Past-paper walk-through

Structure of Ionic Solids ▪ 2.3

eXercise

Questions in this set

- 2026 Q7
- 2021 Q6
- 2017 Q6
- 2016 Q1

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 7

2026 ▪ Q7

The following information applies to parts A and B.
Sodium metal reacts with oxygen gas according to Equation 1.

Equation 1: $4\,\mathrm{Na}(s) + \mathrm{O_2}(g) \rightarrow 2\,\mathrm{Na_2O}(s) \qquad \Delta H^\circ_{rxn} = -828\ \mathrm{kJ/mol}_{rxn}$

Standard enthalpies of formation are provided in Table 1.
| Substance | ΔH°_f (kJ/mol) | |—|—| | $\mathrm{Na}(s)$ | 0 | | $\mathrm{O_2}(g)$ | 0 | | $\mathrm{Na_2O}(s)$ | ? |
(a) Based on the information given, **calculate** the value of ΔH°_f for $\mathrm{Na_2O}(s)$. Show the work that leads to your answer.
(b) An 18.4 g sample of $\mathrm{Na}(s)$ reacts with 12.8 g of $\mathrm{O_2}(g)$ according to Equation 1. **Calculate** the total amount of heat, in kilojoules, released during this process. Show the work that leads to your answer.

Question 7

(c) Lattice enthalpy can be defined as the energy required to separate an ionic crystal into gaseous ions. $Rb_2O(s)$ and $Na_2O(s)$ have similar crystal structures, and their lattice enthalpies are given in Table 2.
| Compound | Lattice Enthalpy (kJ/mol) | |—|—| | $Na_2O(s)$ | 2481 | | $Rb_2O(s)$ | 2163 |
Using Coulomb's law, **explain** why the lattice enthalpy of $Rb_2O(s)$ is smaller than that of $Na_2O(s)$.

Table 2

Compound	Lattice Enthalpy (kJ/mol)
$Na_2O\,(s)$	2481
$Rb_2O\,(s)$	2163

Table 1

Substance	ΔH_f° (kJ/mol)
$Na(s)$	0
$O_2(g)$	0
$Na_2O(s)$	?

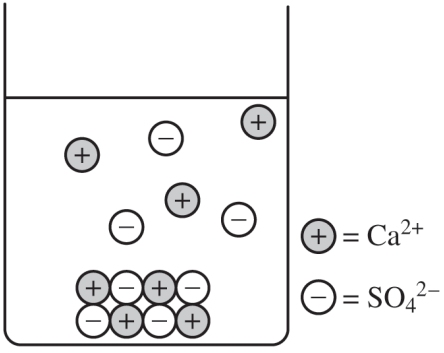
Question 6

2021 ▪ Q6

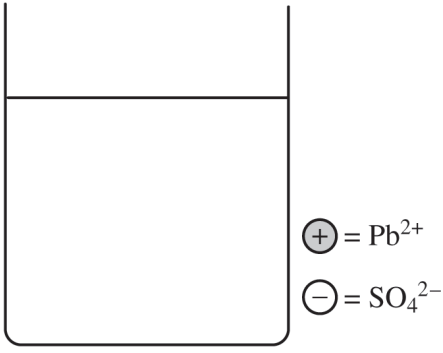
A student is studying the properties of $CaSO_4$ and $PbSO_4$. The student has samples of both compounds, which are white powders.

(a) The student tests the electrical conductivity of each solid and observes that neither solid conducts electricity. Describe the structures of the solids that account for their inability to conduct electricity.

Question 6



Higher Conductivity Solution



Lower Conductivity Solution

Question 6

2021 ▪ Q6

A student is studying the properties of $CaSO_4$ and $PbSO_4$. The student has samples of both compounds, which are white powders.

(b) The student places excess $CaSO_4(s)$ in a beaker containing 100 mL of water and places excess $PbSO_4(s)$ in another beaker containing 100 mL of water. The student stirs the contents of the beakers and then measures the electrical conductivity of the solution in each beaker. The student observes that the conductivity of the solution in the beaker containing the $CaSO_4(s)$ is higher than the conductivity of the solution in the beaker containing the $PbSO_4(s)$.

Which compound is more soluble in water, $CaSO_4(s)$ or $PbSO_4(s)$? Justify your answer based on the results of the conductivity test.

Question 6

2021 ▪ Q6

A student is studying the properties of $CaSO_4$ and $PbSO_4$. The student has samples of both compounds, which are white powders.

(c) The left side of the diagram below shows a particulate representation of the contents of the beaker containing the $CaSO_4(s)$ from the solution conductivity experiment.

[Diagram: two beakers side by side, each containing liquid. Left beaker, labeled "Higher Conductivity Solution": scattered small circles marked "+" (labeled Ca^{2+}) and "−" (labeled SO_4^{2-}) floating individually in the liquid (several of each, dispersed), plus a small cluster of undissolved solid at the bottom made of alternating "+" and "−" circles packed together. Right beaker, labeled "Lower Conductivity Solution": empty/blank, to be filled in by the student, with the same legend $+ = Pb^{2+}$, $- = SO_4^{2-}$.]

Question 6

Draw a particulate representation of $PbSO_4(s)$ and the ions dissolved in the solution in the beaker on the right in the diagram. Draw the particles to look like those shown to the right of the beaker. Draw an appropriate number of dissolved ions relative to the number of dissolved ions in the beaker on the left.

Question 6

2021 ▪ Q6

A student is studying the properties of $CaSO_4$ and $PbSO_4$. The student has samples of both compounds, which are white powders.

(d) The student attempts to increase the solubility of $CaSO_4(s)$ by adding 10.0 mL of 2 M $H_2SO_4(aq)$ to the beaker, and observes that additional precipitate forms in the beaker. Explain this observation.

Solution 6

(a)

Mark scheme

- Ionic solids do not have free-moving (mobile) ions — the ions are locked in fixed positions within the rigid crystal lattice — so there are no charge carriers able to move through the solid. Therefore there is no conduction of electricity.

Solution 6

(b)

Mark scheme

- CaSO4. The greater electrical conductivity of the CaSO4(aq) solution relative to the PbSO4(aq) solution implies a higher concentration of dissolved ions, which comes from CaSO4 dissolving/dissociating to a greater extent than PbSO4 — i.e., CaSO4 is more soluble than PbSO4.

Solution 6

(c)

Mark scheme

- The particulate diagram for the (lower-conductivity) PbSO4 beaker should show solid PbSO4 undissolved at the bottom (drawn similarly to the solid CaSO4 shown in the higher-conductivity beaker), together with fewer dissociated Pb2+ and SO4^2- ions dispersed in the solution than are shown in the CaSO4 beaker — reflecting PbSO4's lower solubility — while still showing an equal number of Pb2+ cations and SO4^2- anions in solution (1:1 stoichiometry / charge balance).

Solution 6

(d)

Mark scheme

- The additional precipitate is CaSO4 that forms in response to the increased [SO4^2-] introduced by the added H2SO4(aq). By Le Chatelier's principle (the reaction quotient Q now exceeds Ksp), the added common ion SO4^2- shifts the dissolution equilibrium of CaSO4 toward the solid, forming more CaSO4(s) — the common-ion effect.

Question 6

2017 ▪ Q6

Answer the following questions about $Mg(OH)_2$. At $25°C$, the value of the solubility product constant, K_{sp}, for $Mg(OH)_2(s)$ is 1.8×10^{-11}.

(a) Calculate the number of grams of $Mg(OH)_2$ (molar mass 58.32 g/mol) that is dissolved in 100. mL of a saturated solution of $Mg(OH)_2$ at $25°C$.

(b) The energy required to separate the ions in the $Mg(OH)_2$ crystal lattice into individual $Mg^{2+}(g)$ and $OH^-(g)$ ions, as represented in the table below, is known as the lattice energy of $Mg(OH)_2(s)$. As shown in the table, the lattice energy of $Sr(OH)_2(s)$ is less than the lattice energy of $Mg(OH)_2(s)$. Explain why in terms of periodic properties and Coulomb's law.

Reaction	Lattice Energy (kJ/mol)
$Mg(OH)_2(s) \rightarrow Mg^{2+}(g) + 2\,OH^-(g)$	2900
$Sr(OH)_2(s) \rightarrow Sr^{2+}(g) + 2\,OH^-(g)$	2300

Question 6

Reaction	Lattice Energy (kJ/mol)
$Mg(OH)_2(s) \rightarrow Mg^{2+}(g) + 2\ OH^-(g)$	2900
$Sr(OH)_2(s) \rightarrow Sr^{2+}(g) + 2\ OH^-(g)$	2300

Solution 6

(a)

Mark scheme

- Ksp = [Mg2+][OH-]^2 = (x)(2x)^2 = 4x^3 = 1.8x10^-11. x = cube root(1.8x10^-11 / 4) = 1.65x10^-4 M = [Mg2+] = solubility of Mg(OH)2. Mass = 0.100 L x (1.65x10^-4 mol/L) x (58.32 g Mg(OH)2 / 1 mol Mg(OH)2) = 9.6x10^-4 g Mg(OH)2. 1 point earned for calculating the solubility of Mg(OH)2; 1 point earned for calculating the correct mass based on the solubility of Mg(OH)2.

Solution 6

(b) Mark scheme

- The Sr2+ ion is larger than the Mg2+ ion because it has additional occupied energy levels (shells), since Sr is below Mg in the same group. Coulomb's law states that the force of attraction between a cation and an anion is inversely proportional to the square of the distance between them. Since the distance between Mg2+ and OH- is shorter than the distance between Sr2+ and OH-, the attractive forces in Mg(OH)2 are stronger, and therefore its lattice energy (2900 kJ/mol) is greater than that of Sr(OH)2 (2300 kJ/mol). 1 point earned for the correct comparison of cation sizes; 1 point earned for indicating that smaller interionic distances lead to a greater lattice energy.

Question 1

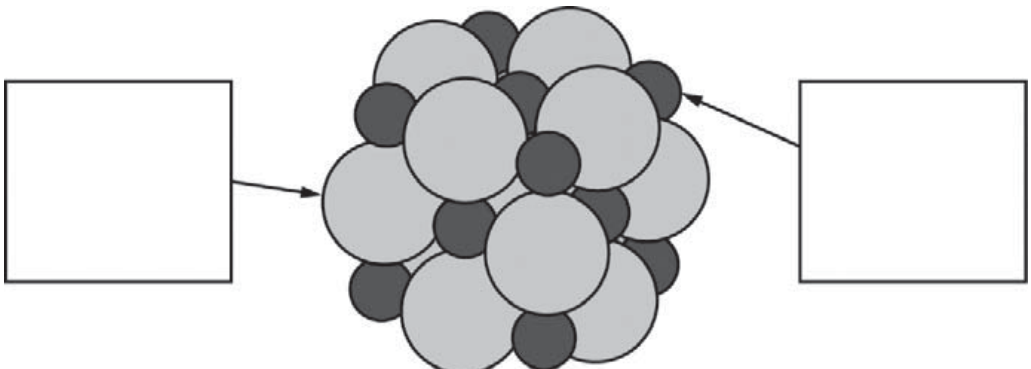
2016 ▪ Q1

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

- $q = mc\Delta T = (110.0\text{ g})(4.18\text{ J}/(\text{g}\cdot{}^\circ\text{C}))(35.6^\circ\text{C} - 15.0^\circ\text{C}) = 9{,}470\text{ J}$ 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).