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# **OZONE DEPLETION**

Fact Sheet Series for  
Key Stage 4 and A-Level

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## ***Glossary***

# Introduction

Ozone is both beneficial and harmful to us. Near the ground, ozone forming as a result of chemical reactions involving traffic pollution and sunlight may cause a number of respiratory problems, particularly for young children. However, high up in the atmosphere (19-30km) in a region known as the stratosphere, ozone filters out incoming radiation from the Sun in the "cell damaging" ultraviolet part of the spectrum. Without ozone in the stratosphere, life on earth would not have evolved. Thus with the development of the ozone layer came the formation of more advanced life forms.

Concentrations of ozone in the stratosphere fluctuate naturally in response to variations in weather conditions and amounts of energy being released from the sun, and to major volcanic eruptions. Nevertheless, during the 1970s it was realised that man-made emissions of CFCs and other chemicals used in refrigeration, aerosols and cleansing agents may destroy significant amounts of ozone in the stratosphere, thereby letting through more of the harmful ultraviolet radiation. Then, in 1985, a large "ozone hole" was discovered above the continent of Antarctica during the springtime. This has reappeared every year. In response to this, and additional fears about more widespread global ozone depletion, 24 nations signed the Montreal Protocol on Substances that Deplete the Ozone Layer (1987). This legally binding international treaty called for participating developed nations to reduce the use of CFCs and other ozone depleting substances. In 1990 and again in 1992, subsequent amendments to the Protocol brought forward the phase out date for CFCs for developed countries to 1995.

Protecting the ozone layer is essential. Ultraviolet radiation from the Sun can cause a variety of health problems in humans, including skin cancers, eye cataracts and a reduction in the ability to fight off disease. Furthermore, ultraviolet radiation can be damaging to

microscopic life in the surface oceans which forms the basis of the world's food chain, certain varieties of crops including rice and soya, and polymers used in paints and clothing. A loss of ozone in the stratosphere may even affect the global climate.

International agreements have gone a long way to safeguarding this life-supporting shield. Nevertheless, for there to be real and long-lasting success, everyone must become part of the solution. Individual efforts taken together can be powerful forces for environmental change. There are a number of things that we, as individuals, can do to both protect the ozone layer. These include proper disposal of old refrigerators, the use of halon-free fire extinguishers and the recycling of foam and other non-disposable packaging. Finally, we should all be aware that whilst emissions of ozone depleters are now being controlled, the ozone layer is not likely to fully repair itself for several decades. Consequently, we should take precautions when exposing ourselves to the Sun.

The Atmospheric Research & Information Centre (aric), through its Atmosphere, Climate and Environment Information Programme, has compiled a series of 20 topical fact sheets concerning the subject of ozone depletion. The series is divided into three sections - the *science of ozone depletion* (10), the *impacts of ozone depletion* (6), and *managing ozone depletion* (4). Together, they describe what ozone, the ozone layer, ozone depletion and the ozone hole are, how ozone depletion occurs, mankind's influence, its impacts, and the international agreements put in place to control it. The fact sheet series is aimed at students involved in Key Stage 4 of the National Curriculum (GCSE) and higher. Although some of the concepts covered by the fact sheets may be challenging, a glossary is provided to compliment the main text, which sometimes contains words and phrases that may seem unfamiliar to the reader. aric hope that the reader will find this fact sheet series a useful information resource on ozone depletion.

# 1. What Is Ozone?

## ***Introduction***

Without ozone, life on Earth would not have evolved. The first stage of single cell organism development requires an oxygen-free environment. This type of environment existed on earth over 3000 million years ago. As the primitive forms of plant life multiplied and evolved, they began to release minute amounts of oxygen through the photosynthesis reaction (which converts carbon dioxide into oxygen). The build up of oxygen in the atmosphere led to the formation of the ozone layer in the upper atmosphere or stratosphere. This layer filters out incoming radiation in the "cell damaging" ultraviolet part of the spectrum. Thus with the development of the ozone layer came the formation of more advanced life forms.

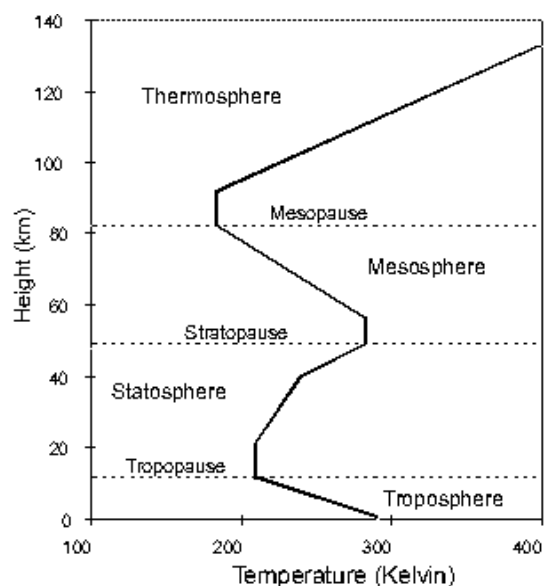
## ***Oxygen and Ozone***

Ozone is a form of oxygen. The oxygen we breathe is in the form of oxygen molecules ( $O_2$ ) - two atoms of oxygen bound together. Ozone, on the other hand, consists of three atoms of oxygen bound together ( $O_3$ ). Most of the atmosphere's ozone occurs in the upper atmosphere called the stratosphere. Ozone is colourless and has a very harsh odour. Normal oxygen, which we breathe, has two oxygen atoms and is colourless and odourless. Ozone is much less common than normal oxygen. Out of each 10 million air molecules, about 2 million are normal oxygen, but only 3 are ozone.

## ***Where is Ozone Found?***

Most ozone is produced naturally in the upper atmosphere or stratosphere. While ozone can be found through the entire atmosphere, the greatest concentration occurs at an altitude of about 25 km. This band of ozone-rich air is known as the "ozone layer". The stratosphere ranges from an altitude of 10km to 50km and it lies above the troposphere (or lower atmosphere). Stratospheric ozone shields us from the harmful effects of the Sun's ultra-violet radiation. Ozone also occurs in very small amounts in the troposphere (200 parts per billion). It is produced at ground level through a reaction between sunlight and volatile organic compounds (VOCs) and nitrogen oxides (NO<sub>x</sub>), some of which are produced by human activities such as driving cars. Ground-level ozone is a component of urban smog, and can damage certain crops and trees, and can be harmful to human health. As there is increased solar radiation during the summer months, there tends to be a larger number of urban ozone episodes at this time. Ground level ozone is blown easily by surface winds to regions well beyond its source. As a pollutant it should not be confused with the separate problem of stratospheric ozone depletion.

### ***Structure of the Atmosphere***



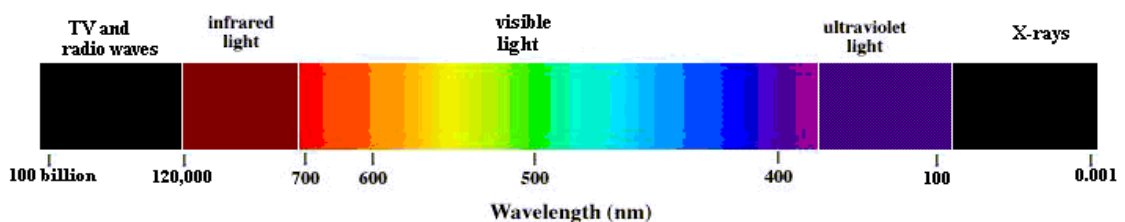
Even though both types of ozone are exactly the same molecule, their presence in different parts of the atmosphere has very different consequences. Stratospheric ozone blocks harmful solar radiation - all life on Earth has adapted to this filtered solar radiation. Ground-level ozone, in contrast, is simply a pollutant. It will absorb some incoming solar radiation, but it cannot make up for stratospheric ozone loss. This fact sheet series is concerned with stratospheric ozone depletion.

## 2. Ultraviolet Radiation

### ***What is Ultraviolet Radiation?***

Ultraviolet radiation is one form of radiant energy coming from the sun. The various forms of energy, or radiation, are classified according to wavelength, measured in nanometres (one nm is a millionth of a millimetre). The shorter the wavelength, the more energetic the radiation. In order of decreasing energy, the principal forms of radiation are gamma rays, X rays, UV (ultraviolet radiation), visible light, infrared radiation, microwaves, and radio waves. There are three categories of UV radiation:

- UV-A, between 320 and 400 nm
- UV-B, between 280 and 320 nm
- UV-C, between 200 and 280 nm

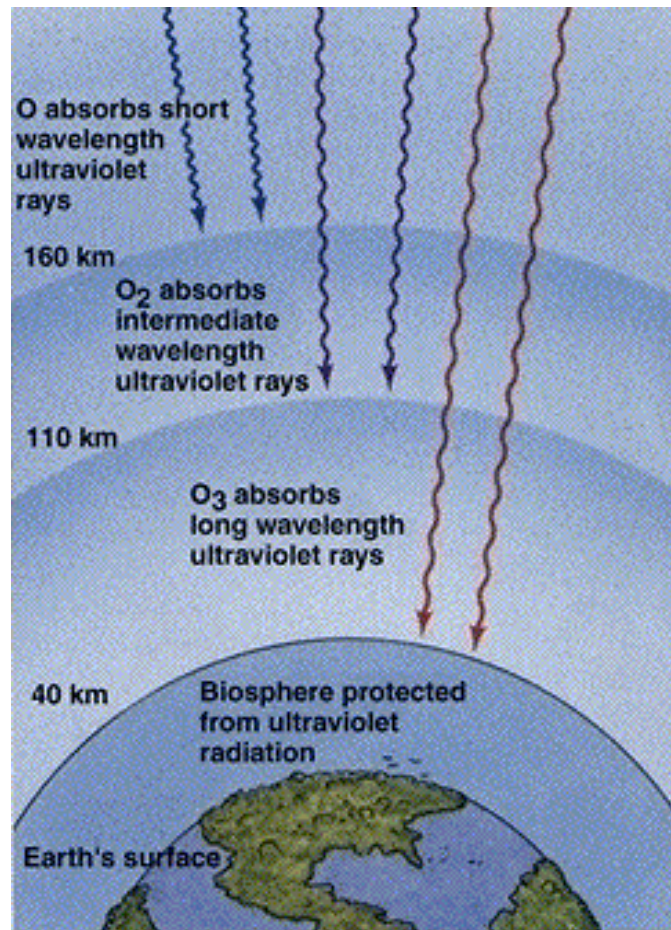


1 metre [m] = 1,000,000,000 nanometres [nm]

### ***How Harmful is UV?***

Generally, the shorter the wavelength, the more biologically damaging UV radiation can be if it reaches the Earth in sufficient quantity. UV-A is the least damaging (longest wavelength) form of UV radiation and reaches the Earth in greatest quantity. Most UV-A rays pass right through the ozone layer in the stratosphere. UV-B

radiation can be very harmful. Fortunately, most of the sun's UV-B radiation is absorbed by ozone in the stratosphere. UV-C radiation is potentially the most damaging because it is very energetic. Fortunately, all UV-C is absorbed by oxygen and ozone in the stratosphere and never reaches the Earth's surface.



In summary, the danger from ultraviolet radiation comes mainly from the UV-B range of the spectrum, although UV-A poses some risk if exposure is long enough, or the sunshine is particularly strong.

### ***Influences on UV Radiation Reaching the Earth?***

Although the ozone layer is the one constant defence against UV penetration, several other factors can have an effect:

Latitude: The sun's rays are the most intense near the equator where they impact the Earth's surface at the most direct angle.

Season: During winter months, the sun's rays strike at a more oblique angle than they do in the summer. This means that all solar radiation travels a longer path through the atmosphere to reach the Earth, and is therefore less intense.

Time of day: Daily changes in the angle of the sun influence the amount of UV radiation that passes through the atmosphere. When the sun is low in the sky, its rays must travel a greater distance through the atmosphere and may be scattered and absorbed by water vapour and other atmospheric components. The greatest amount of UV reaches the Earth around midday when the sun is at its highest point.

Altitude. The air is thinner and cleaner on a mountain top - more UV reaches there than at lower elevations.

Cloud cover. Clouds can have a marked impact on the amount of UV radiation that reaches the Earth's surface; generally, thick clouds block more UV than thin cloud cover.

Rain: Rainy conditions reduce the amount of UV transmission.

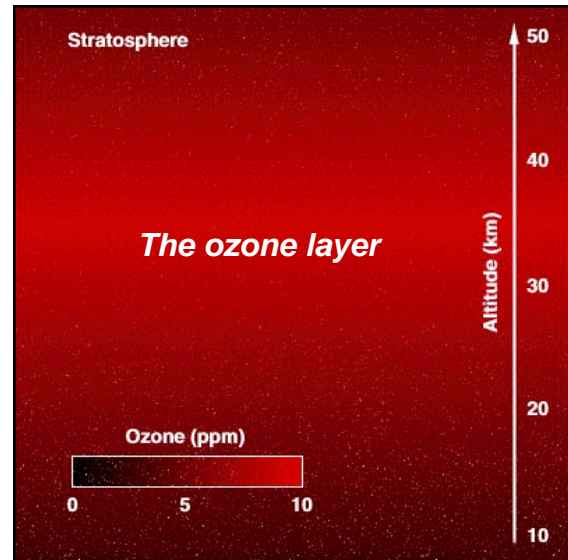
Air pollution: Like clouds, urban smog can reduce the amount of UV radiation reaching the Earth.

Land cover: Incoming UV radiation is reflected from most surfaces. Snow reflects up to 85 per cent, dry sand and concrete can reflect up to 12%. Water reflects only five per cent. Reflected UV can damage people, plants, and animals just as direct UV does.

## 3. The Ozone Layer

### ***Introduction***

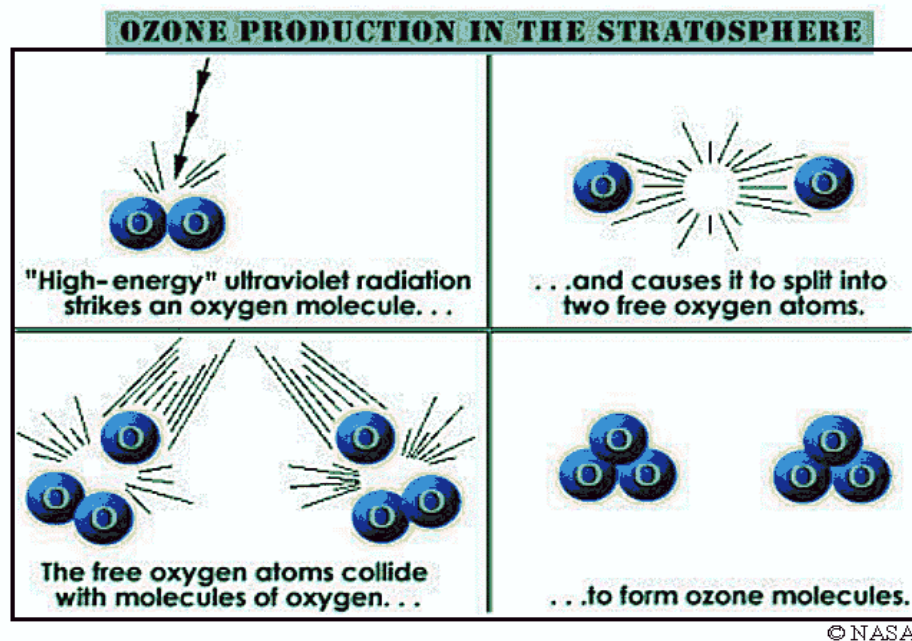
The ozone layer is a layer of ozone particles scattered between 19 and 30 kilometres (12 to 30 miles) up in the Earth's atmosphere, in a region called the stratosphere. The concentration of ozone in the ozone layer is usually under 10 parts ozone per million. Without the ozone layer, UV radiation would not be stopped from entering the Earth's atmosphere and arriving at the surface, causing untold damage to most living species. In the 1970s, scientists discovered that chlorofluorocarbons (CFCs) could destroy ozone in the stratosphere. Since CFCs had been in use as refrigerants, coolants, and propellants for aerosol cans since the 1930s, this posed a major problem.



### ***The Formation of Stratospheric Ozone***

Ozone is created in the stratosphere when highly energetic solar radiation strikes molecules of oxygen ( $O_2$ ) and cause the two oxygen atoms to split apart. If a freed atom bumps into another  $O_2$ , it joins up, forming ozone ( $O_3$ ). This process is known as photolysis. Ozone is also naturally broken down in the stratosphere by sunlight and by a chemical reaction with various compounds containing nitrogen, hydrogen and chlorine. These chemicals all occur naturally in the atmosphere in very small amounts.

In an unpolluted atmosphere there is a balance between the amount of ozone being produced and the amount of ozone being destroyed. As a result, the total concentration of ozone in the stratosphere remains relatively constant. At different temperatures and pressures (i.e. varying altitudes within the stratosphere), there are different formation and destruction reaction rates. Thus, the amount of ozone within the stratosphere varies according to altitude. Ozone concentrations are highest between 19 and 23 km.



### ***Distribution of Stratospheric Ozone***

Most of the ozone in the stratosphere is formed over the equatorial belt, where the level of solar radiation is greatest. It is transported by latitudinal air movements towards polar latitudes. Consequently, the amount of stratospheric ozone above a location on the Earth varies naturally with latitude, season, and from day-to-day. Under normal circumstances highest ozone values are found over the Canadian Arctic and Siberia, whilst the lowest values are found around the equator. The ozone layer over Canada is normally thicker in winter and early spring, varying naturally by about 25% between January

and July. Weather conditions can also cause considerable daily variations.

It is generally believed that if the stratospheric ozone concentration is disturbed, it takes some time for the chemical system to return to its original balance or new equilibrium (between formation and destruction). The time this takes depends on the altitude in the stratosphere. Above 40km, it may take a few minutes for an equilibrium to be re-established, while below 30 km altitude it can take several days.

To summarise, ozone is constantly produced and destroyed in the stratosphere, by reactions involving sunlight and oxygen. It is a mistake to think of it as a finite resource, like oil, that can be destroyed once and for all. What could happen is that the balance of the present equilibrium that exists to maintain the layer may be shifted, either in favour of less ozone or more.

### ***Why is the Ozone Layer Important?***

Ozone's unique physical properties allow the ozone layer to act as our planet's sunscreen, providing an invisible filter to help protect all life forms from the Sun's damaging ultraviolet (UV) rays. Most incoming UV radiation is absorbed by ozone and prevented from reaching the Earth's surface. Without the protective effect of ozone, life on Earth would not have evolved in the way it has.

## 4. Ozone Depletion In The Stratosphere

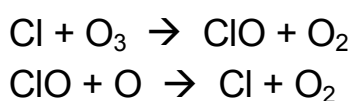
### **Introduction**

Ozone depletion occurs when the natural balance between the production and destruction of stratospheric ozone is tipped in favour of destruction. Although natural phenomena can cause temporary ozone loss, chlorine and bromine released from man-made synthetic compounds are now accepted as the main cause of this depletion.

### **What Causes Ozone Depletion?**

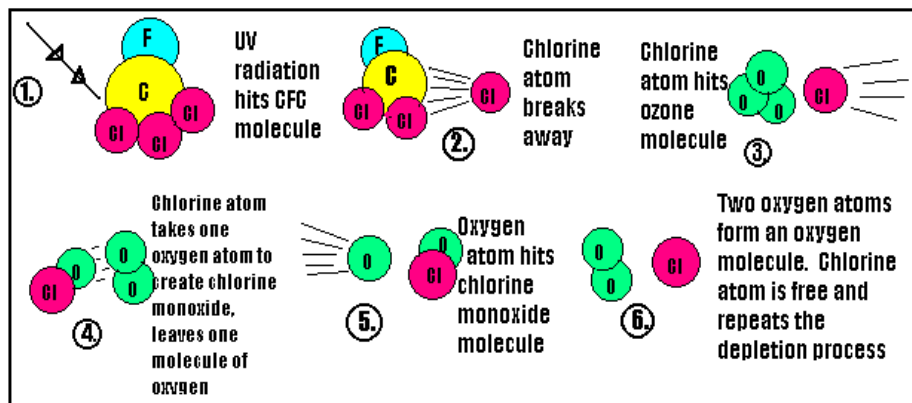
It was first suggested, by Drs. M. Molina and S. Rowland in 1974, that a man-made group of compounds known as the chlorofluorocarbons (CFCs) were likely to be the main source of ozone depletion. However, this idea was not taken seriously until the discovery of the ozone hole over Antarctica in 1985.

Chlorofluorocarbons are not "washed" back to Earth by rain or destroyed in reactions with other chemicals. They simply do not break down in the lower atmosphere and they can remain in the atmosphere from 20 to 120 years or more. As a consequence of their relative stability, CFCs are instead transported into the stratosphere where they are eventually broken down by ultraviolet radiation, releasing free chlorine. The chlorine becomes actively involved in the process of destruction of ozone. The net result is that two molecules of ozone are replaced by three of molecular oxygen, leaving the chlorine free to repeat the process:



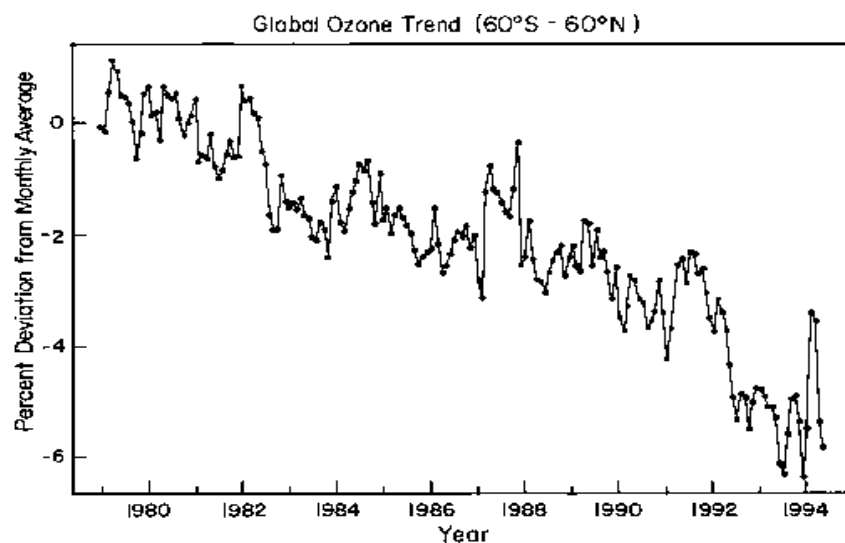
Ozone is converted to oxygen, leaving the chlorine atom free to repeat the process up to 100,000 times, resulting in a reduced level of ozone. Bromine compounds, or halons, can also destroy stratospheric ozone. Compounds containing chlorine and bromine from man-made synthetic compounds are known as industrial halocarbons.

### The Destruction of Ozone



### How Long has Ozone Depletion been Occurring?

Based on data collected since the 1950s, scientists have determined that ozone levels were relatively stable until the late 1970s. Severe depletion over the Antarctic has been occurring since 1979 and a general downturn in global ozone levels has been observed since the early 1980s.



## ***How Much of the Ozone Layer has been Depleted Around the World?***

Global ozone levels have declined an average of about 3% between 1979 and 1991. This rate of decline is about three times faster than that recorded in the 1970s. In addition to Antarctica, ozone depletion now affects almost all of North America, Europe, Russia, Australia, New Zealand, and a sizeable part of South America. Short term losses of ozone can be much greater than the long term average. In Canada, ozone depletion is usually greatest in the late winter and early spring. In 1993, for example, average ozone values over Canada were 14% below normal from January to April.

# 5. Chlorofluorocarbons

## ***Introduction***

Man-made CFCs are the main cause of stratospheric ozone depletion. CFCs have a lifetime of about 20 to 100 years, and consequently one free chlorine atom from a CFC molecule can do a lot of damage, destroying ozone molecules for a long time. Although emissions of CFCs around the developed world have largely ceased due to international control agreements, the damage to the stratospheric ozone layer will continue for a number of years to come.

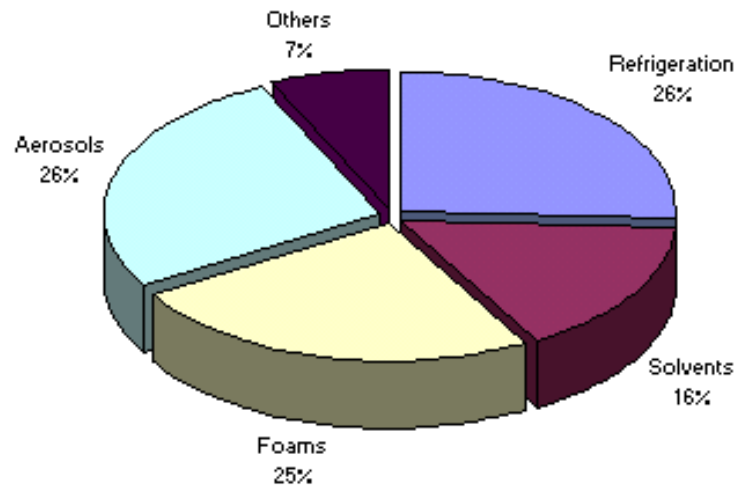
## ***What are CFCs?***

Chlorofluorocarbons or CFCs (also known as freon) are non-toxic, non-flammable and non-carcinogenic. They contain fluorine atoms, carbon atoms and chlorine atoms. The 5 main CFCs include CFC-11 (trichlorofluoromethane -  $\text{CFCl}_3$ ), CFC-12 (dichlorodifluoromethane -  $\text{CF}_2\text{Cl}_2$ ), CFC-113 (trichlorotrifluoroethane -  $\text{C}_2\text{F}_3\text{Cl}_3$ ), CFC-114 (dichlorotetrafluoroethane -  $\text{C}_2\text{F}_4\text{Cl}_2$ ), and CFC-115 (chloropentafluoroethane -  $\text{C}_2\text{F}_5\text{Cl}$ ).

## ***Use of CFCs***

In the past, CFCs have been widely used as coolants in refrigeration and air conditioners, as solvents in cleaners, particularly for electronic circuit boards, as blowing agents in the production of foam (e.g. fire extinguishers), and as propellants in aerosols. Indeed, much of the modern lifestyle of the mid-20th century had been made possible by the use of CFCs.

The pie chart below shows the uses of CFCs in various products before the 1987 Montreal Protocol, which required countries to phase out their usage to protect the ozone layer.



No new CFCs have been produced since 1995 in developed nations. Total usage of CFCs has also fallen dramatically, particularly by aerosols. The only aerosols using CFCs in the developed world are asthma inhalers and these too are being phased out. Aerosol propellants now use only 4.9% of total use of CFC-11 and CFC-12 in the world today.

### ***How do CFCs Destroy the Ozone Layer?***

Emissions of CFCs to date have accounted for roughly 80% of total stratospheric depletion. Whilst chlorine is a natural threat to ozone, CFCs which contain chlorine are a man-made problem. Although CFC molecules are several times heavier than air, winds mix the atmosphere to altitudes far above the top of the stratosphere much faster than molecules can settle according to their weight. CFCs are insoluble in water and relatively unreactive in the lower atmosphere but are quickly mixed and reach the stratosphere regardless of their weight. When UV radiation hits a CFC molecule it causes one chlorine atom to break away. The chlorine atom then hits an ozone

molecule consisting of three oxygen atoms and takes one of the oxygen molecules, destroying the ozone molecule and turning it into oxygen. When an oxygen molecule hits the molecule of chlorine monoxide, the two oxygen atoms join and form an oxygen molecule. When this happens, the chlorine atom is free and can continue to destroy ozone. Naturally occurring chlorine has the same effect in the ozone layer, but has a shorter life span.

### ***Control of CFCs***

Since 1995, emissions of new CFCs in the developed world have been completely phased out. As evidence accumulated that man-made CFCs were contributing to stratospheric ozone depletion, scientists urged nations to control the use of CFCs. In 1987, the *Montreal Protocol on Substances that Deplete the Ozone Layer* was negotiated and signed by 24 countries. The Protocol called for the parties to phase down the use of CFCs, as well as other ozone depleting chemicals such as halons and other man-made halocarbons. Although emissions of CFCs have fallen dramatically as a result of the Montreal Protocol, because each chlorine molecule remains in the atmosphere for such a long time, damage done to stratospheric ozone will persist for many years to come.

## ***6. Other Ozone Depleting Substances***

### ***Introduction***

CFCs are not the only ozone-depleting chemicals (ODCs). A number of other halocarbon species are capable of destroying ozone in the stratosphere. Halocarbons include the chlorofluorocarbons (CFCs), the hydrochlorofluorocarbons (HCFCs), methylhalides, carbon tetrachloride (CCl<sub>4</sub>), carbon tetrafluoride (CF<sub>4</sub>), and the halons (bromide species). Although the HCFCs do not contribute significantly to the destruction of the ozone layer, they, along with the other halocarbons are all considered to be powerful greenhouse gases and contribute towards global warming.

### ***Hydrochlorofluorocarbons***

Hydrochlorofluorocarbons or HCFCs contain chlorine but, unlike CFCs, they also contain hydrogen (the H) which causes them to break down in the lower atmosphere (troposphere). They are called transition chemicals because they are considered an interim step between strong ozone-depleters and replacement chemicals that are entirely ozone-friendly. Unfortunately, like CFCs, they are strong greenhouse gases and contribute towards global warming.

### ***Carbon Tetrachloride***

Carbon tetrachloride (CCl<sub>4</sub>), despite its toxicity, was first used in the early 1900s as a fire extinguishant, and more recently as an industrial solvent, an agricultural fumigant, and in many other industrial processes including petrochemical refining, and pesticide and pharmaceuticals production. Recently it has also been used in the production of CFC-11 and CFC-12. It has accounted for less

than 8% of total ozone depletion. The use of carbon tetrachloride in developed countries has been prohibited since the beginning of 1996 under the Montreal Protocol.

### ***Methyl Chloroform***

Methyl chloroform, also known as 1,1,1 trichloroethane is a versatile, all-purpose industrial solvent used primarily to clean metal and electronic parts. It was introduced in the 1950s as a substitute for carbon tetrachloride. Methyl chloroform has accounted for roughly 5% of total ozone depletion. The use of methyl chloroform in developed countries has been prohibited since the beginning of 1996 under the Montreal Protocol.

### ***Halons***

Halons, unlike CFCs, contain bromine, which also destroys ozone in the stratosphere. Halons are used primarily as fire suppressants. Halon-1301 has an ozone depleting potential 10 times that of CFC-11. Although the use of halons in developed countries has been phased out since 1996, the atmospheric concentration of these potent, long-lived ozone destroyers is still rising by an estimated 11 to 15% annually. To date halons have accounted for about 5% of global ozone depletion.

### ***Methyl Bromide***

Methyl bromide, another bromine-containing halocarbon, has been used as a pesticide since the 1960s. Today, scientists estimate that human sources of methyl bromide are responsible for approximately 5 to 10% of global ozone depletion.

# ***7. The Ozone Hole: Antarctica***

## ***Introduction***

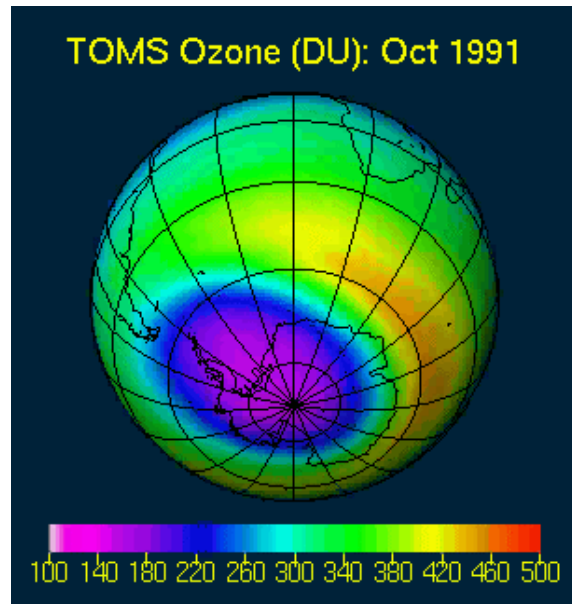
Why is the ozone hole over Antarctica? That is one of the first questions that comes to mind when people think about the ozone hole. Every winter and spring since the late 1970s, an ozone hole has formed in the stratosphere above the Antarctic continent. In recent years this hole has become both larger and deeper, in the sense that more and more ozone is being destroyed. As summer approaches, the hole repairs itself, only to reform during the following spring.

## ***Measuring the Ozone Hole***

The most common ozone measurement unit is the Dobson Unit (DU). The Dobson Unit is named after atmospheric ozone pioneer G.M.B. Dobson who carried out the earliest studies on ozone in the atmosphere from the 1920s to the 1970s. A DU measures the total amount of ozone in an overhead column of the atmosphere. Dobson Units are measured by how thick the layer of ozone would be if it were compressed into one layer at 0 degrees Celsius and with a pressure of one atmosphere above it. Every 0.01 millimetre thickness of the layer is equal to one Dobson Unit. The average amount of ozone in the stratosphere across the globe is about 300 DU (or a thickness of only 3mm at 0°C and 1 atmospheric pressure!). Highest levels of ozone are usually found in the mid to high latitudes, in Canada and Siberia (360DU).

## ***Why is the Hole over the Antarctic?***

Observed ozone over the British Antarctic Survey station at Halley Bay first revealed obvious decreases in the early 1980s compared to data obtained since 1957. The ozone hole is formed each year when there is a sharp decline (currently up to 60%) in the total ozone over most of Antarctica for a period of about two months during southern hemisphere spring (September and October).



Man-made emissions of CFCs occur mainly in the northern hemisphere, with about 90% released in Europe, Russia, Japan, and North America. Gases such as CFCs that are insoluble in water and relatively unreactive are mixed throughout the lower atmosphere and rise from the lower atmosphere into the stratosphere; winds then move this air poleward.

Normally, chlorine and bromine is inactive, locked up in stable compounds, and does not destroy the ozone. However, during the Antarctic winter months (June to August) when the region receives no sunlight, the stratosphere becomes cold enough ( $-80^{\circ}\text{C}$ ) for high level [ice] clouds to form, called Polar Stratospheric Clouds (PSCs). These PSCs provide an ideal catalytic surface on which the chlorine can react with the ozone, thus destroying the ozone layer. This reaction requires sunlight, and therefore only begins when the Sun returns to Antarctica in spring (September to October), before the PSCs have had a chance to melt. The ozone hole disappears again when the Antarctic air warms up enough during late spring and summer

During the southern hemisphere winter, Antarctica is isolated from the rest of the world by a natural circulation of wind called the polar vortex. This prevents atmospheric mixing of stratospheric ozone, thus contributing to the depletion of ozone. Although some ozone depletion occurs over the Arctic, meteorological conditions there are very different to Antarctica and so far have prevented the formation of ozone holes as large as in the southern hemisphere.

## ***8. The Ozone Hole: The Arctic***

### ***Introduction***

Unlike the Arctic, the Antarctic is isolated from the rest of the world during the winter and spring by a natural circulation of wind called the polar vortex. This prevents atmospheric mixing of stratospheric ozone, thus contributing to the depletion of ozone. However, even small depletions in the Arctic region would give cause for considerable concern due to the higher populations in the higher latitudes of the northern hemisphere.

### ***Do Ozone Holes Form Over The Arctic?***

Arctic ozone depletion has not been as marked as over the Antarctic for two reasons: a) the stratospheric temperatures are seldom below  $-80^{\circ}\text{C}$  due to frequent exchange of air masses with the mid latitudes; b) the Arctic air vortex usually dissipates in late winter before sunlight returns to initiate the ozone destruction. The differences between the two regions result in part from the larger land mass in the northern hemisphere, which causes more activity in the atmosphere.

Nevertheless, analysis of satellite data reveals that the loss of ozone in the northern hemisphere is now proceeding faster than previously thought. In 1989, NASA's Airborne Arctic Stratospheric Expedition, the first comprehensive research expedition to explore the Arctic region, found that the Arctic stratosphere in winter has almost as much chlorine monoxide as is found in Antarctica, the same destructive chlorine that causes the Antarctic ozone hole. While no Arctic ozone losses comparable with those in the Antarctic have occurred, localised Arctic ozone losses have been observed in winter concurrent with observation of elevated levels of reactive chlorine, made available through man-made emissions of CFCs.

Ozone losses have increased greatly in the 1990s in the Arctic and in late 1997 were the greatest ever observed, according to measurements by NASA satellites.

The rate of loss in mid-latitudes has reached 8% per decade in late winter and spring, and significant loss is now encroaching on the growing season. This compares with the yearly-averaged global mean decrease in the amount of ozone of about 3% in the last decade.

### ***Climate Change and Ozone Depletion in the Arctic***

An ozone hole in the Arctic is expected to grow larger over the coming decades as a result of man-made greenhouse gas emissions which may cause climate change, before recovering after 2020. Loss of ozone in the Arctic by 2020 could be about double what would occur without greenhouse gases. Though greenhouse gases cause atmospheric warming at the Earth's surface, they cool the stratosphere by trapping more heat below, in the troposphere. Since ozone chemistry is very sensitive to temperature, particularly at  $-80^{\circ}\text{C}$  when Polar Stratospheric Clouds can form, this stratospheric cooling may result in more ozone depletion in the Arctic.

Temperatures are slightly warmer in the Arctic than the Antarctic during their respective winter and spring seasons, with the result that ozone loss in the northern hemisphere has been lower than that in the southern hemisphere. But the Arctic stratosphere has gradually cooled over the last decade, resulting in the increased ozone loss. Computer models predict that temperature and wind changes induced by greenhouse gas emissions may allow a stronger and longer-lasting atmospheric vortex to form above the Arctic, as in the Antarctic, causing an increase in ozone depletion.

Because of international controls on the emission of ozone-depleting chemicals, those gases are expected to peak about the year 2000.

However, greenhouse gas emissions continue to increase, despite international efforts to control them, and Arctic ozone depletion may continue to worsen until the 2010s, with two-thirds of atmospheric ozone lost in the most severely affected areas.

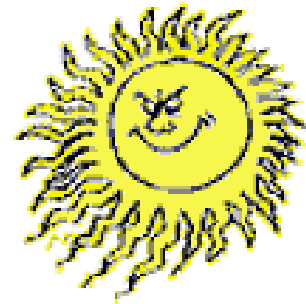
## ***9. Natural Influences On Stratospheric Ozone***

### ***Introduction***

Despite all of our harmful chemicals going into the atmosphere, some people still argue that stratospheric ozone depletion is just part of a natural variation. Natural variations which influence the amount of ozone in the upper atmosphere include solar activity, volcanic eruptions and changes in atmospheric circulation - the planetary winds.

### ***The Sun's Influence on Ozone***

Stratospheric ozone is primarily created by ultraviolet (UV) radiation coming from the Sun. The Sun's energy release does vary, especially over the 11-year sunspot cycle. During the active phase of the 11-year sunspot cycle, more ozone is produced with the increased UV coming to Earth. This



phenomenon can boost the average ozone concentration over the poles by about 4%, but when this is averaged out over the whole earth, the world average ozone increase is about 2%.

Observations since the 1960s have shown that total global ozone levels have decreased by 1-2% from the maximum to the minimum of a typical cycle. However, since downward trends in ozone levels are much larger than 1-2%, particularly at the higher latitudes, the Sun's output cannot be wholly responsible.

Unusual solar activity can cause the ozone levels in the upper stratosphere to be substantially depleted, but since most of the

ozone is in the middle stratosphere, the effect on the total ozone column is negligible.

### ***Atmospheric Winds and Ozone***

A natural cycle in which prevailing tropical winds in the lower stratosphere vary over a time span of about two years can also influence the amount of ozone in the stratosphere. A change from easterly flow to westerly flow can bring up to a 3% increase in ozone over certain locations, but it is usually cancelled out when the total ozone of the Earth is averaged.

### ***Volcanic Eruptions and Ozone***



Volcanic eruptions are one of the few natural things that can have a diminishing effect on the ozone layer. Large eruptions can potentially inject significant quantities of chlorine (via hydrochloric acid - HCl) directly in the stratosphere where the highest concentrations of ozone are found. However, the vast majority of volcanic eruptions are too weak to reach the stratosphere, around 10 km above the surface. Thus, any HCl emitted in the eruption remains in the troposphere where it is quickly dissolved and washed out by rain. [Note that CFCs do not dissolve in water and can therefore reach the stratosphere through atmospheric mixing.] In addition, there is no historical record that shows significant increases in chlorine in the stratosphere following even the most major eruptions.

It is also possible that ice particles containing sulphuric acid from large volcanic eruptions may contribute to ozone loss. When chlorine compounds resulting from the break-up of man-made CFCs

in the stratosphere are present, the sulphate particles serve to convert them into more active forms that may cause more rapid ozone depletion. In 1991 Mt. Pinatubo in the Philippines erupted tonnes of dust and gas high into the atmosphere which caused global reductions in the ozone layer for 2 to 3 years. Thus, whilst large volcanic eruptions may increase the rate of stratospheric ozone depletion, it is more probable that the presence of chlorine from man-made CFC emissions is the chief cause of ozone loss in the first instance.

# **10. Monitoring Ozone Depletion**

## ***Introduction***

In 1974, after millions of tons of CFCs had been manufactured and sold, chemists F. Sherwood Rowland and Mario Molina of the University of California began to wonder where all these CFCs ended up. Rowland and Molina theorised that short waves of ultraviolet radiation from the Sun in the stratosphere would break up CFCs, and that the free chlorine atoms would then enter into a chain reaction, destroying ozone. Many people, however, remained unconvinced of the danger until the mid-1980s, when a severe annual depletion of ozone was first monitored by the British Antarctic Survey above Antarctica. The depletion above the South Pole was so severe that the British geophysicist, Joe Farman, who first measured it assumed his spectrophotometer must be broken and sent the device back to England to be repaired. Once the depletion was verified, it came to be known throughout the world through a series of NASA satellite photos as the Antarctic Ozone Hole.

## ***Evidence for Stratospheric Ozone Depletion***

Laboratory studies, backed by satellite and ground-based measurements, show that chlorine reacts very rapidly with ozone. They also show that the chlorine oxide formed in that reaction undergoes further processes that regenerate the original chlorine, allowing the sequence to be repeated very many times (a "chain reaction"). Similar reactions also take place between bromine and ozone. Many other reactions are often also taking place simultaneously in the stratosphere, making the connections among the changes difficult to untangle. Nevertheless, whenever chlorine (or bromine) and ozone are found together in the stratosphere, the ozone-destroying reactions must be taking place. Observations of

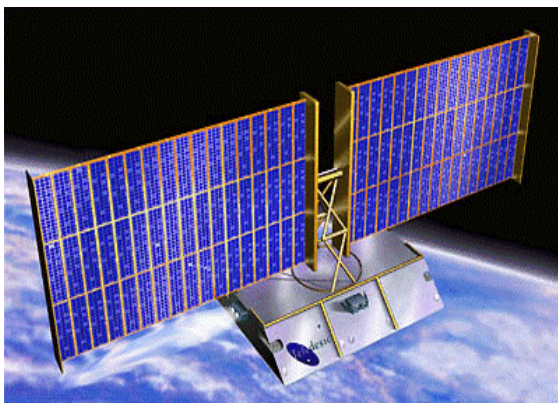
the Antarctic ozone hole have given a convincing and unmistakable demonstration of these processes.

### ***Monitoring of Ozone Depletion***

There has been much monitoring of the condition of the ozone layer in the last decade since the Antarctic ozone hole was first discovered by the British Antarctic Survey. This has utilised satellites and other ground-based resources that are dedicated to observing the destruction of stratospheric ozone. The main satellite that monitors the ozone is the TOMS (Total Ozone Mapping Spectrometer) satellite. The TOMS satellite measures the ozone levels from the back-



scattered sunlight in the ultraviolet (UV) range. Another satellite is NASA's UARS (Upper Atmosphere Research Satellite) which was launched in September 1991. This satellite is unique because it was configured to not only measure ozone levels, but also levels of ozone-depleting chemicals. GOME, launched in April 1995 on the



ERS-2 satellite, marks the beginning of a long-term European ozone monitoring effort. Scientists expect to receive high quality data on the global distribution of ozone and several other climate-influencing trace gases in the Earth's atmosphere.

The German Neumayer Antarctic Research Station was completed in March of 1992, which is located on the Ekstsoem Ice Shelf. This ground-based station studies geographical, meteorological, and air chemistry conditions.

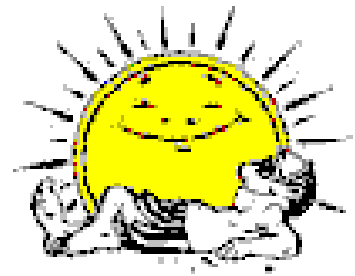
In 1987, Canada became the first country in the world to focus on the Arctic ozone layer, following the discovery of the ozone hole over the Antarctic. A cross-country network of monitoring stations has kept continuous watch on Canada's ozone layer for more than three decades. The existence of these early records, before any major human influence on the upper atmosphere, is vital to understanding the changes that have occurred in the ozone layer.

In the UK, stratospheric ozone levels are monitored every winter and spring at Cambourne, in Cornwall and Lerwick, in the Shetland Isles.

# **11. Health Effects Of Ozone Depletion: Skin Cancer**

## **Introduction**

Ozone's unique physical properties allow the ozone layer to act as our planet's sunscreen, providing an invisible filter to help protect all life forms from the Sun's damaging ultraviolet (UV) rays. Most incoming UV radiation is absorbed by ozone and prevented from reaching the Earth's surface. Without the protective effect of ozone, life on Earth would not have evolved the way it has. The ozone layer protects us from the harmful effects of certain wavelengths of ultraviolet (UV) light from the Sun. The danger to human skin from ultraviolet radiation comes mainly from the UV-B range of the spectrum, although UV-A poses some risk if exposure is long enough. Any significant decrease of ozone in the stratosphere would result in an increase of UV-B radiation reaching the Earth's surface, and of skin cancers.



## **UV-B and Skin Cancer**

The most well-known effect of UV radiation is the slight reddening or burning of the skin in sunshine. This change of colour is caused by an expansion of the skin's blood vessels. For most people burning is followed by tanning within a couple of days. A permanent tan will occur when the UV radiation causes a pigment called melanin to form in the pigment cells of the skin. Over a period of years, exposure to radiation originating from the Sun causes damages in the skin's connective tissues, so-called photo-ageing. This shows itself as a thickening of the skin, as wrinkles and decreasing

elasticity. Elastine and collagen fibres determining the firmness and elasticity of the skin are damaged. UV radiation increases the risk of getting skin cancer.

Research has shown that even small amounts of UV-B radiation can cause considerable harm. UV-B damages the genetic material of DNA and is related to some types of skin cancer. It is important to note, however, that UV-B radiation has always had this effect on humans. In recent years non-melanoma skin cancer has become more prevalent in many parts of the world because people are spending more time in the Sun and are exposing more of their skin in the process.

The relationship between the occurrence of milder non-melanoma skin cancers and time spent in the Sun is well documented. Such cancers generally occur in people in their 70s and 80s on areas of the skin usually exposed to sunlight (such as the face or hands). Malignant melanoma, however, usually occurs in younger people and in skin areas not necessarily exposed to sunlight. It tends to occur most commonly among groups of people less likely to have spent significant amounts of time outdoors.

The risk of developing malignant melanoma is directly related to the sensitivity of an individual's skin to the Sun (i.e., fair-skinned are more susceptible than darker skinned individuals). The victims are almost exclusively Caucasians, particularly fair-skinned Caucasians. The incidence of malignant melanoma has been increasing among light-skinned populations around the world for decades.



## ***Ozone Depletion and Skin Cancer***

Ozone in the stratosphere protects Earth from damaging amounts of ultraviolet (UV) radiation. A depleted ozone layer would allow more of the Sun's rays to reach Earth's surface. An increase in the levels of UV-B reaching the Earth as a result of ozone depletion may compound the effects of spending more time in the Sun. According to some estimates a sustained 10% global loss of ozone may lead to a 26% increase in the incidence of skin cancers among fair skinned people. The US Environmental Protection Agency estimates that a 2% increase in UV-B radiation would result in a 2 to 6% increase in non-melanoma skin cancer. Increases in UV radiation relative to levels in the 1970s are estimated to be as much as 7% at Northern Hemisphere mid-latitudes during the winter and spring, 4% at Northern Hemisphere mid-latitudes in summer and autumn, and 6% at Southern Hemisphere mid-latitudes on a year-round basis.

Australia, with high sunshine levels, has very high skin cancer rates. An estimated 2 out of every 3 people in most parts of the country will develop some form of skin cancer. In Queensland, where UV-B radiation is the highest, the probability jumps to 3 in every 4. In America, in 1935, the chances of developing the more serious malignant melanoma was 1 in 1500. In 1991 it had soared to 1 in 150, and it is predicted that by the beginning of the new millennium it will be 1 in 75.

## ***12. Health Effects Of Ozone Depletion: Eye Disorders***

### ***Introduction***

Ozone's unique physical properties allow the ozone layer to act as our planet's sunscreen, providing an invisible filter to help protect all life forms from the Sun's damaging ultraviolet (UV) rays. Most incoming UV radiation is absorbed by ozone and prevented from reaching the Earth's surface. Without the protective effect of ozone, life on Earth would not have evolved the way it has. The ozone layer protects us from the harmful effects of certain wavelengths of ultraviolet (UV) light from the Sun. The danger to our eyes from ultraviolet radiation comes mainly from the UV-B range of the spectrum, although UV-A poses some risk if exposure is long enough. Any significant decrease of ozone in the stratosphere would result in an increase of UV-B radiation reaching the Earth's surface, and of eye disorders.



### ***UV-B and Eye Disorders***

UV-B radiation can damage the cornea leading to photokeratitis or "snow blindness", and can also cause cataracts through damage to the lens and the retina.

Strong UV radiation can cause inflammation of the cornea leading to photokeratitis or "snow blindness". Symptoms of this kind of an infection include the eyes becoming reddish, a sensitivity to light, enhanced excretion of tears, the feeling of having some dirt in one's eye, and pain. The trauma appears 3-12 hours after exposure. Thanks to the quick regeneration of the eye cells, symptoms will

normally disappear within a few days. A long-term exposure to UV radiation may cause permanent damage to the cornea.

UV radiation also enhances the dimming of the eye's lens, which means that potential cataracts begin to evolve at earlier ages. A cataract is a partial or complete opacity of the lens of the eye and the largest cause of blindness in the world. Part of the UV radiation reaches the back of the eye, causing cells in the retina to slowly begin to deteriorate. Damage will in time particularly occur to near vision. If not operated upon blindness can occur. Radiation is partly absorbed in the lens of an adult eye, but will go right through the lens of a child, reaching the back of the eye. For this reason, children's eyes in particular should be protected against strong sunlight.

Other common eye diseases associated with increased UV-B radiation are eye cancer, conjunctivitis and pterygium. Conjunctivitis is an inflammation of the membrane covering the anterior portion of the eyeball. Pterygium is a thickening of the membrane that covers the eyeball.

### ***Ozone Depletion and Eye Disorders***

As the ozone layer gets thinner, UV-B radiation at the surface of the Earth increases. If the ozone amount decreases by 10% during the spring and summer, the annual UV dose increases by about 12%.

Cataracts and blindness are among the most common eye diseases associated with further ozone layer depletion and increased UV-B at the Earth's surface. Unlike the skin, which can adapt to UV radiation by becoming browner and thicker, the eye does not have any such defence mechanisms. On the contrary, research shows that eyes become more sensitive with increased exposure to radiation. This can damage the cornea, the lens and the retina.

Increased exposure to UV radiation from ozone depletion is expected to increase the number of people experiencing cataracts. A 1% decrease in stratospheric ozone may result in 100,000 to 150,000 additional cases of blindness due to eye cataracts world-wide.

## ***13. Health Effects Of Ozone Depletion: Immunological Effects***

### ***Introduction***

Ozone's unique physical properties allow the ozone layer to act as our planet's sunscreen, providing an invisible filter to help protect all life forms from the Sun's damaging ultraviolet (UV) rays. Without the protective effect of ozone, life on Earth would not have evolved the way it has. The ozone layer protects us from the harmful effects of certain wavelengths of ultraviolet (UV) light from the Sun.

Because skin is an important immunological organ, the immune system is vulnerable to modification by environmental agents, including UV-B radiation. Demonstrations that immunity can be perturbed by exposing skin to UV radiation raise the concern that ozone depletion might adversely influence immunity to infectious diseases. The danger to our immune system from ultraviolet radiation comes mainly from the UV-B range of the spectrum, although UV-A poses some risk if exposure is long enough. Any significant decrease of ozone in the stratosphere would result in an increase of UV-B radiation reaching the Earth's surface, and a weakening of immunity against disease.

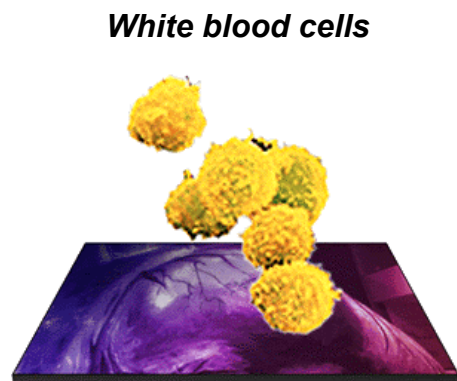
### ***UV-B and the Immune System***

UV radiation from the Sun can benefit health, generating vitamin D production in the skin. The required amount of radiation is, however, quite small: in summer, an exposure of 15 minutes to the hands and face is adequate. Vitamin D is also found in food. A normal diet will provide enough vitamin D for people even in winter. In the treatment of some skin diseases such as psoriasis, UV radiation is being effectively exploited. Under a doctor's control, the benefit from the

treatment is much greater than any consequential increase in skin cancer risk.

However, over exposure to UV-B radiation can impair the body's ability to fight off disease, in addition to causing cancer and a range of eye disorders. UV-B suppresses the immune system, irrespective of skin colour, making it easier for tumours to take hold and spread.

Ultraviolet radiation suppresses allergic reactions of the skin and affects the immune system. When skin has been over-exposed to ultraviolet radiation, the activity of antibody-producing white blood cells is suppressed. These effects are not



restricted to the part of skin actually subject to exposure, but may also occur on shielded parts of skin and in the whole immune system. As a result, the body fails to produce the antigens required for defence against a variety of diseases. This could have serious consequences, including a much diminished effectiveness of vaccinations.

At the present time, the significance of the immune system weakening caused by UV radiation is not properly understood. The weakening can possibly act to promote the development of skin cancers and worsen infectious diseases stemming from bacteria, viruses and tropical parasites. It may also activate viruses already present on the skin, such as herpes, and lead to an increase in diseases like measles, malaria, tuberculosis, leprosy and fungal infections, all of which have a stage involving the skin. People carrying the herpes virus should protect their faces against strong sunlight.

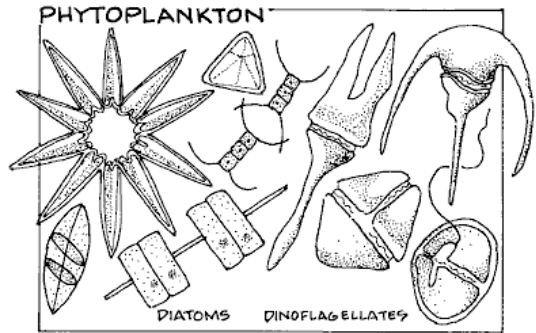
## ***Ozone Depletion and the Immune System***

Scientific research suggests that sunburn can alter the distribution and function of disease-fighting white blood cells in humans for up to 24 hours after exposure to the Sun. In addition, repeated exposure to UV radiation may cause more long-lasting damage to the body's immune system. Whilst little research has been conducted on the effects of decreasing stratospheric ozone on human immunity, it is likely that continued destruction of the ozone layer will lead to further health complications, in addition to skin cancers and eye disorders, as a result of the suppression of our ability to fight off disease.

# 14. Ozone Depletion & Aquatic Life

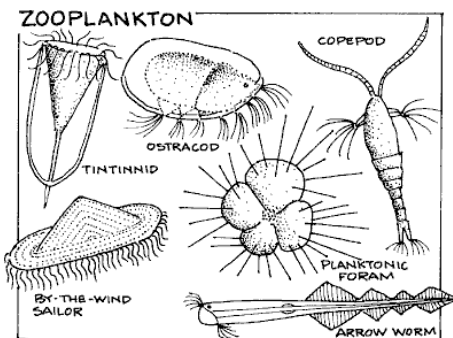
## Introduction

Phytoplankton and zooplankton, microscopic marine organisms which play crucial roles in complex ecological food webs, are sensitive to UV radiation. Because UV-B radiation is absorbed by only a few layers of cells, large organisms are



more protected, whilst smaller ones, such as unicellular organisms in aquatic ecosystems, are among the most severely affected by UV radiation. Depletion of the ozone layer could have drastic effects on plankton and other small marine organisms at the base of the ocean

food chain. These creatures are highly sensitive to UV radiation because they lack protective outer layers. The increase in UV radiation threatens growth and survival of the tiny creatures that provide the original food source for the rest of the ocean food chain.



## UV-B and Marine Organisms

Plankton form the foundation of aquatic food webs. Plankton productivity is limited to the euphotic zone, the upper layer of the water column in which there is sufficient sunlight to support the photosynthesis of food. Since UV radiation has the ability to penetrate up to 20 metres down in clear water, plankton and other light dependent organisms often experience cell damage, much as human DNA can be damaged by the strong solar radiation. Both plant

(phytoplankton) and animal (zooplankton) species are damaged by UV-radiation even at current levels. As with certain land plants, some species are more sensitive to UV-light at critical stages in their life cycle, and changes in radiation may shorten the breeding period to intolerable levels. As plankton make up the base of the marine food chain, changes in their number and species composition will influence fish and shellfish production world-wide. These kinds of losses will have a direct impact on the food supply.

Solar UV-B radiation has also been found to cause damage to the early developmental stages of fish, shrimp, crab, amphibians and other animals. The most severe effects are decreased reproductive capacity and impaired larval development. Even at current levels, solar UV-B radiation is a limiting factor, and small increases in UV-B exposure could result in a significant reduction in the size of the population of animals that eat these smaller creatures.

### ***Ozone Depletion and Marine Organisms***

Research indicates that many plankton species already seem to be at or near their maximum tolerance of UV radiation. Thus, even small increases in UV-B levels may have a dramatic impact on plankton life and on entire marine ecosystems. Some research suggests that ozone depletion is more likely to change the composition of living organisms on the ocean's surface than to reduce its overall mass.

If ozone-layer depletion reached 15% over temperate waters, it would take less than five days in summer for half the zooplankton in the top metre of these waters to die from the increased radiation. Additionally, large amounts of young fish, shrimp and crabs would die before reaching their reproductive age. Less food would be available for adult fish and other higher forms of marine life, and therefore for human consumption. This is of particular relevance, as more than 30% of the world's animal protein for human consumption

comes from the sea. One study of plankton estimates that a 25% reduction in ozone would lead to a 10% loss in primary production throughout the sunlit, biologically rich upper layer of the ocean, and a 35% reduction near the surface of the water.

Effects of the ozone hole in Antarctica have already been seen in some of the organisms. Most of the Antarctic organisms have a low tolerance for UV radiation since for most of the year, hardly any direct sunlight reaches the continent. With the reduced ozone in springtime, UV-B radiation has been able to penetrate the atmosphere with a higher intensity. Already, on the base of the Antarctica food chain, an impact has been felt. UV-B radiation has already reduced the plankton populations by between 6% and 12%. Consequently, species higher up have felt the impact.

# 15. Ozone Depletion & Land Vegetation

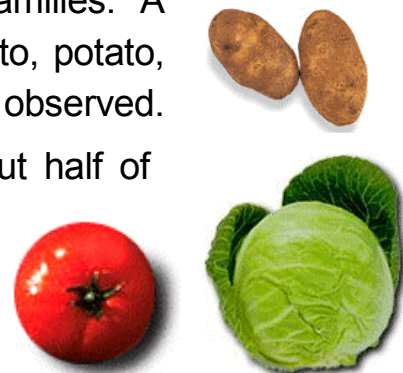
## Introduction

Excessive UV-B inhibits the growth processes of almost all green plants. There is concern that ozone depletion may lead to a loss of plant species and reduce global food supply. Any change in the balance of plant species can have serious effects, since all life is interconnected. Plants form the basis of the terrestrial food web, prevent soil erosion and water loss, and are the primary producers of oxygen and a primary sink (storage site) for carbon dioxide, a greenhouse gas.

## UV-B and Land Plants

Exposure to UV-B radiation may have a dramatic effect on terrestrial plant life, although the impacts are at present poorly understood. Absorption of UV radiation varies widely from one organism to the next. In general, UV radiation deleteriously affects plant growth by reducing leaf size and limiting the area available for energy capture during photosynthesis. Plant stunting and a reduction in total dry weight are also typically seen in UV-irradiated plants, with a reduction in the nutrient content and the growth of the plants, especially in the legume and cabbage families. A reduction in quality of certain types of tomato, potato, sugar beet and soya bean has also been observed.

Forests also appear to be vulnerable. About half of the species of conifer seedlings so far studied have been adversely affected by UV-B at a variety of levels. Although old needles are able to protect themselves by



strengthening their outer wax coating and by increasing the amount of protective pigment, young growing pine needles, in contrast, suffer easily.

Indirect changes caused by UV-B radiation (such as flowering and germination rates, changes in plant form and how nutrients are distributed within the plant) may be more important than damaging effects of the radiation itself. These changes can have important implications for plant competitive balance, plant diseases, and biogeochemical cycles. However, reliable scientific information on the effects of UV on plants is limited. Only four out of 10 terrestrial plant ecosystems (temperate forest, agricultural, temperate grassland, and tundra and alpine ecosystems) have been studied. In addition, much of the existing data come from greenhouses where plants are more sensitive to UV-B than those grown outdoors. There are indications that some weeds are more UV-B resistant than crops. Many organisms have developed mechanisms for protecting themselves from UV-B, for example by avoiding exposure, shielding themselves with pigment and repairing damaged DNA or tissue damage. However, for many organisms these mechanisms may not be sufficient to protect against increased levels of UV-B.

In summary, physiological and developmental processes of plants are affected by UV-B radiation, even by the amount of UV-B in present-day sunlight. Despite mechanisms to reduce or repair these effects and a limited ability to adapt to increased levels of UV-B, plant growth can be directly affected by UV-B radiation.

### ***Ozone Depletion and Land Plants***

The greatest risks connected with the depletion of ozone in the stratosphere are ecological. Exposure tests made in USA and Australia have showed that over one hundred species of land plant could be sensitive to increases in UV-B radiation as a result of stratospheric ozone depletion. Some research has suggested that a

25% ozone depletion could result in a comparable reduction in total soya bean crop yield.

International research has revealed that some species of rice suffer from even minor increases in UV radiation. With the help of research, as well as the efficient breeding and cultivation of strong species it will be possible to be prepared for years with a considerably decreased prevailing level of ozone.

## **16. Other Effects Of Ozone Depletion**

### **Introduction**

As well as the effects to human health, land plants and aquatic life, which may occur as a consequence of ozone depletion, there are other impacts which could result from prolonged destruction of ozone in the stratosphere. These include damage to polymers used in buildings, paints and packaging, and changes in biogeochemical cycles affecting ground-level pollution (smog), acid rain and even climate change.

### **Damage to Polymers**

Ozone depletion will cause many materials to degrade faster. These materials include PVC (used in window and door frames, pipes and gutters, etc.), nylon and polyester. They are all composed of compounds known as polymers. Synthetic polymers, naturally occurring biopolymers, as well as some other materials of commercial interest are adversely affected by solar UV radiation. Today's materials are somewhat protected from UV-B by special additives. Therefore, any increase in solar UV-B levels as a result of ozone depletion will therefore accelerate their breakdown, limiting how long they are useful outdoors. Shorter wavelength (i.e. more energetic) UV-B radiation is mainly responsible for photo-damage ranging from discoloration to loss of mechanical integrity in polymers exposed to solar radiation.



The use of higher levels of conventional light stabilisers in polymer-based materials are likely to be employed to mitigate the effects of increased UV levels in sunlight. However, it is not certain how

resistant such light stabilisers are themselves to increased levels of UV-radiation. In addition, their use will add to the cost of plastic products in target applications. With plastics rapidly displacing conventional materials in numerous applications, this is an important consideration particularly in the developing world.

It is not certain yet how other materials, including rubber, paints, wood, paper and textiles will be affected by increased UV radiation resulting from ozone depletion.

### ***Effects on Biogeochemical Cycles***

Increases in solar UV radiation could affect terrestrial and aquatic biogeochemical cycles, thereby altering both sources and sinks of greenhouse and chemically-important trace gases e.g., carbon dioxide (CO<sub>2</sub>), carbon monoxide (CO), carbonyl sulphide (COS) and possibly other gases, including ozone. These potential changes would contribute to biosphere-atmosphere feedbacks that attenuate or reinforce the atmospheric build-up of these gases. Likely effects include an increase in smog in urban centres, and acid rain in rural areas.

### ***Effects on Climate***

Whilst increases of UV radiation as a result of ozone depletion may affect the production and removal of carbon dioxide, the main greenhouse gas, ozone depletion itself can influence the global climate. Ozone is also a greenhouse gas, and as well as filtering out the incoming short-wave solar radiation, can absorb much of the outgoing long-wave terrestrial radiation (infrared radiation). If stratospheric ozone is destroyed, ozone's greenhouse effect is reduced and this could lead to a global cooling,



offsetting some of the warming that may be occurring as a result of man-made emissions of carbon dioxide, methane and nitrous oxide. Ironically, when the ozone layer starts to repair itself in the next century as a result of a control on CFCs, this cooling potential will be lost. More significantly, the replacement chemicals to CFCs, the HCFCs, which themselves do not harm the ozone layer, are very strong greenhouse gases, and are further contributing to the potential problem of global warming.

# 17. The Montreal Protocol

## ***Introduction***

In 1985 an international agreement, the Vienna Convention, was signed after three years of negotiating under the auspices of the United Nations Environment Programme. The Vienna Convention established mechanisms for international co-operation in research, monitoring, and exchange of data on emissions, on concentrations of CFCs and halons, and on the status of stratospheric ozone. It also set a framework for international negotiations on actual reductions of emissions. That same year, 1985, marked another seminal development in the evolution of scientific and public policy recognition of the stratospheric ozone issue - the discovery of the Antarctic ozone hole. On the basis of the Vienna Convention (1985), *the Montreal Protocol on Substances that Deplete the Ozone Layer* was negotiated and signed by 24 countries and by the European Economic Community in September 1987. The Protocol called for the Parties to phase down the use of CFCs, halons and other man-made halocarbons.

## ***The Protocol***

The Montreal Protocol represented a landmark in the international environmentalist movement. For the first time whole countries were legally bound to reducing and eventually phasing out altogether the use of CFCs and other ozone depleting chemicals. Failure to comply was accompanied by stiff penalties. The original Protocol aimed to decrease the use of chemical compounds destructive to ozone in the upper atmosphere by 50% by the year 1999. The agreement was supplemented by agreements made in London in 1990 and in Copenhagen in 1992, by which the same countries promised to stop using CFCs and most of the other chemical compounds destructive to

ozone by the end of 1995. The Protocol has been subsequently amended twice more, at Montreal in 1997 and at Beijing in 1999.

In most cases it has been fairly easy to develop and introduce compounds and methods to replace CFC compounds. CFC use in aerosols and foam plastic packaging has already been abandoned in most countries. On the other hand, compounds capable of replacing CFC compounds in cooling devices and insulating materials are still under development.

In order to deal with the special difficulties experienced by developing countries it was agreed that they would be given 10 years grace, so long as their use of CFCs did not grow significantly. China and India, for example, are strongly increasing the use of air conditioning and cooling devices. Using CFC compounds in these devices would be cheaper than using replacement compounds harmless to ozone. An international fund has therefore been set up to help these countries to introduce new and environmentally more friendly technologies and chemicals. The depletion of the ozone layer is a world-wide problem which does not respect the frontiers between different countries. It can only be affected through determined international co-operation.

### ***The Timetable***

#### *Montreal Protocol (1987)*

CFCs (11, 12, 113, 114, 115): Phase down 1986 levels by 20% by 1994; 50% by 1999.

#### *London Amendment (1990)*

CFCs 13, 111, 112, 211, 212, 213, 214, 215, 216, 217: Phase down 1989 levels 20% by 1993; 85% by 1997; 100% by 2000.

Halons (1211, 1301, 2402): Phase down 1986 levels 50% by 1995; 100% by 2000.

Carbon Tetrachloride: Phase down 1989 levels 85% by 1995; 100% by 2000.

*Copenhagen Amendment (1992)*

CFCs: phase out by 1995

Halons: phase out by 1993

Carbon Tetrachloride: phase out by 1995

HCFCs: phase down 1989 levels 35% by 2004; 90% by 2014; 100% by 2029.

The Beijing Amendment (1999) has introduced a freezing of HCFC production by 2003.

## **18. Can Ozone Depletion Be Reversed?**

### ***Introduction***

Can the hole in the ozone layer be repaired? Yes. If concentrations of ozone-destroying chemicals are reduced, the natural balance between ozone creation and destruction can be restored. However, this might require the complete elimination of CFCs, halons, carbon tetrachloride, methyl chloroform, and methyl bromide. In late 1991, scientists estimated that even with the current global schedule to eliminate ozone-destroying substances, the ozone layer would not return to 'normal' (pre-1980 chlorine levels) until the middle of the 21st century. Nevertheless, the 1998 World Meteorological Organization Scientific Assessment of Ozone Depletion observed that abundance of ozone-depleting compounds in the lower atmosphere (below the stratosphere) is now slowly declining from a peak in 1994.

### ***Phasing Out CFCs***

The initial concern about the ozone layer in the 1970s led to a ban on the use of CFCs as aerosol propellants in several countries, including the U.S. However, production of CFCs and other ozone-depleting substances grew rapidly afterwards as new uses were discovered. Through the 1980s, other uses expanded and the world's nations became increasingly concerned that these chemicals would further harm the ozone layer. In 1985, the Vienna Convention was adopted to formalise international co-operation on this issue. Additional efforts resulted in the signing of the Montreal Protocol in 1987. After the original Protocol was signed, new measurements showed worse damage to the ozone layer than was originally expected. In 1992, reacting to the latest scientific assessment of the ozone layer, the Parties decided to completely end production of halons by the

beginning of 1994 and of CFCs by the beginning of 1996 in developed countries.

Between 1986 and 1991, world-wide consumption of CFCs-11, CFC-12 and CFC-113 decreased by 40%, ahead of the schedule outlined in the Montreal Protocol and faster even than called for in the more ambitious 1990 London Amendment to the Montreal Protocol. Manufacturers, who were earlier convinced that CFCs were unique and irreplaceable, were finding themselves moving quickly to alternative processes and chemicals. Hydrocarbons have replaced CFCs as aerosol propellants and as blowing agents for foams, and as cleansing solvents in electronics manufacturing. HCFCs, which have much smaller ozone depleting potentials have replaced CFCs for refrigeration and air conditioning.

### ***Are International Agreements Enough?***

Without the Montreal Protocol, continued use of CFCs and other compounds would have tripled the stratospheric abundance of chlorine and bromine by 2050. Because of measures taken under the Protocol, emissions of ozone-depleting substances are already falling. Under current agreements, the stratospheric concentrations of chlorine and bromine are expected to reach their maximum within a few years and then slowly decline, although concentrations of chlorine are already falling in the troposphere. With evidence that international agreements to phase out the use of ozone depleting chemicals appear to be working, both NASA (the North American Space Agency) and NOAA (the National Oceanographic and Atmospheric Administration) in the United States of America have expressed confidence that, all other things being equal, the stratospheric ozone layer should return to normal by the middle of the next century. The recovery of the ozone layer will be gradual because of the long times required for CFCs to be removed from the atmosphere; some take as long as several hundred years. Nevertheless, the likelihood remains that deep ozone holes will

continue to form annually in the polar regions, well into the next century. This situation will persist until stratospheric chlorine levels decrease.

According to the Intergovernmental Panel on Climate Change (IPCC), even if the control measures of the 1990 London and 1992 Copenhagen Amendments were to be implemented by all nations, the abundance of stratospheric chlorine and bromine will increase over the next several years. The Antarctic ozone hole, caused by industrial halocarbons, will therefore recur each spring. In addition, since these gases are also responsible for the observed reduction in middle and high latitude stratospheric ozone, the depletion at these latitudes is predicted to continue unabated for at least 5 to 10 years.

# ***19. Waste Regulation & Trade Control Of Ozone Depleters***

## ***Introduction***

Under the terms of the Montreal Protocol developed nations have ceased production of new CFCs, halons and other ozone depleting chemicals. Trade controls on the supply of these substances have been put in place to ensure compliance with the Protocol. Existing CFCs are re-used and recycled where possible. Nevertheless, the increasing price of CFCs as a result of the ban on new production has led to a wave of international smuggling.

## ***Waste Regulation and Recycling***

Usually, when ozone depleting substances are discarded or removed from equipment during the course of maintenance they become controlled waste. In Britain, the Environmental Protection Act (1990) has ensured that waste chemicals which may contribute to stratospheric ozone depletion are disposed of as carefully as possible to avoid any release to the atmosphere.

The production and consumption of new halons (halocarbons containing bromine) has already ceased under the terms of the Montreal Protocol. However, whilst replacements have been developed these cannot be used in existing systems, which can only be maintained with recycled halons using surplus material from redundant installations. In the UK the Halon Users' National Consortium (HUNC) is managing the installed banks of halons, acting as a clearing house putting those who need to continue to use halons in contact with those who do not.

The Montreal Protocol and subsequent amendments have demanded that existing CFCs should be recovered, recycled and re-used where possible. Commercial users of refrigeration and air conditioning appliances can contact the Refrigeration Industry Board to ensure that best industrial practice is maintained during the disposal or re-use of CFCs. Domestic users of old refrigerators can contact their local authority to find out if it operates a CFC recovery and recycling scheme.

### ***Trade Controls***

The Montreal Protocol works through a system of trade barriers controlling supply to the market of ozone depleting chemicals. Imports of newly produced CFCs and halons by developed countries have already been banned, as have imports and exports in carbon tetrachloride and 1,1,1 trichloroethane. Developing countries have been granted a period of grace to comply with the Montreal Protocol, to avoid undue stresses on their fledgling economies.

### ***CFCs Smuggling***

As a result of the decline in the production and use of CFCs, and the continuation of CFC production in developing countries (allowed under the provisions of the Montreal Protocol until 2010), the lure of illegal trade in CFCs is obvious. Significant volumes of illegal imports of CFCs into Western Europe have been reported, even though production in Western Europe ceased at the end of 1994. The Montreal Protocol currently does not require Parties to it to implement controls against illegal trade. However, the eighth meeting of the Conference of Parties, held in November 1996 in Costa Rica, urged countries to install verification programs to reduce illegal trade in ozone-depleting substances.

## ***20. Saving The Ozone Layer & Protecting Our Health***

### ***Introduction***

International agreements, if legally binding, go a long way to solving environmental problems like that of ozone depletion. However, for there to be real and long-lasting success, everyone must become part of the solution. The collective impact of environmental citizenship is much greater than the sum of the parts. Individual efforts taken together can be powerful forces for environmental change. There are a number of things that we, as individuals, can do to both protect the ozone layer and to safeguard our health against the effects of increasing ultraviolet radiation.

### ***Protecting our Health***



Sunglasses that provide 99-100% UV-A and UV-B protection will greatly reduce sun exposure that can lead to cataracts and other eye damage. Check the label when buying sunglasses.

A hat with a wide brim offers good sun protection to your eyes, ears, face, and the back of your neck - areas particularly prone to overexposure to the Sun.



Tightly-woven, loose-fitting clothes offer excellent protection against UV. Any clothing is better than none at all.

A sunscreen with protection factor of at least 15 blocks most harmful UV radiation. Apply sunscreen liberally and reapply every 2 hours

when working, playing, or exercising outdoors. Even waterproof sunscreen can come off when you dry yourself off with a towel.

The Sun's UV rays are strongest between 10 a.m. and 4 p.m. To the extent you can, limit exposure to the Sun during these hours.

Sunlamps damage the skin and unprotected eyes and are best avoided entirely.

## ***Protecting the Ozone Layer***

There are a number of steps that we can all take, both as individuals and as groups, to protect the Earth's fragile shield. We have all been part of the ozone depletion problem, through the use of chemicals in everyday products. However, we can all be part of the solution.



Following the Montreal Protocol most ODCs have or are being phased out of use in most target applications such as aerosols, refrigeration and air conditioning (e.g. in cars). However, consumer products bought prior to international agreements may still be in use in our homes and offices and cannot easily be replaced. Large appliances, such as refrigerators, have long lifetimes and early replacement would entail great cost. Proper care and maintenance of equipment to ensure that the CFCs they contain are never released to the stratosphere should be applied. Remember, a single CFC molecule can destroy 100,000 ozone molecules.

In addition, if purchasing fire extinguishers try to avoid any that contain halons. Purchase carbon dioxide, water, or dry chemical extinguishers instead. Finally, although foam packaging is CFC-free, some products contain HCFCs, which while far less damaging to the ozone layer, could contribute substantially to global warming. Avoid those that do. Use and re-use non-disposable packaging.

# Glossary

## **Anthropogenic**

Man-made or human induced.

## **Atmosphere**

A mixture of gases surrounding the Earth. Earth's atmosphere consists of 79.1% nitrogen (by volume), 20.9% oxygen, 0.036% *carbon dioxide* and trace amounts of other gases. It can be divided into a number of layers according to thermal properties (temperature). The layer nearest the earth is the *troposphere* (up to about 10-15km above the surface), next is the *stratosphere* (up to about 50km). There is little mixing of gases between layers.

## **British Antarctic Survey (BAS)**

A scientific body engaged in all aspects of research on the continent of Antarctica.

## **Carbon dioxide (CO<sub>2</sub>)**

A molecule formed from one atom of carbon and two of oxygen. Carbon dioxide (CO<sub>2</sub>) is a greenhouse gas of major concern in the study of global warming. It is estimated that the amount in the air is increasing by 0.27% annually. *Anthropogenic* carbon dioxide is emitted mainly through the burning of fossil fuels and deforestation.

## **Chlorofluorocarbons (CFCs)**

Synthetically produced compounds containing varying amounts of chlorine, fluorine and carbon. Used in industrial processes and as a propellant for gases and sprays. In the *atmosphere* they are responsible for the depletion of *ozone* and can destroy as many as 10,000 molecules of ozone in their long *lifetime*. Their use is now currently restricted under the *Montreal Protocol*.

**Concentration**

A measure of the atmospheric content of a gas, defined in terms of the proportion of the total volume that it accounts for. *Greenhouse gases* are trace gases in the *atmosphere* and are usually measured in parts per million by volume (ppmv), parts per billion by volume (ppbv) or parts per trillion (million million) by volume (pptv).

**Copenhagen Amendment**

A second amendment to the Montreal Protocol to speed up the phase out of chemicals that deplete the ozone layer.

**DNA**

Deoxyribonucleic acid, the basic unit of chromosomes which make up all living organisms

**Dobson Unit (DU)**

A unit measuring the total amount of ozone in a vertical column above the Earth's surface in the stratosphere. A value of less than 200DU is associated with the presence of an ozone hole.

**Halocarbons**

Man-made substances including the *chlorofluorocarbons* and *halons*.

**Halons**

These man-made substances are similar to *chlorofluorocarbons* but contain bromine. They also destroy the *ozone layer*.

**Hydrochlorofluorocarbons (HCFCs)**

Synthetically produced compounds containing varying amounts of hydrogen, chlorine, fluorine and carbon. Used as replacements for *chlorofluorocarbons*. They have large *global warming potentials* and current emissions are helping to enhance the natural *greenhouse effect*.

**Hydrofluorocarbons (HFCs)**

Synthetically produced compounds containing varying amounts of hydrogen, fluorine and carbon. Used as replacements for *chlorofluorocarbons*. They have large *global warming potentials* and current emissions are helping to enhance the natural *greenhouse effect*.

**London Amendment**

A first amendment to the Montreal Protocol to speed up the phase out of chemicals that deplete the ozone layer.

**Montreal Protocol**

The discovery of an ozone hole over Antarctica prompted action to control the use of gases which have a destructive effect on the *ozone layer*. From this concern emerged the Montreal Protocol on substances that deplete the ozone layer, signed by 24 countries in 1987. It came into force in 1989 and has since been ratified by 120 countries. The original agreement was to control and phase out the production and supply of ozone depleting chemicals, specifically CFCs (*chlorofluorocarbons*) and derivatives. A meeting in 1992 was held in Copenhagen to revise the Protocol. This meeting agreed to bring forward the phase out of *halons* to 1994, and CFCs and other *halocarbons* to 1996. These targets have since been met.

**Nanometre**

$10^{-9}$  metre (or one billionth of a metre).

**Nitrogen Oxides (NO<sub>x</sub>)**

Atmospheric pollutants consisting of one molecule of nitrogen and varying numbers of oxygen molecules. They are produced in the emissions of vehicle exhausts and from power stations.

**Ozone hole**

*Stratospheric* ozone depletion over the Antarctic. The hole appears every southern hemisphere spring (August to October) before disappearing during the summer months (December / January).

## Ozone Layer

The *ozone* in the *stratosphere* is very diffuse, occupying a region many kilometres in thickness, but is conventionally described as a layer to aid understanding.

## Ozone (O<sub>3</sub>)

Ozone consists of three atoms of oxygen bonded together in contrast to normal atmospheric oxygen which consists of two atoms of oxygen. Ozone is formed in the *atmosphere* and is extremely reactive and thus has a short *lifetime*. In the *stratosphere* ozone is both an effective *greenhouse gas* (absorber of *infra-red radiation*) and a filter for solar *ultra-violet radiation*. Ozone in the *troposphere* can be dangerous since it is toxic to human beings and living matter. Elevated levels of ozone in the troposphere exist in some areas, especially large cities as a result of *photolytic* reactions of *hydrocarbons* and oxides of nitrogen, released from vehicle emissions and power stations.

## Plankton

Aquatic and usually microscopic organisms that feed in the world's oceans. Phytoplankton feed by *photosynthesis* whilst zooplankton refers to animal life forms.

## Photolysis

A chemical reaction involving sunlight in which molecules are split into their constituent atoms. Also known as photodissociation.

## Photosynthesis

The process by which green plants use light to synthesise organic compounds from carbon dioxide and water. In the process oxygen and water are released. Increased levels of carbon dioxide can increase net photosynthesis in some plants. Plants create a very important sink for carbon dioxide. See also carbon cycle.

**Polar Stratospheric Clouds (PSCs)**

High altitude clouds that form in the stratosphere above Antarctica during the Southern Hemisphere winter. Their presence seems to initiate the ozone loss experienced during the ensuing Southern Hemisphere spring.

**Polar Vortex**

A circumpolar wind circulation which isolates the Antarctic continent during the cold Southern Hemisphere winter, heightening ozone depletion.

**Pollutant**

Strictly too much of any substance in the wrong place or at the wrong time is a pollutant. More specifically, atmospheric pollution may be defined as 'the presence of substances in the atmosphere, resulting from man-made activities or from natural processes, causing adverse effects to man and the environment'.

**Radiation**

Energy emitted in the form of electromagnetic waves. Radiation has differing characteristics depending upon the wavelength. Radiation from the Sun has a short wavelength (ultra-violet) whilst energy re-radiated from the Earth's surface and the atmosphere has a long wavelength (infra-red).

**Spectrum**

The range of wavelengths of electromagnetic radiation.

**Stratosphere**

A layer in the *atmosphere* above the *troposphere* extending upwards to about 50km. The stratosphere contains much of the total atmospheric *ozone*. The temperature in this region increases with height and can exceed 0°C in the summer. The air density here is much less than in the troposphere. It is not thought that the stratosphere has much influence on the weather on the Earth's surface.

**Stratospheric ozone depletion**

Loss of *ozone* in the *stratosphere* due to its *photolytic* destruction by the *chlorofluorocarbons* and *halons*. Most commonly associated with the annual appearance of an *ozone hole* over the Antarctic every southern hemisphere springtime.

**Tropopause**

The boundary between the *troposphere* and the *stratosphere*.

**Troposphere**

The lowest layer of the *atmosphere*. The altitude of the troposphere varies with latitude, from about 16km at the equator to only 8km at the poles. Normally there is a decrease in temperature with height. This layer contains 75% of the total gaseous mass of the atmosphere and virtually all the water vapour and *aerosols*. This zone is responsible for most of the weather phenomena experienced and where atmospheric turbulence is most marked.

**Ultraviolet radiation (UV)**

Electromagnetic *radiation* of higher frequencies and shorter wavelength than visible light. There are three categories of UV radiation: UV-A, between 320 and 400 nm; UV-B, between 280 and 320 nm; UV-C, between 200 and 280 nm.

**Volatile organic compounds**

These are an important class of air pollutant found in the atmosphere at ground level in urban and industrial centres. They are usually defined as carbon-containing organic compounds present in the atmosphere as gases, excluding elemental carbon, carbon monoxide, methane and *carbon dioxide*.

**Wavelength**

A measure of the length of electromagnetic radiation waves.

## Extra Reading

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