Answer on Question #56945 - Chemistry - General Chemistry

Question:

A solution is made by mixing 500.0 mL of 4.0 M NH3 and 500.0 mL of 0.50 M AgNO3. Ag+ reacts with NH3 to form AgNH3+ and Ag(NH3)2+ according to the equilibrium reactions:

Ag+ + NH3 ↔ AgNH3+ K¬1 = 2.1 x 103

AgNH3+ + NH3 ↔ Ag(NH3)2+ K¬2 = 8.2 x 103

Assuming no change in volume on mixing calculate the concentrations of all species in solution: [Ag+], [NO3-], [NH3], [AgNH3+] and [Ag(NH3)2+].

Answer:

After mixing the initial concentrations of $AgNO_3$ and NH_3 are of 0.5 and 4 mol/L. Since $AgNO_3$ dissociates completely, the concentration of NO_3^- is 0.5 mol/L too.

The equilibrium constants are connected with concentrations of the components as follows:

$K_1 = [AgNH_3^+]/([Ag^+][NH_3])$

$K_2 = [Ag(NH_3)_2^+]/([AgNH_3^+][NH_3])$

The common equilibrium constant for the formation of $[Ag(NH_3)_2]^+$:

$Ag^+ + 2NH_3 \rightarrow [Ag(NH_3)_2]^+$

$K = K_1K_2 = [Ag(NH_3)_2^+]/([Ag^+][NH_3]^2) = 1.722\times10^7$

Assuming that $[Ag(NH_3)_2^+] = z$, we get $[Ag^+] = 0.5 - z$ and $[NH_3] = 4 - 2z$.

Substituting the parameters into the equilibrium constant expression, it is obtained:

$K = z/[(0.5-z)(4-2z)^2] = 1.722\times10^7$

$z = 4K(0.5-z)(2-z)^2$

$z = 4K(0.5-z)(4 - 4z + z^2)$

$z = 4K(2 - 2z + 0.5z^2 - 4z + 4z^2 - z^3)$

$z = 8K - 24Kz + 18Kz^2 - 4Kz^3$

$2Kz^3 - 9Kz^2 + (12K+0.5)z - 4K = 0$

$3.444z^3 - 15.498z^2 + 20.664z - 6.888 = 0$

The solution of the cubic equation gives:

$z_1 = 0.4999999999999998$

Thus, $[Ag(NH_3)_2^+] = z = 0.4999999999999998$ mol/L

then

$[Ag^+] = 0.5 - 0.4999999999999998 = 2\times10^{-16}$ mol/L

and

$[NH_3] = 4 - 2z \approx 3$ mol/L

Using the expression for K_1 the concentration of $AgNH_3^+$ is found:

$[AgNH_3^+] = K_1[Ag^+][NH_3] = 2.1\times10^3\times 2\times10^{-16}\times3 = 1.26\times10^{-12}$ mol/L

Finally, the concentrations of all components are:

$[NO_3^-] = 0.5$ mol/L

$[Ag^+] = 2\times10^{-16}$ mol/L

$[NH_3] \approx 3$ mol/L

$[AgNH_3^+] = 1.26\times10^{-12}$ mol/L

$[Ag(NH_3)_2^+] = 0.4999999999999998$ mol/L