Question 1

$$HC_2H_3O_2(aq) + H_2O(l) \rightleftarrows H_3O^+(aq) + C_2H_3O_2^-(aq)$$

The dissociation of ethanoic acid, $HC_2H_3O_2(aq)$, is represented above. A student is given the task of determining the value of K_a for $HC_2H_3O_2(aq)$ using two different experimental procedures.

(a) The student is first asked to prepare 100.0 mL of 0.115 *M* $HC_2H_3O_2(aq)$ using a 2.000 *M* standard solution.

(i) Calculate the volume, in mL, of 2.000 *M* $HC_2H_3O_2(aq)$ the student needs to prepare 100.0 mL of 0.115 *M* $HC_2H_3O_2(aq)$.

$M_iV_i = M_fV_f$ $V_i = \dfrac{(0.115\ M)(100.0\ \text{mL})}{2.000\ M} = 5.75\ \text{mL}$	1 point is earned for the correct volume.

(ii) Describe the procedure the student should use to prepare 100.0 mL of 0.115 *M* $HC_2H_3O_2(aq)$ using appropriate equipment selected from the list below. Assume that the student uses appropriate safety equipment.

- 100 mL beaker
- 100 mL graduated cylinder
- 100 mL volumetric flask
- Eye dropper
- 500 mL wash bottle filled with distilled water
- 2.000 *M* $HC_2H_3O_2(aq)$ in a 50 mL buret

Use the buret to deliver 5.75 mL of 2.000 *M* $HC_2H_3O_2$ to the 100 mL volumetric flask. Then add distilled water from the wash bottle to the flask (adding the last few drops with an eyedropper) until the volume of liquid in the flask is at the calibration mark.	1 point is earned for dispensing from the buret. 1 point is earned for diluting the solution to the calibration mark of the volumetric flask.

Question 1 (continued)

(b) Using a pH probe, the student determines that the pH of 0.115 M $HC_2H_3O_2(aq)$ is 2.92.

(i) Using the pH value, calculate the value of K_a for $HC_2H_3O_2(aq)$.

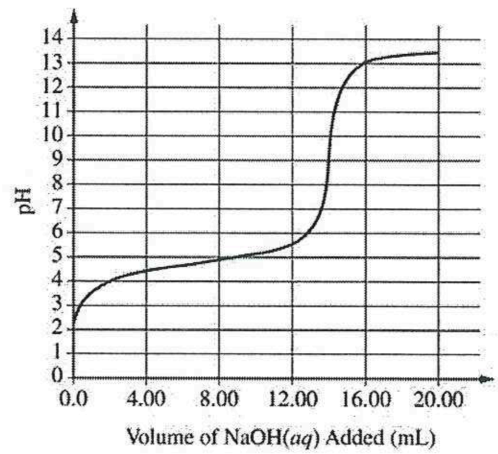
$pH = 2.92 \Rightarrow [H_3O^+] = 10^{-2.92} = 0.0012\ M$ $K_a = \frac{[H_3O^+][C_2H_3O_2^-]}{[HC_2H_3O_2]}$ Since $[H_3O^+] = [C_2H_3O_2^-]$, then $K_a = \frac{(0.0012)(0.0012)}{(0.115 - 0.0012)} = \frac{(0.0012)^2}{(0.114)} = 1.3 \times 10^{-5}$	1 point is earned for correct conversion of pH to $[H_3O^+]$. 1 point is earned for a value of K_a consistent with the student's value of $[H_3O^+]$.

(ii) Calculate the percent dissociation of ethanoic acid in 0.115 M $HC_2H_3O_2(aq)$.

Percent dissociation = $\frac{[C_2H_3O_2^-]}{[HC_2H_3O_2]_o} = \frac{0.0012}{0.115} \times 100 = 1.0\%$	1 point is earned for the correct percent dissociation.

In a separate experimental procedure, the student titrates 10.0 mL of the 2.000 M $HC_2H_3O_2(aq)$ with an $NaOH(aq)$ solution of unknown concentration. The student monitors the pH during the titration. The following titration curve was created using the experimental data presented in the table.

Volume of NaOH(*aq*) Added (mL)	pH
0.00	2.23
2.00	3.99
4.00	4.37
6.00	4.65
8.00	4.90
10.00	5.17
12.00	5.55
14.00	9.35
16.00	13.04
18.00	13.31
20.00	13.46



Question 1 (continued)

(c) Write the balanced net ionic equation for the reaction that occurs when $HC_2H_3O_2(aq)$ and $NaOH(aq)$ are combined.

$HC_2H_3O_2(aq) + OH^-(aq) \rightarrow C_2H_3O_2^-(aq) + H_2O(l)$	1 point is earned for the correct equation.

(d) Calculate the molar concentration of the $NaOH(aq)$ solution.

From the pH curve, the equivalence point occurs at 14.0 mL. $10.0\text{ mL} \times \frac{2.000\text{ mol }HC_2H_3O_2}{1000\text{ mL}} = 0.0200\text{ mol }HC_2H_3O_2(aq)$	1 point is earned for determining the moles of acid.
$0.0200\text{ mol }HC_2H_3O_2(aq) \times \frac{1\text{ mol NaOH}}{1\text{ mol }HC_2H_3O_2} = 0.0200\text{ mol NaOH}$ $\frac{0.0200\text{ mol NaOH}}{0.0140\text{ L solution}} = 1.43\ M\ NaOH(aq)$	1 point is earned for determining the molar concentration of the base.

(e) Explain how the student can estimate the value of K_a for $HC_2H_3O_2(aq)$ using the titration curve.

At the half-equivalence point (~7.0 mL) the pH of the solution is equal to the pK_a of the acid. The antilog of the negative pH is equal to the value of K_a.	1 point is earned for a correct explanation (numerical explanation not required).

Question 7

A student has 100. mL of 0.400 M $CuSO_4(aq)$ and is asked to make 100. mL of 0.150 M $CuSO_4(aq)$ for a spectrophotometry experiment. The following laboratory equipment is available for preparing the solution: centigram balance, weighing paper, funnel, 10 mL beaker, 150 mL beaker, 50 mL graduated cylinder, 100 mL volumetric flask, 50 mL buret, and distilled water.

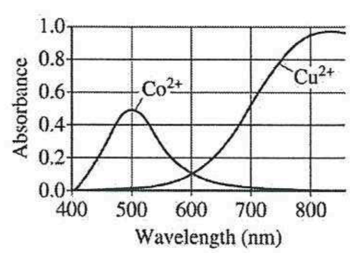
(a) Calculate the volume of 0.400 M $CuSO_4(aq)$ required for the preparation.

$M_1 V_1 = M_2 V_2$ $V_2 = \frac{(0.150\ M)(0.100\ \text{L})}{0.400\ M}$ $V_2 = 0.0375\ \text{L} \times \frac{1000\ \text{mL}}{1\ \text{L}} = 37.5\ \text{mL}$	1 point is earned for the correct volume.

(b) Briefly describe the essential steps to most accurately prepare the 0.150 M $CuSO_4(aq)$ from the 0.400 M $CuSO_4(aq)$ using the equipment listed above.

Use the buret to dispense 37.5 mL of $CuSO_4$ solution into the volumetric flask. Fill to the mark with distilled water.	1 point is earned for using the buret to measure 37.5 mL of 0.400 M $CuSO_4$ solution. 1 point is earned for adding the $CuSO_4$ solution to the volumetric flask and filling to the mark with distilled water.

The student plans to conduct a spectrophotometric analysis to determine the concentration of $Cu^{2+}(aq)$ in a solution. The solution has a small amount of $Co(NO_3)_2(aq)$ present as a contaminant. The student is given the diagram below, which shows the absorbance curves for aqueous solutions of $Co^{2+}(aq)$ and $Cu^{2+}(aq)$.



(c) The spectrophotometer available to the student has a wavelength range of 400 nm to 700 nm. What wavelength should the student use to minimize the interference from the presence of the $Co^{2+}(aq)$ ions?

700 nm (Any wavelength from 650 to 700 nm is acceptable.)	1 point is earned for a correct wavelength.

Question 4

A student is doing experiments with $CO_2(g)$. Originally, a sample of the gas is in a rigid container at 299 K and 0.70 atm. The student increases the temperature of the $CO_2(g)$ in the container to 425 K.

(a) Describe the effect of raising the temperature on the motion of the $CO_2(g)$ molecules.

The average speed of the molecules increases as temperature increases.	1 point is earned for the correct answer.

(b) Calculate the pressure of the $CO_2(g)$ in the container at 425 K.

Both the volume and the number of molecules are constant, therefore $\frac{P_1}{T_1} = \frac{P_2}{T_2} \quad \Rightarrow \quad \frac{0.70 \text{ atm}}{299 \text{ K}} = \frac{P_2}{425 \text{ K}} \quad \Rightarrow \quad P_2 = 0.99 \text{ atm}$	1 point is earned for the correct answer.

(c) In terms of kinetic molecular theory, briefly explain why the pressure of the $CO_2(g)$ in the container changes as it is heated to 425 K.

Faster-moving gas particles collide more frequently with the walls of the container, thus increasing the pressure. OR Faster-moving gas particles collide more forcefully with the walls of the container, thus increasing the pressure.	1 point is earned for a correct explanation.

(d) The student measures the actual pressure of the $CO_2(g)$ in the container at 425 K and observes that it is less than the pressure predicted by the ideal gas law. Explain this observation.

The attractive forces between CO_2 molecules result in a pressure that is lower than that predicted by the ideal gas law.	1 point is earned for a correct explanation.

Question 3

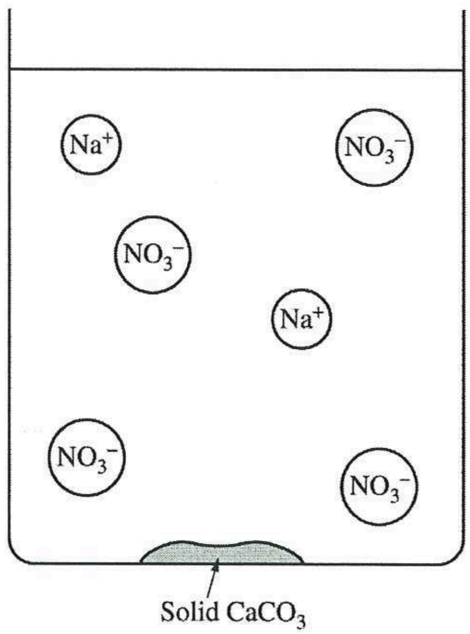
A student is given 50.0 mL of a solution of Na_2CO_3 of unknown concentration. To determine the concentration of the solution, the student mixes the solution with excess 1.0 M $Ca(NO_3)_2(aq)$, causing a precipitate to form. The balanced equation for the reaction is shown below.

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

(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 <u>initial</u> concentration of $CO_3^{2-}(aq)$. (Do not do any numerical calculations.)

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

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 $[OH^-]$ from the measured value.

1 point is earned for a valid method of determining the <u>initial</u> 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.