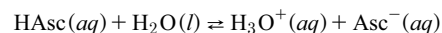


2. Answer the following questions about ascorbic acid (vitamin C).

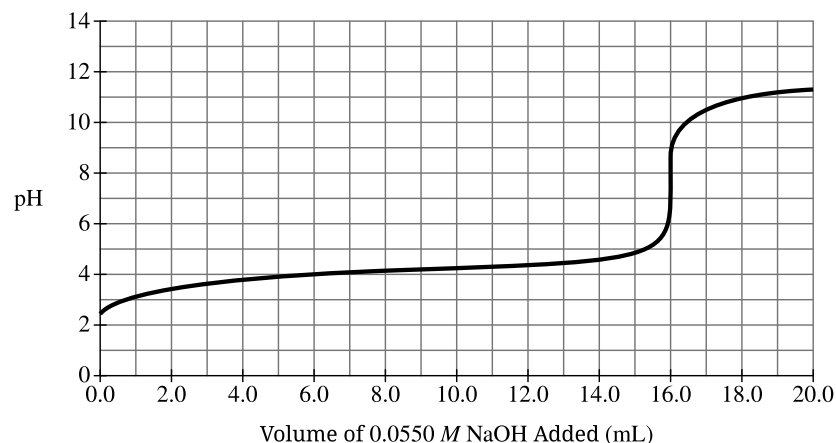
A. A student combusts a sample of ascorbic acid, $C_xH_yO_z$, to determine its chemical composition. The only products of the reaction are 0.2400 mol of CO_2 and 2.883 g of H_2O .

- Calculate the number of moles of H_2O produced.
- The mole ratio of carbon (C) to oxygen (O) is 1:1 in ascorbic acid. Based on this information and your answer to part A (i), determine the empirical formula of ascorbic acid.

B. Ascorbic acid, $HAsc(aq)$, acts as a weak acid, as shown in the equation.



The following titration curve was produced when a 10.0 mL sample of $HAsc(aq)$ was titrated using 0.0550 M $NaOH(aq)$.



- Calculate the molar concentration of the ascorbic acid solution.
- From the titration curve, determine the approximate pK_a of ascorbic acid.
- What is the value of the ratio $\frac{[Asc^-]}{[HAsc]}$ when the pH of the solution is 4.7?

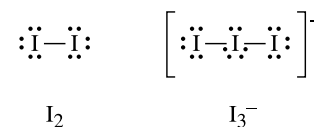
C. Dehydroascorbic acid (DHAsc) can be produced by reacting ascorbic acid with the triiodide ion, I_3^- , as represented by the following equation.



The student runs three trials of the reaction with different initial concentrations of $HAsc$ and I_3^- , producing the following data.

Trial	$[HAsc] (M)$	$[I_3^-] (M)$	Initial Rate of DHAsc Formation (M/s)
1	0.450	1.200	2.457×10^{-4}
2	0.450	0.600	1.229×10^{-4}
3	0.900	1.200	4.914×10^{-4}

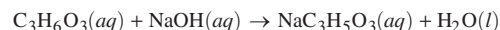
- The rate law for the reaction is $rate = k[HAsc][I_3^-]$. Explain how the data in the table support the conclusion that the reaction is first order with respect to $[HAsc]$.
 - Calculate the value of the rate constant, k , for the reaction. Include units with your answer.
- D. The triiodide ion, I_3^- , is significantly more soluble in water than elemental iodine, I_2 , is. Identify an intermolecular force between I_3^- and water that is **not** present between I_2 and water, which could explain the difference in solubility. Lewis diagrams for I_2 and I_3^- are provided.



Begin your response to **QUESTION 1** on this page.**CHEMISTRY****SECTION II****Time—1 hour and 45 minutes****7 Questions**

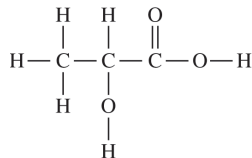
Directions: Questions 1–3 are long free-response questions that require about 23 minutes each to answer and are worth 10 points each. Questions 4–7 are short free-response questions that require about 9 minutes each to answer and are worth 4 points each.

For each question, show your work for each part in the space provided after that part. Examples and equations may be included in your responses where appropriate. For calculations, clearly show the method used and the steps involved in arriving at your answers. You must show your work to receive credit for your answer. Pay attention to significant figures.



1. A student is studying the reaction between lactic acid, $\text{C}_3\text{H}_6\text{O}_3$, and sodium hydroxide, NaOH , as represented in the balanced equation above.

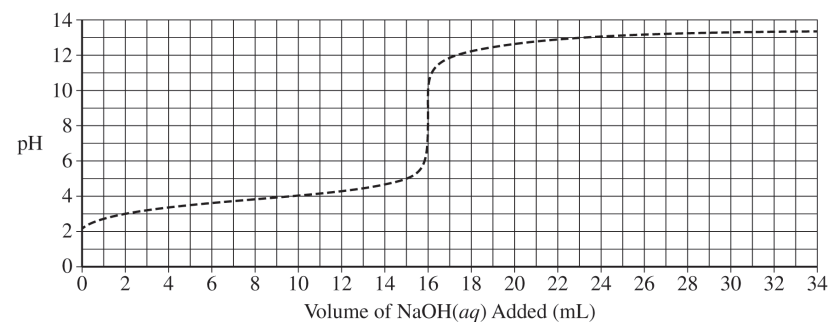
(a) The structural formula of lactic acid is shown in the following diagram. Circle the hydrogen atom that most readily participates in the chemical reaction with sodium hydroxide.



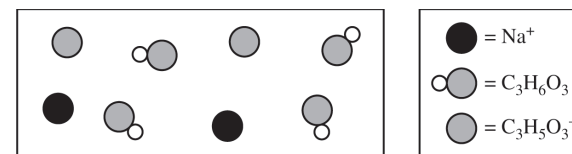
- (b) The student begins the experiment by dissolving 10.22 g of sodium hydroxide (molar mass 40.00 g/mol) in enough water to produce 500. mL of solution. Calculate the molarity of the sodium hydroxide solution.

GO ON TO THE NEXT PAGE.Continue your response to **QUESTION 1** on this page.

The student uses the sodium hydroxide solution from part (b), a buret, a pH meter, and a 100 mL Erlenmeyer flask to titrate a 25.0 mL sample of lactic acid solution. The student's data are shown in the following graph.



- (c) Use the information in the graph to determine the approximate $\text{p}K_a$ of lactic acid. _____



- (d) The preceding diagram represents the relative amounts of major species in a sample of the solution in the flask at one point during the titration. (Note that water molecules are omitted.)

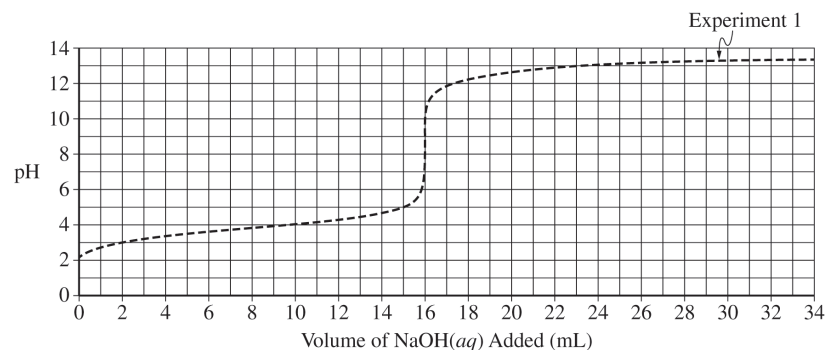
- (i) Draw an X on the preceding titration curve at a point in the titration where the reaction mixture would be represented by this diagram.
- (ii) Justify your answer.

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Continue your response to **QUESTION 1** on this page.

Experiment	Mass of NaOH(<i>s</i>) (grams)	Volume of Solution (mL)	Titration Curve
1	10.22	500.	Already shown on graph
2	20.44	500.	?

- (iii) The student repeats the experiment but uses a solution of NaOH(*aq*) with twice the concentration, as shown in the preceding table. On the following graph, draw the titration curve that would be expected for experiment 2.



- (e) In a third experiment, the student investigates the enthalpy of the reaction between lactic acid and sodium hydroxide. The student combines 100.0 mL of a 0.500 *M* lactic acid solution at 20.0°C with 100.0 mL of a 0.500 *M* NaOH solution at 20.0°C in a calorimeter. The final temperature of the resulting combined solution is 23.2°C. Assume that the density of each solution before combining is 1.00 g/mL and that the specific heat capacity of the combined solution is 4.2 J / (g · °C).

- (i) Calculate the quantity of heat produced in the reaction, in J.

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Continue your response to **QUESTION 1** on this page.

- (ii) Calculate the molar enthalpy of reaction, in kJ / mol_{rxn}. Include the sign in your answer.

- (iii) The student claims that if heat is lost from the calorimeter to the surrounding air during the reaction, then the experimental value of the molar enthalpy of reaction will be smaller in magnitude than the actual value. Do you agree or disagree with the student's claim? Justify your answer.

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2. A chemical reaction between maleic acid ($\text{H}_2\text{C}_4\text{H}_2\text{O}_4$) and sodium bicarbonate (NaHCO_3) occurs in the presence of water to produce carbon dioxide and sodium maleate ($\text{Na}_2\text{C}_4\text{H}_2\text{O}_4$), as represented by the following equation.



- (a) A student combines equal masses of $\text{H}_2\text{C}_4\text{H}_2\text{O}_4(s)$ chunks and $\text{NaHCO}_3(s)$ chunks with sufficient water at 20.0°C . The student determines that 0.0114 mol of $\text{CO}_2(g)$ is produced after the reaction goes to completion.

(i) Calculate the number of grams of $\text{CO}_2(g)$ produced.

(ii) The $\text{CO}_2(g)$ produced from the reaction at 20.0°C was collected and found to have a pressure of 1.25 atm . Calculate the volume of $\text{CO}_2(g)$, in liters.

- (b) The student performs a second experiment that is identical to the first except that the student grinds the chunks of $\text{H}_2\text{C}_4\text{H}_2\text{O}_4(s)$ and $\text{NaHCO}_3(s)$ into powder before combining the powder with water.

(i) What happens to the surface area of the reactants when the student grinds the chunks into powder?

(ii) The rate-determining step for the overall reaction is the dissolving of the solids. Would the time required for the dissolving of the solids in the second experiment be longer than, shorter than, or the same as the time required in the first experiment? Justify your answer based on the collisions between particles.

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Continue your response to **QUESTION 2** on this page.

- (iii) When the reaction is complete, will the volume of $\text{CO}_2(g)$ at the end of the second experiment be greater than, less than, or equal to the volume at the end of the first experiment? Justify your answer.

The student conducts additional trials of the experiment and produces the following data table.

Trial	Mass of $\text{H}_2\text{C}_4\text{H}_2\text{O}_4$ (grams)	Mass of NaHCO_3 (grams)	Moles of CO_2 Produced (mol)
3	1.543	1.251	0.01489
4	1.543	1.686	0.02007

- (c) Based on the student's data, identify the limiting reactant in trial 3. Justify your answer.

- (d) The reaction has a value of ΔS° greater than zero. Using particle-level reasoning, explain why the entropy increases as the reaction progresses.

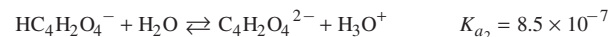
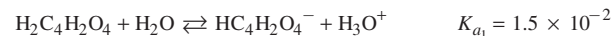
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Continue your response to **QUESTION 2** on this page.

The student notices that the temperature of the reaction mixture decreases as the reaction takes place and correctly determines that the reaction is endothermic.

- (e) The student claims that the reaction is thermodynamically favorable at all temperatures because $\Delta S_{rxn}^{\circ} > 0$ and the reaction is endothermic. Do you agree or disagree with the student's claim? Justify your answer.

Next, the student investigates the acid-base behavior of maleic acid. The student notes that maleic acid is a diprotic acid. The two acid dissociation processes that occur are represented by the following equations.



- (f) Calculate the $\text{p}K_{a2}$ value for the $\text{HC}_4\text{H}_2\text{O}_4^-$ ion.

- (g) A buffer solution with a pH of 7.00 is prepared using $\text{C}_4\text{H}_2\text{O}_4^{2-}$ and $\text{HC}_4\text{H}_2\text{O}_4^-$. Calculate the ratio

$$\frac{[\text{C}_4\text{H}_2\text{O}_4^{2-}]}{[\text{HC}_4\text{H}_2\text{O}_4^-]} \text{ in this solution.}$$

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CHEMISTRY**SECTION II**

Time—1 hour and 45 minutes

7 Questions

YOU MAY USE YOUR CALCULATOR FOR THIS SECTION.

Directions: Questions 1–3 are long free-response questions that require about 23 minutes each to answer and are worth 10 points each. Questions 4–7 are short free-response questions that require about 9 minutes each to answer and are worth 4 points each.

For each question, show your work for each part in the space provided after that part. Examples and equations may be included in your responses where appropriate. For calculations, clearly show the method used and the steps involved in arriving at your answers. You must show your work to receive credit for your answer. Pay attention to significant figures.

4. A student reacts 0.300 g of methyl salicylate ($\text{C}_8\text{H}_8\text{O}_3$) with a stoichiometric amount of a strong base. This product is then acidified to produce salicylic acid crystals ($\text{HC}_7\text{H}_5\text{O}_3$).

- (a) For every 1 mole of $\text{C}_8\text{H}_8\text{O}_3$ (molar mass 152.15 g/mol) reactant used, 1 mole of salicylic acid crystals ($\text{HC}_7\text{H}_5\text{O}_3$, molar mass 138.12 g/mol) is produced. Calculate the maximum mass, in grams, of $\text{HC}_7\text{H}_5\text{O}_3$ that could be produced in this reaction.

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Continue your response to **QUESTION 1** on this page.

As part of the experimental procedure to purify the $\text{HC}_7\text{H}_5\text{O}_3$ crystals after the reaction is complete, the crystals are filtered from the reaction mixture, rinsed with distilled water, and dried. Some physical properties of $\text{HC}_7\text{H}_5\text{O}_3$ are given in the following table.

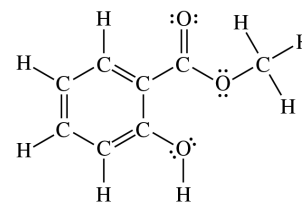
Properties of Salicylic Acid ($\text{HC}_7\text{H}_5\text{O}_3$)	
Melting point	159°C
Solubility in H_2O at 25°C	2.2 g/L
Specific heat capacity	$1.17 \text{ J}/(\text{g}\cdot^\circ\text{C})$
Heat of fusion	27.1 kJ/mol

- (b) The student's experiment results in an 87% yield of dry $\text{HC}_7\text{H}_5\text{O}_3$. The student suggests that some of the $\text{HC}_7\text{H}_5\text{O}_3$ crystals dissolved in the distilled water during the rinsing step. Is the student's claim consistent with the calculated percent yield value? Justify your answer.

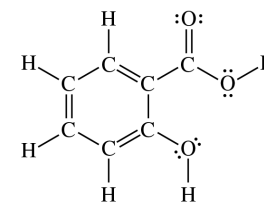
- (c) Given the physical properties in the table, calculate the quantity of heat that must be absorbed to increase the temperature of a 0.105 g sample of dry $\text{HC}_7\text{H}_5\text{O}_3$ (molar mass 138.12 g/mol) crystals from 25°C to the melting point of 159°C and melt the crystals completely.

GO ON TO THE NEXT PAGE.Continue your response to **QUESTION 1** on this page.

The structures and melting points for methyl salicylate and salicylic acid are shown.



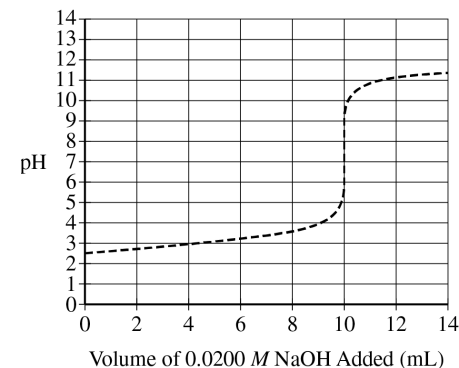
Methyl Salicylate
Melting Point: -9°C



Salicylic Acid
Melting Point: 159°C

- (d) The same three types of intermolecular forces (London dispersion forces, dipole-dipole interactions, and hydrogen bonding) exist among molecules of each substance. Explain why the melting point of salicylic acid is higher than that of methyl salicylate.

The student titrates 20.0 mL of 0.0100 M $\text{HC}_7\text{H}_5\text{O}_3(aq)$ with 0.0200 M NaOH, using a probe to monitor the pH of the solution. The data are plotted producing the following titration curve.

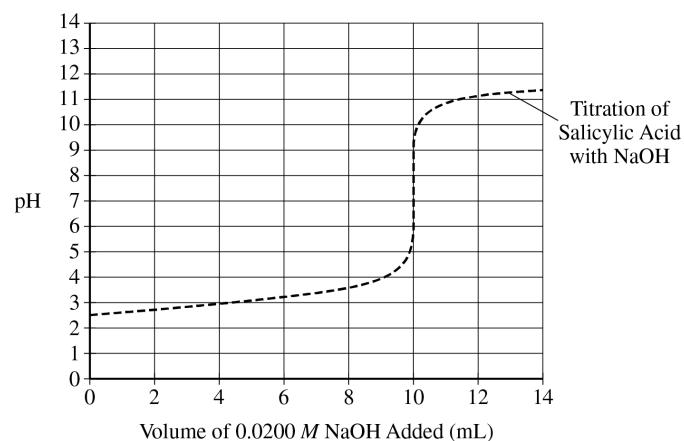
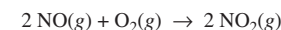
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Continue your response to **QUESTION 1** on this page.

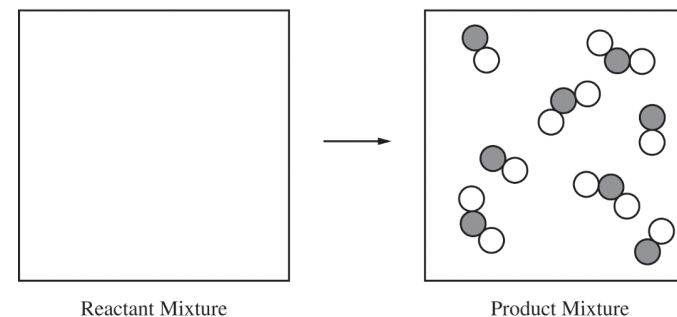
- (e) Using the information in the graph, estimate the pK_a of $HC_7H_5O_3$. _____
- (f) When the pH of the titration mixture is 4.00, is there a higher concentration of the weak acid, $HC_7H_5O_3$, or its conjugate base, $C_7H_5O_3^-$, in the flask? Justify your answer.

- (g) The student researches benzoic acid ($HC_7H_5O_2$) and finds that it has similar properties to salicylic acid ($HC_7H_5O_3$). The K_a for benzoic acid is 6.3×10^{-5} . Calculate the value of pK_a for benzoic acid.

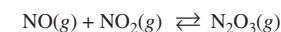
- (h) The student performs a second titration, this time titrating 20.0 mL of a 0.0100 M benzoic acid solution with 0.0200 M NaOH. Sketch the curve that would result from this titration of benzoic acid on the following graph, which already shows the original curve from the titration of 20.0 mL of 0.0100 M salicylic acid. The initial pH of the benzoic acid solution is 3.11.

**GO ON TO THE NEXT PAGE.**

2. A student investigates the reactions of nitrogen oxides. One of the reactions in the investigation requires an equimolar mixture of $NO(g)$ and $NO_2(g)$, which the student produces by using the reaction represented above.
- (a) The particle-level representation of the equimolar mixture of $NO(g)$ and $NO_2(g)$ in the flask at the completion of the reaction between $NO(g)$ and $O_2(g)$ is shown below in the box on the right. In the box below on the left, draw the particle-level representation of the reactant mixture of $NO(g)$ and $O_2(g)$ that would yield the product mixture shown in the box on the right. In your drawing, represent oxygen atoms and nitrogen atoms as indicated below.



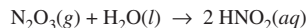
The student reads in a reference text that $NO(g)$ and $NO_2(g)$ will react as represented by the equation below. Thermodynamic data for the reaction are given in the table below the equation.



ΔH_{298}°	ΔS_{298}°	ΔG_{298}°
$-40.4 \text{ kJ/mol}_{rxn}$	$-138.5 \text{ J/(K} \cdot \text{mol}_{rxn})$	$0.87 \text{ kJ/mol}_{rxn}$

- (b) The student begins with an equimolar mixture of $NO(g)$ and $NO_2(g)$ in a rigid reaction vessel and the mixture reaches equilibrium at 298 K.
- Calculate the value of the equilibrium constant, K , for the reaction at 298 K.
 - If both P_{NO} and P_{NO_2} in the vessel are initially 1.0 atm, will $P_{N_2O_3}$ at equilibrium be equal to 1.0 atm? Justify your answer.
- (c) The student hypothesizes that increasing the temperature will increase the amount of $N_2O_3(g)$ in the equilibrium mixture. Indicate whether you agree or disagree with the hypothesis. Justify your answer.

$\text{N}_2\text{O}_3(g)$ reacts with water to form nitrous acid, $\text{HNO}_2(aq)$, a compound involved in the production of acid rain. The reaction is represented below.



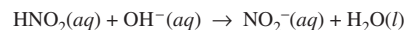
(d) The skeletal structure of the HNO_2 molecule is shown in the box below.

- (i) Complete the Lewis electron-dot diagram of the HNO_2 molecule in the box below, including any lone pairs of electrons.

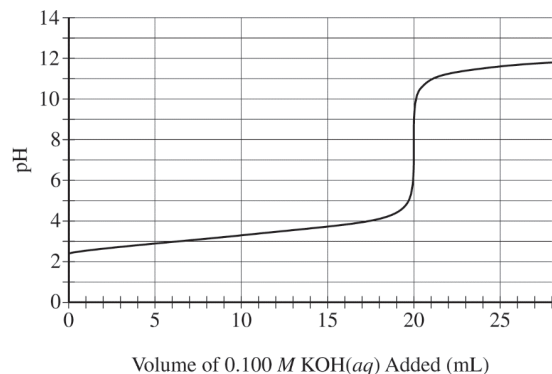


- (ii) Based on your completed diagram above, identify the hybridization of the nitrogen atom in the HNO_2 molecule.

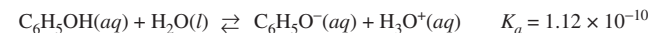
To produce an aqueous solution of HNO_2 , the student bubbles $\text{N}_2\text{O}_3(g)$ into distilled water. Assume that the reaction goes to completion and that HNO_2 is the only species produced. To determine the concentration of $\text{HNO}_2(aq)$ in the resulting solution, the student titrates a 100. mL sample of the solution with 0.100 M $\text{KOH}(aq)$. The neutralization reaction is represented below.



The following titration curve shows the change in pH of the solution during the titration.



- (e) Use the titration curve and the information above to
- determine the initial concentration of the $\text{HNO}_2(aq)$ solution
 - estimate the value of $\text{p}K_a$ for $\text{HNO}_2(aq)$
- (f) During the titration, after a volume of 15 mL of 0.100 M $\text{KOH}(aq)$ has been added, which species, $\text{HNO}_2(aq)$ or $\text{NO}_2^-(aq)$, is present at a higher concentration in the solution? Justify your answer.



4. Phenol is a weak acid that partially dissociates in water according to the equation above.

- (a) What is the pH of a 0.75 M $\text{C}_6\text{H}_5\text{OH}(aq)$ solution?
- (b) For a certain reaction involving $\text{C}_6\text{H}_5\text{OH}(aq)$ to proceed at a significant rate, the phenol must be primarily in its deprotonated form, $\text{C}_6\text{H}_5\text{O}^-(aq)$. In order to ensure that the $\text{C}_6\text{H}_5\text{OH}(aq)$ is deprotonated, the reaction must be conducted in a buffered solution. On the number scale below, circle each pH for which more than 50 percent of the phenol molecules are in the deprotonated form ($\text{C}_6\text{H}_5\text{O}^-(aq)$). Justify your answer.

1 2 3 4 5 6 7 8 9 10 11 12 13 14