Past-paper walk-through

Solutions and Mixtures ▪ 3.7

eXercise

Questions in this set

- 2025 Q1
- 2022 Q6
- 2019 Q3

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 1

2025 ▪ Q1

Answer the following questions about magnesium.

(a) An incomplete mass spectrum for magnesium is shown in the diagram.

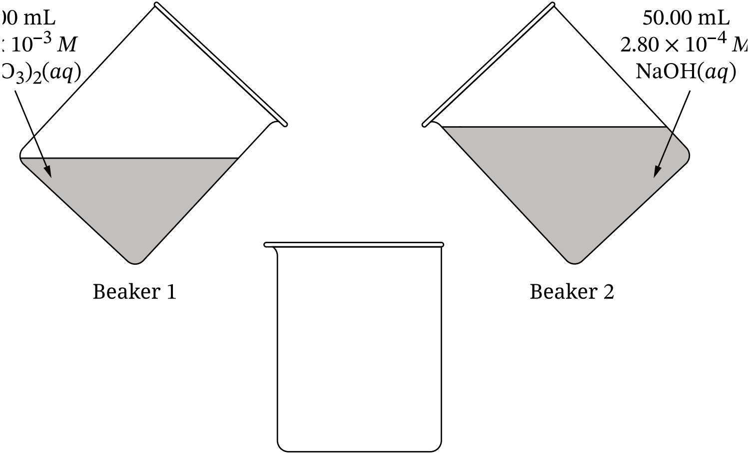
[Bar graph titled “Relative Abundance” vs. “Mass (amu)”; y-axis from 0 to 100 in increments of 20; x-axis shows tick marks at 24, 25, 26; a single thick vertical bar is drawn at mass 24 reaching a relative abundance of about 79.]

The percent abundance of magnesium-24 is 79%. The percent abundances of the other two natural isotopes of magnesium, magnesium-25 and magnesium-26, are approximately equal.

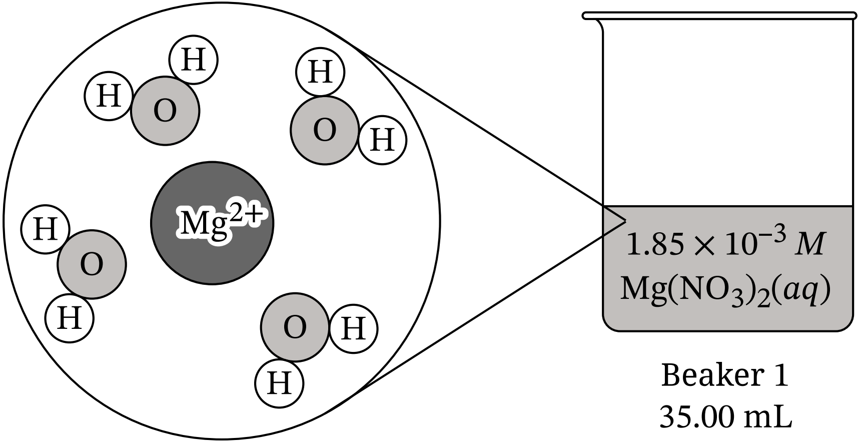
(a)(i) Complete the mass spectrum in part A by drawing thick lines in the appropriate locations to represent the percent abundance of magnesium-25 and magnesium-26.

(a)(ii) Describe the difference in atomic structure that accounts for the difference in mass between magnesium-25 and magnesium-26.

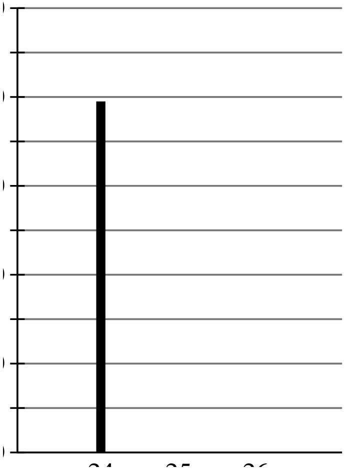
Question 1



Question 1



Question 1



Question 1

2025 ▪ Q1

Answer the following questions about magnesium.

(b) A student prepares a 1.85×10^{-3} *M* solution of $Mg(NO_3)_2(aq)$ in beaker 1 and a 2.80×10^{-4} *M* solution of NaOH(aq) in beaker 2, as shown.

[Particle diagram: a magnesium ion, Mg^{2+}, at the center surrounded by six water molecules (H2O), each oriented with its oxygen atom pointing toward the central Mg^{2+} ion and its two hydrogen atoms pointing outward.]

[Beaker 1: labeled "1.85×10^{-3} *M* $Mg(NO_3)_2(aq)$", "Beaker 1", "35.00 mL".]

[Beaker 2: labeled "2.80×10^{-4} *M* NaOH(aq)", "Beaker 2", "50.00 mL".]

The particle diagram shown represents a magnesium ion, Mg^{2+}, in beaker 1. A sodium ion, Na^{+}, in beaker 2 has a weaker attraction to water than the Mg^{2+} does. Explain this phenomenon using Coulomb's law and each of the following.

(b)(i) The relative charge of the ions

Question 1

(b)(ii) The relative radii of the ions

Question 1

2025 ▪ Q1

Answer the following questions about magnesium.

(c) Calculate the pH of the solution in beaker 2.

Question 1

2025 ▪ Q1

Answer the following questions about magnesium.

(d) A student combines 35.00 mL of 1.85×10^{-3} M $Mg(NO_3)_2(aq)$ with 50.00 mL of 2.80×10^{-4} M $NaOH(aq)$, as shown in the diagram. Calculate $[Mg^{2+}]$ after the two solutions are combined but before any reaction takes place. (Assume that volumes are additive.)

[Diagram of two conical/Erlenmeyer flasks being poured into an empty Beaker 3. Left flask: "35.00 mL", "1.85×10^{-3} M", "$Mg(NO_3)_2(aq)$", labeled "Beaker 1". Right flask: "50.00 mL", "2.80×10^{-4} M", "$NaOH(aq)$", labeled "Beaker 2". Both flasks have an arrow pointing down into the empty "Beaker 3" between them.]

Question 1

2025 ▪ Q1

Answer the following questions about magnesium.

(e) The dissolution of magnesium hydroxide is represented by the following equation.

$$\mathrm{Mg(OH)_2}(s) \rightleftharpoons \mathrm{Mg^{2+}}(aq) + 2\,\mathrm{OH^-}(aq) \qquad K_{sp} = 5.61 \times 10^{-12}$$

(e)(i) Write the expression for the solubility product constant, K_{sp}.

(e)(ii) After the two solutions are combined in beaker 3 as described in part D, but before any reaction takes place, $\left[\mathrm{OH^-}\right] = 1.65 \times 10^{-4}$ M. Using your answer to part D, calculate the value of the reaction quotient, Q.

(e)(iii) Using the reaction quotient, Q, predict whether a precipitate should form as the mixture in beaker 3 approaches equilibrium. Justify your answer.

Question 1

2025 ▪ Q1

Answer the following questions about magnesium.

(f) In a separate experiment, the student adds $HNO_3(aq)$ to decrease the pH of a saturated solution containing undissolved $Mg(OH)_2(s)$. Does the amount of undissolved $Mg(OH)_2(s)$ increase, decrease, or remain the same as the $HNO_3(aq)$ is added? Justify your answer.

Solution 1

(a)

Mark scheme

- No separate response required — this is the context/stem describing the incomplete mass spectrum (magnesium-24 at 79% abundance) that parts (i) and (ii) below refer to.

(a)(i)

Mark scheme

- Draw two vertical bars at masses 25 and 26, each reaching a relative abundance of approximately 10 to 11 (since Mg-25 and Mg-26 together make up the remaining ~21% and are approximately equal, so roughly 10–11% each).

Solution 1

(a)(ii)

Mark scheme

- Magnesium-26 has one more neutron than magnesium-25 does (Mg-25 has 13 neutrons, Mg-26 has 14 neutrons; both isotopes have 12 protons, since they are the same element).

Solution 1

(b)

Mark scheme

- No separate response required — this is the context/stem introducing the 1.85×10^{-3} M $Mg(NO_3)_2$(aq) and 2.80×10^{-4} M NaOH(aq) solutions (with a particle diagram of hydrated Mg^{2+}) that parts (i) and (ii) below refer to.

(b)(i)

Mark scheme

- The charge on the sodium ion (Na^+, $+1$) is less than the charge on the magnesium ion (Mg^{2+}, $+2$). A smaller charge results in a weaker Coulombic attraction between Na^+ and water.

Solution 1

(b)(ii)

Mark scheme

- The Na^+ ion is larger (has a greater ionic radius) than the Mg^{2+} ion, so the distance between Na^+ and the oxygen atom of the water molecule will be greater. As distance increases, Coulombic attraction decreases, so Na^+ is less strongly attracted to water than Mg^{2+}.

Solution 1

(c)

Mark scheme

- pOH $= -\log(2.80 \times 10^{-4}) = 3.553.$ pH $= 14 -$ pOH $= 14 - 3.553 = 10.447.$

Solution 1

(d)

Mark scheme

- Using $M_1 V_1 = M_2 V_2$: $M_2 = \dfrac{(1.85 \times 10^{-3}\ M)(0.03500\ \text{L})}{0.03500\ \text{L} + 0.05000\ \text{L}} = 7.62 \times 10^{-4}\ M$.
  So $[\text{Mg}^{2+}]$ after combining but before reaction is $7.62 \times 10^{-4}\ M$.

Solution 1

(e)

Mark scheme

- No separate response required — this is the context/stem giving the $Mg(OH)_2$ dissolution equilibrium and $K_{sp} = 5.61 \times 10^{-12}$ that parts (i)–(iii) below refer to.

(e)(i)

Mark scheme

- $K_{sp} = [Mg^{2+}][OH^-]^2$.

Solution 1

(e)(ii)

Mark scheme

- Using $[Mg^{2+}] = 7.62 \times 10^{-4}$ M (from part D) and $[OH^-] = 1.65 \times 10^{-4}$ M (given): $Q = [Mg^{2+}][OH^-]^2 = (7.62 \times 10^{-4})(1.65 \times 10^{-4})^2 = 2.07 \times 10^{-11}$.

(e)(iii)

Mark scheme

- Q $(2.07 \times 10^{-11}) > K_{sp}$ (5.61×10^{-12}), so a precipitate should form. Equivalently: the concentration of ions in solution (represented by Q) is greater than that of a saturated solution, so a precipitate will form.

Solution 1

(f)

Mark scheme

- The amount of undissolved $Mg(OH)_2(s)$ will decrease. The H^+ from $HNO_3(aq)$ reacts with OH^-, decreasing $[OH^-]$ and causing $Q < K_{sp}$. As a result, more $Mg(OH)_2(s)$ will dissolve until equilibrium is reestablished, resulting in less undissolved $Mg(OH)_2(s)$.

Question 6

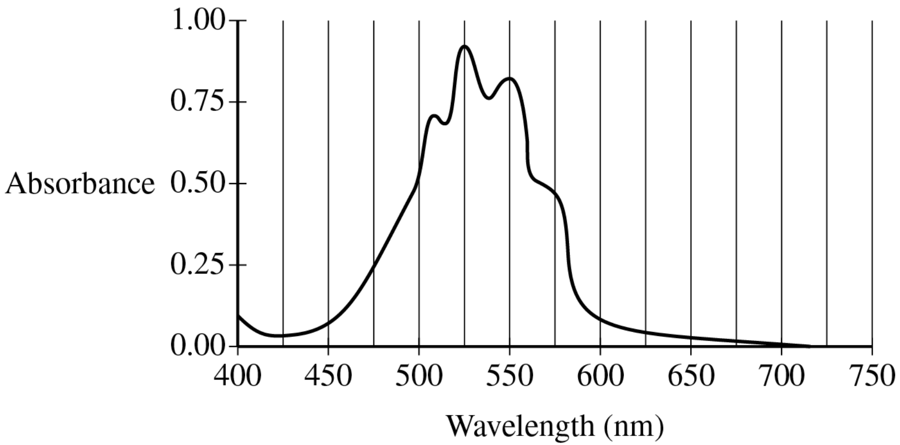
2022 ▪ Q6

A student wants to determine the concentration of permanganate, $MnO_4^-(aq)$, in a solution. The student plans to use colorimetric analysis because solutions containing $MnO_4^-(aq)$ have a purple color.
[Graph: "Absorbance" (y-axis, 0.00 to 1.00) vs. "Wavelength (nm)" (x-axis, 400 to 750). The curve begins near 0 absorbance at 400 nm, rises to a local peak near 0.80 around 510-520 nm, dips slightly to about 0.75 near 530-540 nm, rises again to a second peak of about 0.85 near 545-555 nm, then falls steeply back toward 0 absorbance by about 580-600 nm, remaining near 0 from 600-750 nm. Vertical gridlines mark 400, 450, 500, 550, 600, 650, 700, 750 nm.]
(a) To determine the optimum wavelength for an experiment that measures the concentration of $MnO_4^-(aq)$, the student takes a sample of the solution and measures the amount of light absorbed by the sample over a range of wavelengths. The data are

Question 6

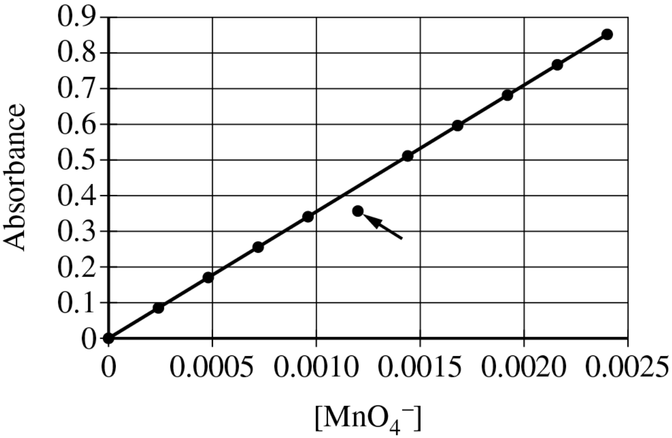
plotted in the graph shown. Identify the optimum wavelength that the student should use for the experimental procedure.

Question 6



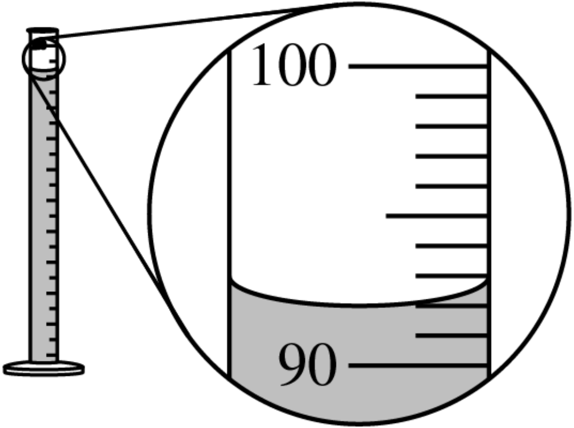
Absorbance
1.00
0.75
0.50
0.25
0.00
400
450
500
550
600
650
700
750
Wavelength (nm)

Question 6



Absorbance
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.0005
0.0010
0.0015
0.0020
0.0025
[MnO_4^-]

Question 6



Question 6

2022 ▪ Q6

A student wants to determine the concentration of permanganate, $MnO_4^-(aq)$, in a solution. The student plans to use colorimetric analysis because solutions containing $MnO_4^-(aq)$ have a purple color.

[Graph: "Absorbance" (y-axis, 0.00 to 1.00) vs. "Wavelength (nm)" (x-axis, 400 to 750). The curve begins near 0 absorbance at 400 nm, rises to a local peak near 0.80 around 510-520 nm, dips slightly to about 0.75 near 530-540 nm, rises again to a second peak of about 0.85 near 545-555 nm, then falls steeply back toward 0 absorbance by about 580-600 nm, remaining near 0 from 600-750 nm. Vertical gridlines mark 400, 450, 500, 550, 600, 650, 700, 750 nm.]

(b) The student uses a stock solution of 2.40×10^{-3} M $KMnO_4(aq)$ to prepare the standard solutions of $MnO_4^-(aq)$ that are needed to construct a calibration curve.

Question 6

[Diagram of a 100.0 mL graduated cylinder with a magnified circular inset showing the liquid meniscus between the "100" and "90" mL gradation marks; the shaded liquid level in the inset sits a little above the "90" mark, roughly at the 92-93 mL region.]

(b)(i) The student uses a 100.0 mL graduated cylinder to measure a certain volume of $KMnO_4(aq)$ stock solution, as shown in the diagram given. What volume should the student record?

(b)(ii) Calculate the volume, in mL, of 2.40×10^{-3} *M* $KMnO_4(aq)$ that is required to produce 100.0 mL of a standard 1.68×10^{-3} *M* $MnO_4^-(aq)$ solution.

Question 6

2022 ▪ Q6

A student wants to determine the concentration of permanganate, $MnO_4^-(aq)$, in a solution. The student plans to use colorimetric analysis because solutions containing $MnO_4^-(aq)$ have a purple color.

[Graph: "Absorbance" (y-axis, 0.00 to 1.00) vs. "Wavelength (nm)" (x-axis, 400 to 750). The curve begins near 0 absorbance at 400 nm, rises to a local peak near 0.80 around 510-520 nm, dips slightly to about 0.75 near 530-540 nm, rises again to a second peak of about 0.85 near 545-555 nm, then falls steeply back toward 0 absorbance by about 580-600 nm, remaining near 0 from 600-750 nm. Vertical gridlines mark 400, 450, 500, 550, 600, 650, 700, 750 nm.]

(c) The student designs the following procedure to produce a calibration curve.

Step 1: Prepare several standard solutions that have known $MnO_4^-(aq)$ concentrations by dilution of the stock solution.

Step 2: Rinse the cuvette with distilled water.

Question 6

Step 3: Rinse the cuvette with the standard solution and fill the cuvette with the standard solution.
Step 4: Measure the absorbance of the standard solution with the colorimeter.
Step 5: Repeat steps 2-4 for each of the standard solutions.
The data are plotted in the calibration curve shown. One of the data points (indicated with an arrow) on the calibration curve is below the line of best fit.
[Calibration curve graph: x-axis "$[MnO_4^-]$" from 0 to 0.0025 (gridlines at 0.0005, 0.0010, 0.0015, 0.0020, 0.0025); y-axis "Absorbance" from 0 to 0.9 (gridlines every 0.1). Data points rise roughly linearly from (0,0) to about (0.0024, 0.85), lying close to a straight line of best fit drawn through them. One data point near $x \approx 0.0011$, $y \approx 0.32$ lies noticeably below the line of best fit (the line at that x-value would be around 0.40-0.42); this point is indicated with an arrow pointing to it.]

Question 6

Assuming that all lab equipment is functioning properly, identify which one of the procedural steps the student could have executed incorrectly that would explain why the marked data point is below the line of best fit. Justify your answer.

Solution 6

(a)

Mark scheme

- 525 nm — the wavelength of maximum absorbance, read from the absorbance-versus-wavelength graph.

Solution 6

(b)

Mark scheme

- This is the stem/introduction to part (b): the student uses a 2.40×10^{3} M KMnO4(aq) stock solution to prepare the standard MnO4 (aq) solutions needed for a calibration curve, and reads a graduated cylinder (diagram shows the meniscus between the 90 and 100 mL marks). No points are allocated to the stem itself — the graded sub-parts are 6bi and 6bii.

Solution 6

(b)(i)

Mark scheme

- 92.0 mL — the volume read from the graduated cylinder, estimating the meniscus to the nearest 0.1 mL between the 90 and 100 mL gradation marks.

(b)(ii)

Mark scheme

- $V1 = M2V2 \ / \ M1 = (1.68 \times 10^{3}\ M)(100.0\ mL) \ / \ (2.40 \times 10^{3}\ M) = 70.0$ mL.

Solution 6

(c)

Mark scheme

- The student could have improperly executed step 3. If the cuvette was not rinsed with the standard solution prior to being filled for the absorbance measurement, the standard solution would be diluted by the remaining distilled water, and the measured absorbance would be lower than what it should be.

Question 3

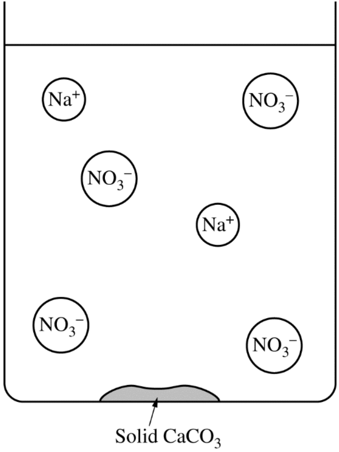
2019 ▪ Q3

A student is given 50.0 mL of a solution of Na_2CO_3 of unknown concentration. To determine the concentration of the solution, the student mixes the solution with excess 1.0 M $Ca(NO_3)_2(aq)$, causing a precipitate to form. The balanced equation for the reaction is shown below.

$$Na_2CO_3(aq) + Ca(NO_3)_2(aq) \rightarrow 2\,NaNO_3(aq) + CaCO_3(s)$$

(a) Write the net ionic equation for the reaction that occurs when the solutions of Na_2CO_3 and $Ca(NO_3)_2$ are mixed.

Question 3



Question 3

Volume of Na_2CO_3 solution	50.0 mL
Volume of 1.0 M $Ca(NO_3)_2$ added	100.0 mL
Mass of $CaCO_3$ precipitate collected	0.93 g

Question 3

2019 ▪ Q3

A student is given 50.0 mL of a solution of Na_2CO_3 of unknown concentration. To determine the concentration of the solution, the student mixes the solution with excess 1.0 M $Ca(NO_3)_2(aq)$, causing a precipitate to form. The balanced equation for the reaction is shown below.

$$Na_2CO_3(aq) + Ca(NO_3)_2(aq) \rightarrow 2\,NaNO_3(aq) + CaCO_3(s)$$

(b) The diagram below is incomplete. Draw in the species needed to accurately represent the major ionic species remaining in the solution after the reaction has been completed.

Question 3

[Diagram of a beaker of solution after reaction: floating ion labels Na^+, NO_3^-, NO_3^-, Na^+, NO_3^-, NO_3^- scattered above a layer of gray solid labelled ”Solid $CaCO_3$” at the bottom of the beaker]

The student filters and dries the precipitate of $CaCO_3$ (molar mass 100.1 g/mol) and records the data in the table below.

Volume of Na_2CO_3 solution	50.0 mL
Volume of 1.0 M $Ca(NO_3)_2$ added	100.0 mL
Mass of $CaCO_3$ precipitate collected	0.93 g

Question 3

2019 ▪ Q3

A student is given 50.0 mL of a solution of Na_2CO_3 of unknown concentration. To determine the concentration of the solution, the student mixes the solution with excess 1.0 M $Ca(NO_3)_2(aq)$, causing a precipitate to form. The balanced equation for the reaction is shown below.

$$Na_2CO_3(aq) + Ca(NO_3)_2(aq) \rightarrow 2\,NaNO_3(aq) + CaCO_3(s)$$

(c) Determine the number of moles of Na_2CO_3 in the original 50.0 mL of solution.

Question 3

2019 ▪ Q3

A student is given 50.0 mL of a solution of Na_2CO_3 of unknown concentration. To determine the concentration of the solution, the student mixes the solution with excess 1.0 M $Ca(NO_3)_2(aq)$, causing a precipitate to form. The balanced equation for the reaction is shown below.

$$Na_2CO_3(aq) + Ca(NO_3)_2(aq) \rightarrow 2\,NaNO_3(aq) + CaCO_3(s)$$

(d) The student realizes that the precipitate was not completely dried and claims that as a result, the calculated Na_2CO_3 molarity is too low. Do you agree with the student's claim? Justify your answer.

Question 3

2019 ▪ Q3

A student is given 50.0 mL of a solution of Na_2CO_3 of unknown concentration. To determine the concentration of the solution, the student mixes the solution with excess 1.0 M $Ca(NO_3)_2(aq)$, causing a precipitate to form. The balanced equation for the reaction is shown below.

$$Na_2CO_3(aq) + Ca(NO_3)_2(aq) \rightarrow 2\,NaNO_3(aq) + CaCO_3(s)$$

(e) After the precipitate forms and is filtered, the liquid that passed through the filter is tested to see if it can conduct electricity. What would be observed? Justify your answer.

Question 3

The student decides to determine the molarity of the same Na_2CO_3 solution using a second method. When Na_2CO_3 is dissolved in water, $CO_3^{2-}(aq)$ hydrolyzes to form $HCO_3^-(aq)$, as shown by the following equation.

$$CO_3^{2-}(aq) + H_2O(l) \rightleftharpoons HCO_3^-(aq) + OH^-(aq) \qquad K_b = \frac{[HCO_3^-][OH^-]}{[CO_3^{2-}]} = 2.1 \times 10^{-4}$$

Question 3

2019 ▪ Q3

A student is given 50.0 mL of a solution of Na_2CO_3 of unknown concentration. To determine the concentration of the solution, the student mixes the solution with excess 1.0 M $Ca(NO_3)_2(aq)$, causing a precipitate to form. The balanced equation for the reaction is shown below.

$$Na_2CO_3(aq) + Ca(NO_3)_2(aq) \rightarrow 2\,NaNO_3(aq) + CaCO_3(s)$$

(f)(i) The student decides to first determine $[OH^-]$ in the solution, then use that result to calculate the initial concentration of $CO_3^{2-}(aq)$.
Identify a laboratory method (not titration) that the student could use to collect data to determine $[OH^-]$ in the solution.

Question 3

(f)(ii) Explain how the student could use the measured value in part (f)(i) to calculate the initial concentration of $CO_3^{2-}(aq)$. (Do not do any numerical calculations.)

Question 3

2019 ▪ Q3

A student is given 50.0 mL of a solution of Na_2CO_3 of unknown concentration. To determine the concentration of the solution, the student mixes the solution with excess 1.0 M $Ca(NO_3)_2(aq)$, causing a precipitate to form. The balanced equation for the reaction is shown below.

$$Na_2CO_3(aq) + Ca(NO_3)_2(aq) \rightarrow 2\,NaNO_3(aq) + CaCO_3(s)$$

(g) In the original Na_2CO_3 solution at equilibrium, is the concentration of $HCO_3^-(aq)$ greater than, less than, or equal to the concentration of $CO_3^{2-}(aq)$? Justify your answer.

Question 3

2019 ▪ Q3

A student is given 50.0 mL of a solution of Na_2CO_3 of unknown concentration. To determine the concentration of the solution, the student mixes the solution with excess 1.0 *M* $Ca(NO_3)_2(aq)$, causing a precipitate to form. The balanced equation for the reaction is shown below.

$$Na_2CO_3(aq) + Ca(NO_3)_2(aq) \rightarrow 2\,NaNO_3(aq) + CaCO_3(s)$$

(h) The student needs to make a CO_3^{2-}/HCO_3^- buffer. Is the Na_2CO_3 solution suitable for making a buffer with a pH of 6? Explain why or why not.

Solution 3

(a)

Mark scheme

- Ca^{2} (aq) + $CO3^{2}$ (aq) $\rightarrow$ CaCO3(s). 1 point for the correct net ionic equation (spectator ions Na and NO3 omitted).

Solution 3

(b)

Mark scheme

- The completed diagram should show one Ca^{2} ion added among the floating Na and NO3 ions: Ca(NO3)2 was added in excess (100.0 mL of 1.0 M vs. only 50.0 mL of dilute Na2CO3), so some unreacted Ca^{2} remains in solution along with the spectator Na and NO3 ions. 1 point for drawing a Ca^{2} ion in the solution.

Solution 3

(c)

Mark scheme

- 0.93 g $CaCO_3$ $\times$ (1 mol $CaCO_3$ / 100.1 g) $=$ 0.0093 mol $CaCO_3$. Since the reaction is 1:1 (Na_2CO_3 : $CaCO_3$), 0.0093 mol $CaCO_3$ $\times$ (1 mol Na_2CO_3 / 1 mol $CaCO_3$) $=$ 0.0093 mol Na_2CO_3. 1 point for the correct answer (0.0093 mol).

Solution 3

(d)

Mark scheme

- Disagree. If the precipitate was not completely dried, residual water increases the measured mass of the 'CaCO3' precipitate above its true mass. This makes the calculated moles of CaCO3 (and therefore of Na2CO3) too high, not too low — so the calculated Na2CO3 molarity would actually be too HIGH, contrary to the student's claim. 1 point for disagreeing with valid justification.

Solution 3

(e)

Mark scheme

- The filtrate would conduct electricity, because dissolved ions remain in solution — specifically Na (aq), the excess Ca^2 (aq) (from the excess Ca(NO3)2 added), and NO3 (aq). 1 point for the correct answer (conducts) with valid justification listing the ions present.

Solution 3

(f)(i)

Mark scheme

- Measure the pH of the solution using a pH meter (a non-titration laboratory method for determining [OH]). 1 point for identifying a valid method.

Solution 3

(f)(ii)

Mark scheme

- From the measured pH: pOH = 14 − pH, then [OH] = 10ˆ(−pOH). 1 point for this valid method of determining [OH] from the measured value. Then, using the Kb expression Kb = [HCO3][OH]/[CO3^{2}] with an ICE table (I: ci, 0, 0; C: −x, +x, +x; E: ci−x, x, x, where x = [OH] = [HCO3] at equilibrium since they form in a 1:1 ratio from water), solve ci = (x^2/Kb) + x for the initial concentration ci of CO3^{2} (equal to the sum of the equilibrium [CO3^{2}] and [HCO3]). 1 point for this valid method of determining the initial concentration of CO3^{2} from [OH].

Solution 3

(g)

Mark scheme

HCO3 is less than [CO3^{2}]. The small value of Kb (2.1×10 , much less than 1) indicates that the reactants (H2O and CO3^{2}) are favored at equilibrium over the products, so only a small fraction of CO3^{2} hydrolyzes to HCO3 . 1 point for the correct answer (less than) with valid justification.

Solution 3

(h)

Mark scheme

- No, the Na2CO3 solution is not suitable for making a pH-6 buffer. The pKa of HCO3 (the conjugate acid in this $CO3^{2}$ /HCO3 system) is 10.32. A buffer is most effective when the desired pH is close to the pKa of its weak-acid component; pH 6 is far from pKa 10.32, so this system cannot buffer effectively at pH 6. 1 point for the correct answer (no) with a valid explanation referencing pKa.