2019

AP® CollegeBoard

AP® Chemistry

Sample Student Responses and Scoring Commentary

Inside:

Free Response Question 3

☑ Scoring Guideline

☑ Student Samples

☑ Scoring Commentary

Question 3

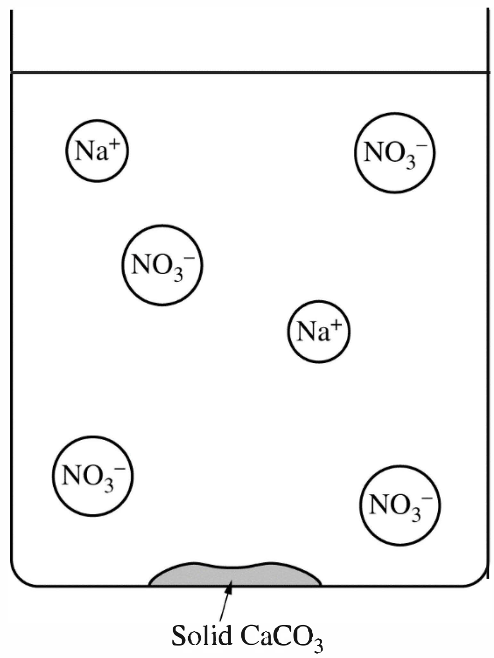
A student is given 50.0 mL of a solution of Na_2CO_3 of unknown concentration. To determine the concentration of the solution, the student mixes the solution with excess 1.0 M $Ca(NO_3)_2(aq)$, causing a precipitate to form. The balanced equation for the reaction is shown below.

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

(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.

$Ca^{2+}(aq) + CO_3^{2-}(aq) \rightarrow CaCO_3(s)$	1 point is earned for the correct equation.

(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.



The drawing shows one Ca^{2+} ion.	1 point is earned for drawing a Ca^{2+} ion.

Question 3 (continued)

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

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

$0.93\text{ g }CaCO_3 \times \frac{1\text{ mol }CaCO_3}{100.1\text{ g}} = 0.0093\text{ mol }CaCO_3$ $0.0093\text{ mol }CaCO_3 \times \frac{1\text{ mol }Na_2CO_3}{1\text{ mol }CaCO_3} = 0.0093\text{ mol }Na_2CO_3$	1 point is earned for the correct answer.

(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.

Disagree. The presence of water in the solid will cause the measured mass of the precipitate to be greater than the actual mass of $CaCO_3$. As a result, the calculated number of moles of $CaCO_3$ and moles of Na_2CO_3 will be greater than the actual moles present. Therefore the calculated concentration of $Na_2CO_3(aq)$ will be too high.	1 point is earned for the correct answer with valid justification.

(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.

The liquid conducts electricity because ions ($Na^+(aq)$, $Ca^{2+}(aq)$, and $NO_3^-(aq)$) are present in the solution.	1 point is earned for the correct answer with valid justification.

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.

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

Question 3 (continued)

(f) The student decides to first determine $[OH^-]$ in the solution, then use that result to calculate the initial concentration of $CO_3^{2-}(aq)$.

(i) Identify a laboratory method (not titration) that the student could use to collect data to determine $[OH^-]$ in the solution.

Determine the pH of the solution using a pH meter.	1 point is earned for identifying a valid method.

(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.)

First determine $[OH^-]$ using $pOH = 14 - pH$, then $[OH^-] = 10^{-pOH}$.

1 point is earned for a valid method of determining $[OH^-]$ from the measured value.

Then, use the K_b expression and an ICE table (see example below) to determine $[CO_3^{2-}]$ and $[HCO_3^-]$ at equilibrium. The initial concentration of CO_3^{2-}, c_i, is equal to the sum of the equilibrium concentrations of CO_3^{2-} and HCO_3^-.

	$CO_3^{2-}(aq)$	$+ \ H_2O(l)$	$\rightleftarrows$	$HCO_3^-(aq)$	$+ \ OH^-(aq)$
I	c_i	---		0	0
C	$-x$	---		$+x$	$+x$
E	$c_i - x$	---		x	x

$$K_b = \frac{(x)(x)}{c_i - x} \quad \Rightarrow \quad c_i = \frac{(x)(x)}{K_b} + x$$

1 point is earned for a valid method of determining the initial concentration of CO_3^{2-}.

(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.

Less than. The small value of K_b, 2.1×10^{-4}, indicates that the reactants are favored.	1 point is earned for the correct answer with a valid justification.

(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.

No, the Na_2CO_3 solution is not suitable. The pK_a of HCO_3^- is 10.32. Buffers are effective when the required pH is approximately equal to the pK_a of the weak acid. An acid with a pK_a of 10.32 is not appropriate to prepare a buffer with a pH of 6.	1 point is earned for the correct answer with a valid explanation.

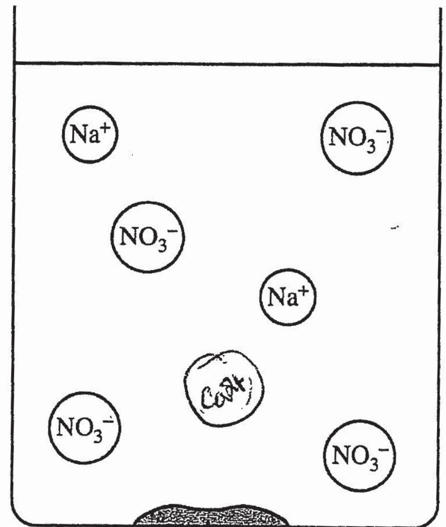
3A 1 of 3

3. 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.

(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.



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

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

(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.

(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.

GO ON TO THE NEXT PAGE.

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.

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

(f) The student decides to first determine $[OH^-]$ in the solution, then use that result to calculate the initial concentration of $CO_3^{2-}(aq)$.

(i) Identify a laboratory method (not titration) that the student could use to collect data to determine $[OH^-]$ in the solution.

(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.)

→ (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.

→ (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.

a) $CO_3^{2-}(aq) + Ca^{2+}(aq) \rightarrow CaCO_3(s)$

(~~2Na⁺~~ $+ CO_3^{2-} + Ca^{2+} +$ ~~2NO₃⁻~~ $\rightarrow CaCO_3 +$ ~~2Na⁺ + 2NO₃⁻~~)

c) $.93\text{g } CaCO_3 \cdot \frac{\text{mol}}{100.1\text{g}} = 9.3 \times 10^{-3} \text{ mol } CaCO_3 = 9.3 \times 10^{-3} \text{ mol } Na_2CO_3$

d) No, if the precipate was not completely dried, ~~a the~~ when ~~it~~ the $CaCO_3$ was massed, ~~it woul~~ it ~~would been~~ would have been recorded that there was a higher mass, ~~would have been recorded in~~ in $CaCO_3$ in reality ~~reality~~. A mass of $CaCO_3$ that's too high would lead to a higher # of moles calculated of Na_2CO_3, which would ultimately lead to a calculated Na_2CO_3 molarity that is too ~~low~~ high, not too low,

e) The liquid would be able to conduct electricity because there would be Na^+, NO_3^-, & Ca^{2+} ions present in the solution and ions can conduct electricity as a result of their charge and ~~that~~ their mobility as aqueous ions in solution

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GO ON TO THE NEXT PAGE.

f)(i) The student could use a pH meter to determine $[OH^-]$. pH could be subtracted from 14 to find the pOH, and then $[OH^-] = 10^{-pOH}$ could be used to find $[OH^-]$.

(ii) $[OH^-] = [HCO_3^-]$ since OH^- and HCO_3^- are in a 1:1 mole ratio in the reaction. Thus, you could use the equation $K_b = \frac{[HCO_3^-][OH^-]}{[CO_3^{2-}]}$ ~~since~~ and solve for $[CO_3^{2-}]$ since all the other values are known ($K_b = 2.1 \times 10^{-4}$, $[HCO_3^-] =$ $[OH^-]$ = value found using method described in f(i)). This would give you the $[CO_3^{2-}]$ at equilibrium, which you could convert to moles. If you then convert $[OH^-]$ to moles, you could add moles CO_3^{2-} and moles OH^- in order to find the initial moles of CO_3^{2-}, which you could then divide by the volume to find initial $[CO_3^{2-}]$.

g) $[HCO_3^-] < [CO_3^{2-}]$ b/c K is very small, which means the reaction is ~~reactants favored~~. Since CO_3^{2-} is a reactant and HCO_3^- is a product, CO_3^{2-} must have a higher concentration.

h) $K_w = K_a \cdot K_b$

$1 \times 10^{-14} = K_a \cdot 2.1 \times 10^{-4}$

$K_a = 4.8 \times 10^{-11}$ pKa = 10

the Na_2CO_3 is not suitable b/c ~~pKa = 10~~ the pKa of HCO_3^- is 10, which is much higher than a pH of 6 that is suitable.

GO ON TO THE NEXT PAGE.

3B 1 of 3

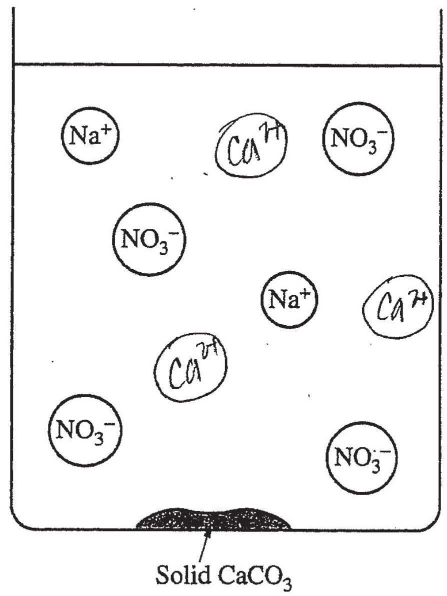
3. A student is given 50.0 mL of a solution of Na_2CO_3 of unknown concentration. To determine the concentration of the solution, the student mixes the solution with excess 1.0 *M* $Ca(NO_3)_2(aq)$, causing a precipitate to form. The balanced equation for the reaction is shown below.

50 mL   1 M excess

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

(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.

(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.



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

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

(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.

(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.

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.

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

(f) The student decides to first determine $[OH^-]$ in the solution, then use that result to calculate the initial concentration of $CO_3^{2-}(aq)$.

(i) Identify a laboratory method (not titration) that the student could use to collect data to determine $[OH^-]$ in the solution. pH meter

(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.)

(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.

(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.

(a.) $Na^+ + CO_3^{2-} + Ca^{2+} + NO_3^- \rightarrow Na^+ + NO_3^- + CaCO_3$

$CO_3^{2-}{}_{(aq)} + Ca^{2+}{}_{(aq)} \rightarrow CaCO_3(s)$

(b.) Drew in Ca^{2+} because $Ca(NO_3)_2$ is in excess so there will be some leftover.

(c.) $.93g\ CaCO_3 \times \frac{1\ mol}{100.1g} = .0092$ mols $CaCO_3 \times \frac{1\ mol\ Na_2CO_3}{1\ mol\ CaCO_3} = .0092$ mols Na_2CO_3

(d.) $\frac{.0092\ mols\ Na_2CO_3}{.050\ L} = .184\ M\ Na_2CO_3$. If the precipitate had not been dried totally, the mass of $CaCO_3$ would be too large, causing the # of mols $CaCO_3$ to be too high and thus making the molarity of Na_2CO_3 too HIGH, not too LOW, like the student said, so I disagree.

(e.) There would be some conduction because of the free ~~ions~~ charged ions in solution (NO_3^- and Na^+) which were originally an ionic solid and ionic solids when aqueous or molten can conduct.

(f.) i) the student could use a pH meter to determine the pH, subtract

GO ON TO THE NEXT PAGE.

that value from 14, ^for the pOH^ and then do the calculation " $[OH^-] = 10^{-pOH}$ " to get the $[OH^-]$. ii) Since all of the components involved are in a 1:1 stoich ratio, the $[OH^-]$ and $[HCO_3^-]$ at equilibrium is the amount that was ~~subtracted~~ used from the CO_3^{2-} initially, and you can plug in the unknowns into the K_b expression to get CO_3^{2-} at equilibrium, and then solve " $[CO_3^{2-}]_{initial} - [OH^-] = [CO_3^{2-}]_{eq.}$ "

(g.) The concentration of $HCO_3^-(aq)$ at equilibrium is equal to the concentration of $CO_3^{2-}(aq)$ because they are in a 1:1 stoich ratio so the amount of CO_3^{2-} used is the same as the HCO_3^- formed.

(h.) $K_a \cdot K_b \Rightarrow 1.0 \times 10^{-14} = 2.1 \times 10^{-4}\ (K_a) \Rightarrow K_a = 4.7 \times 10^{-11}$

Good buffers are created when $pK_a = pH$

$pK_a = -\log(K_a)$ so $pK_a = -\log(4.7 \times 10^{-11}) \Rightarrow pK_a = 10.32$.

$10.32 \neq 6$ and is not close to it either, so the Na_2CO_3 solution is not suitable for making a buffer w/ a pH of 6.

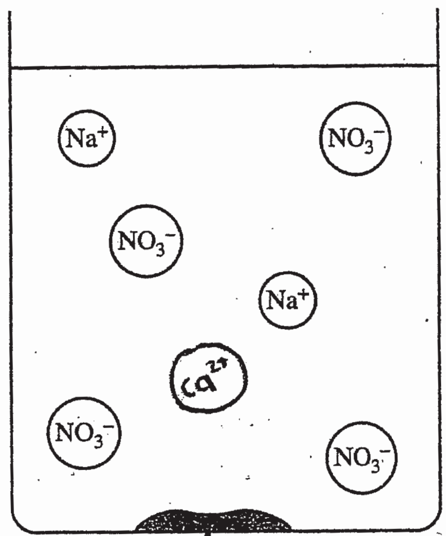
GO ON TO THE NEXT PAGE.

3. 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.

(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.



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

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

(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.

(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.

GO ON TO THE NEXT PAGE.

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.

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

(f) The student decides to first determine $[OH^-]$ in the solution, then use that result to calculate the initial concentration of $CO_3^{2-}(aq)$.

(i) Identify a laboratory method (not titration) that the student could use to collect data to determine $[OH^-]$ in the solution.

(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.)

(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.

(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.

a) $CO_3^{2-}(aq) + Ca^{2+}(aq) \rightarrow CaCO_3(s)$

c) $.093 \text{ g } CaCO_3 \times \frac{1 \text{ mol } CaCO_3}{100.1 \text{ g } CaCO_3} \times \frac{1 \text{ mol } Na_2CO_3}{1 \text{ mol } CaCO_3} = \boxed{9.3 \times 10^{-3} \text{ mol}}$

d) Disagree, the additional mass of the liquid led to a larger no. of moles of Na_2CO_3 calculated than what was actually consumed. A greater no. of moles leads to a greater M, so the M originally calculated was too high

e) It will conduct electricity as it has the remaining Na^+, NO_3^-, and Ca^{2+} ions in the solution. Ions can conduct electricity in the aqueous state

f) i) The student could take the pH of the remaining solution

ii The pH can be used to determine the $[OH^-]$ through $pOH = -\log[OH^-]$; $14 = pH + pOH$, then could do an ICE table with the known $[OH^-]$ produced to find $[CO_3^{2-}]$ consumed

g) $[CO_3^{2-}] > [HCO_3^-]$ as the CO_3^{2-} is a weak base and will not fully dissociate into its conjugate acid (salt)

GO ON TO THE NEXT PAGE.

ADDITIONAL PAGE FOR ANSWERING QUESTION 3

h) It is suitable, as the CO_3^{2-} is a weak base with a stronger conjugate acid, so it's pH will be more acidic, but still weak.

GO ON TO THE NEXT PAGE.

Question 3

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

Overview

The broad goal in this question is for students to determine the concentration of Na_2CO_3 in an aqueous solution of unknown concentration using two different methods: gravimetric analysis and pH determination. Part (a) asks for the balanced net-ionic equation for the precipitation of $CaCO_3$ from an aqueous solution of Na_2CO_3 and $Ca(NO_3)_2$ (LO 3.2; SP 1.5,7.1). Part (b) focuses on the conceptual understanding of the experiment by providing an incomplete particulate representation of the reaction vessel and having the student draw the missing species (LO 3.4; SP 2.2, 5.1, 6.4).

The next three parts deal with the mechanics of the precipitation experiment. Part (c) requires students to interpret a data table to calculate, from the mass of $CaCO_3$ precipitate, the number of moles of Na_2CO_3 that were present in the original aqueous solution (LO 3.4; SP 2.2, 5.1, 6.4). Part (d) is an error analysis question where students predict and then explain the effect that an incompletely dried precipitate would have on the calculated molarity of the Na_2CO_3 solution (LO 1.19; SP 4.2, 5.1, 6.4). Part (e) asks students to predict and explain whether the filtrate would be electrically conductive, requiring them to recognize the presence of ions and connect that characteristic to conductivity (LO 2.10; SP 4.2, 5.1, 6.4).

The remainder of the question deals with a second method for determining the concentration of Na_2CO_3. In part (f) students identify a laboratory method other than titration for determining $[OH^-]$ in the solution. The "not titration" constraint examines the breadth of students' laboratory knowledge while avoiding the complexities of titration in relating the equilibrium concentration of OH^- to the concentration of a polybasic ion like CO_3^{2-} in the next part of the question. The second section of part (f) asks for a description of the mathematical routine that would lead from the measured value of $[OH^-]$ to the initial concentration of Na_2CO_3 in the original solution. This question bypasses algorithmic problem-solving to assess a conceptual understanding of the experimental method. Both sections of part (f) address LO 6.16; SP 2.2 and 6.4. In part (g) students are asked to compare the relative concentrations of HCO_3^- vs. CO_3^{2-} in the original Na_2CO_3 solution and justify their answer (LO 6.17; SP 6.4). Part (h) presents a scenario in which students need to prepare a buffer solution with a pH of 6 and asks students to explain whether the Na_2CO_3 solution could be used to prepare this buffer (LO 6.18; SP 2.3, 4.2, 6.4). This question assesses students' ability to evaluate the relative concentrations of a weak acid/conjugate base pair in relation to the pH of the solution.

Sample: 3A
Score: 10

In part (a) the student earned 1 point for the correct net ionic equation (spectator ions crossed out). In part (b) the student earned 1 point for drawing one Ca^{2+} ion on the diagram, balancing charge, and accounting for the excess Ca^{2+}. In part (c) the student earned 1 point for the correct calculation of 9.3×10^{-3} mol of Na_2CO_3. The response earned 1 point in part (d) for correctly indicating that the student was not correct and justifying it by explaining that if the precipitate was not dried, a higher mass would be observed, which would lead to a higher calculated value of moles of Na_2CO_3, which leads to a calculated molarity of Na_2CO_3 that is too high. In part (e) the student earned 1 point for correctly indicating that the liquid would conduct electricity due to the ions in the solution. In part (f)(i) the student earned 1 point for indicating that a pH meter could be used to measure the pH of the solution. The student earned 1 point in part (f)(ii) for correctly describing how the pH measured in part (f)(i) could be converted into pOH and how the pOH could be used to calculate the $[OH^-]$. The second point was earned for explaining that the $[CO_3^{2-}]$ at equilibrium could be determined by substituting into the K_b equation with $[OH^-] = [HCO_3^-]$. Solving

Question 3 (continued)

for $[CO_3^{2-}]$ and adding the $[OH^-]$ would result in the initial $[CO_3^{2-}]$. In part (g) the student earned 1 point for indicating that the $[HCO_3^-] < [CO_3^{2-}]$ because the K_b is very small, and reactants are favored. In part (h) the student earned 1 point for calculating the pK_a of CO_3^{2-} and indicating that it is much higher than pH 6 so it would not be suitable to make a buffer.

Sample: 3B
Score: 8

In part (a) the student earned 1 point for the correct net ionic equation. In part (b) the point was not earned. Three Ca^{2+} ions are added to the diagram without any additional NO_3^-, so the charge is not balanced. In part (c) the student earned 1 point for the correct calculation of 0.0092 mol of Na_2CO_3. In part (d) the response earned 1 point. The response correctly disagrees with the student and justifies the answer by explaining that a wet precipitate would lead to a higher observed mass, which would lead to a higher calculated value of moles of Na_2CO_3, which leads to a calculated molarity of Na_2CO_3 that is too high. In part (e) the student earned 1 point for correctly indicating that the liquid would conduct electricity due to the ions in the solution. The response earned 1 point in part (f)(i) for indicating that a pH meter could be used to measure the pH of the solution. The response earned 1 point in part (f)(ii) for correctly describing how the pH measured in part (f)(i) could be converted into pOH (pOH = 14 – pH) and how to use the pOH to calculate the $[OH^-]$. The second point was earned for explaining that the $[CO_3^{2-}]$ at equilibrium could be determined by substituting into the K_b equation, assuming that $[OH^-] = [HCO_3^-]$ and solving for $[CO_3^{2-}]_{eq}$.

The initial $[CO_3^{2-}]$ could be found by substituting into the equation $[CO_3^{2-}]_{initial} - [OH^-] = [CO_3^{2-}]_{eq}$ and solving for $[CO_3^{2-}]_{initial}$. In part (g) the point was not earned. The response indicates that the $[HCO_3^-]$ would be equal to $[CO_3^{2-}]$ at equilibrium. In part (h) the student earned 1 point for correctly calculating the pK_a of the conjugate acid and correctly concluding that the pK_a is too far from the desired pH.

Sample: 3C
Score: 6

The response earned 1 point in part (a) for the correct net ionic equation. In part (b) the student earned 1 point for drawing one Ca^{2+} ion on the diagram. The response earned 1 point in part (c) for the correct calculation of 9.3×10^{-3} mol of Na_2CO_3. In part (d) the response earned 1 point for correctly disagreeing with the student and justifying the answer by explaining that a wet precipitate would lead to a higher observed mass, which would lead to a higher calculated value of moles of Na_2CO_3, which leads to a calculated molarity of Na_2CO_3 that is too high. In part (e) the student earned 1 point for correctly indicating that the liquid would conduct electricity due to ions in solution. In part (f)(i) the point was not earned. There is no method indicated for determining pH. In part (f)(ii) the student earned 1 point for correctly describing how the pH measured in part (f)(i) could be converted into $[OH^-]$ ($-\log [OH^-] = 14 - pH$). The second point was not earned. The response does not explain how to calculate the equilibrium $[CO_3^{2-}]$. In part (g) the point was not earned. Although the response correctly indicates that $[CO_3^{2-}] >$ $[HCO_3^-]$, the justification is insufficient. In part (h) the point was not earned. The response indicates that Na_2CO_3 would be suitable for making a pH 6 buffer.