AP* Solubility Equilibrium Free Response Questions

1985

Average score = 2.87
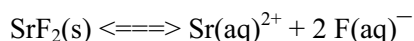
a) two points

$SrSO_4(s) \Longleftrightarrow Sr(aq)^{2+} + SO_4{}^{2-}(aq)$
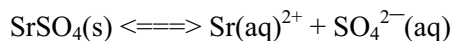
at equilibrium: $[SO_4{}^{2-}] = x = [Sr^{2+}]$

$(x)(x) = K_{sp} = 7.6 \times 10^{-7}$

$(x) = 8.7 \times 10^{-4}$ mol / liter = solubility of $SrSO_4$

b) three ponts

$SrF_2(s) \Longleftrightarrow Sr(aq)^{2+} + 2 F(aq)^-$

at equilibrium: $[Sr^{2+}] = x$, $[F^-] = 2x$

$K_{sp} = [Sr^{2+}][F^-]^2 = (x)(2x)^2 = 7.9 \times 10^{-10}$

$x = 5.8 \times 10^{-4}$ mol / liter = solubility of SrF_2

c) two points

Solve for $[Sr^+$ required for precipitation of each salt.

$K_{sp} = [Sr^{2+}][F^-]^2 = 7.9 \times 10^{-10}$

$= (x)(0.020 \text{ mole} / 1.0 \text{ L})^2 = 7.9 \times 10^{-10}$

$x = 2.0 \times 10^{-6}$ M

$K_{sp} = [Sr^{2+}][SO_4{}^{2-}] = 7.6 \times 10^{-7}$

$= (y)(0.10 \text{ mole}/1.0 \text{ liter}) = 7.6 \times 10^{-7}$

$y = 7.6 \times 10^{-6}$ M

Since 2.0×10^{-6} M $< 7.6 \times 10^{-6}$ M, SrF_2 must precipitate first.

When SrF_2 precipitates, $[Sr^{2+}] = 2.0 \times 10^{-6}$ M

d) two points

The second precipitate to form is $SrSO_4$, which appears when $[Sr^{2+}] = 7.6 \times 10^{-6}$ M (Based on calculation in Part c.)

When $[Sr^{2+}] = 7.6 \times 10^{-6}$ M, $[F^-]$ is determined as follows:

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$K_{sp} = [Sr^{2+}][F^-]^2 = 7.9 \times 10^{-10}$

$= (7.6 \times 10^{-6}) (z)^2 = 7.9 \times 10^{-10}$

$z = 1.0 \times 10^{-2} M$

%F^- still in solution $= 1.0 \times 10^{-2} / 2.0 \times 10^{-2} \times 100 = 50.\%$

1990.

1. The solubility of iron(II) hydroxide, $Fe(OH)_2$, is 1.43×10^{-3} gram per liter at $25°$ C.

   (a) Write a balanced equation for the solubility equilibrium.

   (b) Write the expression for the solubility product constant, K_{sp}, and calculate its value.

   (c) Calculate the pH of a saturated solution of $Fe(OH)_2$ at $25°$ C.

   (d) A 50.0-milliliter sample of 3.00×10^{-3}-molar $FeSO_4$ solution is added to 50.0 milliliters of 4.00×10^{-6}-molar NaOH solution. Does a precipitate of $Fe(OH)_2$ form? Explain and show calculations to support your answer.

(a) $Fe(OH)_2 \rightleftharpoons Fe^{2+} + 2OH^-$ (1)
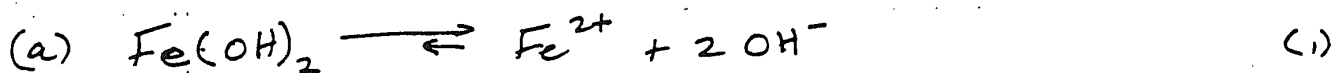
(b) $K_{sp} = [Fe^{2+}][OH^-]^2$ (1)

  M.W. of $Fe(OH)_2 = 55.85 + 2(16.0) + 2(1.008)$

                 $= 89.87 \text{ g/mol}$

$1.43 \times 10^{-3} g \times \dfrac{1 \text{ mol}}{89.87 g} = 1.59 \times 10^{-5}$ mol $Fe(OH)_2$ (1)

                 $= 1.59 \times 10^{-5}$ mol Fe^{2+}

                 $= 3.18 \times 10^{-5}$ mol OH^- (1)

$K_{sp} = (1.59 \times 10^{-5})(3.18 \times 10^{-5})^2$

     $= 1.61 \times 10^{-14}$ (1)

(c) $[H^+] = \dfrac{1.0 \times 10^{-14}}{[OH^-]} = \dfrac{1.0 \times 10^{-14}}{3.18 \times 10^{-5}} = 3.14 \times 10^{-10}$

   $pH = -\log[H^+] = 9.50$

OR $pOH = -\log[OH^-] = -\log(3.18 \times 10^{-5}) = 4.50$ (1)

     $pH = 14 - pOH = 9.50$

(d) 50.0 mL 3.0×10^{-3} M Fe^{2+} gs to 100 mL $= 1.5 \times 10^{-3}$ M Fe^{2+} } (1)

   50.0 mL 4.0×10^{-6} M OH^- gs to 100 mL $= 2.0 \times 10^{-6}$ M OH^-

  $Q = [Fe^{2+}][OH^-]^2 = (1.5 \times 10^{-3})(2.0 \times 10^{-6})^2$ (1)

     $= 6.0 \times 10^{-15}$

Precipitate will <u>not</u> form since $Q < K_{sp}$ (1)

Summary of Standards:

(a) one point awarded for correct expression including formula and charges and stoichiometry

(b) one point awarded for completely correct expression for K_{sp}
one point awarded for correct calculation of Fe^{2+} molarity
one point awarded for recognizing 2:1 ratio of $[OH^-]:[Fe^{2+}]$
one point for correct substitution and calculation of K_{sp}

(c) one point for correct calculation of pH (no matter where they get their $[OH^-]$)

(d) one point for calculation of both molarities
one point for correct substitution and calculation of Q
one point for correct conclusion (whatever Q and K_{sp} are used)

(a) K_{sp} = $[Mg^{2+}][F^-]^2$
  = $(1.21 \times 10^{-3})(2 \times 1.21 \times 10^{-3})^2$ *(1 pt.)*
  = 7.09×10^{-9} *(1 pt.)*

Note: if number of significant figures in final answer differs by
more than one from the appropriate number, 1 point is
deducted ONCE PER PROBLEM.

(b) K_{sp} = $[Mg^{2+}](2x + 0.100)^2$ $2x \ll 0.100$ *(1 pt.) for proper substitution*
7.09×10^{-9} = $[Mg^{2+}](0.010)^2$
$[Mg^{2+}]$ = $(7.09 \times 10^{-9})/(10^{-2})$
  = 7.09×10^{-7} M *(1 pt.)*

Note: OK if 0.102 is used for $[F^-]$, then K_{sp} = 6.76×10^{-7}

(c) $[Mg^{2+}]$: $100.0 \times 3.00 \times 10^{-3}$ = $300.0 \times [Mg^{2+}]$
        $[Mg^{2+}]$ = 1.00×10^{-3} M *(1 pt.) if both concentrations are correct*

   $[F^-]$: $200.0 \times 2.00 \times 10^{-3}$ = $300.0 \times [F^-]$
        $[F^-]$ = 1.33×10^{-3} M

 Q = Ion Product = $[Mg^{2+}][F^-]^2$
          = $(1.00 \times 10^{-3})(1.33 \times 10^{-3})^2$ **
          = 1.77×10^{-9} *(1 pt.)*

Since $Q < K_{sp}$, no precipitate will form   *(1 pt.)*

Note: conclusion must be consistent with Q value.

** Correct substitution and calculation of the *wrong*
concentration values earns the second point, but not
the first.

(d) Solubility of MgF_2 decreases with increasing
temperature, thus dissolution process is <u>exothermic</u>   *(1 pt.)*

  $MgF_2(s) \rightleftharpoons Mg^{2+} + 2 F^- + Q$ (or H)
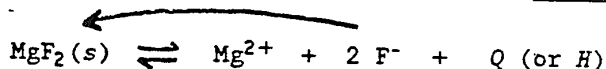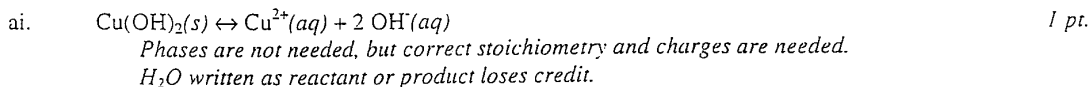
Reason:

EITHER

  i) Increased temperature puts a stress on the system
(Le Châtelier). The system will reduce the stress
by shifting the equilibrium in the endothermic (left)
direction

OR,   *(1 pt.)*

  ii) a data supported argument such as comparing ion
concentrations, calculating second K_{sp} and giving
proper interpretations.

199

ai. $Cu(OH)_2(s) \leftrightarrow Cu^{2+}(aq) + 2\ OH^-(aq)$ *1 pt.*

         Phases are not needed, but correct stoichiometry and charges are needed.
         H_2O written as reactant or product loses credit.

aii. $\dfrac{1.72 \times 10^{-6}\ \text{g}}{97.57\ \text{g}/\text{mol}} = 1.763 \times 10^{-8}\ \text{moles of Cu(OH)}_2$ $\Leftarrow$ Need not be   *1 pt.*
                                                         explicitly computed

     $\dfrac{1.763 \times 10^{-8}\ \text{moles}}{0.100\ \text{liter}} = 1.76 \times 10^{-7}\ \text{moles}/\text{liter}$ *1 pt.*

         1 pt for mass-to-moles conversion;
         1 pt for volume conversion.

aiii. $[Cu^{2+}] = 1.76 \times 10^{-7}\ M$ *1 pt.*
        $[OH^-] = 2(1.76 \times 10^{-7}\ M) = 3.52 \times 10^{-7}\ M$

        $K_{sp} = [Cu^{2+}][OH^-]^2 = (1.76 \times 10^{-7}\ M)(3.52 \times 10^{-7}\ M)^2$ *1 pt.*
            $= 2.18 \times 10^{-20}$

         1 point for correct concentrations of Cu^{2+} and OH^-.
         1 point for correct substitution into K_{sp} expression and answer.
         (If answer does not give an explicit statement for $[OH^-]$, but goes directly to Ksp
            expression, both points can be earned if the $[Cu^{2+}]$ and $[OH^-]$ are correctly used,
            and the answer is correct.)

bi. $pH = 9.35 \Rightarrow pOH = 4.65 \Rightarrow [OH^-] = 2.24 \times 10^{-5}\ M$ *(no sig fig restriction)*   *1 pt.*

     $[Zn^{2+}] = \dfrac{K_{sp}}{[OH^-]^2} = \dfrac{7.7 \times 10^{-17}}{(2.24 \times 10^{-5})^2} = 1.5 \times 10^{-7}$ *1 pt.*
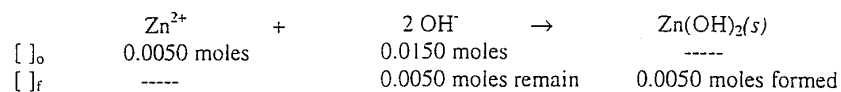
        1 point for determining correct $[OH^-]$.
        1 point for correct answer. (Assume $[Zn^{2+}]$ equals the solubility in $\text{moles}/\text{liter}$)
        If $[OH^-]$ is assumed to be $2[Zn^{2+}]$, no credit possible. (NOT $K_{sp} = 4x^3$).
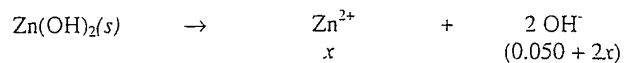
bii.   If answer clearly indicates the following precipitation reaction, credit can be earned for
       calculation of moles OH⁻ or [OH⁻].   *1 pt.*
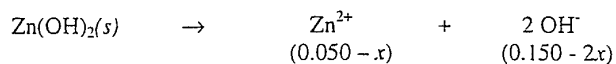
$$Zn^{2+} \quad + \quad 2\ OH^- \quad \rightarrow \quad Zn(OH)_2(s)$$

[ ]₀   0.0050 moles   0.0150 moles   -----
[ ]f   -----   0.0050 moles remain   0.0050 moles formed

or

[ ]f $[OH^-] = \dfrac{0.0050\ \text{moles}}{0.100\ \text{liter}} = 0.050\ M$

$$Zn(OH)_2(s) \quad \rightarrow \quad \underset{x}{Zn^{2+}} \quad + \quad \underset{(0.050 + 2x)}{2\ OH^-}$$

$$K_{sp} = 7.7 \times 10^{-17} = [Zn^{2+}] \cdot [OH^-]^2 = (x)(0.050 + 2x)^2 \cong (x)(0.050)^2 \qquad \textit{1 pt.}$$

$$x = [Zn^{2+}] = 3.1 \times 10^{-14}\ M$$

Alternatively

$$Zn(OH)_2(s) \quad \rightarrow \quad \underset{(0.050 - x)}{Zn^{2+}} \quad + \quad \underset{(0.150 - 2x)}{2\ OH^-}$$

$$K_{sp} = 7.7 \times 10^{-17} = [Zn^{2+}] \cdot [OH^-]^2 = (0.050 - x)(0.150 - 2x)^2 \qquad \textit{1 pt.}$$

Solving for x and subtracting x from 0.050 M to obtain [Zn²⁺]   *1 pt.*