

From Zumdahl & Zumdahl 9<sup>th</sup> Edition p. 785:

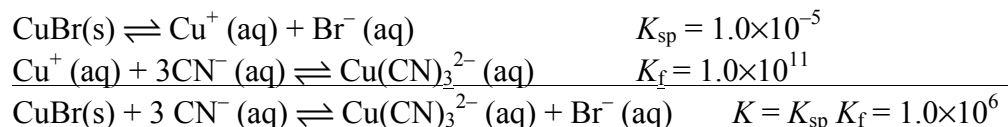
99. The copper(I) ion forms a complex ion with  $\text{CN}^-$  according to the following equation:



- Calculate the solubility of  $\text{CuBr}(\text{s})$  ( $K_{\text{sp}} = 1.0 \times 10^{-5}$ ) in 1.0 L of 1.0 M NaCN
- Calculate the concentration of  $\text{Br}^-$  at equilibrium
- Calculate the concentration of  $\text{CN}^-$  at equilibrium

### Solution

First put the two reactions together to get the overall reaction AND equilibrium constant:



With reactions that have large equilibrium constants (this is similar to FRQ #6 from 2016), the key is to take them to completion first, then re-equilibrate in the *reverse* direction so that the change  $x$  can be made small enough to neglect compared to starting concentrations. Taking the reaction to completion first is valid because with such a large  $K$ , nearly all of the limiting reactant will be converted to product.

Starting with 1.0 L of 1.0 M NaCN, we have 1.0 mol  $\text{CN}^-$ . Let's assume that there is sufficient  $\text{CuBr}$  to form a saturated solution (leaving some solid behind), then we convert all of the  $\text{CN}^-$  to product:

Set up an "ICF" table (stoichiometry):

	$\text{CuBr}(\text{s}) + 3 \text{CN}^- (\text{aq}) \rightleftharpoons \text{Cu}(\text{CN})_3^{2-} (\text{aq}) + \text{Br}^- (\text{aq})$			
I (mol)	–	1.0	0	0
C (mol)	–	–1.0	+ $\frac{1}{3}(1.0)$	+ $\frac{1}{3}(1.0)$
F (mol)	–	0	0.33	0.33

Now convert to concentrations (in this case  $\text{M} = \text{mol}$  since  $V = 1.0 \text{ L}$ ) and use ICE to re-equilibrate in the *reverse* direction, ensuring that  $x$  will be small. I'm setting  $x = \text{change in } [\text{CN}^-]$  to make the math easier:

	$\text{CuBr}(\text{s}) + 3 \text{CN}^- (\text{aq}) \rightleftharpoons \text{Cu}(\text{CN})_3^{2-} (\text{aq}) + \text{Br}^- (\text{aq})$			
I (M)	–	0	0.33	0.33
C (M)	–	+ $x$	– $\frac{1}{3}x$	– $\frac{1}{3}x$
E (M)	–	$x$	$0.33 - \frac{1}{3}x$	$0.33 - \frac{1}{3}x$

Now set up  $K$  and solve for  $x$ , neglecting the  $\frac{1}{3}x$  in the numerator:

$$K = \frac{[\text{Cu}(\text{CN})_3^{2-}][\text{Br}^-]}{[\text{CN}^-]^3} = \frac{(0.33 - \frac{1}{3}x)^2}{x^3} \approx \frac{(0.33)^2}{x^3} = 1.0 \times 10^6; x^3 = \frac{0.33^2}{1.0 \times 10^6}; x = [\text{CN}^-] = 0.0048 \text{ M}$$

- Thus, solubility =  $[\text{Cu}(\text{CN})_3^{2-}] = [\text{Br}^-] = 0.33 \text{ M}$
- $[\text{Br}^-] = 0.33 \text{ M}$
- $[\text{CN}^-] = 0.0048 \text{ M}$