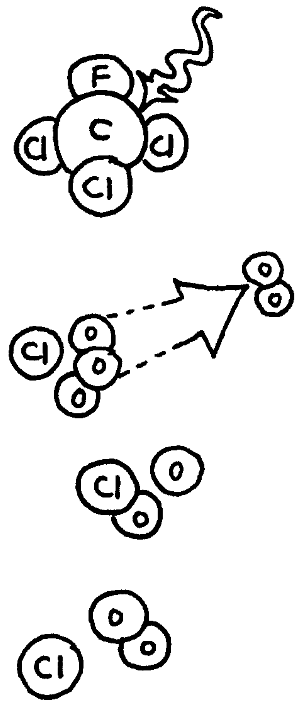
Ozone Models

Key Concepts

1. The close connection between atmosphere and ocean is an important factor influencing the health of our Ocean Planet.
2. Ozone is a part of the stratosphere that acts as a natural filter of ultraviolet (UV) radiation which is damaging to most life.
3. Ozone is being destroyed by compounds released into the atmosphere by human activities.



Background

The ocean and atmosphere are in close partnership on our Ocean Planet. The ocean's influence on weather patterns is well documented, while atmospheric winds influence large scale movements of ocean currents. Just as chemicals dumped into the ocean (such as oil spills) have biological effects beyond the site of the spill, chemicals "dumped" into the atmosphere may also have far-reaching effects on living things.

The atmosphere influences the heating and cooling of the planet by tempering the amount of the Sun's energy which reaches the Earth's surface and moderating the re-radiation of that energy into space. It "filters" solar radiation, allowing infrared (heat) and visible light energy to reach the Earth's surface while blocking ultraviolet (UV) rays which are damaging to most life forms.

Ozone, a component of part of the upper atmosphere (the stratosphere) that acts as a natural screen for ultraviolet radiation, is being destroyed by human-made compounds. In 1992, concentrations of this gas over the Antarctic reached their lowest levels since measuring began in the 1960's. Scientists estimated an area of depleted ozone in the Antarctic that is larger than the United States and deep enough to hold Mount Everest.

If the depletion of the ozone layer in the stratosphere continues, increases in UV radiation reaching Earth's surface will be a serious concern. Plants and animals would be affected. Even the tiny planktonic plants (phytoplankton) in the ocean might be destroyed by an increase in UV radiation. Large-scale destruction of phytoplankton could possibly decrease the amount of carbon dioxide (CO_2) that is removed from the atmosphere by photosynthesis, resulting in more CO_2, a greenhouse gas, in our atmosphere. Phytoplankton also serve as the base of the oceanic food chain, and changes in their populations could have serious environmental consequences.

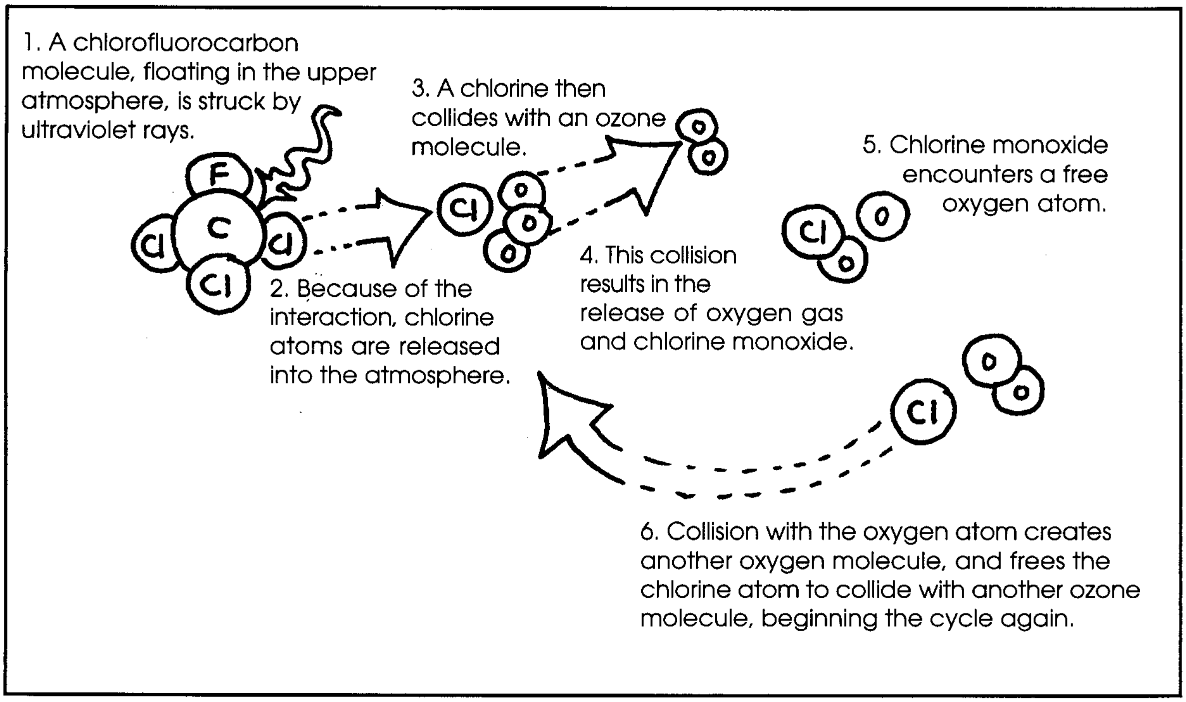
Although scientists are still gathering atmospheric data from NASA's Upper Atmosphere Research Satellite and other instruments to understand the problem better, they believe the severe ozone depletion in the Antarctic is linked to weather systems, low temperatures, the first light of the polar spring, and human-made chemicals.

To fully understand the problem, one needs to know more about ozone itself. A three-atom molecule of oxygen (O_3), ozone can be both good and bad for human life. In the troposphere - the layer of air we breathe - ozone is a health hazard. It is a primary component of smog, and is considered a greenhouse gas because it prevents heat from escaping into space.

Higher up in the stratosphere where 90% of the ozone resides, however, ozone forms a protective layer that blocks the Sun's ultraviolet radiation which is known to cause cataracts and skin cancer in humans, as well as damage to crops, forests, and phytoplankton.

Ozone molecules are constantly being produced and destroyed by natural chemical processes. Of particular concern, however, is the role of human-made chemicals - primarily halons, a class of chemicals used in fire extinguishers, and chlorofluorocarbons (CFCs), used as refrigerants and in plastic-foam manufacturing and aerosols.

Once these chemicals are released into the troposphere, they slowly migrate upward into the upper atmosphere or stratosphere. There the Sun's ultraviolet radiation initiates a process that decomposes these chemicals and releases chlorine atoms. It is known that chlorine destroys ozone in laboratory experiments. The illustration on the next page shows what scientists believe happens in the stratosphere:



Once the chlorine atom is released from the chlorofluorocarbon it becomes a catalyst, increasing the rate of degradation of the ozone while undergoing no permanent change in composition itself. This catalytic activity is particularly significant in the atmosphere over Antarctica because of a unique set of weather conditions called the polar vortex which acts as a circular wind jet, isolating air for weeks at a time. Because there is no influx of new air, the chlorine and other catalysts eat away at the ozone and a hole is created. Researchers have observed that if weather patterns disturb the flow of air within this whirlpool, the ozone hole doesn't get quite as large as it does under calm conditions.

Since its existence was discovered in 1985, the ozone hole has continued to concern scientists and the public. Scientists have yet to discover a similar hole over the North Pole, although ozone levels are declining in the Northern hemisphere as well as in the Southern, indicating the problem of ozone depletion is widespread and serious.

Materials

For each group of 4 students:

- small cup
- 10-15 white or yellow jelly beans (to represent oxygen atoms)
- 5 or 6 green jelly beans (to represent chlorine atoms)
- toothpicks (to represent the bonds between atoms)
- white poster paper
- crayons or colored pencils

Teaching Hints

In “Ozone Models” students build simple molecular models from jellybeans and toothpicks, then use the models to reproduce the steps in the chemical degradation of an ozone molecule.

Procedure:

1. Students will get the most out of this activity if they have at least a rudimentary knowledge of the structure of the molecules of oxygen, ozone and chlorine monoxide. If your students are unfamiliar with this material, provide a simple introduction such as the following. Say:

   For thousands of years, people wondered what were the “building blocks” of all the things we see around us. They coined the name “Atom” for what was originally thought to be the smallest particles making up an element. As it turned out, atoms are actually composed of protons, neutrons, and electrons (which, in turn, are composed of other things). Protons carry a positive electric charge, while neutrons carry no electric charge. Protons and neutrons form the nucleus, or center of the atom. Electrons, which carry a negative charge, revolve around the nucleus in a kind of electron cloud.

   Atoms can gain, lose, or share electrons. When atoms share electrons, bonds form between the atoms, and they become molecules. Molecules may be composed of atoms from the same element or atoms from different elements. For example, oxygen molecules (O_2), are made of 2 atoms of oxygen, but water molecules (H_2O), are made of 2 atoms of hydrogen and 1 atom of oxygen. The small number to the right of the chemical symbol tells how many atoms of each element are in the molecule.

   Scientists can, and do, measure many familiar gases in the atmosphere, such as ozone (O_3), oxygen (O_2), carbon dioxide (CO_2), and water vapor (H_2O). They also measure less well-known gases such as chlorine monoxide (ClO).

2. Introduce students to the process of ozone destruction by reproducing the diagram of "An Ozone Breakdown Cycle" on the board as you talk through the steps.

3. Divide your class into groups of 4 students.

4. Ask the groups to make a rough "comic strip" style sketch of what happens when chlorine destroys ozone, and how the cycle repeats itself. Have the students illustrate the atoms and the bonds between them to show the interactions. If generating a "comic strip" is a new concept to your class, you may need to talk them through it while drawing on the chalkboard.

5. Pass out the jelly beans and toothpicks to each group. Promise them they will have a chance to eat their models after they have completed the activity!

6. Tell the class that they will be using the candy and toothpicks to model the events that go on in the stratosphere during the destruction of ozone. Ask:

   What do you think the jelly beans and toothpicks represent in the model?

   (The jelly beans represent the atoms of oxygen, chlorine; and the toothpicks represent the bonds between atoms.)

7. Have students work in their groups to create a model for each step of the process.

8. After the models are complete, have students lay each model on the white poster paper and label it, showing the steps in this process of ozone destruction. They may choose to use the crayons to indicate interactions between the molecules.

   A possible scenario follows:

   Step 1: a "free" chlorine atom (green jelly bean)

   Step 2: an ozone molecule (O_3)

   Step 3: chlorine and ozone interact yielding an oxygen molecule (O_2) and chlorine monoxide (ClO) molecule.

   Step 4: free oxygen atom approaching the ClO molecule

   Step 5: the oxygen atom interacts with ClO yielding an oxygen molecule (O_2) and one free chlorine atom which is free to begin the cycle again.

9 . Display the posters of the labeled steps and ask the following questions as a review and wrap up for the activity.

Analysis and Interpretation Questions

1. What is one way chlorine gets into the stratosphere?

(Chlorine gets into the stratosphere from the upward drifting of man-made chemicals such as chlorofluorocarbons used in manufacturing and refrigerants.)

2. How can a single chlorine atom be so destructive to the Earth's ozone layer?

(Single chlorine atoms can be so destructive because they act as a catalyst and are continually "recycled", being regenerated when the chlorine monoxide bond is broken by an oxygen atom. The chlorine atom is then free to "steal" another oxygen atom from another ozone molecule and begin the process again.)

3. How might we reduce our impact on the ozone layer?

(Answers will vary. Use this question as a springboard to emphasize that the day-to-day choices we all make can have far-reaching consequences.)

Key Words

chlorine monoxide - a molecule composed of one atom of chlorine and one atom of oxygen which plays a role in the degradation of ozone; chlorine monoxide is formed when a chlorine atom strikes an ozone molecule, "stealing" one of the oxygen atoms and destroying the ozone.

ozone - a form of oxygen whose molecule is composed of three atoms of oxygen (O_3) and which is a powerful oxidizing agent and is therefore biologically corrosive; found mainly in the stratosphere where it absorbs ultraviolet rays thereby preventing them from reaching the Earth.

stratosphere - the region of the atmosphere (15-45 km up) extending up from the troposphere characterized by little vertical change in temperature; 90% of atmospheric ozone is in the stratosphere

troposphere - the lower portion of our atmosphere where weather exists (0-15 km high)

Extensions

1. Ask the students to model a chlorofluorocarbon ($CFCl_3$) molecule with their jelly beans and toothpicks.

"Ozone Models" is adapted from "Atmospheric Detectives" which may be found in the *Atlas 2 Teacher's Guide* available from: NASA Ames Teacher Resource Center; Moffett Field, CA 94035 and used here with permission.