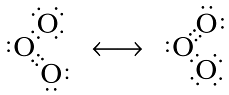
APPLICATION *The Environment*

Ozone

Ozone, O_3, is an allotrope of oxygen that is important for life on Earth. Like O_2, O_3 is a gas at room temperature. However, unlike O_2, O_3 is a poisonous bluish gas with an irritating odor at high concentrations. The triatomic ozone molecule is angular (bent) with a bond angle of about 116.5°. The O—O bonds in ozone are shorter and stronger than a single bond, but longer and weaker than a double bond. The ozone molecule is best represented by two resonance hybrid structures.



Ozone forms naturally in Earth's atmosphere more than 24 km above the Earth's surface in a layer called the stratosphere. There, O_2 molecules absorb energy from ultraviolet light and split into free oxygen atoms.

$$O_2(g) \xrightarrow{\text{ultraviolet light}} 2O$$

A free oxygen atom has an unpaired electron and is highly reactive. A chemical species that has one or more unpaired or unshared electrons is referred to as a *free radical*. A free radical is a short-lived fragment of a molecule. The oxygen free radical can react with a molecule of O_2 to produce an ozone molecule.

$$O + O_2(g) \longrightarrow O_3(g)$$

A molecule of O_3 can then absorb ultraviolet light and split to produce O_2 and a free oxygen atom.

$$O_3(g) \xrightarrow{\text{ultraviolet light}} O_2(g) + O$$

The production and breakdown of ozone in the stratosphere are examples of *photochemical* processes, in which light causes a chemical reaction.

In this way, O_3 is constantly formed and destroyed in the stratosphere, and its concentration is determined by the balance among these reactions. The breakdown of ozone absorbs the sun's intense ultraviolet light in the range of wavelengths between 290 nm and 320 nm. Light of these wavelengths damages and kills living cells, so if these wavelengths were to reach Earth's surface in large amounts, life would be impossible. Even now, the normal amount of ultraviolet light reaching Earth's surface is a major cause of skin cancer and the damage to DNA molecules that causes mutations. One life-form that is very sensitive to ultraviolet radiation is the phytoplankton in the oceans. These organisms carry out photosynthesis and are the first level of oceanic food webs.

Ozone and Air Pollution

Ozone in the lower atmosphere is a harmful pollutant. Ozone is highly reactive and can oxidize organic compounds. The products of these reactions are harmful substances that, when mixed with air, water vapor, and dust, make up *photochemical smog*. This mixture is the smog typically found in cities.

Typically, ozone is produced in a complex series of reactions involving unburned hydrocarbons and nitrogen oxides given off from engines in the form of exhaust and from fuel-burning power plants. When fuel burns explosively in the cylinder of an internal-combustion engine, some of the nitrogen in the cylinder also combines with oxygen to form NO, a very reactive nitrogen oxide free radical.

$$N_2(g) + O_2(g) \longrightarrow 2NO$$

When the free radical reaches the air, it reacts with oxygen to produce NO_2 radicals, which react with water in the air to produce HNO_3.

$$2NO + O_2(g) \longrightarrow 2NO_2$$
$$3NO_2 + H_2O(l) \longrightarrow NO + 2HNO_3(aq)$$

In sunlight, nitrogen dioxide decomposes to give nitric oxide and an atom of oxygen. Note that the NO produced is free to undergo the previous reaction once more.

$$NO_2 \xrightarrow{\text{sunlight}} NO + O$$

Just as it is in the stratosphere, a free oxygen atom in the lower atmosphere is highly reactive and reacts with a molecule of diatomic oxygen to form ozone.

$$O + O_2(g) \longrightarrow O_3(g)$$