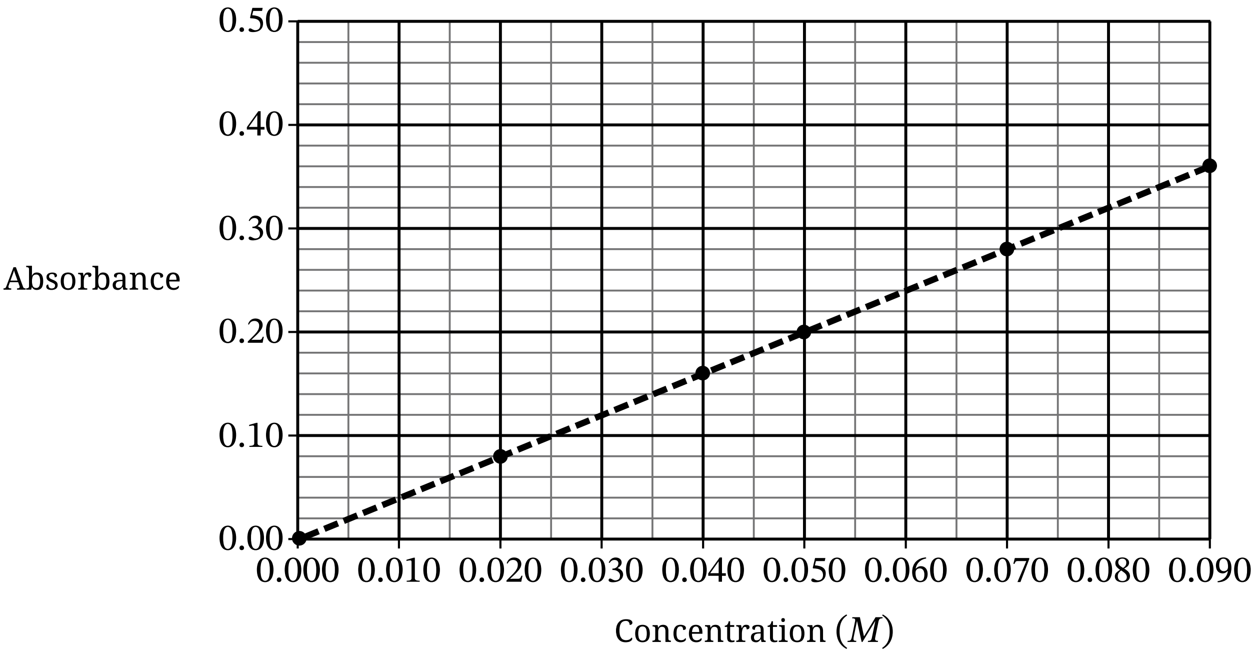
Question 6: Version J

6. 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.

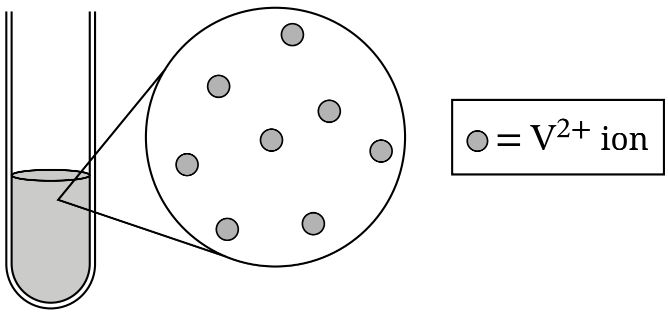
Figure 1



Part A

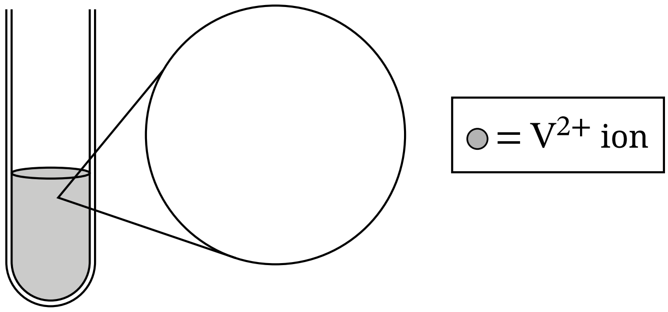
The student measures an absorbance of 0.32 for a $V^{2+}(aq)$ solution. The concentration of V^{2+} ions in the solution is represented by the particle diagram in the circle in Figure 2. In the circle in Figure 3, **draw** the correct number of V^{2+} ions to represent the concentration of a solution with an absorbance of 0.08. (Water molecules have been omitted for clarity. Assume that each particle diagram represents the same volume.)

Figure 2



Absorbance = 0.32

Figure 3



Absorbance = 0.08

Part B

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.

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

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

Part 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.

7. 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* $NaCl(aq)$.

(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.

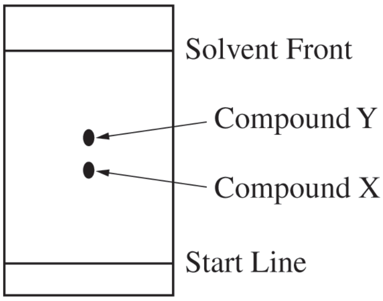
- Solid NaCl
- Distilled water
- Weighing paper and scoop
- Balance
- 100.0 mL volumetric flask
- 50.0 mL graduated cylinder
- Pipet
- 150 mL beakers
- Chromatography paper

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.	
3.	Swirl the mixture to dissolve the solid NaCl.
4.	
5.	Stopper and invert the mixture several times to ensure that the mixture is homogeneous.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 7** on this page.

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.



(c) 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.

STOP

END OF EXAM

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

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

(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.

(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.

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

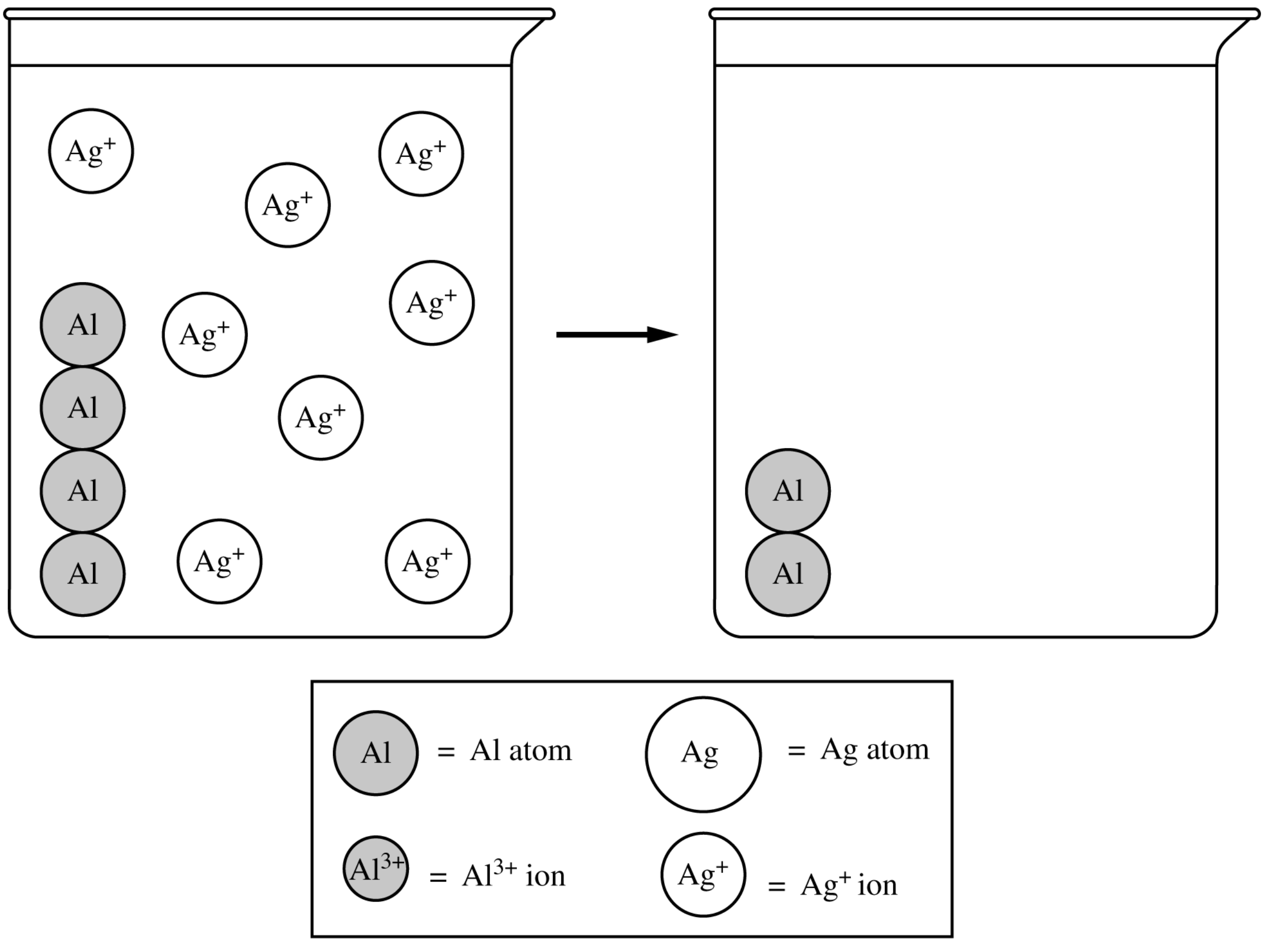
Step	Step Description
1.	Use weighing paper to measure the determined mass of solid $AgNO_3$ on a balance.
2.	

GO ON TO THE NEXT PAGE.

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.

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

(d) 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.



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

GO ON TO THE NEXT PAGE.

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

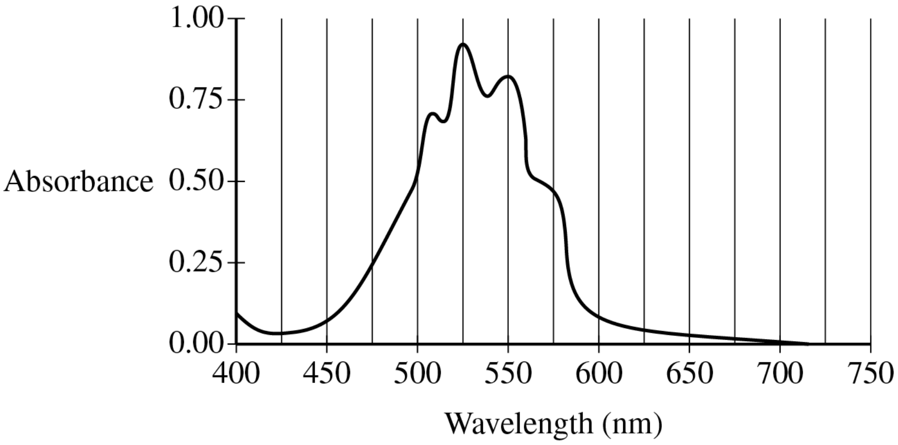
(e) Using the standard reduction potentials, calculate the value of $E°$ for the reaction.

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

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

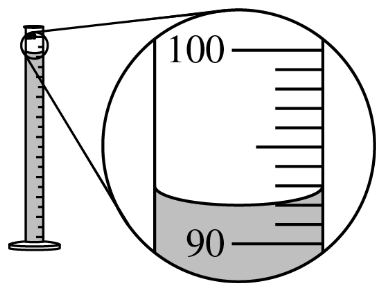
GO ON TO THE NEXT PAGE.

. 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.



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

(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.



(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?

(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.

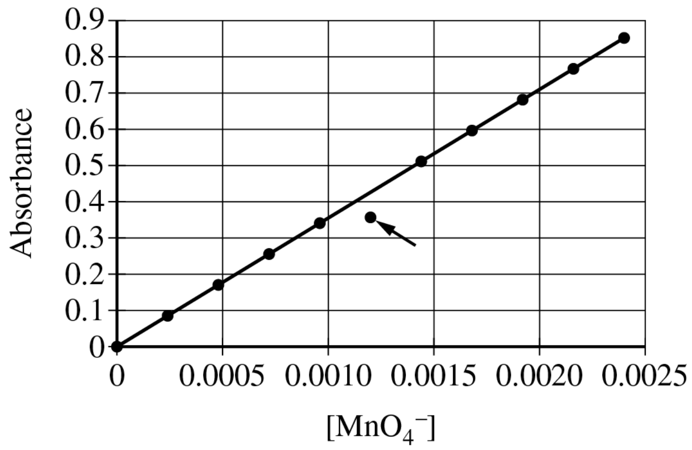
GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 6** on this page.

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.
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.



(c) 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.

GO ON TO THE NEXT 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.

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

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

GO ON TO THE NEXT PAGE.

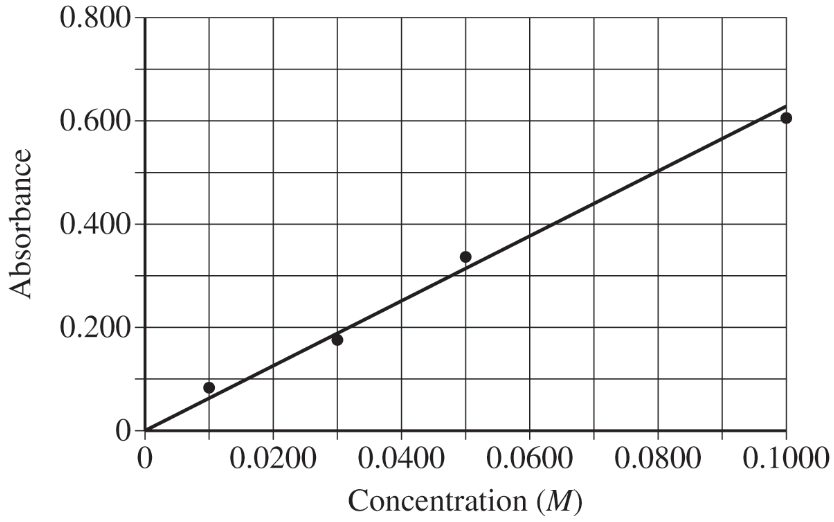
For the spectrophotometry experiment, the student first makes a standard curve. The student uses a 0.1000 M solution of $CuSO_4(aq)$ to make three more solutions of known concentration (0.0500 M, 0.0300 M, and 0.0100 M) in 50.00 mL volumetric flasks.

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

(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.

GO ON TO THE NEXT 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.

(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.

GO ON TO THE NEXT PAGE.

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

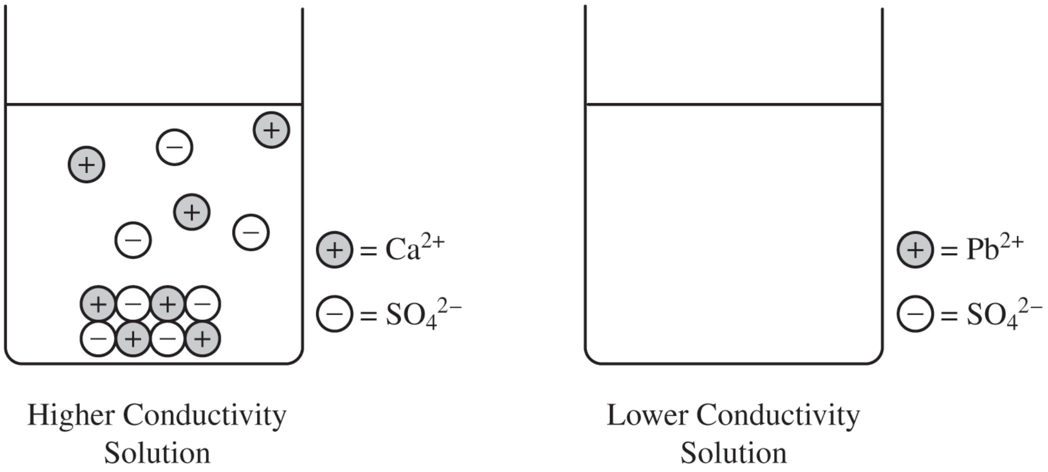
(a) The student tests the electrical conductivity of each solid and observes that neither solid conducts electricity. Describe the structures of the solids that account for their inability to conduct electricity.

The student places excess $CaSO_4(s)$ in a beaker containing $100\,\text{mL}$ of water and places excess $PbSO_4(s)$ in another beaker containing $100\,\text{mL}$ 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 $PbSO_4(s)$.

(b) 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.

GO ON TO THE NEXT PAGE.

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.



(c) 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.

(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.

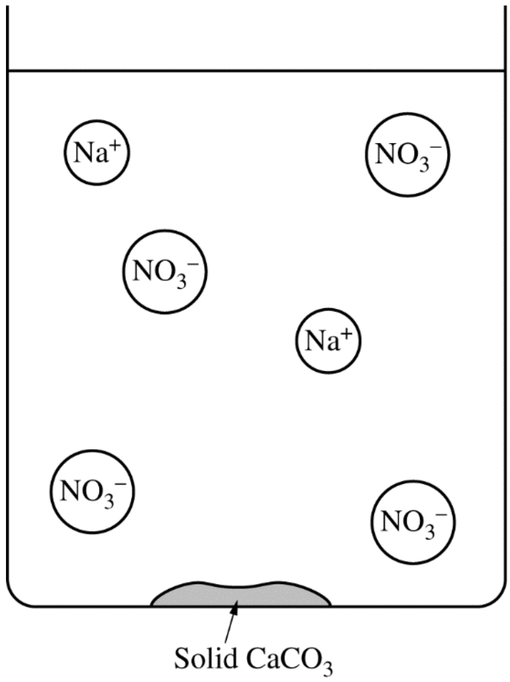
GO ON TO THE NEXT PAGE.

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.

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 <u>initial</u> 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.

4. 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 <u>four</u> water molecules with proper orientation around the Ca^{2+} ion.

   Represent water molecules as .