Past-paper walk-through

pH and pKa ▪ 8.7

eXercise

Questions in this set

- 2025 Q2
- 2024 Q1
- 2024 Q2
- 2022 Q1
- 2018 Q2
- 2016 Q4

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 2

2025 ▪ Q2

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

(a) A student combusts a sample of ascorbic acid, $C_xH_yO_x$, 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.

(a)(i) Calculate the number of moles of H_2O produced.

(a)(ii) 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.

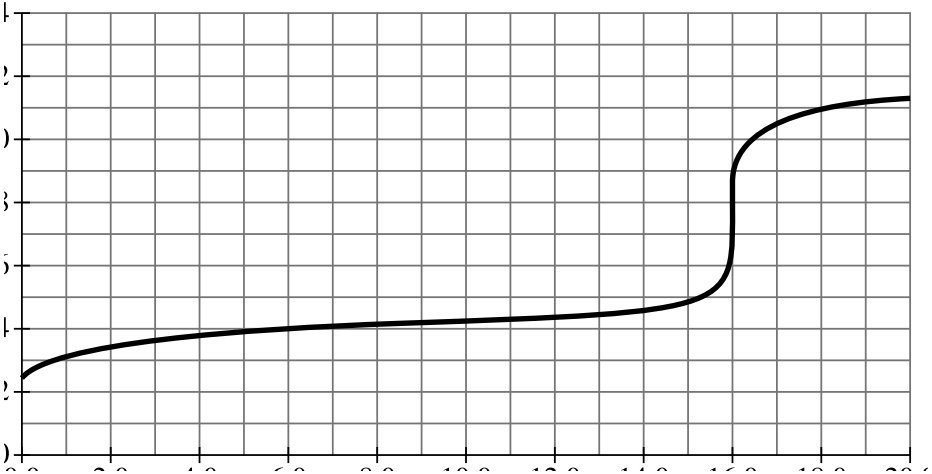
Question 2

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}

i. The rate law for the reaction is $rate = k[\text{HAsc}][I_3^-]$. Explain how the data in the table support the conclusion that the reaction is first order with respect to $[\text{HAsc}]$.

ii. Calculate the value of the rate constant, k, for the reaction. Include units with your

Question 2



Question 2

2025 ▪ Q2

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

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

$$\mathrm{HAsc}(aq) + \mathrm{H_2O}(l) \rightleftharpoons \mathrm{H_3O^+}(aq) + \mathrm{Asc^-}(aq)$$

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

[Titration curve graph: x-axis "Volume of 0.0550 M NaOH Added (mL)" from 0.0 to 20.0 in increments of 2.0; y-axis "pH" from 0 to 14 in increments of 2. The curve starts at about (0.0, 2.6), rises gradually and levels into a broad buffer region around pH 4 from about 2 mL to 14 mL, has a small inflection/bump near (14.0, 4.5)-(15.0,

Question 2

5.2), then rises steeply (equivalence point) through the region 15.0-16.5 mL up to about pH 10.5, then levels off gradually approaching about (20.0, 11.3).]

(b)(i) Calculate the molar concentration of the ascorbic acid solution.

(b)(ii) From the titration curve, determine the approximate pK_a of ascorbic acid.

(b)(iii) What is the value of the ratio $\frac{[\text{Asc}^-]}{[\text{HAsc}]}$ when the pH of the solution is 4.7?

Question 2

2025 ▪ Q2

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

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

$$HAsc + I_3^- \rightarrow DHAsc + 3\,I^- + 2\,H^+$$

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}

Question 2

(c)(i) The rate law for the reaction is $rate = k[\text{HAsc}][\text{I}_3^-]$. Explain how the data in the table support the conclusion that the reaction is first order with respect to [HAsc].
(c)(ii) Calculate the value of the rate constant, k, for the reaction. Include units with your answer.

Question 2

2025 ▪ Q2

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

(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.

[Lewis structures: I_2 shown as two iodine atoms singly bonded together, each with three lone pairs. I_3^- shown in brackets with an overall negative charge, as three iodine atoms in a row connected by single bonds (I—I—I), each terminal iodine with three lone pairs and the central iodine with two lone pairs.]

Solution 2

(a)

Mark scheme

- No separate response required — this is the context/stem describing the combustion of ascorbic acid ($C_xH_yO_x$) producing 0.2400 mol CO_2 and 2.883 g H_2O, which parts (i) and (ii) below use.

(a)(i)

Mark scheme

- moles $H_2O = 2.883$ g $H_2O \times \dfrac{1 \text{ mol } H_2O}{18.02 \text{ g } H_2O} = 0.1600$ mol H_2O.

Solution 2

(a)(ii)

Mark scheme

- moles H $= 0.1600$ mol $H_2O \times \dfrac{2 \text{ mol H}}{1 \text{ mol } H_2O} = 0.3200$ mol H (this step may be left implicit). Using mol C $= 0.2400$ mol $CO_2 \times \dfrac{1 \text{ mol C}}{1 \text{ mol } CO_2} = 0.2400$ mol C and the given 1:1 C:O ratio:
  $x : y : z = (\text{mol C}) : (\text{mol H}) : (\text{mol O}) = 0.2400 : 0.3200 : 0.2400 = 3 : 4 : 3.$
  Therefore the empirical formula of ascorbic acid is $C_3H_4O_3$.

Solution 2

(b)

Mark scheme

- No separate response required — this is the context/stem describing HAsc(aq) as a weak acid and presenting the titration curve (10.0 mL HAsc titrated with 0.0550 M NaOH) that parts (i)–(iii) below refer to.

Solution 2

(b)(i)

Mark scheme

- Reading the volume of NaOH at the equivalence point (16.0 mL) from the curve:

$$0.0160 \text{ L NaOH} \times \frac{0.0550 \text{ mol NaOH}}{1 \text{ L NaOH}} \times \frac{1 \text{ mol HAsc}}{1 \text{ mol NaOH}} = 8.80 \times 10^{-4} \text{ mol HAsc.}$$

$$\text{Molarity} = \frac{8.80 \times 10^{-4} \text{ mol HAsc}}{0.0100 \text{ L}} = 0.0880 \ M \text{ HAsc.}$$

Solution 2

(b)(ii)

Mark scheme

- From the titration curve, the pK_a (the pH at the half-equivalence point) is approximately 4.1 (acceptable range 4.0–4.3).

Solution 2

(b)(iii)

Mark scheme

- Using the Henderson–Hasselbalch equation: $\mathrm{pH} = \mathrm{p}K_a + \log\left(\dfrac{[\mathrm{Asc}^-]}{[\mathrm{HAsc}]}\right)$.

  $4.7 = 4.1 + \log\left(\dfrac{[\mathrm{Asc}^-]}{[\mathrm{HAsc}]}\right)$, so $\dfrac{[\mathrm{Asc}^-]}{[\mathrm{HAsc}]} = 10^{0.6} = 4.0$.

Solution 2

(c)

Mark scheme

- No separate response required — this is the context/stem describing the reaction of ascorbic acid (HAsc) with triiodide (I_3^-) to form DHAsc, and the table of three trials' initial concentrations and rates, that parts (i) and (ii) below use.

Solution 2

(c)(i)

Mark scheme

- Comparing trials 1 and 3: $\frac{4.914 \times 10^{-4}}{2.457 \times 10^{-4}} = \left(\frac{0.900}{0.450}\right)^{a}$, thus $a = 1$. The rate doubles when [HAsc] is doubled while $[I_3^-]$ is held constant, indicating the reaction is first order with respect to [HAsc].

Solution 2

(c)(ii)

Mark scheme

- Using rate $= k[\text{HAsc}][\text{I}_3^-]$ and trial 1 data: $k = \dfrac{\text{rate}}{[\text{HAsc}][\text{I}_3^-]} = \dfrac{2.457 \times 10^{-4}\ M/\text{s}}{(0.450\ M)(1.200\ M)} = 4.55 \times 10^{-4}\ M^{-1}\text{s}^{-1}$. Units: $M^{-1}\text{s}^{-1}$.

Solution 2

(d)

Mark scheme

- Ion-dipole attractions are present between I_3^- ions and water but not between I_2 molecules and water. Because I_3^- is a charged ion, it attracts the polar water molecules via ion-dipole forces, giving it much greater solubility than the neutral, nonpolar I_2.

Question 1

2024 ▪ Q1

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

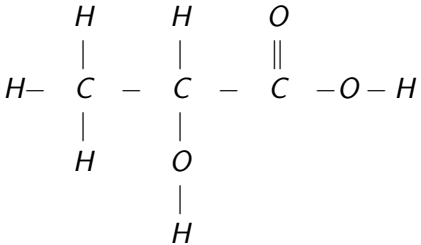
1. A student is studying the reaction between lactic acid, $C_3H_6O_3$, and sodium hydroxide, NaOH, as represented in the balanced equation above.

(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

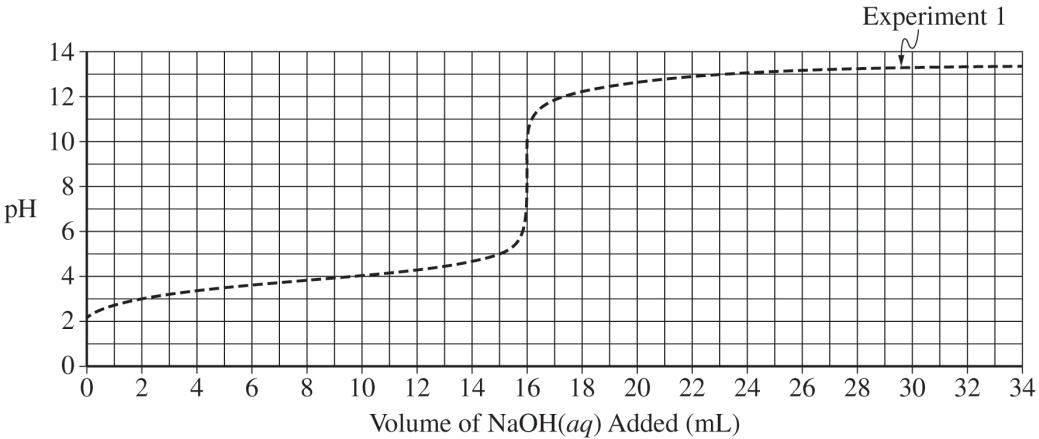
Question 1

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

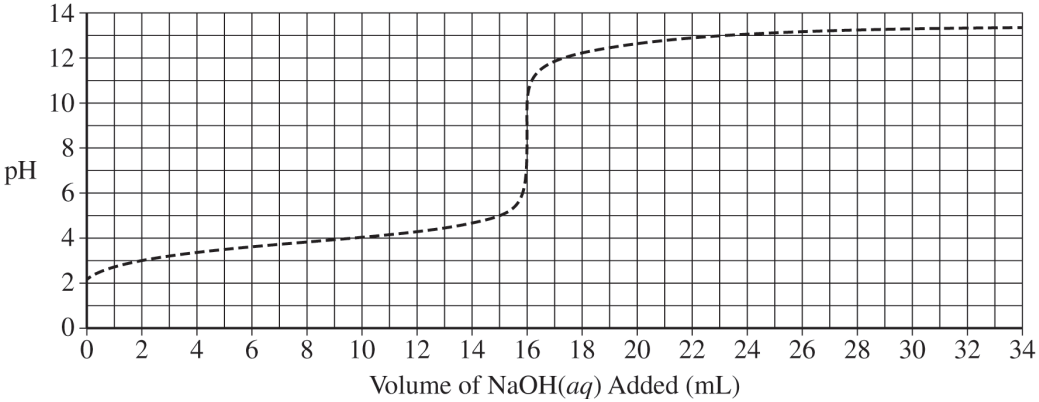


The hydrogen to circle is the one on the hydroxyl oxygen attached to the carbonyl carbon (the carboxylic acid —C(=O)—O—H proton).]

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


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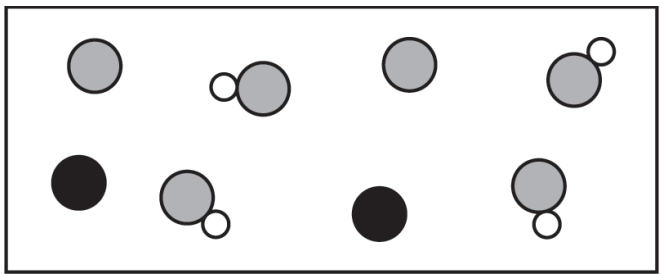
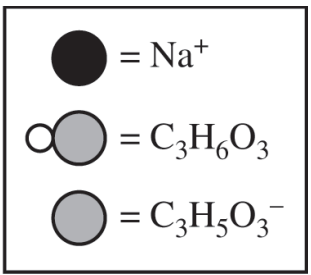
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34
Volume of NaOH(aq) Added (mL)

Question 1





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 ($-\mathrm{C}(=\mathrm{O})-\mathrm{O}-\mathrm{H}$). 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

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

Solution 1

(f)(ii)

Mark scheme

- $q_{rxn} = -q_{soln} = -2700\ \text{J} = -2.7\ \text{kJ}$.
  $\Delta H_{rxn} = \dfrac{q_{rxn}}{\text{mol}} = \dfrac{-2.7\ \text{kJ}}{(0.100\ \text{L})(0.500\ \text{mol/L})} = -54\ \text{kJ/mol}_{rxn}$. (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 2

2024 ▪ Q2

$$H_2C_4H_2O_4(aq) + 2\,NaHCO_3(aq) \rightarrow 2\,CO_2(g) + 2\,H_2O(l) + Na_2C_4H_2O_4(aq)$$

2. A chemical reaction between maleic acid ($H_2C_4H_2O_4$) and sodium bicarbonate ($NaHCO_3$) occurs in the presence of water to produce carbon dioxide and sodium maleate ($Na_2C_4H_2O_4$), as represented by the following equation.

(a)(i) A student combines equal masses of $H_2C_4H_2O_4(s)$ chunks and $NaHCO_3(s)$ chunks with sufficient water at 20.0°C. The student determines that 0.0114 mol of $CO_2(g)$ is produced after the reaction goes to completion.

Calculate the number of grams of $CO_2(g)$ produced.

(a)(ii) The $CO_2(g)$ produced from the reaction at 20.0°C was collected and found to have a pressure of 1.25 atm. Calculate the volume of $CO_2(g)$, in liters.

Question 2

2024 ▪ Q2

$$H_2C_4H_2O_4(aq) + 2\,NaHCO_3(aq) \rightarrow 2\,CO_2(g) + 2\,H_2O(l) + Na_2C_4H_2O_4(aq)$$

2. A chemical reaction between maleic acid ($H_2C_4H_2O_4$) and sodium bicarbonate ($NaHCO_3$) occurs in the presence of water to produce carbon dioxide and sodium maleate ($Na_2C_4H_2O_4$), as represented by the following equation.

(b)(i) The student performs a second experiment that is identical to the first except that the student grinds the chunks of $H_2C_4H_2O_4(s)$ and $NaHCO_3(s)$ into powder before combining the powder with water.

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

Question 2

(b)(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.

(b)(iii) When the reaction is complete, will the volume of $CO_2(g)$ 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.

Question 2

2024 ▪ Q2

$$H_2C_4H_2O_4(aq) + 2\,NaHCO_3(aq) \rightarrow 2\,CO_2(g) + 2\,H_2O(l) + Na_2C_4H_2O_4(aq)$$

2. A chemical reaction between maleic acid ($H_2C_4H_2O_4$) and sodium bicarbonate ($NaHCO_3$) occurs in the presence of water to produce carbon dioxide and sodium maleate ($Na_2C_4H_2O_4$), as represented by the following equation.

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

Trial	Mass of $H_2C_4H_2O_4$ (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

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

Question 2

2024 ▪ Q2

$$H_2C_4H_2O_4(aq) + 2\,NaHCO_3(aq) \rightarrow 2\,CO_2(g) + 2\,H_2O(l) + Na_2C_4H_2O_4(aq)$$

2. A chemical reaction between maleic acid ($H_2C_4H_2O_4$) and sodium bicarbonate ($NaHCO_3$) occurs in the presence of water to produce carbon dioxide and sodium maleate ($Na_2C_4H_2O_4$), as represented by the following equation.

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

Question 2

2024 ▪ Q2

$$H_2C_4H_2O_4(aq) + 2\,NaHCO_3(aq) \rightarrow 2\,CO_2(g) + 2\,H_2O(l) + Na_2C_4H_2O_4(aq)$$

2. A chemical reaction between maleic acid ($H_2C_4H_2O_4$) and sodium bicarbonate ($NaHCO_3$) occurs in the presence of water to produce carbon dioxide and sodium maleate ($Na_2C_4H_2O_4$), as represented by the following equation.

(e) The student notices that the temperature of the reaction mixture decreases as the reaction takes place and correctly determines that the reaction is endothermic.
The student claims that the reaction is thermodynamically favorable at all temperatures because $\Delta S^\circ_{rxn} > 0$ and the reaction is endothermic. Do you agree or disagree with the student's claim? Justify your answer.

Question 2

2024 ▪ Q2

$$H_2C_4H_2O_4(aq) + 2\,NaHCO_3(aq) \rightarrow 2\,CO_2(g) + 2\,H_2O(l) + Na_2C_4H_2O_4(aq)$$

2. A chemical reaction between maleic acid ($H_2C_4H_2O_4$) and sodium bicarbonate ($NaHCO_3$) occurs in the presence of water to produce carbon dioxide and sodium maleate ($Na_2C_4H_2O_4$), as represented by the following equation.

(f) 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.

$$H_2C_4H_2O_4 + H_2O \rightleftharpoons HC_4H_2O_4^- + H_3O^+ \qquad K_{a_1} = 1.5 \times 10^{-2}$$

$$HC_4H_2O_4^- + H_2O \rightleftharpoons C_4H_2O_4^{2-} + H_3O^+ \qquad K_{a_2} = 8.5 \times 10^{-7}$$

Question 2

Calculate the pK_{a_2} value for the $HC_4H_2O_4^-$ ion.

Question 2

2024 ▪ Q2

$$H_2C_4H_2O_4(aq) + 2\,NaHCO_3(aq) \rightarrow 2\,CO_2(g) + 2\,H_2O(l) + Na_2C_4H_2O_4(aq)$$

2. A chemical reaction between maleic acid ($H_2C_4H_2O_4$) and sodium bicarbonate ($NaHCO_3$) occurs in the presence of water to produce carbon dioxide and sodium maleate ($Na_2C_4H_2O_4$), as represented by the following equation.

(g) A buffer solution with a pH of 7.00 is prepared using $C_4H_2O_4^{2-}$ and $HC_4H_2O_4^-$. Calculate the ratio

$$\frac{[C_4H_2O_4^{2-}]}{[HC_4H_2O_4^-]}$$

in this solution.

Solution 2

(a)(i)

Mark scheme

- 0.0114 mol $CO_2 \times \dfrac{44.01\ \text{g}}{1\ \text{mol}} = 0.502\ \text{g}\ CO_2$.

Solution 2

(a)(ii)

Mark scheme

- Using $PV = nRT$:
  $$V = \frac{nRT}{P} = \frac{(0.0114\ \text{mol})(0.08206\ \text{L} \cdot \text{atm}/(\text{mol} \cdot \text{K}))(293\ \text{K})}{1.25\ \text{atm}} = 0.219\ \text{L}.$$

Solution 2

(b)(i)

Mark scheme

- Claim: the surface area of the solid reactants increases when the chunks are ground into powder.

(b)(ii)

Mark scheme

- Shorter than. The powdered solids have a larger surface area than the solid chunks, so collisions between water molecules and the solid surface particles occur more frequently, resulting in a faster rate of dissolution and a shorter time to dissolve the solids.

Solution 2

(b)(iii)

Mark scheme

- Equal to. Both experiments begin with the same amount (mass) of reactants, so they produce the same number of moles of $CO_2(g)$ under the same conditions of pressure and temperature; therefore the final volume of CO_2 will be the same regardless of particle size (rate changes, but the final amount/volume does not).

Solution 2

(c) Mark scheme

- $NaHCO_3$ is the limiting reactant (accept either justification): changing the mass of $NaHCO_3$ alters the amount of CO_2 produced, OR $NaHCO_3$ has the smaller theoretical yield of CO_2:
  1.543 g $H_2C_4H_2O_4 \times \dfrac{1 \text{ mol}}{116.07 \text{ g}} \times \dfrac{2 \text{ mol } CO_2}{1 \text{ mol acid}} = 0.02659$ mol CO_2 (if acid were limiting) vs. 1.251 g $NaHCO_3 \times \dfrac{1 \text{ mol}}{84.01 \text{ g}} \times \dfrac{2 \text{ mol } CO_2}{2 \text{ mol } NaHCO_3} = 0.01489$ mol CO_2 (if $NaHCO_3$ limiting) — the smaller value ($NaHCO_3$) is the actual limiting reactant, matching the trial's observed 0.01489 mol CO_2.

Solution 2

(d)

Mark scheme

- The entropy change is positive because the aqueous/solid reactants produce 2 moles of gas (CO_2) particles, according to the balanced equation. Gases are far more dispersed (occupy many more microstates) than condensed (solid/aqueous) phases, so the entropy of the products is greater than that of the reactants.

Solution 2

(e)

Mark scheme

- Disagree. Accept either justification: (1) The reaction is endothermic ($\Delta H > 0$) with a positive entropy change ($\Delta S > 0$), so it is only thermodynamically favorable at a high enough temperature where the magnitude of $-T\Delta S$ exceeds ΔH — NOT at all temperatures. (2) For a reaction to be thermodynamically favorable ($\Delta G < 0$) at ALL temperatures, it must be exothermic ($\Delta H < 0$) AND have $\Delta S > 0$ — this reaction is endothermic, so it fails that requirement.

Solution 2

(f)

Mark scheme

- Given $K_{a_2} = 8.5 \times 10^{-7}$ for the second dissociation of maleic acid: $\mathrm{p}K_{a_2} = -\log(8.5 \times 10^{-7}) = 6.07$.

Solution 2

(g)

Mark scheme

- Using the Henderson–Hasselbalch equation: $\mathrm{pH} = \mathrm{p}K_{a_2} + \log \dfrac{[\mathrm{C_4H_2O_4^{2-}}]}{[\mathrm{HC_4H_2O_4^-}]}$.

  Solving: $\dfrac{[\mathrm{C_4H_2O_4^{2-}}]}{[\mathrm{HC_4H_2O_4^-}]} = 10^{(\mathrm{pH}-\mathrm{p}K_{a_2})} = 10^{(7.00-6.07)} = 8.5.$

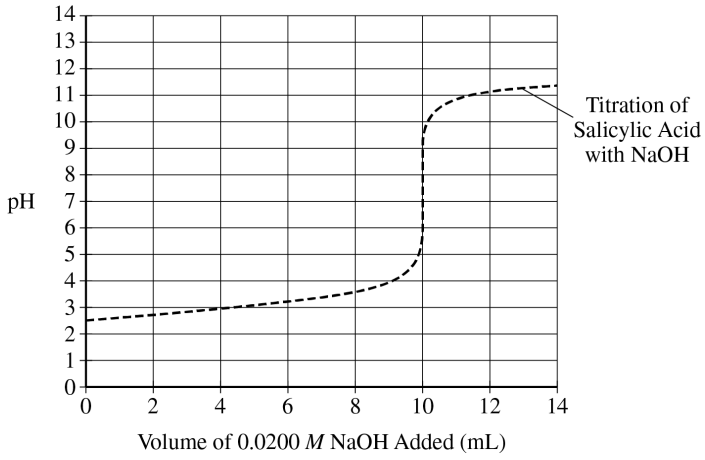
Question 1

2022 ▪ Q1

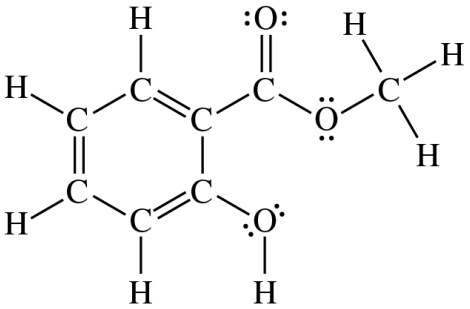
A student reacts 0.300 g of methyl salicylate ($C_8H_8O_3$) with a stoichiometric amount of a strong base. This product is then acidified to produce salicylic acid crystals ($HC_7H_5O_3$).

(a) For every 1 mole of $C_8H_8O_3$ (molar mass 152.15 g/mol) reactant used, 1 mole of salicylic acid crystals ($HC_7H_5O_3$, molar mass 138.12 g/mol) is produced. Calculate the maximum mass, in grams, of $HC_7H_5O_3$ that could be produced in this reaction.

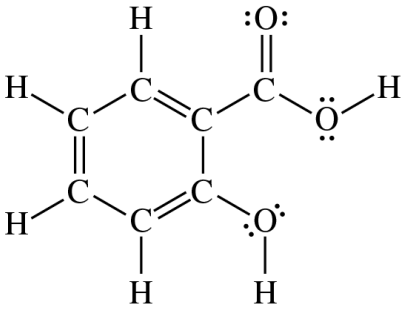
Question 1


14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
pH
0
2
4
6
8
10
12
14
Volume of 0.0200 *M* NaOH Added (mL)
Titration of
Salicylic Acid
with NaOH

Question 1

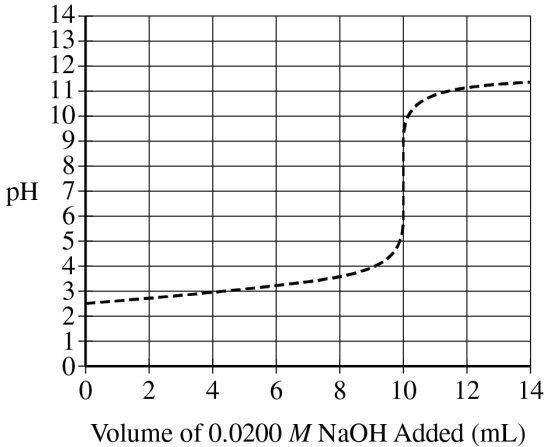


Methyl Salicylate
Melting Point: –9°C



Salicylic Acid
Melting Point: 159°C

Question 1


pH
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
0
2
4
6
8
10
12
14
Volume of 0.0200 *M* NaOH Added (mL)

Question 1

2022 ▪ Q1

A student reacts 0.300 g of methyl salicylate ($C_8H_8O_3$) with a stoichiometric amount of a strong base. This product is then acidified to produce salicylic acid crystals ($HC_7H_5O_3$).

(b) As part of the experimental procedure to purify the $HC_7H_5O_3$ crystals after the reaction is complete, the crystals are filtered from the reaction mixture, rinsed with distilled water, and dried. Some physical properties of $HC_7H_5O_3$ are given in the following table.

Properties of Salicylic Acid ($HC_7H_5O_3$)	
Melting point	159°C
Solubility in H_2O at 25°C	2.2 g/L
Specific heat capacity	1.17 J/(g · °C)
Heat of fusion	27.1 kJ/mol

The student's experiment results in an 87

Question 1

2022 ▪ Q1

A student reacts 0.300 g of methyl salicylate ($C_8H_8O_3$) with a stoichiometric amount of a strong base. This product is then acidified to produce salicylic acid crystals ($HC_7H_5O_3$).

(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 $HC_7H_5O_3$ (molar mass 138.12 g/mol) crystals from $25°C$ to the melting point $159°C$ and melt the crystals completely.

Question 1

2022 ▪ Q1

A student reacts 0.300 g of methyl salicylate ($C_8H_8O_3$) with a stoichiometric amount of a strong base. This product is then acidified to produce salicylic acid crystals ($HC_7H_5O_3$).

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

[Two skeletal/Lewis structural formulas of benzene-ring compounds are shown side by side, drawn with explicit H atoms and lone pairs. Left: Methyl Salicylate, Melting Point: $-9°C$ — a benzene ring with an ester group $-C(=O)-O-CH_3$ and an adjacent $-O-H$ hydroxyl group on the ring. Right: Salicylic Acid, Melting Point: $159°C$ — the same benzene ring but with a carboxylic acid group $-C(=O)-O-H$ and the adjacent $-O-H$ hydroxyl group on the ring.]

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.

Question 1

The student titrates 20.0 mL of 0.0100 *M* $HC_7H_5O_3(aq)$ with 0.0200 *M* NaOH, using a probe to monitor the pH of the solution. The data are plotted producing the following titration curve.

[Titration curve graph: x-axis "Volume of 0.0200 M NaOH Added (mL)" from 0 to 14; y-axis "pH" from 0 to 14. The curve starts near pH 2-3 at 0 mL, rises gradually and gently through the buffer region, then shows a steep equivalence-point jump at approximately 10 mL (rising from about pH 7 to pH 11), then levels off near pH 12-13 as more NaOH is added.]

Question 1

2022 ▪ Q1

A student reacts 0.300 g of methyl salicylate ($C_8H_8O_3$) with a stoichiometric amount of a strong base. This product is then acidified to produce salicylic acid crystals ($HC_7H_5O_3$).

(e) Using the information in the graph, estimate the pK_a of $HC_7H_5O_3$.

Question 1

2022 ▪ Q1

A student reacts 0.300 g of methyl salicylate ($C_8H_8O_3$) with a stoichiometric amount of a strong base. This product is then acidified to produce salicylic acid crystals ($HC_7H_5O_3$).

(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.

Question 1

2022 ▪ Q1

A student reacts 0.300 g of methyl salicylate ($C_8H_8O_3$) with a stoichiometric amount of a strong base. This product is then acidified to produce salicylic acid crystals ($HC_7H_5O_3$).

(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.

Question 1

2022 ▪ Q1

A student reacts 0.300 g of methyl salicylate ($C_8H_8O_3$) with a stoichiometric amount of a strong base. This product is then acidified to produce salicylic acid crystals ($HC_7H_5O_3$).

(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.

[A second copy of the titration curve graph, titled "Titration of Salicylic Acid with NaOH," showing the same original salicylic-acid curve as in part (d) (x-axis "Volume of 0.0200 M NaOH Added (mL)" from 0 to 14; y-axis "pH" from 0 to 14; gradual rise from about pH 2-3 through a buffer region, then a steep jump near 10 mL up to about

Question 1

pH 11, leveling off near pH 12-13), onto which the student is to sketch the new benzoic-acid titration curve.]

Solution 1

(a)

Mark scheme

- Maximum mass of HC7H5O3: 0.300 g C8H8O3 × (1 mol C8H8O3 / 152.15 g) × (1 mol HC7H5O3 / 1 mol C8H8O3) × (138.12 g / 1 mol HC7H5O3) = 0.272 g HC7H5O3.

Solution 1

(b)

Mark scheme

- Yes (consistent). Because the acid is soluble in water, some crystals may dissolve during rinsing, causing the mass of the collected precipitate to be lower than expected. This would lead to a percent yield less than 100%.

Solution 1

(c)

Mark scheme

- q_heat $= mc\Delta T = (0.105\ \text{g})(1.17\ \text{J/(g} \cdot \text{°C))(159°C} - 25°\text{C}) = 16.5\ \text{J}$ (1 point for either q value). q_melt $= 0.105\ \text{g} \times (1\ \text{mol} / 138.12\ \text{g}) \times (27{,}100\ \text{J} / 1\ \text{mol}) = 20.6\ \text{J}$ (1 point for the other q value and the total). q_total $=$ q_heat $+$ q_melt $= 16.5\ \text{J} + 20.6\ \text{J} = 37.1\ \text{J}$.

Solution 1

(d)

Mark scheme

- Molecules of salicylic acid have more hydrogen bonding sites than molecules of methyl salicylate have, which leads to stronger intermolecular forces and a higher melting point for salicylic acid.

Solution 1

(e)

Mark scheme

- The pKa is approximately 3, estimated from the titration curve graph at the half-equivalence point.

Solution 1

(f)

Mark scheme

- The conjugate base, $C_7H_5O_3^-$, is present at higher concentration. Justification (either accepted): at pH = 4.00 the titration is beyond the half-equivalence point, where $[HC_7H_5O_3] = [C_7H_5O_3^-]$; thus $[C_7H_5O_3^-]$ must be greater than $[HC_7H_5O_3]$. OR: because the pH of the solution is greater than the pKa of the acid, the majority of the molecules will be deprotonated.

Solution 1

(g)

Mark scheme

- $\text{pKa} = -\log(6.3 \times 10^{-5}) = 4.20$.

Solution 1

(h)

Mark scheme

- Sketch of the benzoic acid titration curve (consistent with part (g)): (1 point) the curve starts at pH $\approx$ 3.11 (the given initial pH) and passes through its pKa (4.20, from part (g)) at the half-equivalence volume of 5 mL. (1 point) the curve inflects vertically at 10 mL, showing the same volume of NaOH needed to reach the equivalence point as the original salicylic acid curve, since both are 20.0 mL of 0.0100 M acid titrated with the same 0.0200 M NaOH.

Question 2

2018 ▪ Q2

$$2\,\mathrm{NO}(g) + \mathrm{O_2}(g) \rightarrow 2\,\mathrm{NO_2}(g)$$

A student investigates the reactions of nitrogen oxides. One of the reactions in the investigation requires an equimolar mixture of $\mathrm{NO}(g)$ and $\mathrm{NO_2}(g)$, which the student produces by using the reaction represented above.

(a) The particle-level representation of the equimolar mixture of $\mathrm{NO}(g)$ and $\mathrm{NO_2}(g)$ in the flask at the completion of the reaction between $\mathrm{NO}(g)$ and $\mathrm{O_2}(g)$ 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 $\mathrm{NO}(g)$ and $\mathrm{O_2}(g)$ 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.

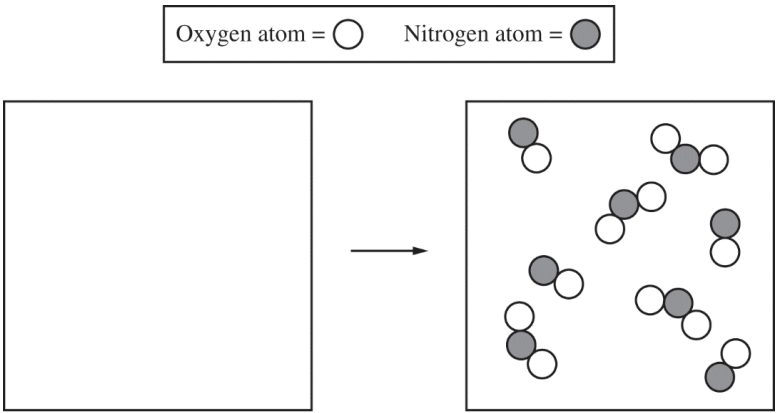
Question 2

[Key: Oxygen atom = open (white) circle; Nitrogen atom = filled (gray) circle.]
[Two boxes side by side connected by an arrow. Left box labeled "Reactant Mixture" is empty (for the student to draw in). Right box labeled "Product Mixture" shows a particle-level representation containing 6 NO molecules (each one open circle bonded to one filled circle) and 6 NO_2 molecules (each one filled circle bonded to two open circles), scattered randomly in the box.]
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.

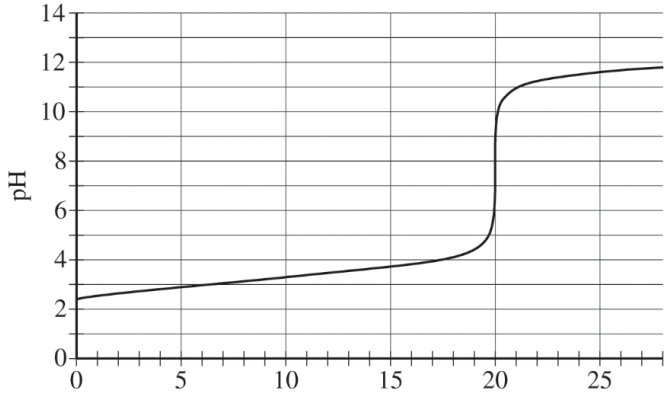
$$NO(g) + NO_2(g) \rightleftharpoons N_2O_3(g)$$

| ΔH°_{298} | ΔS°_{298} | ΔG°_{298} | |—|—|—| | -40.4 kJ/mol$_{rxn}$ | -138.5 J/(K $\cdot$ mol$_{rxn}$) | 0.87 kJ/mol$_{rxn}$ |

Question 2


Oxygen atom =
Nitrogen atom =
Reactant Mixture
Product Mixture

Question 2



Question 2

$$\mathrm{NO}(g) + \mathrm{NO_2}(g) \rightleftarrows \mathrm{N_2O_3}(g)$$

ΔH°_{298}	ΔS°_{298}	ΔG°_{298}
$-40.4\ \mathrm{kJ/mol}_{rxn}$	$-138.5\ \mathrm{J/(K \cdot mol}_{rxn})$	$0.87\ \mathrm{kJ/mol}_{rxn}$

Question 2

2018 ▪ Q2

$$2\,\mathrm{NO}(g) + \mathrm{O_2}(g) \rightarrow 2\,\mathrm{NO_2}(g)$$

A student investigates the reactions of nitrogen oxides. One of the reactions in the investigation requires an equimolar mixture of $\mathrm{NO}(g)$ and $\mathrm{NO_2}(g)$, which the student produces by using the reaction represented above.

(b)(i) The student begins with an equimolar mixture of $\mathrm{NO}(g)$ and $\mathrm{NO_2}(g)$ 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.

(b)(ii) If both P_{NO} and $P_{\mathrm{NO_2}}$ in the vessel are initially 1.0 atm, will $P_{\mathrm{N_2O_3}}$ at equilibrium be equal to 1.0 atm? Justify your answer.

Question 2

2018 ▪ Q2

$$2\,NO(g) + O_2(g) \rightarrow 2\,NO_2(g)$$

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.

(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.

$N_2O_3(g)$ reacts with water to form nitrous acid, $HNO_2(aq)$, a compound involved in the production of acid rain. The reaction is represented below.

Question 2

$$N_2O_3(g) + H_2O(l) \rightarrow 2\,HNO_2(aq)$$

Question 2

2018 ▪ Q2

$$2\,\mathrm{NO}(g) + \mathrm{O_2}(g) \rightarrow 2\,\mathrm{NO_2}(g)$$

A student investigates the reactions of nitrogen oxides. One of the reactions in the investigation requires an equimolar mixture of $\mathrm{NO}(g)$ and $\mathrm{NO_2}(g)$, which the student produces by using the reaction represented above.

(d)(i) The skeletal structure of the $\mathrm{HNO_2}$ molecule is shown in the box below.

[Box showing the skeletal structure: H O N O, written left to right in a line.]

Complete the Lewis electron-dot diagram of the $\mathrm{HNO_2}$ molecule in the box below, including any lone pairs of electrons.

(d)(ii) Based on your completed diagram above, identify the hybridization of the nitrogen atom in the $\mathrm{HNO_2}$ molecule.

Question 2

To produce an aqueous solution of HNO_2, the student bubbles $N_2O_3(g)$ into distilled water. Assume that the reaction goes to completion and that HNO_2 is the only species produced. To determine the concentration of $HNO_2(aq)$ in the resulting solution, the student titrates a 100. mL sample of the solution with 0.100 M $KOH(aq)$. The neutralization reaction is represented below.

$$HNO_2(aq) + OH^-(aq) \rightarrow NO_2^-(aq) + H_2O(l)$$

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

[Titration curve graph: Y-axis pH from 0 to 14 in increments of 2. X-axis "Volume of 0.100 M KOH(aq) Added (mL)" from 0 to 25+ in increments of 5. The curve starts around pH 2.3 at 0 mL, rises very gradually and slightly through a small buffer region

Question 2

to about pH 4 near 15-18 mL, then rises steeply (equivalence point) around 20 mL up to about pH 12, then levels off gradually toward pH 12-13 by 25 mL.]

Question 2

2018 ▪ Q2

$$2\,NO(g) + O_2(g) \rightarrow 2\,NO_2(g)$$

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.

(e)(i) Use the titration curve and the information above to determine the initial concentration of the $HNO_2(aq)$ solution.

(e)(ii) Use the titration curve and the information above to estimate the value of pK_a for $HNO_2(aq)$.

Question 2

2018 ▪ Q2

$$2\,\mathrm{NO}(g) + \mathrm{O_2}(g) \rightarrow 2\,\mathrm{NO_2}(g)$$

A student investigates the reactions of nitrogen oxides. One of the reactions in the investigation requires an equimolar mixture of $\mathrm{NO}(g)$ and $\mathrm{NO_2}(g)$, which the student produces by using the reaction represented above.

(f) During the titration, after a volume of 15 mL of 0.100 *M* $\mathrm{KOH}(aq)$ has been added, which species, $\mathrm{HNO_2}(aq)$ or $\mathrm{NO_2^-}(aq)$, is present at a higher concentration in the solution? Justify your answer.

Solution 2

(a)

Mark scheme

- The reactant mixture must contain 8 NO(g) molecules and 2 O2(g) molecules. As 2 NO(g) + O2(g) -> 2 NO2(g) proceeds (O2 limiting), 4 NO react with the 2 O2 to form 4 NO2, leaving 4 NO unreacted, giving the equimolar 4 NO : 4 NO2 product mixture shown. 1 point is earned for correctly representing the molecules of NO and O2 (8 NO + 2 O2, drawn as separate diatomic particles using the given atom key); 1 point is earned for correctly representing atom conservation between the reactant and product boxes (same total number of N atoms and O atoms in both boxes).

Solution 2

(b)(i)

Mark scheme

- DeltaG = -RT ln K, so K = e^(-DeltaG/RT) = e^[-870 J/mol / ((8.314 J/(mol K))(298 K))] = e^(-0.351) = 0.70. 1 point is earned for the correct calculation of K.

Solution 2

(b)(ii)

Mark scheme

- No, P(N2O3) will not equal 1.0 atm at equilibrium. P(N2O3) would only equal 1.0 atm if the reaction went to completion; the value of K (0.70, not much greater than 1) indicates that a substantial amount of reactants (NO and NO2) will remain at equilibrium, so P(N2O3) will be less than 1.0 atm. 1 point is earned for the correct choice ('no') and a valid justification based on the value of K.

Solution 2

(c)

Mark scheme

- Disagree. Because the reaction NO(g) + NO2(g) <=> N2O3(g) is exothermic (DeltaH_298 = -40.4 kJ/mol_rxn), increasing the temperature will favor the formation of the reactants (shift left), according to Le Chatelier's principle, so the amount of N2O3(g) will decrease, not increase. 1 point is earned for the correct choice (disagree) AND a correct justification.

Solution 2

(d)(i)

Mark scheme

- Completed Lewis structure of HNO2 (skeleton H-O-N-O): H is single-bonded to O; that O is single-bonded to N and carries 2 lone pairs; N is double-bonded to the terminal O and carries 1 lone pair; the terminal O carries 2 lone pairs. Formal charges are all zero and every atom (except H) has a complete octet. 1 point is earned for a valid diagram showing all lone pairs and correct bonding (H-O-N=O with 2 lone pairs on each O and 1 lone pair on N).

Solution 2

(d)(ii)

Mark scheme

- The nitrogen atom is sp2 hybridized (it is bonded to 2 O atoms and has 1 lone pair, i.e., 3 electron domains, giving trigonal planar / sp2 geometry). 1 point is earned for the correct answer, sp2.

Solution 2

(e)(i)

Mark scheme

- At the equivalence point (from the titration curve), 20. mL of 0.100 M KOH has been added: 20. mL x 0.100 mol KOH/1000 mL = 0.0020 mol KOH added, which equals 0.0020 mol HNO2 originally present (1:1 stoichiometry of HNO2 + OH- -> NO2- + H2O). Initial concentration = 0.0020 mol HNO2 / 0.100 L = 0.020 M HNO2. 1 point is earned for the correct calculation of the initial concentration.

Solution 2

(e)(ii)

Mark scheme

- pKa is approximately 3.4, read from the pH at the half-equivalence volume (10 mL) on the titration curve, where pH = pKa. 1 point is earned for an acceptable estimate of pKa (values near 3.4 accepted).

Solution 2

(f)

Mark scheme

- NO2-(aq) is present at the higher concentration. The equivalence point is at 20 mL, so the half-equivalence point is at 10 mL; after 15 mL of KOH has been added, the titration is past the half-equivalence point, so more of the conjugate base (NO2-) than the acid (HNO2) is present. 1 point is earned for the correct choice AND a valid justification.

Question 4

2016 ▪ Q4

$$C_6H_5OH(aq) + H_2O(l) \rightleftharpoons C_6H_5O^-(aq) + H_3O^+(aq) \qquad K_a = 1.12 \times 10^{-10}$$

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* $C_6H_5OH(aq)$ solution?

(b) For a certain reaction involving $C_6H_5OH(aq)$ to proceed at a significant rate, the phenol must be primarily in its deprotonated form, $C_6H_5O^-(aq)$. In order to ensure that the $C_6H_5OH(aq)$ 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 ($C_6H_5O^-(aq)$). Justify your answer.

[Number scale from 1 to 14, in increments of 1: 1 2 3 4 5 6 7 8 9 10 11 12 13 14]

Solution 4

(a)

Mark scheme

- Ka = [C6H5O−][H3O+]/[C6H5OH]; 1.12×10^−10 = $x^2/(0.75 - x)$, assuming x << 0.75. x^2 = 8.4×10^−11, so x = $\sqrt{}$(8.4×10^−11) = 9.2×10^−6 M = [H3O+]. pH = −log(9.2×10^−6) = 5.04. 1 point for a correct setup and calculation of [H+], 1 point for the correct pH value based on a correctly-set-up [H+] calculation.

Solution 4

(b)

Mark scheme

- Numbers 10 through 14 should be circled. When pH $>$ pKa, the deprotonated form predominates; pKa $= -\log(1.12\times10\hat{}-10) = 9.95$, so at pH 10 and above [C6H5O$-$] $>$ [C6H5OH]. 1 point for circling pH values 10–14, 1 point for the justification referencing pKa ≈ 9.95 and the condition pH $>$ pKa.