Ozone in the Atmosphere

Why are we concerned with ozone? This simple molecule affects us in very important ways. It protects us, as well as all animals and plants on our planet, from the harm that ultraviolet radiation from the sun would cause. Ozone is a very reactive molecule and too much of it close to the ground causes damage to our lungs.

First, a little about its properties. Ozone, or O_3, is produced when elemental oxygen, O_2, is broken apart by an electric discharge or UV light. The sharp odor after a lightning storm is due to ozone. Ozone is much more reactive with other molecules than O_2. It is a gas with a slight blue color under normal conditions with a boiling point of -119 deg C and a melting point of -192.5 deg C. The solid has a dark blue-violet color.

While we examine the chemistry of ozone, we'll explore the bonding in simple molecules, the nature of energy, some key chemical reactions, and the energy changes caused by chemical reactions. Last time you reviewed Lewis structures and electronic bookkeeping. This is a simple but adequate bonding model that tells us about the number of bonds atoms can make and something about electron density in molecules. Today we'll have an overview of ozone. The next lectures concern different types of energy and the way light energy interacts with ozone.

Outline

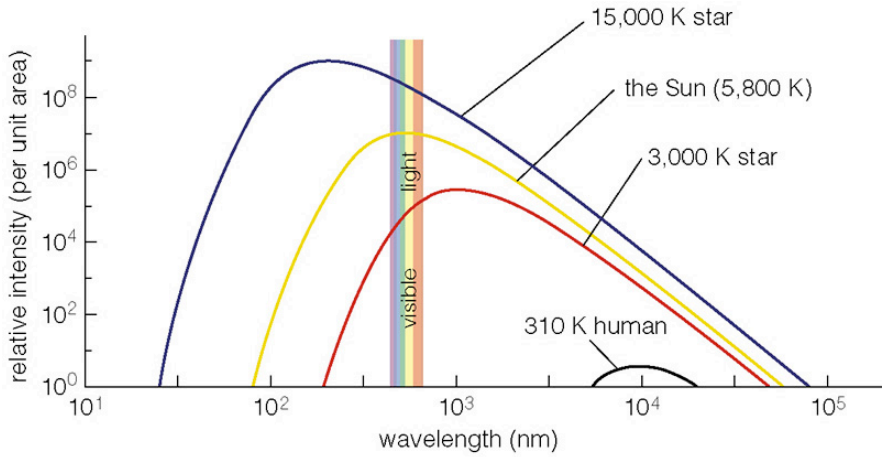
The Ozone Layer

The Solar Spectrum

To understand the importance of ozone in the atmosphere, we first must understand the nature of the energy that comes to us from the sun. The sun and other stars are very hot and so radiate energy. Specifically, we call this energy electromagnetic energy.

We can characterize electromagnetic radiation according to its wavelength. Remember that the energy of the radiation is inversely proportional to the wavelength.

$$E = hc/\lambda$$



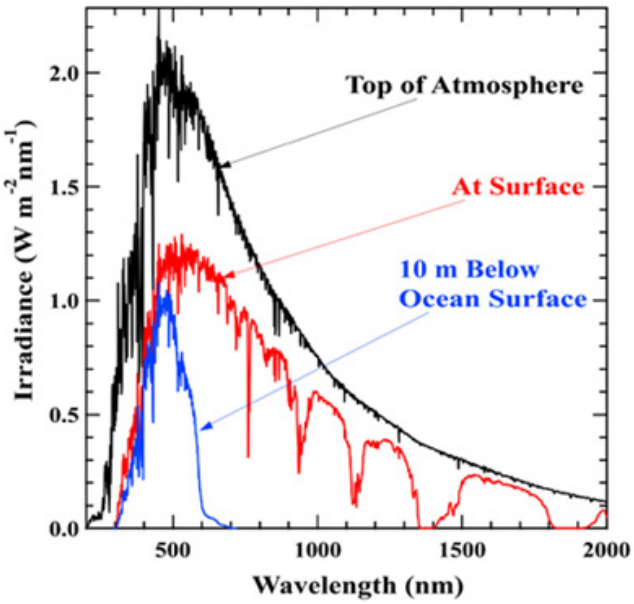
The shape of the intensity vs. wavelength curve depends on the temperature of the emitting object. The higher the temperature, the higher is the maximum intensity and the lower the wavelength of this maximum.

The maximum intensity of the sun's output of radiation is in the visible light region.

At the top of the atmosphere, approximately 7% of the radiation is in the ultraviolet, 41% in the visible, and 52% in the infrared.

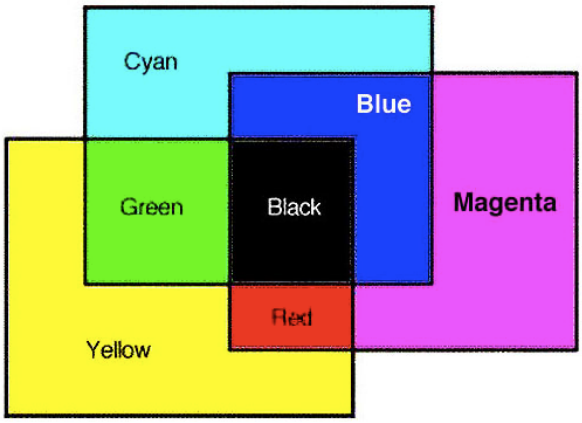
The intensity of electromagnetic radiation that reaches the surface of our planet is considerably less than that at the top of the atmosphere. Something in the atmosphere filters out energy. The highest energy light is most effectively filtered out.

This is very important because high energy light (gamma rays, x-rays, UV-radiation) penetrates the cells of living things and causes damage to them.



Molecular Filters

Consider the figure at right. The magenta filter blocks some wavelength of light, the cyan and yellow filter block others. When the 3 filters are combined, all wavelengths of visible light are blocked and the color appears black.



The atmosphere consists of many molecular and atomic filters that each block a certain range of wavelengths of light. With the combined effect of all of these, most of the harmful radiation from the sun is blocked before it reaches the plants and animals on the surface of the Earth.

In the highest region of the atmosphere, the ionosphere, atoms such as N absorb very high energy light and lose electrons.

$$N + \text{energy} \longrightarrow N^+ + e^-$$

Below that, in the mesosphere, strongly-bonded molecules such as N_2 absorb energy and break apart.

$$N_2 + \text{energy} \longrightarrow 2\ N$$

Below that, in the stratosphere, ozone absorbs nearly all the ultraviolet radiation (between 200 and 310 nm).

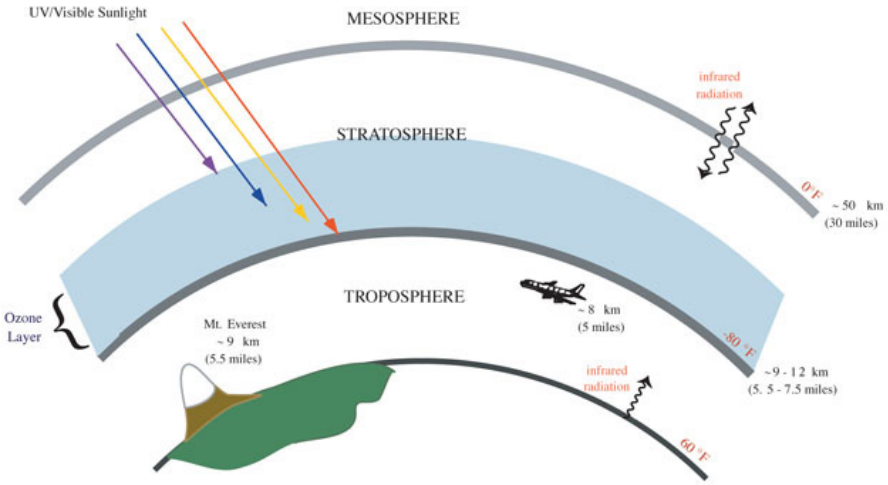
In the lowest region of the atmosphere, the troposphere, colored molecules absorb some visible light and other molecules (H_2O, CO_2) absorb infrared or heat energy.

Ozone in the Stratosphere

Ozone has a low concentration throughout the atmosphere but there is a region in the stratosphere where its concentration is higher than anywhere else. About 90% of the ozone in the atmosphere is located within a band centered at 25 km above the surface.

Ozone's concentration within the ozone layer is 0.2 to 0.4 ppm. Typical concentrations in unpolluted air closer to the surface is 0.03 ppm.

The ozone in the ozone layer absorbs 97-99% of all the ultraviolet light that passes into the stratosphere.



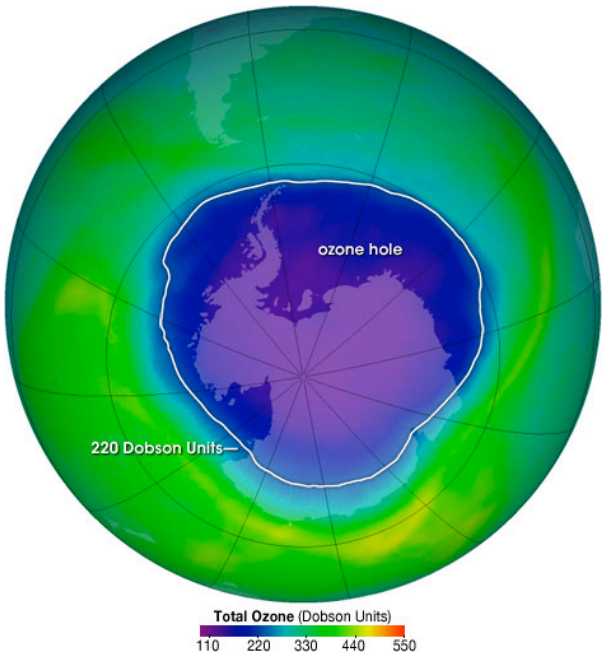
The Ozone Hole

Until recently, the concentration of ozone in the stratosphere was nearly constant. However, man-make chemicals such as the FREON used in refrigerators and air conditioners destroy it.

Over the course of the winter, reactive molecules build up in stratospheric clouds over the poles. The light and heat of the early spring causes these molecules to combine with ozone, resulting in a hole in the ozone layer.

UV radiation can reach the Earth's surface under this hole in the protective ozone layer.

International treaties are now limiting the amount of ozone-damaging chemicals that are released.



Ozone and Smog

Ozone and Health

Ozone in the stratosphere protects us from dangerous UV radiation but ozone close to the Earth is toxic to both animals and plants.

People exposed to ozone develop respiratory symptoms (coughing, throat irritation, wheezing) and loss of some lung function. People with asthma, older adults, and infants are particularly sensitive. Long-term exposure to ozone may cause people to develop asthma.

Air Quality and Smog

As you drive from Champaign-Urbana towards Chicago you see a brown layer on the horizon. It is worse in the summer than in the winter. Once you arrive in the city, you might notice some odor or irritation to your lungs and it's harder to exercise. Plants don't seem to grow as well as they do back in Champaign-Urbana.

What is the cause of all this? It is **photochemical smog**.

Geography also plays a role. In Chicago, the "windy city", the smog never gets as bad as it does in Los Angeles because the winds from across the plains dilute it. The Los Angeles basin holds the air above LA and prevents the smog from dissipating.

Photochemical smog is a mixture of many organic and inorganic gas phase molecules. It contains ozone, nitrogen oxides, and organic molecules. Typically, we estimate the amount of smog by measuring the concentration of one component, ozone.

Smog is:

- Toxic to plants and animals
- Decreases photosynthesis activity by ~50%s
- Responsible for 10-40% yearly loss in the growth of crops outside the cities
- Responsible for a 50% loss of trees in Los Angeles area

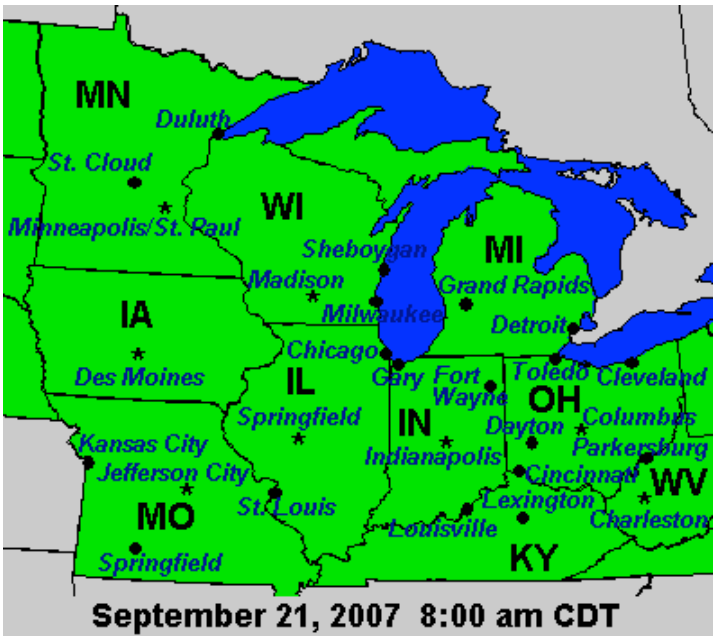
What is needed to form smog?

1. volatile organic molecules from internal combustion engines or power plants
2. nitrogen oxides from internal combustion engines or power plants
3. sunlight
4. oxygen

The Air Quality Index is an index that is used to report daily air quality and the concentration of the five most common ambient air pollutants: ground-level ozone, particulate matter, carbon monoxide, sulfur dioxide, and nitrogen dioxide.

Air Quality Index (AQI) values	Levels of Health Concern	Colors
When the AQI is in this range:	...air quality conditions are:	...as symbolized by this color:
0 to 50	Good	Green
51 to 100	Moderate	Yellow
101 to 150	Unhealthy for Sensitive Groups	Orange
151 to 200	Unhealthy	Red
201 to 300	Very Unhealthy	Purple
301 to 500	Hazardous	Maroon

The ozone level changes day-to-day. You can check the level today on the ozone map. Note that the ozone level goes up through the day and is reduced at night. Metropolitan areas on the east and west coasts of the US typically have a higher ozone level than we do in central Illinois. A picture from a day in 2007 is shown below.



Industrial Applications of Ozone

Wastewater Disinfection

Ozone kills many bacteria, protozoa, and viruses that cause disease in humans. It destroys the cell walls of the organisms, reacts with many molecules within the cell, and damages nucleic acids in the nucleus.

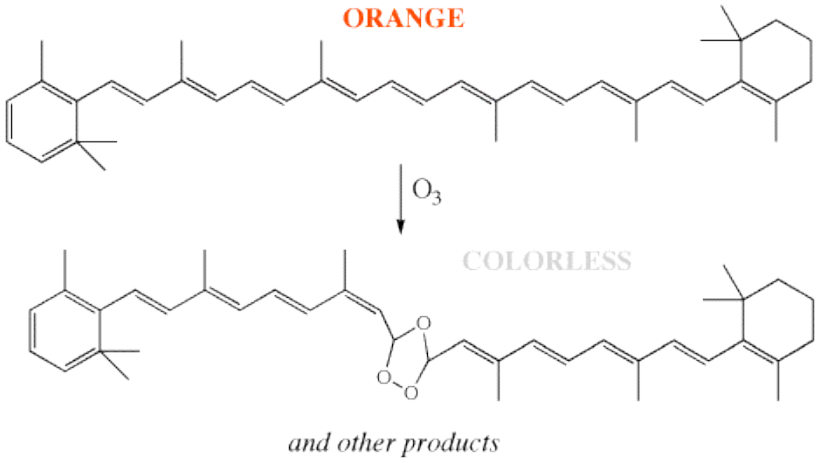
For wastewater treatment, ozone is generated on site by passing an electric discharge through oxygen or air.

Ozone is more effective than chlorine for wastewater treatment but it is expensive, the gas is toxic and corrosive, and it doesn't work well when the water has high levels of suspended solids.

Bleaching

The color in colored materials is often due to conjugated carbon-carbon double bonds in the molecules that make it up. A conjugated molecule has carbon-carbon double bonds alternating with carbon-carbon single bonds.

Ozone adds to some of the carbon-carbon double bonds and eliminates the color.



and other products

Using ozone as a bleach can be better for the environment than bleaches like Clorox (NaOCl) because it doesn't add harmful byproducts in water.

Chemical Synthesis: Ozonolysis

Ozone reacts with carbon-carbon double bonds. In combination with other reactants, it adds oxygen and breaks these bonds. Ozonolysis is an important step in the synthesis of many pharmaceutical agents.

Ozone reacts with the double bond in this molecule. After several steps (not shown here) a new molecule with a C-OH unit is formed. Molecules that have carbon connected to OH groups are called alcohols.

In this example, ozone again reacts with a carbon-carbon double bond. After additional steps, the product of the reaction is a new molecule with a CHO unit. Molecules like this are called aldehydes.