Past-paper walk-through

pH and pOH of Strong Acids and Bases ▪ 8.2

eXercise

Questions in this set

- 2026 Q3
- 2025 Q1
- 2019 Q3
- 2014 Q2

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 3

2026 ▪ Q3

Nitrous acid, HNO_2, is a weak acid that ionizes according to Equation 1.

Equation 1: $HNO_2(aq) + H_2O(l) \rightleftharpoons NO_2^-(aq) + H_3O^+(aq)$ $\quad K_a = 5.6 \times 10^{-4}$ at 298 K

(a) Identify a conjugate acid-base pair in the equation. Be sure to clearly label which is the acid and which is the base.

Question 3

Table 1

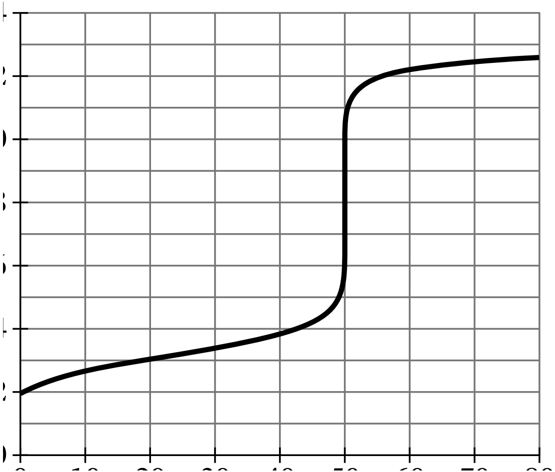
Chemical Equation	Equilibrium Constant
$HNO_2(aq) + H_2O(l) \rightleftarrows NO_2^-(aq) + H_3O^+(aq)$	$K_a = 5.6 \times 10^{-4}$
$H_2O(l) + H_2O(l) \rightleftarrows H_3O^+(aq) + OH^-(aq)$	$K_w = 1.0 \times 10^{-14}$
$HNO_2(aq) + OH^-(aq) \rightarrow NO_2^-(aq) + H_2O(l)$	$K_2 = \ ?$

Question 3

Table 2

Indicator Name	Acid Color	pH Range of Color Change	Base Color
Methyl orange	Red	3.1–4.4	Yellow
Thymol blue	Yellow	8.0–9.6	Blue
Clayton yellow	Yellow	12.2–13.2	Orange

Question 3



Question 3

2026 ▪ Q3

Nitrous acid, HNO_2, is a weak acid that ionizes according to Equation 1.

$$\text{Equation 1: } HNO_2(aq) + H_2O(l) \rightleftharpoons NO_2^-(aq) + H_3O^+(aq) \qquad K_a = 5.6 \times 10^{-4} \text{ at } 298 \text{ K}$$

(b)(i) A solution of $HNO_2(aq)$ with an initial concentration of 0.125 M has a pH of 2.09.
Calculate the value of $[H_3O^+]$ in the solution. Show the work that leads to your answer.
(b)(ii) **Calculate** $[HNO_2]$ at equilibrium. Show the work that leads to your answer.

Question 3

2026 ▪ Q3

Nitrous acid, HNO_2, is a weak acid that ionizes according to Equation 1.

$$\text{Equation 1: } HNO_2(aq) + H_2O(l) \rightleftharpoons NO_2^-(aq) + H_3O^+(aq) \qquad K_a = 5.6 \times 10^{-4} \text{ at } 298 \text{ K}$$

(c)(i) In an experiment, the solution of 0.125 M $HNO_2(aq)$ is heated to 333 K. The new equilibrium concentrations are determined to be $[HNO_2] = 0.114$ M, $[NO_2^-] = 0.0109$ M, and $[H_3O^+] = 0.0109$ M.
Calculate the value of K_a for HNO_2 at 333 K. Show the work that leads to your answer.
(c)(ii) Is the reaction represented by Equation 1 endothermic or exothermic? **Justify** your answer by comparing K_a values at 298 K and 333 K.

Question 3

2026 ▪ Q3

Nitrous acid, HNO_2, is a weak acid that ionizes according to Equation 1.

$$\text{Equation 1: } HNO_2(aq) + H_2O(l) \rightleftharpoons NO_2^-(aq) + H_3O^+(aq) \qquad K_a = 5.6 \times 10^{-4} \text{ at } 298 \text{ K}$$

(d) The following information applies to parts D, E, and F.
In a second experiment, a student is given a bottle containing HNO_2 with an unknown molarity. To determine the concentration of the $HNO_2(aq)$ in the bottle, the student titrates 35.0 mL of the $HNO_2(aq)$ with 0.16 M $NaOH(aq)$ at 298 K, which reacts according to Equation 2.

$$\text{Equation 2: } HNO_2(aq) + OH^-(aq) \rightarrow NO_2^-(aq) + H_2O(l)$$

Question 3

The results of the titration are summarized in Figure 1.
[Figure 1: Titration curve, pH vs. Volume of 0.16 M NaOH Added (mL); y-axis pH 0 to 14 in increments of 2, x-axis 0 to 80 mL in increments of 10; curve starts near $(0, 2)$, rises gradually to about $(40, 4)$, then rises steeply (equivalence point) between about 45-55 mL up to about pH 12, then levels off gradually to approximately $(80, 12.7)$.]
Using Figure 1, **identify** the pH at the equivalence point.

Question 3

2026 ▪ Q3

Nitrous acid, HNO_2, is a weak acid that ionizes according to Equation 1.

$$\text{Equation 1: } HNO_2(aq) + H_2O(l) \rightleftharpoons NO_2^-(aq) + H_3O^+(aq) \qquad K_a = 5.6 \times 10^{-4} \text{ at } 298 \text{ K}$$

(e) Using Figure 1, **calculate** the molarity $HNO_2(aq)$ of in the bottle. Show the work that leads to your answer.

Question 3

2026 ▪ Q3

Nitrous acid, HNO_2, is a weak acid that ionizes according to Equation 1.

$$\text{Equation 1: } HNO_2(aq) + H_2O(l) \rightleftharpoons NO_2^-(aq) + H_3O^+(aq) \qquad K_a = 5.6 \times 10^{-4} \text{ at } 298 \text{ K}$$

(f) **Draw** an X on Figure 1 to represent a point in the titration where $[HNO_2] > [NO_2^-]$ in the reaction mixture.

Question 3

2026 ▪ Q3

Nitrous acid, HNO_2, is a weak acid that ionizes according to Equation 1.

$$\text{Equation 1: } HNO_2(aq) + H_2O(l) \rightleftharpoons NO_2^-(aq) + H_3O^+(aq) \qquad K_a = 5.6 \times 10^{-4} \text{ at } 298 \text{ K}$$

(g) Equilibrium constants at 298 K are shown in Table 1 for the acid ionization reaction represented by Equation 1, K_a; the autoionization of water, K_w; and the neutralization reaction represented by Equation 2, K_2.

Chemical Equation	Equilibrium Constant
$HNO_2(aq) + H_2O(l) \rightleftharpoons NO_2^-(aq) + H_3O^+(aq)$	$K_a = 5.6 \times 10^{-4}$
$H_2O(l) + H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$	$K_w = 1.0 \times 10^{-14}$
$HNO_2(aq) + OH^-(aq) \rightarrow NO_2^-(aq) + H_2O(l)$	$K_2 = ?$

Question 3

Calculate the value of K_2 for Equation 2 at 298 K. Show the work that leads to your answer.

Question 3

2026 ▪ Q3

Nitrous acid, HNO_2, is a weak acid that ionizes according to Equation 1.

$$\text{Equation 1: } \mathrm{HNO_2}(aq) + \mathrm{H_2O}(l) \rightleftharpoons \mathrm{NO_2^-}(aq) + \mathrm{H_3O^+}(aq) \qquad K_a = 5.6 \times 10^{-4} \text{ at } 298\ \mathrm{K}$$

(h) The student decides to repeat the experiment, this time using an indicator, and has access to the indicators in Table 2.

Indicator Name	Acid Color	pH Range of Color Change	Base Color
Methyl orange	Red	3.1–4.4	Yellow
Thymol blue	Yellow	8.0–9.6	Blue
Clayton yellow	Yellow	12.2–13.2	Orange

Question 3

The student conducts a second titration by adding two drops of methyl orange indicator to 35.0 mL of the $HNO_2(aq)$ solution and titrating the solution with 0.16 M $NaOH(aq)$ until a color change from red to yellow occurs.
The student claims that methyl orange was the best choice for the indicator. Do you agree or disagree? **Justify** your answer.

Question 1

2025 ▪ Q1

Answer the following questions about magnesium.

(a) An incomplete mass spectrum for magnesium is shown in the diagram.

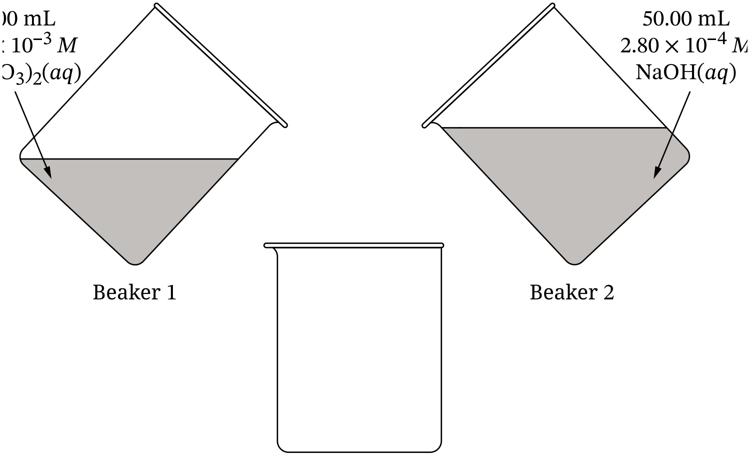
[Bar graph titled “Relative Abundance” vs. “Mass (amu)”; y-axis from 0 to 100 in increments of 20; x-axis shows tick marks at 24, 25, 26; a single thick vertical bar is drawn at mass 24 reaching a relative abundance of about 79.]

The percent abundance of magnesium-24 is 79%. The percent abundances of the other two natural isotopes of magnesium, magnesium-25 and magnesium-26, are approximately equal.

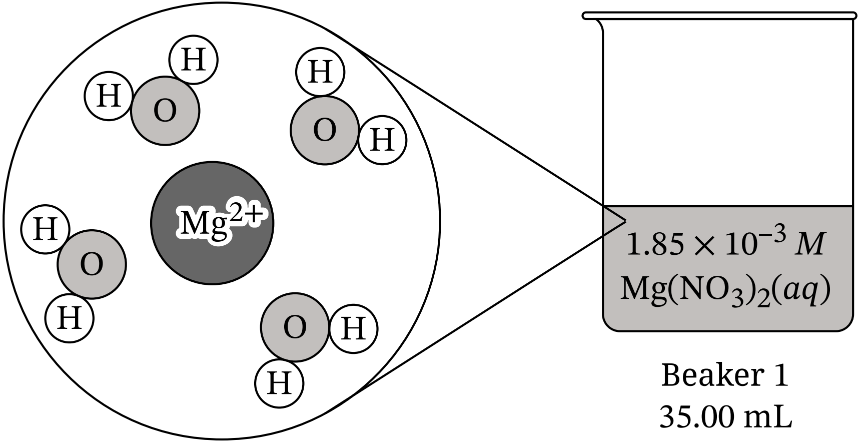
(a)(i) Complete the mass spectrum in part A by drawing thick lines in the appropriate locations to represent the percent abundance of magnesium-25 and magnesium-26.

(a)(ii) Describe the difference in atomic structure that accounts for the difference in mass between magnesium-25 and magnesium-26.

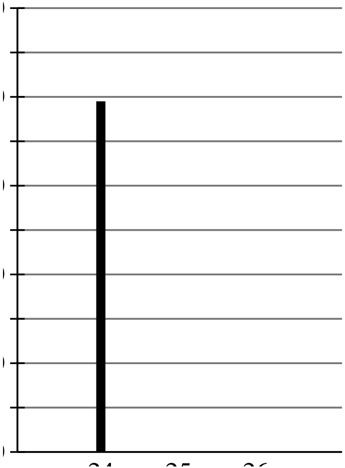
Question 1



Question 1



Question 1



Question 1

2025 ▪ Q1

Answer the following questions about magnesium.

(b) A student prepares a 1.85×10^{-3} *M* solution of $Mg(NO_3)_2(aq)$ in beaker 1 and a 2.80×10^{-4} *M* solution of $NaOH(aq)$ in beaker 2, as shown.
[Particle diagram: a magnesium ion, Mg^{2+}, at the center surrounded by six water molecules (H2O), each oriented with its oxygen atom pointing toward the central Mg^{2+} ion and its two hydrogen atoms pointing outward.]
[Beaker 1: labeled "1.85×10^{-3} *M* $Mg(NO_3)_2(aq)$", "Beaker 1", "35.00 mL".]
[Beaker 2: labeled "2.80×10^{-4} *M* $NaOH(aq)$", "Beaker 2", "50.00 mL".]
The particle diagram shown represents a magnesium ion, Mg^{2+}, in beaker 1. A sodium ion, Na^{+}, in beaker 2 has a weaker attraction to water than the Mg^{2+} does. Explain this phenomenon using Coulomb's law and each of the following.
(b)(i) The relative charge of the ions

Question 1

(b)(ii) The relative radii of the ions

Question 1

2025 ▪ Q1

Answer the following questions about magnesium.

(c) Calculate the pH of the solution in beaker 2.

Question 1

2025 ▪ Q1

Answer the following questions about magnesium.

(d) A student combines 35.00 mL of 1.85×10^{-3} M $Mg(NO_3)_2(aq)$ with 50.00 mL of 2.80×10^{-4} M $NaOH(aq)$, as shown in the diagram. Calculate $[Mg^{2+}]$ after the two solutions are combined but before any reaction takes place. (Assume that volumes are additive.)

[Diagram of two conical/Erlenmeyer flasks being poured into an empty Beaker 3. Left flask: "35.00 mL", "1.85×10^{-3} M", "$Mg(NO_3)_2(aq)$", labeled "Beaker 1". Right flask: "50.00 mL", "2.80×10^{-4} M", "$NaOH(aq)$", labeled "Beaker 2". Both flasks have an arrow pointing down into the empty "Beaker 3" between them.]

Question 1

2025 ▪ Q1

Answer the following questions about magnesium.

(e) The dissolution of magnesium hydroxide is represented by the following equation.

$$\mathrm{Mg(OH)_2}(s) \rightleftharpoons \mathrm{Mg^{2+}}(aq) + 2\,\mathrm{OH^-}(aq) \qquad K_{sp} = 5.61 \times 10^{-12}$$

(e)(i) Write the expression for the solubility product constant, K_{sp}.

(e)(ii) After the two solutions are combined in beaker 3 as described in part D, but before any reaction takes place, $[\mathrm{OH^-}] = 1.65 \times 10^{-4}$ M. Using your answer to part D, calculate the value of the reaction quotient, Q.

(e)(iii) Using the reaction quotient, Q, predict whether a precipitate should form as the mixture in beaker 3 approaches equilibrium. Justify your answer.

Question 1

2025 ▪ Q1

Answer the following questions about magnesium.

(f) In a separate experiment, the student adds $HNO_3(aq)$ to decrease the pH of a saturated solution containing undissolved $Mg(OH)_2(s)$. Does the amount of undissolved $Mg(OH)_2(s)$ increase, decrease, or remain the same as the $HNO_3(aq)$ is added? Justify your answer.

Solution 1

(a)

Mark scheme

- No separate response required — this is the context/stem describing the incomplete mass spectrum (magnesium-24 at 79% abundance) that parts (i) and (ii) below refer to.

(a)(i)

Mark scheme

- Draw two vertical bars at masses 25 and 26, each reaching a relative abundance of approximately 10 to 11 (since Mg-25 and Mg-26 together make up the remaining ~21% and are approximately equal, so roughly 10–11% each).

Solution 1

(a)(ii)

Mark scheme

- Magnesium-26 has one more neutron than magnesium-25 does (Mg-25 has 13 neutrons, Mg-26 has 14 neutrons; both isotopes have 12 protons, since they are the same element).

Solution 1

(b)

Mark scheme

- No separate response required — this is the context/stem introducing the 1.85×10^{-3} M $Mg(NO_3)_2$(aq) and 2.80×10^{-4} M NaOH(aq) solutions (with a particle diagram of hydrated Mg^{2+}) that parts (i) and (ii) below refer to.

(b)(i)

Mark scheme

- The charge on the sodium ion (Na^+, $+1$) is less than the charge on the magnesium ion (Mg^{2+}, $+2$). A smaller charge results in a weaker Coulombic attraction between Na^+ and water.

Solution 1

(b)(ii)

Mark scheme

- The Na^{+} ion is larger (has a greater ionic radius) than the Mg^{2+} ion, so the distance between Na^{+} and the oxygen atom of the water molecule will be greater. As distance increases, Coulombic attraction decreases, so Na^{+} is less strongly attracted to water than Mg^{2+}.

Solution 1

(c)

Mark scheme

- pOH $= -\log(2.80 \times 10^{-4}) = 3.553.$ pH $= 14 -$ pOH $= 14 - 3.553 = 10.447.$

Solution 1

(d)

Mark scheme

- Using $M_1V_1 = M_2V_2$: $M_2 = \dfrac{(1.85 \times 10^{-3}\ M)(0.03500\ \mathsf{L})}{0.03500\ \mathsf{L} + 0.05000\ \mathsf{L}} = 7.62 \times 10^{-4}\ M$.
  So $[\mathrm{Mg}^{2+}]$ after combining but before reaction is $7.62 \times 10^{-4}\ M$.

Solution 1

(e)

Mark scheme

- No separate response required — this is the context/stem giving the $Mg(OH)_2$ dissolution equilibrium and $K_{sp} = 5.61 \times 10^{-12}$ that parts (i)–(iii) below refer to.

(e)(i)

Mark scheme

- $K_{sp} = [Mg^{2+}][OH^-]^2$.

Solution 1

(e)(ii)

Mark scheme

- Using $[\mathrm{Mg}^{2+}] = 7.62 \times 10^{-4}\ M$ (from part D) and $[\mathrm{OH}^-] = 1.65 \times 10^{-4}\ M$ (given): $Q = [\mathrm{Mg}^{2+}][\mathrm{OH}^-]^2 = (7.62 \times 10^{-4})(1.65 \times 10^{-4})^2 = 2.07 \times 10^{-11}$.

(e)(iii)

Mark scheme

- $Q\ (2.07 \times 10^{-11}) > K_{sp}\ (5.61 \times 10^{-12})$, so a precipitate should form. Equivalently: the concentration of ions in solution (represented by Q) is greater than that of a saturated solution, so a precipitate will form.

Solution 1

(f)

Mark scheme

- The amount of undissolved $Mg(OH)_2(s)$ will decrease. The H^+ from $HNO_3(aq)$ reacts with OH^-, decreasing $[OH^-]$ and causing $Q < K_{sp}$. As a result, more $Mg(OH)_2(s)$ will dissolve until equilibrium is reestablished, resulting in less undissolved $Mg(OH)_2(s)$.

Question 3

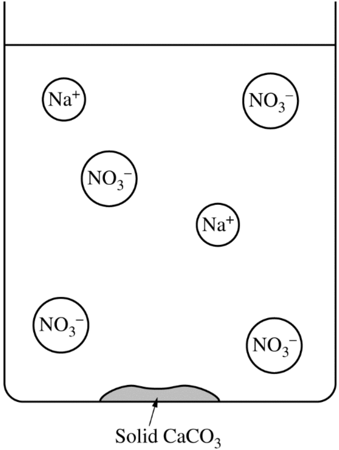
2019 ▪ Q3

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.

Question 3



Question 3

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

Question 3

2019 ▪ Q3

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.

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

(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.

Question 3

[Diagram of a beaker of solution after reaction: floating ion labels Na^{+}, NO_3^-, NO_3^-, Na^{+}, NO_3^-, NO_3^- scattered above a layer of gray solid labelled "Solid $CaCO_3$" at the bottom of the beaker]

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

Question 3

2019 ▪ Q3

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.

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

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

Question 3

2019 ▪ Q3

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.

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

(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.

Question 3

2019 ▪ Q3

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.

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

(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.

Question 3

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.

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

Question 3

2019 ▪ Q3

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.

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

(f)(i) The student decides to first determine $[OH^-]$ in the solution, then use that result to calculate the initial concentration of $CO_3^{2-}(aq)$.
Identify a laboratory method (not titration) that the student could use to collect data to determine $[OH^-]$ in the solution.

Question 3

(f)(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.)

Question 3

2019 ▪ Q3

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.

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

(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.

Question 3

2019 ▪ Q3

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.

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

(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.

Solution 3

(a)

Mark scheme

- Ca^{2} (aq) + $CO3^{2}$ (aq) → CaCO3(s). 1 point for the correct net ionic equation (spectator ions Na and NO3 omitted).

Solution 3

(b)

Mark scheme

- The completed diagram should show one Ca^{2} ion added among the floating Na and NO3 ions: Ca(NO3)2 was added in excess (100.0 mL of 1.0 M vs. only 50.0 mL of dilute Na2CO3), so some unreacted Ca^{2} remains in solution along with the spectator Na and NO3 ions. 1 point for drawing a Ca^{2} ion in the solution.

Solution 3

(c)

Mark scheme

- 0.93 g $CaCO_3 \times$ (1 mol $CaCO_3$ / 100.1 g) $=$ 0.0093 mol $CaCO_3$. Since the reaction is 1:1 (Na_2CO_3 : $CaCO_3$), 0.0093 mol $CaCO_3 \times$ (1 mol Na_2CO_3 / 1 mol $CaCO_3$) $=$ 0.0093 mol Na_2CO_3. 1 point for the correct answer (0.0093 mol).

Solution 3

(d)

Mark scheme

- Disagree. If the precipitate was not completely dried, residual water increases the measured mass of the 'CaCO3' precipitate above its true mass. This makes the calculated moles of CaCO3 (and therefore of Na2CO3) too high, not too low — so the calculated Na2CO3 molarity would actually be too HIGH, contrary to the student's claim. 1 point for disagreeing with valid justification.

Solution 3

(e)

Mark scheme

- The filtrate would conduct electricity, because dissolved ions remain in solution — specifically Na (aq), the excess Ca^{2} (aq) (from the excess Ca(NO3)2 added), and NO3 (aq). 1 point for the correct answer (conducts) with valid justification listing the ions present.

Solution 3

(f)(i)

Mark scheme

- Measure the pH of the solution using a pH meter (a non-titration laboratory method for determining [OH]). 1 point for identifying a valid method.

Solution 3

(f)(ii)

Mark scheme

- From the measured pH: pOH = 14 − pH, then [OH] = 10ˆ(−pOH). 1 point for this valid method of determining [OH] from the measured value. Then, using the Kb expression Kb = [HCO3][OH]/[CO3^2] with an ICE table (I: ci, 0, 0; C: −x, +x, +x; E: ci−x, x, x, where x = [OH] = [HCO3] at equilibrium since they form in a 1:1 ratio from water), solve ci = (x^2/Kb) + x for the initial concentration ci of CO3^2 (equal to the sum of the equilibrium [CO3^2] and [HCO3]). 1 point for this valid method of determining the initial concentration of CO3^2 from [OH].

Solution 3

(g)

Mark scheme

HCO3 is less than [CO3^{2}]. The small value of Kb (2.1×10 , much less than 1) indicates that the reactants (H2O and CO3^{2}) are favored at equilibrium over the products, so only a small fraction of CO3^{2} hydrolyzes to HCO3 . 1 point for the correct answer (less than) with valid justification.

Solution 3

(h)

Mark scheme

- No, the Na2CO3 solution is not suitable for making a pH-6 buffer. The pKa of HCO3 (the conjugate acid in this CO3^{2} /HCO3 system) is 10.32. A buffer is most effective when the desired pH is close to the pKa of its weak-acid component; pH 6 is far from pKa 10.32, so this system cannot buffer effectively at pH 6. 1 point for the correct answer (no) with a valid explanation referencing pKa.

Question 2

2014 ▪ Q2

$$CH_3CH_2COOH(aq) + H_2O(l) \rightleftharpoons CH_3CH_2COO^-(aq) + H_3O^+(aq)$$

Propanoic acid, CH_3CH_2COOH, is a carboxylic acid that reacts with water according to the equation above. At $25°C$ the pH of a 50.0 mL sample of 0.20 M CH_3CH_2COOH is 2.79.

(a) Identify a Brønsted-Lowry conjugate acid-base pair in the reaction. Clearly label which is the acid and which is the base.

Question 2

2014 ▪ Q2

$$CH_3CH_2COOH(aq) + H_2O(l) \rightleftharpoons CH_3CH_2COO^-(aq) + H_3O^+(aq)$$

Propanoic acid, CH_3CH_2COOH, is a carboxylic acid that reacts with water according to the equation above. At $25°C$ the pH of a 50.0 mL sample of 0.20 M CH_3CH_2COOH is 2.79.

(b) Determine the value of K_a for propanoic acid at $25°C$.

Question 2

2014 ▪ Q2

$$CH_3CH_2COOH(aq) + H_2O(l) \rightleftharpoons CH_3CH_2COO^-(aq) + H_3O^+(aq)$$

Propanoic acid, CH_3CH_2COOH, is a carboxylic acid that reacts with water according to the equation above. At $25°C$ the pH of a 50.0 mL sample of 0.20 M CH_3CH_2COOH is 2.79.

(c)(i) For each of the following statements, determine whether the statement is true or false. In each case, explain the reasoning that supports your answer.
The pH of a solution prepared by mixing the 50.0 mL sample of 0.20 M CH_3CH_2COOH with a 50.0 mL sample of 0.20 M NaOH is 7.00.

(c)(ii) For each of the following statements, determine whether the statement is true or false. In each case, explain the reasoning that supports your answer.

Question 2

If the pH of a hydrochloric acid solution is the same as the pH of a propanoic acid solution, then the molar concentration of the hydrochloric acid solution must be less than the molar concentration of the propanoic acid solution.

Question 2

2014 ▪ Q2

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Propanoic acid, CH_3CH_2COOH, is a carboxylic acid that reacts with water according to the equation above. At $25°C$ the pH of a 50.0 mL sample of 0.20 *M* CH_3CH_2COOH is 2.79.

(d) A student is given the task of determining the concentration of a propanoic acid solution of unknown concentration. A 0.173 *M* NaOH solution is available to use as the titrant. The student uses a 25.00 mL volumetric pipet to deliver the propanoic acid solution to a clean, dry flask. After adding an appropriate indicator to the flask, the student titrates the solution with the 0.173 *M* NaOH, reaching the end point after 20.52 mL of the base solution has been added.
Calculate the molarity of the propanoic acid solution.

Question 2

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Propanoic acid, CH_3CH_2COOH, is a carboxylic acid that reacts with water according to the equation above. At $25°C$ the pH of a 50.0 mL sample of 0.20 M CH_3CH_2COOH is 2.79.

(e) The student is asked to redesign the experiment to determine the concentration of a butanoic acid solution instead of a propanoic acid solution. For butanoic acid the value of pK_a is 4.83. The student claims that a different indicator will be required to determine the equivalence point of the titration accurately. Based on your response to part (b), do you agree with the student's claim? Justify your answer.

Solution 2

(a)

Mark scheme

- A valid Brønsted-Lowry conjugate acid-base pair: CH_3CH_2COOH (acid) and $CH_3CH_2COO^-$ (base); OR equivalently H_3O^+ (acid) and H_2O (base). Credit requires clearly labeling which species is the acid and which is the base.

Solution 2

(b) Mark scheme

- $[H_3O^+] = 10^{-pH} = 10^{-2.79} = 1.6 \times 10^{-3}$ M (1 point for solving for [H3O+]). Set up the Ka expression with $[CH_3CH_2COO^-] = [H_3O^+]$ and $[CH_3CH_2COOH] = 0.20 - [H_3O^+] \approx 0.20$ M: $K_a = \dfrac{[CH_3CH_2COO^-][H_3O^+]}{[CH_3CH_2COOH]}$ (1 point for the correct Ka expression or correct substitution). Solving: $K_a = \dfrac{(1.6 \times 10^{-3})^2}{0.20} = 1.3 \times 10^{-5}$ (1 point for the correct numeric Ka value).

Solution 2

(c)(i)

Mark scheme

- False. The conjugate base CH3CH2COO- formed at equivalence undergoes hydrolysis, $CH_3CH_2COO^- + H_2O \rightleftharpoons CH_3CH_2COOH + OH^-$, giving a solution with pH > 7, not exactly 7.00.

Solution 2

(c)(ii)

Mark scheme

- True. HCl is a strong acid that ionizes completely, so fewer moles of HCl are needed to produce the same $[H3O+]$ (and hence the same pH) as the propanoic acid solution, which only partially ionizes; therefore the HCl solution's molar concentration must be less than the propanoic acid solution's.

Solution 2

(d)

Mark scheme

- At the equivalence point, moles acid = moles base delivered. Moles NaOH = 0.02052 L × 0.173 mol/L = 3.55×10^{-3} mol = moles propanoic acid (1 point for correctly finding moles of acid that reacted). Molarity of acid = 3.55×10^{-3} mol / 0.02500 L = 0.142 M (1 point for the correct molarity). Equivalent method: since the acid is monoprotic, $M_A V_A = M_B V_B \Rightarrow M_A = (0.173\ M)(20.52\ \text{mL})/(25.00\ \text{mL}) = 0.142\ M$.

Solution 2

(e)

Mark scheme

- Disagree with the student's claim (1 point for disagreeing with a valid justification). From part (b), pKa for propanoic acid $= -\log(1.3 \times 10^{-5}) = 4.89$. Because butanoic acid's pKa (4.83) is so close to propanoic acid's pKa (4.89), the pH at the equivalence point of the butanoic acid titration should be close enough to that of the propanoic acid titration that the original indicator remains appropriate (1 point for numerically comparing the two pKa, Ka, or equivalence-point pH values).