2001 AP® CHEMISTRY FREE-RESPONSE QUESTIONS

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, 8.9×10^{-5} 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 1.6×10^{-5} and the value of K_{sp} for $AgCl(s)$ is 1.8×10^{-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.

AP® CHEMISTRY
2001 SCORING GUIDELINES

Question 1

(10 points)

(a) (i) $AgCl(s) \rightarrow Ag^+(aq) + Cl^-(aq)$ ***1 point***

- Correct charges needed to earn credit.
- Phases not necessary to earn credit.

(ii) $\frac{8.9 \times 10^{-5}\ g}{143.32\ \text{g/mol}} = 6.2 \times 10^{-7}\ \text{mol}$ (in 100 mL) ***1 point***

$(6.2 \times 10^{-7}\ \text{mol}/100\ \text{mL})\ (1{,}000\ \text{mL}/1.000\ \text{L}) =$ **6.2×10^{-6} mol/L** ***1 point***

Note: The first point is earned for the correct number of moles; the second point is earned for the conversion from moles to molarity.

(iii) $K_{sp} = [Ag^+][Cl^-] = (6.2 \times 10^{-6})^2 =$ **3.8×10^{-11}** ***1 point***

Note: Students earn one point for squaring their result for molarity in (a) (ii).

(b) (i) $n_{Cl^-} = (0.060\ \text{L})\ (0.040\ \text{mol/L}) = 0.0024\ \text{mol}$ ***1 point***

$[Cl^-] = (0.0024\ \text{mol})/(0.120\ \text{L}) = 0.020\ \text{mol/L} =$ **0.020 *M***

$n_{Pb^{2+}} = (0.060\ \text{L})\ (0.030\ \text{mol/L}) = 0.0018\ \text{mol}$

$[Pb^{2+}] = (0.0018\ \text{mol})/(0.120\ \text{L}) = 0.015\ \text{mol/L} =$ **0.015 *M***

$Q = [Pb^{2+}][Cl^-]^2 = (0.015)(0.020)^2 =$ **6.0×10^{-6}** ***1 point***

$Q < K_{sp}$, therefore no precipitate forms ***1 point***

Note: One point is earned for calculating the correct molarities; one point is earned for calculating Q; one point is earned for determining whether or not a precipitate will form.

(ii) $[Pb^{2+}] = \frac{K_{sp}}{[Cl^-]^2} = \frac{1.6 \times 10^{-5}}{(0.25)^2} =$ **2.6×10^{-4} *M*** ***1 point***

Question 1 (cont.)

(iii) for AgCl solution: $[Cl^-] = \dfrac{K_{sp}^{AgCl}}{[Ag^+]} = \dfrac{1.8 \times 10^{-10}}{0.120} = \mathbf{1.5 \times 10^{-9}\ M}$ ***1 point***

for $PbCl_2$ solution: $[Cl^-] = \sqrt{\dfrac{K_{sp}^{PbCl_2}}{[Pb^{2+}]}} = \sqrt{\dfrac{1.6 \times 10^{-5}}{0.150}} = \mathbf{1.0 \times 10^{-2}\ M}$

The $[Cl^-]$ will reach a concentration of $1.5 \times 10^{-9}\ M$ before it reaches a concentration of $1.0 \times 10^{-2}\ M$, (or $1.5 \times 10^{-9} << 1.0 \times 10^{-2}$), therefore AgCl(*s*) will precipitate first. ***1 point***

Note: One point is earned for calculating $[Cl^-]$ in saturated solutions with the appropriate Ag^+ and Pb^{2+} concentrations; one point is earned for concluding which salt will precipitate first, based on the student's calculations.

1A

CHEMISTRY

Section II

(Total time—90 minutes)

Part A

Time—40 minutes

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

   (a) At 10°C, 8.9×10^{-5} 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 1.6×10^{-5} and the value of K_{sp} for $AgCl(s)$ is 1.8×10^{-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.

1.(a)(i) $AgCl(s) \rightleftharpoons Ag^+(aq) + Cl^-(aq)$

(ii) 8.9×10^{-5} g AgCl / 143.5 g/mol = 6.2×10^{-7} mol AgCl

6.2×10^{-7} mol AgCl / .1 L = 6.2×10^{-6} M AgCl

6.2×10^{-6} mol L^{-1}

(iii) $K_{sp} = [Ag^+][Cl^-]^2$

$K_{sp} = (6.2 \times 10^{-6})^2 = 3.84 \times 10^{-11}$

ADDITIONAL PAGE FOR ANSWERING QUESTION 1.

(b)(i) .06 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}

$PbCl_2 \rightleftharpoons Pb^{+2} + 2Cl^-$

$Q = [Pb^{+2}][Cl^-]^2 = (.015\ M\ Pb^{+2})(.02\ M\ Cl^-)^2$

$Q = 6 \times 10^{-6}$

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

$K_{sp} > Q$

No precipitate will form.

(ii) $K_{sp} = 1.6 \times 10^{-5}$ .25 mol Cl^- / 1 L = .25 M Cl^-

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

$1.6 \times 10^{-5} = [Pb^{+2}][.25]^2$

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

(iii) $AgCl \rightleftharpoons Ag^+ + Cl^-$ $K_{sp} = 1.8 \times 10^{-10}$

$Q = [Ag^+][Cl^-]$. Q must be greater than K_{sp}

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

$1.8 \times 10^{-10} < [.12\ M\ Ag^+][Cl^-]$

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

$PbCl_2 \rightleftharpoons Pb^{+2} + 2Cl^-$ $K_{sp} = 1.6 \times 10^{-5}$

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

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

$1.6 \times 10^{-5} < [.15\ M\ Pb^{+2}][Cl^-]^2$

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

AgCl will precipitate first because a smaller concentration of Cl^- is necessary to form a precipitate.

AP® CHEMISTRY
2001 SCORING COMMENTARY

Question 1

Sample 1A (Score 10)

This response earned a perfect score of 10 points.

Sample 1B (Score 9)

This response earned a total of 9 points. The calculations were done correctly, but in part (b) (iii) the student misinterpreted the results of the calculations and drew an incorrect conclusion about which compound would precipitate first. This was a common error.

Sample 1C (Score 6)

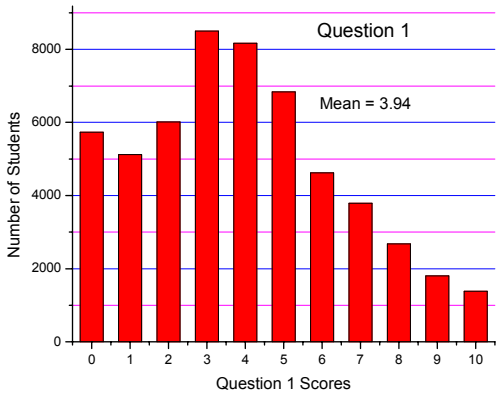
This response earned a total of 6 points. The student correctly calculated the number of moles of ions present in part (b) (i), but did not then use these values to calculate Q or to make a prediction about whether or not a precipitate would form. Therefore, the student earned only 1 out of the 3 points available in part (b) (i). In part (b) (iii), the student did not recognize the need to calculate $[Cl^-]$ for both solutions and, from these, to predict which compound would precipitate first.

Student Performance Q&A:
2001 AP® Chemistry Free-Response Questions

The following comments are provided by the Chief Faculty Consultant regarding the 2001 free-response questions for AP Chemistry. *They are intended to assist AP workshop consultants as they develop training sessions to help teachers better prepare their students for the AP Exam*. They give an overview of each question and its performance, including typical student errors. General comments regarding the skills and content that students frequently have the most problems with are included. Some suggestions for improving student performance in these areas are also included. Consultants are encouraged to use their expertise to create strategies for teachers to improve student performance in specific areas.

Question 1

The traditional "equilibrium" problem dealt with the solubility and the K_{sp} values of AgCl(*s*) and $PbCl_2$(*s*). The histogram below shows that the mode was 3 (out of 10 possible points) with an arithmetic mean of 3.94 points.



Common errors on Question 1 included:

Part (a)

- Many wrote the "equation for the dissociation of AgCl(*s*)" as a double replacement reaction. ("AgCl + HOH $\rightarrow$ AgOH + HCl")
- Many were unable to use the solubility information, from part (a) (ii), to calculate a K_{sp}

Part (b)

- Students frequently misinterpreted the relative magnitudes of numbers involving negative exponents. (Which is larger, 1×10^{-6}, or 1×10^{-5} ?)
- The squared term was often omitted in the K_{sp} for $PbCl_2$. ($K_{sp} = [Pb^{2+}][Cl^-]^2$)
- Part (b) (iii), dealing with selective solubilities, was most frequently omitted. When attempted, students often simply compared K_{sp} values, rather than comparing the $[Cl^-]$ needed to induce precipitation. This was the most poorly understood part of the question.

General comments on Question 1:

Many students indicated that they had not ever seen "K_{sp}'s". This is an important part of the equilibrium section in the AP curriculum, and should not be neglected. Emphasis should be placed on selected solubility concepts, as probed in part (b) (iii), and on questions such as "would a precipitate form under these conditions?".