Kinetics

Just as it is useful to know which substances are formed from a given set of reactants, it is equally important to know how rapidly chemical reactions occur and to understand the factors that control their speeds. The area of chemistry concerned with the speed at which reactions occur is called **kinetics**.

Reaction Rates

The rate of a chemical reaction, or the reaction rate, is the rate at which reactants disappear and products appear. The amount of reactants and products is better described as the concentration of reactants and products. Thus, the **reaction rate** is the change in concentration of reactants and products in a certain amount of time.

The concentrations of the reactants and products in a chemical reaction are not directly observable. Instead, we typically observe how other properties change and then use those changes to determine the concentrations. There are a number of properties that can be observed in order to determine the rate of a reaction.

- Pressure
    - a change in pressure can be measured using a manometer or a gas syringe
    - this method is used when the reaction results in a change in the number of moles of gas present in the reaction chamber (resulting in a change in pressure)

- pH
    - pH is an indication of how acidic or basic a solution is
    - a pH meter can measure the change in pH over time
    - this data can be used to determine the concentration of hydrogen ions over time

- Color
    - a spectrometer can be used to measure the concentration of a reactant or product that absorbs or gives off light in a chemical reaction

- Temperature
    - temperature changes can be monitored with a thermometer

- Conductivity
    - electrodes can be placed in the reaction mixture to measure the increase or decrease in conductivity of the products
    - this method is usually used when nonionic reactants form ionic products

Calculating Reaction Rates

The rate of a chemical reaction cannot be calculated from the balanced chemical reaction. Instead, it must be determined experimentally. The rate of reaction can be found by measuring the concentration of a reactant or product at various times throughout the reaction.

Since concentration is expressed as molarity (M) or moles per liter (mol/L), the units used to measure reaction rates are usually molarity per second (M/s) or moles per liter per second ($mol/L \cdot s$).

Example 1
Consider the reaction below.

$$2NO_2(g) \rightarrow 2NO(g) + O_2(g)$$

Suppose a chemist begins with 0.040 $mol/L\ NO_2$ and measures the concentration every 5 seconds. The table below shows the recorded data.

Time (s)	$[NO_2]$ $(mol/L \cdot s)$
0	0.040
5.0	0.031
10.0	0.025
15.0	0.021
20.0	0.018

Using the formula below, determine the average reaction rate for each 5 second interval.

$$average\ rate\ of\ reaction = \frac{\Delta[reactant\ or\ product]}{\Delta t}$$

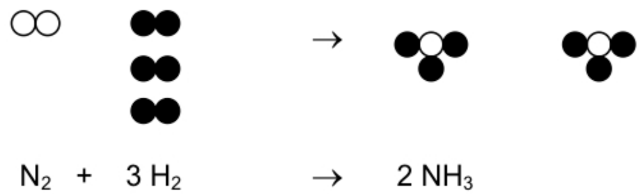
Reaction rates usually change throughout a chemical reaction. For this reason, the time interval between the two measurements must be small and the rate found is an average.

Reaction Rates and Stoichiometry

Consider the following reaction.

$$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$$

At the molecular level, this reaction would be expressed as shown below.



For every N_2 molecule that is consumed, 3 H_2 molecules will be consumed. This means that the rate of consumption of H_2 is three times the rate of consumption of N_2. Similarly, the rate of production of NH_3 is double the rate of consumption of N_2.

The individual rates can be expressed mathematically as

$$rate\ N_2 = x \qquad rate\ H_2 = 3x \qquad rate\ NH_3 = 2x$$

Where x is a factor that is common to each rate and the numbers are the coefficients from the balanced chemical equation.

If the rate of one of the compounds is known, then you can determine the rates of the other compounds by first finding the value of x.

Example 2
Consider the reaction $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$. If the hydrogen reacts at a rate of $1.5\ mol/L \cdot s$, what is the rate of production of ammonia (NH_3)?

It is also possible to determine how the rate of one compound in a reaction relates to the rate of any other compound in the same reaction.

Example 3

Consider the reaction $N_2(g)+3H_2(g)\rightarrow 2NH_3(g)$. How does the rate of disappearance of hydrogen compare to the rate of appearance of ammonia?

These comparisons are sometimes referred to as rate expressions.

Worksheet

1. State three examples of properties that could be used to measure a reaction rate.

2. What units are used to express reaction rate?

3. Consider the following reaction:

$$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$$

   a) How does the rate of disappearance of hydrogen compare to the rate of disappearance of nitrogen?

   b) How does the rate of production of ammonia compare to the rate of disappearance of nitrogen?

4. For the reaction shown below, it was found that the rate of consumption of B was $0.30\ mol/L \cdot s$.

$$2A + B \rightarrow 3C$$

   a) What was the rate of consumption of A?

   b) What was the rate of formation of C?

5. Consider the following reaction:

$$2N_2O_5(g) \rightarrow 4NO_2(g) + O_2(g)$$

   At a certain temperature, the rate of consumption of N_2O_5 is $2.5 \times 10^{-6}\ \text{mol}/L \cdot s$. How fast are NO_2 and O_2 being formed?

6. Write the rate expressions for the following reactions in terms of the disappearance of the reactants and the appearance of the products.

   a) $3O_2(g) \rightarrow 2O_3(g)$

   b) $4NH_3(g) + 5O_2(g) \rightarrow 4NO(g) + 6H_2O(g)$

   c) $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$

7. In a combustion reaction, 8.0 *mol* of methane gas reacts completely in a 2.0 *L* container containing excess oxygen gas in 3.2 *s*.

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$

a) Calculate the average rate of consumption of methane gas in $mol/L \cdot s$.

b) Calculate the average rate of consumption of oxygen gas in $mol/L \cdot s$.

c) Calculate the average rate of consumption of carbon dioxide gas in $mol/L \cdot s$.

d) Calculate the average rate of consumption of water vapor in $mol/L \cdot s$.

8. Hydrogen iodide and oxygen react to form iodine gas and water vapor, as shown below.

$$4HI(g) + O_2(g) \rightarrow 2I_2(g) + 2H_2O(g)$$

If oxygen gas is being consumed at a rate of 0.0042 $mol/L \cdot s$,

a) what is the rate of formation of iodine gas in $mol/L \cdot s$?

b) what is the rate of formation of water vapor in $mol/L \cdot s$?

c) what is the rate of formation of hydrogen iodide gas in $mol/L \cdot s$?

9. Consider the following reaction:

$$4NO_2(g) + O_2(g) \rightarrow 2N_2O_5(g)$$

If oxygen is being consumed at a rate of 0.024 $mol/L \cdot s$,

a) calculate the rate at which N_2O_5 is being formed.

b) calculate the rate at which NO_2 is being consumed.