Chem 115 POGIL Worksheet - Week #6 - Answers
Oxidation Numbers, Redox Reactions, Solution Concentration, and Titrations

Key Questions, Exercises, and Problems

1. Assign the oxidation numbers of each element in the following chemical species: HCl, H_2O, NH_3, NO_3^-, $K_2Cr_2O_7$, Hg_2Cl_2, $HgCl_2$, $Al(OH)_3$, Na_3PO_4

HCl	H_2O	NH_3	NO_3^-	$K_2Cr_2O_7$
+1 -1	2(+1) -2	-3 3(+1)	+5 3(-2)	2(+1) 2(+6) 7(-2)

Hg_2Cl_2	$HgCl_2$	$Al(OH)_3$	Na_3PO_4
2(+1) 2(-1)	+2 2(-1)	+3 3(-2 +1)	3(+1) +5 4(-2)

2. Which element is oxidized and which element is reduced in the following reactions?

   $Zn(s) + 2\ HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$
   Zn is oxidized (0 → 2+) and H is reduced (+1 → 0)

   $Fe_2O_3(s) + 2\ Al(s) \rightarrow 2\ Fe(s) + Al_2O_3(s)$
   Fe is reduced (3+ → 0) and Al is oxidized (0 → 3+)

   $14\ HNO_3 + 3\ Cu_2O \rightarrow 6\ Cu(NO_3)_2 + 2\ NO + 7\ H_2O$
   N is reduced (5+ → 2+) and Cu is oxidized (1+ → 2+)

   $I^- + 2\ MnO_4^- + H_2O \rightarrow IO_3^- + 2\ MnO_2 + 2\ OH^-$
   I is oxidized (1– → 5+) and Mn is reduced (7+ → 4+)

3. Describe how you would go about making exactly 500 mL of 0.100 M $NaNO_3(aq)$ solution, using reagent grade $NaNO_3(s)$ (f.w. = 85.0 u).

   The concentration 0.100 M means we would have 0.100 mol $NaNO_3$ per liter of solution. We are making up only a half a liter (500 mL), so we need 0.0500 mol $NaNO_3$. The mass of $NaNO_3$ needed would be (0.0500 mol)(85.0 g/mol) = 4.25 g. We would carefully weigh out 4.25 g $NaNO_3$, add it quantitatively (without losing any) to a 500-mL volumetric flask, dilute with water to the mark, and mix thoroughly.

4. Starting with a 0.100 M $NaNO_3$ solution, how would you go about preparing exactly 100 mL of 0.0250 M $NaNO_3$ solution?

   A 100-mL solution of 0.0250 M $NaNO_3$ contains 2.50 millimoles of $NaNO_3$; i.e.,

$$\text{mmol NaNO}_3 = (100\ \text{mL})(0.0250\ \text{M}) = 2.50\ \text{mmol NaNO}_3$$

What volume of our stock 0.100 M $NaNO_3$ solution would supply 2.50 mmol of $NaNO_3$? Our stock solution has 0.100 mmol $NaNO_3$ per milliliter of solution, so the volume needed would be

$$V = (2.50\ \text{mmol})(1\ \text{mL}/0.100\ \text{mmol}) = 25.0\ \text{mL}$$

Alternately using $M_iV_i = M_fV_f$, we could write

$$V_i = \frac{M_fV_f}{M_i} = \frac{(2.50 \times 10^{-2}\ \text{M})(100\ \text{mL})}{0.100\ \text{M}} = 25.0\ \text{mL}$$

Therefore, we would pipet a 25.0-mL aliquot of our stock solution into a 100-mL volumetric flask, dilute to the mark with water, and mix thoroughly.

5. How many milliliters of 0.0250 M $CuSO_4$ solution contain 1.75 g of solute? (f.w. $CuSO_4$ = 159.6 u)

$$\text{mmol CuSO}_4 = (1.75\ \text{g CuSO}_4)(\text{mol CuSO}_4/159.6\ \text{g CuSO}_4)$$
$$= 0.0109_6\ \text{mol CuSO}_4 = 10.9_6\ \text{mmol CuSO}_4$$

$$V = (10.9_6\ \text{mmol})(1\ \text{mL}/0.0250\ \text{mmol}) = 418._6\ \text{mL} = 439\ \text{mL}$$

6. Which of the following has the highest concentration of sodium ion: 0.20 M NaCl, 0.13 M Na_2SO_4, 0.080 M Na_3PO_4?

A 0.20 M NaCl solution has $[Na^+]$ = 0.20 M; a 0.13 M Na_2SO_4 solution has $[Na^+]$ = 0.26 M; a 0.080 M Na_3PO_4 solution has $[Na^+]$ = 0.24 M. Therefore, the 0.13 M Na_2SO_4 solution has the highest sodium ion concentration.

7. Indicate the concentrations of all ions in a solution prepared by mixing 45.0 mL of 0.200 M Na_2SO_4 and 65.0 mL of 0.300 M $Al_2(SO_4)_3$.

The volume of the mixture is 45.0 mL + 65.0 mL = 110.0 mL. We need to calculate the numbers of millimoles of each ion and then divide those by the total volume to get each ion concentration. Note that we have two sources of sulfate ion in the mixture.

$$\text{mmol Na}^+ = (0.200\ \text{M})(45.0\ \text{mL})(2) = 18.0\ \text{mmol Na}^+$$
$$\text{mmol SO}_4^{2-} = (0.200\ \text{M})(45.0\ \text{mL})(1) + (0.300\ \text{M})(65.0\ \text{mL})(3)$$
$$= 9.00\ \text{mmol SO}_4^{2-} + 58.5\ \text{mmol SO}_4^{2-} = 67.5\ \text{mmol SO}_4^{2-}$$
$$\text{mmol Al}^{3+} = (0.300\ \text{M})(65.0\ \text{mL})(2) = 39.0\ \text{mmol Al}^{3+}$$

$[Na^+]$ = 18.0 mmol/110 mL = 0.163_6 M = 0.164 M
$[SO_4^{2-}]$ = 67.5 mmol/110 mL = 0.613_6 = 0.614 M
$[Al^{3+}]$ = 39.0 mmol/110 mL = 0.354_5 M = 0.355 M

8. How many grams of $PbCl_2$ (f.w. = 278.1 u) are produced by the reaction

$$Pb(NO_3)_2(aq) + 2\ NaCl(aq) \rightarrow PbCl_2(s) + 2\ NaNO_3(aq)$$

when 25.00 mL of 0.4567 M $Pb(NO_3)_2$ solution and 25.00 mL of 0.9876 M NaCl(*aq*) solution are mixed?

This is a limiting reagent problem, so like all such problems we need to start by calculating the numbers of moles of each reagent. Because we have small volumes of dilute solutions, it will be more convenient to do this in terms of millimoles.

$$\text{mmol } Pb(NO_3)_2 = (0.4567\text{ M})(25.00\text{ mL}) = 11.42\text{ mmol } Pb(NO_3)_2$$

$$\text{mmol NaCl} = (0.9876\text{ M})(25.00\text{ mL}) = 24.69\text{ mmol NaCl}$$

From the stoichiometry of the balanced equation, we see that we need twice as many millimoles of NaCl as we have millimoles of $Pb(NO_3)_2$. In other words, to consume all the $Pb(NO_3)_2$, we need 22.84 millimoles of NaCl:

$$\text{mmol NaCl needed} = (11.42\text{ mmol } Pb(NO_3)_2)\left(\frac{2\text{ mmol NaCl}}{\text{mmol } Pb(NO_3)_2}\right) = 22.48\text{ mmol NaCl}$$

We have 24.69 millimoles of NaCl, more than enough to consume all of the $Pb(NO_3)_2$. Therefore $Pb(NO_3)_2$ is the limiting reagent, and we will base our calculation of the grams of $PbCl_2(s)$ on 11.42 millimol of $Pb(NO_3)_2$.

$$\text{g } PbCl_2 = (11.42\text{ mmol } Pb(NO_3)_2)\left(\frac{1\text{ mol } Pb(NO_3)_2}{10^3\text{ mmol } Pb(NO_3)_2}\right)\left(\frac{1\text{ mol } PbCl_2}{1\text{ mol } Pb(NO_3)_2}\right)$$

$$\times\left(\frac{278.1\text{ g } PbCl_2}{\text{mol } PbCl_2}\right) = 3.176\text{ g } PbCl_2$$

9. Define the following terms: analyte, titrant, equivalence point, end point.

analyte	the unknown sample in a titration
titrant	the standard solution delivered from a buret into the analyte sample
equivalence point	the volume of titrant needed for complete reaction with titrant
end point	the volume of titrant at which the equivalence point is detected by the change in color of an indicator or other means.

10. The following represent *skeletal* reaction equations for some possible titrations. For each, assume that the first species is the analyte and the second species is the titrant. Balance each equation. For each millimole of analyte, how many millimoles of titrant are needed for complete reaction in each case?

$HC_2H_3O_2(aq) + NaOH(aq) \rightarrow H_2O(l) + NaC_2H_3O_2(aq)$ 1 mmol titrant/mmol analyte

$Ca(OH)_2(aq) + 2\ HCl(aq) \rightarrow 2\ H_2O(l) + CaCl_2(aq)$ 2 mmol titrant/mmol analyte

$H_3PO_4(aq) + 3\ KOH(aq) \rightarrow 3\ H_2O(l) + K_3PO_4(aq)$ 3 mmol titrant/mmol analyte

11. A 25.00-mL sample of an unknown monoprotic acid is titrated to an equivalence point with 32.42 mL of 0.1000 M NaOH solution. What was the original concentration of acid in the sample?

The titration reaction equation is

$$HA(aq) + NaOH(aq) \rightarrow H_2O(l) + NaA(aq)$$

where HA represents the unknown acid. The stoichiometry is 1:1, so at the equivalence point

$$\text{mmol HA} = \text{mmol HCl}$$

$$M_{HA}V_{HA} = M_{NaOH}V_{NaOH}$$

$$M_{HA} = \frac{(32.42\,\text{mL})(0.1000\,\text{M})}{25.00\,\text{mL}} = 0.1297\,\text{M}$$

12. How many milliliters of 0.1200 M HCl solution are needed to completely neutralize 50.00 mL of 0.1012 M $Ba(OH)_2$ solution?

The titration reaction equation is

$$Ba(OH)_2(aq) + 2\ HCl(aq) \rightarrow 2\ H_2O(l) + BaCl_2(aq)$$

The stoichiometery is 1:2, so at the equivalence point

$$\text{mmol HCl} = 2 \times \text{mmol Ba(OH)}_2$$

$$V_{HCl}M_{HCl} = 2 \times V_{Ba(OH)_2}M_{Ba(OH)_2}$$

$$V_{HCl} = \frac{(50.00\,\text{mL})(0.1012\,\text{M})(2)}{0.1200\,\text{M}} = 84.33\,\text{mL}$$

13. A 20.00-mL sample of a chloride-containing solution was titrated with 0.4000 M $AgNO_3$ solution, requiring 28.62 mL to reach the equivalence point. Write the balanced reaction equation for this titration. What was the concentration of Cl^- ion in the original sample? How many grams of precipitate were formed?

The titration reaction equation is

$$Cl^-(aq) + AgNO_3(aq) \rightarrow AgCl(s) + NO_3^-(aq)$$

Therefore,

$$\text{mmol } AgNO_3 = \text{mmol } Cl^-(aq)$$

and the concentration of chloride ion in the original sample is

$$M_{Cl^-} = \frac{(28.62\,\text{mL})(0.4000\,\text{M})}{20.00\,\text{mL}} = 0.5724\,\text{M}$$

For every millimole of Cl^- ion in the sample, one millimole of AgCl(*s*) forms (f.w. Ag Cl = 143.32 u).

$$\text{mmol AgCl} = \text{mmol } Cl^- = (20.00\text{ mL})(0.5724\text{ M}) = 11.44_8\text{ mmol AgCl}$$

$$\text{g AgCl} = (0.01144_8\text{ mol})(143.32\text{ g/mol}) = 1.640_7\text{ g} = 1.641\text{ g}$$