Past-paper walk-through

Beer-Lambert Law ▪ 3.13

eXercise

Questions in this set

- 2026 Q6
- 2022 Q6
- 2021 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 6

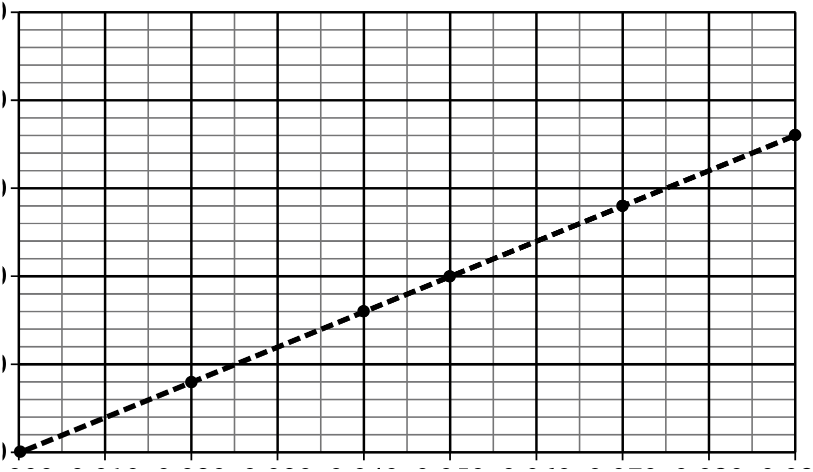
2026 ▪ Q6

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 " = V^2 ion"; captioned "Absorbance = 0.08".]

Question 6



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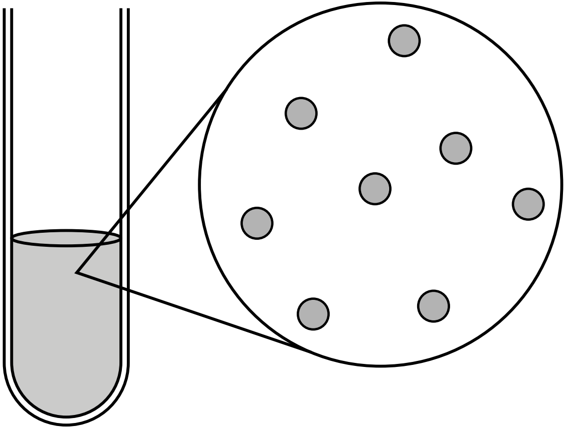
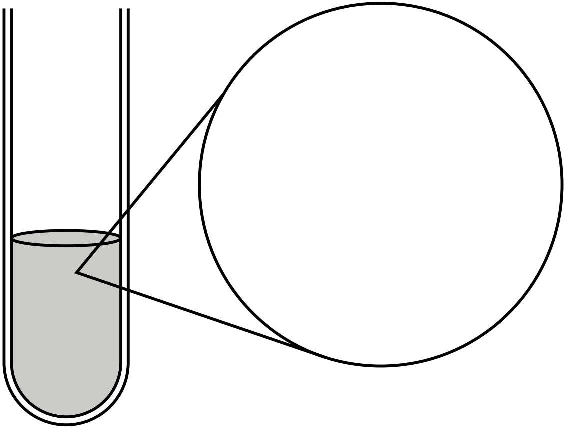


Question 6



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.

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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.

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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 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

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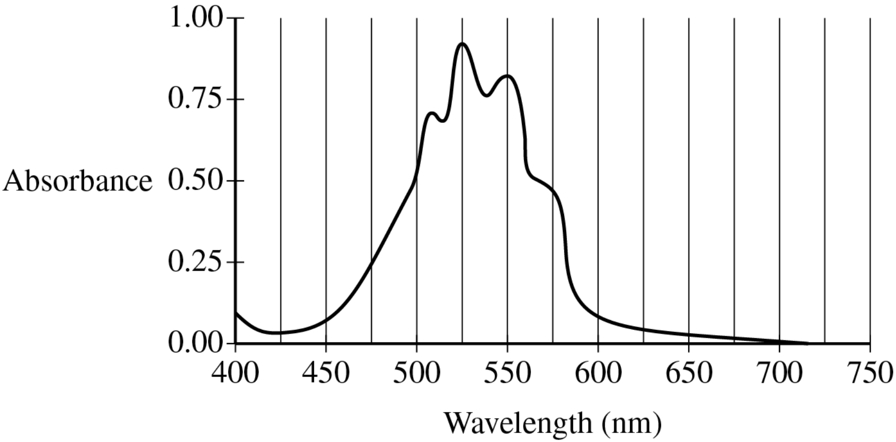
plotted in the graph shown. Identify the optimum wavelength that the student should use for the experimental procedure.

Question 6



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

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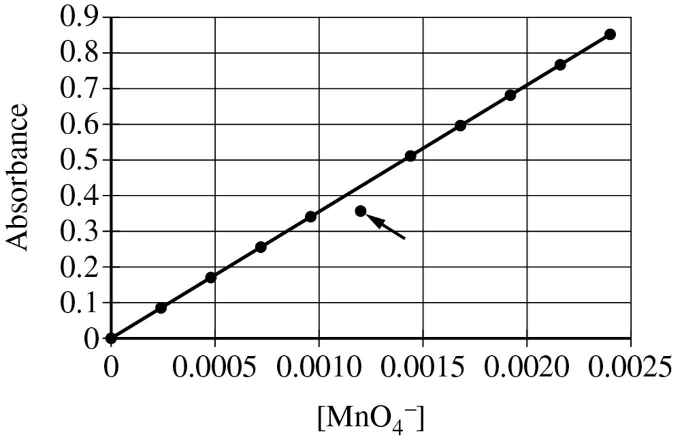

Absorbance
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.0005
0.0010
0.0015
0.0020
0.0025
[MnO4−]

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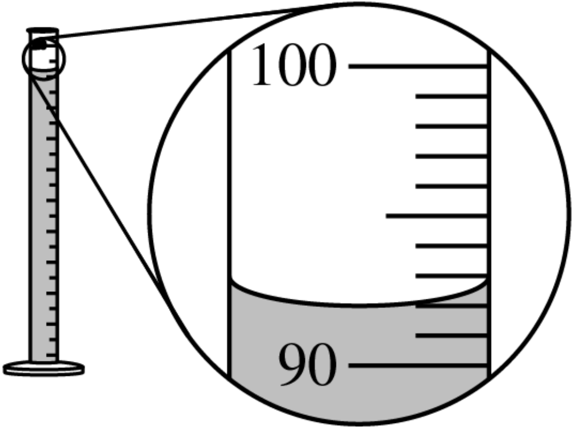

Question 6

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.

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[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 $2.40 \times 10^{\ 3}$ 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

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

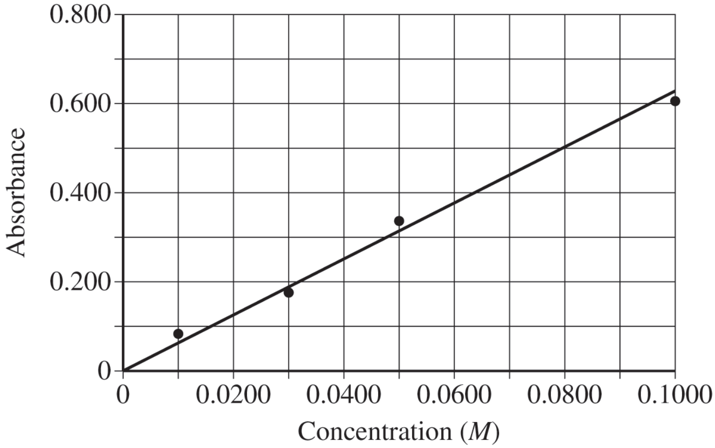
A student is given the task of determining the molar concentration of a $CuSO_4$ solution using two different procedures, precipitation and spectrophotometry.

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.
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| | | |—|—| | 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 = $\frac{0.00159 \text{ mol CuSO}_4}{0.0500 \text{ L}} = 0.0318\ M$ (0.0319 M if decimals are carried through).

Solution 3

(d)

Mark scheme

- Using the dilution equation $M_1 V_1 = M_2 V_2$:
  $V_1 = \dfrac{(0.0500\ M)(50.00\ \text{mL})}{0.1000\ M} = 25.0$ 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 ($A = bc$), 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.