7.4 Stoichiometry Calculations Using Enthalpy

LEARNING OBJECTIVE

1. Perform stoichiometry calculations using energy changes from thermochemical equations.

In [Chapter 5 "Stoichiometry and the Mole"](#), we related quantities of one substance to another in a chemical equation by performing calculations that used the balanced chemical equation; the balanced chemical equation provided equivalences that we used to construct conversion factors. For example, in the balanced chemical equation

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(\ell)$$

we recognized the equivalences

2 mol H_2 ⇔ 1 mol O_2 ⇔ 2 mol H_2O

where ⇔ is the mathematical symbol for "is equivalent to." In our thermochemical equation, however, we have another quantity—energy change:

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(\ell) \quad \Delta H = -570 \text{ kJ}$$
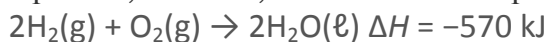
This new quantity allows us to add another equivalence to our list:

2 mol H_2 ⇔ 1 mol O_2 ⇔ 2 mol H_2O ⇔ −570 kJ

That is, we can now add an energy amount to the equivalences—the enthalpy change of a balanced chemical reaction. This equivalence can also be used to construct conversion factors so that we can relate enthalpy change to amounts of substances reacted or produced.

Note that these equivalences address a concern. When an amount of energy is listed for a balanced chemical reaction, what amount(s) of reactants or products does it refer to? The answer is that relates to the number of moles of the substance as indicated by its coefficient in the balanced chemical reaction. Thus, 2 mol of H_2 are related to −570 kJ, while 1 mol of O_2 is related to −570 kJ. This is why the unit on the energy change is kJ, not kJ/mol.

For example, consider the thermochemical equation
$H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$ ΔH = −184.6 kJ

The equivalences for this thermochemical equation are
1 mol H_2 ⇔ 1 mol Cl_2 ⇔ 2 mol HCl ⇔ −184.6 kJ
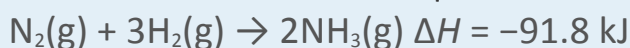
Suppose we asked how much energy is given off when 8.22 mol of H_2 react. We would construct a conversion factor between the number of moles of H_2 and the energy given off, −184.6 kJ:

$$8.22 \ \text{mol } H_2 \times \frac{-184.6 \text{ kJ}}{1 \ \text{mol } H_2} = -1{,}520 \text{ kJ}$$

The negative sign means that this much energy is given off.

EXAMPLE 8

Given the thermochemical equation
$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$ ΔH = −91.8 kJ

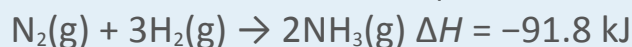how much energy is given off when 222.4 g of N_2 reacts?

Solution

The balanced thermochemical equation relates the energy change to moles, not grams, so we first convert the amount of N_2 to moles and then use the thermochemical equation to determine the energy change:

$$222.4 \ \cancel{g \ N_2} \times \frac{1 \ \cancel{mol \ N_2}}{28.00 \ \cancel{g \ N_2}} \times \frac{-91.8 \ kJ}{1 \ \cancel{mol \ N_2}} = -729 \ kJ$$

Test Yourself

Given the thermochemical equation
$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$ $\Delta H = -91.8$ kJ
how much heat is given off when 1.00 g of H_2 reacts?

Answer

   −15.1 kJ

Like any stoichiometric quantity, we can start with energy and determine an amount, rather than the other way around.

EXAMPLE 9

Given the thermochemical equation
$N_2(g) + O_2(g) \rightarrow 2NO(g)$ $\Delta H = 180.6$ kJ
if 558 kJ of energy are supplied, what mass of NO can be made?

Solution

This time, we start with an amount of energy:

$$558 \ \cancel{kJ} \times \frac{2 \ \cancel{mol \ NO}}{180.6 \ \cancel{kJ}} \times \frac{30.0 \ g \ NO}{1 \ \cancel{mol \ NO}} = 185 \ g \ NO$$

How many grams of N_2 will react if 100.0 kJ of energy are supplied?
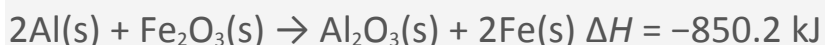$N_2(g) + O_2(g) \rightarrow 2NO(g)$ $\Delta H = 180.6$ kJ

Answer

15.5 g

Chemistry Is Everywhere: Welding with Chemical Reactions

One very energetic reaction is called the *thermite reaction*. Its classic reactants are aluminum metal and iron(III) oxide; the reaction produces iron metal and aluminum oxide:

$2Al(s) + Fe_2O_3(s) \rightarrow Al_2O_3(s) + 2Fe(s)$ $\Delta H = -850.2$ kJ

When properly done, the reaction gives off so much energy that the iron product comes off as a *liquid*. (Iron normally melts at 1,536°C.) If carefully directed, the liquid iron can fill spaces between two or more metal parts and, after it quickly cools, can weld the metal parts together. Thermite reactions are used for this purpose even today. For civilian purposes, they are used to reweld broken locomotive axles that cannot be easily removed for repair. They are used to weld railroad tracks together. Thermite reactions can also be used to separate thin pieces of metal if, for whatever reason, a torch doesn't work.

A small clay pot contains a thermite mixture. It is reacting at high temperature in the photo and will eventually produce molten metal to join the railroad tracks below it.

*Source: Photo courtesy of Skatebiker,http://commons.wikimedia.org/wiki/File:Velp-thermitewelding-1.jpg.*

Thermite reactions are also used for military purposes. Thermite mixtures are frequently used with additional components as incendiary devices—devices that start fires. Thermite reactions are also useful in disabling enemy weapons: a piece of artillery doesn't work so well when it has a hole melted into its barrel because of a thermite reaction!
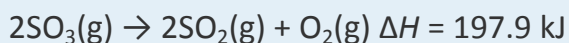
KEY TAKEAWAY

- The energy change of a chemical reaction can be used in stoichiometry calculations.

1. Write the equivalences that this balanced thermochemical equation implies.

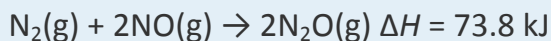 $PCl_3(g) + Cl_2(g) \rightarrow PCl_5(g)$ $\Delta H = -87.9$ kJ
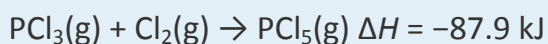
2. Write the equivalences that this balanced thermochemical equation implies.

   $2SO_3(g) \rightarrow 2SO_2(g) + O_2(g)$ $\Delta H = 197.9$ kJ

3. How many kilojoules are given off when 17.8 mol of $CH_4(g)$ react?

   $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(\ell)$ $\Delta H = -890.1$ kJ
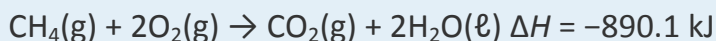
4. How many kilojoules are absorbed when 0.772 mol of $N_2(g)$ reacts?

   $N_2(g) + 2NO(g) \rightarrow 2N_2O(g)$ $\Delta H = 73.8$ kJ

5. How many kilojoules are absorbed when 23.09 mol of $C_6H_6(\ell)$ are formed?

   $6C(s) + 3H_2(g) \rightarrow C_6H_6(\ell)$ $\Delta H = 49.0$ kJ
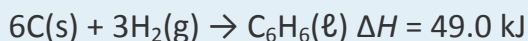
6. How many kilojoules are given off when 8.32 mol of Mg react?

   $2Mg(s) + O_2(g) \rightarrow 2MgO(s)$ $\Delta H = -1,213$ kJ

7. Glucose is the main fuel metabolized in animal cells:

   $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ $\Delta H = -2,799$ kJ
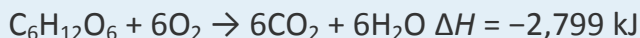
   How much energy is given off when 100.0 g of $C_6H_{12}O_6$ react?

8. Given the thermochemical equation

   $2Al(s) + Fe_2O_3(s) \rightarrow Al_2O_3(s) + 2Fe(s)$ $\Delta H = -850.2$ kJ
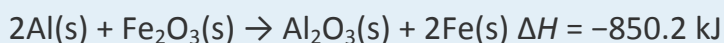
how much energy is given off when 288 g of Fe are produced?

9. Given the thermochemical equation

   $2CO_2(g) \rightarrow 2CO(g) + O_2(g)$ $\Delta H = 566$ kJ
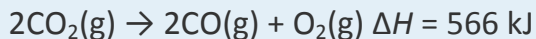
   how much energy is absorbed when 85.2 g of CO_2 are reacted?

10. Given the thermochemical equation

    $2Na^+(aq) + SO_4{}^{2-}(aq) \rightarrow Na_2SO_4(s)$ $\Delta H = 819.8$ kJ
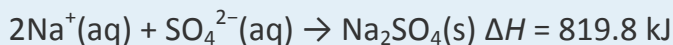
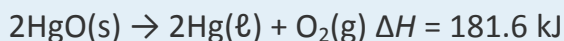   how much energy is absorbed when 55.9 g of $Na^+(aq)$ are reacted?
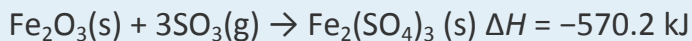
11. $NaHCO_3$ decomposes when exposed to heat:

    $2NaHCO_3(s) \rightarrow Na_2CO_3(s) + CO_2(g) + H_2O(\ell)$ $\Delta H = 91.5$ kJ
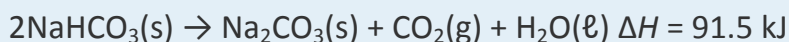
    What mass of $NaHCO_3$ is decomposed by 256 kJ?

12. HgO decomposes when exposed to heat:

    $2HgO(s) \rightarrow 2Hg(\ell) + O_2(g)$ $\Delta H = 181.6$ kJ

    What mass of O_2 can be made with 100.0 kJ?

13. For the thermochemical equation

    $Fe_2O_3(s) + 3SO_3(g) \rightarrow Fe_2(SO_4)_3 (s)$ $\Delta H = -570.2$ kJ

    what mass of SO_3 is needed to generate 1,566 kJ?

14. For the thermochemical equation

    $H_2(g) + Br_2(\ell) \rightarrow 2HBr(g)$ $\Delta H = -72.6$ kJ
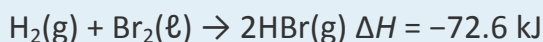
    what mass of HBr will be formed when 553 kJ of energy are given off?

ANSWERS

1. 1 mol of $PCl_3 \Leftrightarrow$ 1 mol of $Cl_2 \Leftrightarrow$ 1 mol of $PCl_5 \Leftrightarrow -87.9$ kJ

3. 15,800 kJ

5. 1,130 kJ

7. 1,554 kJ

9. 548 kJ

11. 470 g

13. 6.60×10^2 g