Stoichiometry

Consider the chemical equation: $Br_2(l) + 3\ F_2(g) \longrightarrow 2\ BrF_3(l)$

It is a balanced equation as written. Every atom of bromine (Br) on the reactant side (left side) of the arrow is exactly accounted for on the product side. Likewise the six atoms of fluorine that start out as fluorine gas molecules (F_2) end up in BrF_3 molecules. We can picture the reaction like this:

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like this:   Br–Br  +  F–F  +  F–F  +  F–F  ——→  F–Br–F   +  F–Br–F
                                                    |            |
                                                    F            F
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So 1 molecule of Br_2 reacts with 3 molecules of F_2 to give 2 molecules of BrF_3. If this reaction between molecules were run 6.022×10^{23} times, then 6.022×10^{23} molecules (= 1 mole of Br_2) would react with 3 moles of F_2 and produce 2 moles of BrF_3. The reaction could be run any number of times on the molecular level. By this equation every molecule of Br_2 would react with three molecules of F_2 to produce 2 molecules of BrF_3, or every mole of Br_2 would react with 3 moles of F_2 to produce 2 moles of BrF_3.

Problem 1. Calculate the number of moles of BrF_3 that can be produced from 5.0 moles of Br_2 and excess (more than enough to completely react) F_2.

We can write the problem this way: 5.0 mol Br_2 = ? mole BrF_3

then $$5.0 \text{ mol } Br_2 = 5.0 \text{ mol } Br_2 \times \frac{2 \text{ mol } BrF_3}{1 \text{ mol } Br_2} = 10.0 \text{ mol } BrF_3$$

The conversion factor $\frac{2 \text{ mol } BrF_3}{1 \text{ mol } Br_2}$ is a valid dimensional analysis conversion factor, because the numerator and denominator are equivalent according to the chemical equation. To have 1 mole of Br_2 before the reaction is to have 2 moles of BrF_3 after the reaction.

If the starting quantity is in grams, then it would only require a conversion from grams to moles, and the problem would be solved easily. For example:

Problem 2. Determine the number of moles of BrF_3 that can be produced from 400.0 g of Br_2 and excess F_2. 400.0 g Br_2 = ? g BrF_3

$$400.0 \text{ g } Br_2 = 400.0 \text{ g } Br_2 \times \frac{1 \text{ mol } Br_2}{159.8 \text{ g } Br_2} \times \frac{2 \text{ mol } BrF_3}{1 \text{ mol } Br_2} = 5.01 \text{ mol } BrF_3$$

Problem 3. Determine the grams of BrF_3 that can be produced from 75.2 g Br_2 and excess F_2

75.2 g Br_2 = ? g BrF_3

$$75.2 \text{ g } Br_2 = 75.2 \text{ g } Br_2 \times \frac{1 \text{ mol } Br_2}{159.8 \text{ g } Br_2} \times \frac{2 \text{ mol } BrF_3}{1 \text{ mol } Br_2} \times \frac{136.9 \text{ g } BrF_3}{1 \text{ mol } BrF_3} = 129. \text{ g } BrF_3$$

This is a fairly standard form for stoichiometry solutions. First convert **grams to moles**, then convert **moles to moles** using coefficients in the equation, then convert **moles to grams**. Notice that the third factor in this solution need not include the 2 moles of BrF_3. The 2 moles is accounted for in the mole to moles conversion factor.

Calculations need not always start from reactants to calculate products. One can calculate reactants starting with products (See Problem 4), or calculate reactants starting from other reactants (See Problem 6), or calculate products starting from other products (See Problem 8).

Problem 4. Calculate the grams of F_2 required in the production of 185.0 g of BrF_3.

$$185.0 \text{ g } BrF_3 = ? \text{ g } F_2$$

$$185.0 \text{ g } BrF_3 = 185.0 \text{ g } BrF_3 \times \frac{1 \text{ mol } BrF_3}{136.9 \text{ g } BrF_3} \times \frac{3 \text{ mol } F_2}{2 \text{ mol } BrF_3} \times \frac{38.00 \text{ g } F_2}{1 \text{ mol } F_2} = 77.25 \text{ g } F_2$$

Elemental phosphorus is produced industrially from calcium phosphate rock by:

$$2\, Ca_3(PO_4)_2(s) + 10\, C(s) + 6\, SiO_2(s) \longrightarrow P_4(g) + 10\, CO(g) + 6\, CaSiO_3(s)$$

Use this equation to solve the following problems:

Problem 5. Calculate the grams of $P_4(g)$ that can be formed from 1.500×10^4 g of $Ca_3(PO_4)_2$ and excess carbon and silicon dioxide.

Problem 6. Calculate the grams of SiO_2 needed to react with 1.500×10^4 g of $Ca_3(PO_4)_2$.

Problem 7. Calculate the grams of carbon needed in the production of 500.0 g of phosphorus.

Problem 8. Calculate the grams of $CaSiO_3$ that will be produced in the production of 1800.0 g of phosphorus.

Problem 9. Calculate the moles of carbon monoxide gas that will be produced in the reaction of 7000. g of $Ca_3(PO_4)_2$.

Answers:

5. 2996. g P_4
6. 8716. g SiO_2
7. 484.7 g C
8. 1.013×10^4 g $CaSiO_3$
9. 112.8 mol CO

Solutions:

5. $1.500\text{x}10^4$ g of $Ca_3(PO_4)_2$ = ? g P_4

$$1.500\text{x}10^4 \text{ g of } Ca_3(PO_4) \times \times \frac{1 \text{ mol } Ca_3(PO_4)_2}{310.2 \text{ g } Ca_3(PO_4)_2} \times \frac{1 \text{ mol } P_4}{2 \text{ mol } Ca_3(PO_4)_2} \times \frac{123.9 \text{ g } P_4}{1 \text{ mol } P_4} = 2996. \text{ g } P_4$$

6. $1.500\text{x}10^4$ g $Ca_3(PO_4)_2$ = ? g SiO_2

$$1.500\text{x}10^4 \text{ g } Ca_3(PO_4)_2 \times \frac{1 \text{ mol } Ca_3(PO_4)_2}{310.2 \text{ g } Ca_3(PO_4)_2} \times \frac{6 \text{ mol } SiO_2}{2 \text{ mol } Ca_3(PO_4)_2} \times \frac{60.09 \text{ g } SiO_2}{1 \text{ mol } SiO_2} = 8716. \text{ g } SiO_2$$

7. 500.0 g P_4 = ? g C

$$500.0 \text{ g } P_4 = 500.0 \text{ g } P_4 \times \frac{1 \text{ mol } P_4}{123.9 \text{ g } P_4} \times \frac{10 \text{ mol C}}{1 \text{ mol } P_4} \times \frac{12.01 \text{ g C}}{1 \text{ mol C}} = 484.7 \text{ g C}$$

8. 1800.0 g P_4 = ? g $CaSiO_3$

$$1800.0 \text{ g } P_4 = 1800.0 \text{ g } P_4 \times \frac{1 \text{ mol } P_4}{123.90 \text{ g } P_4} \times \frac{6 \text{ mol } CaSiO_3}{1 \text{ mol } P_4} \times \frac{116.16 \text{ g } CaSiO_3}{1 \text{ mol } CaSiO_3} = 10126. \text{ g } CaSiO_3$$

9. 7000. g $Ca_3(PO_4)_2$ = ? mol CO

$$7000.\text{g of } Ca_3(PO_4) = 7000. \text{ g } Ca_3(PO_4) \times \frac{1 \text{ mol } Ca_3(PO_4)_2}{310.2 \text{ g } Ca_3(PO_4)_2} \times \frac{10 \text{ mol CO}}{2 \text{ mol } Ca_3(PO_4)_2} = 112.8 \text{ mol CO}$$