6.9

Types of Chemical Reactions: Combustion

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

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

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

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

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

hydrocarbon + oxygen → carbon dioxide + water + energy

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

$$CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(g) + \text{energy (complete combustion)}$$

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

$$C_xH_y + O_2 \rightarrow CO_2 + H_2O + \text{energy}$$

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

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.

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.

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

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.

$$C_4H_{10}(g) + 5\ O_2(g) \rightarrow 2\ CO_2(g) + 5\ H_2O(g) + CO(g) + C(s) + \text{energy}$$

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.

To learn more about the effects of carbon monoxide on the body,
GO TO NELSON SCIENCE

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.

GO TO NELSON SCIENCE

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)).

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

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 → oxide	+ energy
General chemical equation:	$A + O_2 \rightarrow AO$	+ energy
Example:	$2\ Mg(s) + O_2(g) \rightarrow 2\ MgO(s)$	+ energy

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

Combustion of Hydrogen

Hydrogen reacts (burns) with oxygen to form water:

$2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(g) + \text{energy}$

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:

$2\ H_2O(g) + \text{energy} \rightarrow 2\ H_2(g) + O_2(g)$

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.

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.

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)).

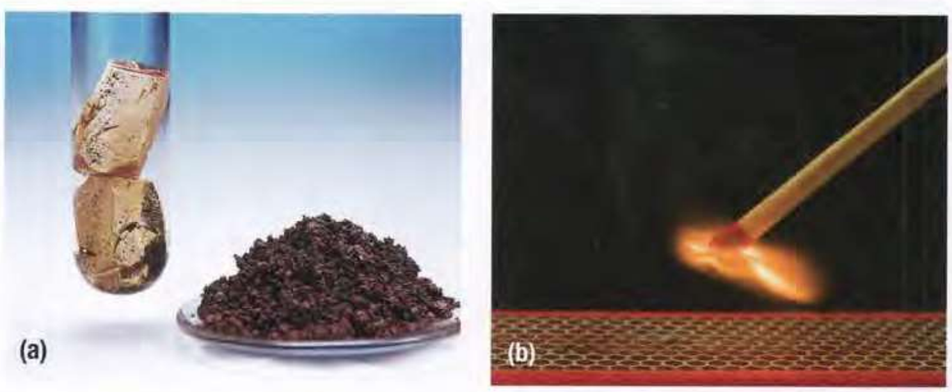

Figure 3 (a) White phosphorus is so reactive that it has to be stored in oil to prevent it from coming into contact with the air. Red phosphorus is relatively unreactive. (b) Safety matches will ignite only if they are scraped against the red phosphorus on the match box.

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:

$P_4(s) + 5\ O_2(g) \rightarrow P_4O_{10}(g) + \text{energy}$

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.

GO TO NELSON SCIENCE

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_2(g) + energy
   (b) __ Ca(s) + __ ______ → __ CaO(s) + energy
   (c) __ C_3H_8(g) + __ O_2(g) → __ ________ + __ ________ + energy
   (d) __ C_2H_4(g) + __ O_2(g) → __ ________ + __ ________ + energy
3. Propane is used as a fuel in camping stoves (Figure 4). It is a hydrocarbon with the chemical formula C_3H_8. 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?

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

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

6.10 Corrosion

corrosion the breakdown of a metal resulting from reactions with chemicals in its environment

With just a few exceptions, such as gold and platinum, most metal elements corrode. **Corrosion** is the breakdown of a metal as a result of chemical reactions with its environment. Metalworkers have, over the centuries, given different names to corrosion reactions involving different metals. Silver, for example, tarnishes when it comes in contact with sulfur compounds in air.

Beneficial Corrosion

In some cases, the corrosion of a metal is beneficial. For example, when aluminum is exposed to air, it quickly corrodes to form aluminum oxide—one of the hardest substances known. Aluminum oxide tightly coats the underlying aluminum metal, preventing any further corrosion from occurring. This explains why aluminum camping pans can be safely left outside in the rain, while a cast iron pan rusts in a matter of days. Zinc and copper are other common metals that form protective coatings when they corrode. Copper develops an attractive greenish patina after being exposed to the atmosphere for several months (Figure 1). This patina is so corrosion resistant that a copper roof remains weatherproof for up to 75 years.

Figure 1 A colorful patina develops on copper roofs over several years

Rust

Rust is the familiar reddish-brown flaky material produced when metals containing iron corrode. Unlike the corrosion products of aluminum and copper, rust does not stick well to the underlying steel. Instead, rust is very porous and readily flakes away from the surface of steel. As it does, fresh steel is exposed for further corrosion. This process continues until the steel is completely corroded or "eaten away." All that remains is a trail of rust flakes!

LEARNING TIP

Corrosion and Rusting

The terms *corrosion* and *rusting* are often used interchangeably. Strictly speaking, corrosion is a general term that can be applied to any metal that reacts with chemicals in the environment. Rusting, however, refers specifically to the corrosion of metals that contain iron, such as steel.

Causes of Rust

The corrosion of iron or rusting is a complex process that is affected by many things: the presence of air, water, and electrolytes, along with acidity and mechanical stress.

OXYGEN AND WATER

The most obvious factors necessary for the corrosion of iron are oxygen (in air) and water. Steel will not corrode if it is kept away from water and oxygen. This is why steel lasts much longer in dry climates than in Ontario.

ELECTROLYTES

Contrary to popular belief, salt (sodium chloride) does not actually cause corrosion of iron. It does, however, speed up corrosion once it starts. This is because salt is an electrolyte that helps the rusting process along. The combination of road salt and saltwater spray off the ocean affects both the bodies of cars and the metal supports of bridges.

LEARNING TIP

Electrolytes

In Chapter 5, you learned that electrolytes are compounds that, when dissolved in water, conduct electricity.

Preventing Corrosion

Several strategies are used to prevent corrosion in various situations. Some are more effective than others, but none are perfect. These strategies can be divided into three categories: using corrosion-resistant materials, protective coatings, and galvanizing.

Protective Coatings

A simple way to prevent corrosion is to cover the metal with a rust-inhibiting paint, chrome, or plastic coating. This strategy works well on above-ground structures provided that the metal remains completely covered. However, once the coating is chipped or scratched, corrosion is inevitable (Figure 2).

Figure 2 This bridge, spanning Halifax Harbour, is exposed to all the factors that speed up corrosion. It requires constant care to keep it corrosion-free.

DID YOU KNOW?

The Eiffel Tower

The world-famous icon of France is an iron tower. Preventing the Eiffel Tower from rusting requires the application of 50 to 60 tonnes of paint every seven years.

Corrosion-Resistant Materials

A straightforward way of preventing corrosion is to use materials that do not rust. For example, decades ago, car bumpers were made out of steel, which tended to rust if they became dented or scratched. Today, most bumpers are made of plastic. Plastic does not corrode and is lighter than steel. This helps reduce the overall weight of the car and improve fuel efficiency.

If steel is the only appropriate material for a specific object, improving its corrosion resistance will be an advantage. For example, the steel used by the auto industry today has more corrosion-resistant additives than ever before. New cars and bridges remain rust-free longer, even in Ontario's challenging winter conditions.

Many other corrosion-resistant alloys have been developed as well. An alloy is a metal produced by blending metals (and sometimes non-metals) in specific proportions. For example, most cutlery is made from stainless steel, an alloy of various elements, including iron, carbon, nickel, and chromium. Surgical-grade stainless steel, which is used to make medical tools and implants, contains enough chromium to make the steel corrosion-proof almost indefinitely (Figure 3).

Figure 3 This surgical implant is made of stainless steel, an alloy designed to resist corrosion inside the body.

galvanized steel steel that has been coated with a protective layer of zinc, which forms a hard, insoluble oxide

Galvanizing

Galvanized steel is steel that has been coated with a thin layer of zinc. Galvanizing protects steel because zinc corrodes before the iron in the steel does. As zinc corrodes, it forms a protective oxide layer that sticks to both the zinc layer and any steel that may be exposed. The corrosion protection remains intact even if there are nicks or scratches in the zinc layer. That is why galvanizing steel provides better rust protection than painting it (Figure 4).

READING TIP

Making Inferences

Think about what you already know to help you make inferences. For example, you might recall seeing rusted nails in an old wooden fence. You might also have seen a galvanized chain-link fence that has not rusted. Consequently, you infer that galvanized metal resists corrosion better than non-galvanized metal.

Figure 4 Galvanized steel is corrosion resistant and requires no maintenance.

IN SUMMARY

- Corrosion is the breakdown of a metal as it reacts with chemicals in the environment.
- Corrosion of some metals forms a tough protective layer that prevents further corrosion.
- Rusting is the corrosion of iron and steel. Rust does not form a protective layer but continues flaking away until the metal is severely damaged.
- Rusting occurs in the presence of oxygen and water and is made worse by electrolytes such as salt.
- Corrosion can be slowed or avoided by using corrosion-resistant materials, covering the metal with a protective layer (for example, paint), or galvanizing with zinc.

CHECK YOUR LEARNING TREATMENT

1. (a) Before reading about it in this section, what did you think rust was?
   (b) Describe similarities and differences between what you already knew about rust and what you learned about it as you read this section. K/U T/I
2. (a) In your own words, define "corrosion."
   (b) Describe the difference between corrosion and rusting. K/U
3. (a) What two substances react to form rust?
   (b) What other factors help rust form quickly? K/U
4. Consider an experiment in which an aluminum soft drink can and a steel soup can are left outside for a few days. Use your knowledge of the corrosion of steel and aluminum to predict how they would look different after a week exposed to rainy weather. Explain your prediction. K/U T/I
5. Why is it important for a car to be clean and dry before being treated with a rust-proofing product? A
6. A car design company predicts that the bodies of automobiles will last much longer in the islands of the Caribbean than in Canada. Explain this prediction. K/U A
7. Why is galvanized steel preferred for outdoor uses? K/U T/I A