2017

AP® CollegeBoard

AP Chemistry

Sample Student Responses and Scoring Commentary

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Question 6

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.

$1.8 \times 10^{-11} = [Mg^{2+}][OH^-]^2 = (x)(2x)^2 = 4x^3$ $x = \sqrt[3]{\dfrac{1.8 \times 10^{-11}}{4}} = 1.65 \times 10^{-4}\ M = [Mg^{2+}] = [Mg(OH)_2]$ $0.100\ \text{L} \times \dfrac{1.65 \times 10^{-4}\ \text{mol}}{1\ \text{L}} \times \dfrac{58.32\ \text{g}\ Mg(OH)_2}{1\ \text{mol}\ Mg(OH)_2} = 9.6 \times 10^{-4}\ \text{g}\ Mg(OH)$	1 point is earned for calculating the solubility of $Mg(OH)_2$. 1 point is earned for calculating the correct mass based on the solubility of $Mg(OH)_2$.

(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

The Sr^{2+} ion is larger than the Mg^{2+} ion because it has additional occupied energy levels (or shells). Coulomb's law states that the force of attraction between cation and anion is inversely proportional to the square of the distance between them. Since the distance between Mg^{2+} and OH^- is shorter than the distance between Sr^{2+} and OH^-, the attractive forces in $Mg(OH)_2$ are stronger and, therefore, its lattice energy is greater.	1 point is earned for the correct comparison of cation sizes. 1 point is earned for indicating that smaller interionic distances lead to a greater lattice energy.

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(6) $Mg(OH)_2 \rightleftharpoons Mg^{2+} + 2OH^-$

(a) $K_{sp} = [Mg^{2+}][OH^-]^2$; $[OH^-]_{eq} = 2[Mg^{2+}]_{eq}$ (given stoichiometry)

$K_{sp} = [Mg^{2+}](2[Mg^{2+}])^2 = 1.8 \cdot 10^{-11}$

$4[Mg^{2+}]^3 = 1.8 \cdot 10^{-11} \rightarrow [Mg^{2+}]_{eq} = 1.7 \cdot 10^{-4}\ M$

$1.7 \cdot 10^{-4} M\ Mg^{2+}(.1L) = 1.7 \cdot 10^{-5}\ mol\ Mg^{2+}$

$1.7 \cdot 10^{-5} mol\ Mg^{2+} \left(\frac{mol\ Mg(OH)_2}{mol\ Mg^{2+}}\right)\left(\frac{58.32g}{mol\ Mg(OH)_2}\right) = \boxed{9.6 \cdot 10^{-4} g\ Mg(OH)_2}$

(b) Lattice energy is directly proportional to the coulombic attraction between ions in an ionic compound. Coulomb's law states: $F \propto \frac{q_1q_2}{d^2}$, where q is charge and d is distance between ions. Between $Sr(OH)_2(s)$ and $Mg(OH)_2$, charges are consistant but since Sr^{2+}'s outermost valence electrons are on a higher energy level than Mg^{2+}'s valence electron's, Sr^{2+} has a greater ionic radius, thus increasing d which decreases the force of attraction according to Coulomb's law, decreasing the lattice energy of $Sr(OH)_2$ to be less than that of $Mg(OH)_2$.

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a) $Mg(OH)_2 \rightarrow Mg^{2+} + 2OH^-$

$ksp = \overset{x}{[Mg^{2+}]}\overset{2x^2}{[OH^-]^2}$

$\frac{1.8 \times 10^{-11}}{4} = \frac{4x^3}{4}$ $\quad M = \frac{mol}{L}$

$\sqrt{4.5 \times 10^{-12}} = \sqrt{x^3}$ $\quad x = 1.65 \times 10^{-4} M \times .1L = 1.65 \times 10^{-5} mol \times \frac{58.32g}{1 mol}$

$= \boxed{9.63 \times 10^{-4} g\ Mg(OH)_2}$

b) Sr^{2+} has a larger atomic radius than Mg^{2+}. Therefore, the attraction of $Sr(OH)_2$ is weaker than the attraction of $Mg(OH)_2$, so less energy is required to seperate $Sr(OH)_2$ into ions.

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a) $\frac{.1\,L}{} \left| \frac{1.8\times10^{-11}\,mol}{1\,L} \right| \frac{58.32\,g}{1\,mol} \Rightarrow 1.050 \times 10^{-10}\,g$

b) The valence electrons of Sr are farther away than those of Mg due to the size of the atom. The further away from the nucleus the electrons are, the less attractions the less attraction they have to the protons. Thus, the energy required by Sr will be leass than Mg.

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Question 6

Overview

This question required students to determine the solubility of a sparingly soluble salt in aqueous solution and then to provide a rationalization for the differences in lattice energy between two crystalline ionic compounds.

In this question the Learning Objectives (LO) assessed were 2.24, 2.28, 2.30, 2.32, and 6.22. The Science Practices (SP) assessed were 1.1, 2.2, 2.3, 6.2, 6.4, and 7.1.

In part (a) students were asked to determine the solubility of a saturated $Mg(OH)_2$ solution, given the K_{sp} for the salt. In part (b) students were provided with a definition of lattice energy. They were given the lattice energies of $Mg(OH)_2$ and $Sr(OH)_2$, which are 2900 kJ/mol and 2300 kJ/mol, respectively. With this information, they were required to provide a rationale for the relative strengths of the lattice energies. A proper rationalization, at the AP Chemistry level, uses the relative sizes of magnesium and strontium cations to qualitatively gauge the interionic distance between the cation and hydroxide and its effect on the magnitude of the interionic Coulombic interaction.

Sample: 6A
Score: 4

This response earned 4 of 4 possible points. The student earned 2 points in part (a) for correctly calculating the solubility of $Mg(OH)_2$, and then determining the mass of $Mg(OH)_2$ in solution. The response earned 2 points in part (b). The student states Coulomb's law, and specifically defines d as the distance between ions. The student indicates that Sr^{2+} has a greater ionic radius due to its valence electrons being "on a higher energy level" than those of Mg^{2+}, then connects an increase in the ionic radius to an increase in the distance between ions for $Sr(OH)_2$, leading to a smaller lattice energy.

Sample: 6B
Score: 3

This response earned 3 of 4 possible points. The student earned 2 points in part (a) for correctly calculating the solubility of $Mg(OH)_2$, identified as x, and determining the mass of $Mg(OH)_2$ in solution. The response earned 1 point in part (b). The student indicates that Sr^{2+} has a larger radius than Mg^{2+}. However, the student discusses a non-specific "attraction of $Sr(OH)_2$," rather than the distance between cation and anion, as the primary factor in Coulombic interaction.

Sample: 6C
Score: 1

This response earned 1 of 4 possible points. In part (a) the student incorrectly identifies the K_{sp} of $Mg(OH)_2$ as its molar solubility. The student does determine the mass of $Mg(OH)_2$ dissolved based on this incorrect number, so 1 point was earned in part (a). In part (b) the student correctly determines the relative sizes of Mg and Sr atoms (these relative sizes are consistent with the relative sizes of the respective ions), so 1 point was earned. However, the student discusses the relative attraction between the atomic nucleus and the electrons in the atom rather than the relative attraction between ions, so the second point in part (b) was not earned.