Combustion Analysis

This technique requires that you burn a sample of the unknown substance in a large excess of oxygen gas. The combustion products will be trapped separately from each other and the weight of each combustion product will be determined. From this, you will be able to calculate the empirical formula of the substance. This technique has been most often applied to organic compounds.

Some points to make about combustion analysis:

1. The elements making up the unknown substance almost always include carbon and hydrogen. Oxygen is often involved and nitrogen is involved sometimes. Other elements can be involved, but problems with C and H tend to predominate followed by C, H and O and then by C, H, O and N.
2. We must know the mass of the unknown substance before burning it.
3. All the carbon in the sample winds up as CO_2 and all the hydrogen in the sample winds up as H_2O.
4. If oxygen is part of the unknown compound, then its oxygen winds up incorporated into the oxides. The mass of oxygen in the sample will almost always be determined by subtraction.
5. Often the N is determined via a second experiment and this introduces a bit of complexity to the problem. Nitrogen dioxide is the usual product when nitrogen is involved. Sometimes the nitrogen product is N_2, sometimes NH_3.
6. Sometimes the problem asks you for the empirical formula and sometimes for the molecular formula (or both). Two points:
   a. You have to know the molar mass to get to the molecular formula
   b. You have to calculate the empirical formula first, even if the question doesn't ask for it.

Here is a brief overview of the solution steps before doing the example problems:

1. Determine the grams of each element present in the original compound. Carbon is always in CO_2 in the ratio (12.011 g / 44.0098 g), hydrogen is always in H_2O in the ratio (2.0158 g / 18.0152 g), etc.
2. Convert grams of each element to the number of moles. You do this by dividing the grams by the atomic weight of the element. Many times students will want to use 2.016 for hydrogen, thinking that it is H_2. This is wrong, use 1.008 for H.
3. Divide each molar amount by the lowest value, seeking to modify the molar amounts into small, whole numbers.

Steps 2 and 3 are the technique for determining the empirical formula. Step one is required because you have all your carbon, for example, in the form of CO_2 instead of a simpler problem where it tells you how much carbon is present.

Finally, a common component of this type of problem is to provide the molecular weight of the substance and ask for the molecular formula. For example, the empirical formula of benzene is CH while the molecular formula is C_6H_6.

Problem #1: A 1.50 g sample of hydrocarbon (containing only carbon and hydrogen) undergoes complete combustion to produce 4.40 g of CO_2 and 2.70 g of H_2O. What is the empirical formula of this compound?

Solution:

1. Determine the grams of carbon in 4.40 g CO_2 and the grams of hydrogen in 2.70 g H_2O.
   carbon: 4.40 g x (12.011 g / 44.0098 g) = 1.20083 g C
   hydrogen: 2.70 g x (2.0158 g / 18.0152 g) = 0.3021482 g H

2. Convert grams of C and H to their respective amount of moles.
   carbon: 1.20083 g / 12.011 g/mol = 0.09998 mol C
   hydrogen: 0.3021482 g / 1.0079 g/mol = 0.2998 mol H

3. Divide each molar amount by the lowest value, seeking to modify the above molar amounts into small, whole numbers.
   carbon: 0.09998 mol / 0.09998 mol = 1
   hydrogen: 0.2998 mol / 0.09998 mol = 2.9986 = 3

We have now arrived at the answer: the empirical formula of the substance is CH_3

Problem #2: A 0.2500 g sample of a compound known to contain carbon, hydrogen and oxygen undergoes complete combustion to produce 0.3664 g of CO_2 and 0.1500 g of H_2O. What is the empirical formula?

Solution:

1. Determine the grams of carbon in 0.3664 g CO_2 and the grams of hydrogen in 0.1500 g H_2O.
   carbon: 0.3664 g x (12.011 g / 44.0098 g) = 0.1000 g C
   hydrogen: 0.1500 g x (2.0158 g / 18.0152 g) = 0.01678 g H

2. Determine the grams of oxygen in the sample by subtraction.
   0.2500 sample − (0.1000 g C + 0.01678 g H) = 0.1332 g O
   Notice that the subtraction is the mass of the sample minus the sum of the carbon and hydrogen in the sample.

3. Convert grams of C, H and O to their respective amount of moles.
   carbon: 0.1000 g / 12.011 g / mol = 0.008325 mol
   hydrogen: 0.01678 g / 1.0079 g/mol = 0.01665 mol
   oxygen: 0.1332 g / 15.9994 g/mol = 0.008327 mol

4. Divide each molar amount by the lowest value, seeking to modify the molar amounts into small, whole numbers.
   carbon: 0.008325 mol / 0.008325 mol = 1
   hydrogen: 0.01665 mol / 0.008325 mol = 2
   oxygen: 0.008327 mol / 0.008325 mol = 1

We have now arrived at the answer: the empirical formula of the substance is CH_2O
