

## Types of Chemical Reactions: Combustion



**Figure 1** Propane was the fuel in this dramatic combustion reaction in north Toronto.

**combustion** the rapid reaction of a substance with oxygen to produce oxides and energy; burning

**complete combustion** a combustion reaction of hydrocarbons that uses all the available fuel and produces only carbon dioxide, water, and energy; occurs when the supply of oxygen is plentiful

### DID YOU KNOW?

#### Is Your Classroom Putting You to Sleep?

Carbon dioxide is exhaled by students and produced by the school heating system. This gas accumulates in a classroom over the course of a day if ventilation is inadequate. Excess carbon dioxide can cause headaches and drowsiness.

In the early hours of August 2, 2008, a north Toronto neighbourhood was rocked by a loud explosion. Startled residents stared out their windows in disbelief as a giant fireball rose high into the night sky. Why? A nearby propane storage depot was on fire (Figure 1)! Large chunks of metal, probably from exploded propane storage tanks, littered the area. Shockwaves from the explosion shattered windows and ripped doors off their hinges. Firefighters rushed to the scene, but all they could do was cool the remaining propane tanks with water and wait for the fireball to burn itself out.

Extinguishing a propane blaze is almost impossible. People were shocked and angry that propane—a highly explosive fuel—had been stored and handled in a way that led to such a damaging explosion.

## What Is Combustion?

**Combustion** is a chemical reaction in which a fuel “burns” or reacts quickly with oxygen. The products of this reaction are usually an oxide and energy. Propane,  $C_3H_8$ , is one of a group of molecular compounds called hydrocarbons. As their name implies, these compounds contain only the elements hydrogen and carbon. Most hydrocarbons originate from fossil fuels. The combustion of hydrocarbons powers cars and buses, warms homes, generates electricity, and even lights up the candles on your birthday cake.

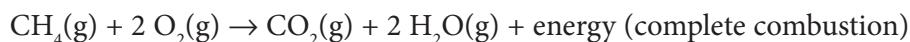
## Complete Combustion of Hydrocarbons

The products of a hydrocarbon combustion reaction can vary. They depend on the availability of oxygen. If oxygen is plentiful, hydrocarbons burn completely to release the energy they contain. The only products of complete combustion are carbon dioxide and water. The word equation for the **complete combustion** of a hydrocarbon is

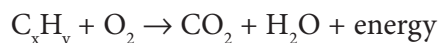


Carbon dioxide is an important greenhouse gas. You will learn more about this product of combustion in Unit B: Climate Change.

Methane,  $CH_4(g)$ , is a typical hydrocarbon. Natural gas is mostly composed of methane. The balanced chemical equation for the complete combustion of methane is



The complete combustion of hydrocarbons can be represented by the general equation

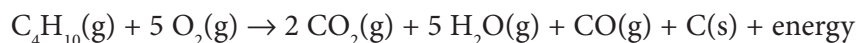


During complete combustion, fuels burn cleanly with no sooty residue.


## Incomplete Combustion of Hydrocarbons

If the oxygen supply is limited, **incomplete combustion** may occur, releasing carbon monoxide gas and carbon (soot), in addition to carbon dioxide and water. An orange, flickering flame often indicates incomplete combustion.

Butane gas,  $C_4H_{10}(g)$ , is burned as fuel in some portable stoves. If the stove burner is not adjusted properly, or if there is not enough oxygen, incomplete combustion could occur.



### Carbon Monoxide

Carbon monoxide,  $CO(g)$ , is an odourless, colourless gas that is highly toxic. Symptoms of carbon monoxide poisoning include headache, dizziness, nausea, and respiratory problems. These are fairly general symptoms, so carbon monoxide may not immediately be identified as the cause. Many people have died from inhaling carbon monoxide. It is often produced as a result of the incomplete combustion of fuels in a confined space. Carbon monoxide is typically found in a home with a poorly ventilated furnace or in a closed garage in which a vehicle is running. 

**incomplete combustion** a combustion reaction of hydrocarbons that may produce carbon monoxide, carbon, carbon dioxide, soot, water, and energy; occurs when the oxygen supply is limited

To learn more about the effects of carbon monoxide on the body,



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### CITIZEN ACTION

#### Carbon Monoxide Detectors

Carbon monoxide in homes is particularly dangerous at night because people who are asleep are totally unaware of the symptoms of carbon monoxide poisoning. To prevent deaths from faulty home furnaces or stoves, we are advised to install carbon monoxide detectors in our homes. These devices save lives every year.



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#### What Can You Do to Help?

Contact your local fire department. Find out what they recommend regarding carbon monoxide detectors. How many detectors should you have in your home? Where should they be placed? Why? Consider protecting your family from carbon monoxide poisoning.

### Soot

Soot is made up of particles of carbon. Soot is evidence of incomplete combustion, which causes pollution and wastes energy. Soot is common in older vehicles with poorly maintained engines (Figure 2(a)). Forest fires also produce huge quantities of soot that travel far downwind (Figure 2(b)).

### Other Combustion Reactions

Many other substances—besides hydrocarbons—undergo combustion reactions. Elements, for example, react with oxygen to form oxides. Magnesium burns to produce magnesium oxide just as carbon burns to produce carbon dioxide.

General word equation: element + oxygen  $\rightarrow$  oxide + energy

General chemical equation:  $A + O_2 \rightarrow AO + \text{energy}$

Example:  $2 Mg(s) + O_2(g) \rightarrow 2 MgO(s) + \text{energy}$

You might have noticed that combustion reactions involving elements are also synthesis reactions: they follow the pattern  $A + B \rightarrow AB$ .



**Figure 2** Two signs of incomplete combustion are (a) soot production and (b) orange flames.

### DID YOU KNOW?

#### Iceland: A Hydrogen Powerhouse

Iceland has ambitious plans. It intends to be the first country to completely switch from fossil fuels to hydrogen. Iceland was formed from volcanoes, so it has abundant stores of geothermal energy. Icelandic scientists plan to use this energy to extract hydrogen from seawater.

### DID YOU KNOW?

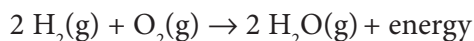
#### Phosphorus from Urine

Like many alchemists of his time, Hennig Brandt was preoccupied with trying to turn objects into gold. In 1669, Brandt chose urine as his starting material because it is gold coloured. Brandt boiled urine until it became a thick paste. He continued heating this paste, collecting and condensing the vapours produced. Much to his disappointment, instead of gold, he had produced a white solid that glowed in the dark. Brandt named this substance “phosphorus,” which means “light-giving” in Greek.

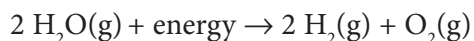
**Figure 3** (a) White phosphorus is so reactive that it has to be stored in oil to prevent it from coming into contact with the air. Red phosphorus is relatively unreactive. (b) Safety matches will ignite only if they are scraped against the red phosphorus on the match box.

## Combustion of Hydrogen

Hydrogen reacts (burns) with oxygen to form water:



Hydrogen is already being used as a fuel in a few technologies. The source of hydrogen is usually water. The decomposition reaction that produces hydrogen from water is the exact reverse of the hydrogen combustion reaction:



The energy on the reactant side of this equation usually comes from electricity.

At first glance, hydrogen is an ideal fuel because

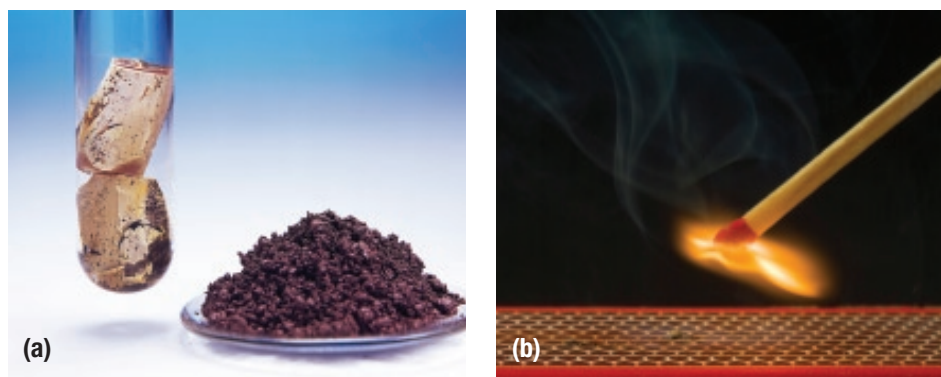
- it burns cleanly, producing only water and energy, and
- there is an almost endless supply of water to produce hydrogen. As long as you have energy to decompose the water, you have a source of hydrogen.

However, some technical problems have to be overcome before hydrogen becomes a common vehicle fuel.

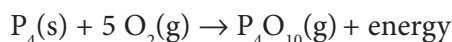
- Making hydrogen requires energy. What non-polluting source of energy can be used?
- The engines for hydrogen-fuelled cars are currently very expensive to make.
- Hydrogen is an explosive gas. It is difficult to transport and store.

## Combustion of Phosphorus

The combustion of phosphorus has particularly interesting applications. Phosphorus comes in two forms: white and red phosphorus (Figure 3(a)). You might have seen red phosphorus on the striking strip of a package of safety matches (Figure 3(b)).



When you rub a match against the striking strip, the friction releases heat energy. This energy converts red phosphorus into white phosphorus, which instantly burns in the air:



The heat from this reaction ignites the chemicals in the head of the match.

The combustion of non-metals is an important first step in the formation of acid precipitation. You will learn more about these reactions in Chapter 7.



## RESEARCH THIS FIREFIGHTING WITH AN MSDS

**SKILLS:** Researching, Identifying Alternatives, Defending a Decision, Communicating

SKILLS HANDBOOK  
4.A.

How you put out a fire depends on the properties of the fuel. An MSDS can provide firefighters with valuable tips on how to put out a fire, particularly with chemical fires.

1. Research the MSDS for the following substances: propane, olive oil, and magnesium.



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2. Determine the best method of putting out a fire involving each of these substances.
- A. Create a poster or other information campaign to share your discoveries with others. Explain, in your campaign, why the specific methods are effective. T/I C A

## IN SUMMARY

- Hydrocarbons often react with oxygen in combustion reactions. Complete combustion produces only carbon dioxide and water; incomplete combustion may produce carbon (soot), carbon monoxide, carbon dioxide, and water.
- Some metals react with oxygen in combustion reactions, producing oxides of the metal (e.g., magnesium oxide, MgO).
- Hydrogen reacts with oxygen in combustion reactions, producing water. This is a possible future source of energy for vehicles.



## CHECK YOUR LEARNING

1. (a) Describe an idea in this section that could affect your life.  
(b) Why is this idea important? K/U A
2. Complete these skeleton equations. Remember to balance the equations, where necessary, by adding coefficients before the chemical symbols. K/U T/I  
(a) \_\_\_\_\_ (s) + \_\_\_\_\_ (g) → \_\_\_\_\_ SO<sub>2</sub>(g) + energy  
(b) \_\_\_ Ca(s) + \_\_\_ \_\_\_\_\_ → \_\_\_ CaO(s) + energy  
(c) \_\_\_ C<sub>3</sub>H<sub>8</sub>(g) + \_\_\_ O<sub>2</sub>(g) → \_\_\_\_\_ + \_\_\_\_\_ + energy  
(d) \_\_\_ C<sub>2</sub>H<sub>4</sub>(g) + \_\_\_ O<sub>2</sub>(g) → \_\_\_\_\_ + \_\_\_\_\_ + energy
3. Propane is used as a fuel in camping stoves (Figure 4). It is a hydrocarbon with the chemical formula C<sub>3</sub>H<sub>8</sub>. Propane is a gas at room temperature and pressure but becomes a liquid when compressed. K/U T/I A  
(a) Write the general equation for the complete combustion of a hydrocarbon.  
(b) Write the balanced chemical equation for the complete combustion of propane.  
(c) Examine the Hazardous Household Products Symbols (HHPS) on the label. Outline the precautions you should take when using this product.  
(d) Why is it unwise to use a camping stove inside a tent?
4. Explain why you can save money on home heating fuel if you keep your gas furnace clean and operating at peak efficiency. A
5. (a) Give at least two reasons why the use of hydrogen fuel is potentially better for the environment than gasoline.  
(b) What is meant by the statement “hydrogen is only as environmentally clean as the energy used to make it”? K/U A
6. List the five types of reactions that have been discussed in this chapter so far. K/U
7. (a) Use specific examples to show that some combustion reactions are also synthesis reactions.  
(b) Under what conditions does this occur? A



**Figure 4** Propane is highly flammable. Note the warnings on the container.