(20) I. For each of the compounds below, answer the following questions:

1. Will an aqueous solution of this compound be acidic or basic?

2. Give a balanced chemical equation to support your answer in part 1. (Use single or double arrows as appropriate.)

3. Identify the conjugate acid/conjugate base pairs in your equation.

HF

acidic

\[ HF + H_2O \rightleftharpoons H_3O^+ + F^- \]

\[ \text{base} \quad \text{acid} \]

NH₃

basic

\[ NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^- \]

\[ \text{acid} \quad \text{base} \]

KCN

basic

\[ KCN \rightarrow K^+ + CN^- \]

\[ \text{base} \quad \text{acid} \]

\[ CN^- + H_2O \rightleftharpoons HCN + OH^- \]

\[ \text{acid} \quad \text{base} \]

StyHBr

acidic

(\text{where Sty = strychnine})

\[ StyHBr \rightleftharpoons StyH^+ + Br^- \]

\[ \text{acid} \quad \text{base} \]

\[ StyH^+ + H_2O \rightleftharpoons Sty + H_3O^+ \]

\[ \text{base} \quad \text{acid} \]
(12) II. a. A solution is prepared by dissolving 0.090 g of PbI₂ in 1.00 L of hot water and cooling the solution to 25°C. Will solid PbI₂ precipitate from this solution when it is cooled to 25°C? (K_{sp} of PbI₂ at 25°C is 1.4 x 10^{-8})

\[ \text{PbI}_2(s) \rightleftharpoons \text{Pb}^{2+}(aq) + 2 \text{I}^-(aq) \]

\[ Q = [\text{Pb}^{2+}][\text{I}^{-}]^2 = (1.95 \times 10^{-4})(3.90 \times 10^{-4})^2 \]

\[ Q = 2.97 \times 10^{-11} \]

\( (0.090 \text{g})(\frac{1 \text{ mol}}{461.9 \text{g}}) = 1.95 \times 10^{-4} \text{ mol} \)

\( Q < K_{sp} \) : PbI₂ does not precipitate.

b. Will the PbI₂ solubility change if the pH is decreased (made more acidic)? Explain.

There is no change in the solubility. 

I⁻ does not hydrolyze, because it is the conjugate base of a strong acid, HII⁻.

Pb²⁺ might hydrolyze, producing an acidic solution. Thus:

\[ \text{PbI}_2 \text{ would make PbI}_2 \text{ less soluble.} \]

(15) III. a. What structural feature of the strychnine molecule allows it to function as a base?

A nitrogen atom with a non-bonded pair of electrons

b. The original form of strychnine in the tonic prescribed for Mrs. Inglethorpe in *The Mysterious Affair at Styles* was likely strychnine sulfate, (styH₂)₂SO₄. The solubility product of strychnine sulfate is 1.44 x 10⁻⁴. Write a balanced chemical equation for the solubility equilibrium for strychnine sulfate.

\[ (\text{styH}_2)_2 \text{SO}_4(s) \rightleftharpoons 2\text{styH}^+ + \text{SO}_4^{2-} \]

c. Based on the data in part b, what is the maximum solubility (in g/L) of strychnine sulfate? (molecular weight of strychnine sulfate = 766 g/mol).

\[ K_{sp} = [\text{styH}^+]^2 [\text{SO}_4^{2-}] \]

\[ 1.44 \times 10^{-4} = K_{sp} = (2x)^2(x) \]

\[ 4x^3 = 1.44 \times 10^{-4} \]

\[ x^3 = 3.6 \times 10^{-5} \]

\[ x = 3.3 \times 10^{-2} \text{ mol} \frac{1}{L} \]

\[ (3.3 \times 10^{-2} \text{ mol} \frac{1}{L})(766 \text{ g/mol}) = 25.3 \text{ g/L} \]
IV. Consider the titration of 40.0 mL of 0.10 M formic acid, HCHO₂, $K_a = 1.77 \times 10^{-4}$

Calculate the pH of this solution upon addition of the following volumes of 0.10 M NaOH (Show all work, including chemical equations):

a. 0 mL NaOH

\[
\begin{align*}
\text{HCHO}_2 &\rightleftharpoons \text{H}^+ + \text{CHO}_2^- \\
\text{Initial} & \quad 0.10 \quad 0 \quad 0 \\
\Delta & \quad -x \quad +x \quad +x \\
@ \text{Equl} & \quad (0.1-0)x \quad x \quad x \\
\end{align*}
\]

\[
K_a = \frac{[\text{H}^+][\text{CHO}_2^-]}{[\text{HCHO}_2]} = 1.77 \times 10^{-4} = \frac{x^2}{0.1} \\
x^2 = 1.77 \times 10^{-5} \\
x = 4.21 \times 10^{-3} \\
P\text{H} = -\log x = 2.38
\]

b. 20.0 mL NaOH

This is the half-equivalence point.

\[P\text{H} = pK_a = -\log (1.77 \times 10^{-4}) = 3.75\]

c. 40.0 mL NaOH

40 mL HCHO₂ + 40 mL 0.10 M NaOH → NaCHO₂ + H₂O

\[
\begin{align*}
\text{(1 mol/kg)}(0.04 M) & \rightarrow 0.004 M \\
\text{(1 mol/kg)}(0.04 M) & \rightarrow 0.004 M \\
\text{NaCHO}_2 & \rightarrow \text{Na}^+ + \text{CHO}_2^- \\
\text{CHO}_2^- + \text{H}_2\text{O} & \rightarrow \text{HCHO}_2 + \text{OH}^- \\
\end{align*}
\]

\[
K_b = \frac{K_w}{K_a} = \frac{10^{-14}}{1.77 \times 10^{-4}} \\
K_b = 5.65 \times 10^{-11} \\
K_b = \frac{[\text{HCHO}_2][\text{OH}^-]}{[\text{CHO}_2^-]} \\
x^2 = 2.82 \times 10^{-12} \\
x = 1.68 \times 10^{-6} = [\text{OH}^-] \\
P\text{OH} = -\log x = 5.77 \\
P\text{H} = 14 - P\text{OH} = 8.23
\]
d. What is the pH of 0.10 M NaOH?

\[ \text{NaOH} \rightarrow \text{Na}^+ + \text{OH}^- \]

\[ \text{pOH} = -\log [\text{OH}^-] = -\log (0.1) = 1 \]

\[ \text{pH} = 14 - \text{pOH} = 13 \]

(12) V. How would you prepare a buffer solution at pH = 3.82 from m-chlorobenzoic acid, \( K_a = 1.04 \times 10^{-4} \), and its sodium salt? Be as specific as possible. Show calculations.

\[ \text{pH} = \text{p}K_a + \log \left( \frac{[\text{conjugate base}]}{[\text{acid}]} \right) \]

\[ \log \left( \frac{[\text{conjugate base}]}{[\text{acid}]} \right) = \text{pH} - \text{p}K_a = 3.82 - 3.98 = -0.16 \]

\[ \log \left( \frac{[\text{conjugate base}]}{[\text{acid}]} \right) = -0.16 \]

\[ \frac{[\text{conjugate base}]}{[\text{acid}]} = 0.69 \]

The buffer solution should be prepared by mixing a solution of the acid with a solution of the sodium salt of the acid. The ratio of the concentrations of the sodium salt and the acid must be 0.69.