CHM1311 B: Principles of Chemistry

Prof. N. Goto

Assignment #1

Due Sept 26th, at the beginning of class

Assignments can be submitted individually, or by groups of up to 4 students.

1) Name: ________________ **Student ID:** ______________

2) Name: ________________ **Student ID:** ______________

3) Name: ________________ **Student ID:** ______________

4) Name: ________________ **Student ID:** ______________

Solutions must be written legibly, in the space provided. Adequate detail to the calculation (including units, appropriate sig figs) must be provided to make it possible for other students to understand how you arrived at the final solution. If more space is needed, use the back of the page. Do not add extra pages, as they will not be marked. Assignment pages must be stapled together.

NOTE: For each question an on-line resource in WileyPLUS is given in brackets that can walk you through a similar type of problem. (ILW = Interactive Learning Ware.)

Question 1. (ILW 1.21)
5 marks

Use the data in the following table to calculate the molar mass of naturally occurring element:

Isotope	Isotopic Molar Mass (g/mol)	Abundance (%)
^{136}Ce	135.9071	0.185
^{138}Ce	137.9060	0.251
^{140}Ce	139.9054	88.450
^{142}Ce	141.9092	11.114

MASS FROM:

$^{136}Ce = 135.9071\ \frac{g}{mol} \times \frac{0.185\%}{100\%} = 0.2514\ g/mol$

$^{137}Ce = 137.9060\ \frac{g}{mol} \times \frac{0.251\%}{100\%} = 0.3461\ g/mol$

$^{140}Ce = 139.9054\ \frac{g}{mol} \times \frac{88.450\%}{100\%} = 123.746\ \frac{g}{mol}$

$^{142}Ce = 141.9092\ \frac{g}{mol} \times \frac{11.114\%}{100\%} = 15.7718\ \frac{g}{mol}$

$140.12\ \frac{g}{mol}$

Question 2. (ILW 39 and FAQ: How do I write an equation to describe the dissociation of an ionic compound?)

Solution A is prepared by dissolving 83.9 g of K_3PO_4 in enough water to make 1.50 L of solution.
Solution B is 2.5 L of 0.684 M KCl.

a) What is the molar concentration of K_3PO_4 in Solution A? (3 marks)

$$M_{K_3PO_4} = (3\times 39.10 + 30.97 + 4\times 16.00)\frac{g}{mol} = 212.27\frac{g}{mol}$$

$$c = \frac{n}{V} = \frac{m}{MV} = \frac{83.9\,g}{(212.27\,g/mol)(1.50\,L)}$$

$$= 0.264\,M$$

b) What volume of Solution A will give 2.50 g of K_3PO_4? (2 marks)

$$V = \frac{m}{Mc} = \frac{2.50\,g}{(212.27\,g/mol)(0.264\,M)}$$

$$= 44.7\,mL$$

c) If 25.0 mL of Solution B is mixed with 35.00 mL of Solution A, what is the concentration of K^+ ions in the final solution? (4 marks)

$$C_K = \frac{n_{K,A} + n_{K,B}}{V_A + V_B}$$

$$= \frac{c_A V_A \times \frac{3\,mol\,K^+}{1\,mol\,K_3PO_4} + c_B V_B \times \frac{1\,mol\,K^+}{1\,mol\,KCl}}{V_A + V_B}$$

$$= \frac{(0.2635\,M)(35.00\,\cancel{m}L)\times 3 + (0.684\,M)(25.0\,\cancel{m}L)}{35.00\,\cancel{m}L + 25.0\,\cancel{m}L} = 0.746\,M$$

Question 3. (ILW 1.35)

One dose of an antibiotic was found to contain 53.6 mg penicillin G ($C_{16}H_{18}N_2O_4S$) in one pill.

a) How many carbon atoms are in a 53.6 mg sample of penicillin G? (3 marks)

$$N_c = n_c N_A = n_{PenG}\times\frac{16\,mol\,C}{1\,mol\,PenG} N_A = \frac{m_{PenG}}{M_{PenG}}\times\frac{16\,mol\,C}{1\,mol\,PenG}\times N_A$$

$$M_{PenG} = (16\times 12.01 + 18\times 1.008 + 14.01\times 2 + 16.00\times 4 + 32.06)\,g/mol = 334.384\,g/mol$$

$$= \frac{(53.6\,mg)(10^{-3}\,g/mg)}{334.384\,g/mol}\times\frac{16\,mol\,C}{1\,mol\,PenG}\times 6.022\times 10^{23}\,\frac{ATOMS}{mol}$$

$$= 1.54\times 10^{21}\,ATOMS$$

b) What mass of carbon is this? (2 marks)

$$m_c = n_c M_c = \frac{N_c}{N_A} M_c = \frac{1.54\times 10^{21}\,ATOMS}{6.022\times 10^{23}\,\frac{ATOMS}{mol}}\;12.01\,g/mol$$

$$= 30.8\,mg$$

Question 4. (ILW 1.61)
Ammonia gas undergoes oxidation to produce liquid water and molecular nitrogen.
a) Write the balanced chemical equation for this reaction. Be sure to include the phases. (2 marks)

$$2\,NH_{3(g)} + \frac{3}{2}O_{2(g)} \rightarrow 3H_2O_{(l)} + N_{2(g)}$$

b) What is the mass of ammonia gas that is required to completely react with 780 kg of molecular oxygen? (3 marks)

$$m_{NH_3} = n_{NH_3} M_{NH_3} = n_{O_2} \times \frac{2\text{ mol } NH_3}{\frac{3}{2}\text{ mol } O_2} M_{NH_3}$$

$$= \frac{m_{O_2}}{M_{O_2}} \times \frac{2\text{ mol } NH_3}{\frac{3}{2}\text{ mol } O_2} M_{NH_3}$$

$$= \frac{(780\text{ kg})}{2\times 16.00\text{ g/mol}} \times \frac{4}{3} \underbrace{(14.01+3\times 1.008)}_{17.034} \frac{g}{mol} = 550\text{ kg}$$

Question 5. (Office hours video, 1.93)
Hydrogen fluoride is produced industrially by the action of sulphuric acid on CaF_2. Suppose 312 kg of CaF_2 is treated with an excess of sulphuric acid and 106 kg of HF is produced. What is the percent yield of HF? (6 marks)

$$CaF_{2(s)} + H_2SO_{4(aq)} \rightarrow 2HF_{(g)} + CaSO_{4(s)}$$

THEORETICAL YIELD: $m_{HF} = n_{HF} M_{HF} = n_{CaF_2} \times \frac{2\text{ mol HF}}{1\text{ mol } CaF_2} M_{HF}$

$$= \frac{m_{CaF_2}}{M_{CaF_2}} \times \frac{2\text{ mol HF}}{1\text{ mol } CaF_2} \times M_{HF}$$

$$= \frac{312\text{ kg}}{\underbrace{(40.08+2\times 19.00)}_{78.08}\frac{g}{mol}} \times 2 \times \underbrace{(1.008+19.00)}_{20.008}\text{ g/mol}$$

$$= 159.\bar{9}\text{ kg}$$

$$\%\text{ YIELD} = \frac{\text{ACTUAL YIELD}}{\text{THEORETICAL YIELD}} \times 100\%$$

$$= \frac{106\text{ kg}}{159.9\text{ kg}} \times 100\% = 66.3\%$$

Question 6. (Video for 1.75)

The following unbalanced reaction is called the thermite reaction. It releases tremendous amounts of energy and is sometimes used to generate heat for welding.

$$Al\,(s) + Fe_3O_4\,(s) \rightarrow Fe\,(s) + Al_2O_3\,(s)$$

a) Write the balanced chemical equation for this reaction. (1 mark)

$$8\,Al_{(s)} + 3\,Fe_3O_{4(s)} \rightarrow 9\,Fe_{(s)} + 4\,Al_2O_{3(s)}$$

b) Determine the masses of all the substances present after the reaction if 120. g of Al and 711 g of Fe_3O_4 react to completion. Enter your final answers in the table below. (10 marks)

THEORETICAL YIELD OF $Fe_{(s)}$ FROM $Al_{(s)}$: $n_{Fe} = n_{Al} \times \frac{9\text{ mol Fe}}{8\text{ mol Al}} = \frac{m_{Al}}{M_{Al}} \times \frac{9}{8}$

$= \frac{120\,g}{26.98\,g/mol\,Al} \times \frac{9\text{ mol Fe}}{8\text{ mol Al}} = 5.00\text{ mol}$

THEORETICAL YIELD OF $Fe_{(s)}$ FROM Fe_3O_4: $n_{Fe} = n_{Fe_3O_4} \times \frac{9\text{ mol Fe}}{3\text{ mol }Fe_3O_4}$

$M_{Fe_3O_4} = (3\times55.85 + 4\times16.00)\,g/mol = 231.55\,g/mol$

$M_{Al_2O_3} = (2\times26.98 + 3\times16.00)\,g/mol = 101.96\,g/mol$

$= \frac{m_{Fe_3O_4}}{M_{Fe_3O_4}} \times \frac{9\text{ mol Fe}}{3\text{ mol }Fe_3O_4}$

$= \frac{711\,g}{231.55\,g/mol} \times \frac{9\text{ mol Fe}}{3\text{ mol }Fe_3O_4}$

$= 9.21\text{ mol}$

$\therefore$ Al IS LIMITING, $m_{Al} = 0\,kg$

$m_{Fe} = n_{Fe} M_{Fe} = (5.00\,mol)(55.85\,g/mol) = 279\,g$

$m_{Fe_3O_4} = n_{Fe} \times \frac{3\text{ mol }Fe_3O_4}{9\text{ mol Fe}} \times M_{Fe_3O_4} = (5.00\text{ mol Fe})\frac{3\text{ mol }Fe_3O_4}{9\text{ mol Fe}}(231.55\,\frac{g}{mol}) = 386\,g$ $\therefore$ REMAINING $Fe_3O_4 = 711\,g - 386\,g = 325\,g$

$m_{Al} + m_{Fe_3O_4} = m_{Fe} + m_{Al_2O_3}$ $\therefore m_{Al_2O_3} = m_{Al} + m_{Fe_3O_4} - m_{Fe} = 120 + 386 - 279 = 227\,g$

	Al (s)	Fe_3O_4(s)	Fe (s)	Al_2O_3 (s)
Mass (in g)	0	325	280	227

Question 7. (Office hours video, 21.3)

a) What is Z, A and N for the nuclide of the actinide thorium with a neutron:proton ratio of 1.5? (2 marks) Z = NUMBER OF PROTONS = 90

N = NUMBER OF NEUTRONS = Z × 1.5 = 135

A = MASS NUMBER = Z + N = 90 + 135 = 225

b) What is the nuclear symbol for the lead isotope that contains 128 neutrons? (2 marks)

Z = 82 N = 128

^{210}Pb (OR $^{210}_{82}Pb$)

Question 8. (Student's solution manual for problem 1.65)

Nitric acid is produced by a three-step synthesis called the Ostwald process:

$$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$$
$$2NO + O_2 \rightarrow 2NO_2$$
$$3NO_2 + H_2O \rightarrow 2HNO_3 + NO$$

The NO is recycled so that every mole of ammonia theoretically yields one mole of nitric acid. Starting with 626 kg of ammonia, what mass of nitric acid can be produced if each step is 94.5 % efficient? (5 marks)

$$\text{THEORETICAL YIELD} = m_{HNO_3} = \frac{m_{NH_3}}{M_{NH_3}} \times \frac{1\text{ mol } HNO_3}{1\text{ mol } NH_3} \times M_{HNO_3}$$

$$= \frac{626\text{ kg}}{17.034\text{ g/mol}} \times \frac{1\text{ mol } HNO_3}{1\text{ mol } NH_3} \times \underbrace{(1.008+14.01+3\times16.00)}_{63.008}\frac{g}{mol}$$

$$= 231\bar{6}\text{ kg}$$

$$\%\text{ YIELD OVERALL} = 0.945 \times 0.945 \times 0.945 \times 100\% = 84.3\%$$

$$= \frac{\text{ACTUAL YIELD}}{\text{THEORETICAL YIELD}} \times 100\%$$

$$\therefore \text{ACTUAL YIELD} = \frac{\%\text{ YIELD}}{100\%} \times \text{THEORETICAL YIELD}$$

$$= 0.843 \times 231\bar{6}\text{ kg} = 195\bar{4}\text{ kg}$$

Question 9. (Additional Interactive LearningWare Problem 10)

A 31.15 g sample of an unknown organic compound is subjected to combustion analysis. The sample gives 51.07 g of CO_2 and 20.91 g of H_2O. When this sample is analyzed for sulfur content, it is found to be 23.9% by mass. What is the empirical formula of the compound? (8 marks)

$$n_C = \frac{m_{CO_2}}{M_{CO_2}} = \frac{51.07\text{ g}}{44.01\text{ g/mol}} = 1.160\bar{4}\text{ mol}$$

$$n_H = \frac{m_{H_2O}}{M_{H_2O}} \times \frac{2\text{ mol H}}{1\text{ mol } H_2O} = \frac{20.91\text{ g}}{18.016\text{ g/mol}} \times \frac{2\text{ mol H}}{1\text{ mol } H_2O} = 2.321\bar{3}\text{ mol}$$

$$m_S = m_{TOTAL} \times \frac{\%S}{100\%} = 31.15 \times 0.239 = 7.44\text{ g}$$

$$n_S = \frac{m_S}{M_S} = \frac{7.44\text{ g}}{32.06\text{ g/mol}} = 0.232\bar{2}\text{ mol}$$

$$m_O = m_{TOTAL} - m_C - m_H - m_S = m_{TOTAL} - n_C M_C - n_H M_H - m_S$$

$$= 31.15\text{ g} - (1.160\bar{4}\text{ mol})(12.01\tfrac{g}{mol}) - (2.321\bar{3}\text{ mol})(1.008\text{ g/mol}) - 7.44\text{ g}$$

$$= 7.42\bar{9}\text{ g}$$

$$n_O = \frac{m_O}{M_O} = \frac{7.429\text{ g}}{16.00\text{ g/mol}} = 0.464\bar{3}\text{ mol}$$

$$\therefore \text{EMPIRICAL FORMULA IS } C_{\frac{1.1604}{0.2322}} H_{\frac{2.3213}{0.2322}} S_{\frac{0.2322}{0.2322}} O_{\frac{0.4643}{0.2322}}$$

$$= C_5H_{10}SO_2$$