Past-paper walk-through

Atomic Structure and Electron Configuration ▪ 1.5

eXercise

Questions in this set

- 2026 Q1
- 2025 Q1
- 2023 Q1
- 2022 Q3
- 2021 Q2
- 2019 Q5
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- 2016 Q1
- 2015 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 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 $3.95\ \mathrm{J/(g \cdot °C)}$.)

(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 1

2025 ▪ Q1

Answer the following questions about magnesium.

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

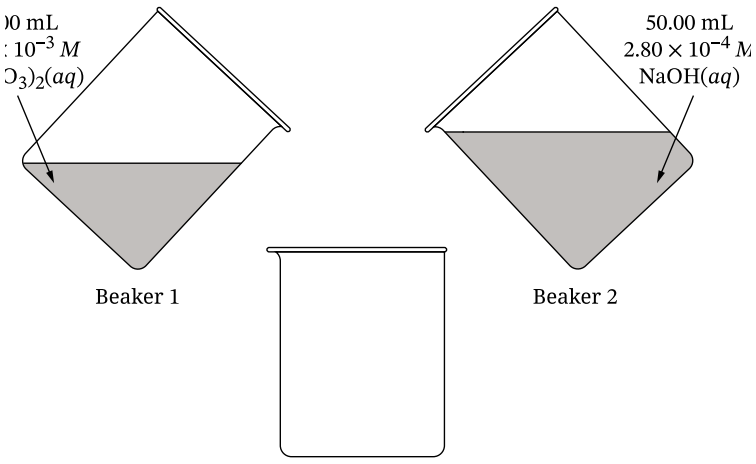
[Bar graph titled "Relative Abundance" vs. "Mass (amu)"; y-axis from 0 to 100 in increments of 20; x-axis shows tick marks at 24, 25, 26; a single thick vertical bar is drawn at mass 24 reaching a relative abundance of about 79.]

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

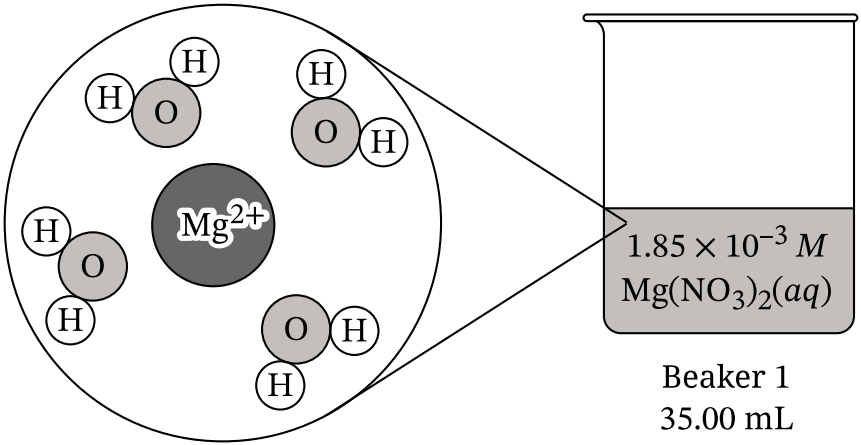
(a)(i) Complete the mass spectrum in part A by drawing thick lines in the appropriate locations to represent the percent abundance of magnesium-25 and magnesium-26.

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

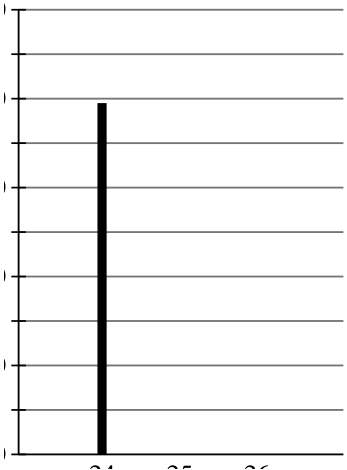
Question 1


)0 mL
: 10^{-3} M
$O_3)_2(aq)$
Beaker 1
50.00 mL
2.80×10^{-4} M
NaOH(aq)
Beaker 2

Question 1



Question 1



Question 1

2025 ▪ Q1

Answer the following questions about magnesium.

(b) A student prepares a 1.85×10^{-3} *M* solution of $Mg(NO_3)_2(aq)$ in beaker 1 and a 2.80×10^{-4} *M* solution of $NaOH(aq)$ in beaker 2, as shown.

[Particle diagram: a magnesium ion, Mg^{2+}, at the center surrounded by six water molecules (H2O), each oriented with its oxygen atom pointing toward the central Mg^{2+} ion and its two hydrogen atoms pointing outward.]

[Beaker 1: labeled "1.85×10^{-3} *M* $Mg(NO_3)_2(aq)$", "Beaker 1", "35.00 mL".]

[Beaker 2: labeled "2.80×10^{-4} *M* $NaOH(aq)$", "Beaker 2", "50.00 mL".]

The particle diagram shown represents a magnesium ion, Mg^{2+}, in beaker 1. A sodium ion, Na^+, in beaker 2 has a weaker attraction to water than the Mg^{2+} does. Explain this phenomenon using Coulomb's law and each of the following.

(b)(i) The relative charge of the ions

Question 1

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

Question 1

2025 ▪ Q1

Answer the following questions about magnesium.

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

Question 1

2025 ▪ Q1

Answer the following questions about magnesium.

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

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

Question 1

2025 ▪ Q1

Answer the following questions about magnesium.

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

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

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

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

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

Question 1

2025 ▪ Q1

Answer the following questions about magnesium.

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

Solution 1

(a)

Mark scheme

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

(a)(i)

Mark scheme

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

Solution 1

(a)(ii)

Mark scheme

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

Solution 1

(b)

Mark scheme

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

(b)(i)

Mark scheme

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

Solution 1

(b)(ii)

Mark scheme

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

Solution 1

(c)

Mark scheme

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

Solution 1

(d)

Mark scheme

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

Solution 1

(e)

Mark scheme

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

(e)(i)

Mark scheme

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

Solution 1

(e)(ii)

Mark scheme

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

(e)(iii)

Mark scheme

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

Solution 1

(f)

Mark scheme

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

Question 1

2023 ▪ Q1

Answer the following questions related to manganese compounds.

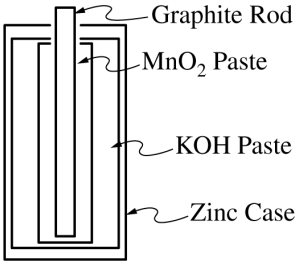
(a)(i) Manganese has several common oxidation states.

Write the complete electron configuration for an Mn atom in the ground state.

(a)(ii) When manganese forms cations, electrons are lost from which subshell first?

Identify both the number and letter associated with the subshell.

Question 1



Reduction Half-Reaction	$E°$ (V)
$Zn^{2+}(aq) + 2\ e^- \rightarrow Zn(s)$	−0.76
$ZnO(s) + H_2O(l) + 2\ e^- \rightarrow Zn(s) + 2\ OH^-(aq)$	−1.28
$2\ MnO_2(s) + H_2O(l) + 2\ e^- \rightarrow Mn_2O_3(s) + 2\ OH^-(aq)$	0.15

Question 1

2023 ▪ Q1

Answer the following questions related to manganese compounds.

(b) A student performs an experiment to produce a manganese salt of unknown composition, $Mn_xCl_y(aq)$, and determine its empirical formula. The student places a sample of $Mn(s)$ in a beaker containing excess $HCl(aq)$, as represented by the following equation.

$$x\ Mn(s) + y\ HCl(aq) \rightarrow Mn_xCl_y(aq) + \frac{y}{2}H_2(g)$$

The student heats the resulting mixture until only $Mn_xCl_y(s)$ remains in the beaker. The data are given in the following table.

Question 1

Quantity	Value
Mass of empty beaker	60.169 g
Mass of beaker and $Mn(s)$	61.262 g
Mass of beaker and Mn_xCl_y after heating to constant mass	62.673 g

Calculate the mass of Cl in the sample of $Mn_xCl_y(s)$ remaining in the beaker.

Question 1

2023 ▪ Q1

Answer the following questions related to manganese compounds.

(c) Calculate the number of moles of Cl in the sample of $Mn_xCl_y(s)$ remaining in the beaker.

Question 1

2023 ▪ Q1

Answer the following questions related to manganese compounds.

(d) The student determines that 0.0199 mol of Mn was used in the experiment. Use the data to determine the empirical formula of the $Mn_xCl_y(s)$.

Question 1

2023 ▪ Q1

Answer the following questions related to manganese compounds.

(e) The student repeats the experiment using the same amounts of Mn and HCl and notices that some of the Mn_xCl_y splatters out of the beaker as it is heated to dryness. Will the number of moles of Cl calculated for this trial be greater than, less than, or equal to the number calculated in part (c)? Justify your answer.

Question 1

2023 ▪ Q1

Answer the following questions related to manganese compounds.

(f) Another compound of manganese, MnO_2, is used in alkaline batteries, represented by the following diagram.

[Diagram of an alkaline battery: a graphite rod runs through the center, surrounded by MnO_2 paste, then KOH paste, enclosed by a zinc case.]

Some half-reactions are given in the table.

Reduction Half-Reaction	E° (V)
$Zn^{2+}(aq) + 2\,e^- \rightarrow Zn(s)$	-0.76
$ZnO(s) + H_2O(l) + 2\,e^- \rightarrow Zn(s) + 2\,OH^-(aq)$	-1.28
$2\,MnO_2(s) + H_2O(l) + 2\,e^- \rightarrow Mn_2O_3(s) + 2\,OH^-(aq)$	0.15

(f)(i) Based on the half-reactions given in the table, write the balanced net ionic equation for the reaction that has the greatest thermodynamic favorability.

(f)(ii) Calculate the value of E°_{cell} for the overall reaction.

Question 1

(f)(iii) Calculate the value of ΔG° in kJ/mol_{rxn}.
(f)(iv) A student claims that the total mass of an alkaline battery decreases as the battery operates because the anode loses mass. Do you agree with the student's claim? Justify your answer.

Solution 1

(a)(i)

Mark scheme

- Ground-state Mn (Z=25) electron configuration: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^5$ (equivalently $[\mathrm{Ar}] 4s^2 3d^5$). Either full or noble-gas-core notation is accepted.

(a)(ii)

Mark scheme

- Electrons are lost first from the 4s subshell (number = 4, letter = s) when Mn forms cations, consistent with the configuration in part (a)(i) — the 4s electrons are removed before the 3d electrons.

Solution 1

(b)

Mark scheme

- Mass of Cl in the sample = mass of dry beaker + Mn_xCl_y minus mass of the empty beaker: 62.673 g − 61.262 g = 1.411 g Cl.

Solution 1

(c)

Mark scheme

- Convert mass of Cl to moles: 1.411 g Cl $\times \dfrac{1 \text{ mol Cl}}{35.45 \text{ g Cl}} = 0.03980$ mol Cl.

Solution 1

(d)

Mark scheme

- Mole ratio Cl:Mn $= \dfrac{0.03980 \text{ mol Cl}}{0.0199 \text{ mol Mn}} = \dfrac{2 \text{ mol Cl}}{1 \text{ mol Mn}}$, so the empirical formula is $MnCl_2$.

Solution 1

(e)

Mark scheme

- Less than. If some of the mass of aqueous Mn_xCl_y is lost due to splattering, the final mass of the dry beaker and Mn_xCl_y will be decreased, which will decrease the calculated mass and number of moles of chlorine in the dry solid.

Solution 1

(f)

Mark scheme

- This is introductory/stem text describing the alkaline battery (MnO_2/Zn cell) and giving the reduction half-reaction table; it poses no separate question of its own. The scoring guidelines award all 4 points for this context across parts (f)(i)–(f)(iv) below, so no points are attached to this stem leaf.

Solution 1

(f)(i)

Mark scheme

- Combine the MnO_2 reduction half-reaction with the reverse of the less-favorable Zn/ZnO half-reaction: $2\,MnO_2(s) + H_2O(l) + 2e^- \rightarrow Mn_2O_3(s) + 2\,OH^-(aq)$ and $Zn(s) + 2\,OH^-(aq) \rightarrow ZnO(s) + H_2O(l) + 2e^-$. Adding gives the overall balanced net ionic equation: $2\,MnO_2(s) + Zn(s) \rightarrow Mn_2O_3(s) + ZnO(s)$.

Solution 1

(f)(ii)

Mark scheme

- $E^{\circ}_{cell} = E^{\circ}_{cathode} - E^{\circ}_{anode} = 0.15\ \text{V} - (-1.28\ \text{V}) = 1.43\ \text{V}.$

Solution 1

(f)(iii)

Mark scheme

- $\Delta G^\circ = -nFE^\circ = -\dfrac{2 \text{ mol } e^-}{1 \text{ mol}_{rxn}} \times 96{,}485 \text{ C} \times \dfrac{1.43 \text{ J}}{1 \text{ C}} \times \dfrac{1 \text{ kJ}}{1000 \text{ J}} = -276 \text{ kJ/mol}_{rxn}.$

Solution 1

(f)(iv)

Mark scheme

- Disagree. The battery is enclosed (sealed), so no mass enters or leaves the system — no change in total mass will occur. (Also accept: all reactants and products are in the solid phase, so with no gases entering or exiting the sealed battery, the total mass stays the same.)

Question 3

2022 ▪ Q3

Answer the following questions relating to the element aluminum, Al.

(a) Write the complete ground-state electron configuration of an Al atom.

Question 3

2022 ▪ Q3

Answer the following questions relating to the element aluminum, Al.

(b) Based on principles of atomic structure, explain why the radius of the Al atom is larger than the radius of the Al^{3+} ion.

A student plans to combine solid aluminum with an aqueous solution of silver ions. The student determines the mass of solid $AgNO_3$ needed to prepare the solution with a specific concentration.

Question 3

2022 ▪ Q3

Answer the following questions relating to the element aluminum, Al.

(c) In the following table, briefly list the steps necessary to prepare 200.0 mL of an aqueous solution of $AgNO_3$ using only equipment selected from the choices given. Assume that all appropriate safety measures are already in place. Not all equipment or lines in the table may be needed.

Available equipment: Solid $AgNO_3$ · Weighing paper and scoop · 250 mL beakers · Distilled water · 200.00 mL volumetric flask · Pipet · Balance · 50.0 mL graduated cylinder

Step	Step Description
1.	Use weighing paper to measure the determined mass of solid $AgNO_3$ on a balance.
2.	

Question 3

2022 ▪ Q3

Answer the following questions relating to the element aluminum, Al.

(d) After preparing the solution, the student places some of the solution into a beaker and adds a sample of aluminum. The reaction represented by the following equation occurs.

$$\mathrm{Al}(s) + 3\,\mathrm{Ag}^{+}(aq) \rightarrow \mathrm{Al}^{3+}(aq) + 3\,\mathrm{Ag}(s)$$

The following diagram gives an incomplete particulate representation of the reaction. The beaker on the left represents the system before the mixture reacts. Complete the drawing on the right to represent the system after the reaction has occurred. Be sure to include 1) the correct type and number of particles based on the number shown on the left and 2) the relative spacing to depict the appropriate phases.

Question 3

[Two beaker diagrams side by side connected by a rightward arrow. Left beaker ("before reaction"): shown containing 4 "Al" (shaded circles, representing solid Al atoms clustered at the bottom) and 6 "Ag^+" (open circles, representing dissolved silver ions distributed throughout the liquid). Right beaker ("after reaction," to be completed by the student): shown only with 2 "Al" solid particles remaining at the bottom, with the rest of the beaker left blank for the student to draw in the products. A key box below states: "Al" (shaded circle) = Al atom; "Ag" (open circle) = Ag atom; "Al^{3+}" (circle) = Al^{3+} ion; "Ag^+" (open circle) = Ag^+ ion.]

The student finds the standard reduction potentials given in the table, which are related to the reaction that occurs.

| Half-Reaction | E° | |—|—| | $Ag^+(aq) + e^- \rightarrow Ag(s)$ | 0.80 V | |
$Al^{3+}(aq) + 3\,e^- \rightarrow Al(s)$ | -1.66 V |

Question 3

2022 ▪ Q3

Answer the following questions relating to the element aluminum, Al.

(e) Using the standard reduction potentials, calculate the value of E° for the reaction.

Question 3

2022 ▪ Q3

Answer the following questions relating to the element aluminum, Al.

(f) Based on the value of E°, would the standard free energy change of the reaction under standard conditions, ΔG°, be positive, negative, or zero? Justify your answer.

Question 3

2022 ▪ Q3

Answer the following questions relating to the element aluminum, Al.

(g) Once the reaction appears to stop progressing, would the change in free energy, ΔG, be positive, negative, or zero? Justify your answer.

Solution 3

(a)

Mark scheme

- Ground-state electron configuration of Al: $1s^2 2s^2 2p\ 3s^2 3p^1$ (equivalently $[Ne]3s^2 3p^1$).

Solution 3

(b)

Mark scheme

- The highest occupied electron shell (n = 3) of the Al atom is at a greater average distance from the nucleus than the highest occupied electron shell (n = 2) of the Al^{3} ion, so the Al atom has the larger radius.

Solution 3

(c)

Mark scheme

- Steps to prepare 200.0 mL of AgNO3(aq) solution (may be consolidated): (1 point) partially fill the 200.00 mL volumetric flask with some distilled water; add the weighed solid AgNO3(s) to the volumetric flask; swirl to dissolve the solid. (1 point, correct step for quantitative dilution) after the solid is dissolved, fill the flask to the calibration (200.00 mL) mark and mix.

Solution 3

(d)

Mark scheme

- Particulate drawing of the beaker after Al(s) + 3Ag (aq) $\rightarrow$ Al^3 (aq) + 3Ag(s) reacts (1 point each criterion): conservation of matter — draw 4 Al and 8 Ag particles total (matching the atoms present before reaction, some as product, some as leftover ions); conservation of charge — draw 2 Ag ions and 2 Al^3 ions remaining (i.e., 2 of the 4 Al atoms became Al^3 , consuming 6 of the 8 Ag to form 6 Ag atoms, leaving 2 Ag unreacted); correct phases of matter — show 6 Ag atoms as solid (clustered together) and 2 Al^3 ions as aqueous (dispersed in solution).

Solution 3

(e)

Mark scheme

- $E^\circ = E^\circ\text{red} - E^\circ\text{ox} = 0.80\ \text{V} - (-1.66\ \text{V}) = 2.46\ \text{V}$ (equivalently $E^\circ = 0.80\ \text{V} + 1.66\ \text{V} = 2.46\ \text{V}$).

Solution 3

(f)

Mark scheme

- Negative. The reaction has a positive value of E°, indicating that it is thermodynamically favorable and would therefore have a negative value of ΔG° ($\Delta G^\circ = -nFE^\circ$).

Solution 3

(g)

Mark scheme

- Zero. Once the reaction stops progressing, the system has reached equilibrium: this implies Ecell $= 0$ (no more driving force for the reaction), and since $\Delta G = -nFE_{cell}$, $\Delta G = 0$ at equilibrium.

Question 2

2021 ▪ Q2

Answer the following questions about the element Si and some of its compounds.

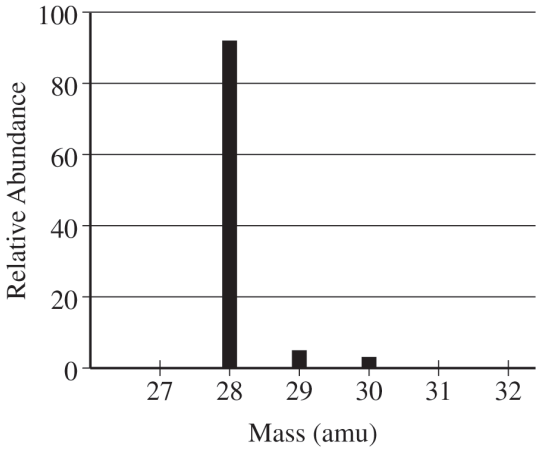
(a)(i) The mass spectrum of a pure sample of Si is shown below.

[Bar graph: Relative Abundance (y-axis, 0 to 100) vs. Mass (amu) (x-axis, 27 to 32). A tall bar of relative abundance ~92 at mass 28; a very small bar at mass 29 (~3); a very small bar at mass 30 (~4); negligible/no bars at 27, 31, 32.]

How many protons and how many neutrons are in the nucleus of an atom of the most abundant isotope of Si?

(a)(ii) Write the ground-state electron configuration of Si.

Question 2



Question 2

2021 ▪ Q2

Answer the following questions about the element Si and some of its compounds.

(b) Two compounds that contain Si are SiO_2 and SiH_4.

At 161 K, SiH_4 boils but SiO_2 remains as a solid. Using principles of interparticle forces, explain the difference in boiling points.

Question 2

2021 ▪ Q2

Answer the following questions about the element Si and some of its compounds.

(c) At high temperatures, SiH_4 decomposes to form solid silicon and hydrogen gas. Write a balanced equation for the reaction.

Question 2

2021 ▪ Q2

Answer the following questions about the element Si and some of its compounds.

(d) A table of absolute entropies of some substances is given below.

Substance	S° (J/(mol $\cdot$ K))
$H_2(g)$	131
$Si(s)$	18
$SiH_4(g)$	205

Explain why the absolute molar entropy of $Si(s)$ is less than that of $H_2(g)$.

Question 2

2021 ▪ Q2

Answer the following questions about the element Si and some of its compounds.

(e) Calculate the value, in J/(mol $\cdot$ K), of ΔS° for the reaction.

Question 2

2021 ▪ Q2

Answer the following questions about the element Si and some of its compounds.

(f) The reaction is thermodynamically favorable at all temperatures. Explain why the reaction occurs only at high temperatures.

Question 2

2021 ▪ Q2

Answer the following questions about the element Si and some of its compounds.

(g) A partial photoelectron spectrum of pure Si is shown below. On the spectrum, draw the missing peak that corresponds to the electrons in the $3p$ sublevel.

[Photoelectron spectrum: Relative Number of Electrons (y-axis) vs. Binding Energy (MJ/mol) (x-axis, logarithmic scale decreasing left to right: 1,000, 100, 10, 1, 0.1). Peaks shown (from left to right, i.e. highest to lowest binding energy): a small peak near ~180 (between 1,000 and 100), a small peak near ~20 (between 100 and 10), a tall peak near ~10, and a small peak near ~1.5 (between 1 and 0.1). No peak is shown corresponding to the $3p$ sublevel — the student must draw it in at the appropriate position and relative height.]

Question 2

2021 ▪ Q2

Answer the following questions about the element Si and some of its compounds.

(h) Using principles of atomic structure, explain why the first ionization energy of Ge is lower than that of Si.

Question 2

2021 ▪ Q2

Answer the following questions about the element Si and some of its compounds.

(i) A single photon with a wavelength of 4.00×10^{-7} m is absorbed by the Si sample. Calculate the energy of the photon in joules.

Solution 2

(a)(i)

Mark scheme

- The mass spectrum's tallest peak (highest relative abundance, ~92%) is at mass 28, so Si-28 is the most abundant isotope. Silicon's atomic number is 14, so this isotope has 14 protons and $(28 - 14 =)$ 14 neutrons.

(a)(ii)

Mark scheme

- Accept either equivalent form of the ground-state electron configuration of Si: $1s^2 2s^2 2p^6 3s^2 3p^2$, or the noble-gas-core notation $[\text{Ne}]3s^2 3p^2$.

Solution 2

(b)

Mark scheme

- SiH4 is composed of discrete molecules, so the only intermolecular forces between SiH4 molecules are (relatively weak) London dispersion forces. SiO2, by contrast, is a network covalent solid with strong covalent Si–O bonds extending throughout the entire structure. Because London dispersion forces are much weaker than covalent bonds, SiH4 boils at a much lower temperature (it is already a gas at 161 K) while SiO2 remains solid.

Solution 2

(c)

Mark scheme

- $SiH_4(g) \rightarrow Si(s) + 2\,H_2(g)$ (state symbols not required; equation is already balanced).

Solution 2

(d)

Mark scheme

- H2(g) molecules are more highly dispersed (able to move freely and occupy a much larger volume) than Si(s) atoms, and therefore have higher absolute molar entropy. Silicon is a solid, so its atoms are held in fixed positions within the lattice, are far less dispersed, and consequently have lower absolute molar entropy than H2(g).

Solution 2

(e)

Mark scheme

- $\Delta S^\circ_{rxn} = S^\circ_{\text{products}} - S^\circ_{\text{reactants}} = [18 + 2(131)] - 205 = +75$ J/(mol$_{rxn}$ · K), using S°: Si(s)=18, H2(g)=131 ($\times$2 mol), SiH4(g)=205, all in J/(mol · K).

Solution 2

(f)

Mark scheme

- High temperature is required so the reactant SiH4 molecules have sufficient thermal (kinetic) energy to overcome the activation energy barrier of the reaction. A negative ΔG° (thermodynamic favorability) only indicates the reaction is spontaneous, not that it proceeds at an appreciable rate at low temperature — reaction rate is a kinetic property governed separately by activation energy.

Solution 2

(g)

Mark scheme

- The missing peak (representing the Si 3p electrons) should be drawn as the rightmost peak on the spectrum — i.e., at the lowest binding energy (below the existing 1 MJ/mol region), since 3p electrons are Si's outermost/valence electrons and thus the most weakly bound. Its height should reach the second gridline above the horizontal axis, reflecting that the 3p sublevel holds 2 electrons.

Solution 2

(h)

Mark scheme

- The valence electrons of a Ge atom occupy a higher principal energy level/shell (n=4) than those of a Si atom (n=3), so the average distance between the nucleus and the valence electrons is greater in Ge than in Si. This greater separation results in weaker Coulombic attraction between the Ge nucleus and its valence electrons, making them less tightly bound and therefore easier to remove — giving Ge a lower first ionization energy than Si.

Solution 2

(i)

Mark scheme

- $E = h\nu = h\dfrac{c}{\lambda} = (6.626 \times 10^{-34}\ \text{J} \cdot \text{s})\left(\dfrac{2.998 \times 10^{8}\ \text{m/s}}{4.00 \times 10^{-7}\ \text{m}}\right) = 4.97 \times 10^{-19}\ \text{J}.$

Question 5

2019 ▪ Q5

The complete photoelectron spectrum of an element in its ground state is represented below.

[Graph: Photoelectron spectrum; y-axis "Relative Number of Electrons" (unscaled, gridlines shown, no numeric values), x-axis "Binding Energy per Electron (J)" plotted with decreasing energy to the right (values labelled at each peak, diagonally, right to left as printed): a short peak at 647×10^{-18}; two adjacent short peaks near 70.2×10^{-18} and 55.7×10^{-18} (the taller of the pair, at 55.7×10^{-18}, reaches near the top of the graph); two adjacent peaks at 7.10×10^{-18} (short) and 4.07×10^{-18} (tall, reaching near the top); and a short peak at 0.980×10^{-18}]

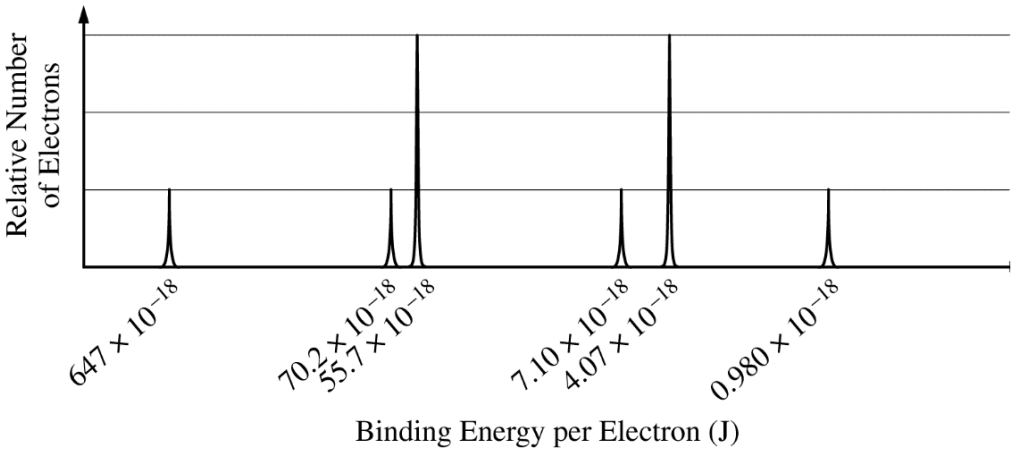
(a)(i) Based on the spectrum, write the ground-state electron configuration of the element.

(a)(ii) Based on the spectrum, identify the element.

Question 5

(b) Calculate the wavelength, in meters, of electromagnetic radiation needed to remove an electron from the valence shell of an atom of the element.

Question 5


Relative Number of Electrons
647×10^{-18}
70.2×10^{-18}
55.7×10^{-18}
7.10×10^{-18}
4.07×10^{-18}
0.980×10^{-18}
Binding Energy per Electron (J)

Solution 5

(a)(i)

Mark scheme

- $1s^2\ 2s^2\ 2p\ \ 3s^2\ 3p\ \ 4s^2$ (equivalently $[Ar]4s^2$). 1 point for the correct ground-state electron configuration, based on the spectrum's six peak groups (binding energies 647, 70.2, 55.7, 7.10, 4.07, 0.980×10^{1} J) with relative heights matching 2,2,6,2,6,2 electrons in the 1s,2s,2p,3s,3p,4s subshells.

Solution 5

(a)(ii)

Mark scheme

- Calcium (Ca), $Z = 20$, consistent with the electron configuration $[Ar]4s^2$ identified in part (a)(i). 1 point for the correct element.

Solution 5

(b)

Mark scheme

- The energy required to remove a valence electron equals the smallest binding energy shown, $E = 0.980 \times 10^{-1}$ J (the 4s electron). 1 point for correctly identifying this as the required energy (may be implicit in the calculation). Using $E = h\nu = hc/\lambda \Rightarrow \lambda = hc/E = (6.626 \times 10^{-3}\ \text{J} \cdot \text{s})(2.998 \times 10\ \text{m/s}) / (0.980 \times 10^{-1}\ \text{J}) = 2.03 \times 10$ m. 1 point for the correct wavelength.

Question 3

2018 ▪ Q3

Answer the following questions relating to Fe and its ions, Fe^{2+} and Fe^{3+}.

(a) Write the ground-state electron configuration of the Fe^{2+} ion.

| Ion | Ionic Radius (pm) | |—|—| | Fe^{2+} | 92 | | Fe^{3+} | 79 |

Question 3

Mass of $Fe(s)$ with inert impurity	6.724 g
Mass of $Fe_2O_3(s)$ produced	7.531 g

Question 3

Ion	Ionic Radius (pm)
Fe^{2+}	92
Fe^{3+}	79

Question 3

2018 ▪ Q3

Answer the following questions relating to Fe and its ions, Fe^{2+} and Fe^{3+}.

(b) The radii of the ions are given in the table above. Using principles of atomic structure, explain why the radius of the Fe^{2+} ion is larger than the radius of the Fe^{3+} ion.

Question 3

2018 ▪ Q3

Answer the following questions relating to Fe and its ions, Fe^{2+} and Fe^{3+}.

(c) Fe^{3+} ions interact more strongly with water molecules in aqueous solution than Fe^{2+} ions do. Give one reason for this stronger interaction, and justify your answer using Coulomb's law.

A student obtains a solution that contains an unknown concentration of $Fe^{2+}(aq)$. To determine the concentration of $Fe^{2+}(aq)$ in the solution, the student titrates a sample of the solution with $MnO_4^-(aq)$, which converts $Fe^{2+}(aq)$ to $Fe^{3+}(aq)$, as represented by the following equation.

$$5\,Fe^{2+}(aq) + MnO_4^-(aq) + 8\,H^+(aq) \rightarrow 5\,Fe^{3+}(aq) + Mn^{2+}(aq) + 4\,H_2O(l)$$

Question 3

2018 ▪ Q3

Answer the following questions relating to Fe and its ions, Fe^{2+} and Fe^{3+}.

(d) Write the balanced equation for the half-reaction for the oxidation of $Fe^{2+}(aq)$ to $Fe^{3+}(aq)$.

Question 3

2018 ▪ Q3

Answer the following questions relating to Fe and its ions, Fe^{2+} and Fe^{3+}.

(e) The student titrates a 10.0 mL sample of the $Fe^{2+}(aq)$ solution. Calculate the value of $[Fe^{2+}]$ in the solution if it takes 17.48 mL of added 0.0350 M $KMnO_4(aq)$ to reach the equivalence point of the titration.

To deliver the 10.0 mL sample of the $Fe^{2+}(aq)$ solution in part (e), the student has the choice of using one of the pieces of glassware listed below.

- 25 mL buret - 25 mL graduated cylinder - 25 mL beaker - 25 mL volumetric flask

Question 3

2018 ▪ Q3

Answer the following questions relating to Fe and its ions, Fe^{2+} and Fe^{3+}.

(f) Explain why the 25 mL volumetric flask would be a poor choice to use for delivering the required volume of the $Fe^{2+}(aq)$ solution.

In a separate experiment, the student is given a sample of powdered $Fe(s)$ that contains an inert impurity. The student uses a procedure to oxidize the $Fe(s)$ in the sample to $Fe_2O_3(s)$. The student collects the following data during the experiment.

| | | |—|—| | Mass of $Fe(s)$ with inert impurity | 6.724 g | | Mass of $Fe_2O_3(s)$ produced | 7.531 g |

Question 3

2018 ▪ Q3

Answer the following questions relating to Fe and its ions, Fe^{2+} and Fe^{3+}.

(g) Calculate the number of moles of Fe in the $Fe_2O_3(s)$ produced.

Question 3

2018 ▪ Q3

Answer the following questions relating to Fe and its ions, Fe^{2+} and Fe^{3+}.

(h) Calculate the percent by mass of Fe in the original sample of powdered Fe(s) with the inert impurity.

Question 3

2018 ▪ Q3

Answer the following questions relating to Fe and its ions, Fe^{2+} and Fe^{3+}.

(i) If the oxidation of the Fe(s) in the original sample was incomplete so that some of the 7.531 g of product was FeO(s) instead of Fe_2O_3(s), would the calculated mass percent of Fe(s) in the original sample be higher, lower, or the same as the actual mass percent of Fe(s)? Justify your answer.

Solution 3

(a)

Mark scheme

- Ground-state electron configuration of Fe2+: 1s2 2s2 2p6 3s2 3p6 3d6, i.e., [Ar]3d6 (the two 4s electrons are removed first when Fe forms Fe2+). 1 point is earned for the correct electron configuration.

Solution 3

(b)

Mark scheme

- Both ions have the same nuclear charge (26 protons), but Fe^{2+} has one more electron in its outermost (3d) shell than Fe^{3+}. The greater number of electrons in that shell for Fe^{2+} results in greater electron-electron repulsion, which leads to a larger radius. 1 point is earned for a valid explanation.

Solution 3

(c)

Mark scheme

- By Coulomb's law, F is proportional to q1*q2/r^2 (need not be explicitly stated). Fe^{3+} has a higher charge than Fe^{2+}, so it attracts the partially negative O of water molecules more strongly. OR: the smaller ionic radius of Fe^{3+} allows it to get closer to a water molecule, increasing the force of attraction (smaller r increases F). 1 point is earned for a valid explanation using Coulomb's law.

Solution 3

(d)

Mark scheme

- Half-reaction: Fe2+(aq) -> Fe3+(aq) + e-. 1 point is earned for the correct half-reaction.

Solution 3

(e)

Mark scheme

- 17.48 mL x 0.0350 mol KMnO4/1000 mL = 0.000612 mol KMnO4. Using the stoichiometry 5 Fe2+ : 1 MnO4-: 0.000612 mol KMnO4 x (5 mol Fe2+/1 mol KMnO4) = 0.003059 mol Fe2+. [Fe2+] = 0.003059 mol / 0.0100 L = 0.306 M. 1 point is earned for calculating the number of moles of KMnO4 (may be implicit); 1 point is earned for the correct concentration of Fe2+.

Solution 3

(f)

Mark scheme

- A 25 mL volumetric flask is designed to contain (measure) only 25.00 mL precisely, it has a single calibration mark and cannot accurately deliver a smaller, arbitrary volume like 10.0 mL. 1 point is earned for a valid explanation.

Solution 3

(g)

Mark scheme

- 7.531 g Fe2O3 x (1 mol Fe2O3/159.70 g Fe2O3) = 0.04716 mol Fe2O3. 0.04716 mol Fe2O3 x (2 mol Fe/1 mol Fe2O3) = 0.09431 mol Fe. 1 point is earned for the correct calculation.

Solution 3

(h)

Mark scheme

- 0.09431 mol Fe x 55.85 g Fe/mol = 5.267 g Fe. Percent by mass = (5.267 g Fe / 6.724 g sample) x 100 = 78.33%. 1 point is earned for the correct calculation of mass percent, based on the answer to part (g).

Solution 3

(i)

Mark scheme

- The calculated mass percent of Fe would be LOWER than the actual mass percent. A sample containing any FeO (rather than only Fe2O3) has a higher actual mass percent of Fe than a completely oxidized (Fe2O3-only) sample would, because FeO has a higher Fe:O mass ratio. So when the moles of Fe are calculated assuming all 7.531 g of product is Fe2O3, the calculated number of moles of Fe (and hence the calculated mass percent of Fe) will be lower than the true value. 1 point is earned for the correct answer (lower) and a valid explanation.

Question 1

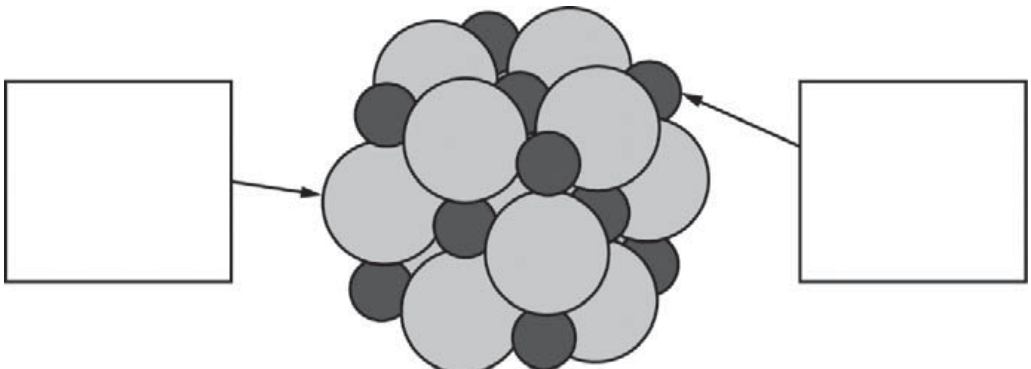
2016 ▪ Q1

A student investigates the enthalpy of solution, ΔH_{soln}, for two alkali metal halides, LiCl and NaCl. In addition to the salts, the student has access to a calorimeter, a balance with a precision of ± 0.1 g, and a thermometer with a precision of $\pm 0.1^{\circ}$C.

(a)(i) To measure ΔH_{soln} for LiCl, the student adds 100.0 g of water initially at 15.0°C to a calorimeter and adds 10.0 g of LiCl(s), stirring to dissolve. After the LiCl dissolves completely, the maximum temperature reached by the solution is 35.6°C. Calculate the magnitude of the heat absorbed by the solution during the dissolution process, assuming that the specific heat capacity of the solution is 4.18 J/(g $\cdot^{\circ}$ C). Include units with your answer.

(a)(ii) Determine the value of ΔH_{soln} for LiCl in kJ/mol$_{rxn}$.

Question 1



Question 1

Ion	Ionic Radius (pm)
Li^+	76
Na^+	102

Question 1

2016 ▪ Q1

A student investigates the enthalpy of solution, ΔH_{soln}, for two alkali metal halides, LiCl and NaCl. In addition to the salts, the student has access to a calorimeter, a balance with a precision of ± 0.1 g, and a thermometer with a precision of $\pm 0.1°C$.

(b) To explain why ΔH_{soln} for NaCl is different than that for LiCl, the student investigates factors that affect ΔH_{soln} and finds that ionic radius and lattice enthalpy (which can be defined as the ΔH associated with the separation of a solid crystal into gaseous ions) contribute to the process. The student consults references and collects the data shown in the table below.

| Ion | Ionic Radius (pm) | |—|—| | Li^+ | 76 | | Na^+ | 102 |

Write the complete electron configuration for the Na^+ ion in the ground state.

Question 1

2016 ▪ Q1

A student investigates the enthalpy of solution, ΔH_{soln}, for two alkali metal halides, LiCl and NaCl. In addition to the salts, the student has access to a calorimeter, a balance with a precision of ± 0.1 g, and a thermometer with a precision of $\pm 0.1^{\circ}$C.

(c) Using principles of atomic structure, explain why the Na^+ ion is larger than the Li^+ ion.

Question 1

2016 ▪ Q1

A student investigates the enthalpy of solution, ΔH_{soln}, for two alkali metal halides, LiCl and NaCl. In addition to the salts, the student has access to a calorimeter, a balance with a precision of ± 0.1 g, and a thermometer with a precision of $\pm 0.1^{\circ}$C.

(d) Which salt, LiCl or NaCl, has the greater lattice enthalpy? Justify your answer.

Question 1

2016 ▪ Q1

A student investigates the enthalpy of solution, ΔH_{soln}, for two alkali metal halides, LiCl and NaCl. In addition to the salts, the student has access to a calorimeter, a balance with a precision of ± 0.1 g, and a thermometer with a precision of $\pm 0.1°C$.

(e) Below is a representation of a portion of a crystal of LiCl. Identify the ions in the representation by writing the appropriate formulas (Li^+ or Cl^-) in the boxes below.

[Diagram: a cluster of packed spheres representing a portion of a LiCl crystal lattice, showing larger light-gray spheres and smaller dark-gray spheres packed together. Two empty boxes flank the cluster, each connected by an arrow pointing to a sphere in the cluster (one arrow points to a dark-colored sphere, one arrow points to a light-colored sphere), for the student to label which ion (Li+ or Cl-) each represents.]

Question 1

2016 ▪ Q1

A student investigates the enthalpy of solution, ΔH_{soln}, for two alkali metal halides, LiCl and NaCl. In addition to the salts, the student has access to a calorimeter, a balance with a precision of ± 0.1 g, and a thermometer with a precision of $\pm 0.1^{\circ}$C.

(f) The lattice enthalpy of LiCl is positive, indicating that it takes energy to break the ions apart in LiCl. However, the dissolution of LiCl in water is an exothermic process. Identify all particle-particle interactions that contribute significantly to the dissolution process being exothermic. For each interaction, include the particles that interact and the specific type of intermolecular force between those particles.

Solution 1

(a)(i)

Mark scheme

- $q = mc\Delta T = (110.0\text{ g})(4.18\text{ J}/(\text{g}\cdot{}^\circ\text{C}))(35.6^\circ\text{C} - 15.0^\circ\text{C}) = 9{,}470\text{ J} \approx 9.47$ kJ. (Total mass = 100.0 g water + 10.0 g LiCl = 110.0 g.) 1 point for the correct setup ($mc\Delta T$ with correct total mass and ΔT), 1 point for the correct answer with units (9.47 kJ or 9,470 J).

Solution 1

(a)(ii)

Mark scheme

- 10.0 g LiCl $\times$ (1 mol LiCl / 42.39 g LiCl) = 0.236 mol LiCl. ΔH_soln = -9.47 kJ / 0.236 mol LiCl = -40.1 kJ/mol_rxn. 1 point for the correct number of moles of LiCl, 1 point for the correct ΔH_soln value with the correct (negative) sign.

Solution 1

(b)

Mark scheme

- Complete ground-state electron configuration for the Na+ ion: $1s^2\ 2s^2\ 2p$. 1 point for the complete, correct configuration (10 electrons, isoelectronic with Ne).

Solution 1

(c)

Mark scheme

- The valence electrons in the Na+ ion occupy a higher principal energy level (n = 2) than the valence electrons in the Li+ ion (n = 1); electrons in higher principal energy levels are, on average, farther from the nucleus, making Na+ larger. 1 point for a correct explanation based on occupied principal energy levels.

Solution 1

(d)

Mark scheme

- LiCl has the greater lattice enthalpy. Because the Li+ ion is smaller than the Na+ ion, the Coulombic attractions between ions in LiCl are stronger than in NaCl, giving LiCl a greater lattice enthalpy. 1 point for the correct choice (LiCl) with correct justification (smaller ionic radius $\rightarrow$ stronger Coulombic attraction $\rightarrow$ greater lattice enthalpy).

Solution 1

(e)

Mark scheme

- In the packing diagram, the larger spheres are Cl− ions and the smaller spheres are Li+ ions (Cl− is the larger ion). 1 point for correctly identifying both ions (the Cl− box and the Li+ box) consistent with relative ion size.

Solution 1

(f)

Mark scheme

- Ion-dipole interactions occur between Li+ ions and polar water molecules, and between Cl− ions and polar water molecules; these favorable interactions make the dissolution exothermic despite the positive lattice enthalpy. 1 point for identifying the particles that interact (the ions and polar water molecules), 1 point for correctly naming the interaction type (ion-dipole).

Question 1

2015 ▪ Q1

Metal-air cells are a relatively new type of portable energy source consisting of a metal anode, an alkaline electrolyte paste that contains water, and a porous cathode membrane that lets in oxygen from the air. A schematic of the cell is shown above. Reduction potentials for the cathode and three possible metal anodes are given in the table below.

[Schematic diagram of a metal-air cell: a "Voltmeter" box connected via a "Switch" to two electrode leads. An arrow labeled e^- points down into the right electrode. The cell body is divided into three vertical regions labeled (left to right) "Metal", "Electrolyte Paste", and a stippled region with an arrow pointing to it labeled $O_2(g)$. The bottom of the left region is labeled "Anode" and the bottom of the right region is labeled "Cathode".]

Question 1

| Half Reaction | E at pH 11 and 298 K (V) | |—|—| |
$O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$ | $+0.34$ | |
$ZnO(s) + H_2O(l) + 2e^- \rightarrow Zn(s) + 2OH^-(aq)$ | -1.31 | |
$Na_2O(s) + H_2O(l) + 2e^- \rightarrow 2Na(s) + 2OH^-(aq)$ | -1.60 | |
$CaO(s) + H_2O(l) + 2e^- \rightarrow Ca(s) + 2OH^-(aq)$ | -2.78 |

(a)(i) Early forms of metal-air cells used zinc as the anode. Zinc oxide is produced as the cell operates according to the overall equation below.

$$2Zn(s) + O_2(g) \rightarrow 2ZnO(s)$$

Using the data in the table above, calculate the cell potential for the zinc-air cell.

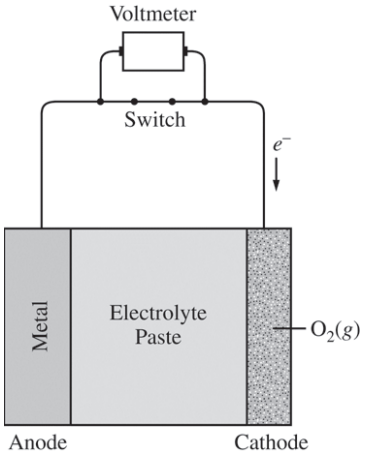
(a)(ii) The electrolyte paste contains OH^- ions. On the diagram of the cell above, draw an arrow to indicate the direction of migration of OH^- ions through the electrolyte as the cell operates.

Question 1

schematic of the cell is shown above. Reduction potentials for the cathode and three possible metal a
given in the table below.

Half Reaction	E at pH 11 and 298 K (V)
$O_2(g) + 2\,H_2O(l) + 4\,e^- \rightarrow 4\,OH^-(aq)$	+0.34
$ZnO(s) + H_2O(l) + 2\,e^- \rightarrow Zn(s) + 2\,OH^-(aq)$	–1.31
$Na_2O(s) + H_2O(l) + 2\,e^- \rightarrow 2\,Na(s) + 2\,OH^-(aq)$	–1.60
$CaO(s) + H_2O(l) + 2\,e^- \rightarrow Ca(s) + 2\,OH^-(aq)$	–2.78

Question 1


Voltmeter
Switch
e^-
Metal
Electrolyte Paste
$O_2(g)$
Anode
Cathode

Question 1

2015 ▪ Q1

Metal-air cells are a relatively new type of portable energy source consisting of a metal anode, an alkaline electrolyte paste that contains water, and a porous cathode membrane that lets in oxygen from the air. A schematic of the cell is shown above. Reduction potentials for the cathode and three possible metal anodes are given in the table below.

[Schematic diagram of a metal-air cell: a "Voltmeter" box connected via a "Switch" to two electrode leads. An arrow labeled e^- points down into the right electrode. The cell body is divided into three vertical regions labeled (left to right) "Metal", "Electrolyte Paste", and a stippled region with an arrow pointing to it labeled $O_2(g)$. The bottom of the left region is labeled "Anode" and the bottom of the right region is labeled "Cathode".]

| Half Reaction | E at pH 11 and 298 K (V) | |—|—| | $O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$ | $+0.34$ | | $ZnO(s) + H_2O(l) + 2e^- \rightarrow Zn(s) + 2OH^-(aq)$ | -1.31 | |
$Na_2O(s) + H_2O(l) + 2e^- \rightarrow 2Na(s) + 2OH^-(aq)$ | -1.60 | |
$CaO(s) + H_2O(l) + 2e^- \rightarrow Ca(s) + 2OH^-(aq)$ | -2.78 |

Question 1

(b)(i) A fresh zinc-air cell is weighed on an analytical balance before being placed in a hearing aid for use. As the cell operates, does the mass of the cell increase, decrease, or remain the same?
(b)(ii) Justify your answer to part (b)(i) in terms of the equation for the overall cell reaction.

Question 1

2015 ▪ Q1

Metal-air cells are a relatively new type of portable energy source consisting of a metal anode, an alkaline electrolyte paste that contains water, and a porous cathode membrane that lets in oxygen from the air. A schematic of the cell is shown above. Reduction potentials for the cathode and three possible metal anodes are given in the table below.

[Schematic diagram of a metal-air cell: a "Voltmeter" box connected via a "Switch" to two electrode leads. An arrow labeled e^- points down into the right electrode. The cell body is divided into three vertical regions labeled (left to right) "Metal", "Electrolyte Paste", and a stippled region with an arrow pointing to it labeled $O_2(g)$. The bottom of the left region is labeled "Anode" and the bottom of the right region is labeled "Cathode".]

| Half Reaction | E at pH 11 and 298 K (V) | |—|—| | $O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$ | $+0.34$ | | $ZnO(s) + H_2O(l) + 2e^- \rightarrow Zn(s) + 2OH^-(aq)$ | -1.31 | |
$Na_2O(s) + H_2O(l) + 2e^- \rightarrow 2Na(s) + 2OH^-(aq)$ | -1.60 | |
$CaO(s) + H_2O(l) + 2e^- \rightarrow Ca(s) + 2OH^-(aq)$ | -2.78 |

Question 1

(c)(i) The zinc-air cell is taken to the top of a mountain where the air pressure is lower. Will the cell potential be higher, lower, or the same as the cell potential at the lower elevation?

(c)(ii) Justify your answer to part (c)(i) based on the equation for the overall cell reaction and the information above.

Question 1

2015 ▪ Q1

Metal-air cells are a relatively new type of portable energy source consisting of a metal anode, an alkaline electrolyte paste that contains water, and a porous cathode membrane that lets in oxygen from the air. A schematic of the cell is shown above. Reduction potentials for the cathode and three possible metal anodes are given in the table below.

[Schematic diagram of a metal-air cell: a "Voltmeter" box connected via a "Switch" to two electrode leads. An arrow labeled e^- points down into the right electrode. The cell body is divided into three vertical regions labeled (left to right) "Metal", "Electrolyte Paste", and a stippled region with an arrow pointing to it labeled $O_2(g)$. The bottom of the left region is labeled "Anode" and the bottom of the right region is labeled "Cathode".]

| Half Reaction | E at pH 11 and 298 K (V) | |—|—| | $O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$ | $+0.34$ | | $ZnO(s) + H_2O(l) + 2e^- \rightarrow Zn(s) + 2OH^-(aq)$ | -1.31 | |
$Na_2O(s) + H_2O(l) + 2e^- \rightarrow 2Na(s) + 2OH^-(aq)$ | -1.60 | |
$CaO(s) + H_2O(l) + 2e^- \rightarrow Ca(s) + 2OH^-(aq)$ | -2.78 |

Question 1

(d) Metal-air cells need to be lightweight for many applications. In order to transfer more electrons with a smaller mass, Na and Ca are investigated as potential anodes. A 1.0 g anode of which of these metals would transfer more electrons, assuming that the anode is totally consumed during the lifetime of a cell? Justify your answer with calculations.

Question 1

2015 ▪ Q1

Metal-air cells are a relatively new type of portable energy source consisting of a metal anode, an alkaline electrolyte paste that contains water, and a porous cathode membrane that lets in oxygen from the air. A schematic of the cell is shown above. Reduction potentials for the cathode and three possible metal anodes are given in the table below.

[Schematic diagram of a metal-air cell: a "Voltmeter" box connected via a "Switch" to two electrode leads. An arrow labeled e^- points down into the right electrode. The cell body is divided into three vertical regions labeled (left to right) "Metal", "Electrolyte Paste", and a stippled region with an arrow pointing to it labeled $O_2(g)$. The bottom of the left region is labeled "Anode" and the bottom of the right region is labeled "Cathode".]

| Half Reaction | E at pH 11 and 298 K (V) | |—|—| | $O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$ | $+0.34$ | | $ZnO(s) + H_2O(l) + 2e^- \rightarrow Zn(s) + 2OH^-(aq)$ | -1.31 | |
$Na_2O(s) + H_2O(l) + 2e^- \rightarrow 2Na(s) + 2OH^-(aq)$ | -1.60 | |
$CaO(s) + H_2O(l) + 2e^- \rightarrow Ca(s) + 2OH^-(aq)$ | -2.78 |

Question 1

(e)(i) The only common oxide of zinc has the formula ZnO. Write the electron configuration for a Zn atom in the ground state.
(e)(ii) From which sublevel are electrons removed when a Zn atom in the ground state is oxidized?

Solution 1

(a)(i)

Mark scheme

- E_cell = E_cathode - E_anode = 0.34 V - (-1.31 V) = 1.65 V, using the given standard reduction potentials for the O2/OH- cathode half-reaction and the ZnO/Zn anode half-reaction. 1 point for the correct cell potential (1.65 V).

Solution 1

(a)(ii)

Mark scheme

- The arrow should point to the left: OH- ions migrate from the cathode (right, where O2 is reduced and OH- is produced) toward the anode (left, where Zn is oxidized and OH- is consumed) through the electrolyte as the cell operates. 1 point for correctly indicating this right-to-left direction of migration.

Solution 1

(b)(i)

Mark scheme

- The mass of the cell increases as it operates. 1 point for correctly indicating an increase in cell mass.

Solution 1

(b)(ii)

Mark scheme

- Oxygen gas from the surrounding air enters the cell and reacts with Zn(s), producing ZnO(s); because mass (from O2) is added from outside the cell and ZnO(s) has more mass than the original Zn(s), the total mass of the cell increases as it operates. 1 point for this justification referencing the overall cell reaction 2Zn(s) + O2(g) -> 2ZnO(s).

Solution 1

(c)(i)

Mark scheme

- The cell potential will be lower at the top of the mountain, where air pressure (and thus the partial pressure of O2) is lower. 1 point for correctly indicating a lower cell potential.

Solution 1

(c)(ii)

Mark scheme

- O2(g), a reactant in the overall cell reaction, is at a lower partial pressure at the higher elevation; a lower O2 pressure makes the reaction quotient Q larger (closer to the equilibrium constant K). By the Nernst equation E_cell = E_cell_standard - (RT/nF) ln Q, moving Q closer to K decreases the magnitude of the cell potential. 1 point for a justification that relates lower O2 pressure/concentration to a larger Q, or a qualitative Nernst-equation argument reaching the same conclusion.

Solution 1

(d) Mark scheme

- For Na: 1.0 g Na x (1.0 mol Na / 22.99 g Na) x (1.0 mol e- / 1.0 mol Na) = 0.043 mol e-. For Ca: 1.0 g Ca x (1.0 mol Ca / 40.08 g Ca) x (2.0 mol e- / 1.0 mol Ca) = 0.050 mol e-. Because each mole of Ca releases 2 mol of electrons (vs. 1 mol for Na) and this outweighs Ca's larger molar mass, the 1.0 g Ca anode transfers more electrons (0.050 mol vs. 0.043 mol) and the cell with the Ca anode would transfer more electrons. 1 point for correctly calculating moles of electrons for both Na and Ca; 1 point for correctly taking 1 vs. 2 mol of electrons per mole of metal into account and reaching the correct conclusion that Ca transfers more electrons.

Solution 1

(e)(i)

Mark scheme

- Ground-state electron configuration of Zn: 1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^10, equivalently written [Ar] 4s^2 3d^10. 1 point for the correct configuration.

Solution 1

(e)(ii)

Mark scheme

- Electrons are removed from the 4s sublevel when a ground-state Zn atom is oxidized (for transition/post-transition metals, the outermost ns electrons are lost before the (n-1)d electrons). 1 point for the correct answer (4s sublevel).