

Past-paper walk-through

Molecular Structure of Acids and Bases ■ 8.6

eXercise

Questions in this set

- 2025 Q7
- 2024 Q1

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 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.

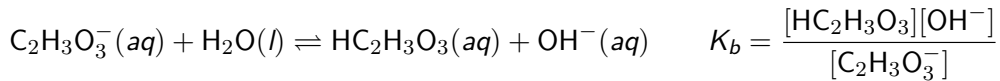
[Lewis structure of the glycolate ion in brackets with an overall negative charge:

$\text{H}-\text{O}-\text{C}(\text{—H})(\text{—H})-\text{C}(=\text{O})-\text{O}:$, 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



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2025 ■ Q7

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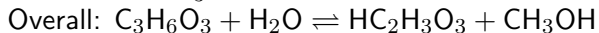
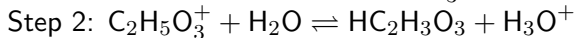
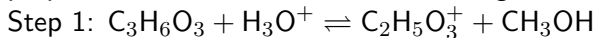
(b) At 25°C , a 2.5 M solution of glycolate is found to have $[\text{OH}^-] = 1.3 \times 10^{-5}\text{ M}$.

(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

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[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

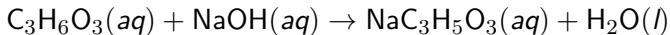
(c)

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 1

2024 ■ Q1



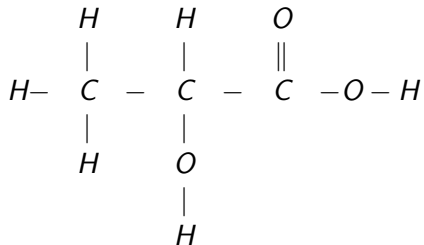
1. A student is studying the reaction between lactic acid, $\text{C}_3\text{H}_6\text{O}_3$, and sodium hydroxide, NaOH , as represented in the balanced equation above.

(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.

[Structural (Lewis) formula of lactic acid: a chain $\text{H}-\text{C}-\text{C}-\text{C}(=\text{O})-\text{O}-\text{H}$, drawn as:
Top row: H, H, O(double bond)
The first carbon bears an H above, an H below, and a bond to the second carbon.
The second carbon bears an OH group below it (O bonded down to an H).
The third carbon is a carbonyl carbon ($\text{C}=\text{O}$, double bond to

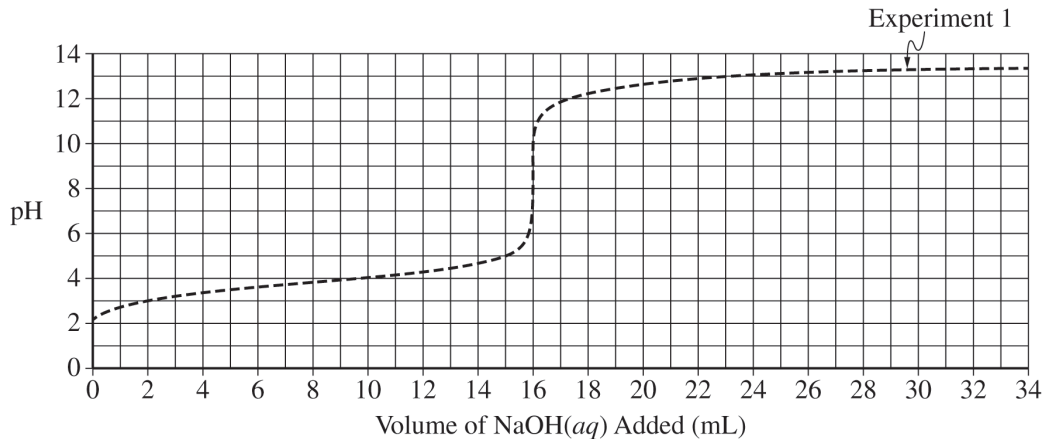
Question 1

O above) bonded to an —O—H (single-bonded hydroxyl oxygen then H) on the right.
Full skeleton:

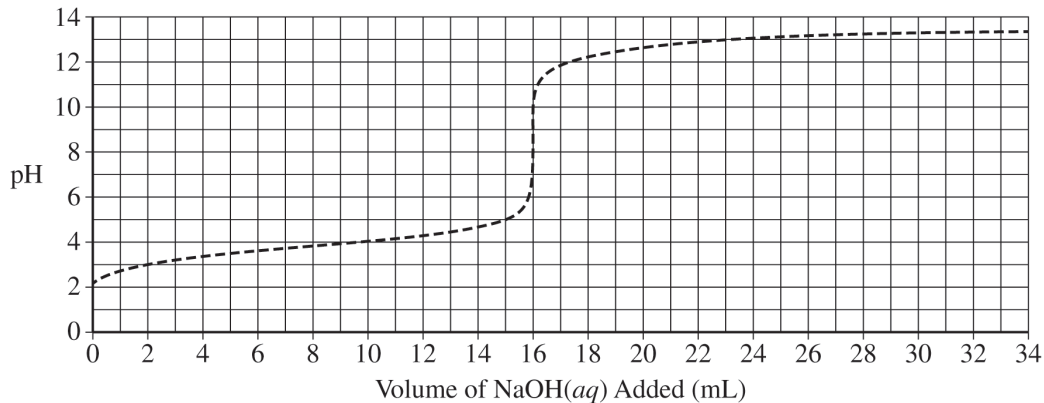


The hydrogen to circle is the one on the hydroxyl oxygen attached to the carbonyl carbon (the carboxylic acid —C(=O)—O—H proton).]

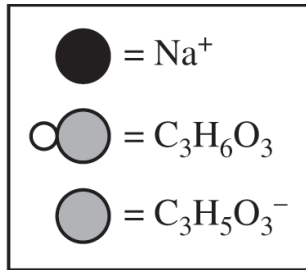
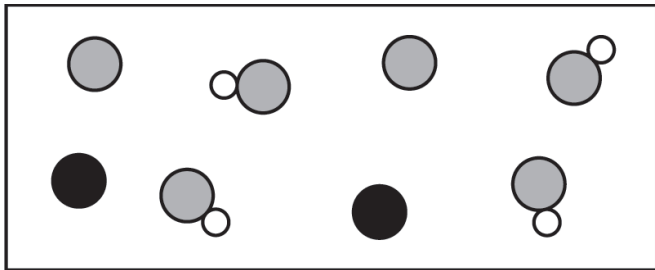
Question 1



Question 1

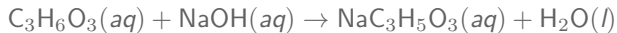


Question 1



Question 1

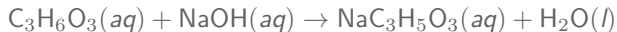
2024 ■ Q1



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.
(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.

Question 1

2024 ■ Q1



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.

(c) 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. The student's data are shown in the following graph.

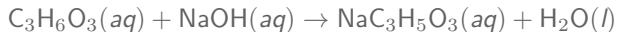
[Graph: titration curve of pH vs. Volume of $\text{NaOH}(aq)$ Added (mL); x-axis 0 to 34 mL in increments of 2, y-axis pH 0 to 14 in increments of 2. Curve starts near pH 2-3 at $V=0$, rises slowly/gradually (buffer region) from about $V=2$ to $V=14$, then shows a

Question 1

steep equivalence-point jump between about $V=15$ and $V=17$ (pH rising sharply from about 4 to about 11-12), then levels off and rises slowly to about pH 13 by $V=34$.] Use the information in the graph to determine the approximate pK_a of lactic acid.

Question 1

2024 ■ Q1



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.

(d)(i) [Particle diagram box showing the relative amounts of major species in a sample of the solution in the flask at one point during the titration. Water molecules are omitted. Key: solid black circle = Na^+ ; circle half-white/half-gray (with a small white circle attached) = $\text{C}_3\text{H}_6\text{O}_3$; circle half-black/half-gray (with a small white circle attached) = $\text{C}_3\text{H}_5\text{O}_3^-$. The box contains 2 large gray/white two-tone circles (labeled as $\text{C}_3\text{H}_6\text{O}_3$ -type), 2 large gray/black two-tone circles (labeled as $\text{C}_3\text{H}_5\text{O}_3^-$ -type), and 2

Question 1

small solid black circles (Na^+), with small white circles attached to some of the larger circles.]

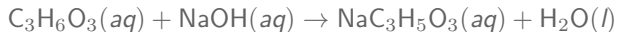
The preceding diagram represents the relative amounts of major species in a sample of the solution in the flask at one point during the titration. (Note that water molecules are omitted.)

Draw an X on the preceding titration curve at a point in the titration where the reaction mixture would be represented by this diagram.

(d)(ii) Justify your answer.

Question 1

2024 ■ Q1



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.

(e) The following table shows two experiments:

Experiment	Mass of $\text{NaOH}(s)$ (grams)	Volume of Solution (mL)	Titration Curve
1	10.22	500.	Already shown on graph
2	20.44	500.	?

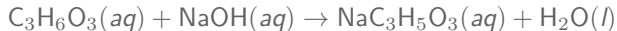
Question 1

The student repeats the experiment but uses a solution of $\text{NaOH}(aq)$ 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.

[Blank graph titled “Experiment 1” with a faint curve of Experiment 1 shown as reference (pH vs. Volume of $\text{NaOH}(aq)$ Added (mL), x-axis 0 to 34 mL, y-axis pH 0 to 14); student draws the Experiment 2 curve on the same axes.]

Question 1

2024 ■ Q1



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.

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

Question 1

(f)(ii) Calculate the molar enthalpy of reaction, in $\text{kJ/mol}_{\text{rxn}}$. Include the sign in your answer.

(f)(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.

Solution 1

(a)

Mark scheme

- Circle the rightmost hydrogen atom — the acidic O–H proton on the carboxylic acid group ($-\text{C}(=\text{O})-\text{O}-\text{H}$). This H is the most acidic (bonded to O, adjacent to the electron-withdrawing carbonyl) and is the one that reacts with NaOH in the acid–base neutralization.

Solution 1

(b)

Mark scheme

$$\blacksquare \text{ Molarity} = \frac{(10.22 \text{ g}) \left(\frac{1 \text{ mol}}{40.00 \text{ g}} \right)}{0.500 \text{ L}} = 0.511 \text{ M}.$$

Solution 1

(c)

Mark scheme

- $pK_a = 3.9$ (acceptable range: 3.7–4.0), read as the pH at the half-equivalence point of the titration curve (where $pH = pK_a$).

Solution 1

(d)(i)

Mark scheme

- The particle diagram shows more lactic acid (HA) particles than lactate (A^-) particles present in solution at that point during the titration. The X should be placed on the titration curve (from part c) at a volume ≥ 3 mL and < 8 mL — i.e., before the half-equivalence point, consistent with acid predominating over conjugate base at that point.

Solution 1

(d)(ii)

Mark scheme

- Justification: more acid (HA) particles are present than conjugate base (A^-) particles, meaning the titration is before the half-equivalence point (where $[HA] = [A^-]$).

Solution 1

(e) Mark scheme

- Draw the titration curve expected for Experiment 2 (NaOH solution with twice the concentration titrating the same lactic acid sample). Two criteria are scored:
(1) Equivalence point — doubling the NaOH concentration means HALF the volume is needed to deliver the same moles of base, so the new equivalence point should be at 8 mL (half of Experiment 1's 16 mL equivalence volume), NOT at 16 mL.
(2) Shape — the drawn curve should begin at the same initial pH as Experiment 1's curve, rise gradually through a buffer region, rise sharply at a volume different from 16 mL (i.e., near 8 mL), and end (plateau) at a final pH similar to Experiment 1's curve.

Solution 1

(f)

Mark scheme

- $q = mc\Delta T = (200.0 \text{ g})(4.2 \text{ J/(g} \cdot ^\circ\text{C)})(23.2^\circ\text{C} - 20.0^\circ\text{C}) = 2700 \text{ J}$ (heat absorbed by the combined solution).

Solution 1

(f)(ii)

Mark scheme

$$\blacksquare q_{rxn} = -q_{soln} = -2700 \text{ J} = -2.7 \text{ kJ.}$$

$$\Delta H_{rxn} = \frac{q_{rxn}}{\text{mol}} = \frac{-2.7 \text{ kJ}}{(0.100 \text{ L})(0.500 \text{ mol/L})} = -54 \text{ kJ/mol}_{rxn}. \text{ (Sign must be included: negative, exothermic.)}$$

Solution 1

(f)(iii)

Mark scheme

- Agree. Heat lost from the system to the surroundings would result in a lower final (measured) temperature, which produces smaller measured values of ΔT , q_{soln} , and thus $|\Delta H_{rxn}|$ than the true (actual) value — so the experimental molar enthalpy will be smaller in magnitude than the actual value.