

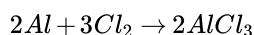
## 20.6: Mole-Mass and Mass-Mass Calculations

### Learning Objectives

- From a given number of moles of a substance, calculate the mass of another substance involved using the balanced chemical equation.
- From a given mass of a substance, calculate the moles of another substance involved using the balanced chemical equation.
- From a given mass of a substance, calculate the mass of another substance involved using the balanced chemical equation.

Mole-mole calculations are not the only type of calculations that can be performed using balanced chemical equations. Recall that the molar mass can be determined from a chemical formula and used as a conversion factor. We can add that conversion factor as another step in a calculation to make a **mole-mass calculation**, where we start with a given number of moles of a substance and calculate the mass of another substance involved in the chemical equation, or vice versa.

For example, suppose we have the balanced chemical equation



Suppose we know we have 123.2 g of  $Cl_2$ . How can we determine how many moles of  $AlCl_3$  we will get when the reaction is complete? First and foremost, *chemical equations are not balanced in terms of grams; they are balanced in terms of moles*. So to use the balanced chemical equation to relate an amount of  $Cl_2$  to an amount of  $AlCl_3$ , we need to convert the given amount of  $Cl_2$  into moles. We know how to do this by simply using the molar mass of  $Cl_2$  as a conversion factor. The molar mass of  $Cl_2$  (which we get from the atomic mass of Cl from the periodic table) is 70.90 g/mol. We must invert this fraction so that the units cancel properly:

$$123.2 \cancel{\text{ g } Cl_2} \times \frac{1 \text{ mol } Cl_2}{70.90 \cancel{\text{ g } Cl_2}} = 1.738 \text{ mol } Cl_2$$

Now that we have the quantity in moles, we can use the balanced chemical equation to construct a conversion factor that relates the number of moles of  $Cl_2$  to the number of moles of  $AlCl_3$ . The numbers in the conversion factor come from the coefficients in the balanced chemical equation:

$$\frac{2 \text{ mol } AlCl_3}{3 \text{ mol } Cl_2}$$

Using this conversion factor with the molar quantity we calculated above, we get

$$1.738 \cancel{\text{ mol } Cl_2} \times \frac{2 \text{ mol } AlCl_3}{3 \cancel{\text{ mol } Cl_2}} = 1.159 \text{ mol } AlCl_3$$

So, we will get 1.159 mol of  $AlCl_3$  if we react 123.2 g of  $Cl_2$ .

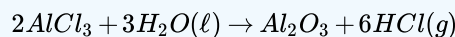
In this last example, we did the calculation in two steps. However, it is mathematically equivalent to perform the two calculations sequentially on one line:

$$123.2 \cancel{\text{ g } Cl_2} \times \frac{1 \text{ mol } Cl_2}{70.90 \cancel{\text{ g } Cl_2}} \times \frac{2 \text{ mol } AlCl_3}{3 \cancel{\text{ mol } Cl_2}} = 1.159 \text{ mol } AlCl_3$$

The units still cancel appropriately, and we get the same numerical answer in the end. Sometimes the answer may be slightly different from doing it one step at a time because of rounding of the intermediate answers, but the final answers should be effectively the same.

### ✓ Example 20.6.1

How many moles of HCl will be produced when 249 g of  $\text{AlCl}_3$  are reacted according to this chemical equation?



#### Solution

We will do this in two steps: convert the mass of  $\text{AlCl}_3$  to moles and then use the balanced chemical equation to find the number of moles of HCl formed. The molar mass of  $\text{AlCl}_3$  is 133.33 g/mol, which we have to invert to get the appropriate conversion factor:

$$249 \text{ g } \cancel{\text{AlCl}_3} \times \frac{1 \text{ mol } \cancel{\text{AlCl}_3}}{133.33 \text{ g } \cancel{\text{AlCl}_3}} = 1.87 \text{ mol } \text{AlCl}_3$$

Now we can use this quantity to determine the number of moles of HCl that will form. From the balanced chemical equation, we construct a conversion factor between the number of moles of  $\text{AlCl}_3$  and the number of moles of HCl:

$$\frac{6 \text{ mol HCl}}{2 \text{ mol } \cancel{\text{AlCl}_3}}$$

Applying this conversion factor to the quantity of  $\text{AlCl}_3$ , we get

$$1.87 \text{ mol } \cancel{\text{AlCl}_3} \times \frac{6 \text{ mol HCl}}{2 \text{ mol } \cancel{\text{AlCl}_3}} = 5.61 \text{ mol HCl}$$

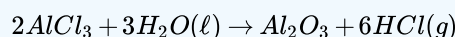
Alternatively, we could have done this in one line:

$$249 \text{ g } \cancel{\text{AlCl}_3} \times \frac{1 \text{ mol } \cancel{\text{AlCl}_3}}{133.33 \text{ g } \cancel{\text{AlCl}_3}} \times \frac{6 \text{ mol HCl}}{2 \text{ mol } \cancel{\text{AlCl}_3}} = 5.60 \text{ mol HCl}$$

The last digit in our final answer is slightly different because of rounding differences, but the answer is essentially the same.

### ? Exercise 20.6.1

How many moles of  $\text{Al}_2\text{O}_3$  will be produced when 23.9 g of  $\text{H}_2\text{O}$  are reacted according to this chemical equation?



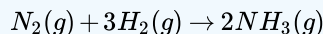
#### Answer

0.442 mol

A variation of the mole-mass calculation is to start with an amount in moles and then determine an amount of another substance in grams. The steps are the same but are performed in reverse order.

### ✓ Example 20.6.2

How many grams of  $\text{NH}_3$  will be produced when 33.9 mol of  $\text{H}_2$  are reacted according to this chemical equation?



#### Solution

The conversions are the same, but they are applied in a different order. Start by using the balanced chemical equation to convert to moles of another substance and then use its molar mass to determine the mass of the final substance. In two steps, we have

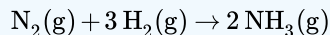
$$33.9 \text{ mol } \cancel{\text{H}_2} \times \frac{2 \text{ mol NH}_3}{3 \text{ mol } \cancel{\text{H}_2}} = 22.6 \text{ mol NH}_3$$

Now, using the molar mass of  $\text{NH}_3$ , which is 17.03 g/mol, we get

$$22.6 \cancel{\text{mol NH}_3} \times \frac{17.03 \text{ g NH}_3}{1 \cancel{\text{mol NH}_3}} = 385 \text{ g NH}_3$$

### ? Exercise 20.6.2

How many grams of N<sub>2</sub> are needed to produce 2.17 mol of NH<sub>3</sub> when reacted according to this chemical equation?

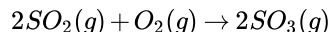


#### Answer

30.4 g (Note: here we go from a product to a reactant, showing that mole-mass problems can begin and end with any substance in the chemical equation.)

It should be a trivial task now to extend the calculations to **mass-mass calculations**, in which we start with a mass of some substance and end with the mass of another substance in the chemical reaction. For this type of calculation, the molar masses of two different substances must be used—be sure to keep track of which is which. Again, however, it is important to emphasize that before the balanced chemical reaction is used, the mass quantity must first be converted to moles. Then the coefficients of the balanced chemical reaction can be used to convert to moles of another substance, which can then be converted to a mass.

For example, let us determine the number of grams of SO<sub>3</sub> that can be produced by the reaction of 45.3 g of SO<sub>2</sub> and O<sub>2</sub>:



First, we convert the given amount, 45.3 g of SO<sub>2</sub>, to moles of SO<sub>2</sub> using its molar mass (64.06 g/mol):

$$45.3 \text{ g SO}_2 \times \frac{1 \text{ mol SO}_2}{64.06 \text{ g SO}_2} = 0.707 \text{ mol SO}_2$$

Second, we use the balanced chemical reaction to convert from moles of SO<sub>2</sub> to moles of SO<sub>3</sub>:

$$0.707 \text{ mol SO}_2 \times \frac{2 \text{ mol SO}_3}{2 \text{ mol SO}_2} = 0.707 \text{ mol SO}_3$$

Finally, we use the molar mass of SO<sub>3</sub> (80.06 g/mol) to convert to the mass of SO<sub>3</sub>:

$$0.707 \text{ mol SO}_3 \times \frac{80.06 \text{ g SO}_3}{1 \text{ mol SO}_3} = 56.6 \text{ g SO}_3$$

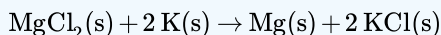
We can also perform all three steps sequentially, writing them on one line as

$$45.3 \text{ g SO}_2 \times \frac{1 \text{ mol SO}_2}{64.06 \text{ g SO}_2} \times \frac{2 \text{ mol SO}_3}{2 \text{ mol SO}_2} \times \frac{80.06 \text{ g SO}_3}{1 \text{ mol SO}_3} = 56.6 \text{ g SO}_3$$

We get the same answer. Note how the initial and all the intermediate units cancel, leaving grams of SO<sub>3</sub>, which is what we are looking for, as our final answer.

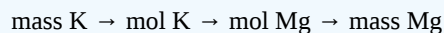
### ✓ Example 20.6.3

What mass of Mg will be produced when 86.4 g of K are reacted?



#### Solution

We will simply follow the steps

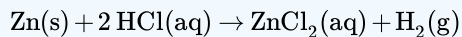


In addition to the balanced chemical equation, we need the molar masses of K (39.09 g/mol) and Mg (24.31 g/mol). In one line,

$$86.4 \cancel{g K} \times \frac{1 \cancel{mol K}}{39.09 \cancel{g K}} \times \frac{1 \cancel{mol Mg}}{2 \cancel{mol K}} \times \frac{24.31 \cancel{g Mg}}{1 \cancel{mol Mg}} = 26.87 \cancel{g Mg}$$

### ? Exercise 20.6.3

What mass of H<sub>2</sub> will be produced when 122 g of Zn are reacted?



**Answer**

3.77 g

### Summary

- Mole quantities of one substance can be related to mass quantities using a balanced chemical equation.
- Mass quantities of one substance can be related to mass quantities using a balanced chemical equation.
- In all cases, quantities of a substance must be converted to moles before the balanced chemical equation can be used to convert to moles of another substance.

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