Question 1
(10 points)

Answer the following questions about the solubility and reactions of the ionic compounds $M(OH)_2$ and MCO_3, where M represents an unidentified metal.

(a) Identify the charge of the M ion in the ionic compounds above.

2+	1 point is earned for the correct charge.

(b) At 25°C, a saturated solution of $M(OH)_2$ has a pH of 9.15.

(i) Calculate the molar concentration of $OH^-(aq)$ in the saturated solution.

pOH = 14 – pH pOH = 14 – 9.15 = 4.85 $[OH^-] = 10^{-4.85} = 1.4 \times 10^{-5}\ M$	1 point is earned for the correct concentration.

(ii) Write the solubility-product constant expression for $M(OH)_2$.

$K_{sp} = [M^{2+}]\,[OH^-]^2$	1 point is earned for the correct expression.

(iii) Calculate the value of the solubility-product constant, K_{sp}, for $M(OH)_2$ at 25°C.

$[M^{2+}] = \frac{1}{2}[OH^-] = \frac{1}{2}(1.4 \times 10^{-5}\ M) = 7.0 \times 10^{-6}\ M$ $K_{sp} = [M^{2+}]\,[OH^-]^2 = (7.0 \times 10^{-6})(1.4 \times 10^{-5})^2$ $= 1.4 \times 10^{-15}$	1 point is earned for the correct relationship between $[M^{2+}]$ and $[OH^-]$. 1 point is earned for the correct value.

(c) For the metal carbonate, MCO_3, the value of the solubility-product constant, K_{sp}, is 7.4×10^{-14} at 25°C. On the basis of this information and your results in part (b), which compound, $M(OH)_2$ or MCO_3, has the greater molar solubility in water at 25°C ? Justify your answer with a calculation.

For $M(OH)_2$: $[M^{2+}]$ and molar solubility $= 7.0 \times 10^{-6}\ M$ For MCO_3 : $K_{sp} = 7.4 \times 10^{-14} = [M^{2+}][CO_3^{2-}]$ $[M^{2+}]$ and molar solubility $= 2.7 \times 10^{-7}\ M$ Because $7.0 \times 10^{-6}\ M > 2.7 \times 10^{-7}\ M$, $M(OH)_2$ has the greater molar solubility.	1 point is earned for the molar solubility of MCO_3. 1 point is earned for an answer consistent with the calculated molar solubility.

Question 1 (continued)

(d) MCO_3 decomposes at high temperatures, as shown by the reaction represented below.

$$MCO_3(s) \rightleftarrows MO(s) + CO_2(g)$$

A sample of MCO_3 is placed in a previously evacuated container, heated to 423 K, and allowed to come to equilibrium. Some solid MCO_3 remains in the container. The value of K_p for the reaction at 423 K is 0.0012.

(i) Write the equilibrium-constant expression for K_p of the reaction.

$K_p = P_{CO_2}$	1 point is earned for the correct expression.

(ii) Determine the pressure, in atm, of $CO_2(g)$ in the container at equilibrium at 423 K.

$P_{CO_2} = 0.0012$ atm	1 point is earned for the correct pressure.

(iii) Indicate whether the value of $\Delta G°$ for the reaction at 423 K is positive, negative, or zero. Justify your answer.

$\Delta G° = -RT \ln K$ $K = 0.0012 < 1$, thus $\ln K$ is negative; therefore $\Delta G°$ is positive.	1 point is earned for the correct answer with justification.

1A

ADDITIONAL PAGE FOR ANSWERING QUESTION 1

1.

(a) M^{2+}, Because $(OH^-)_2$ and CO_3^{2-}. Answer: 2+

(b) (I) $[OH^-] = 10^{-4.85}$

$= 1.41 \times 10^{-5}$ M

(II) $M(OH)_2 \longrightarrow M^{2+} + 2OH^-$ $K_{sp} = [M^{2+}][OH^-]^2$

(III) $K_{sp} = [M^{2+}][OH^-]^2$

$= \frac{[OH^-]}{2} \cdot [OH^-]^2$

$= 1.41 \times 10^{-15}$

(c) $MCO_3 \longrightarrow M^{2+} + CO_3^{2-}$ $K_{sp} = [M^{2+}][CO_3^{2-}]$

molar solubility → $[M^{2+}]$

(I) MCO_3

$[M^{2+}] = \sqrt{K_{sp}}$

$= 2.72 \times 10^{-7}$ M

(II) $M(OH)_2$

$[M^{2+}] = \sqrt[3]{\frac{K_{sp}}{4}}$

= ~~... $\times 10^{-6}$ M~~ 7.06×10^{-6} M

∴ (II) > (I)

∴ $M(OH)_2$ has the greater molar solubility in water at 25°C

(d) (I) $K_p = P_{CO_2}$

(II) $K_p = P_{CO_2} = 0.0012$ (at 423K)

∴ $P_{CO_2(g)} = 0.0012$ atm

(III) $\Delta G° = -RT \ln K$

$= -(8.31 \text{ J} \cdot \text{mol}^{-1} \cdot \text{K}^{-1}) \times (423 \text{ K}) \times \ln(0.0012)$

$= +2.36 \times 10^4 \text{ J} \cdot \text{mol}^{-1}$ > 0

~~negative~~ ∴ positive

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ADDITIONAL PAGE FOR ANSWERING QUESTION 1

Q1) a) +2

b) i) $POH = -\log[OH^-] \Rightarrow POH = 14 - PH = 14 - 9.15 = 4.85$

$\Rightarrow POH = -\log[OH^-] \Rightarrow 4.85 = -\log[OH^-]$

$\therefore [OH^-] = 1.4 \times 10^{-5}$ M

ii) $M(OH_2)_2 \rightleftharpoons M^{2+} + 2OH^-$

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

iii) $M(OH)_2 \rightleftharpoons M^{2+} + 2OH^-$

$M(OH)_2$	M^{2+}	$2OH^-$
C_M	—	—
$-x$	$+x$	$+2x$
$C_M - x$	x	$2x$

$2x = [OH^-] = 1.4 \times 10^{-5} \Rightarrow x = 7.0 \times 10^{-6}$ M

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

$= (2x)^2 (x) = 2x^3 \Rightarrow K_{sp} = 2(7.0 \times 10^{-6})^3$

$K_{sp} = 6.86 \times 10^{-16}$

c) MCO_3 has greater solubility because it has greater K_{sp} value: $7.4 \times 10^{-14} > 6.86 \times 10^{-16}$

d) i) $K_p = P_{CO_2}$

ii) $MCO_3 \rightleftharpoons MO + CO_2$

MCO_3	MO	CO_2
////	////	—
		$+x$
		x

$K_p = x = .0012$ atm

iii) ΔG is positive and the reaction is non spountinous because the value of $K_p < 1$

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1C

(a) 2

(b) (i) 1.41×10^{-5}

(ii) M^{2+}

(iii) 1.40×10^{-15}

(c) At 25°C { solubility of $M(OH)_2 = 7.0 \times 10^{-6}$
solubility of $MCO_3 = 2.7 \times 10^{-7}$

$7.0 \times 10^{-6} < 2.7 \times 10^{-7}$

∴ At 25°C, compound MCO_3 has the ~~greate~~ greater molar solubility than compound $M(OH)_2$

(d) (i) ~~$[CO_2] =$~~ $P_{CO_2} = 0.0012$

(ii) 0.0012 atm

(iii) ~~Kp < 1~~

Because $\Delta S >>> 0$. The value of $\Delta G°$ is negative

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Question 1

Sample: 1A
Score: 10

This response earned all 10 available points. Part (a) earned 1 point for the correct charge on the M ion. Part (b)(i) earned 1 point for the correct value for the concentration of the hydroxide ion, part (b)(ii) earned 1 point for the K_{sp} expression, and part b(iii) earned 2 points: 1 point for recognizing the relationship between $[M^{2+}]$ and $[OH^-]$, where $[M^{2+}] = [OH^-]/2$, and 1 point for calculating the correct value of the K_{sp}. Part (c) earned 2 points: 1 point for calculating the molar solubility of MCO_3, and 1 point for correctly comparing the molar solubility of MCO_3 with the previously calculated molar solubility of $M(OH)_2$ from (b)(iii). All 3 points were earned in part (d): 1 point for the correct expression for K_p in part (d)(i), 1 point in part (d)(ii) for recognizing that the value of K_p was the given pressure of CO_2, and 1 point in part (d)(iii) for showing that the value of $\Delta G°$ would be positive.

Sample: 1B
Score: 7

Part (b)(iii) earned 1 point for recognizing that there are twice as many OH^- as M^{2+} ions in this solution, but the second point was not earned because of the incorrect mathematics ($(2x)^2(x) \neq 2x^3$), which led to an incorrect value for the K_{sp}. No points were earned in part (c) as the answer just compares the K_{sp} values, which is not the same as comparing the molar solubilities.

Sample: 1C
Score: 4

Although the answer to part (b)(i) is correct, it did not earn the point as no work is shown. The incorrect expression for the K_{sp} did not earn the point in part (b)(ii), and the lack of any work meant that no points were earned in part (b)(iii). In part (c) the answer correctly compares the relative values for the solubilities of MCO_3 and $M(OH)_2$ and earned 1 point, but no work is presented to show how the values for the solubilities were obtained, so the other point was not earned. In part (d) 2 of the 3 possible points were earned: 1 point for an acceptable expression for K_p in part (d)(i), and 1 point for recognizing in part (d)(ii) that the value of K_p was the pressure of CO_2. Part (d)(iii) did not earn the point for the focus on the sign of ΔS, which could not lead to the correct answer.