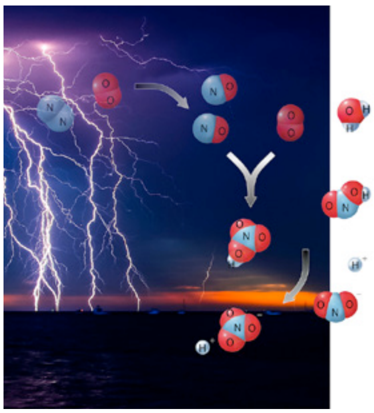
Chapter 9: Detailed Summary

How Chemicals React



The chemical equation shows the substances about to react, called the *reactants*, to the left of an arrow that points to the newly formed substances, called *products*. The products are made of the very same atoms that made up the reactants. As such, there are no new atoms…only new arrangements of those same atoms. The number of times each atom appears before the arrow, therefore, must be equal to the number of times it appears after the arrow. Such an equation is said to be *balanced*. To balance an equation requires changing the *coefficients* that may appear before the chemical formula for a reactant or product. The subscripts on a reactant or product must never be changed because that would be the creation of a new substance.

Chemistry is a lot like cooking. Both involve the measuring of ingredients that combine to form a product that is wholly different. Chemists, however, need to measure their ingredients not by the cupful but by the atom. It's impossible to count out individual atoms, however, so the chemist measures atoms in bulk. How then does the chemist know how many atoms there are in a given bulk of material? This is the topic of Sections 9.2 and 9.3, which discuss the concept of *relative mass*. By knowing the relative masses of atoms or molecules, the chemist is able to calculate the number of atoms or molecules within any given sample. The relative mass is the atomic mass, or *formula mass,* as found from the periodic table. The formula mass of H_2O, for example, is 18 amu, which tells us that 18 grams of H_2O contains 6.02×10^{23} molecules of H_2O, which is the same as 1 *mole* of H_2O.

All chemical reactions involve the input and output of energy. The input of energy allows for the breaking of chemical bonds within the reactants. As the new bonds of the products form, energy is then released. Different bonds, however, contain different amounts of energy. It might take, for example, 100 kJ to break the bonds of the reactants. The new bonds that form in the products, however, may release 150 kJ of energy. This reaction, therefore, produces a net release of 50 kJ of energy. A reaction that results in the net release of energy is *exothermic*; a reaction that results in the net absorption of energy is *endothermic*. We can use tables of bond energies to estimate the net amount of energy that a reaction might release or absorb.

Energy tends to disperse. It flows from where it is concentrated to where it is spread out. *Entropy* is a measure of this natural spreading of energy. Chemical reactions that lead to an overall dispersal (spreading) of energy are favored—they will tend to be self-sustaining, requiring no continual input of energy. An example is the combustion of a fuel. Conversely, reactions that lead to a concentration of energy tend not be self-sustaining. An example is the growth of a plant through photosynthesis—without the Sun, the plant dies.

In order for a reaction to occur, the atoms or molecules of reactants need to make contact, which is usually in the form of a collision. Not every impact, however, will result in the formation of products. First, the colliding molecules must be in the proper spatial orientation. Second, they must collide with sufficient force to break old bonds so that new bonds may be formed. These barriers may be overcome by increasing the concentration of the reactants or by increasing their temperature. These and other barriers to the formation of products give rise to the reaction's *activation energy*, which is the minimum energy that must be available in order for the reaction to progress forward to products. When the concentration or temperature of the reactants is increased, there is a greater proportion of reactant with sufficient energy to overcome this barrier. As a result, the *rate* at which products form increases.

Another way to increase the rate of a chemical reaction is to provide a catalyst. A *catalyst* functions by providing an alternative pathway for the reactants to follow in order to form products. Ozone, O_3, for example, doesn't readily transform into molecular oxygen, O_2, because of a relatively high activation energy. Ozone molecules, however, do readily react with chlorine atoms to form a by-product that decomposes into molecular oxygen. The chlorine is thus regenerated to catalyze the transformation of more ozone molecules. Chlorine in this case behaves as a catalyst in that it speeds up the rate of reaction and is itself regenerated to facilitate further chemical reactions.

Within the stratosphere is a region where ozone, O_3, is synthesized by the action of sunlight on oxygen, O_2. This region, known as the ozone layer, shields much of the Sun's ultraviolet rays from reaching Earth's surface, which is a good thing for most living creatures. In the 1970s, researchers discovered that chlorofluorocarbons released by humans were destroying the ozone layer, particularly over the Antarctic pole. International restrictions on the production and use of chlorofluorocarbons has resulted in decreases in atmospheric concentrations of chlorofluorocarbons. Even with these measures in place, however, residual atmospheric chlorofluorocarbons, with concomitant ozone depletion, will remain with us for centuries.

Chemical reactions can be reversible, which means as the reactants form products, the products can react to re-form the reactants. The extent of reversibility depends upon the reaction as well as the reaction conditions. A reaction that is readily reversible is the formation of N_2O_4 from two molecules of NO_2. When the forward and reverse reaction rates are equal, the number of reactants and products stays the same, which is a state called *chemical equilibrium*. As per *Le Chatelier's Principle*, a change in conditions can cause the reaction system to find a different equilibrium state.

Summary of Terms

Activation energy The minimum energy required in order for a chemical reaction to proceed.

Avogadro's number The number of particles—6.02 ´ 10^{23}—contained in 1 mole of anything.

Bond energy The amount of energy required to pull two bonded atoms apart, which is the same as the amount of energy released when the two atoms are brought together into a bond.

Catalyst Any substance that increases the rate of a chemical reaction without itself being consumed by the reaction.

Chemical equation A representation of a chemical reaction in which reactants are drawn before an arrow that points to the products.

Chemical equilibrium A state in which the forward and reverse rates of a reaction are equal.

Endothermic A term that describes a chemical reaction in which there is a net absorption of energy.

Entropy A measure of an amount of energy that has been dispersed. Wherever there is a spreading of energy, there is a corresponding *increase* in entropy.

Exothermic A term that describes a chemical reaction in which there is a net release of energy.

Formula mass The sum of the atomic masses of the elements in a chemical formula.

Law of mass conservation Matter is neither created nor destroyed during a chemical reaction—atoms merely rearrange, without any apparent loss or gain of mass, to form new molecules.

Le Chatelier's principle If a stress is applied to a system in chemical equilibrium, the system changes to relieve the stress.

Molar mass The mass of 1 mole of a substance.

Products The new materials formed in a chemical reaction.

Reactants The reacting substances in a chemical reaction.

Reaction rate A measure of how quickly the concentration of products in a chemical reaction increases or the concentration of reactants decreases.

Thermodynamics An area of science concerned with the role energy plays in chemical reactions and other energy dependent processes.