AP® Chemistry
2001 Sample Student Responses

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CHEMISTRY
Section II
(Total time—90 minutes)

Part A
Time—40 minutes

YOU MAY USE YOUR CALCULATOR FOR PART A.

CLEARLY SHOW THE METHOD USED AND THE STEPS INVOLVED IN ARRIVING AT YOUR ANSWERS. It is to your advantage to do this, since you may obtain partial credit if you do and you will receive little or no credit if you do not. Attention should be paid to significant figures.

Be sure to write all your answers to the questions on the lined pages following each question in the booklet with the pink cover. Do NOT write your answers on the green insert.

Answer Question 1 below. The Section II score weighting for this question is 20 percent.

1. Answer the following questions relating to the solubility of the chlorides of silver and lead.

(a) At 10°C, 8.9 \times 10^{-5} \text{ g of AgCl(s)} will dissolve in 100. mL of water.

(i) Write the equation for the dissociation of AgCl(s) in water.

(ii) Calculate the solubility, in mol L^{-1}, of AgCl(s) in water at 10°C.

(iii) Calculate the value of the solubility-product constant, \( K_{sp} \), for AgCl(s) at 10°C.

(b) At 25°C, the value of \( K_{sp} \) for PbCl_2(s) is 1.6 \times 10^{-5} and the value of \( K_{sp} \) for AgCl(s) is 1.8 \times 10^{-10}.

(i) If 60.0 mL of 0.0400 \text{ M NaCl(aq)} is added to 60.0 mL of 0.0300 \text{ M Pb(NO}_3\text{)}_2(aq), will a precipitate form? Assume that volumes are additive. Show calculations to support your answer.

(ii) Calculate the equilibrium value of \([\text{Pb}^{2+}(\text{aq})]\) in 1.00 L of saturated PbCl_2 solution to which 0.250 mole of NaCl(s) has been added. Assume that no volume change occurs.

(iii) If 0.100 \text{ M NaCl(aq)} is added slowly to a beaker containing both 0.120 \text{ M AgNO}_3(aq) and 0.150 \text{ M Pb(NO}_3\text{)}_2(aq) at 25°C, which will precipitate first, AgCl(s) or PbCl_2(s)? Show calculations to support your answer.
(b)(i) 0.6 L X .04 m = .0024 mol Cl⁻/12 L = .02 m Cl⁻
.06 L X .03 m = .0018 mol Pb^{2+}/12 L = .015 m Pb^{2+}
PbCl₂ ⇌ Pb^{2+} + 2Cl⁻

\[Q = [\text{Pb}^{2+}] [\text{Cl}^-]^2 = (0.15 \text{ m Pb}^{2+})(0.02 \text{ m Cl}^-)^2 = 6 \times 10^{-10}\]

\[K_{sp} = 1.6 \times 10^{-5}\]

\[K_{sp} > Q\]

No precipitate will form.

(ii) \[K_{sp} = 1.6 \times 10^{-5}\]

\[K_{sp} = [\text{Pb}^{2+}] [\text{Cl}^-]^2\]

\[1.6 \times 10^{-5} = [\text{Pb}^{2+}] \cdot (.25)^2\]

\[2.56 \times 10^{-4} = [\text{Pb}^{2+}]\]

(iii) \[\text{AgCl} \rightleftharpoons \text{Ag}^+ + \text{Cl}^-\]

\[K_{sp} = 1.8 \times 10^{-10}\]

\[Q = [\text{Ag}^+] [\text{Cl}^-] = 1.8 \times 10^{-10}\]

\[1.8 \times 10^{-10} < [\text{Ag}^+] [\text{Cl}^-]\]

\[1.8 \times 10^{-10} < [\cdot 12 \text{ m Ag}^+] [\text{Cl}^-]\]

\[1.5 \times 10^{-9} < [\text{Cl}^-]\]

\[\text{PbCl}_2 \rightleftharpoons \text{Pb}^{2+} + 2\text{Cl}^-\]

\[K_{sp} = 1.6 \times 10^{-5}\]

\[Q = [\text{Pb}^{2+}] [\text{Cl}^-]^2\]

\[1.6 \times 10^{-5} < [\text{Pb}^{2+}] [\text{Cl}^-]^2\]

\[1.6 \times 10^{-5} < (0.15 \text{ m Pb}^{2+}) [\text{Cl}^-]^2\]

\[1.03 \times 10^{-2} < [\text{Cl}^-]\]

Ag₃Cl will precipitate first because a smaller concentration of Cl⁻ is necessary to form a precipitate.
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(b) At 25°C, the value of K_{sp} for PbCl_{2}(s) is 1.6 x 10^{-5} and the value of K_{sp} for AgCl(s) is 1.8 x 10^{-10}.
   (i) If 60.0 mL of 0.0400 M NaCl(aq) is added to 60.0 mL of 0.0300 M Pb(NO_{3})_{2}(aq), will a precipitate form? Assume that volumes are additive. Show calculations to support your answer.
   (ii) Calculate the equilibrium value of [Pb^{2+}(aq)] in 1.00 L of saturated PbCl_{2} solution to which 0.250 mole of NaCl(s) has been added. Assume that no volume change occurs.
   (iii) If 0.100 M NaCl(aq) is added slowly to a beaker containing both 0.120 M AgNO_{3}(aq) and 0.150 M Pb(NO_{3})_{2}(aq) at 25°C, which will precipitate first, AgCl(s) or PbCl_{2}(s)? Show calculations to support your answer.

\[ \text{a) i. } \text{AgCl}(s) \rightleftharpoons Ag^{+}(aq) + Cl^{-}(aq) \]
\[ \text{ii. } \frac{8.9 \times 10^{-5} \text{ g}}{1000 \text{ mL}} = \frac{1 \text{ mol}}{143.4 \text{ g}} = 6.2 \times 10^{-6} \text{ mol/L} \]
\[ \text{iii. } K_{sp} = [Ag^{+}][Cl^{-}] \]
\[ = (6.2 \times 10^{-6} \text{ M})^2 \]
\[ = 3.9 \times 10^{-11} \text{ mol}^2/\text{L}^2 \]
b) i. $2\text{Cl}^- + \text{Pb}^{2+} \rightarrow \text{PbCl}_2$

\[
\begin{align*}
[\text{Cl}^-] &= \frac{60.0 \text{ mL}(0.0400 \text{ M})}{120.0 \text{ mL}} \\
&= 0.0200 \text{ M}
\end{align*}
\]

\[
\begin{align*}
[\text{Pb}^{2+}] &= \frac{60.0 \text{ mL}(0.0300 \text{ M})}{120.0 \text{ mL}} \\
&= 0.0150 \text{ M}
\end{align*}
\]

\[Q = [\text{Pb}^{2+}][\text{Cl}^-]^2\]

\[= (0.0150 \text{ M})(0.0200 \text{ M})^2\]

\[= 6.00 \times 10^{-6}\]

\[K_{sp} = 1.8 \times 10^{-5}\]

\[K_{sp} > Q \therefore \text{no precipitate will form}\]

ii. $\text{PbCl}_2 \rightarrow \text{Pb}^{2+} + 2\text{Cl}^-$

\[
\begin{align*}
[\text{Cl}^-] &= \frac{0.250 \text{ mol}}{1.00 \text{ L}} \\
&= 0.250 \text{ M}
\end{align*}
\]

\[K_{sp} = [\text{Pb}^{2+}][\text{Cl}^-]^2\]

\[= \frac{1.8 \times 10^{-5}}{(0.250)^2}\]

\[= 2.6 \times 10^{-6}\text{ M}\]

iii. when $Q = K_{sp}$, precipitate starts forming

$Q$ for $\text{AgCl} = [\text{Ag}^+][\text{Cl}^-]$

\[= (0.120 \text{ M})(\text{?})\]

\[K_{sp} = [\text{Ag}^+][\text{Cl}^-] \times 1.8 \times 10^{-10} \text{ M}^2\]

\[= 0.120 \text{ M} \times 1.0 \times 10^{-9} \text{ M}\]

\[= 1.2 \times 10^{-9} \text{ M}\]

$Q$ for $\text{PbCl}_2 = [\text{Pb}^{2+}][\text{Cl}^-]^2$

\[= 0.150 \text{ M}[\text{Cl}^-]^2\]

\[K_{sp} = [\text{Pb}^{2+}][\text{Cl}^-]^2 \times 1.6 \times 10^{-5} \text{ M}\]

\[= (0.150 \text{ M})(1.6 \times 10^{-5})\]

\[= 1.0 \times 10^{-8} \text{ M}\]

PbCl$_2$ will precipitate first
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   (b) At 25°C, the value of $K_{sp}$ for PbCl$_2$(s) is $1.6 \times 10^{-5}$ and the value of $K_{sp}$ for AgCl(s) is $1.8 \times 10^{-10}$.
      (i) If 60.0 mL of 0.0400 M NaCl(aq) is added to 60.0 mL of 0.0300 M Pb(NO$_3$)$_2$(aq), will a precipitate form? Assume that volumes are additive. Show calculations to support your answer.
      (ii) Calculate the equilibrium value of [Pb$^{2+}$(aq)] in 1.00 L of saturated PbCl$_2$ solution to which 0.250 mole of NaCl(s) has been added. Assume that no volume change occurs.
      (iii) If 0.100 M NaCl(aq) is added slowly to a beaker containing both 0.120 M AgNO$_3$(aq) and 0.150 M Pb(NO$_3$)$_2$(aq) at 25°C, which will precipitate first, AgCl(s) or PbCl$_2$(s)? Show calculations to support your answer.

\[ \text{(a) } \text{AgCl(s) } \rightarrow \text{Ag}^+(aq) + \text{Cl}^-(aq) \]

\[ \text{(b) } \text{mol/L} = \frac{8.9 \times 10^{-5} \text{ g}}{143.323 \text{ g/mol}} \times \frac{1 \text{ mol}}{6.2 \times 10^{-7} \text{ L}} = 6.2 \times 10^{-6} \text{ mol/L} \]

\[ [\text{AgCl}] = 6.2 \times 10^{-7} \times \frac{6.2 \times 10^{-6} \text{ M}}{0.100 \text{ L}} = 6.2 \times 10^{-13} \text{ M} \]
iii) \[ K_{sp} = [Ag^{+}][Cl^{-}] \]

\[ = \left[ 2.209 \times 10^{-7} \right][6.209 \times 10^{-6}] \]

\[ = 5.86 \times 10^{-13} \]

\[ K_{sp} = 5.9 \times 10^{-5} \]

b) \[ NaCl(aq) + Pb(NO_3)_2(aq) \rightarrow 2NaNO_3(aq) + PbCl_2(s) \]

- moles Pb = 0.0300 mol x 0.0600 L = 0.0018 mol

- moles Cl = 0.0400 mol x 0.0600 L = 0.0024 mol

0.0012 mol of PbCl_2 will be formed, however, this amount is so small that it is almost negligible.

ii) \[ PbCl_2(s) \rightarrow Pb^{2+} + 2Cl^- \]

\[ K_{sp}(PbCl_2) = 1.6 \times 10^{-5} = [Pb^{2+}][Cl^-]^2 \]

\[ NaCl \rightarrow Na^+ + Cl^- \]

\[ K_{sp} = 1.6 \times 10^{-5} = [Cl^-][Cl^-] \]

\[ \text{Assume } x + 0.250 = 0.250 \]

\[ x = 2.5 \times 10^{-4} \]

\[ [Pb^{2+}] = 2.5 \times 10^{-4} \]

iii) \[ NaCl + AgNO_3 \rightarrow NaNO_3 + AgCl \] \[ 2NaCl + Pb(NO_3)_2 \rightarrow 2NaNO_3 + PbCl_2 \]

\[ K_{sp}(AgCl) = 1.8 \times 10^{-10} \]

\[ K_{sp}(PbCl_2) = 1.6 \times 10^{-5} \]

Since AgCl has a lower solubility than PbCl_2, the AgCl(s) will be precipitated out first.