specified that Fe^{2+} is present, students should know that $Fe(OH)_2$ is formed and hence describe the coloured ppt as "green", rather than "grey-green" ppt. Grey-green ppt is not given credit as grey-green ppt describes the colour of $Cr(OH)_3(s)$ rather $Fe(OH)_2(s)$.

3(a)(ii)

test	Observations
Add 1 cm depth of **FA 1** to a test-tube. Add aqueous sodium hydroxide slowly, with shaking, until no further change is seen. Swirl and filter the mixture, collecting the filtrate in a test-tube. The filtrate is **FA 6** which should be retained for use in **(iii)**.	White ppt. formed, soluble in excess NaOH(aq) to form a colourless solution. Green ppt. formed, insoluble in excess NaOH(aq). Green ppt. turns brown in contact with air/upon standing. Colourless filtrate Green/brown residue . Green residue turned brown on standing.

Comments:

- A significant number of students thought that Cr^{3+} is present and describe the coloured ppt formed as grey-green rather than green. Cr^{3+} cannot be present as the dark green complex of $[Cr(OH)_6]^{3-}$ is not formed with excess NaOH(aq), since a colourless (rather than dark green) filtrate is obtained from filtration.
- The coloured ppt is clearly $Fe(OH)_2$ and not $Cr(OH)_3$ as it turns brown upon standing. Hence, the colour of the coloured ppt should be described as "green" and not "grey-green".
- A number of students did not record the white ppt and its solubility in excess NaOH(aq). When NaOH(aq) (or $NH_3(aq)$) is added to a sample containing two cations, the colours of the two ppts formed and their solubilities in excess NaOH(aq) (or $NH_3(aq)$) must be given.

3(a)(iii)

test	Observations
Add 1 cm depth of **FA 6** to a test-tube. Add dilute hydrochloric acid slowly, with shaking, until no further change is seen.	 White ppt. formed, soluble in excess HC*l*(aq) to form a colourless solution.

Comments:

- A number of students did not observe the white ppt formed. For a successful junction test, students should note the following:
  - Add excess NaOH(aq) (about 3 to 4 times the volume of FA 1) and shake the mixture well to form the complex $[Al(OH)_4]^-$. If too little NaOH(aq) is added, the complex is not formed and if too much NaOH(aq) is added, the concentration of $[Al(OH)_4]^-$ is too low (as more dilute HC*l* is required to neutralise the excess NaOH(aq) resulting in dilution of the solution in the test-tube).
  - Add dilute HC*l* dropwise to 1 cm depth of the filtrate. After every drop, observe for the appearance of a white ppt at the junction of the aq NaOH added and the filtrate, before the addition of the next drop. If a complex is present, the ppt would appear after a few drops.

3(a)(iv) **X** is Al^{3+}.
In test 3(a)(i), **FA 1** reacted with Na_2CO_3(aq) to give a white ppt. of $Al(OH)_3$ together with the effervescence of CO_2 gas.

Comments:

- Besides Al^{3+}, Zn^{2+} also forms a white ppt soluble in excess NaOH(aq). Hence, students using only evidence from 3(a)(ii) to identify Al^{3+} are not given credit.

3(b)(i)

test	observations
Add 1 cm depth of **FA 1** to a test-tube. Add 5 drops of aqueous barium chloride. Then add dilute hydrochloric acid slowly, with shaking, until no further change is seen.	 white ppt formed. white ppt remained insoluble in excess dilute hydrochloric acid.

Comments:

- Generally well done.
- As CO_3^{2-} and SO_3^{2-} also form white ppt with $BaCl_2$, to confirm the presence of SO_4^{2-}, dilute HC*l* is added. $BaSO_4$ is insoluble in dilute HC*l* but $BaCO_3$ and $BaSO_3$ are soluble in dilute HC*l*, and hence the insolubility of the white ppt in dilute HC*l* confirms the presence of SO_4^{2-} ions.

3(b)(ii) **Y** is SO_4^{2-}.

Comments:

- Generally well done.

3(c)

1 To 1 cm depth of solution **Z** in a test-tube, add $NH_3(aq)$ drop-wise till in excess and shake the mixture thoroughly.

2 Filter the mixture into a clean test-tube. Wash the residue with deionised water. $Cr(OH)_3$ is obtained as the residue.

3 To the filtrate, add HC*l*(aq) dropwise until maximum ppt is obtained. (**Or** To the filtrate, add excess HC*l*(aq) followed by excess aq NaOH to obtain the precipitate)

4 Filter the mixture and wash the residue with deionised water. $Cu(OH)_2$ is obtained as the residue.

OR

1 To 1 cm depth of solution **Z** in a test-tube, add NaOH(aq) drop-wise till in excess and shake the mixture thoroughly.

2 Filter the mixture into a clean test-tube. Wash the residue with deionised water. $Cu(OH)_2$ is obtained as the residue.

3 To the filtrate, add HC*l*(aq) dropwise until maximum ppt is obtained. (**Or** To the filtrate, add excess HC*l*(aq) followed by excess aq NH_3 to obtain the precipitate).

4 Filter the mixture and wash the residue with deionised water. $Cr(OH)_3$ is obtained as the residue.

Key Points:
- Add aqueous NH_3 / aqueous NaOH in excess.
- Add dilute HC*l* dropwise till maximum ppt. is obtained.
- Filter the mixture.
- Correct identity of the residues obtained, i.e. $Cr(OH)_3$ and $Cu(OH)_2$.

Comments:
- Generally well done.
- As the question requires the cations present to be obtained as two separate precipitates, students who add excess NaOH(aq) to one portion of **Z** and excess $NH_3(aq)$ to another portion are not given full credit.

4(a) In NaOH(aq), the $[OH^-]$ increases. OH^- exerts a common ion effect and hence the solubility of $Ca(OH)_2$ decreases.

Comments:
- Generally well done.
- Note that we usually compare ionic product with K_{sp} when mixing solutions to determine if precipitation of sparingly soluble salts occur upon mixing.

4(b) Pre-calculations

$Ca(OH)_2(s) \rightleftharpoons Ca^{2+}(aq) + 2OH^-(aq)$

$[OH^-(aq)]$ in **FA 7** = 2(0.005) + 0.020 = 0.0300 mol dm^{-3}

Assume volume of **FA 7** used for titration = 25.0 cm^3
Amount of $OH^-(aq)$ in 25.0 cm^3 = 0.03 x 25.0/1000 = 7.50 x 10^{-4} mol
Amount of HC*l* required = 7.50 x 10^{-4} mol

Assume average titre = 25.00 cm^3 (accept 10 – 30 cm^3 based on capacity of pipette)
[HC*l*] required = 7.50 x 10^{-4} / 0.025 = 0.0300 mol dm^{-3}

Volume of 0.250 mol dm^{-3} HC*l* required to prepare 250 cm^3 of 0.03 mol dm^{-3} HC*l*
= 0.03 x 250 / 0.25 = 30.00 cm^3

Preparation of **FA 8**

1. Fill a burette/pipette with 0.250 mol dm^{-3} HC*l*.
2. Add 30.00 cm^3 from the burette into a 250 cm^3 volumetric flask.
3. Top up to the mark with deionised water.
4. Stopper and shake thoroughly.
5. Label this solution **FA 8**.

Preparation of **FA 7** and titration

1. Using a measuring cylinder, transfer 150 cm^3 of 0.020 mol dm^{-3} aqueous sodium hydroxide into a (dry) 250 cm^3 conical flask/beaker.
2. Using a spatula, add solid $Ca(OH)_2$ into the flask. Stir the contents of the flask using a glass rod until no more solid can dissolve.
3. Immerse the flask in a water bath maintained at 25°C and place a thermometer into the flask to monitor the temperature of the solution.
4. Allow the solution to stand for a few minutes with occasional stirring or swirling.
   (Note: This is to ensure that system has reached equilibrium, i.e. solution is saturated, before filtration to remove the undissolved solid)
5. Filter the solution through a dry filter paper into a dry 250 cm^3 conical flask. Label the filtrate **FA 7**.
   (Note: Dry filter paper and conical flask need to be used to prevent any water from shifting the equilibrium position, i.e. to ensure that solution obtained through filtration remains saturated.)
6. Pipette 25.0 cm^3 of **FA 7** into a 250 cm^3 conical flask. Add 2-3 drops of methyl orange indicator into the conical flask.
7. Titrate the solution against **FA 8** in the burette. The end-point is reached when the solution in the conical flask changes from yellow to orange colour.
8. Repeat the titration to get at least two consistent results (i.e. at least two titres which do not differ by more than 0.10 cm^3).
9. Repeat steps 1 to 9.

Key Points for preparation of FA 7 and titration:

- Add $Ca(OH)_2$ to at least 150 cm^3 of 0.0200 mol dm^{-3} NaOH(aq) until no more can dissolve with stirring/mixing/agitation or left to stand to reach equilibrium
- Leave to stand in water bath maintained at 25°C
- Filter (undissolved $Ca(OH)_2$) using dry filter paper/filter funnel and dry conical flask/ beaker
- Pipette 25.0 cm^3 of **FA 7** and place HC*l* (in burette)
- End-point colour change (yellow → orange)
- Repeat titration to obtain consistent titration results

Calculations:

Let average titre = y cm^3
Amount of H^+ = amount of $OH^-(aq)$ in 25.0 cm^3 of **FA 7**
= 0.03y/1000 mol
= 3y x 10^{-5} mol

$[OH^-(aq)]$ in **FA 7** = 3y x 10^{-5} / 0.025 = 0.0012y mol dm^{-3}
$[Ca^{2+}(aq)]$ in **FA 7** = ½ (0.0012y – 0.020) = z mol dm^{-3}

Solubility of $Ca(OH)_2$ in 0.020 mol dm^{-3} aqueous sodium hydroxide at 25 °C
= z mol dm^{-3}

Solubility product of $Ca(OH)_2$ at 25 °C
= $[Ca^{2+}(aq)]\ [OH^-(aq)]^2$
= $z(0.0012y)^2\ mol^3\ dm^{-9}$

Comments:

Pre-calculations

- The pre-calculations were poorly done. While most students knew that they needed to calculate the suitable [HC*l*] for titration and the volume of 0.250 mol dm^{-3} HC*l* required to prepare FA 8, many students went on to calculate the mass of $Ca(OH)_2(s)$ required to prepare a saturated solution. The mass of $Ca(OH)_2(s)$ was not required to prepare its saturated solution; one only needs to add $Ca(OH)_2(s)$ until no more dissolves in the solvent.
- Students need to understand why they were asked to prepare 150 cm^3 of FA 7 (a saturated solution of $Ca(OH)_2$ in 0.020 mol dm^{-3} aqueous sodium hydroxide). The stated volume is sufficient for a student to do an average of 3 titrations using 25.0 cm^3 aliquot each time to obtain consistent results. Hence, you should not be titrating the entire 150 cm^3 of FA 7.
- In their pre-calculations, many students did not account for **all** the $OH^-(aq)$ present in FA 7; they either considered the amount of $OH^-(aq)$ from NaOH(aq) only or the amount of $OH^-(aq)$ from $Ca(OH)_2(aq)$ only. This resulted in an incorrect [HC*l*] in FA 8. The total $[OH^-(aq)]$ in FA 7 should be the sum of $[OH^-(aq)]$ from $Ca(OH)_2(aq)$ **and** 0.020 mol dm^{-3} aqueous NaOH. When the desired [HC*l*] for titration was determined, students usually were able to calculate the volume of 0.250 mol dm^{-3} HC*l* required for dilution.

Preparation of FA 8 (diluted HCl)

- In the preparation of FA 8, many students did not realise that they needed to use an accurate apparatus, such as a burette or pipette, to transfer the 0.250 mol dm^{-3} HC*l* into a 250 cm^3 volumetric flask. Many used a measuring cylinder which has a much larger uncertainty and hence would result in an inaccurate [HC*l*] for titration.

Preparation of FA 7 and titration

- There were many common errors in the preparation of FA 7. Some students incorrectly tried to dissolve the calculated mass of $Ca(OH)_2(s)$ to prepare a saturated solution. Some proceeded on without filtering because they assumed all the calculated $Ca(OH)_2(s)$ added had dissolved. Some prepared the saturated solution in a volumetric flask which is not meant for dissolving of solids. Others prepared a small volume of saturated $Ca(OH)_2(aq)$ and then topped up to the mark in a 150 cm^3 volumetric flask hoping that the solution was still saturated!
- Many students did not use a water bath to maintain the temperature at 25 °C. The water bath should be used during dissolution of $Ca(OH)_2(s)$ and equilibration and **NOT** after filtration. Other common mistakes include not allowing enough time for equilibration and not using dry apparatus such as dry filter paper, funnel and beaker during the preparation of FA 7 which could result in a lower calculated solubility. The rest of the procedure involving titration were generally well-done.

Calculations of solubility and K_{sp}

- The calculations of solubility and K_{sp} were poorly done.
- Many students were confused by the amount of $OH^-(aq)$ and $[OH^-(aq)]$ and attempted incorrectly to calculate the solubility without converting amounts into concentration terms.
- Many students did not know that the amount of HC*l* used for titration gave the total amount of $OH^-(aq)$ in 25.0 cm^3 of FA 7 (if 25.0 cm^3 pipette was used).
- Many students also did not know how to calculate $[Ca^{2+}(aq)]$.
- The solubility, s, calculated in this question is that in 0.020 mol dm^{-3} aqueous NaOH and not in water. Hence, $K_{sp} = [Ca^{2+}(aq)]\ [OH^-(aq)]^2 = (s)(2s + 0.020)^2$ (Note: $K_{sp} \neq 4s^3$).