Past-paper walk-through

Representations of Solutions ▪ 3.8

eXercise

Questions in this set

- 2026 Q6
- 2024 Q7
- 2022 Q3
- 2022 Q6
- 2021 Q3
- 2021 Q6
- 2019 Q3
- 2015 Q4

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 6

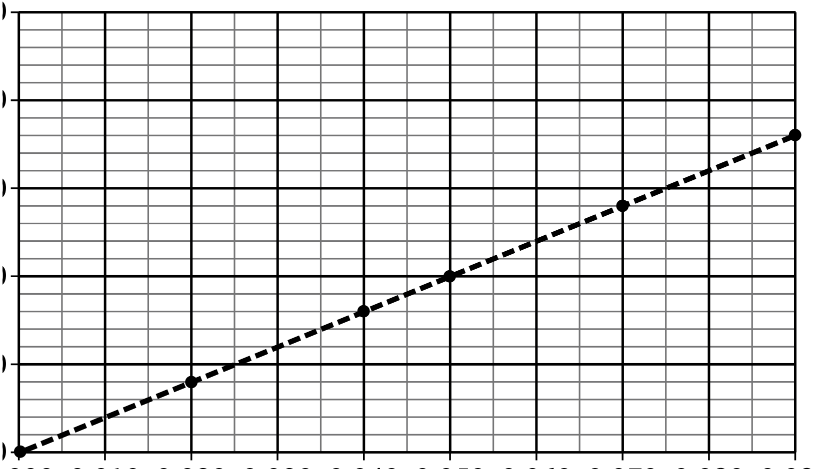
2026 ▪ Q6

A student performs a spectrophotometry experiment with $V^{2+}(aq)$ solutions and produces the calibration curve shown in Figure 1 by measuring the absorbance of several solutions of known concentration.
[Figure 1: Graph of Absorbance vs. Concentration (M); y-axis 0.00 to 0.50 in increments of 0.10, x-axis 0.000 to 0.090 M in increments of 0.010; dashed straight best-fit line through the origin $(0.000, 0.00)$ and points approximately $(0.020, 0.08)$, $(0.040, 0.16)$, $(0.050, 0.20)$, $(0.070, 0.28)$, ending near $(0.090, 0.36)$.]
(a) The student measures an absorbance of 0.32 for a $V^{2+}(aq)$ solution. The concentration of V^{2+} ions in the solution is represented by the particle diagram in the circle in Figure 2. In the circle in Figure 3, **draw** the correct number of V^{2+} ions to represent the concentration of a solution with an absorbance of 0.08. (Water

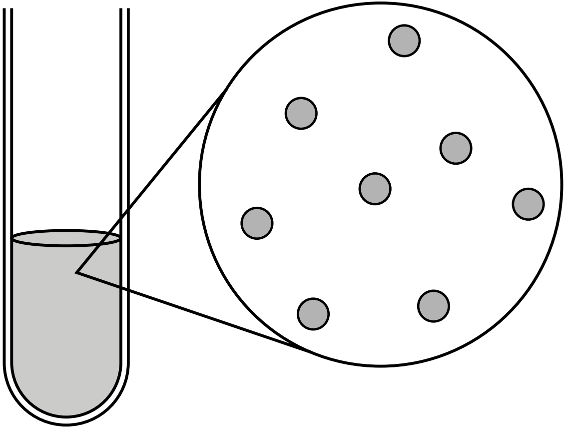
Question 6

molecules have been omitted for clarity. Assume that each particle diagram represents the same volume.)
[Figure 2: A test tube with a magnified circle showing 7 dots labeled V^{2+} ion, scattered inside the circle; captioned "Absorbance = 0.32".]
[Figure 3: A test tube with an empty magnified circle (student draws V^{2+} ions inside), legend "$\circ = V^{2+}$ ion"; captioned "Absorbance = 0.08".]

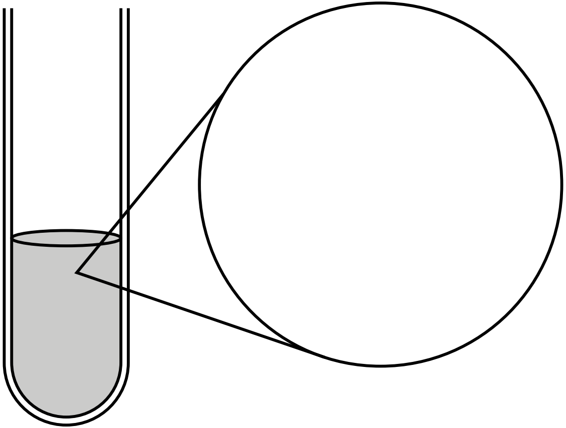
Question 6



Question 6



Question 6



Question 6

2026 ▪ Q6

A student performs a spectrophotometry experiment with $V^{2+}(aq)$ solutions and produces the calibration curve shown in Figure 1 by measuring the absorbance of several solutions of known concentration.

[Figure 1: Graph of Absorbance vs. Concentration (M); y-axis 0.00 to 0.50 in increments of 0.10, x-axis 0.000 to 0.090 M in increments of 0.010; dashed straight best-fit line through the origin $(0.000, 0.00)$ and points approximately $(0.020, 0.08)$, $(0.040, 0.16)$, $(0.050, 0.20)$, $(0.070, 0.28)$, ending near $(0.090, 0.36)$.]

(b)(i) The student measures the absorbance of a different $V^{2+}(aq)$ solution with an unknown molarity, but the absorbance is higher than 0.36 (the upper limit of the graph). The student then transfers 3.00 mL of this $V^{2+}(aq)$ solution to a 25.0 mL volumetric flask, dilutes to the mark on the flask with distilled water, and measures the absorbance of the diluted solution.

Question 6

The absorbance of the diluted solution is 0.22. **Determine** the molarity of $V^{2+}(aq)$ in the diluted solution.

(b)(ii) **Determine** the molarity of $V^{2+}(aq)$ in the original, undiluted solution. Show the work that leads to your answer.

Question 6

2026 ▪ Q6

A student performs a spectrophotometry experiment with $V^{2+}(aq)$ solutions and produces the calibration curve shown in Figure 1 by measuring the absorbance of several solutions of known concentration.

[Figure 1: Graph of Absorbance vs. Concentration (M); y-axis 0.00 to 0.50 in increments of 0.10, x-axis 0.000 to 0.090 M in increments of 0.010; dashed straight best-fit line through the origin $(0.000, 0.00)$ and points approximately $(0.020, 0.08)$, $(0.040, 0.16)$, $(0.050, 0.20)$, $(0.070, 0.28)$, ending near $(0.090, 0.36)$.]

(c) The concentration of $V^{2+}(aq)$ calculated in part B (ii) is lower than the actual concentration of the undiluted solution. The student claims that the calculated concentration is too low because during the dilution step, the final level of the solution was higher than the mark on the volumetric flask. Do you agree or disagree? **Justify** your answer.

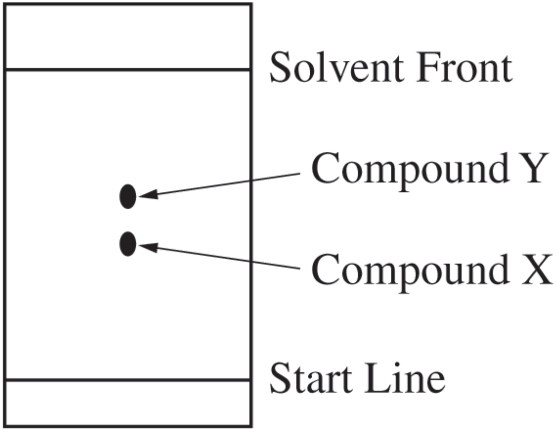
Question 7

2024 ▪ Q7

1. A student conducts a chromatography experiment and needs to prepare 100.0 mL of 0.340 M NaCl(aq) to use as the solvent.

(a) Calculate the mass of solid NaCl (molar mass 58.44 g/mol) needed to prepare the 100.0 mL of 0.340 M NaCl(aq).

Question 7



Question 7

2024 ▪ Q7

1. A student conducts a chromatography experiment and needs to prepare 100.0 mL of 0.340 *M* $NaCl(aq)$ to use as the solvent.

(b) In the following table, briefly list the additional steps necessary to prepare the 100.0 mL of 0.340 *M* $NaCl(aq)$ solution using only materials selected from the choices given. Assume that all appropriate safety measures are already in place. Not all materials in the list may be needed.

Question 7

Materials available: Solid NaCl, Distilled water, Weighing paper and scoop, Balance, 100.0 mL volumetric flask, 50.0 mL graduated cylinder, Pipet, 150 mL beakers, Chromatography paper.

Step	Step Description and Materials Used
1.	Use the weighing paper and scoop to measure the correct mass of solid NaCl on the balance.
2.	________________ (student fills in)
3.	Swirl the mixture to dissolve the solid NaCl.
4.	________________ (student fills in)
5.	Stopper and invert the mixture several times to ensure that the mixture is homogeneous.

Question 7

Fill in steps 2 and 4.

Question 7

2024 ▪ Q7

1. A student conducts a chromatography experiment and needs to prepare 100.0 mL of 0.340 *M* NaCl(*aq*) to use as the solvent.

(c) The student uses the NaCl(*aq*) solvent to separate a mixture of compounds X and Y in a chromatography experiment. After 30 minutes, the student removes the chromatography paper from the chamber. The results of the experiment are shown. [Diagram: a rectangular chromatography-paper strip inside a chamber. From top to bottom: a horizontal line labeled “Solvent Front” near the top; below it, two spot markers close together labeled with arrows — the upper spot labeled “Compound Y” and, just below it, the lower spot labeled “Compound X”; near the bottom, a horizontal line labeled “Start Line”.]

Question 7

A second student conducts the same chromatography experiment but removes the chromatography paper from the chamber after 15 minutes instead of 30 minutes. Predict the effect, if any, this would have on the separation distance between compounds X and Y in the new experiment. Explain your reasoning.

Solution 7

(a)

Mark scheme

- Mass of NaCl needed $= 0.1000\ \text{L} \times \dfrac{0.340\ \text{mol}}{1\ \text{L}} \times \dfrac{58.44\ \text{g}}{1\ \text{mol}} = 1.99\ \text{g NaCl}$.

Solution 7

(b)

Mark scheme

- Step 2: Combine the solid NaCl and some distilled water in a 100.0 mL volumetric flask (to dissolve the solid). Step 4: Fill the volumetric flask with distilled water to the calibration (100.0 mL) mark (bring the solution to its final, precise volume).

Solution 7

(c)

Mark scheme

- The separation between compounds X and Y would decrease: the solvent front will not travel as far up the chromatography paper, so the two spots have less distance/time over which to separate before the paper is removed from the chamber.

Question 3

2022 ▪ Q3

Answer the following questions relating to the element aluminum, Al.

(a) Write the complete ground-state electron configuration of an Al atom.

Question 3

2022 ▪ Q3

Answer the following questions relating to the element aluminum, Al.

(b) Based on principles of atomic structure, explain why the radius of the Al atom is larger than the radius of the Al^{3+} ion.

A student plans to combine solid aluminum with an aqueous solution of silver ions.

The student determines the mass of solid $AgNO_3$ needed to prepare the solution with a specific concentration.

Question 3

2022 ▪ Q3

Answer the following questions relating to the element aluminum, Al.

(c) In the following table, briefly list the steps necessary to prepare 200.0 mL of an aqueous solution of $AgNO_3$ using only equipment selected from the choices given. Assume that all appropriate safety measures are already in place. Not all equipment or lines in the table may be needed.

Available equipment: Solid $AgNO_3$ · Weighing paper and scoop · 250 mL beakers · Distilled water · 200.00 mL volumetric flask · Pipet · Balance · 50.0 mL graduated cylinder

| Step | Step Description | |—|—| | 1. | Use weighing paper to measure the determined mass of solid $AgNO_3$ on a balance. | | 2. | | | | | | | | | | | | | |

Question 3

2022 ▪ Q3

Answer the following questions relating to the element aluminum, Al.

(d) After preparing the solution, the student places some of the solution into a beaker and adds a sample of aluminum. The reaction represented by the following equation occurs.

$$\mathrm{Al}(s) + 3\,\mathrm{Ag}^{+}(aq) \rightarrow \mathrm{Al}^{3+}(aq) + 3\,\mathrm{Ag}(s)$$

The following diagram gives an incomplete particulate representation of the reaction. The beaker on the left represents the system before the mixture reacts. Complete the drawing on the right to represent the system after the reaction has occurred. Be sure to include 1) the correct type and number of particles based on the number shown on the left and 2) the relative spacing to depict the appropriate phases.

Question 3

[Two beaker diagrams side by side connected by a rightward arrow. Left beaker ("before reaction"): shown containing 4 "Al" (shaded circles, representing solid Al atoms clustered at the bottom) and 6 "Ag^+" (open circles, representing dissolved silver ions distributed throughout the liquid). Right beaker ("after reaction," to be completed by the student): shown only with 2 "Al" solid particles remaining at the bottom, with the rest of the beaker left blank for the student to draw in the products. A key box below states: "Al" (shaded circle) = Al atom; "Ag" (open circle) = Ag atom; "Al^{3+}" (circle) = Al^{3+} ion; "Ag^+" (open circle) = Ag^+ ion.]

The student finds the standard reduction potentials given in the table, which are related to the reaction that occurs.

| Half-Reaction | E° | |—|—| | $Ag^+(aq) + e^- \rightarrow Ag(s)$ | 0.80 V | | $Al^{3+}(aq) + 3\,e^- \rightarrow Al(s)$ | -1.66 V |

Question 3

2022 ▪ Q3

Answer the following questions relating to the element aluminum, Al.

(e) Using the standard reduction potentials, calculate the value of E° for the reaction.

Question 3

2022 ▪ Q3

Answer the following questions relating to the element aluminum, Al.

(f) Based on the value of E°, would the standard free energy change of the reaction under standard conditions, ΔG°, be positive, negative, or zero? Justify your answer.

Question 3

2022 ▪ Q3

Answer the following questions relating to the element aluminum, Al.

(g) Once the reaction appears to stop progressing, would the change in free energy, ΔG, be positive, negative, or zero? Justify your answer.

Solution 3

(a)

Mark scheme

- Ground-state electron configuration of Al: $1s^2 2s^2 2p^6 3s^2 3p^1$ (equivalently $[Ne]3s^2 3p^1$).

Solution 3

(b)

Mark scheme

- The highest occupied electron shell (n = 3) of the Al atom is at a greater average distance from the nucleus than the highest occupied electron shell (n = 2) of the Al^{3+} ion, so the Al atom has the larger radius.

Solution 3

(c)

Mark scheme

- Steps to prepare 200.0 mL of AgNO3(aq) solution (may be consolidated): (1 point) partially fill the 200.00 mL volumetric flask with some distilled water; add the weighed solid AgNO3(s) to the volumetric flask; swirl to dissolve the solid. (1 point, correct step for quantitative dilution) after the solid is dissolved, fill the flask to the calibration (200.00 mL) mark and mix.

Solution 3

(d)

Mark scheme

- Particulate drawing of the beaker after $Al(s) + 3Ag^{+}(aq) \rightarrow Al^{3+}(aq) + 3Ag(s)$ reacts (1 point each criterion): conservation of matter — draw 4 Al and 8 Ag particles total (matching the atoms present before reaction, some as product, some as leftover ions); conservation of charge — draw 2 Ag^{+} ions and 2 Al^{3+} ions remaining (i.e., 2 of the 4 Al atoms became Al^{3+}, consuming 6 of the 8 Ag^{+} to form 6 Ag atoms, leaving 2 Ag^{+} unreacted); correct phases of matter — show 6 Ag atoms as solid (clustered together) and 2 Al^{3+} ions as aqueous (dispersed in solution).

Solution 3

(e)

Mark scheme

- $E^\circ = E^\circ red - E^\circ ox = 0.80\ V - (-1.66\ V) = 2.46\ V$ (equivalently $E^\circ = 0.80\ V + 1.66\ V = 2.46\ V$).

Solution 3

(f)

Mark scheme

- Negative. The reaction has a positive value of E°, indicating that it is thermodynamically favorable and would therefore have a negative value of ΔG° ($\Delta G^\circ = -nFE^\circ$).

Solution 3

(g)

Mark scheme

- Zero. Once the reaction stops progressing, the system has reached equilibrium: this implies Ecell $= 0$ (no more driving force for the reaction), and since $\Delta G = -nFEcell$, $\Delta G = 0$ at equilibrium.

Question 6

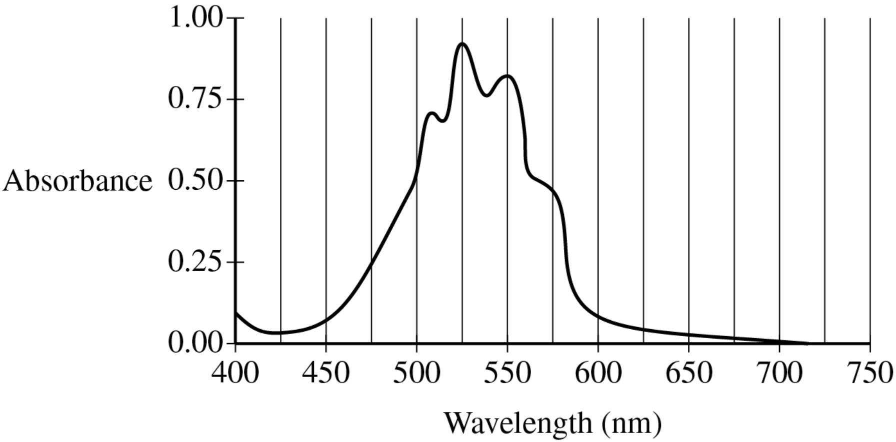
2022 ▪ Q6

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

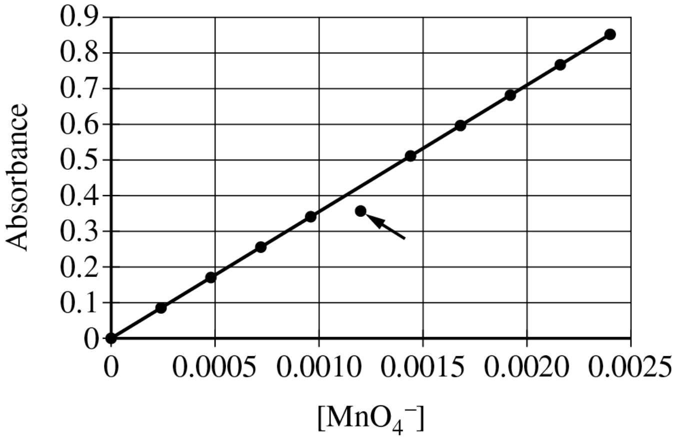
plotted in the graph shown. Identify the optimum wavelength that the student should use for the experimental procedure.

Question 6



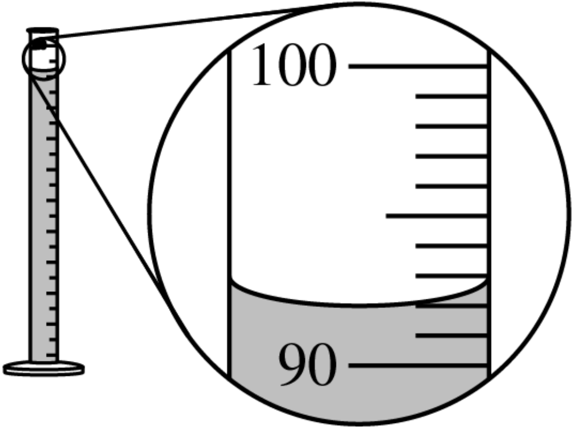
Absorbance
1.00
0.75
0.50
0.25
0.00
400
450
500
550
600
650
700
750
Wavelength (nm)

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
[MnO4−]

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

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

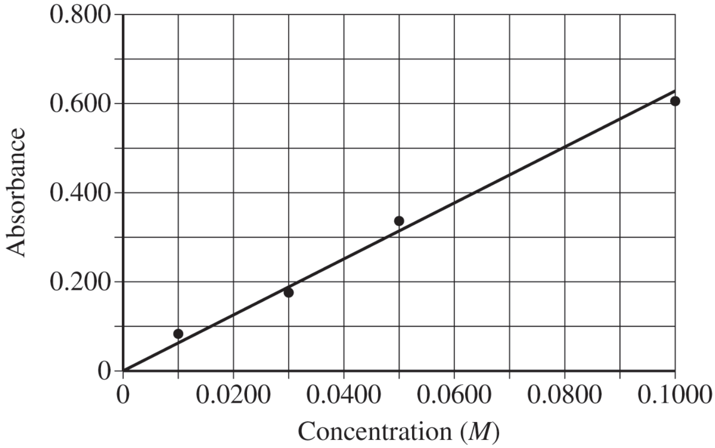
2021 ▪ Q3

A student is given the task of determining the molar concentration of a $CuSO_4$ solution using two different procedures, precipitation and spectrophotometry.
For the precipitation experiment, the student adds 20.0 mL of 0.200 M $Ba(NO_3)_2$ to 50.0 mL of the $CuSO_4(aq)$. The reaction goes to completion, and a white precipitate forms. The student filters the precipitate and dries it overnight. The data are given in the following table.

Mass of dry filter paper	0.764 g
Volume of $CuSO_4(aq)$	50.0 mL
Volume of 0.200 M $Ba(NO_3)_2$	20.0 mL
Mass of filter paper and dried precipitate	1.136 g

(a) Write a balanced net ionic equation for the precipitation reaction.

Question 3


0.800
0.600
0.400
0.200
0
Absorbance
0
0.0200
0.0400
0.0600
0.0800
0.1000
Concentration (M)

Question 3

2021 ▪ Q3

A student is given the task of determining the molar concentration of a $CuSO_4$ solution using two different procedures, precipitation and spectrophotometry.
For the precipitation experiment, the student adds 20.0 mL of 0.200 M $Ba(NO_3)_2$ to 50.0 mL of the $CuSO_4(aq)$. The reaction goes to completion, and a white precipitate forms. The student filters the precipitate and dries it overnight. The data are given in the following table.
| | | |—|—| | Mass of dry filter paper | 0.764 g | | Volume of $CuSO_4(aq)$ | 50.0 mL | | Volume of 0.200 M $Ba(NO_3)_2$ | 20.0 mL | | Mass of filter paper and dried precipitate | 1.136 g |

(b) Calculate the number of moles of precipitate formed.

Question 3

2021 ▪ Q3

A student is given the task of determining the molar concentration of a $CuSO_4$ solution using two different procedures, precipitation and spectrophotometry.
For the precipitation experiment, the student adds 20.0 mL of 0.200 M $Ba(NO_3)_2$ to 50.0 mL of the $CuSO_4(aq)$. The reaction goes to completion, and a white precipitate forms. The student filters the precipitate and dries it overnight. The data are given in the following table.
| | | |—|—| | Mass of dry filter paper | 0.764 g | | Volume of $CuSO_4(aq)$ | 50.0 mL | | Volume of 0.200 M $Ba(NO_3)_2$ | 20.0 mL | | Mass of filter paper and dried precipitate | 1.136 g |

(c) Calculate the molarity of the original $CuSO_4$ solution.

Question 3

2021 ▪ Q3

A student is given the task of determining the molar concentration of a $CuSO_4$ solution using two different procedures, precipitation and spectrophotometry.
For the precipitation experiment, the student adds 20.0 mL of 0.200 M $Ba(NO_3)_2$ to 50.0 mL of the $CuSO_4(aq)$. The reaction goes to completion, and a white precipitate forms. The student filters the precipitate and dries it overnight. The data are given in the following table.

Mass of dry filter paper	0.764 g
Volume of $CuSO_4(aq)$	50.0 mL
Volume of 0.200 M $Ba(NO_3)_2$	20.0 mL
Mass of filter paper and dried precipitate	1.136 g

(d) For the spectrophotometry experiment, the student first makes a standard curve. The student uses a 0.1000 M solution of $CuSO_4(aq)$ to make three more solutions of known concentration (0.0500 M, 0.0300 M, and 0.0100 M) in 50.00 mL volumetric flasks.

Question 3

Calculate the volume of 0.1000 M $CuSO_4(aq)$ needed to make 50.00 mL of 0.0500 M $CuSO_4(aq)$.

Question 3

2021 ▪ Q3

A student is given the task of determining the molar concentration of a $CuSO_4$ solution using two different procedures, precipitation and spectrophotometry.
For the precipitation experiment, the student adds 20.0 mL of 0.200 M $Ba(NO_3)_2$ to 50.0 mL of the $CuSO_4(aq)$. The reaction goes to completion, and a white precipitate forms. The student filters the precipitate and dries it overnight. The data are given in the following table.

Mass of dry filter paper	0.764 g
Volume of $CuSO_4(aq)$	50.0 mL
Volume of 0.200 M $Ba(NO_3)_2$	20.0 mL
Mass of filter paper and dried precipitate	1.136 g

(e) Briefly describe the procedure the student should follow to make 50.00 mL of 0.0500 M $CuSO_4(aq)$ using 0.1000 M $CuSO_4(aq)$, a 50.00 mL volumetric flask, and other standard laboratory equipment. Assume that all appropriate safety precautions will be taken.

Question 3

2021 ▪ Q3

A student is given the task of determining the molar concentration of a $CuSO_4$ solution using two different procedures, precipitation and spectrophotometry.
For the precipitation experiment, the student adds 20.0 mL of 0.200 M $Ba(NO_3)_2$ to 50.0 mL of the $CuSO_4(aq)$. The reaction goes to completion, and a white precipitate forms. The student filters the precipitate and dries it overnight. The data are given in the following table.
| | | |—|—| | Mass of dry filter paper | 0.764 g | | Volume of $CuSO_4(aq)$ | 50.0 mL | | Volume of 0.200 M $Ba(NO_3)_2$ | 20.0 mL | | Mass of filter paper and dried precipitate | 1.136 g |

(f) The standard curve is given below.
[Graph: Absorbance (y-axis, 0 to 0.800, gridlines every 0.200) vs. Concentration (M) (x-axis, 0 to 0.1000, gridlines every 0.0200). Four data points plotted approximately at (0.0100, 0.090), (0.0300, 0.190), (0.0500, 0.330), and (0.1000, 0.610), with a best-fit straight line drawn through them from near the origin up through the highest point.]

Question 3

The absorbance of the $CuSO_4$ solution of unknown concentration is 0.219. Determine the molarity of the solution.

Question 3

2021 ▪ Q3

A student is given the task of determining the molar concentration of a $CuSO_4$ solution using two different procedures, precipitation and spectrophotometry.
For the precipitation experiment, the student adds 20.0 mL of 0.200 M $Ba(NO_3)_2$ to 50.0 mL of the $CuSO_4(aq)$. The reaction goes to completion, and a white precipitate forms. The student filters the precipitate and dries it overnight. The data are given in the following table.

Mass of dry filter paper	0.764 g
Volume of $CuSO_4(aq)$	50.0 mL
Volume of 0.200 M $Ba(NO_3)_2$	20.0 mL
Mass of filter paper and dried precipitate	1.136 g

(g) A second student performs the same experiment. There are a few drops of water in the cuvette before the second student adds the $CuSO_4(aq)$ solution of unknown concentration. Will this result in a $CuSO_4(aq)$ concentration for the unknown that is greater than, less than, or equal to the concentration determined in part (f)? Justify your answer.

Solution 3

(a)

Mark scheme

- $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$ (state symbols not required).

Solution 3

(b)

Mark scheme

- Mass of precipitate (may be implicit) $= 1.136\text{ g} - 0.764\text{ g} = 0.372\text{ g}$ $BaSO_4$ (1 pt, filter+dry mass minus filter mass). Moles $= 0.372\text{ g} \times \dfrac{1\text{ mol}}{233.39\text{ g}} = 0.00159\text{ mol}$ $BaSO_4$ (1 pt, consistent with the calculated mass).

Solution 3

(c)

Mark scheme

- Since BaSO4 and CuSO4 react 1:1, moles CuSO4 = moles BaSO4 = 0.00159 mol (consistent with part b). Molarity $= \dfrac{0.00159 \text{ mol } \mathrm{CuSO_4}}{0.0500 \text{ L}} = 0.0318\ M$ (0.0319 M if decimals are carried through).

Solution 3

(d)

Mark scheme

- Using the dilution equation $M_1V_1 = M_2V_2$:
  $V_1 = \dfrac{(0.0500\ M)(50.00\ \text{mL})}{0.1000\ M} = 25.0$ mL of the 0.1000 M CuSO4 stock needed.

Solution 3

(e)

Mark scheme

- Correct technique to measure the volume (1 pt): use a 25.0 mL volumetric pipet (a graduated cylinder or buret is also acceptable) to measure out 25.0 mL of the 0.1000 M CuSO4(aq) stock solution. Correct technique to dilute (1 pt): transfer that 25.0 mL of solution into a 50.00 mL volumetric flask and add water up to the calibration mark to bring the total volume to 50.00 mL.

Solution 3

(f)

Mark scheme

- Reading the standard curve's best-fit line, slope $m \approx \dfrac{0.63}{0.1000} = 6.3$ (absorbance per M). Using $y = mx$ with $y = 0.219$: $x = \dfrac{0.219}{6.3} = 0.035\ M$. Any value obtained by correctly reading the graph or by calculation, between 0.032 M and 0.038 M, earns credit.

Solution 3

(g)

Mark scheme

- The measured concentration will be less than that determined in part (f) (1 pt). Justification (1 pt): the leftover water drops in the cuvette dilute the CuSO4(aq) solution of unknown concentration before its absorbance is measured; by the Beer-Lambert law ($A = \varepsilon bc$), a lower concentration gives a lower absorbance, and reading that lower absorbance off the standard curve yields a lower (artificially low) estimated concentration than the true value.

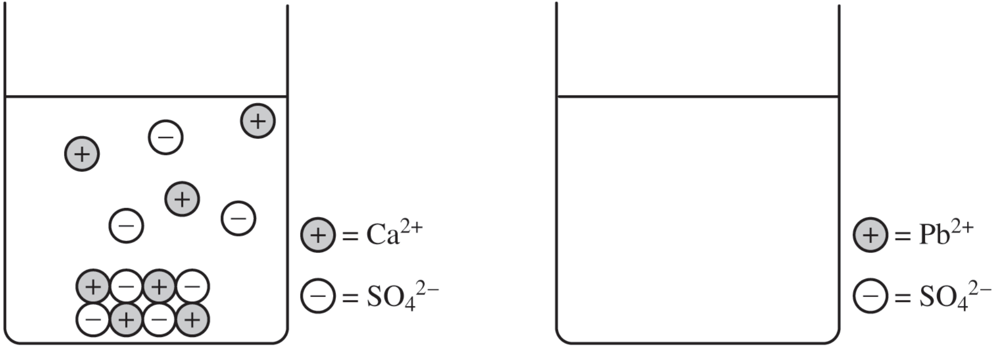
Question 6

2021 ▪ Q6

A student is studying the properties of $CaSO_4$ and $PbSO_4$. The student has samples of both compounds, which are white powders.

(a) The student tests the electrical conductivity of each solid and observes that neither solid conducts electricity. Describe the structures of the solids that account for their inability to conduct electricity.

Question 6



Higher Conductivity Solution

Lower Conductivity Solution

Question 6

2021 ▪ Q6

A student is studying the properties of $CaSO_4$ and $PbSO_4$. The student has samples of both compounds, which are white powders.

(b) The student places excess $CaSO_4(s)$ in a beaker containing 100 mL of water and places excess $PbSO_4(s)$ in another beaker containing 100 mL of water. The student stirs the contents of the beakers and then measures the electrical conductivity of the solution in each beaker. The student observes that the conductivity of the solution in the beaker containing the $CaSO_4(s)$ is higher than the conductivity of the solution in the beaker containing the $PbSO_4(s)$.

Which compound is more soluble in water, $CaSO_4(s)$ or $PbSO_4(s)$? Justify your answer based on the results of the conductivity test.

Question 6

2021 ▪ Q6

A student is studying the properties of $CaSO_4$ and $PbSO_4$. The student has samples of both compounds, which are white powders.

(c) The left side of the diagram below shows a particulate representation of the contents of the beaker containing the $CaSO_4(s)$ from the solution conductivity experiment.

[Diagram: two beakers side by side, each containing liquid. Left beaker, labeled "Higher Conductivity Solution": scattered small circles marked "+" (labeled Ca^{2+}) and "−" (labeled SO_4^{2-}) floating individually in the liquid (several of each, dispersed), plus a small cluster of undissolved solid at the bottom made of alternating "+" and "−" circles packed together. Right beaker, labeled "Lower Conductivity Solution": empty/blank, to be filled in by the student, with the same legend $+ = Pb^{2+}$, $- = SO_4^{2-}$.]

Question 6

Draw a particulate representation of $PbSO_4(s)$ and the ions dissolved in the solution in the beaker on the right in the diagram. Draw the particles to look like those shown to the right of the beaker. Draw an appropriate number of dissolved ions relative to the number of dissolved ions in the beaker on the left.

Question 6

2021 ▪ Q6

A student is studying the properties of $CaSO_4$ and $PbSO_4$. The student has samples of both compounds, which are white powders.

(d) The student attempts to increase the solubility of $CaSO_4(s)$ by adding 10.0 mL of 2 M $H_2SO_4(aq)$ to the beaker, and observes that additional precipitate forms in the beaker. Explain this observation.

Solution 6

(a)

Mark scheme

- Ionic solids do not have free-moving (mobile) ions — the ions are locked in fixed positions within the rigid crystal lattice — so there are no charge carriers able to move through the solid. Therefore there is no conduction of electricity.

Solution 6

(b)

Mark scheme

- $CaSO_4$. The greater electrical conductivity of the $CaSO_4(aq)$ solution relative to the $PbSO_4(aq)$ solution implies a higher concentration of dissolved ions, which comes from $CaSO_4$ dissolving/dissociating to a greater extent than $PbSO_4$ — i.e., $CaSO_4$ is more soluble than $PbSO_4$.

Solution 6

(c)

Mark scheme

- The particulate diagram for the (lower-conductivity) $PbSO_4$ beaker should show solid $PbSO_4$ undissolved at the bottom (drawn similarly to the solid $CaSO_4$ shown in the higher-conductivity beaker), together with fewer dissociated Pb^{2+} and SO_4^{2-} ions dispersed in the solution than are shown in the $CaSO_4$ beaker — reflecting $PbSO_4$'s lower solubility — while still showing an equal number of Pb^{2+} cations and SO_4^{2-} anions in solution (1:1 stoichiometry / charge balance).

Solution 6

(d)

Mark scheme

- The additional precipitate is CaSO4 that forms in response to the increased [SO4^2-] introduced by the added H2SO4(aq). By Le Chatelier's principle (the reaction quotient Q now exceeds Ksp), the added common ion SO4^2- shifts the dissolution equilibrium of CaSO4 toward the solid, forming more CaSO4(s) — the common-ion effect.

Question 3

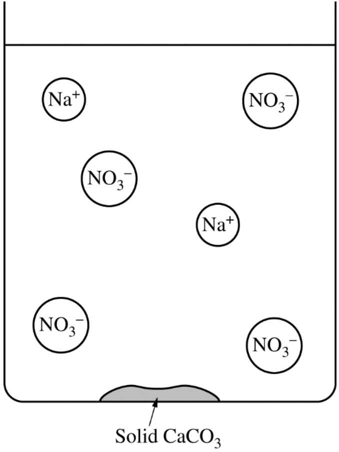
2019 ▪ Q3

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 $[OH^-] = 10\hat{}(-\text{pOH})$. 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 $= (x^2/\text{Kb}) + x$ 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^{-4}, 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

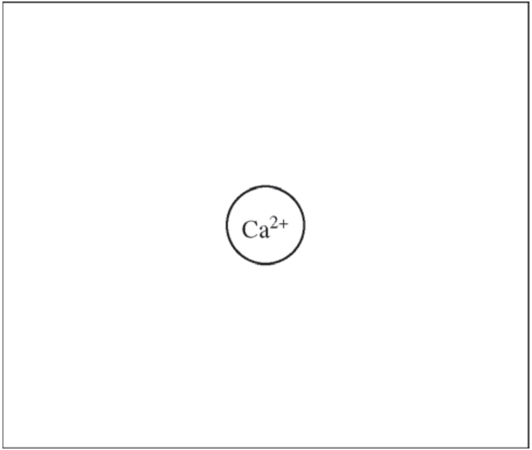
- No, the Na2CO3 solution is not suitable for making a pH-6 buffer. The pKa of $HCO3^{-}$ (the conjugate acid in this $CO3^{2-}/HCO3^{-}$ system) is 10.32. A buffer is most effective when the desired pH is close to the pKa of its weak-acid component; pH 6 is far from pKa 10.32, so this system cannot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

Question 4

2015 ▪ Q4

Answer the following questions about the solubility of $Ca(OH)_2$ ($K_{sp} = 1.3 \times 10^{-6}$).
(a) Write a balanced chemical equation for the dissolution of $Ca(OH)_2(s)$ in pure water.
(b) Calculate the molar solubility of $Ca(OH)_2$ in 0.10 *M* $Ca(NO_3)_2$.
(c) In the box below, complete a particle representation diagram that includes four water molecules with proper orientation around the Ca^{2+} ion.
Represent water molecules as a bent (V-shaped) two-circle symbol representing the two hydrogen atoms attached to a central oxygen.
[A square box containing a circle labeled Ca^{2+} at its center, for the student to add four correctly-oriented water-molecule symbols around it.]

Question 4



Solution 4

(a)

Mark scheme

- Ca(OH)2(s) <-> Ca2+(aq) + 2 OH-(aq). 1 point for the correct balanced dissolution equation.

Solution 4

(b)

Mark scheme

- Ksp = [Ca2+][OH-]^2 = 1.3x10^-6. Let x = molar solubility of Ca(OH)2 in the presence of 0.10 M Ca(NO3)2 (common-ion effect): 1.3x10^-6 = (0.10+x)(2x)^2 ~ (0.10)(4x^2), assuming x << 0.10 (1 point for the correct stoichiometry and setup, including the common-ion approximation). Solving: 1.3x10^-5 = 4x^2, x = 0.0018 M. Molar solubility of Ca(OH)2 = 0.0018 M (1 point for the correct final numeric answer).

Solution 4

(c)

Mark scheme

- The particle diagram should show at least three of the four bent (V-shaped) water molecules correctly oriented around the central Ca2+ ion, with the oxygen (partial-negative/lone-pair) side of each water molecule pointing toward the positively charged Ca2+ ion (i.e., the two hydrogens point outward, away from the ion). 1 point for a diagram meeting this criterion.