Past-paper walk-through

Heat Capacity and Calorimetry ▪ 6.4

eXercise

Questions in this set

- 2026 Q1
- 2025 Q3
- 2024 Q1
- 2024 Q4
- 2023 Q3
- 2022 Q1
- 2021 Q4
- 2019 Q1
- 2018 Q1
- 2017 Q5

Questions in this set

- 2016 Q1
- 2015 Q7

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 1

2026 ▪ Q1

A student performs a calorimetry experiment with KCl.
(a)(i) Consider the K^+ ion in KCl.
Write the complete ground-state electron configuration for the potassium ion, K^+.
(a)(ii) Which has the larger radius, the K^+ ion or the K atom? **Explain** your reasoning using principles of atomic structure.

Question 1

Mass of water	97.5 g
Mass of KCl (s)	6.80 g
Initial temperature of water	24.5°C
Final temperature of solution	21.1°C

Question 1

2026 ▪ Q1

A student performs a calorimetry experiment with KCl.

(b) The following information applies to parts B, C, D, and E.

A student performs an experiment to determine the enthalpy of solution, ΔH_{soln}, of KCl. The student places water in a calorimeter, measures the initial temperature, adds KCl(s), and stirs until the KCl dissolves completely. The temperature is continuously monitored during the experiment. Data from the experiment are given in the following table.

Quantity	Value
Mass of water	97.5 g
Mass of KCl (s)	6.80 g
Initial temperature of water	$24.5°$C
Final temperature of solution	$21.1°$C

Describe how the student can use the temperature readings during the experiment to determine when the dissolution is complete.

Question 1

2026 ▪ Q1

A student performs a calorimetry experiment with KCl.

(c)(i) Use the data in the table to do the following.
Calculate the magnitude of the thermal energy, q, in joules, transferred during the dissolution. Show the work that leads to your answer. (Assume that the solution has a specific heat capacity of 3.95 J$/(\mathrm{g} \cdot {}^\circ\mathrm{C})$.)

(c)(ii) **Calculate** the value of the molar enthalpy of solution, ΔH_{soln}, in kJ/mol, for KCl given that 0.0912 mol of KCl dissolved. Show the work that leads to your answer. Include the sign with your answer.

Question 1

2026 ▪ Q1

A student performs a calorimetry experiment with KCl.

(d) The calorimeter is not perfectly insulated. Would this cause the magnitude of ΔH_{soln} calculated in part C (ii) to be greater than, less than, or equal to the accepted value? **Justify** your answer.

Question 1

2026 ▪ Q1

A student performs a calorimetry experiment with KCl.

(e) The student performs a second experiment using the same mass of water but 6.80 g of RbCl(s) instead of 6.80 g of KCl(s). The magnitude of the molar enthalpy of solution, ΔH_{soln}, of RbCl is approximately equal to that of KCl.

Is the magnitude of ΔT in the RbCl experiment greater than, less than, or equal to that in the KCl experiment? **Justify** your answer. (Assume that the specific heat capacities of the solutions are equal.)

Question 1

2026 ▪ Q1

A student performs a calorimetry experiment with KCl.

(f)(i) RbCl has a K_{sp} of 57 at $20°$C.

Write the net ionic equation for the dissolution of RbCl in pure water.

(f)(ii) **Calculate** the molar solubility of RbCl in a saturated solution at $20°$C. Show the work that leads to your answer.

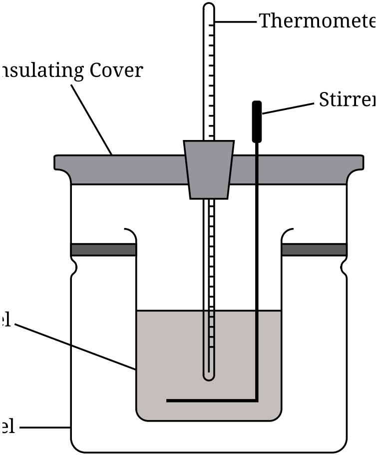
(f)(iii) A second saturated solution is prepared by dissolving RbCl(s) in 1.0 M KCl(aq) at $20°$C instead of in pure water. Will the molar solubility of RbCl in 1.0 M KCl(aq) be greater than, less than, or equal to the molar solubility calculated in part F (ii)? **Justify** your answer.

Question 3

2025 ▪ Q3

White phosphorus is composed of P_4 molecules with a tetrahedral structure, as shown in the diagram on the left. Each P atom is bonded to the other three P atoms by single bonds, as shown in the incomplete Lewis diagram on the right.
[Left: a ball-and-stick tetrahedral structure of P_4, showing four P atoms (spheres) at the vertices of a tetrahedron connected by bonds (sticks).]
[Right: an incomplete Lewis diagram showing four P atoms arranged in a tetrahedral projection (one P at top, one P in the middle/front, two P at the bottom left and right), connected by single bonds forming the P4 skeleton, with no lone pairs drawn yet.]
(a) In the box in part A, complete the Lewis diagram for P_4 by drawing the nonbonding electrons.

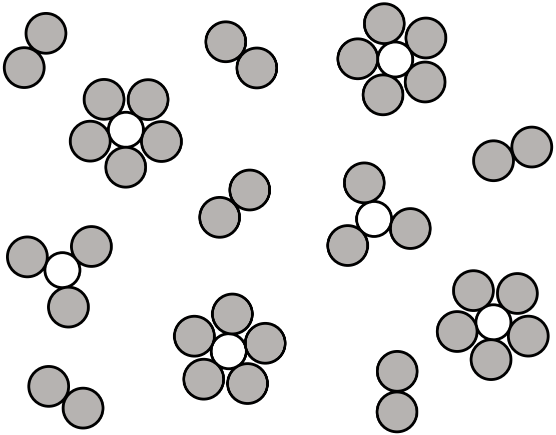
Question 3



Question 3

Mass of P_4O_{10}	0.100 g
Mass of H_2O	100.0 g
Initial temperature	22.00° C
Final temperature	22.38° C
Molar mass of P_4O_{10}	283.9 g/mol
Specific heat of H_2O	4.18 J/(g·°C)

Question 3



Question 3

2025 ▪ Q3

White phosphorus is composed of P_4 molecules with a tetrahedral structure, as shown in the diagram on the left. Each P atom is bonded to the other three P atoms by single bonds, as shown in the incomplete Lewis diagram on the right.

[Left: a ball-and-stick tetrahedral structure of P_4, showing four P atoms (spheres) at the vertices of a tetrahedron connected by bonds (sticks).]

[Right: an incomplete Lewis diagram showing four P atoms arranged in a tetrahedral projection (one P at top, one P in the middle/front, two P at the bottom left and right), connected by single bonds forming the P4 skeleton, with no lone pairs drawn yet.]

(b) The reaction of white phosphorus with oxygen to form $P_4O_{10}(s)$ is thermodynamically favorable at 298 K. The reaction is represented by equation 1.

Equation 1: $P_4(s) + 5\,O_2(g) \rightarrow P_4O_{10}(s)$

Question 3

(b)(i) The entropy change of the reaction, ΔS°, is negative. Using particle-level reasoning, explain why the entropy decreases as the reaction progresses.
(b)(ii) The enthalpy change of the reaction, ΔH°, is also negative. A student claims that the favorability of the reaction is driven by enthalpy and **not** by entropy. Is the student's claim correct? Justify your answer by using the relationship between ΔG°, ΔH°, and ΔS°.

Question 3

2025 ▪ Q3

White phosphorus is composed of P_4 molecules with a tetrahedral structure, as shown in the diagram on the left. Each P atom is bonded to the other three P atoms by single bonds, as shown in the incomplete Lewis diagram on the right.
[Left: a ball-and-stick tetrahedral structure of P_4, showing four P atoms (spheres) at the vertices of a tetrahedron connected by bonds (sticks).]

[Right: an incomplete Lewis diagram showing four P atoms arranged in a tetrahedral projection (one P at top, one P in the middle/front, two P at the bottom left and right), connected by single bonds forming the P4 skeleton, with no lone pairs drawn yet.]

(c) $P_4O_{10}(s)$ reacts exothermically with water to form phosphoric acid, as represented by equation 2.

Equation 2: $P_4O_{10}(s) + 6\,H_2O(l) \rightarrow 4\,H_3PO_4(aq)$

Question 3

A chemist uses a calorimetry experiment to determine the enthalpy change for the reaction, as represented by the following diagram.
[Calorimeter diagram: a coffee-cup-style calorimeter labeled "Thermometer" (inserted through the insulating cover), "Stirrer" (inserted alongside the thermometer), "Insulating Cover" (the lid), "Inner Vessel" (the cup holding the solution, shaded), and "Outer Vessel" (the outer supporting cup).]
The chemist carries out the calorimetry experiment and records the following information.

Quantity	Value
Mass of P_4O_{10}	0.100 g
Mass of H_2O	100.0 g
Initial temperature	$22.00°$C
Final temperature	$22.38°$C
Molar mass of P_4O_{10}	283.9 g/mol
Specific heat of H_2O	4.18 J/$(g \cdot° C)$

(c)(i) Calculate the amount of heat, *q*, released during the experiment, in kJ. Assume that the specific heat of the solution is the same as that of water.

Question 3

(c)(ii) Calculate the value of ΔH°_{rxn} for equation 2 in $\mathrm{kJ/mol}_{rxn}$. Include the sign in your answer.

Question 3

2025 ▪ Q3

White phosphorus is composed of P_4 molecules with a tetrahedral structure, as shown in the diagram on the left. Each P atom is bonded to the other three P atoms by single bonds, as shown in the incomplete Lewis diagram on the right.

[Left: a ball-and-stick tetrahedral structure of P_4, showing four P atoms (spheres) at the vertices of a tetrahedron connected by bonds (sticks).]

[Right: an incomplete Lewis diagram showing four P atoms arranged in a tetrahedral projection (one P at top, one P in the middle/front, two P at the bottom left and right), connected by single bonds forming the P4 skeleton, with no lone pairs drawn yet.]

(d) The chemist weighed out 0.100 g P_4O_{10} of and 100.0 g of H_2O to perform a second trial. In the second trial, some of the solid P_4O_{10} stuck to the weighing paper and was not transferred to the calorimeter. Given that P_4O_{10} is the limiting reactant,

Question 3

would ΔT for the second trial be greater than, less than, or equal to the value in the first trial? Justify your answer.

$P_4(s)$ also reacts readily with $Cl_2(g)$ to produce phosphorus trichloride, $PCl_3(g)$, which in turn reacts with $Cl_2(g)$ in an equilibrium process to produce $PCl_5(g)$. The reactions are represented by equations 3 and 4.

Equation 3: $P_4(s) + 6\,Cl_2(g) \rightarrow 4\,PCl_3(g) \qquad \Delta H_1^\circ = -1148$ kJ/mol$_{rxn}$

Equation 4: $PCl_3(g) + Cl_2(g) \rightleftharpoons PCl_5(g) \qquad \Delta H_2^\circ = -88$ kJ/mol$_{rxn}$

Question 3

2025 ▪ Q3

White phosphorus is composed of P_4 molecules with a tetrahedral structure, as shown in the diagram on the left. Each P atom is bonded to the other three P atoms by single bonds, as shown in the incomplete Lewis diagram on the right.

[Left: a ball-and-stick tetrahedral structure of P_4, showing four P atoms (spheres) at the vertices of a tetrahedron connected by bonds (sticks).]

[Right: an incomplete Lewis diagram showing four P atoms arranged in a tetrahedral projection (one P at top, one P in the middle/front, two P at the bottom left and right), connected by single bonds forming the P4 skeleton, with no lone pairs drawn yet.]

(e) Calculate the standard enthalpy of formation of $PCl_5(g)$ represented by equation 5.

Equation 5: $\frac{1}{4}P_4(s) + \frac{5}{2}Cl_2(g) \rightarrow PCl_5(g) \qquad \Delta H_f^\circ = ?$

The following particle-level diagram represents the contents of the vessel in an equilibrium mixture at 546 K involving equation 4.

Question 3

[Particle diagram: a box containing multiple particles at random positions representing an equilibrium mixture; a key indicates two-atom particles (grey-grey) = Cl_2, four-atom tetrahedral-looking particles (grey with three white) = PCl_3, and six-atom particles (grey with five white) = PCl_5. The box shows several Cl_2 particles (pairs of grey circles), several PCl_3 particles (grey center with three white circles), and several PCl_5 particles (grey center with five white circles) scattered throughout.]

Question 3

2025 ▪ Q3

White phosphorus is composed of P_4 molecules with a tetrahedral structure, as shown in the diagram on the left. Each P atom is bonded to the other three P atoms by single bonds, as shown in the incomplete Lewis diagram on the right.

[Left: a ball-and-stick tetrahedral structure of P_4, showing four P atoms (spheres) at the vertices of a tetrahedron connected by bonds (sticks).]

[Right: an incomplete Lewis diagram showing four P atoms arranged in a tetrahedral projection (one P at top, one P in the middle/front, two P at the bottom left and right), connected by single bonds forming the P4 skeleton, with no lone pairs drawn yet.]

(f) Equation 4 for the reaction that occurs is shown.

Equation 4: $\mathrm{PCl_3}(g) + \mathrm{Cl_2}(g) \rightleftharpoons \mathrm{PCl_5}(g) \qquad \Delta H_2^\circ = -88\ \mathrm{kJ/mol}_{rxn}$

(f)(i) If each particle in the diagram represents a partial pressure of 1.00 atm, what is the value of K_p for the equilibrium mixture at 546 K?

Question 3

(f)(ii) Does the value of K_p increase, decrease, or remain the same when the temperature is increased to 596 K? Justify your answer based on ΔH_2°.

Solution 3

(a)

Mark scheme

- Complete Lewis diagram for P_4: the four P atoms form a tetrahedron, each bonded to the other three P atoms by single bonds, and each P atom bears one lone (nonbonding) pair of electrons — giving each P three bonding pairs plus one lone pair, satisfying the octet rule.

Solution 3

(b)

Mark scheme

- No separate response required — this is the context/stem presenting equation 1 ($P_4(s) + 5\,O_2(g) \rightarrow P_4O_{10}(s)$), thermodynamically favorable at 298 K, that parts (i) and (ii) below refer to.

(b)(i)

Mark scheme

- Because gas particles are more dispersed (have more accessible microstates) than solids, the entropy decreases as the reactants (which include a gas, O_2) convert into the solid product (P_4O_{10}).

Solution 3

(b)(ii)

Mark scheme

- Yes, the student's claim is correct. Given $\Delta G^\circ_{rxn} = \Delta H^\circ_{rxn} - T\Delta S^\circ_{rxn}$, the reaction must have $\Delta G^\circ_{rxn} < 0$ to be favorable. Because the reaction is exothermic, $\Delta H^\circ_{rxn} < 0$ and enthalpy contributes to favorability. $\Delta S^\circ_{rxn} < 0$, so entropy does NOT contribute to favorability — i.e., enthalpy alone drives it.

Solution 3

(c)

Mark scheme

- No separate response required — this is the context/stem describing the calorimetry experiment for the exothermic reaction of $P_4O_{10}(s)$ with water (equation 2: $P_4O_{10}(s) + 6\,H_2O(l) \rightarrow 4\,H_3PO_4(aq)$) that parts (i) and (ii) below use.

Solution 3

(c)(i)

Mark scheme

- $q = mc\Delta T = (100.1\ \text{g})(4.18\ \text{J}/(\text{g}\cdot{}^\circ\text{C}))(22.38^\circ\text{C} - 22.00^\circ\text{C}) = 160\ \text{J} = 0.16\ \text{kJ}$ (reported to the correct number of significant figures).

Solution 3

(c)(ii)

Mark scheme

- $q_{rxn} = -q_{surr} = -0.16\ \text{kJ}$.
  $$\Delta H^\circ_{rxn} = \frac{-0.16\ \text{kJ}}{0.100\ \text{g P}_4\text{O}_{10}} \times \frac{283.9\ \text{g P}_4\text{O}_{10}}{1\ \text{mol P}_4\text{O}_{10}} \times \frac{1\ \text{mol P}_4\text{O}_{10}}{1\ \text{mol}_{rxn}} = -450\ \text{kJ/mol}_{rxn}.$$
  The correct (negative) sign must be included.

Solution 3

(d)

Mark scheme

- Less than. If less P_4O_{10} is present (some stuck to the weighing paper), less thermal energy will be transferred to the water during the reaction, causing the temperature increase (ΔT) to be less than it was with the full 0.100 g of P_4O_{10}.

Solution 3

(e)

Mark scheme

- Using Hess's law:
  $$\Delta H^{\circ}_{f,\mathrm{PCl_5}(g)} = \frac{1}{4}\Delta H^{\circ}_{1} + \Delta H^{\circ}_{2} = \frac{1}{4}(-1148) + (-88) = -375 \text{ kJ/mol.}$$

Solution 3

(f)

Mark scheme

- No separate response required — this is the context/stem presenting equation 4 ($PCl_3(g) + Cl_2(g) \rightleftharpoons PCl_5(g)$, $\Delta H_2^\circ = -88$ kJ/mol$_{rxn}$) that parts (i) and (ii) below refer to.

Solution 3

(f)(i)

Mark scheme

- Reading partial pressures of 1.00 atm per particle from the diagram (4 PCl_5, 2 PCl_3, 6 Cl_2 particles): $K_p = \dfrac{P_{PCl_5}}{(P_{PCl_3})(P_{Cl_2})} = \dfrac{4.00}{(2.00)(6.00)} = \dfrac{1}{3} = 0.333$.

Solution 3

(f)(ii)

Mark scheme

- Decrease. The negative value of ΔH_2° indicates the reaction is exothermic. Because exothermic reactions favor reactant formation at higher temperature (the equilibrium shifts toward reactants as heat is added), the value of K_p decreases.

Question 1

2024 ▪ Q1

$$C_3H_6O_3(aq) + NaOH(aq) \rightarrow NaC_3H_5O_3(aq) + H_2O(l)$$

1. A student is studying the reaction between lactic acid, $C_3H_6O_3$, 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 H—C—C—C(=O)—O—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 (C=O, double bond to

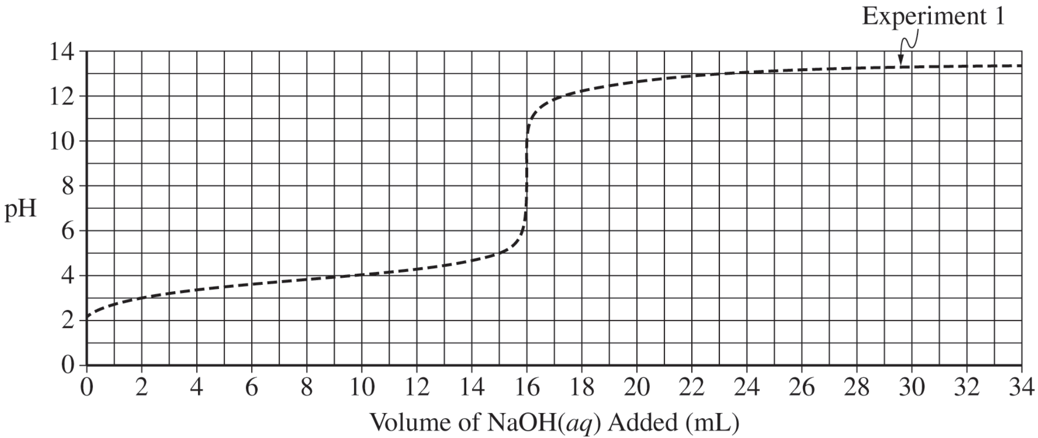
Question 1

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

$$\begin{array}{ccccccc}
 & H & & H & & O & \\
 & | & & | & & \| & \\
H- & C & - & C & - & C & -O-H \\
 & | & & | & & & \\
 & H & & O & & & \\
 & & & | & & & \\
 & & & H & & &
\end{array}$$

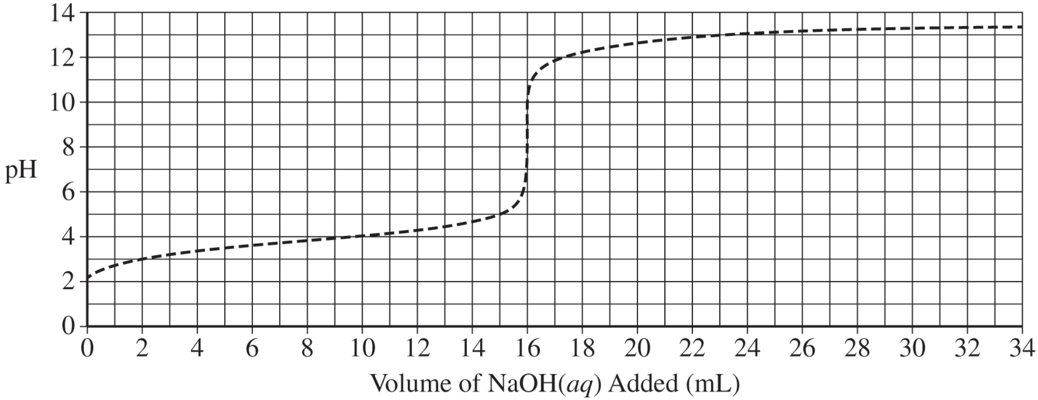
The hydrogen to circle is the one on the hydroxyl oxygen attached to the carbonyl carbon (the carboxylic acid —C(=O)—O—H proton).]

Question 1



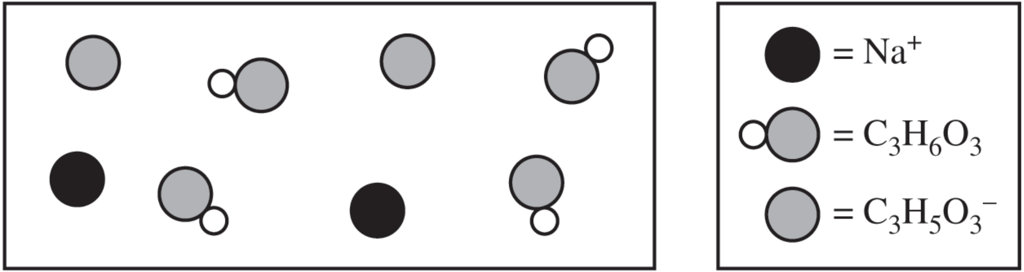
Experiment 1
pH
14
12
10
8
6
4
2
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34
Volume of NaOH(aq) Added (mL)

Question 1



14
12
10
8
6
4
2
0
pH
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34
Volume of NaOH(*aq*) Added (mL)

Question 1



Question 1

2024 ▪ Q1

$$C_3H_6O_3(aq) + NaOH(aq) \rightarrow NaC_3H_5O_3(aq) + H_2O(l)$$

1. A student is studying the reaction between lactic acid, $C_3H_6O_3$, 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

$$C_3H_6O_3(aq) + NaOH(aq) \rightarrow NaC_3H_5O_3(aq) + H_2O(l)$$

1. A student is studying the reaction between lactic acid, $C_3H_6O_3$, 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 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

$$C_3H_6O_3(aq) + NaOH(aq) \rightarrow NaC_3H_5O_3(aq) + H_2O(l)$$

1. A student is studying the reaction between lactic acid, $C_3H_6O_3$, 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) = $C_3H_6O_3$; circle half-black/half-gray (with a small white circle attached) = $C_3H_5O_3^-$. The box contains 2 large gray/white two-tone circles (labeled as $C_3H_6O_3$-type), 2 large gray/black two-tone circles (labeled as $C_3H_5O_3^-$-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

$$C_3H_6O_3(aq) + NaOH(aq) \rightarrow NaC_3H_5O_3(aq) + H_2O(l)$$

1. A student is studying the reaction between lactic acid, $C_3H_6O_3$, and sodium hydroxide, NaOH, as represented in the balanced equation above.

(e) The following table shows two experiments:

Experiment	**Mass of 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 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 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

$$C_3H_6O_3(aq) + NaOH(aq) \rightarrow NaC_3H_5O_3(aq) + H_2O(l)$$

1. A student is studying the reaction between lactic acid, $C_3H_6O_3$, 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 kJ/mol_{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 ($-C(=O)-O-H$). 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

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

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

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

Solution 1

(f)(ii)

Mark scheme

- $q_{rxn} = -q_{soln} = -2700\ \text{J} = -2.7\ \text{kJ}.$
  $\Delta H_{rxn} = \frac{q_{rxn}}{\text{mol}} = \frac{-2.7\ \text{kJ}}{(0.100\ \text{L})(0.500\ \text{mol/L})} = -54\ \text{kJ/mol}_{rxn}$. (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.

Question 4

2024 ▪ Q4

1 A student performs an experiment to determine the specific heat capacity of a metal. The student places a cube of the metal in boiling water so its temperature will be 100.0°C. The student then places the metal cube into a calorimeter that contains water and records the highest temperature of the water. A data table and a diagram of the thermometer at the highest temperature are shown.

Mass of metal cube	98.1 g
Mass of water	52.0 g
Initial temperature of metal cube	100.0°C
Initial temperature of water	25.0°C
Highest temperature of water	?

Question 4

[Diagram: a calorimeter (styrofoam cup) with a thermometer inserted, and a magnified circular inset of the thermometer scale showing markings from below 30 to above 40, with labeled gridlines at “40” and “30”; the liquid column in the thermometer is shown filled to a level between the two labels, with the top of the mercury column reaching a point just below the “40” mark — the fine gradations between 30 and 40 appear to be in increments of 1, with the meniscus resting at approximately 38.]

(a) What should the student report as the highest temperature of the water?

____

Question 4

Mass of metal cube	98.1 g
Mass of water	52.0 g
Initial temperature of metal cube	100.0°C
Initial temperature of water	25.0°C
Highest temperature of water	?