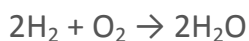


5.3 The Mole in Chemical Reactions

LEARNING OBJECTIVES

1. Balance a chemical equation in terms of moles.
2. Use the balanced equation to construct conversion factors in terms of moles.
3. Calculate moles of one substance from moles of another substance using a balanced chemical equation.

Consider this balanced chemical equation:



We interpret this as “two molecules of hydrogen react with one molecule of oxygen to make two molecules of water.” The chemical equation is balanced as long as the coefficients are in the ratio 2:1:2. For instance, this chemical equation is also

balanced:



This equation is not conventional—because convention says that we use the lowest ratio of coefficients—but it is balanced. So is this chemical equation:

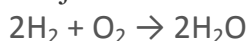


Again, this is not conventional, but it is still balanced. Suppose we use a much larger number:



These coefficients are also in the ratio of 2:1:2. But these numbers are related to the number of things in a mole: the first and last numbers are two times Avogadro's number, while the second number is Avogadro's number. That means that the first

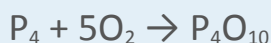
and last numbers represent 2 mol, while the middle number is just 1 mol. Well, why not just use the number of moles in balancing the chemical equation?



is the same balanced chemical equation we started with! What this means is that chemical equations are not just balanced in terms of molecules; *they are also balanced in terms of moles*. We can just as easily read this chemical equation as “two moles of hydrogen react with one mole of oxygen to make two moles of water.” All balanced chemical reactions are balanced in terms of moles.

EXAMPLE 8

Interpret this balanced chemical equation in terms of moles.

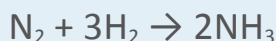


Solution

The coefficients represent the number of moles that react, not just molecules. We would speak of this equation as “one mole of molecular phosphorus reacts with five moles of elemental oxygen to make one mole of tetraphosphorus decoxide.”

Test Yourself

Interpret this balanced chemical equation in terms of moles.



Answer

One mole of elemental nitrogen reacts with three moles of elemental hydrogen to produce two moles of ammonia.



In [Chapter 4 "Chemical Reactions and Equations"](#), [Section 4.1 "The Chemical Equation"](#), we stated that a chemical equation is simply a recipe for a chemical reaction. As such, chemical equations also give us equivalences—equivalences between the reactants and the products. However, now we understand that *these equivalences are expressed in terms of moles*. Consider the chemical equation $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$

This chemical reaction gives us the following equivalences:



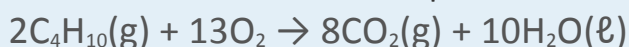
Any two of these quantities can be used to construct a conversion factor that lets us relate the number of moles of one substance to an equivalent number of moles of another substance. If, for example, we want to know how many moles of oxygen will react with 17.6 mol of hydrogen, we construct a conversion factor between 2 mol of H_2 and 1 mol of O_2 and use it to convert from moles of one substance to moles of another:

$$17.6 \cancel{\text{ mol H}_2} \times \frac{1 \text{ mol O}_2}{2 \cancel{\text{ mol H}_2}} = 8.80 \text{ mol O}_2$$

Note how the mol H_2 unit cancels, and mol O_2 is the new unit introduced. This is an example of a **mole-mole calculation**, when you start with moles of one substance and convert to moles of another substance by using the balanced chemical equation. The example may seem simple because the numbers are small, but numbers won't always be so simple!

EXAMPLE 9

For the balanced chemical equation



if 154 mol of O_2 are reacted, how many moles of CO_2 are produced?

Solution



We are relating an amount of oxygen to an amount of carbon dioxide, so we need the equivalence between these two substances. According to the balanced chemical equation, the equivalence is $13 \text{ mol O}_2 \Leftrightarrow 8 \text{ mol CO}_2$

We can use this equivalence to construct the proper conversion factor. We start with what we are given and apply the conversion factor:

$$154 \cancel{\text{ mol O}_2} \times \frac{8 \text{ mol CO}_2}{13 \cancel{\text{ mol O}_2}} = 94.8 \text{ mol CO}_2$$

The mol O₂ unit is in the denominator of the conversion factor so it cancels. Both the 8 and the 13 are exact numbers, so they don't contribute to the number of significant figures in the final answer.

Test Yourself

Using the above equation, how many moles of H₂O are produced when 154 mol of O₂ react?

Answer

118 mol

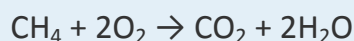
It is important to reiterate that balanced chemical equations are balanced in terms of *moles*. Not grams, kilograms, or liters—but moles. Any stoichiometry problem will likely need to work through the mole unit at some point, especially if you are working with a balanced chemical reaction.

KEY TAKEAWAYS

- Balanced chemical reactions are balanced in terms of moles.
- A balanced chemical reaction gives equivalences in moles that allow stoichiometry calculations to be performed.

EXERCISES

1. Express in mole terms what this chemical equation means.



2. Express in mole terms what this chemical equation means.



3. How many molecules of each substance are involved in the equation in Exercise 1 if it is interpreted in terms of moles?

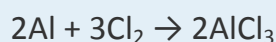
4. How many molecules of each substance are involved in the equation in Exercise 2 if it is interpreted in terms of moles?

5. For the chemical equation



what equivalences can you write in terms of moles? Use the \Leftrightarrow sign.

6. For the chemical equation



what equivalences can you write in terms of moles? Use the \Leftrightarrow sign.

7. Write the balanced chemical reaction for the combustion of C_5H_{12} (the products are CO_2 and H_2O) and determine how many moles of H_2O are formed when 5.8 mol of O_2 are reacted.

8. Write the balanced chemical reaction for the formation of $\text{Fe}_2(\text{SO}_4)_3$ from Fe_2O_3 and SO_3 and determine how many moles of $\text{Fe}_2(\text{SO}_4)_3$ are formed when 12.7 mol of SO_3 are reacted.
9. For the balanced chemical equation
$$3\text{Cu}(\text{s}) + 2\text{NO}_3^-(\text{aq}) + 8\text{H}^+(\text{aq}) \rightarrow 3\text{Cu}^{2+}(\text{aq}) + 4\text{H}_2\text{O}(\ell) + 2\text{NO}(\text{g})$$
how many moles of Cu^{2+} are formed when 55.7 mol of H^+ are reacted?
10. For the balanced chemical equation
$$\text{Al}(\text{s}) + 3\text{Ag}^+(\text{aq}) \rightarrow \text{Al}^{3+}(\text{aq}) + 3\text{Ag}(\text{s})$$
how many moles of Ag are produced when 0.661 mol of Al are reacted?
11. For the balanced chemical reaction
$$4\text{NH}_3(\text{g}) + 5\text{O}_2(\text{g}) \rightarrow 4\text{NO}(\text{g}) + 6\text{H}_2\text{O}(\ell)$$
how many moles of H_2O are produced when 0.669 mol of NH_3 react?
12. For the balanced chemical reaction
$$4\text{NaOH}(\text{aq}) + 2\text{S}(\text{s}) + 3\text{O}_2(\text{g}) \rightarrow 2\text{Na}_2\text{SO}_4(\text{aq}) + 2\text{H}_2\text{O}(\ell)$$
how many moles of Na_2SO_4 are formed when 1.22 mol of O_2 react?
13. For the balanced chemical reaction
$$4\text{KO}_2(\text{s}) + 2\text{CO}_2(\text{g}) \rightarrow 2\text{K}_2\text{CO}_3(\text{s}) + 3\text{O}_2(\text{g})$$
determine the number of moles of both products formed when 6.88 mol of KO_2 react.
14. For the balanced chemical reaction
$$2\text{AlCl}_3 + 3\text{H}_2\text{O}(\ell) \rightarrow \text{Al}_2\text{O}_3 + 6\text{HCl}(\text{g})$$



determine the number of moles of both products formed when 0.0552 mol of AlCl_3 react.

ANSWERS

1. One mole of CH_4 reacts with 2 mol of O_2 to make 1 mol of CO_2 and 2 mol of H_2O .
3. 6.022×10^{23} molecules of CH_4 , 1.2044×10^{24} molecules of O_2 , 6.022×10^{23} molecules of CO_2 , and 1.2044×10^{24} molecules of H_2O
5. 2 mol of $\text{C}_2\text{H}_6 \Leftrightarrow 7 \text{ mol of } \text{O}_2 \Leftrightarrow 4 \text{ mol of } \text{CO}_2 \Leftrightarrow 6 \text{ mol of } \text{H}_2\text{O}$
7. $\text{C}_5\text{H}_{12} + 8\text{O}_2 \rightarrow 5\text{CO}_2 + 6\text{H}_2\text{O}$; 4.4 mol
9. 20.9 mol
11. 1.00 mol
13. 3.44 mol of K_2CO_3 ; 5.16 mol of O_2