UNIT 6

EQUILIBRIUM APPLICATIONS

ANSWERS

Types of Equations

(1)

$$HCl + NaOH \rightarrow NaCl + H_2O$$
$$HCl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(s)} + H_2O_{(aq)}$$
$$H^+_{(aq)} + Cl^-_{(aq)} + Na^+_{(aq)} + OH^-_{(aq)} \rightarrow NaCl_{(s)} + H^+_{(aq)} + OH^-_{(aq)}$$
$$Na^+_{(aq)} + Cl^-_{(aq)} \rightarrow NaCl_{(s)}$$

(2)

$$AgNO_3 + NaCl \rightarrow AgCl + NaNO_3$$
$$AgNO_{3(aq)} + NaCl_{(aq)} \rightarrow AgCl_{(s)} + NaNO_{3(aq)}$$
$$Ag^+_{(aq)} + NO_3^-{}_{(aq)} + Na^+_{(aq)} + Cl^-_{(aq)} \rightarrow AgCl_{(s)} + NO_3^-{}_{(aq)} + Na^+_{(aq)}$$
$$Ag^+_{(aq)} + Cl^-_{(aq)} \rightarrow AgCl_{(s)}$$

(3)

$$CuSO_4 + NaBr \rightarrow CuBr_2 + Na_2SO_4$$
$$CuSO_{4(aq)} + NaBr_{(aq)} \rightarrow CuBr_{2(s)} + Na_2SO_{4(aq)}$$
$$Cu^{+2}{}_{(aq)} + SO_4^{-2}{}_{(aq)} + Na^+_{(aq)} + 2Br^-_{(aq)} \rightarrow CuBr_{2(s)} + Na^+_{(aq)} + SO_4^{-2}{}_{(aq)}$$
$$Cu^{+2}{}_{(aq)} + 2Br^-_{(aq)} \rightarrow CuBr_{2(s)}$$

(4)

$$Pb(NO_3)_{2(aq)} + NaCl_{(aq)} + KI_{(aq)} \rightarrow PbCl_{2(s)} + NaNO_{3(aq)} + KI_{(aq)}$$
$$Pb^{+2}{}_{(aq)} + NO_3^-{}_{(aq)} + Na^+_{(aq)} + 2Cl^-_{(aq)} + K^+_{(aq)} + I^-_{(aq)} \rightarrow NO_3^-{}_{(aq)} + Na^+_{(aq)} + K^+_{(aq)} + I^-_{(aq)} + PbCl_{2(s)}$$
$$Pb^{+2}{}_{(aq)} + 2Cl^-_{(aq)} \rightarrow PbCl_{2(s)}$$

$$Pb(NO_3)_{2(aq)} + NaCl_{(aq)} + KI_{(aq)} \rightarrow PbI_{2(s)} + KNO_{3(aq)} + NaCl_{(aq)}$$
$$Pb^{+2}{}_{(aq)} + NO_3^-{}_{(aq)} + Na^+_{(aq)} + Cl^-_{(aq)} + K^+_{(aq)} + 2I^-_{(aq)} \rightarrow NO_3^-{}_{(aq)} + Na^+_{(aq)} + K^+_{(aq)} + Cl^-_{(aq)} + PbI_{2(s)}$$
$$Pb^{+2}{}_{(aq)} + 2I^-_{(aq)} \rightarrow PbI_{2(s)}$$

$$Pb(NO_3)_{2(aq)} + NaCl_{(aq)} + KI_{(aq)} \rightarrow NaI_{(aq)} + KCl_{(aq)} + Pb(NO_3)_{2(s)}$$
$$Pb^{+2}{}_{(aq)} + 2NO_3^-{}_{(aq)} + Na^+_{(aq)} + Cl^-_{(aq)} + K^+_{(aq)} + I^-_{(aq)} \rightarrow Na^+_{(aq)} + K^+_{(aq)} + Cl^-_{(aq)} + I^-_{(aq)} + Pb(NO_3)_{2(s)}$$
$$Pb^{+2}{}_{(aq)} + 2NO_3^-{}_{(aq)} \rightarrow Pb(NO_3)_{2(s)}$$

(5)

$$CaBr_{2(aq)} + NaOH_{(aq)} + KI_{(aq)} \rightarrow NaBr_{(aq)} + KI_{(aq)} + Ca(OH)_{2(s)}$$
$$Pb^{+2}{}_{(aq)} + 2NO_3^-{}_{(aq)} + Na^+_{(aq)} + Cl^-_{(aq)} + K^+_{(aq)} + I^-_{(aq)} \rightarrow Na^+_{(aq)} + K^+_{(aq)} + 2Br^-_{(aq)} + I^-_{(aq)} + Ca(OH_3)_{2(s)}$$

Solubility and Solubility Product Problems

(1.) 120 mL = 0.12 L

$$\frac{0.12\ L \ * \ 6\ mol/L}{2.0\ L} = 0.36\ mol/L$$

(2.) 5.0 L * 0.1 mol/L = 0.5 mol needed

1 L → 12 mol　　　x = 0.5 mol / 12 mol
x L → 0.5 mol　　　= 0.04167 L

∴ you need to add 41.67 mL of 12 M HCl

(3.) Original amounts:

2 L * 0.6 mol/L $FeCl_3$ → 1.2 mol Fe^{+3}
→ 1.2 x 3 = 3.6 mol Cl^-

1 L * 0.9 mol/L $BaCl_2$ → 0.9 mol Ba^{+2}
→ 0.9 x 2 = 1.8 mol Cl^-

...but now all of them are in 3 L (2 L + 1 L)...

$$\frac{1.2\ mol\ Fe^{+3}}{3L} = 0.4\ M\ Fe^{+3}$$

$$\frac{5.4\ mol\ Cl^-}{3L} = 1.8\ M\ Cl^-$$

$$\frac{0.9\ mol\ Ba^{+2}}{3L} = 0.3\ M\ Ba^{+2}$$

(4.) $AgBr_{(s)} \rightleftharpoons Ag^{+}_{(aq)} + Br^{-}_{(aq)}$ assume 1 L of solution

I	excess	0	0
E	excess - 8.8×10^{-7}	8.8×10^{-7}	8.8×10^{-7}

$K_{sp} = [Ag^{+}_{(aq)}][Br^{-}_{(aq)}] = (8.8 \times 10^{-7})^2 = 7.744 \times 10^{-13}\ (mol/L)^2$

(5.) $CaCO_{3\,(aq)} \rightleftharpoons Ca^{+}_{(aq)} + CO_3^{-}$ assume 1 L of solution

I	excess	0	0
E	excess - x	x	x

$K_{sp} = [Ca^{+}_{(aq)}][CO_3^{-}{}_{(aq)}]$

$4.8 \times 10^{-9} = x^2$

$x = 0.00006928$

∴ the solubility of $CaCO_3$ is 6.928×10^{-5} mol/L

(6.) $Fe(OH)_2 \rightleftharpoons Fe^{+}_{(aq)} + 2OH^{-}_{(aq)}$

I	excess	0	0
E	excess - 3.76×10^{-5}	1.67×10^{-5}	3.34×10^{-5}

$1.5 \times 10^{-3}\ g = x$ mol

$89.85\ g = 1$ mol

∴ solubility is 1.67×10^{-5} mol/L

$K_{sp} = [Fe^{+}_{(aq)}][OH^{-}_{(aq)}]^2$

$= (1.67 \times 10^{-5})(3.34 \times 10^{-5})^2$

$= 1.86 \times 10^{-14}\ mol^3/L^3$

(7.) $MgF_2 \rightleftharpoons Mg^{+2}_{(aq)} + 2F^{-}_{(aq)}$

I	excess	0	0
E	excess - x	x	$2x$

$K_{sp} = [Mg^{+2}_{(aq)}][F^{-}_{(aq)}]^2$

$6.4 \times 10^{-9} = 4x^3$

$x = 1.17 \times 10^{-3}$ mol/L

1.17×10^{-3} mol $= x$ g

1 mol $= 62.3$ g

$x = (1.17 \times 10^{-3}\ \cancel{mol})(62.3\ g)$

$= 0.072891$ g/L

∴ the solubility of MgF_2 in g/L is 0.072891 g/L

(8) $[Mg^{+2}{}_{(aq)}] = \dfrac{0.04\ L * 8 \times 10^{-3}\ mol/L}{0.1\ L}$

$= 0.0032\ mol/L$

$[NO_{3\,(aq)}^{-2}] = \dfrac{0.06\ L * 1 \times 10^{-2}\ mol/L}{0.1\ L}$

$= 0.006\ mol/L$

$MgCO_3 \rightleftharpoons Mg^{+2}{}_{(aq)} + NO_3^{-2}{}_{(aq)}$

but $K_{sp} = 2.6 \times 10^{-5} \doteq [Mg][NO_3]$

L.S.

$= 2.6 \times 10^{-5}$

R.S.

$= (0.0032)(0.006)$

$= 1.92 \times 10^{-5}$

Since RS < LS, no ppt forms.

(9.) $[Ag] = \dfrac{0.025\ L * 4 \times 10^{-3}\ mol/L}{0.1\ L}$ $[CrO_4^{-2}] = \dfrac{0.075\ L * 2 \times 10^{-4}\ mol/L}{0.1\ L}$

$= 0.001\ mol/L$ $= 0.00015\ mol/L$

$Ag_2CrO_4 \rightleftharpoons 2\,Ag^+ + CrO_4^{-2}$

but $k_{sp} = 9.0 \times 10^{-12} \doteq [Ag^+]^2[CrO_4^{-2}]$

L.S. $= 9.0 \times 10^{-12}$

R.S. $= (0.001)^2(0.00015)$

$= 1.5 \times 10^{-10}$

Since Rs > LS, a ppt will form

(10)

	$SrSO_4$	$\rightleftharpoons$	Sr^{+2}	+	SO_4^{-2}
E	excess		?		0.02

$$K_{sp} = [Sr^{+2}][SO_4^{-2}]$$
$$7.6 \times 10^{-7} = [Sr^{+2}](0.02)$$
$$[Sr^{+2}] = 0.000038$$

$\therefore$ the maximum $[Sr^{+2}]$ is 3.8×10^{-5} mol/L before a ppt occurs.

(11) Assume Ksp of $MgCO_3$ > ksp of $CaCO_3$

	$CaCO_3$	$\rightleftharpoons$	Ca^{+2}	+	CO_3^{-2}
E	excess		0.004		?

$$K_{sp} = [Ca^{+2}][CO_3^{-2}]$$
$$4.8 \times 10^{-9} = (0.004)[CO_3^{-2}]$$
$$[CO_3^{-2}]_{max} = 1.2 \times 10^{-6} \text{ mol/L}$$

Since there are 5 L of water, the max amount of $[CO_3^{-2}]$ is $(5 * 1.2 \times 10^{-6} \text{ mol/L}) = 6 \times 10^{-6}$ mol/L

$$x\,g = 6 \times 10^{-6} \text{ mol}$$
$$106\,g = 1 \text{ mol}$$
$$x = 6.36 \times 10^{-4}\,g$$

$\therefore$ only 6.36×10^{-4} g of Na_2CO_3 can be added before a ppt forms.

(12) $Ag^+ + Cl^- \rightarrow AgCl_s$

∴ # of moles of Ag^+ = # of moles of Cl^-

# of moles of Ag^+:

$0.02364\ L \ * \ 0.1\ mol/L$

$= 0.002364\ mol\ Ag^+ \longrightarrow$ ∴ $0.002364\ mol\ Cl^-$

$$[Cl^-] = \frac{0.002364\ mol}{0.125\ L} = 0.018912\ mol/L$$

∴ the $[Cl^-]$ in the sample is $0.018912\ mol/L$

(13.)

	PbI_2	$\rightleftharpoons Pb^{+2}$	$+ \ 2I^-$
I	excess	0	0.1
E	excess − x	x	$0.1 + 2x$

x is solubility of PbI_2 in mol/L

$K_{sp} = [Pb^{+2}][I^-]^2$

$7.9 \times 10^{-9} = (x)(0.1 + 2x)^2 \leftarrow 2x^3$ assume x is small

$7.9 \times 10^{-9} = 0.01\,x$ use 5% rule to check

$x = 7.9 \times 10^{-7}$

✓ check: $\frac{7.9 \times 10^{-7}}{0.1} \times 100\% = 7.9 \times 10^{-4}$

∴ the solubility of PbI_2 in the I^- solution is 7.9×10^{-7} mol/L

(4.) $CaCl_2$ is soluble

$0.1\ mol/L\ CaCl_2 \rightarrow 0.2$ molar Cl^-
$\rightarrow 0.1$ molar Ca^{+2}

	CaF_2 $\rightleftharpoons$	Ca^{+2} +	$2F^-$
I	excess	0.1	0
E	excess $-x$	$0.1+x$	$2x$

$K_{sp} = [Ca^{+2}][F^-]^2$
$3.9\times10^{-11} = (0.1+x)(2x)^2$ ← assume x is small
$3.9\times10^{-11} = 0.4x^2$
$9.75\times10^{-11} = x^2$
$x = 9.874\times10^{-6}$ mol/L

∴ the maximum $[F^-]$ is $2x \Rightarrow 2(9.874\times10^{-6}) = 1.975\times10^{-5}$ mol/L

(5.) Yes, a $Cu(OH)_2$ ppt will probably occur if the concentrations are high enough

molecular formula : $CuSO_{4(aq)} + 2NaOH_{(aq)} \rightarrow Cu(OH)_{2(s)} + Na_2SO_{4(aq)}$

full ionic equation : $Cu^{+2}_{(aq)} + SO_4^{-2}{}_{(aq)} + 2Na^+_{(aq)} + 2OH^-_{(aq)} \rightarrow Cu(OH)_{2(s)} + 2Na^+_{(aq)} + SO_4^{-2}{}_{(aq)}$

net ionic equation : $Cu^{+2}_{(aq)} + 2OH^-_{(aq)} \rightarrow Cu(OH)_{2(s)}$

Ksp Problems

1. $Ag_2SO_{4\,(s)} \rightleftharpoons 2Ag^+_{(aq)} + SO_4^{-2}{}_{(aq)}$

I	excess	0	0
E	excess − x	2x	x

$K_{sp} = 1.2 \times 10^{-5}$

$K_{sp} = [Ag^+_{(aq)}]^2 [SO_4^{-2}{}_{(aq)}]$

$1.2 \times 10^{-5} = [2x]^2[x]$

$1.2 \times 10^{-5} = 4x^3$

$x = 0.01442$

2. $Ag_2SO_{4\,(s)} \rightleftharpoons 2Ag^+_{(aq)} + SO_4^{-2}{}_{(aq)}$

I	excess	0	0.1
E	excess − x	2x	0.1 + x

$K_{sp} = 1.2 \times 10^{-5}$

$K_{sp} = [Ag^+_{(aq)}]^2 [SO_4^{-2}{}_{(aq)}]$

$1.2 \times 10^{-5} = [2x]^2[0.1 + x]$ ← assume x is small compared to 0.1

$1.2 \times 10^{-5} = 0.4x^2$

$x = 0.005477$

$\frac{0.005477}{1\,L} = \frac{x}{0.5\,L}$

$x = 2.73 \times 10^{-3}$ mol

∴ the solubility of $Ag_2S_{(s)}$ is 2.73×10^{-3} mol

(3) $AgCl_{(s)} \rightleftharpoons Ag^+_{(aq)} + Cl^-_{(aq)}$

I	excess	0.004	0
E	excess − x	0.004 + x	x

$K_{sp} = 1.8 \times 10^{-10}$

$K_{sp} = [Ag^+_{(aq)}][Cl^-_{(aq)}]$

$1.8 \times 10^{-10} = (0.004 + x)(x)$ ← assume x is small compared to 0.0

$x = 4.5 \times 10^{-8} \times 0.2\ L$

$= 9 \times 10^{-9}$

mm: 22.98 + 35.04 = 58.38

$m = n \times mm$

$= 9 \times 10^{-9} \times 58.38$

$= 5.25 \times 10^{-7}$

∴ the mass of table salt needed to precipitate the silver as silver chloride is 5.25×10^{-7} g

(4) $Ag^+_{(aq)} + CH_3COO^-_{(aq)} \rightleftharpoons AgCH_3COO_{(s)}$ $K_{sp} = 0.0019$

0.1 M 0.1 M

0.5 L 0.5 L

$n = \frac{0.1}{0.5}$ $n = \frac{0.1}{0.5}$

$= 0.05$ $= 0.05$

after mixing:

$C = \frac{0.05}{1}$ $C = \frac{0.05}{1}$

$= 0.05 M$ $= 0.05 M$

$Q = [Ag^+_{(aq)}][CH_3COO^-_{(aq)}]$

$= (0.05)^2$

$= 0.0025$

$Q > K_{sp}$

∴ a percipitate forms

(5) Ca^{+2} ion precipitates last because it has the greatest K_{sp} value (2.4×10^{-5})

(6) Find the $[SO_4^{-2}]$

$K_{sp} = [Sr^{+2}][SO_4^{-2}]$

3.4×10^{-6}

Put this value into $PbSO_4$ to find $[Pb^{+2}]$

$K_{sp} = [Pb^{+2}][SO_4^{-2}]$

$1.8 \times 10^{-5} = [Pb^{+2}][3.4 \times 10^{-6}]$

$[Pb^{+2}] = 5.29 \times 10^{-3}$

$\therefore$ $[Pb^{+2}]$ when Sr^{+2} begins to precipitate is 5.29×10^{-3} mol/L

(7) $C_3H_{8(g)} + 5O_{2(g)} \rightleftharpoons 3CO_{2(g)} + 4H_2O_{(l)}$

Bonds broken = energy absorbed

$2(C-C) = 2(348) = 696$

$8(C-H) = 8(412) = 3296$

$5(O=O) = 5(498) = \underline{2490}$

$+6482$

Bonds formed = energy released

$6(C=O) = 6(740) = 4440$

$8(O-H) = 8(464) = \underline{3712}$

-8152

$\therefore$ net heat $= +6482 - 8152$

$= -1670$ KJ

(8.) $T = \frac{\Delta H}{\Delta S} = \frac{+44000}{118.89} \frac{J/mol}{J/mol/K} = +370.9\ K = 97.75°C$

$\Delta H = \Sigma \Delta H°_f\ prod - \Sigma \Delta H°_f\ react$
$= 1(-241.8) - 1(-285.8)$
$= +44\ KJ$
$= +44\ 000\ J/mol$

$\Delta S = \Sigma nS\ prod - \Sigma nS\ react$
$= 1(188.84) - 1(69.95)$
$= 118.89\ J/mol/K$