CHM 1045 Week 5 Recitation Handout – SOLUTIONS

I. We generally assume compounds containing metals and nonmetals are ionic and name them accordingly; however, some "organometallic" compounds are molecular. Strictly speaking organometallic compounds contain metal-carbon bonds (recall "everything we are learning this semester is wrong… at some level). Interest in these compounds is driven, in part, by their potential to serve as catalysts.

Iron metal, Fe(*s*), reacts with cyclopentadiene in the gas phase, $C_5H_6(g)$, to produce a light orange solid. The low melting point suggests that this compound is molecular, not ionic. A sample of the purified solid sent for elemental analysis gave the following results: C, 64.61%; H, 5.39%. We can infer that the rest of the mass comes from iron.

A. Determine the empirical formula for the orange product.

Assume 100 g $\Rightarrow$ 64.61 g C, 5.39 g H, and 100 – 64.61 – 5.39 = 30.00 g Fe

64.61 g C x (1 mol/12.01 g) = 5.380 mol C / 0.5375 mol = 10.01
5.39 g H x (1 mol/1.008 g) = 5.347 mol H / 0.5375 mol = 9.948
30.00 g Fe x (1 mol/55.85 g) = 0.5375 mol Fe/0.5375 mol = 1.000

$C_{10.01}H_{9.948}Fe_{1.000} \Rightarrow C_{10}H_{10}Fe$

B. A separate experiment determined the molar mass of the orange product to be 186 g/mol. What is the molecular formula for this compound?

The molar mass for the empirical formula is 10(12.01 g/mol) + 10(1.008 g/mol) + 55.85 g/mol = 183.03 g/mol

which matches the molar mass of the compound, so the molecular formula must also be $C_{10}H_{10}Fe$.

C. The overall <u>unbalanced</u> chemical equation for the reaction that formed the orange product would be

Fe + C_5H_6 $\rightarrow$ (your answer to Part B) + (another molecular product)

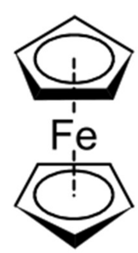
Based on the molecular formula you obtained in Part B, speculate on the other molecular product and write a balanced chemical equation for the reaction that formed the orange product.

$Fe + C_5H_6 \rightarrow C_{10}H_{10}Fe + (?)$ — balance carbon by placing 2 in front of C_5H_6

$Fe + \underline{2}C_5H_6 \rightarrow C_{10}H_{10}Fe + (?)$ — now balance hydrogen by adding H_2 as a product

$$Fe + 2C_5H_6 \rightarrow C_{10}H_{10}Fe + H_2$$

The compound $C_{10}H_{10}Fe$ is named ferrocene, and it is more commonly written as the structural formula $Fe(C_5H_5)_2$.



II. Speaking of iron, we carried out the thermite reaction yesterday at the end of class. The balanced chemical equation for this reaction is given below.

$$Fe_2O_3(s) + 2Al(s) \rightarrow 2Fe(\ell) + Al_2O_3(s)$$

Name Fe_2O_3 iron(III) oxide

Name Al_2O_3 aluminum oxide

Which element is oxidized in this reaction? aluminum (because it lost electrons to form Al^{3+})

Which element is reduced in this reaction? iron (because Fe^{3+} gained electrons to form Fe)

The initial reaction mixture contained 50 g (2 sf) Fe_2O_3 and 25 g Al. What is the theoretical yield of iron in grams? In other words, what mass of iron would be formed assuming the reaction went 100% to completion.

Assuming Fe2O3 is limiting....

50 g Fe2O3 (1 mol/159.69 g) (2 mol Fe/1 mol Fe2O3) (55.85 g Fe/mol) = 35 g Fe

Assuming Al is limiting....

25 g Al (1 mol/26.98 g) (2 mol Fe/2 mol Al) (55.85 g Fe/mol) = 52 g Fe

Less Fe formed based on Fe2O3, so Fe2O3 must be limiting, and 100% completion would give 35 g Fe.

Or, you could look at the (mol Al)/(mol Fe_2O_3) and see that it's more than 2, so Fe_2O_3 must be limiting.

III. [You may not have enough time to complete Problem III, but try to look it over with your group and work on it later as a regular homework problem. This problem pulls together several topics we discussed so far this semester, so it serves a nice (partial) review where you must decide to get to the answers.]

The conversion of Al(s) to Al_2O_3(s) accounts for much of the driving force in this reaction. Theoretical chemists recently reported a potential new form of the element aluminum, consisting of Al_4 units arranged in the same manner carbon atoms are arranged in diamond. (Different physical forms of an element are called *allotropes*.) Beyond its interesting structure, this allotrope of aluminum is predicted to have a very low density (0.61 g/cm^3) compared to the standard form of aluminum (2.7 g/cm^3) which itself is much less dense that other construction metals. See: I. V. Getmanskii, et al. *The Journal of Physical Chemistry C*, **2017**; DOI: 10.1021/acs.jpcc.7b07565.

The standard form of aluminum metal is prepared by electrolyzing aluminum oxide, Al_2O_3, according to the following chemical equation.*

$$2Al_2O_3(s) \rightarrow 4Al(s) + 3O_2(g)$$

**The commercial process, known as the Hall-Héroult Process, is a bit more, but the chemical equation as written above is fine for our purposes.*

Let's assume Al_4(s) could be formed by a similar reaction, shown below

$$2Al_2O_3(s) \rightarrow Al_4(s) + 3O_2(g)$$

A. How much $Al_4(s)$ could be prepared from 2.5 tons of $Al_2O_3(s)$, assuming the reaction went to 100% completion? Give your answer in kg. (The molar mass of Al_2O_3 is 102 g/mol.)

Al_4 => 4Al => 4(26.98 g/mol) = 107.9_2 g/mol

2.5 tons Al_2O_3	2000 lb	453.6 g	1 mol Al_2O_3	1 mol Al_4	108 g Al_4	1 kg
	1 ton	1 lb	102 g	2 mol Al_2O_3	1 mol Al_4	1000 g

= 1200 kg (2 sig figs)

B. What would be the volume, in L, of the amount of $Al_4(s)$ you calculated in Part A?

1200 kg Al_4	1000 g	1 cm^3	1 mL	1 L	1967.2... = 2000 L (2 sig figs)
	1 kg	0.61 g Al_4	1 cm	1000 mL	

C. Now suppose you also prepared the standard form of aluminum from 2.5 tons of $Al_2O_3(s)$, again assuming the reaction went to 100% completion.

$$2Al_2O_3(s) \rightarrow 4Al(s) + 3O_2(g)$$

1. Which reaction would produce the greater <u>mass</u> of aluminum? (circle one)

   formation of $Al_4(s)$ — formation of standard aluminum, Al(*s*) — **[same for both]**

   Explain your reasoning.

   Chemical processes do not change the nucleus. The mass of aluminum in 2.5 tons of Al_2O_3 will be the mass formed in the reaction, independent of whether it is Al_4 or Al.

2. Which reaction would produce the greater <u>volume</u> of aluminum? (circle one)

   [formation of $Al_4(s)$] — formation of standard aluminum, Al(*s*) — same for both

   Explain your reasoning.

   Al_4 is less dense, so it will occupy a greater volume than an equal mass of standard Al.