2021

AP® CollegeBoard

AP® Chemistry

Sample Student Responses and Scoring Commentary

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Free Response Question 3

- ☑ **Scoring Guideline**
- ☑ **Student Samples**
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Question 3: Long Answer — 10 points

(a) For the correct balanced equation (state symbols not required): **1 point**

$$Ba^{2+}(aq) + SO_4{}^{2-}(aq) \rightarrow BaSO_4(s)$$

(b) For the correct calculated value of the mass of precipitate (may be implicit): **1 point**

$$1.136\ \text{g} - 0.764\ \text{g} = 0.372\ \text{g}\ BaSO_4$$

For the correct calculated value of the number of moles, consistent with mass of precipitate: **1 point**

$$0.372\ \text{g} \times \frac{1\ \text{mol}}{233.39\ \text{g}} = 0.00159\ \text{mol}$$

Total for part (b) 2 points

(c) For the correct calculated value, consistent with part (b): **1 point**

$$0.00159\ \text{mol}\ BaSO_4 \times \frac{1\ \text{mol}\ CuSO_4}{1\ \text{mol}\ BaSO_4} = 0.00159\ \text{mol}\ CuSO_4$$

$$\frac{0.00159\ \text{mol}\ CuSO_4}{0.0500\ \text{L}} = 0.0318\ M\ CuSO_4$$ *(0.0319 M if decimals are carried)*

(d) For the correct calculated value: **1 point**

$$M_1V_1 = M_2V_2$$

$$V_1 = \frac{(0.0500\ M)(50.00\ \text{mL})}{(0.1000\ M)} = 25.0\ \text{mL}$$

(e) For a correct technique to measure the volume of solution: **1 point**

First, measure out the correct volume of 0.1000 M $CuSO_4$ solution with a 25.0 mL volumetric pipet (graduated cylinder or buret is acceptable).

For a correct technique to dilute the solution to the final volume: **1 point**

Transfer the 25.0 mL of solution to a 50.00 mL volumetric flask and dilute the solution with water up to the 50.00 mL mark.

Total for part (e) 2 points

(f) For the correct value (between 0.032 *M* and 0.038 *M*): **1 point**

Accept one of the following:

- $y = mx = \frac{0.63}{0.1000}x = 6.3x$

  $x = \frac{y}{6.3} = \frac{0.219\ M}{6.3} = 0.035\ M$
- *Estimated value from the graph within the specified range.*

(g)	For the correct answer: *The concentration will be <u>less than</u> that determined in part (f).*	**1 point**
	For a valid justification: *The additional water will decrease the concentration of $CuSO_4$ in the cuvette. Therefore, there will be a decrease in absorbance (according to the Beer-Lambert law). This dilution results in a lower estimated concentration of $CuSO_4$.*	**1 point**
	Total for part (g)	**2 points**
	Total for question 3	**10 points**

Begin your response to **QUESTION 3** on this page.

3. 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.

$Ba^{2+}_{(aq)} + SO_4^{2-}{}_{(aq)} \leftrightarrow BaSO_{4(s)}$

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

$(1.136 - 0.764)\,g\ BaSO_4 \left(\frac{1\ mol\ BaSO_4}{233.39\ g\ BaSO_4}\right) = 0.00159\ moles\ BaSO_4$

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

$0.00159\ moles\ BaSO_4 \rightarrow 0.00159\ moles\ CuSO_4$

$\frac{0.00159\ moles\ CuSO_4}{0.050\ L\ CuSO_4} = 0.0318\ M\ CuSO_4$

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Continue your response to **QUESTION 3** on this page.

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.

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

$M_1V_1 = M_2V_2$

$x\ mL \cdot 0.1000\ M\ CuSO_{4(aq)} = 50.00\ mL \cdot 0.0500\ M\ CuSO_4$

$x\ mL = \boxed{25.00\ mL}$

(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.

Using a graduated cylinder, the student should measure out 25.0 mL of 0.1000 M $CuSO_{4(aq)}$. He or she should then pour this into the volumetric flask. Next, the student should carefully fill up the volumetric flask to the 50.00 mL mark, using deionized water, using a pipette towards the end to ensure accuracy. The student should be gently swirling the flask to make sure the solution is evenly mixed.

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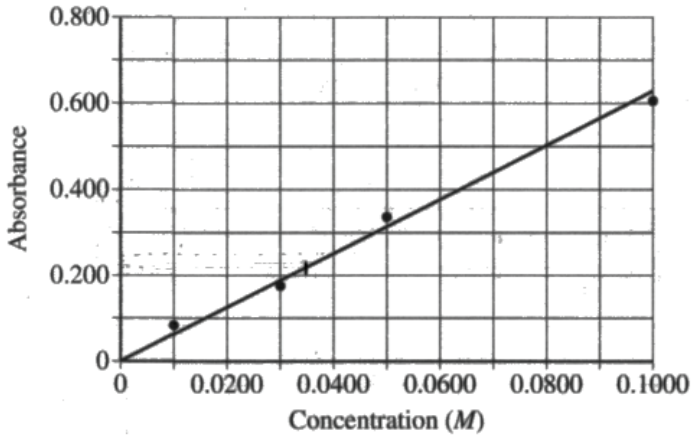
Continue your response to **QUESTION 3** on this page.

The standard curve is given below.



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

0.0350M $CuSO_{4(aq)}$

(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.

Less than. The $CuSO_{4(aq)}$ solution put in the cuvette will be slightly diluted, resulting in a lower measured absorbance & lower concentration determined. than part F.

Begin your response to **QUESTION 3** on this page.

3. 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.

$Ba^{2+} + SO_4^{2-} \rightarrow BaSO_4$

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

1.136g
- .764g
.372g $BaSO_4 \cdot \frac{1\ mol\ BaSO_4}{233.39\ g} = 1.59 \times 10^{-3}\ mol\ BaSO_4$

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

$1.59 \times 10^{-3}\ mol\ BaSO_4 \cdot \frac{1\ mol\ CuSO_4}{1\ mol\ BaSO_4} = \frac{1.59 \times 10^{-3}\ mol\ CuSO_4}{.050\ L}$

$= .0318\ M$

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Continue your response to **QUESTION 3** on this page.

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.

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

$(.1M)(V) = (50mL)(.05M)$

$25\ mL = V$

(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.

The student should measure 25 mL of distilled water in a graduated cylinder. Then add a couple mL of water to a 50mL beaker. Then add the .1M to the beaker follow by the rest of the distilled water, and swirl the solution. This will make 50mL of .05M $CuSO_4$.

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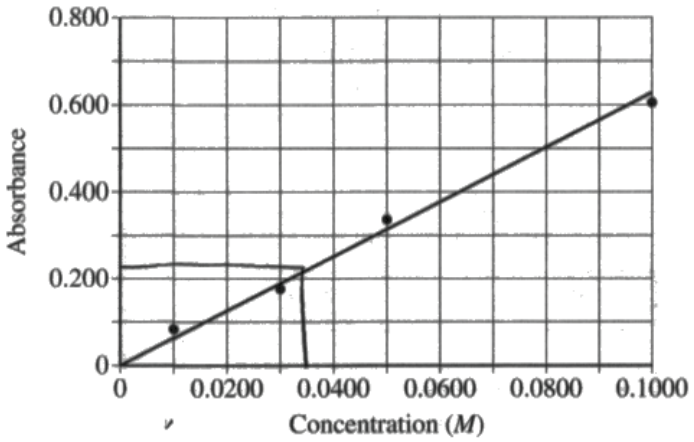
Continue your response to **QUESTION 3** on this page.

The standard curve is given below.



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

The concentration is about .034M.

(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. The concentration will be less than the concentration ([ ]) in f. This is because the added drops of water will diulted the solution, which will allow more light to go through the curvette. This ↓ the absorbance, which will decrease the [ ] because there are the same amount of moles in a larger volume.

Begin your response to **QUESTION 3** on this page.

3. 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

$Ba(NO_3)_2$ $CuSO_4$

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

$Ba + SO_4 \rightarrow BaSO_4(s)$

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

$1.136\ g - 0.764\ g = 0.372\ g$

$0.372\ g \left(\frac{1\ mol\ BaSO_4}{233.39\ g}\right) = 1.59 \times 10^{-3}\ mol\ BaSO_4$

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

$M_1V_1 = M_2V_2$

$0.200\ M\ (0.0200\ L) = M_2\ (0.0500\ L)$

$M_2 = \frac{0.200\ (0.0200)}{0.0500}$

$8.00 \times 10^{-2}\ M\ CuSO_4$

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Continue your response to **QUESTION 3** on this page.

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.

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

$M_1 V_1 = M_2 V_2$

$0.1000\,M\,(V_1) = 0.0500\,M\,(0.05000\,L)$

$V = 0.0250\,L\ CuSO_4$

(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.

1. Calculate the amount of $CuSO_4$ required
2. Measure the volume of $CuSO_4$ using

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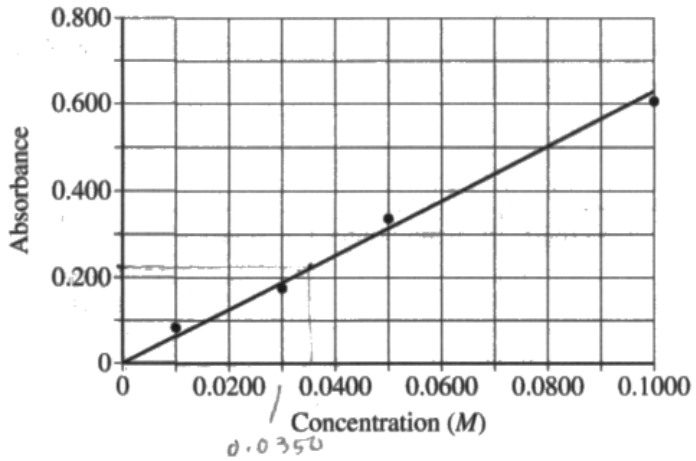
Continue your response to **QUESTION 3** on this page.

The standard curve is given below.



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

$[CuSO_4] = 0.03500M$

(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.

Less. The water will dilute the $CuSO_4(aq)$ solution, thus the absorbance will be less, and the measured concentration will be less than the concentration determined in part f.

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Question 3

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

Question 3 illustrates two different methods for determining the concentration of $CuSO_4$ in an aqueous solution: gravimetric analysis and spectrophotometry. The student begins in part (a) by providing the net ionic equation for the precipitation of $BaSO_4$ (TRA-1.B, 5.E) followed by calculating the number of moles of precipitate that formed, based upon a data table. Part (b) is worth two points: the first for calculating the mass of the precipitate (SPQ-1.A, 5.F) and the second for calculating the number of moles of $BaSO_4$ (SPQ-4.A, 5.F). This information is used in part (c) to calculate the molarity of the original $CuSO_4$ solution (SPQ-3.A, 5.F).

The spectrophotometry experiment begins with the creation of a calibration curve using samples of $CuSO_4(aq)$ of known concentration that are created by diluting a stock solution. The volume of stock solution required to reach a target volume and concentration is calculated in part (d) (SPQ-3.A, 5.F), and then in part (e) the student writes a brief experimental procedure for preparing that solution (two points; both SPQ-3.A, 2.C). The calibration curve is shown in a graph and then used in part (f) to determine the concentration of a solution of $CuSO_4$ based upon its absorbance (SAP-8.C, 5.D). Part (g) is a two-point question about the effect of residual water inside the cuvette; the first point is awarded for predicting that the measured concentration will be less than the actual concentration (SAP-8.C, 6.A) and the second point is for a valid justification (SAP-8.C, 6.G).

Sample: 3A
Score: 10

This response earned 10 points. In part (a) 1 point was earned for the correct net ionic equation. Part (b) earned 2 points; the first point was earned for the correct use of values from the data table to calculate the mass of the precipitate and the second point was earned for the correct number of moles of precipitate reported to the correct number of significant digits. Part (c) earned 1 point for calculating the correct molarity. Part (d) earned 1 point for calculating the correct volume for the dilution. Part (e) earned 2 points; the first point was earned for correctly measuring the volume using a graduated cylinder and the second point was earned for adding distilled water to the 50.0 mL mark on the volumetric flask. Part (f) earned 1 point for giving a concentration within the acceptable range. Part (g) earned 2 points; the first point was earned for the claim “Less than” and the second point was earned for a valid justification.

Sample: 3B
Score: 8

This response earned 8 points. In part (a) 1 point was earned for the correct net ionic equation. Part (b) earned 2 points; the first point was earned for the correct use of values from the data table to calculate the mass of the precipitate and the second point was earned for the correct moles of precipitate reported to the correct number of significant digits. Part (c) earned 1 point for the correct molarity. Part (d) earned 1 point for the correct volume for the dilution (significant figures were not assessed on this part). Part (e) earned 0 points; the first point was not earned because 25 mL of water (instead of the solution) is measured with a graduated cylinder and the second point was not earned because the solution and more water are added to the 50 mL beaker instead of to the volumetric flask. Part (f) earned 1 point for giving a concentration within the acceptable range. Part (g) earned 2 points; the first point was earned for the claim “less than” and the second point was earned for a valid justification.

Question 3 (continued)

Sample: 3C
Score: 6

This response earned 6 points. Part (a) earned 0 points because the charges are not included on the ions in the net ionic equation. Part (b) earned 2 points; the first point was earned for the correct use of values from the data table to calculate the mass of the precipitate and the second point was earned for the correct number of moles of precipitate reported to the correct number of significant digits. Part (c) earned 0 points for incorrectly using the volume and concentration of barium nitrate (the excess reagent) to calculate molarity. Part (d) earned 1 point for the correct volume for the dilution. Part (e) earned 0 points; the first point was not earned because an appropriate measuring instrument is not chosen, and the second point was not addressed. Part (f) earned 1 point for giving a concentration within the acceptable range. Part (g) earned 2 points; the first point was earned for the claim “Less” and the second point was earned for a valid justification.