From Zumdahl & Zumdahl 9th Edition p. 785:

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

$$Cu^+ (aq) + 3CN^- (aq) \rightleftharpoons Cu(CN)_3^{2-} (aq) \qquad K = 1.0\times10^{11}$$

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

Solution

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

$$CuBr(s) \rightleftharpoons Cu^+ (aq) + Br^- (aq) \qquad K_{sp} = 1.0\times10^{-5}$$
$$Cu^+ (aq) + 3CN^- (aq) \rightleftharpoons Cu(CN)_3^{2-} (aq) \qquad K_f = 1.0\times10^{11}$$
$$CuBr(s) + 3\,CN^- (aq) \rightleftharpoons Cu(CN)_3^{2-} (aq) + Br^- (aq) \qquad K = K_{sp}\,K_f = 1.0\times10^{6}$$

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 CN^-. Let's assume that there is sufficient CuBr to form a saturated solution (leaving some solid behind), then we convert all of the CN^- to product:

Set up an "ICF" table (stoichiometry):

	$CuBr(s)$ +	$3\,CN^-(aq)$ $\rightleftharpoons$	$Cu(CN)_3^{2-}(aq)$ +	$Br^-(aq)$
I (mol)	–	1.0	0	0
C (mol)	–	–1.0	+⅓(1.0)	+⅓(1.0)
F (mol)	–	0	0.33	0.33

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

	$CuBr(s)$ +	$3\,CN^-(aq)$ $\rightleftharpoons$	$Cu(CN)_3^{2-}(aq)$ +	$Br^-(aq)$
I (M)	–	0	0.33	0.33
C (M)	–	$+x$	$-⅓\,x$	$-⅓\,x$
E (M)	–	x	$0.33-⅓\,x$	$0.33-⅓\,x$

Now set up K and solve for x, neglecting the ⅓ x in the numerator:

$$K = \frac{[Cu(CN)_3^{2-}][Br^-]}{[CN^-]^3} = \frac{(0.33-\frac{1}{3}x)^2}{x^3} \approx \frac{(0.33)^2}{x^3} = 1.0\times10^6; x^3 = \frac{0.33^2}{1.0\times10^6}; x = [CN^-] = 0.0048\text{ M}$$

a. Thus, solubility = $[Cu(CN)_3^{2-}] = [Br^-] = 0.33$ M
b. $[Br^-] = 0.33$ M
c. $[CN^-] = 0.0048$ M