6.2 Factors Affecting Reaction Rates

Figure 1 Small shavings of wood ignite more easily and burn much faster than a large log with much less surface area.

In the previous section, you learned how to determine average reaction rates and instantaneous reaction rates. When chemists study reaction rates, they carefully describe the conditions under which the reaction takes place. This is because there are many factors that can affect the rate of a chemical reaction, such as the chemical and physical characteristics of the reactant(s), the concentration of the reactant(s), and the temperature at which the reaction takes place. In some cases, the presence of a substance that is not directly involved in the reaction itself can alter the rate of a chemical reaction.

You have probably observed the effect of some of these factors in your daily life. For example, you have likely started a campfire or a fire in a wood-burning stove or fireplace at some point. A wood fire is actually a series of combustion reactions occurring at once. Wood is a complex substance made up of a number of different chemicals, each of which will burn at a different rate. The reactants in a wood fire are oxygen gas and gaseous substances released from wood. It is very difficult to light a fire if you start with a large log. Instead, you usually start with small bits of wood, known as kindling, and maybe some paper. The first combustion reaction occurs when you strike a match or light a lighter. This flame is applied to the kindling, heating it. When the kindling has reached a high enough temperature, some of the chemicals on the surface of the wood enter the gas phase, mix with oxygen in the air, and then begin to burn (**Figure 1**). As more kindling begins to burn, the temperature rises, which increases the rates of the combustion reactions. At some point, the fire will be hot enough that larger pieces of wood will burn readily. You may also change the rate of the combustion reaction if you adjust the position of the logs or blow on the fire. These actions increase the concentration of oxygen that is in contact with the surface of the wood.

Chemical Nature of the Reactants

The chemical nature of a pure substance gives it its chemical properties. A chemical property relates to the behaviour of a pure substance when it undergoes a chemical change or reaction. The tendency of a substance to undergo chemical reactions, such as combustion or oxidation reactions, is an example of a chemical property. The chemical properties of a substance can profoundly affect the reaction rate, as we can see by considering oxidation reactions and the metal elements. Some metals, such as sodium and potassium, are very reactive and react with oxygen (and other substances) so quickly that they are never found naturally in their elemental state. Other metals, such as platinum, gold, and silver, are generally unreactive and so oxidation occurs very slowly (**Figure 2**). This makes these metals ideal for use in jewellery and electronics.

Figure 2 (a) Sodium reacts quickly with oxygen and must be stored covered with mineral oil to avoid exposure to the air. (b) Copper reacts slowly with atmospheric oxygen, forming a layer of brown-black copper oxide. (c) Gold does not oxidize at room temperature—it is resistant to oxidation up to its melting point of 1064 °C.

Concentration of Reactants

You may have seen signs in hospitals warning about smoking or using flames where oxygen gas is in use. Why do you think that is? Oxygen makes up about 20 % of air, but the cylinders of compressed gas used to supply oxygen to patients can be 50 % oxygen gas or higher. These higher concentrations of oxygen gas cause combustion reactions to be rapid, violent, and even explosive.

The rate of many chemical reactions increases at higher concentrations of reactants. Zinc metal will produce zinc chloride and hydrogen gas when placed in a solution of hydrochloric acid (**Figure 3**):

$$Zn(s) + 2\ HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$$

Suppose you conducted an investigation in which you placed the same mass of zinc metal in increasingly concentrated solutions of hydrochloric acid. You would observe that the reaction rate was slow in dilute solutions of hydrochloric acid, where the concentration of this reactant was low. As the concentration of acid increased, so would the reaction rate.

Figure 3 In the reaction between zinc metal and hydrochloric acid, the rate of hydrogen gas formation will increase with the concentration of hydrochloric acid.

Surface Area

The rate of the chemical reaction between zinc metal and hydrochloric acid shown in Figure 3 could also be changed by modifying the zinc to expose more surface area. You could do this by cutting the mass into as many small pieces as possible. Similarly, 1 g of sugar will dissolve in water more quickly if added as powdered sugar than as sugar cubes. Notice that, in both of these examples, the reactants are in different states of matter (solid and liquid). For any reaction in which the reactants are in more than one state of matter, the greater the surface area of the solid, the faster the reaction rate. Since only the atoms or ions at the surface of a solid reactant can interact with other reactants, increasing the surface area of a solid reactant in effect increases its concentration. This is the main reason why kindling lights more quickly than a log. The rate of combustion of fine flour dust can be so rapid that it has caused explosions at flour mills. Workplaces that create fine particles such as flour dust are required to keep the dust under control for the safety of their workers. CAREER LINK

Investigation 6.2.1

Factors Affecting the Rate of Chemical Reactions (page 391)
Now that you have learned about the factors that may affect the rate of a chemical reaction, you will select a reaction to investigate and then evaluate factors that may increase the reaction rate.

Temperature of the Reaction System

In general, the rate of a chemical reaction increases with the temperature at which it is carried out. Chemists have found that the rates of many reactions double for every 10 °C increase in temperature and are halved for every 10 °C decrease. If you mix a bowl of cake batter and leave it sitting on the counter at room temperature for an hour, very little will change. However, if you put the batter in the oven at 175 °C for that same period of time, chemical reactions will occur within the batter that result in a baked cake. Alternatively, you store perishable food in the refrigerator to slow down chemical reactions that will cause the food to spoil (including the chemical reactions that support the growth of micro-organisms). Many packages of medications contain directions for storage in cool places away from heat sources for the same reason.

Cold-blooded animals such as amphibians and reptiles take on the temperature of their surroundings. They are less active during cool nights than warm days because their metabolic rates, or rates at which their bodies use energy, decrease as they lose thermal energy. The infrared image in **Figure 4** shows a cold-blooded animal, a snake, that is at the same cool temperature as its surroundings. This appears as dark blue to black on the infrared image. In contrast, the warm-blooded mouse that it is eating is at much higher temperature than the surroundings, so it appears bright yellow to orange.

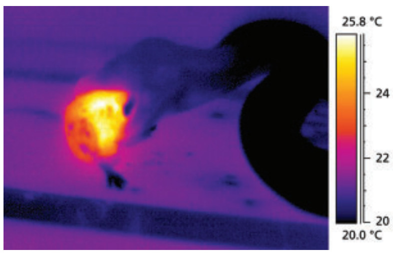

Figure 4 Notice the difference between the temperature of the mouse and the snake that is eating it. In contrast to warm-blooded animals, which maintain and regulate their own body temperature, cold-blooded animals cool down when the temperature of the surroundings drops. This lowers the rates of the chemical reactions that control muscle activity, causing the animal to become less active.

Presence of a Catalyst

catalyst a substance that alters the rate of a chemical reaction without itself being permanently changed

A **catalyst** is a substance that changes the rate of a chemical reaction but remains unchanged during the reaction. Thus, a catalyst can participate in the same reaction over and over again. Often only very small amounts of a catalyst are needed to increase the rate of a reaction.

UNIT TASK BOOKMARK

As you work on your Unit Task on page 402, consider all the different factors that can affect reaction rate.

Many industrial processes involve catalysts. For example, polyethene (also called polyethylene) is a polymer made by passing ethene gas over a metal catalyst. The metal catalyst speeds up the addition reaction that opens the double bond of ethene, allowing ethene molecules to join to make polyethene. Polyethene is used to make many things we use every day, including garbage bags, plastic wrap, squeeze bottles, and insulation for cables. Most other polymers, including synthetic rubber, nylon, polyester, PVC, and Teflon, are also made with the help of metal catalysts. Metal catalysts are used in the catalytic converters in vehicle exhaust systems that are used to reduce harmful pollution (**Figure 5**). They increase the rate at which exhaust gases react with oxygen so that more of the exhaust products will be oxidized into harmless or less harmful substances. Highly toxic carbon monoxide gas is oxidized to carbon dioxide, for example.

Most biological reactions rely on catalysts to allow them to proceed at high rates under moderate temperature. Catalysts produced by living organisms are called **biological catalysts** or biocatalysts. Most biological catalysts are large protein molecules called enzymes.

biological catalyst a catalyst made by a living system

Enzymes control most of the processes in living cells, so they are very important to health. For example, lactase is an enzyme which aids in the digestion of lactose, a sugar found in milk. Babies often have high amounts of lactase, while adults have much less. Someone with little or no lactase is lactose intolerant and has difficulty digesting milk.

Many industrial processes, including the manufacture of beer, yogurt, cheese, medicines, and enzyme-containing detergents, use biocatalysts (**Figure 6**). Most of these enzymes are produced by fermentation processes using bacteria, yeast, or moulds. Enzymes tend to be sensitive to temperature and pH, so much research has gone into finding ways to make enzymes capable of working under industrial conditions. The use of catalysts in industry can also reduce costly and environmentally harmful energy consumption by allowing reactions to proceed rapidly at relatively low temperatures.

heterogeneous catalyst a catalyst in a reaction in which the reactants and the catalyst are in different physical states

homogeneous catalyst a catalyst in a reaction in which the reactants and the catalyst are in the same physical state

Catalysts can be divided into two main types. A **heterogeneous catalyst** exists in a different state of matter from the reactants, usually as a solid. For example, in the polymer manufacturing process and the catalytic converters described previously, the metal catalyst is present in the solid phase, while the reactants are in the gas phase. A **homogeneous catalyst** is one that is in the same phase as the reactants, usually a gas or liquid phase. For example, enzymes and the reactants they catalyze are in aqueous solution, so enzymes are a type of homogenous catalyst.

Figure 5 A catalytic converter converts toxic exhaust emissions from an internal combustion engine into non-toxic substances. A thin layer of the metal catalyst is spread over a honeycomb lattice to increase the surface area of the catalyst, further increasing the reaction rate.

Figure 6 Enzymes called lipases help blue cheeses to ripen.

6.2 Review

Summary

- The rate of any reaction depends on the chemical nature and physical properties of the substances reacting.
- An increase in reactant concentration increases the rate of a reaction.
- When reactants are in different states of matter, an increase in reactant surface area increases the rate of a reaction.
- An increase in temperature increases the rate of a reaction.
- A catalyst increases reaction rate without being consumed in the reaction.
- Biological catalysts control most biological reactions, and most are enzymes.

Questions

1. In each example below, identify the factor that affects the reaction rate. K/U
   (a) Copper metal will turn green over time.
   (b) Milk can last several weeks when refrigerated, but will quickly sour at room temperature.
   (c) The dust in coal mines has been known to explode, whereas whole chunks of coal are difficult to ignite.
   (d) Magnesium metal is not used to make pipes.
   (e) Zeolite is added to large-chain hydrocarbons, causing them to break down into smaller, more useful molecules. The zeolite is then removed and reused.
   (f) Hydrogen peroxide (3 %) purchased in the drugstore is safe to put on open cuts. Hydrogen peroxide (30 %) purchased for the lab can cause very severe burns.
   (g) A glow stick will glow longer when placed in the freezer.
   (h) Signs warn about the dangers of having sparks or open flames near flammable fuels.
   (i) Flour mills ban smoking due to the high probability of explosions.
   (j) Phenylketonuria is a genetic disorder in which the body cannot produce the enzyme phenylalanine hydroxylase. People with this disorder cannot digest phenylalanine, a common amino acid.
2. Identify five different factors likely to affect reaction rate. Give an example of each from life outside your chemistry class that was not discussed in this section. K/U A
3. A research chemist wants to decrease the rate of a reaction by a factor of 4. How should she change the temperature to try to achieve this reduction in rate? Explain your answer. T/I
4. Digestive enzymes are present in very small quantities. Explain why they are not needed in large amounts, even though they are used by almost all biochemical processes in the body. A
5. If metal ores are mixed with carbon, they will react very slowly to produce elemental metal. What are two ways the rate of this reaction might be increased? A
6. A chemical called BHT (butylated hydroxytoluene or 2,6-di-tert-butyl-*p*-cresol) is found in many boxed foods, either in the food itself or in the packaging material (**Figure 7**).
   (a) Conduct research to find out how BHT affects chemical reaction rates. Relate this to its use in boxed foods.
   (b) Carry out a cost-benefit analysis of the use of BHT in the food industry. You may need to conduct additional research. Communicate your findings as an informative pamphlet suitable for distribution to the public. T/I C A

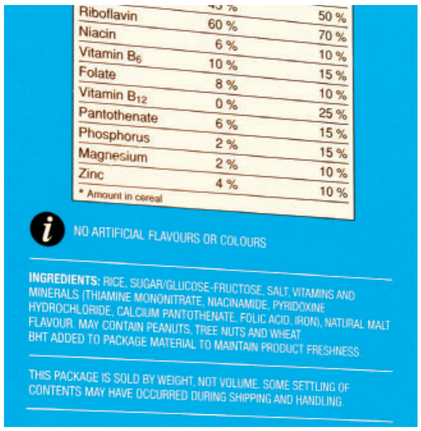

Figure 7 BHT is used in the packaging of this breakfast cereal.

WEB LINK