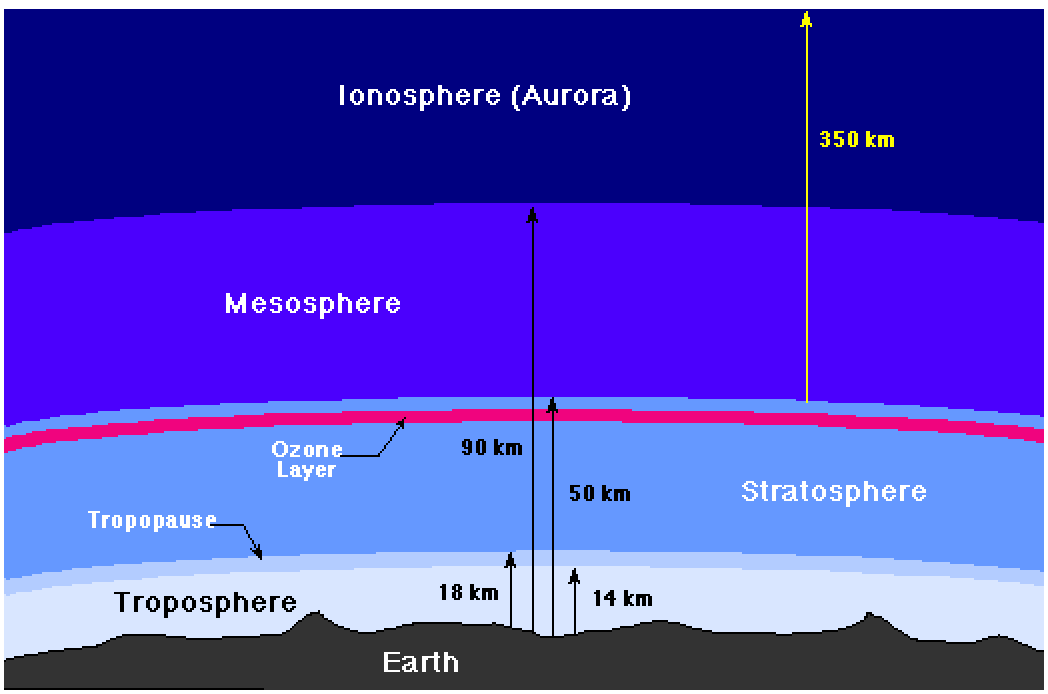
CHAPTER 16. OUR ATMOSPHERE

The Atmosphere and Its Importance

The earth is surrounded by a protective blanket of gases called the atmosphere. About 78% of the atmosphere is nitrogen; about 21% is oxygen. The remaining 1% is made up of a number of trace gases, including carbon dioxide, argon, and water. (The amount of water vapor may vary from 0.1 to 5% of the atmosphere.) The gases of the atmosphere are very important to the survival of life on earth. Oxygen is needed by people and animals. Carbon dioxide is required by plants, and nitrogen from the atmosphere when converted to other chemical forms is used by plants as fertilizer. Water which has evaporated from the oceans is carried in the atmosphere and falls to earth as rain. Ozone in the atmosphere shields us from cancer-causing ultraviolet radiation from the sun. The gases of the atmosphere also play an important role in maintaining the heat balance of the earth. Carbon dioxide and other gases absorb or trap infrared radiation, causing a warm layer of air near the earth. If we did not have the atmosphere, the earth's surface at night would be much too cold for life to survive.



Major Regions of the Atmosphere

The layer of the atmosphere nearest the earth, extending up to about 11 kilometers, is called the troposphere. Most of the gases which make up the air are found near the surface of the earth; the air pressure decreases rapidly with increasing altitude. Jet airplanes normally fly about 8 to 10 kilometers high. At that altitude, though it is still in the troposphere, the air is so thin that the planes must have oxygen masks for each passenger in case the pressure system should fail. People who hike to the top of high mountains may notice they tire more easily as the thinning atmosphere provides less oxygen. They notice also that the temperature is cooler on top of the mountain even in the summer, for they have left the warmer, lower part of the troposphere.

The stratosphere is the layer of the atmosphere directly above the troposphere, extending from about 11 kilometers to 50 kilometers. Here the atmosphere is thinner; more than 99% of the earth's atmosphere lies below a 32-kilometer altitude. Above the stratosphere is the mesosphere, extending to about 80 kilometers, and finally the thermosphere comprises the outer fringe of the earth's atmosphere where it merges with outer space. If you look closely, you can see some of the layers of the atmosphere in this NASA photo taken in space.

The Ozone Layer

The lower stratosphere, from about 11 to 50 kilometers, is called the ozone layer because it holds much of the atmosphere's ozone.

What is ozone, and where does it come from? Oxygen is a molecule made up of two oxygen atoms. Some oxygen molecules in the stratosphere are broken up by high-energy ultraviolet radiation into oxygen atoms.

$$O_2 \xrightarrow{\text{ultraviolet radiation}} 2\,O$$

These highly reactive oxygen atoms react with oxygen molecules to form ozone, which has three oxygen atoms.

$$O + O_2 \text{ -------------->} \; O_3$$

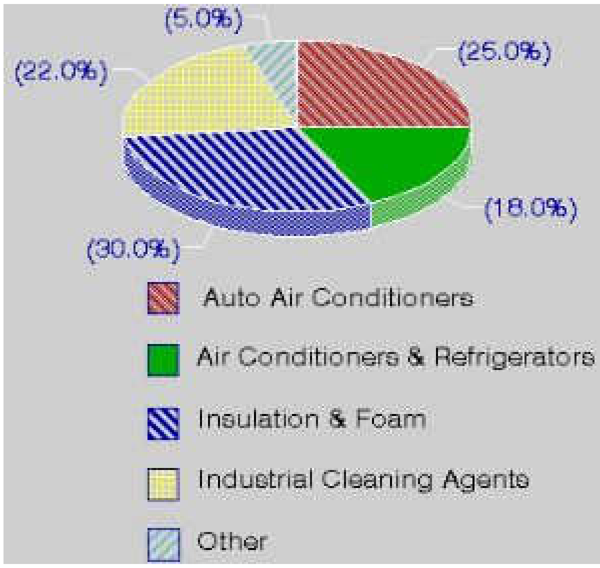
The ozone molecule absorbs ultraviolet radiation (uv); the high energy of the uv radiation breaks up the ozone molecule into an oxygen molecule and an oxygen atom.

$$O_3 \xrightarrow{\text{ultraviolet radiation}} O_2 + O$$

So ozone is constantly being created and destroyed in the ozone layer, and ultraviolet radiation is consumed in each process. Until very recently these processes balanced out, and the amount of ozone remained constant. People living on the surface of the earth were protected from damaging ultraviolet radiation by the chemical reactions taking place in the ozone layer because the ultraviolet radiation is "used up" in these chemical reactions.

Satellite data show that the ozone layer has been thinning at a rate of 0.5% per year since 1978. For each 1% decrease in the ozone layer, the U.S. National Research Council predicts a 2 to 5% increase in skin cancer. Populations nearest the North and South Poles are most at risk. A study of people living at the most southern part of Chile has shown a 56% increase in the deadly skin cancer melanoma over a seven-year period, and a 46% increase in other skin cancers. Crops such as corn, rice, and wheat may be affected, as well as animals and other plants. All these effects are predicted to occur as the DNA in human, plant, and animal cells is damaged by the increasing amounts of high-energy ultraviolet radiation. Why has the ozone been disappearing?

Chemicals called chlorofluorocarbons, or CFC's, have been shown to react with ozone and destroy it; these chemicals, which were among the organic compounds discussed in Chapter 12, contain chlorine, fluorine, and carbon atoms. In the 1970's CFC's were widely used as aerosol propellants, the gases inside spray cans that push out the contents, such as hair spray and deodorant. CFC’s were also used as the refrigerants in the coils of air conditioners and refrigerators.. When the refrigerators and air conditioners are disposed of or when the coils leak, the CFC's escape into the atmosphere.



Although CFC's are normally unreactive, if they encounter the high-energy ultraviolet radiation of the stratosphere, a chlorine atom can be broken off. Using the compound called Freon 12 with the formula CCl_2F_2 as an example, the following reaction occurs.

$$CCl_2F_2 \xrightarrow{\text{ultraviolet radiation}} CClF_2 + Cl$$

A chlorine atom is very reactive, and if one encounters an ozone molecule, they will react together , destroying the ozone molecule:

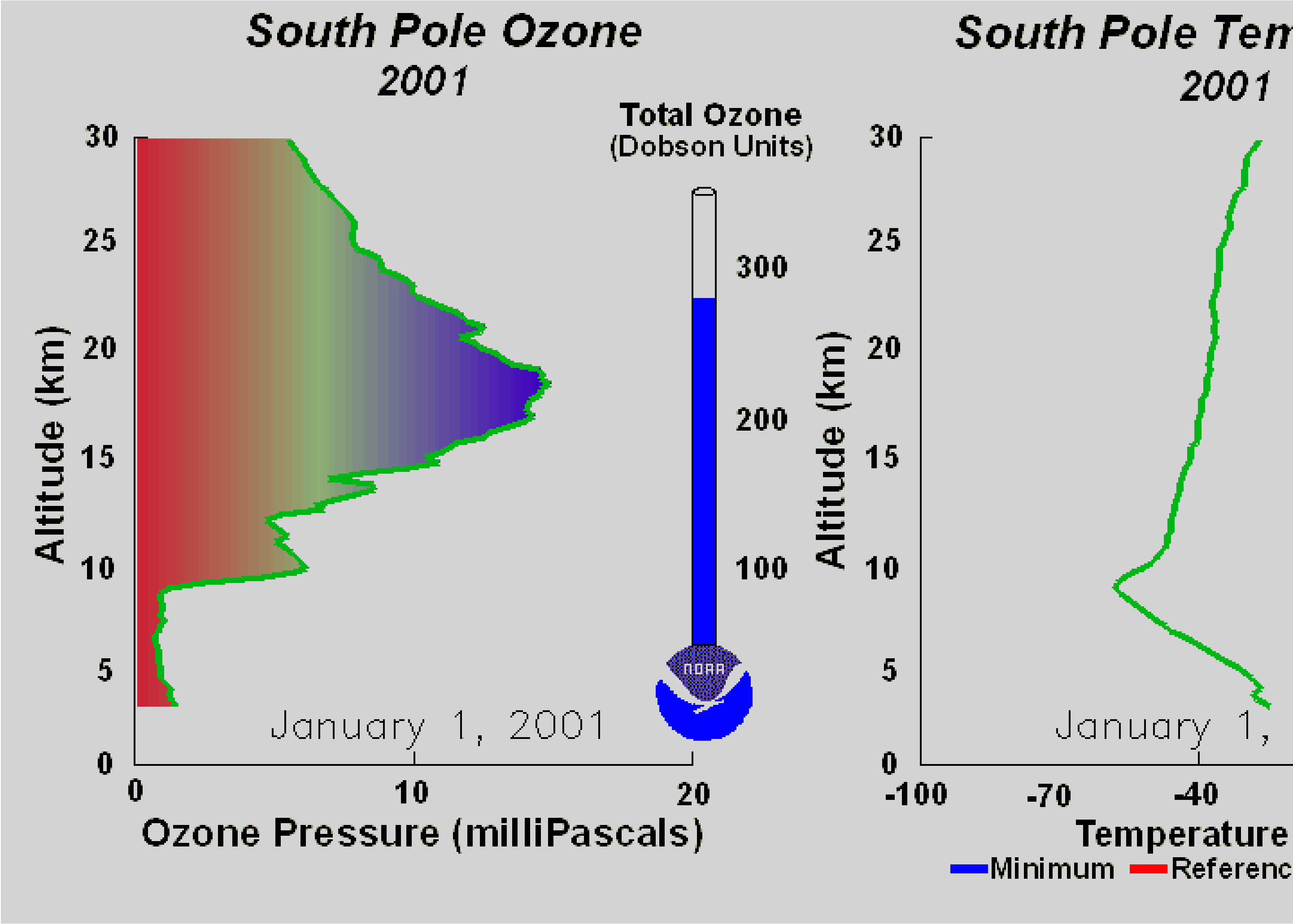
$$Cl + O_3 \longrightarrow ClO + O_2$$

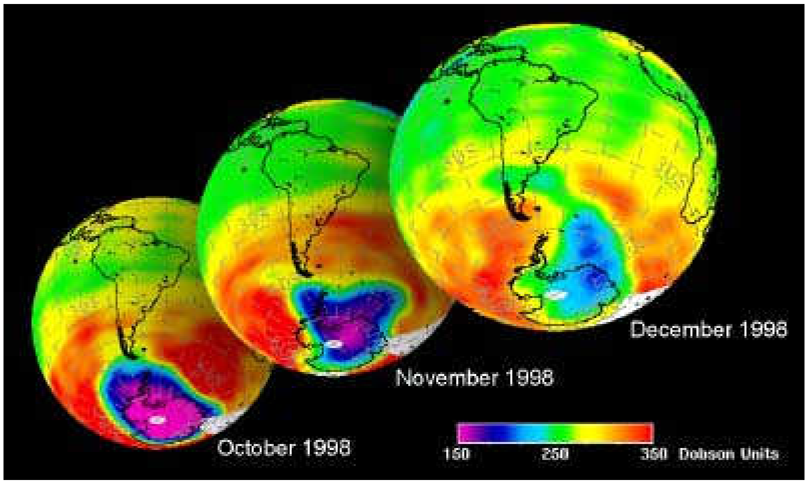
The ClO molecule is quite reactive also, and look what can happen if it encounters an oxygen atom:

$$ClO + O \longrightarrow O_2 + Cl$$

Not only is an oxygen atom consumed, but another free chlorine atom is created, and it can go on to destroy more ozone. That is why it has been said that the chlorine from one CFC molecule can destroy many thousands of ozone molecules, as this series of "chain reactions" repeats over and over.

In 1978 because of predictions that CFC's would destroy the ozone layer the United States banned their use in aerosol spray cans. Canada, Sweden, Norway, and Denmark imposed similar bans. However, many countries continued unrestricted use of CFC's. And even in the U.S. CFC's were still used as refrigerants, sealed inside the coils of refrigerators and air conditioning units. In the Montreal Protocol of 1987, 24 nations, including the United States and the Soviet Union, agreed to reduce CFC production by 50% worldwide by 1999. Later international meetings moved up the timelines for a complete halt to CFC production, with a final deadline of 1996. The discovery that adding a hydrogen atom to a CFC molecule produced a molecule that would break up more easily and hence not build up in the stratosphere led to a whole new family of compounds that are now used as refrigerants and have replaced CFC's. But this may not be enough to prevent serious damage to the ozone layer. CFC's can remain in the atmosphere 40 to 110 years, depending on the type of CFC. Already an extreme thinning of the ozone layer has been observed at the South Pole, which forms a "hole" in the ozone layer at some times of the year. http://www.atmosphere.mpg.de/media/archive/1163.gif shows this fluctuating ozone hole as it was observed in 2001.

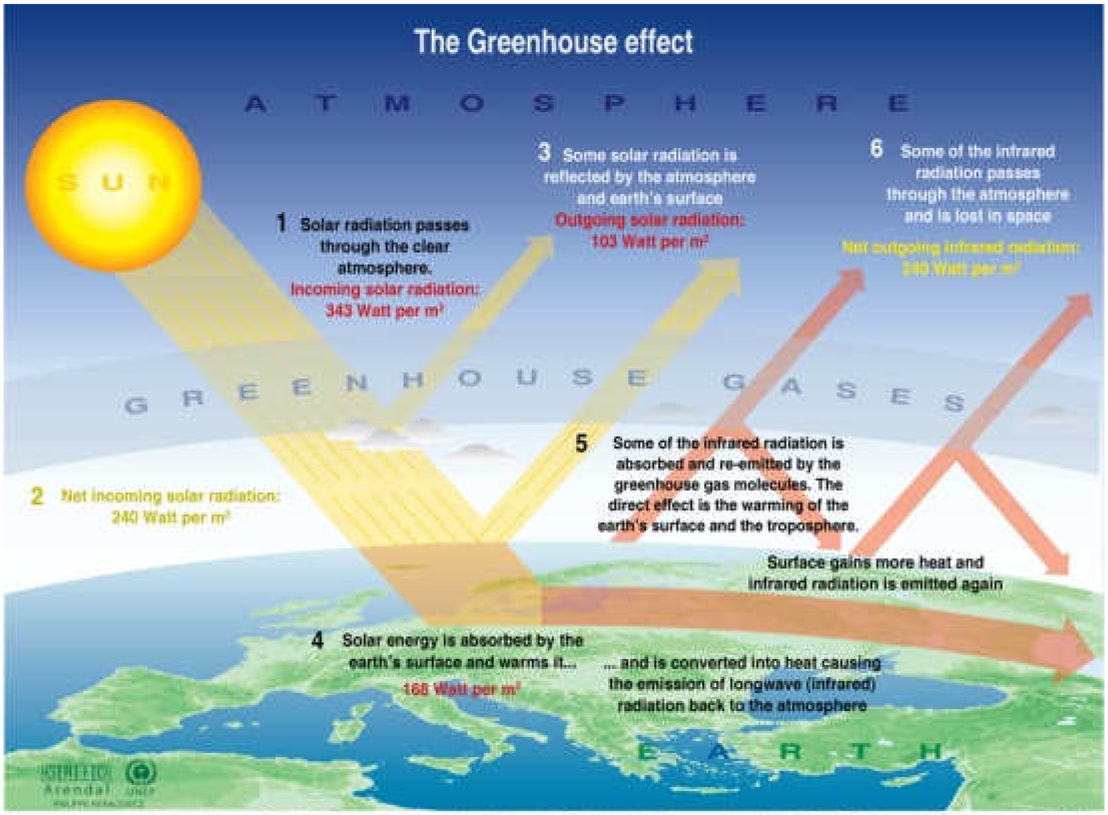




The white spot shows the ozone "hole" in 1998.

The Greenhouse Effect

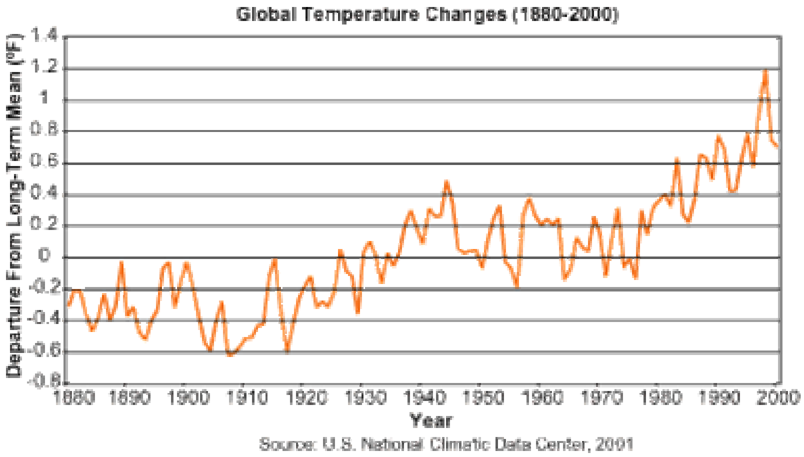
Burning any fuel, including coal, oil, natural gas, or gasoline, produces carbon dioxide, which has the property of absorbing infrared radiation. The energy of the visible light which the sun radiates upon the earth is absorbed by the earth's surface. Having lost some of its energy, it's no longer visible light, but is now energy of a longer wavelength and lower energy- infrared radiation, or heat.
http://www.atmosphere.mpg.de/enid/77f378e2ce112b4302d021e6920f2b10,0/2__Greenhouse__light___biosphere/-_Greenhouse_gases_236.html
Carbon dioxide molecules absorb much of this infrared radiation, because the molecular vibrations in the infrared energy range-
http://osxs.ch.liv.ac.uk/~ng/external/vibrationsCO2.htm so it remains as heat in the atmosphere instead of going out into space. Just as a greenhouse absorbs and traps the sun's heat, the carbon dioxide in the air traps the sun's heat and warms up the earth's atmosphere. A similar effect happens in a car outdoors on a sunny day with the windows up. The car's glass windows act like greenhouse windows, allowing the visible light energy to enter, but not allowing the infrared rays to escape. That trapped infrared radiation can create a very hot car seat!



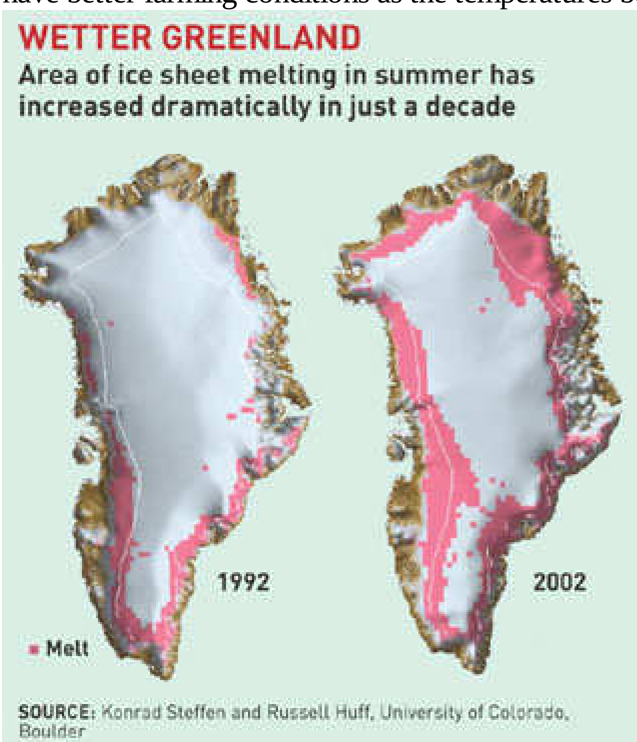
Sources: Okanagan university college in Canada, Department of geography, University of Oxford, school of geography; United States Environmental Protection Agency (EPA), Washington; Climate change 1995, The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge university press, 1996.

Carbon dioxide is a natural and necessary component in the earth's atmosphere. Plants need carbon dioxide as a major building block in the photosynthesis process, and carbon dioxide plays an important role in maintaining the earth's heat balance. But in the last 200 years, since the beginning of the Industrial Revolution, man has upset the balance of nature. We have been burning fossil fuels at an ever-increasing pace. The fuels we burn to heat our homes and run our cars all produce great quantities of carbon dioxide. Much of the electricity we use comes from power plants that burn fossil fuels to produce electrical energy.

Though average global temperatures vary slightly from year to year, it does appear that between 1880 and 1980 the earth's average temperature may have risen by as much as half a degree Celsius, or almost a degree Fahrenheit. This may seem like a small change, but the warming trend is accelerating as carbon dioxide production continues to increase, and as the world's forests that consume carbon dioxide in the photosynthesis process continue to disappear under the pressures of development now.



And even very small temperature changes can have a major impact on the earth. The warming effect on the polar icecap is projected to produce enough melting to raise the level of the oceans by a foot by the year 2100. Eventually, many of our coastal cities might be under water. The force of hurricanes may increase substantially as the earth warms, further eroding the coastline. Inland areas like Kansas and Nebraska may begin to be more like deserts in the new climate. But Canada and Russia would have better farming conditions as the temperatures become warmer



If increasing levels of carbon dioxide are producing the global warming effect that we observe, then scientists predict that the stratosphere would become colder as the troposphere becomes warmer- and that is exactly the trend that is now being observed. Unfortunately, cold temperatures in the stratosphere favor the reactions in which CFC's destroy ozone in the stratosphere. Hence global warming will also tend to reinforce stratospheric ozone depletion.

The issue of global warming and its relation to carbon dioxide levels is very complex. Other gases contribute to the warming effect as well, including CFC's, methane, and nitrogen oxides. The haze of particulates, or smoke, that is another form of air pollution has a cooling effect as it shields the earth from sun, as evidenced by the effect on global temperature the year that the volcanic eruption of Mount Pinatubo in the Philippines blanketed the globe with a layer of volcanic ash in the atmosphere . But increasingly most scientists agree that the carbon dioxide problem is not only real but an immediate concern, and that factors that contribute to the greenhouse effect must be controlled as much as possible. A study released in 2007 on the foreign policy and national security implications of global climate change by the Center for a New American Security and the Center for Strategic and International Studies paints a dire picture of the consequences of the expected degree of global warming of an increase of 1.3 degrees C by 2040 , with massive population migrations, resource scarcity, and increased disease proliferation. It warns also of the possibility of a greater increase than this, with even more drastic consequences.http://www.cnas.org/attachments/contentmanagers/1278/AgeofConsequences_ExecSummary.pdf

Acid Precipitation and Its Causes

Pure, unpolluted rain has a pH of about 5.6. This slight acidity is caused mainly by dissolved carbon dioxide, which reacts with water in a reversible reaction to form carbonic acid, a weak acid. The earliest known measurement of precipitation pH in the United States was a value of 5.9, taken in Maine in 1939. By the mid-1960's pH values less than 5.6 were being recorded regularly East of the Mississippi. In the New York/New England region values of 4.4 were common by 1966. By 1979 the average mean pH of precipitation in New England was 4.4; in parts of New York State, Pennsylvania, and Ontario the value was 4.1. These numbers are averages of values which may vary considerably. One storm in Wheeling, West Virginia registered a pH of 1.5, equalling the dangerously corrosive acidity of battery acid. Statues are marred and metals corroded by this acid bath, and the accumulated acidity affects both the life in the aqueous systems of lakes and ponds and the health of plant life in the forests and cultivated fields.

Much of the acidity found in precipitation is caused by the presence of sulfuric acid. The chemistry of the origin of this acid is well understood. The element sulfur is present as a contaminant in coal, especially in soft coal, or bituminous coal, which is mined in the Northeastern and Midwestern United States, and contains about 2 to 3% sulfur. The anthracite coal mined in the Western States is much lower in sulfur. When the coal is burned or oxidized, the sulfur is oxidized as well, forming sulfur dioxide. The sulfur dioxide can be further oxidized to form sulfur trioxide, which combines with water vapor in the air to form sulfuric acid. The major processes involved can be represented by these simple chemical equations:

$$C + O_2 \rightarrow CO_2$$

$$S + O_2 \rightarrow SO_2$$

$$2SO_2 + O_2 \rightarrow 2SO_3$$

$$SO_3 + H_2O \rightarrow H_2SO_4$$

Sulfuric acid has been shown to be a major component of the acid precipitation that has caused damage to forests in Northern Europe and New England and has affected the ability of bodies of water in these areas, particularly in Scandinavia, to support aquatic life. But sulfur oxides are not the only cause of acid precipitation. Nitrogen oxides have been found as well. These originate in power plants and in the major source of air pollution in the United States, transportation. On the EPA website you can map the sources of sulfur dioxide and the total sulfur deposition for a number of years: http://epamap4.epa.gov/cmap/viewer.htm The data show significant sulfur deposition for each year, in an interesting pattern: the sulfur deposition does not occur in the same places as the power plants, but to the northeast of the sources as prevailing winds carry the pollution. Hence, northern Maine has no polluting power plants, but has significant sulfur deposition causing acid rain, originating in Midwest power plants.

Auto Exhaust Products in the Air We Breathe

By far the most popular means of transportation in the United States is the automobile. But we may be paying a heavy price for this form of transportation in the quality of the air we breathe. There is a long list of pollutants that have been associated with the internal combustion engine. First we will consider the nitrogen oxides.

Normally nitrogen, the major component of our atmosphere, is quite an unreactive molecule. But in the high temperatures of the internal combustion engine it reacts with the oxygen that is also present in the air to produce nitrogen oxides, compounds that contain nitrogen and oxygen. Because there are several nitrogen oxides, they are often referred to in a general way as NO_x, and their formation can be described in the unbalanced equation

$$N_2 + O_2 \longrightarrow NO_x$$

Nitrogen oxides can react with water to form acid in a similar way to the sulfur oxides. The end product, nitric acid or HNO_3, contributes to acid precipitation. Although the automobile is a major source of nitrogen oxides, it is not the only cause of nitric acid in the air. Combustion chambers in power plants can produce nitrogen oxides, and even in nature lightning provides the conditions for the oxidation of nitrogen.

$$N_2 + O_2 \xrightarrow{\text{lightning or high heat}} 2NO$$

$$2NO + O_2 \longrightarrow 2NO_2$$

$$3NO_2 + H_2O \longrightarrow 2HNO_3 + NO$$

The contribution to acid rain is not the only air pollution problem associated with the nitrogen oxides in auto exhaust. In combination with other exhaust products, NO_x is a major contributor to a potent and complex mixture which has been given the name of **photochemical smog.**

Not all the hydrocarbons pumped from the gas pump into the fuel tank are burned as fuel. Some escape into the air at the gasoline station; you can smell them when your tank is filled. Others escape into the atmosphere as incomplete combustion products. Hydrocarbons are themselves unhealthy to breathe. Most important, they are an ingredient in the brown chemical haze called photochemical smog.

The complex nature of this important form of air pollution was discovered by accident by a chemist named Arie J. Haagen-Smit, who was attempting in his research at the California Institute of Technology to discover what chemical compounds were responsible for the flavor and aroma of pineapples. His method was to trap the volatile flavor compounds by condensing them in a container cooled by liquid nitrogen. But to his surprise, when he smelled the contents of the trap, it was not in the least fragrant; he had trapped the contents of the California air, and the results were dark brown with a decidedly unpleasant smell! Analyzing the contents of the material he was able to isolate in his cold trap, Dr. Haagen-Smit was the first to understand the nature of photochemical smog.

A distinctive component of the pungent aroma of the condensed smog was the highly reactive chemical ozone, which we have learned is present miles above the earth in the stratosphere. How, then, did it come to be found in the traffic of the troposphere? Under sunny conditions such as prevailed outside Dr. Haagen-Smit's laboratory in California, the sun's ultraviolet radiation is absorbed by nitrogen dioxide, which then breaks up into nitrogen oxide and an oxygen atom.

$$NO_2 \xrightarrow{\text{ultraviolet radiation}} NO + O$$

A single oxygen atom is highly reactive; those which encounter an oxygen molecule quickly react to form ozone, O_3.

$$O + O_2 \longrightarrow O_3$$

Ozone is a potent form of air pollution. A powerful oxidizing agent, it causes eye irritation even at low concentrations, and causes respiratory distress when air pollution levels are high. It is not uncommon for Los Angeles school children not to be allowed to play outside because of high ozone levels. But Los Angeles is not the only area with dangerous levels of ozone. Government recommended ozone levels are exceeded in many areas of the country, including even Acadia National Park in Maine during some summer weeks. Notice that in the stratosphere ozone is valuable to us because of its reactions that absorb ultraviolet light, but down in the troposphere where we live its high reactivity is very undesirable as it reacts with the tissue of our lungs!

The story of photochemical smog does not end with ozone. The ozone, nitrogen oxides, and hydrocarbons react further with each other to form a long list of compounds, including aldehydes such as formaldehyde and highly irritating compounds called peroxyacyl nitrates, or PANs. The overall effect of these pollutants which have resulted from the action of sunlight on car exhaust is a serious one, particularly on those people with heart or respiratory ailments.

Carbon Monoxide: Silent Killer

Often in the Boston area as in other cities in the northern United States, the newspaper stories seem to be taken from mystery novels: two married college professors found at home in bed- no longer alive. Four young people parked in an SUV in a state forest- all found dead. An elderly woman being dressed by her maid for a social event- both found dead. A policeman with a cup of coffee sitting in his car on a cold day- a corpse. These were not fictional characters from a science fiction novel or the victims of a serial killer. These are true stories of victims of the silent killer, carbon monoxide. In each case, combustion with an inadequate supply of oxygen produced carbon monoxide instead of carbon dioxide as the reaction product with deadly effect. In the case of the college professors and the elderly lady and her maid, the bedrooms were over the garage, and a car engine had been running with the garage door closed. The SUV tailpipe had been backed into a snowbank without the driver's knowledge. And the exhaust system of the police officer's car was leaking exhaust gases into the passenger compartment. To understand how these tragedies could have happened, we need to understand the chemistry of combustion and the biochemistry of our chemical oxygen carrier in the body, hemoglobin.

Gasoline burns with sufficient quantities of oxygen to produce water and carbon dioxide, as shown in the equation for the combustion of octane, a major gasoline component discussed in chapter 10:

$$2C_8H_{18} \quad + \quad 25O_2 \quad \text{--->} \quad 16CO_2 \quad + \quad 18H_2O$$

But if combustion is inefficient because insufficient oxygen is present, carbon monoxide, CO, is formed instead of carbon dioxide. Carbon monoxide has a particularly dangerous mode of poisoning the body by interfering with the body's oxygen supply. To understand why this is so it is necessary to understand how oxygen is supplied to the body. Oxygen, present as a component of the air that is breathed into the lungs, is taken into the body by reacting with a molecule in the blood called hemoglobin. The hemoglobin molecule is a complex one; its most important site is occupied by an iron (Fe) atom which is able to bond with the oxygen. Thus the oxygen is transported through the body in the bloodstream attached to the hemoglobin molecule. In this form the molecule is called oxyhemoglobin. The carbon monoxide molecule CO is similar enough to the O_2 molecule that the hemoglobin molecule will accept it in place of the oxygen molecule, forming a molecule with carbon monoxide bound to the Fe atom which is called carboxyhemoglobin. A hemoglobin molecule tied up in this way with carbon monoxide is not transporting needed oxygen to the body. To make matters worse, the bond of the carbon monoxide to the hemoglobin is quite strong, over 200 times as strong as the bond to oxygen. Thus, although the attachment to the hemoglobin is a reversible reaction, it is quite easy for the carboxyhemoglobin to build up in the body even when it is present at relatively low concentrations in the air. At levels as low as 100 ppm, a headache may result as carboxyhemoglobin levels build to levels as high as 20% and the oxygen supply to the brain begins to be affected. Levels of 1600 to 3000 ppm CO cause coma and possible death as over 50% of the hemoglobin is tied up as carboxyhemoglobin. Auto exhaust contains 1000 to 7000 ppm CO, so it is not surprising that drivers in heavy traffic may be exposed to CO levels of over 100 ppm.

Since the hazards of exposure to carbon monoxide can be so great, it is worthwhile to consider the properties of carbon monoxide. It is important to realize, for example, that carbon monoxide is a colorless, odorless gas. Hence it is possible to be exposed to CO without realizing it. Since the mechanism of toxic action involves interference with oxygen transport to the brain, symptoms include drowsiness and impaired judgment. It is likely, then, that someone affected by CO poisoning will not be able to recognize what is happening and take action to prevent further exposure. The victim will simply lose consciousness slowly. Deaths occur each year to people sitting in parked cars with the engine running; in these cases for a variety of reasons carbon monoxide from the exhaust system has found its way inside the car.

Automobiles are not the only source of carbon monoxide. CO production occurs whenever combustion takes place in the presence of insufficient oxygen. An improperly running furnace can be a source of carbon monoxide. Charcoal, which is mostly carbon, normally forms carbon dioxide when it is burned:

$$C + O_2 \longrightarrow CO_2$$

But if it is burned in an enclosed space, available oxygen will gradually be consumed, so that deadly carbon monoxide will begin to be formed:

$$2C + O_2 \longrightarrow 2CO$$

Another important source of carbon monoxide is cigarettes. Smoke from cigarettes contains between 200 and 400 ppm CO, and smokers suffer chronically from its toxic effects.

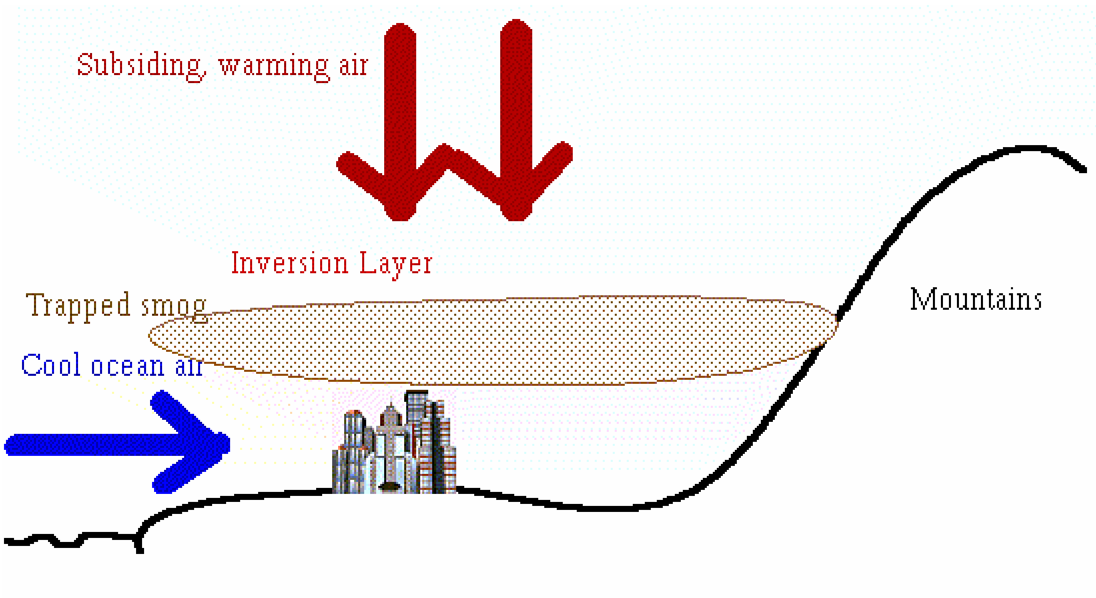
Particulates: Solids and Liquids We Breathe

There is another category of air pollution which is given the general name of **particulates**. These are tiny solid or liquid particles carried in the air we breathe. Particulates can be abrasive and harmful to the lung surface; the action on the body is determined by the particulate composition. **London smog** is a term which describes a form of air pollution common in London until recent years in which the air pollution caused by the extensive burning of coal released into the air a mixture of soot and fly ash particulates along with sulfur oxides. Combined with the naturally foggy air of London, these substances formed a dense, corrosive smog which at its worst was deadly. In one incident in December of 1952, 4000 people died over a five-day period in London from a severe smog episode; the final death toll including those who died later from its effects may have been twice as high.

Asbestos is a form of solid particulate matter with particularly damaging effects on the lungs. Asbestosis is a debilitating disease suffered by workers who have been exposed to asbestos products over a long period of time. The scarring of the lungs in asbestosis causes shortness of breath and fatigue and ultimately may lead to death. Mesothelioma is a cancer of the lungs or stomach lining caused by asbestos. The risk of lung cancer increases significantly on exposure to asbestos, although the cancer often does not develop until 15 to 35 years after exposure. Lung cancer is much more common in those workers exposed to asbestos who were cigarette smokers. This is an example of an important principle called **synergistic effect**, in which one substance enhances the effect of another. In this case the products of smoking have a synergistic effect with asbestos, greatly enhancing its ability to cause lung cancer. Asbestos products were widely used as building materials from the mid-forties to the early 1970's. Asbestos materials were used to fireproof, soundproof, and insulate. Because of concerns that the material might become friable, or flaky, and find its way into the air as particulate matter, as well as its effect upon construction workers, the Environmental Protective Agency in 1973 issued regulations banning the spraying of asbestos-containing insulation. In 1975 the regulation was expanded to prohibit any pipe insulation containing asbestos, regardless of the method of application. In 1978 all uses of asbestos were banned. Programs are underway to remove asbestos from school buildings. It is important, however, in asbestos removal not to release asbestos particles into the air during the removal process.

Weather and Air Pollution

Weather conditions can be a factor in the effect of air pollution. The movement, or lack of movement, of masses of air across the earth's surface can greatly influence the manner in which pollutants are distributed. One important weather pattern is the **atmospheric inversion or thermal inversion**, in which cool, dense air is trapped under a layer of warmer, lighter air. The normal upward-flowing air currents are prevented, and pollution accumulates. Atmospheric inversions can last from a few hours to a few days. They are most common in mountain valleys and coastal areas. Los Angeles, home of some of the worst photochemical smog, is located in an area prone to atmospheric inversions. The London smog which caused so many deaths in 1952 was the result of a temperature inversion.



The current distribution of acid precipitation in the United States is influenced by the pattern of prevailing winds. In order to comply with federal regulation of local emissions, electric power generating stations in the Midwest increased the height of the stacks which carry away emissions. From 1950 to 1980 the average stack height in the Ohio Valley increased from 320 feet to 740 feet, with the highest being over 1000 feet. While the effect on the immediate geographic area of these power plants has been an improvement in air quality, prevailing winds carry the emission plumes from these high stacks toward the Northeast, sometimes traveling 200 miles in a day. Hence areas affected by acid rain may be far from the generating source, and nonindustrial areas like northern New England and northeastern Canada may suffer most severely. Figure 6 shows the sites of the power plants that produce the highest emissions of sulfur dioxide and the areas of the United States most affected by acid rain.

Is There a Solution to Air Pollution?

As we have seen, air pollution is a complex phenomenon, involving varied substances and numerous sources. As solutions are proposed to the various problems air pollution has caused, it is necessary to understand those basic principles we have discussed in order to evaluate the proposals. The situation is far from hopeless. The Clean Air Acts of 1970 and 1977 have already resulted in some successes in producing cleaner air; sulfur dioxide and carbon monoxide have declined significantly since 1975 , although emissions targets have not been fully met. Tetraethyl lead was present as an additive in most gasoline prior to 1975, when EPA regulations began to phase out its use, as it deactivated platinum catalytic converters installed to reduce carbon monoxide and nitrogen oxide emissions.

Air quality improvements will not be achieved without costs. Instead of transferring sulfur dioxide emissions to other areas with high smokestacks, power plants can install scrubbers which can remove up to 90% of sulfur dioxide. Coal can be processed before it is burned to remove acid-forming impurities. But the sulfur-containing byproducts will have to be disposed of somehow. And costs for these processes will be passed on to consumers in the form of higher utility rates. If low-sulfur Western coal is burned in order to reduce sulfur oxide emissions, Eastern coal miners will pay by losing their jobs. Currently many power plants emit the neurotoxin mercury, which ends up in fish and finally in the bodies of those who eat the fish, yet government regulators decline to impose the costs on the power plants that would be required to eliminate mercury emissions.

The greenhouse effect is an especially intractable problem, because any burning of fossil fuels produces carbon dioxide. A variety of reasonable proposals are already being made, however, which will help slow down the warming trend caused by greenhouse gases. Any actions, such as home and factory insulation and gasoline-efficient cars, that decrease the use of fossil fuels will be helpful. The United States, which consumes one-fourth of the world's energy each year, is in a position to make a major impact through conservation measures. The development of improved solar energy technology, wind technology, and other technologies like geothermal energy will provide welcome energy alternatives. Political actions that encourage the retaining of forest land and reforestation efforts will help recover the carbon dioxide balance through the absorption of CO_2 in plant photosynthesis.

Scientists need to find alternatives to CFC's and fossil fuels, and technology for cleaner cars, factories, and power plants must be developed. But everyone has a role to play in limiting the wasteful use of scarce resources and in making intelligent consumer choices.

Web references:
Figures were taken from the following recommended web sites:
http://www.atmosphere.mpg.de/enid/9cfcd064ab773403be3151fb02e47d26,0/Service/Home_142.html
http://daphne.palomar.edu/calenvironment/smog.htm

CONCEPTS TO UNDERSTAND FROM CHAPTER 16

The earth is surrounded by a protective blanket of gases called the **atmosphere**.

The atmosphere is composed of different layers, or regions, each with distinctive composition and characteristics.

The ozone, O_3, molecules in the lower stratosphere absorb ultraviolet radiation from the sun. The thinning of the ozone layer has caused increases in skin cancer, and affects crop growth. Important among the chemicals which have been destroying the ozone layer are the CFC's, or compounds made of carbon, chlorine, and fluorine.

The **greenhouse effect**, or warming of the thermosphere near the earth's surface, is caused by the absorption of infrared radiation by molecules such as carbon dioxide. Increasing amounts of carbon dioxide caused by the burning of fossil fuels have caused an increase in temperature near the earth's surface. Other substances contributing to the greenhouse effect include CFC's, methane, and greenhouse gases.

Particulate air pollution has some cooling effect on the earth's temperature by screening it from the rays of the sun.

Normally, rain has a slightly acid pH of about 5.6 because of carbonic acid formed from dissolved carbon dioxide gas.

$$CO_2 + H_2O \text{ ---> } H_2CO_3$$

Rain in some areas, including the Northeastern U.S., Northern Europe, and Eastern Canada, has become much acidic because of the presence of sulfuric acid, a result of burning coal. This phenomenon is known as **acid rain**. Equations describing this process are as follows:

$$S + O_2 \text{ --> } SO_2$$

$$2SO_2 + O_2 \text{ --> } 2SO_3$$

$$SO_3 + H_2O \text{ --> } H_2SO_4$$

Nitrogen and oxygen from the atmosphere react in the internal combustion engine to form nitrogen oxides:

$$N_2 \quad + \quad O_2 \quad \text{-->} \quad NO_x$$

Nitrogen oxides react with water vapor in the air to form nitric acid, thus contributing to acid rain. They also react with other auto exhaust products in the presence of sunshine, to form **photochemical smog**. Among the components of photochemical smog is the highly reactive and hence unhealthy compound, ozone.

Carbon (such as in coal and charcoal) and hydrocarbons (such as in natural gas and gasoline) when burned in the presence of abundant oxygen produce carbon dioxide. When burned in the presence of limited oxygen they produce toxic carbon monoxide.

Carbon monoxide binds with hemoglobin in the blood in the same way as oxygen does. Its toxicity is the result of depriving the body of oxygen.

London smog is a type of air pollution which results from a combination of sulfuric acid and particulate material.

A **synergistic effect** results when one substance enhances the effect of another. An example of a synergistic effect is the enhanced ability of asbestos to cause lung cancer in smokers.

In a **thermal inversion**, cool, dense air is trapped under warmer air, concentrating air pollution.

Name___________________________ Date __________________
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CHAPTER 16 PROBLEMS

1. Sketch the layers of the atmosphere, labelling each one. Indicate with an arrow and the symbol O_3 where the ozone layer occurs. Indicate with another arrow and the symbol O_2 the layer where you think most of the oxygen in the atmosphere is found.

2. What are some sources of carbon dioxide in the atmosphere? Describe a negative effect of excess carbon dioxide.

3. What are some sources of carbon monoxide in the atmosphere? Describe a negative effect of carbon monoxide.

4. Write the following three equations which explain the formation of acid rain.

a. The equation for the oxidation of sulfur to sulfur dioxide.

b. The equation for the oxidation of sulfur dioxide to sulfur trioxide.

c. The equation for the reaction of sulfur trioxide with water to form sulfuric acid.

5. The ash from the volcanic explosions of Mount Pinatubo in the Philippines is supposed to have lowered the average temperature of the earth in 1991, perhaps by as much as one degree Fahrenheit. What is the reason for this effect?

6. What conditions in southern California make this area especially likely to experience photochemical smog?

7. Name some important functions for the gases of the troposphere.

8. Explain the main causes of acid rain. Why is New England especially effected by acid rain?

9. What is thought to be the major gas contributing to the raising of the earth's average temperature in the past one hundred years? Name some other gases that contribute as well?

10. How do gases interact with electromagnetic radiation to cause the greenhouse effect?

11. What are CFC's? How do they affect the atmosphere?

12. Explain why asbestos workers who smoked were much more likely to develop cancer then those who did not.

13. Occasionally newspaper reports describe the deaths of persons who used charcoal heaters in an enclosed space to keep warm. Write a chemical equation to explain the formation of toxic gas under these circumstances.

14. Describe measures to decrease the formation of sulfur oxides as a byproduct of the combustion of coal.

15. Give the equation for formation of carbon dioxide from coal. Would changing to another fossil fuel take care of the problem of carbon dioxide formation? Explain.