

Past-paper walk-through

Introduction to Acids and Bases ■ 8.1

eXercise

Questions in this set

- 2026 Q3
- 2025 Q7
- 2015 Q6
- 2014 Q2

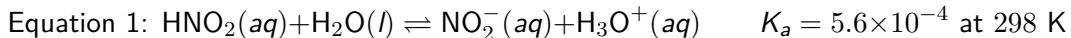
Reading the mark scheme

- **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.



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

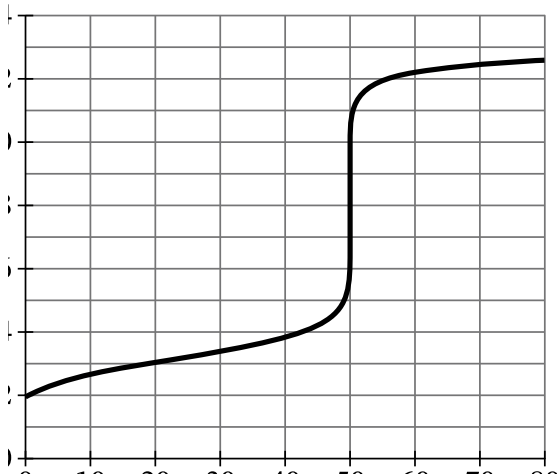
Table 1

Chemical Equation	Equilibrium Constant
$\text{HNO}_2(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{NO}_2^-(aq) + \text{H}_3\text{O}^+(aq)$	$K_a = 5.6 \times 10^{-4}$
$\text{H}_2\text{O}(l) + \text{H}_2\text{O}(l) \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{OH}^-(aq)$	$K_w = 1.0 \times 10^{-14}$
$\text{HNO}_2(aq) + \text{OH}^-(aq) \rightarrow \text{NO}_2^-(aq) + \text{H}_2\text{O}(l)$	$K_2 = ?$

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

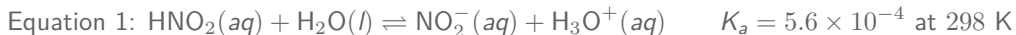
Question 3



Question 3

2026 ■ Q3

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



(b)(i) A solution of $\text{HNO}_2(aq)$ with an initial concentration of 0.125 M has a pH of 2.09.

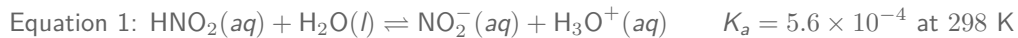
****Calculate**** the value of $[\text{H}_3\text{O}^+]$ in the solution. Show the work that leads to your answer.

(b)(ii) ****Calculate**** $[\text{HNO}_2]$ 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.



(c)(i) In an experiment, the solution of $0.125 \text{ M HNO}_2(aq)$ is heated to 333 K . The new equilibrium concentrations are determined to be $[\text{HNO}_2] = 0.114 \text{ M}$, $[\text{NO}_2^-] = 0.0109 \text{ M}$, and $[\text{H}_3\text{O}^+] = 0.0109 \text{ M}$.

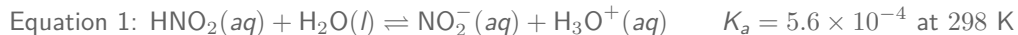
****Calculate**** the value of K_a for HNO_2 at 333 K . Show the work that leads to your answer.

(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

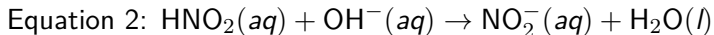
2026 ■ Q3

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



(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 $\text{HNO}_2(aq)$ in the bottle, the student titrates 35.0 mL of the $\text{HNO}_2(aq)$ with 0.16 M $\text{NaOH}(aq)$ at 298 K, which reacts according to Equation 2.



Question 3

The results of the titration are summarized in Figure 1.

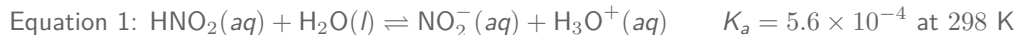
[Figure 1: Titration curve, pH vs. Volume of 0.16 M NaOH Added (mL); y-axis pH 0 to 14 in increments of 2, x-axis 0 to 80 mL in increments of 10; curve starts near (0, 2), rises gradually to about (40, 4), then rises steeply (equivalence point) between about 45-55 mL up to about pH 12, then levels off 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.

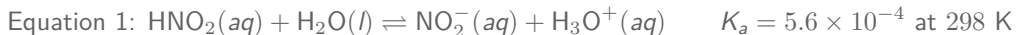


(e) Using Figure 1, ****calculate**** the molarity $\text{HNO}_2(aq)$ of in the bottle. Show the work that leads to your answer.

Question 3

2026 ■ Q3

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

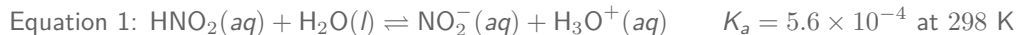


(f) ****Draw**** an X on Figure 1 to represent a point in the titration where $[\text{HNO}_2] > [\text{NO}_2^-]$ in the reaction mixture.

Question 3

2026 ■ Q3

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



(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
$\text{HNO}_2(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{NO}_2^-(aq) + \text{H}_3\text{O}^+(aq)$	$K_a = 5.6 \times 10^{-4}$
$\text{H}_2\text{O}(l) + \text{H}_2\text{O}(l) \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{OH}^-(aq)$	$K_w = 1.0 \times 10^{-14}$
$\text{HNO}_2(aq) + \text{OH}^-(aq) \rightarrow \text{NO}_2^-(aq) + \text{H}_2\text{O}(l)$	$K_2 = ?$

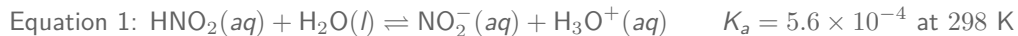
Question 3

****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.



(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 $\text{HNO}_2(aq)$ solution and titrating the solution with 0.16 M $\text{NaOH}(aq)$ 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 7

2025 ■ Q7

Answer the following questions about the glycolate ion, $\text{C}_2\text{H}_3\text{O}_3^-$, which acts as a base in aqueous solution. A Lewis diagram for the ion is provided.

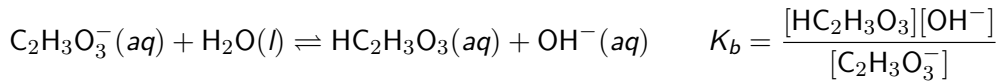
[Lewis structure of the glycolate ion in brackets with an overall negative charge:

$\text{H}-\text{O}-\text{C}(\text{—H})(\text{—H})-\text{C}(=\text{O})-\text{O}:$, i.e., an H atom bonded to an O atom (with two lone pairs) which is bonded to a C atom; that C atom is bonded to two H atoms and to a second C atom; the second C atom is double-bonded to an O atom (with two lone pairs) above it and singly bonded to another O atom (with three lone pairs) on the right.]

(a) On the Lewis diagram in part A, circle the atom that accepts the proton when the glycolate ion reacts with water.

When the glycolate ion reacts with water, it forms glycolic acid, $\text{HC}_2\text{H}_3\text{O}_3$, according to the following equation. The K_b expression for the reaction is provided.

Question 7



Question 7

2025 ■ Q7

Answer the following questions about the glycolate ion, $\text{C}_2\text{H}_3\text{O}_3^-$, which acts as a base in aqueous solution. A Lewis diagram for the ion is provided.

[Lewis structure of the glycolate ion in brackets with an overall negative charge:

$\text{H}-\text{O}-\text{C}(\text{---H})(\text{---H})-\text{C}(=\text{O})-\text{O}:$, i.e., an H atom bonded to an O atom (with two lone pairs) which is bonded to a C atom; that C atom is bonded to two H atoms and to a second C atom; the second C atom is double-bonded to an O atom (with two lone pairs) above it and singly bonded to another O atom (with three lone pairs) on the right.]

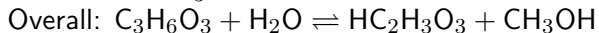
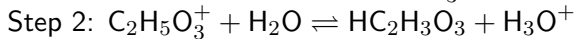
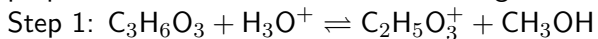
(b) At 25°C , a 2.5 M solution of glycolate is found to have $[\text{OH}^-] = 1.3 \times 10^{-5}\text{ M}$.

(b)(i) Calculate the value of K_b for the glycolate ion.

(b)(ii) Using your answer to part B (i), calculate the value of K_a for glycolic acid at 25°C .

Question 7

Glycolic acid can be produced from the hydrolysis of methyl glycolate, $\text{C}_3\text{H}_6\text{O}_3$. A proposed mechanism for the reaction is given.



Question 7

2025 ■ Q7

Answer the following questions about the glycolate ion, $\text{C}_2\text{H}_3\text{O}_3^-$, which acts as a base in aqueous solution. A Lewis diagram for the ion is provided.

[Lewis structure of the glycolate ion in brackets with an overall negative charge:

$\text{H}-\text{O}-\text{C}(\text{—H})(\text{—H})-\text{C}(=\text{O})-\text{O}:$, i.e., an H atom bonded to an O atom (with two lone pairs) which is bonded to a C atom; that C atom is bonded to two H atoms and to a second C atom; the second C atom is double-bonded to an O atom (with two lone pairs) above it and singly bonded to another O atom (with three lone pairs) on the right.]

(c) A student claims that H_3O^+ is a catalyst for the reaction. Do you agree or disagree? Justify your answer based on the mechanism given.

Solution 7

(a)

Mark scheme

- Circle one of the two equivalent terminal oxygen atoms on the carboxylate (--COO^-) group of the glycolate ion — the atom that accepts the proton (H^+) from water to form glycolic acid. Because of resonance, the two C–O bonds on the carboxylate group are equivalent, so circling either one is acceptable.

Solution 7

(b)

Mark scheme

- No separate response required — this is the context/stem giving $[\text{OH}^-] = 1.3 \times 10^{-5} \text{ M}$ for a 2.5 M glycolate solution at 25°C that parts (i) and (ii) below use.

Solution 7

(b)(i)

Mark scheme

$$\blacksquare K_b = \frac{[\text{HC}_2\text{H}_3\text{O}_3][\text{OH}^-]}{[\text{C}_2\text{H}_3\text{O}_3^-]} = \frac{(1.3 \times 10^{-5})(1.3 \times 10^{-5})}{2.5 - 1.3 \times 10^{-5}} \approx \frac{(1.3 \times 10^{-5})^2}{2.5} = 6.8 \times 10^{-11}.$$

Solution 7

(b)(ii)**Mark scheme**

$$\blacksquare K_a = \frac{K_w}{K_b} = \frac{1.0 \times 10^{-14}}{6.8 \times 10^{-11}} = 1.5 \times 10^{-4} \text{ (using the } K_b \text{ value from part B(i)).}$$

Solution 7

(c)

Mark scheme

- Agree. H_3O^+ is consumed in step 1 of the mechanism and regenerated in step 2, which is consistent with the behavior of a catalyst — it is used up and then reformed, so it is not permanently consumed by the overall reaction.

Question 6

2015 ■ Q6

A student learns that ionic compounds have significant covalent character when a cation has a polarizing effect on a large anion. As a result, the student hypothesizes that salts composed of small cations and large anions should have relatively low melting points.

Compound	Melting Point (°C)
LiI	449
KI	686
LiF	845
NaF	993

Question 6

- (a)** Select two compounds from the table and explain how the data support the student's hypothesis.
- (b)** Identify a compound from the table that can be dissolved in water to produce a basic solution. Write the net ionic equation for the reaction that occurs to cause the solution to be basic.

Question 6

Compound	Melting Point (°C)
LiI	449
KI	686
LiF	845
NaF	993

Solution 6

(a) Mark scheme

- Example: choose LiI and KI. LiI has a small cation (Li^+) and a large anion (I^-); KI has a larger cation (K^+) but the same large anion (I^-). LiI's melting point (449 C) is lower than KI's (686 C), so the compound with the smaller, more polarizing cation on the same large anion has the lower melting point, supporting the hypothesis that small-cation/large-anion salts have relatively low melting points. (Equally acceptable pairs: LiI vs. LiF – same small cation, LiI has the larger anion I^- and the lower melting point, $449\text{ C} < 845\text{ C}$; or LiI vs. NaF – LiI, with its small cation and large anion, has a much lower melting point, 449 C, than NaF, 993 C.)
1 point for choosing an appropriate pair of compounds from {LiI/KI, LiI/LiF,

Solution 6

LiI/NaF ; 1 point for an explanation that correctly supports the hypothesis using the melting-point data.

Solution 6

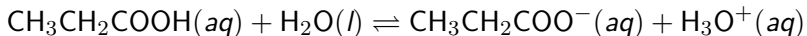
(b)

Mark scheme

- Either LiF or NaF is an acceptable choice: F⁻ is the conjugate base of the weak acid HF, so it hydrolyzes in water to give a basic solution (Li⁺ and Na⁺ are spectator ions and do not affect pH). Net ionic equation: $\text{F}^{-}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{HF}(\text{aq}) + \text{OH}^{-}(\text{aq})$. 1 point for choosing one of the two correct compounds (LiF or NaF); 1 point for writing the correct, balanced net-ionic hydrolysis equation.

Question 2

2014 ■ Q2

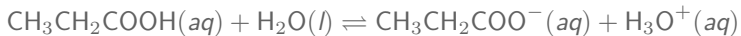


Propanoic acid, $\text{CH}_3\text{CH}_2\text{COOH}$, is a carboxylic acid that reacts with water according to the equation above. At 25°C the pH of a 50.0 mL sample of 0.20 M $\text{CH}_3\text{CH}_2\text{COOH}$ is 2.79.

(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

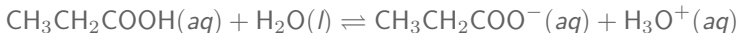


Propanoic acid, $\text{CH}_3\text{CH}_2\text{COOH}$, is a carboxylic acid that reacts with water according to the equation above. At 25°C the pH of a 50.0 mL sample of 0.20 M $\text{CH}_3\text{CH}_2\text{COOH}$ is 2.79.

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

Question 2

2014 ■ Q2



Propanoic acid, $\text{CH}_3\text{CH}_2\text{COOH}$, 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 $\text{CH}_3\text{CH}_2\text{COOH}$ 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 $\text{CH}_3\text{CH}_2\text{COOH}$ with a 50.0 mL sample of 0.20 M NaOH is 7.00.

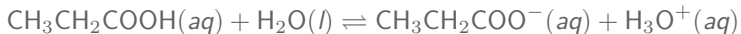
(c)(ii) For each of the following statements, determine whether the statement is true or false. In each case, explain the reasoning that supports your answer.

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



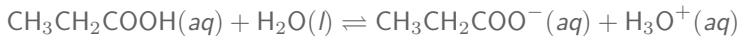
Propanoic acid, $\text{CH}_3\text{CH}_2\text{COOH}$, is a carboxylic acid that reacts with water according to the equation above. At 25°C the pH of a 50.0 mL sample of 0.20 M $\text{CH}_3\text{CH}_2\text{COOH}$ is 2.79.

(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

2014 ■ Q2



Propanoic acid, $\text{CH}_3\text{CH}_2\text{COOH}$, 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 $\text{CH}_3\text{CH}_2\text{COOH}$ 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 $\text{p}K_a$ 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: $\text{CH}_3\text{CH}_2\text{COOH}$ (acid) and $\text{CH}_3\text{CH}_2\text{COO}^-$ (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

- $[\text{H}_3\text{O}^+] = 10^{-\text{pH}} = 10^{-2.79} = 1.6 \times 10^{-3} \text{ M}$ (1 point for solving for $[\text{H}_3\text{O}^+]$). Set up the K_a expression with $[\text{CH}_3\text{CH}_2\text{COO}^-] = [\text{H}_3\text{O}^+]$ and

$$[\text{CH}_3\text{CH}_2\text{COOH}] = 0.20 - [\text{H}_3\text{O}^+] \approx 0.20 \text{ M}: K_a = \frac{[\text{CH}_3\text{CH}_2\text{COO}^-][\text{H}_3\text{O}^+]}{[\text{CH}_3\text{CH}_2\text{COOH}]} \quad (1$$

point for the correct K_a expression or correct substitution). Solving:

$$K_a = \frac{(1.6 \times 10^{-3})^2}{0.20} = 1.3 \times 10^{-5} \quad (1 \text{ point for the correct numeric } K_a \text{ value}).$$

Solution 2

(c)(i)

Mark scheme

- False. The conjugate base $\text{CH}_3\text{CH}_2\text{COO}^-$ formed at equivalence undergoes hydrolysis, $\text{CH}_3\text{CH}_2\text{COO}^- + \text{H}_2\text{O} \rightleftharpoons \text{CH}_3\text{CH}_2\text{COOH} + \text{OH}^-$, giving a solution with $\text{pH} > 7$, 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 $[\text{H}_3\text{O}^+]$ (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 = $0.02052 \text{ L} \times 0.173 \text{ mol/L} = 3.55 \times 10^{-3} \text{ mol}$ = moles propanoic acid (1 point for correctly finding moles of acid that reacted). Molarity of acid = $3.55 \times 10^{-3} \text{ mol} / 0.02500 \text{ L} = 0.142 \text{ M}$ (1 point for the correct molarity). Equivalent method: since the acid is monoprotic,
 $M_A V_A = M_B V_B \Rightarrow M_A = (0.173 \text{ M})(20.52 \text{ mL}) / (25.00 \text{ mL}) = 0.142 \text{ M}.$

Solution 2

(e)

Mark scheme

- Disagree with the student's claim (1 point for disagreeing with a valid justification). From part (b), pK_a for propanoic acid = $-\log(1.3 \times 10^{-5}) = 4.89$. Because butanoic acid's pK_a (4.83) is so close to propanoic acid's pK_a (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 pK_a , K_a , or equivalence-point pH values).