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Mario Molina puts ozone on the political agenda

Teachers notes

Objectives

- To illustrate how scientific theories can influence politics and manufacturing industry.
- To interpret real ozone data.
- To understand that, over time, the composition of the atmosphere has changed and that human influence is responsible for some of the changes.
- To know what chlorofluorocarbons (CFCs) are and their uses.

Outline

The student material is divided into three different sections:

- An information sheet on Mario Molina
- Understanding ozone
- The CFC- ozone story

Two versions of the material have been included:
Version 1 is aimed at the more able 14–16 year old student, providing plenty of opportunity for project work including searching for data on the Internet, interpreting articles and analysing data in order to make an informed decision on environmental issues.
Version 2 is a simpler version, focusing on how ozone protects the earth from UV radiation, what would happen if there was a hole in the ozone layer and what all the fuss about CFCs is really about. A timeline activity is also provided to put the material in context.

Teaching topics

This selection of activities is suitable for 14–16 year olds and could be included when teaching about the properties, reactions and uses of the halogens or about the atmosphere. It could also be used when teaching about health, safety and risk.

Background information

From Molina's initial discovery in December 1973 right up to the present day, CFCs have been discussed by scientists, politicians, research scientists, industrialists, environmental groups and ordinary people. The subject has been, at times, controversial and in the early years the scientific data was limited, the chemistry of the stratosphere was not well understood and some pressure groups tried to say ozone depletion was due to natural causes and not man-made chemicals. As more scientific evidence was collected, showing that ozone depletion was due to man-made chemicals, worldwide governments worked together to ban CFC production. Eventually industry (in developed countries) agreed to stop making the chemicals, just as some developing countries were starting to set up CFC production plants and so a separate agreement had to be made with them.

Rowland and Molina were faced with a real problem of ethics. Should they tell the world and try and stop ozone production or should they just get on with the next piece

of science? This work could be used to present this type of dilemma, and question the responsibility of scientists and the scientific world. There are many newspaper articles which could be used to start discussion, such as 'Pressure on the aerosol business' and 'First moves towards a CFC free Britain', both of which have been included at the end of these teaching notes. Both of these articles show how different groups, such as industry and Friends of the Earth, responded to the threat of ozone destruction. Both articles include some background information to the CFC-ozone problem.

Ozone in the troposphere – health risks

Ozone is a poisonous gas. The World Health organisation recommends a maximum hourly dose of 80 ppb. Many countries give ozone alerts when ozone levels are high. During such an alert, people, especially children and the elderly, are advised to stay inside. The table lists observed symptoms at different ozone levels.

Ozone dosage (hourly levels ppb)	Symptoms
50	Headaches
150	Eye irritation
270	Coughs
290	Chest discomfort

Table 1 Ozone dosage

Ozone chemistry of the stratosphere

Ozone is produced continually in the upper stratosphere where UV radiation from the sun dissociates molecular oxygen to form atomic oxygen.

$O_2 + h\nu \rightarrow O + O$

$O + O_2 \rightarrow O_3$

The reaction occurs very rapidly in the stratosphere over the tropics, where solar radiation is most intense. Circulation in the stratosphere constantly moves ozone away from the tropics towards the poles.

Ozone is destroyed when it constantly absorbs UV light that would otherwise reach the Earth's surface.

$O_3 + h\nu \rightarrow O_2 + O$

There is no net ozone depletion because the process produces atomic oxygen that reacts with molecular oxygen to produce another ozone molecule.

Ozone is continually being destroyed through reactions with naturally occurring radicals of Cl, N, H or O atoms. The ozone hole problem started to occur when the concentrations of chlorine radicals in the stratosphere started to increase as a result of man-made products. The natural cycle of ozone production and destruction was put out of balance, leading to an overall ozone deficit.

Mechanism for CFC-ozone destruction:
First CFCs break down to form chlorine (Cl) radicals.

$CFCl_3(g) + h\nu \rightarrow CFCl_2(g) + Cl(g)$

$CF_2Cl_2(g) + h\nu \rightarrow CF_2Cl(g) + Cl(g)$

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The chlorine radicals then react with ozone in a chain reaction.

$O_3(g) + Cl(g) + h\nu \rightarrow O_2(g) + ClO(g)$

$ClO(g) + O(g) \rightarrow O_2(g) + Cl(g)$

The overall effect on ozone is:

$O_3(g) + O(g) \rightarrow 2O_2(g)$

Sometimes the ClO produced may react with nitrogen compounds but more chlorine radicals are then produced:

$ClO(g) + NO_2(g) \rightarrow ClONO_2(g)$

$ClONO_2(g) + HCl(s) \rightarrow Cl_2(g) + HNO_3(s)$

$Cl_2(g) + h\nu \rightarrow 2Cl(g)$

The chlorine radicals then react with ozone as follows:

$2Cl(g) + 2O_3(g) \rightarrow 2ClO(g) + 2O_2(g)$

$2ClO(g) + M \rightarrow Cl_2O_2(g) + M$ where M is a third body

$Cl_2O_2(g) + h\nu \rightarrow ClO_2(g) + Cl(g)$

$ClO_2(g) + M \rightarrow Cl(g) + O_2(g) + M$

The overall effect on ozone is:

$2O_3(g) \rightarrow 3O_2(g)$

The dramatic seasonal ozone depletion comes at a time of year when there are no oxygen atoms present. In the stratosphere, a stream of air known as the polar vortex circles Antarctica in winter. Air trapped within this vortex becomes extremely cold during the polar night. Temperatures drop low enough to form clouds. The polar stratospheric clouds provide surfaces for chlorine producing reactions (as shown above). By spring the stage is set for chlorine to chew up ozone as the sun rises and ends the long Antarctic polar night. Sunlight splits the molecular chlorine into chlorine atoms that attack ozone, forming molecular oxygen and ClO. The ClO forms a dimer, which in turn, is photolysed to chlorine atoms, which attack more ozone, forming a hole. The hole disappears when the polar vortex finally breaks down after the spring sun warms the air over the Antarctic. Air then sweeps in from lower altitudes, bringing nitrogen oxides that tie up the active chlorine and ozone that fills the hole.

Teaching tips

This topic presents several opportunities for group discussions on topics such as scientific ethics, how scientists communicate their work and the responsibility scientists and consumers have to protect the environment.

When introducing this work, it is extremely important to stress that the CFC-ozone story continues today. Scientists monitor the amount of ozone in the stratosphere daily, and it is this data that will be interpreted during the lesson.

The information sheet on Mario Molina can be used to set the scene either by recounting the story to the class or by getting the students to read it for themselves.

The student sheet ‘Understanding ozone’ introduces the students to ozone.

The CFC-ozone story student sheet offers a structured approach to telling the story and interpreting ozone data.

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The timeline

- This provides a way of telling the story and it sets a context for students to relate to in terms of other things that were happening at the same time. Students should be encouraged to add to the timeline as they research the topic further.
- Making the timeline may not be appropriate for all students. If you feel that the task is not demanding enough for the class, give them a ready made timeline and ask them to discuss in groups the different ways the scientists communicated with the world and the response that the world made.

Interpreting the data

If possible the students look up and download their own data from the Internet. The advantage of the students going to the websites themselves should reinforce the fact that there are many scientists monitoring ozone levels on a daily basis. The topic they are learning about is undergoing scientific investigation all the time.

For those who do not have web access, ozone data obtained by the British Antarctic Survey has been included for 1999-2000.

Resources

- Glue & scissors
- Internet access
- Student worksheets:
  – The timeline
  – Mario Molina (1943–) information sheet
  – Mario Molina version 1 – understanding ozone and
  – Mario Molina version 1 – the CFC-ozone story
  or Mario Molina version 2

Timing

Approximately 30 minutes if given the outline or 60 minutes for groups making up their own outline for the timeline.

One or two lessons or homework for the work with Mario Molina.

Opportunities for ICT

Using the Internet to obtain up to date information.

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Newspaper Articles

Pressure on the aerosol business

by Derek Harris

Britain's aerosol industry is squaring up to resurgence of the ozone controversy, one result of which could mean large capital spending on new equipment and some company closures with job losses.

It could create a particular problem for ICI as principal supplier in Britain of the aerosol propellants called chlorofluorocarbons. These could be outlawed because it is claimed they thin the ozone layer in the stratosphere.

The ozone layer protects the earth from the sun's ultra-violet radiation. An increase in radiation is likely to cause a greater incidence of skin cancer in white people.

Although evidence on ozone depletion has yet to emerge, Sweden is banning most aerosol sprays from January next year. In the United States, Oregon has brought in a shop ban on many aerosols - while allowing hairdressers, for instance, to buy and use aerosol hairsprays. After that questionable start federal agencies have moved in with a ban timetable that will stop the manufacture after October 15 of 'non-essential' aerosols using as propellants the chlorofluocarbons, otherwise known as CFCs.

That means in the United States that a third of the goods bought in aerosol packages, such as hair perfume sprays and deodorants, will have to switch to a different propellant not implicated in the ozone controversy, the rest having already ceased using CFCs.

American manufacturers have switched largely to using hydrocarbons like butane or propane as propellants. But in Europe about 70% of aerosols at present use CFCs as propellants, while in Britain the proportion is probably slightly higher.

This is why United Kingdom aerosol fillers and the CFCs' producers are anxious how far and how quickly the EEC will follow in American footsteps. There has been much pressure in Holland, for a ban on CFC aerosols and it is on the cards that the EEC will decide later this year to start a review of the situation.

Studies on the effect of CFCs are already being carried out in this country and West Germany, adding to the research already being done in the United States.

In terms of collected evidence the ozone controversy is at a stage where at any rate doubts can validly be raised about the continued use of CFCs. But the evidence is largely the rest of work on mathematical models, which in itself has produced questions of validity.

Some counter theories are being advanced which, if proved right, could turn what looked like an ozone disaster into at least a manageable problem and possibly barely a problem at all. But it is likely to be several years before there is conclusive evidence.

That leaves the manufacturers of aerosol-packaged products and the can fillers (not all manufacturers fill their own cans) weighing the question of when to spend their money on change and, indeed, what change.

Aerosol packaged goods are a £250m a year industry at retail sales values. Last year 532.5 million cans were filled with products ranging from insecticides and medical products to paints, foods and artificial snow as well as the toiletry products, which make up half the total sector.

Hair sprays are far the most popular aerosol product, accounting for some 30% of total aerosol production.

Companies like Unilever's Gibbs, Beechams, Reckitt & Colman and the Wellcome Foundation are among the manufacturers involved, but there are also contract fillers of which Aerosols International, part of Cadbury Schweppes, is by far the largest.

The options open to the industry are limited. One answer is as quickly as possible to drop the use of CFCs except for the specialist applications for which there is no substitute, such as in medical products like the bronchodilators used by asthmatics.

That would almost certainly mean a switch to the use of the hydrocarbons, which are already used in Britain as elsewhere, particularly in products, which have a water base such as starches and polishes. Hydrocarbons are cheaper - CFCs being three times the price - but they are also flammable.

At one time some of the smelly molecules - usually sulfur derivatives - in butane/propane mixtures made them unsuitable for applications like toiletries, but much purer hydrocarbons from this point of view are now available.

However it poses problems for those making up a propellant "cocktail" for a particular product because of the desirability of countering the flammability. There are some solubility problems compared with

CFCs. But it is the flammability, which poses the biggest cost problem in that if a can-filling factory is not equipped for hydrocarbons large changes are necessary.

Special storage facilities are needed together with other increased safety arrangements in the factory and also in the supply chain after the product has left the factory gate.

For most manufacturers the cost of factory installations alone is likely to run from between £100,000 and £250,000. It is this sort of cost which smaller fillers may not be able to meet. There are around 120 fillers altogether in the United Kingdom, eight being major manufacturers and 20 particularly small.

Some in the industry believe enough of the smaller establishments would be driven out of business to put at risk at least 1,500 out of the 10,000 jobs in the industry.

Nobody believes it would be acceptable to consumers to go back in applications like hair sprays to the old finger-operated pumps that pre-dated the aerosol packages. The use of carbon dioxide or nitrogen with no flammability problem but producing a coarse and too variable a spray, offers no scope although the possibility of a combination with hydrocarbons is being looked at.

ICI, which has a big stake in CFCs not only in producing for the aerosol market, but also in such applications as refrigerants, has been looking at alternative CFCs.

One possibility is to produce a less stable CFC, which would be broken down during its journey to the stratosphere, thus rendering it harmless to the ozone.

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First moves toward CFC free Britain

Jonathan Porritt

By the end of this year, 90 per cent of aerosols on sale in the UK will be CFC-free. Since aerosols have, until now, accounted for more than 60 per cent of CFC use in this country, eliminating them from this particular industrial sector was obviously the single most important thing Britain could do to help protect the ozone layer.

CFCs - chlorofluorocarbons - are contained in the propellant that carries liquid drops from the nozzle of an aerosol can (and also used in refrigerators and air-conditioning units). Once seen as the perfect chemical - odourless, non-flammable and chemically inert - CFCs are so stable that they can hang around the atmosphere for more than 100 years.

However, they also destroy the ozone layer that protects the earth from about 99 per cent of ultra-violet radiation by releasing chlorine as their molecules break down.

Friends of the Earth's campaign to persuade the aerosol manufacturers to phase out CFCs was launched in 1986, and was over by 1988.

First we published our pamphlet, The Aerosol Connection, a detailed list of aerosols, which were not using CFCs.

This was coupled with as much publicity as we could generate at the time to encourage consumers to find out which aerosols they should be buying.

When this "softly-softly" approach failed to elicit anything other than vaguely hostile rebuffs from the aerosol manufacturers, we felt it necessary to prepare an outright boycott of the best-selling CFC-based products in the UK.

The aerosol industry's decision to get out of CFCs by the end of 1989 was taken just three days before the boycott campaign was launched.

In the light of subsequent events, this was obviously a sound decision. But it was actually based on the fear of consumers turning against all aerosols, not just CFC-based aerosols, rather than on any rational assessment of the scientific position.

Consumer awareness is often a somewhat rudimentary weapon, but the industry accurately read the signs of what was happening. Once the Prince of Wales declared that he had banned all aerosols from his household, they knew they were fighting a losing battle.

As a result, the Government found itself in the enviable position of being able to claim international credit for meeting the Montreal Protocol's original target of a 50 per cent reduction in CFC consumption a full 10 years ahead of the target date.

It was this breakthrough, which has allowed them to campaign so actively for an 85 per cent reduction.

But it is important to realize that the Government had nothing to do with this achievement. Until 1987, the Government was lobbying, primarily at ICI's behest, for a freeze on CFC production or, at best, a mere 20 per cent reduction within the Montreal Protocol. Its much-vaunted "voluntary approach" was all but worthless, in that it meant little more than leaving it to voluntary organizations such as Friends of the Earth and the Consumers' Association.

And there are other cautionary postscripts. In the first place, the Government's skilful handling of its propaganda, portraying itself as "the saviour of the ozone layer" has persuaded many people that the problem has been comprehensively dealt with, and that Friends of the Earth should now direct its attention elsewhere.

As it happens, this is far from true. The US Environmental Protection Agency presented some stark predictions to the recent conference in Helsinki on the Montreal Protocol, indicating that ozone levels are unlikely to stabilize at their 1985 levels until around the year 2070, even if we could completely eliminate all CFCs and other ozone-depleting chemicals by the end of 2000.

Second, there is no evidence to indicate that the overall sales of aerosols were affected in any lasting way. Production of aerosols in 1990 is still expected to be more than 800 million units.

Friends of the Earth therefore takes the position that its success is relative. If we have encouraged individuals to set out on the long green road to genuine sustainability, through more environmentally-sensitive lifestyles, we are well pleased.

But if this surge of consumer power amounts to no more than a panic response to the threat of increased skin cancer, then it would be wrong to wax too lyrical about its long-term environmental benefits.

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Answers

Mario Molina puts the atmosphere and ozone on the political agenda – version 1

A. Understanding ozone

1. Sunbathing

	True	False
A sun tan is healthy		Yes
A tan will protect you from the sun		Yes
You can get burnt on a cloudy day	Yes	
You can get burnt if you are in water	Yes	
With sunscreen to protect me, I can sunbathe for much longer.		Yes

B. The CFC-ozone story

2. Carbon, fluorine, chlorine, covalent bonding.

Timeline questions 1,2,3

Level of response marking could be used here.

Evidence questions

1. From this data only approx. 1970.

2. Yes, the graph shows that the October level of ozone is still going down.

3. The amount of ozone depleting chemicals in the atmosphere should peak around 2000, this means that the hole in the ozone layer should stop getting bigger. It will be about 2045 before the amount of ozone depleting chemicals reach the level they were at before the hole was first identified.

4. If the Montreal Protocol and later amendments had not taken place then the amount of ozone depleting chemicals in the stratosphere would have increased from 2 ppb in 1980 to 20 ppb in 2055. This would have destroyed even more ozone, leading to devastating effects on plant and marine life as well as increased cases of skin cancer and cataracts. Instead it is predicted that by 2055 the amount of ozone depleting chemicals will be back to the levels in 1980 and the hole in the ozone well on the way to recovery.

5. December

6. October

7. Up to 100 Dobson units.

8. Figure 2 shows ozone levels at about 300 Dobson units in Octobers before1997, whereas present October levels are at about 100 Dobson units. A drop of 200 Dobson units!

9. End of December and the beginning of January.

10. August / September

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11. As the temperature increases so does the level of ozone in the stratosphere.

12. See the notes above about the polar vortex (page 46).

Optional questions

13. Camborne in Cornwall and Lerwick in Shetland.

14. Annual rate of change in ozone levels is recorded at –0.32% at Camborne and –0.3% at Lerwick.

15. Total Ozone Mapping Spectrometer.

16 & 17 The data is available it just needs to be found!

The story continues

Teachers will need to use their professional judgement in assessing questions 18–20.

Mario Molina – version 2

1. From left to right, toxic, oxidising agent, irritant.

2. Accept general answers for the first question such as irritates the throat or eyes, toxic if too much is breathed in etc.

3. Life needs to be protected from the UV radiation in the sun.

	True	**False**
A sun tan is healthy		Yes
A tan will protect you from the sun		Yes
You can get burnt on a cloudy day	Yes	
You can get burnt if you are in water	Yes	
With sunscreen to protect me, I can sunbathe for much longer.		Yes

4. Carbon, fluorine and chlorine.

5. Aerosol propellant, foams, air conditioners, refrigerants.

6. Producing products that the consumer wanted such as hair spray, deodorants etc, different types of foams for furnishings.

7. He thought that they might destroy stratospheric ozone. This would mean that harmful UV rays would reach the Earths' surface.

8. They thought that the experiments would take too long, if they were right immediate action would be required.

9. The ozone level as been showing a steady decrease since about 1970. Before then, the level was constant at about 300 Dobson units.

10. Around 1970

11. December

12. October

13. Up to 100 Dobson units.

14. Figure 2 shows ozone levels at about 300 Dobson units in Octobers before1997, whereas present October levels are at about 100 Dobson units. A drop of 200 Dobson units!

15. See the notes above about the polar vortex (page 43).

Teachers will need to use their professional judgement in assessing questions 16–18.

The timeline

The Ozone Story		What else is happening?
	1970	
	1971	
	1972	
	1973	
	1974	
	1975	
	1976	
	1977	
	1978	
	1979	

1980

1981

1982

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1984

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1996

1997

1998

1999

2000

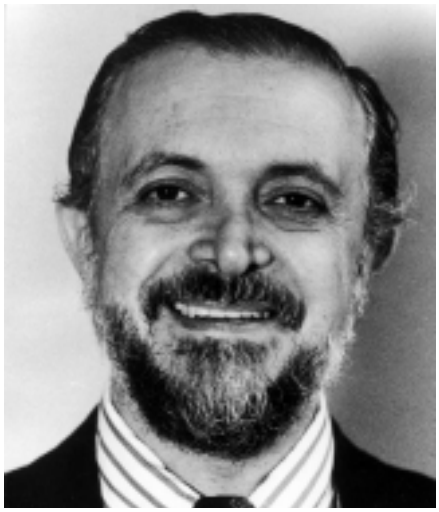
Making the timeline

In the table you will find a number of dates and events, listed in column 1. Cut them out, sort them into the correct order and then stick them on the left hand side of your timeline. If you find out any extra information, add this on to your timeline. In column 2, there are other dates; cut them out and stick them on the right hand side of your timeline. You can also add on other important events.

Column 1	Column 2
1971 It was thought that exhaust gases from a future fleet of supersonic aircraft might damage the ozone.	I was born
6/1975 Oregon becomes the first state to ban CFCs in aerosol sprays.	1980 John Lennon killed in New York.
9/1987 The Montreal Protocol is signed, calling for eventual worldwide CFC reduction of 50% by 1999.	1979 Mrs Thatcher becomes prime minister.
1995 The production of CFCs is banned in developing countries.	I started secondary school.
6/1991 Mount Pinatubo erupts in the Philippines, speeding up the conversion of chlorine already in the stratosphere into forms that destroy ozone.	I started primary school.
Worldwide deadline for zero production of CFCs 2010	1997 Tony Blair became Prime Minister.
1995 Mario Molina shares the Nobel Prize in Chemistry with Sherwood Rowland and Paul Crutzen for his work on CFC and ozone.	1997 Diana Princess of Wales was killed in a car crash.
8 / 1985 NASA's satellite photos confirm the existence of an ozone hole over Antarctica.	1989 The Berlin Wall came down.
12/1973 Molina & Rowland discover that CFCs can destroy ozone in the stratosphere.	1982 The Falklands war.
6/1974 The CFC-ozone theory is published in Nature.	1991 The Gulf War started.
9/1974 The CFC-ozone theory is discussed in public at the American Chemical Society. 10/1978 CFCs used in aerosols are banned in the United States.	1976 The first 'pop video'. Queen and Bohemian Rhapsody.
12/1988 Preliminary findings of an ozone hole over the Arctic are discussed at a scientific conference in Colorado	1990 Nelson Mandela freed from prison
1990 Montreal Protocol strengthened in London. A complete ban on CFCs by the end of the century.	1984 Band aid and feed the world. The first 'pop' fund raising concert with Bob Geldolf.
1992 Copenhagen amendment to the Montreal Protocol. A complete ban on the production and use of CFCs by 1996.	1977 The release of Star Wars.
1985 The Vienna convention called for additional research and international exchange of ozone depletion information.	1988 The first GCSEs were taken.
3/1988 Dupont changes mind and announces that it will stop making things with CFCs.	1981 The opening of the Musical 'Cats' by Andrew Lloyd Weber. Now the longest running musical.

1988 An international meeting confirms that chlorine compounds were the cause of the ozone loss over the Antarctic.	**You may wish to add more things to this side of the timeline.**
1991 Rate of ozone depletion increasing over heavily populated areas.	
1986 Solomon's Antarctic Expedition provided strong evidence for manufactured chlorine compounds destroying ozone.	
1994 Many companies had now stopped making CFC based products.	
1993 Rowland speaks to the public to try and dispel rumours that the cause of ozone destruction was from natural causes.	
1987 Solomon's 2nd Antarctic expedition confirms manufactured chlorine compounds destroy the ozone.	
1986 Neil Harris examines ozone records taken at Arosa Switzerland. His results confirm the same ozone depletion.	
1997 Montreal amendment to the original Montreal Protocol.	
1995 Vienna amendment to the Montreal Protocol.	

Mario Molina (1943–) information sheet



Mario Molina
(Picture reproduced courtesy of Nobel Foundation.)

As a boy, Mario Molina was strongly influenced by his aunt, a chemist in the sugar industry, who later became a teacher. She used to encourage him to carry out chemistry experiments at home in a converted bathroom. From a young age Mario's ambition was to be a research scientist, even though it was not a trendy job for a young Mexican.

Why investigate CFCs and the atmosphere?

Molina went to university and studied chemistry at degree level. He then took a research degree (a PhD) in 1972, at the University of California, Berkeley. Molina then went to Irvine to work with a man called Sherwood Rowland, who had recently heard that the British scientist James Lovelock had discovered some of the refrigerant trichlorofluoromethane (called CFC-11) in the atmosphere of the Northern and Southern hemisphere. He was curious to find out more, and wanted to know the answer to a simple question, 'what happens to CFCs in the environment and were there any consequences?'

Rowland managed to persuade his sponsors to fund the project and Molina started investigating CFCs in October 1973, even though his knowledge of atmospheric chemistry was limited.

Molina got to work, carrying out calculations and he soon started to build up a very worrying picture of the atmosphere. If he was right, it was not good news; if he was wrong he would look stupid. What should he do next?

Molina's theory

CFC's were so inert that there was nothing for them to react with in the atmosphere. So air currents carried them up into the stratosphere, where energy from ultraviolet (UV) radiation would break off a chlorine atom, called a radical. The radical would then start a chain reaction with ozone that would eventually destroy the ozone layer. At the then current CFC atmospheric release rate, Molina calculated that between 7 and 13%

of the ozone would soon be destroyed. This could cause problems since it was known that the ozone layer protected the Earth from harmful UV radiation.

Action

Towards the end of December 1973, Molina discussed his theory with Rowland. At first they both tried to find a mistake in the calculations, but they could not. So just after Christmas 1973, the two scientists went to visit some atmospheric chemists for a second opinion. It was known that nitrogen oxides could destroy ozone and other investigations to do with the release of hydrogen chloride from volcanoes and the ammonium perchlorate fuel planned for the space shuttle were being carried out. No one had yet investigated CFCs; the rough estimates suggested they were perhaps a factor of 100 more significant than the fuel from the space shuttle as a potential source of stratospheric chlorine.

Telling the world

After Molina made his initial discovery, he knew that if he were right, then the Earth would be in serious trouble. CFC molecules can stay in the atmosphere for about 130 years. As a scientist he felt that he had a responsibility to tell the world, and to do something about the ever-growing CFC industry.

Even though there was no experimental evidence, Rowland and Molina published the CFC–ozone theory in the scientific journal *Nature* in June 1974.

Response

Initially there was no response from the scientific world. Concerned that their voices may go unheard, Rowland and Molina discussed their theory for the first time in public, at the American Chemical Society meeting in Atlantic City, in September 1974. This time 'possible ozone depletion' hit the headlines, Molina and Rowland recommended a complete ban on the future release of CFCs to the environment. This triggered an enormous response from governments, industry, the public and environmental groups such as Greenpeace and has subsequently led to measures to reduce and eventually eliminate their use.

Mario Molina puts the atmosphere and ozone on the political agenda

(Version 1)

A. Understanding ozone

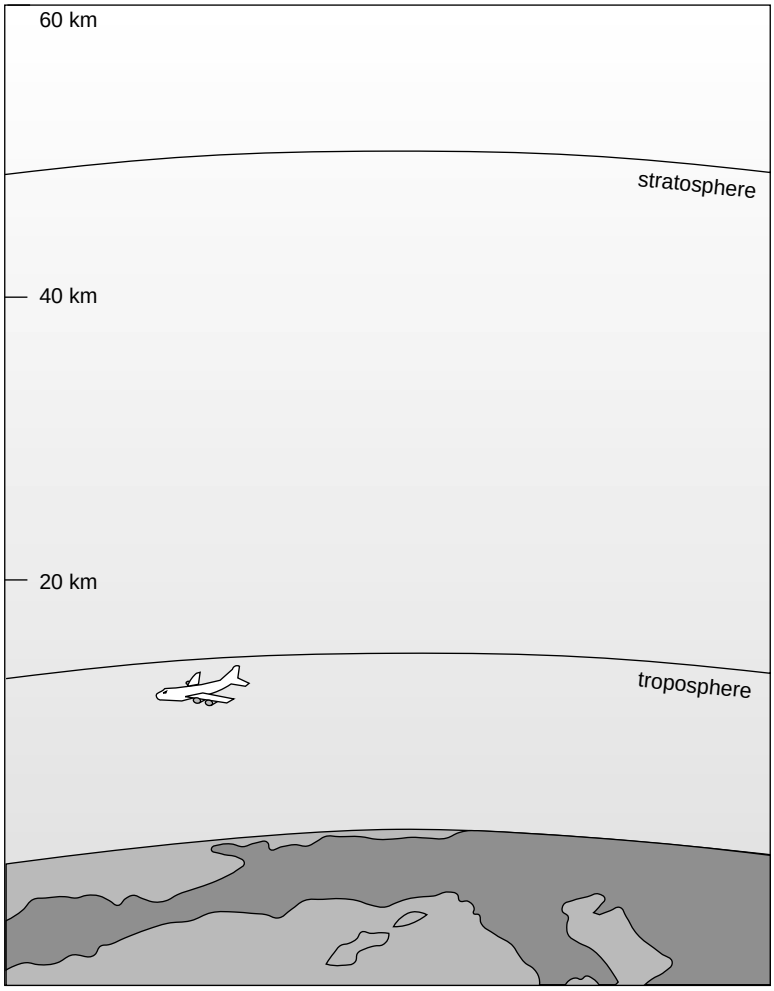


Diagram of our atmosphere
(Reproduced with permission from The Ozone Layer, UNEP/GEMS Environment Library No. 2, 1987, UNEP, Nairobi, Kenya.)

The chemical formula for ozone is O_3. The molecule contains three oxygen atoms. Ozone is quite harmful and is described by the following hazard symbols.

Ozone forms at ground level when pollutants such as nitrogen oxides and unburnt hydrocarbons react in sunlight.

Ozone in the stratosphere absorbs and protects the earth from harmful UV radiation, and is known as the ozone layer. Exposure to too much UV radiation leads to skin cancer and damages plants.

Question 1 How much do you know about sunbathing? Complete the table by ticking the correct box.

	True	**False**
A sun tan is healthy		
A tan will protect you from the sun		
You can get burnt on a cloudy day		
You can get burnt if you are in water		
With sunscreen to protect me, I can sunbathe for much longer.		

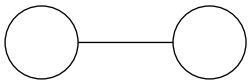
Sunburn facts

Ozone forms naturally in the upper atmosphere. Oxygen from lower levels rises into the stratosphere where it absorbs the sun's energy in the shorter wavelengths of ultraviolet radiation. This separates the two atoms in the molecules. These free atoms then combine with other oxygen molecules to form ozone.

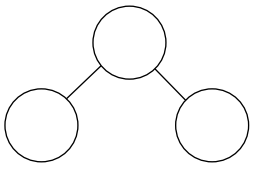
$$O_2 \xrightarrow{\text{short wavelength UV}} 2O$$

$$O_2 + O \longrightarrow O_3$$

$$O_3 \xrightarrow{\text{long wavelength UV}} O_2 + O$$



Oxygen



Ozone

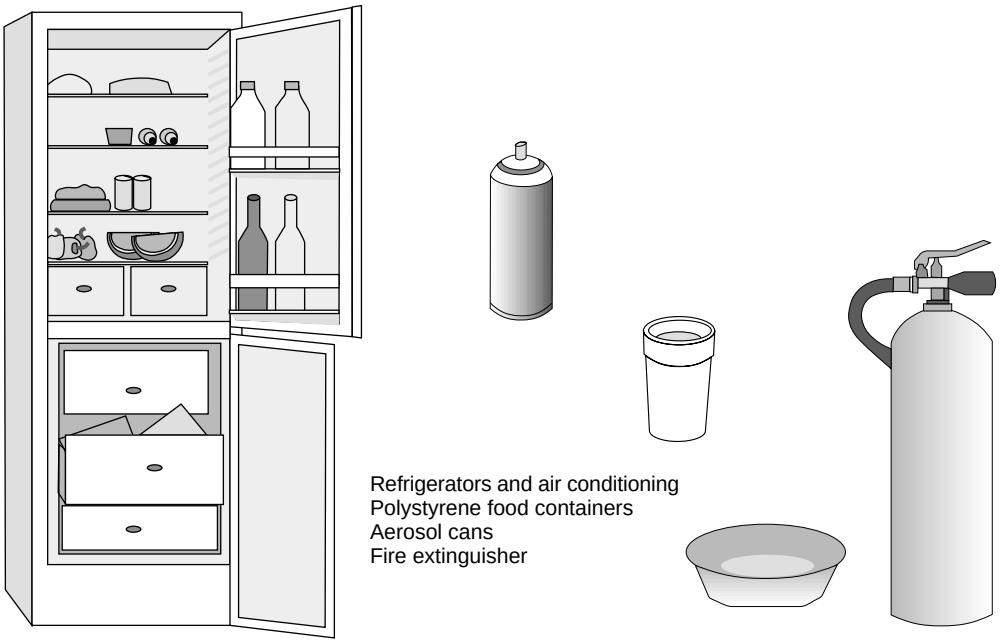
Oxygen and ozone molecules

The amount of ozone does not build-up endlessly since the energy from longer wavelengths of ultraviolet radiation breaks down the ozone molecules to produce oxygen. This process is greatly assisted by the presence in the high atmosphere of substances, such as oxides of nitrogen, which act as catalysts.

There is a very fine balance between the constant ozone production and destruction. Almost all the ultraviolet light from the sun which reaches the atmosphere is absorbed by the ozone layer. If this balance is upset, and too much ozone is destroyed, then UV light would damage plant and marine life and crop production, as well as causing skin cancer and cataracts in humans.

B. The CFC-ozone story

CFCs



The booming CFC industry of the early 1970s

$CFCl_3$ is a CFC used in air conditioners and refrigerators.

Question 1 Name the elements in a CFC molecule.

The molecules are very stable.

What type of bonding do they have?

The problem

After carrying out some calculations in 1973, Mario Molina, a research scientist, believed that CFCs could destroy the ozone layer in the stratosphere, and the Earth would no longer be protected from the harmful UV radiation.

The CFC-ozone story

The CFC-ozone story can be told by using a timeline. Your teacher will either supply you with a ready made timeline or give you a worksheet, so that you can make your own.

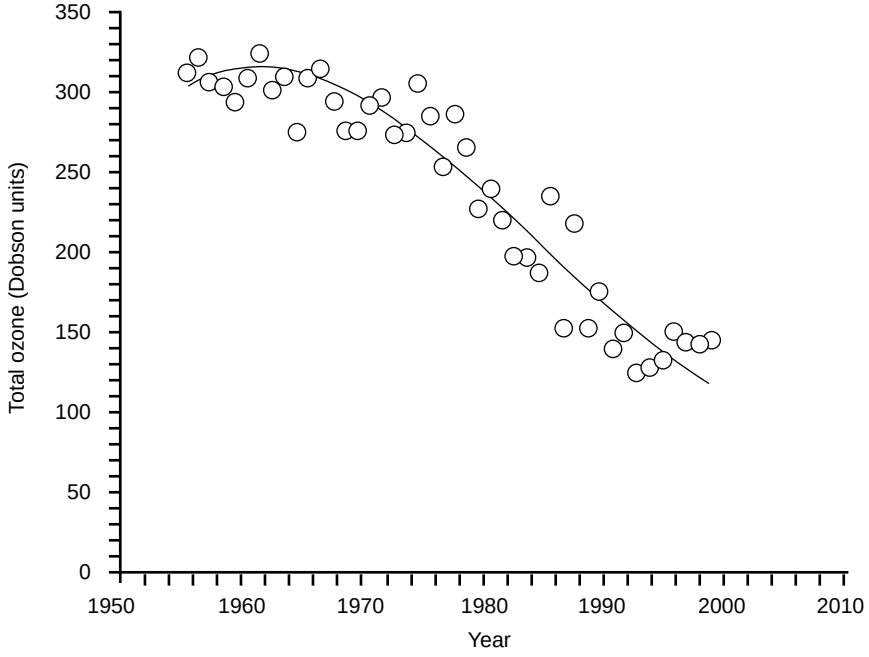
Timeline questions

1. Imagine that it is 1975, and you are working for a company such as Du Pont, that produces CFCs. What is your reaction when the State of Oregon bans the use of CFCs in aerosols?
2. Why do you think Du Pont announced that it would stop CFC production in 1988?
3. Do you agree with Du Pont's 1988 decision?

It is important to realise that the story is not yet over. Every day scientists record the ozone level in the atmosphere, alternative chemicals to CFCs are being researched, and it will be a long time before the hole in the ozone layer is gone.

Looking at the evidence

When Rowland and Molina first told the world their CFC-ozone theory in 1974, it was all based on theory, with no experimental evidence. Laboratory experiments later confirmed and modified the model. The amount of ozone in the stratosphere has been closely monitored at the Halley (since 1956), Rothera (since 1997) and Vernadsky / Faraday (since 1957) stations in Antarctica.

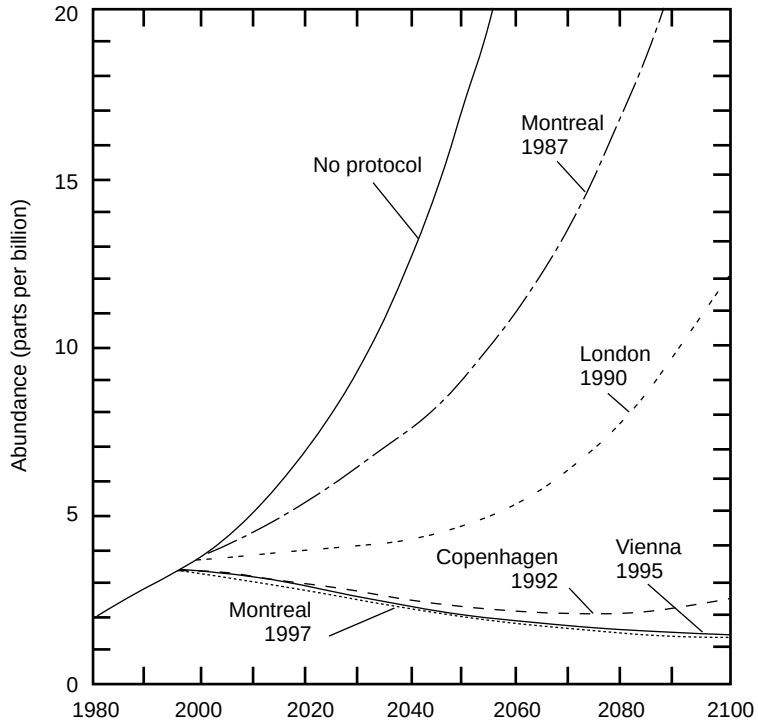


The mean October ozone levels recorded at the Halley station
(Reproduced with kind permission of J Shanklin, British Antarctic Survey (BAS).)

Evidence Questions

1. In which year did the ozone levels start to decrease?

2. From the data, do you think the ozone hole is still getting bigger?



Measured (1960-90) and projected (from 1990 onwards) concentrations of the chlorine in the atmosphere, under the terms of the original Montreal Protocol and later amendments
(Source: Action on Ozone 2000, UNEP, Nairobi, Kenya.)

On 14th September 1987, representatives from 43 different countries met together in Montreal to discuss the ozone problem. At the end of the meeting they agreed to freeze the production and consumption of CFCs at 1986 levels. By 1999, the levels of CFCs would be reduced by 50%.

3. Study the figure above showing the concentration of chlorine in the atmosphere and use the data presented here to either support or reject your answer to question 2.

4. In your own words explain why the Montreal Protocol and the later Amendments were a major breakthrough for the protection of the environment.

At the Antarctic Stations, constant monitoring of ozone levels has revealed that ozone levels naturally fluctuate throughout the year.

Either visit the British Antarctic Survey (BAS) website **http://www.antarctica.ac.uk/met/jds/ozone** (accessed September 2005), look up the ozone data or look at the data your teacher has given you. Then answer the following questions:

5. In which month of the year are the ozone levels highest?

6. In which month of the year are the ozone levels lowest?

7. How much do the ozone levels fluctuate on a daily basis?

8. Compare the present ozone level with the levels recorded before 1977.

9. In which month of the year is the temperature in the stratosphere highest?

10. In which month of the year is the temperature in the stratosphere lowest?

11. Can you find a relationship between ozone levels and temperature in the stratosphere?

12. Suggest a reason why ozone levels fluctuate.

Optional – you will need access to the Internet to work through this section

The Meteorological Office makes regular measurements of ozone at two sites in the United Kingdom. They use TOMS to provide accurate, detailed information. Visit their website at **http://www.metoffice.gov.uk/research/stratosphere/ozone/index.html** (accessed September 2005) (there is a direct link from the BAS site) to find out:

13. Where are the Metereological Office stations?

14. What long-term trends are seen at each station?

15. What does TOMS stand for?

16. Find a satellite picture showing the ozone hole.

17. Find the ozone level over the UK today.

To answer questions 16&17, you may need to surf other websites. A good place to start is at the Centre for Atmospheric Science, Cambridge University, with the 'The Ozone Hole Tour'. **http://www.atm.ch.cam.ac.uk/tour/index.html** (accessed September 2005)

The story continues…

CFCs and Ozone still makes the papers…even with all the data from scientific research, it is still a controversial subject. In developing countries economic reasons have meant that these chemicals are still being used, and even in the developed world there is still controversy. Read the following newspaper extract.

Greens see red / Overseas news
World summary

Sydney: The environmental group Greenpeace has asked a court to order the Olympics Co-ordinating Authority to stop styling the 2000 Olympics as the Green Games because it says that an ozone-depleting chemical will be used in the cooling system at one of the venues

30 March 1999, 'The Times', p.15

18. Do you support the views of Greenpeace? Visit the Greenpeace website at **http://www.greenpeace.org** (accessed September 2005) to find out more.

19. Research and find out about methods of cooling *ie* refrigerants and air conditioning systems that do not use CFCs.

20. Write a word-processed letter to the London 2012 Olympic Games Committee, either supporting Greenpeace or supporting the Olympics Co-ordinating Authority, on the subject of 'Green Games'. You should include scientific / technological evidence to back up your opinion.

Mario Molina puts the atmosphere and ozone on the political agenda

(Version 2)

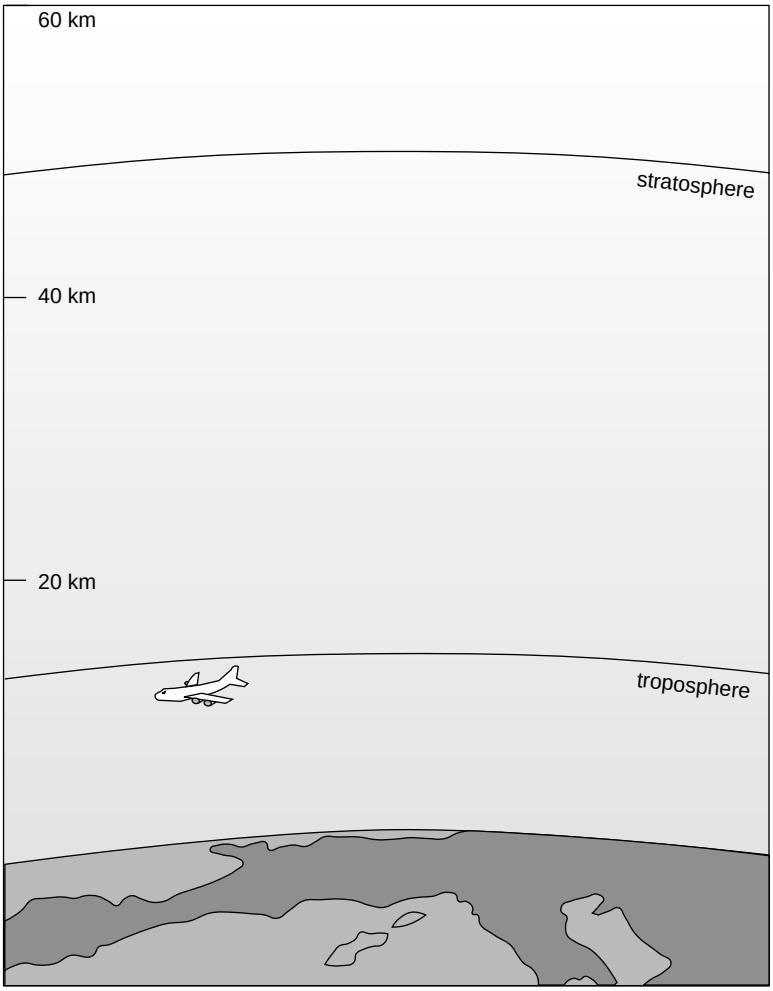
Ozone has three oxygen atoms. Ozone is a strong smelling, pale blue gas, which is poisonous to humans. Ozone is described by the following hazard symbols.

1.

Use the following words to label the hazard symbols.

Irritant	Oxidising agent	Toxic

2. How do you think you would feel if you were exposed to ozone?



A diagram of our atmosphere
(Reproduced with permission from The Ozone Layer, UNEP/GEMS Environment Library No. 2, 1987, UNEP, Nairobi, Kenya.)

The diagram of the atmosphere shows that ozone exists in the troposphere and the stratosphere.

Ozone in the stratosphere absorbs and protects the Earth from harmful UV radiation. Exposure to too much UV radiation leads to skin cancer and damages plant and marine life.

3. Why do you think it is important to look after the ozone layer?

_____

Ozone protects us from the sun

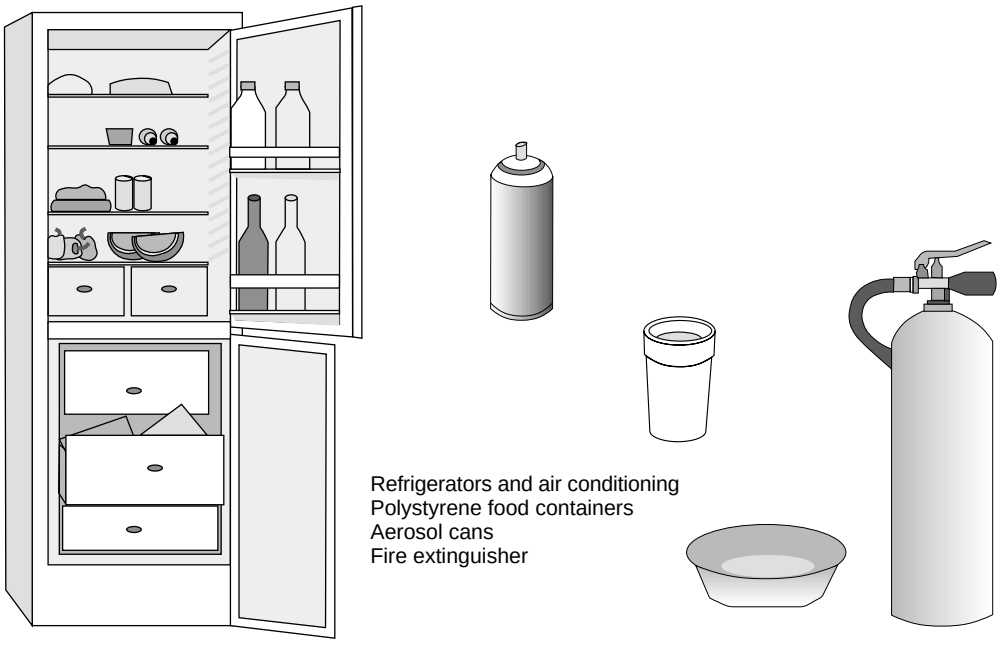
How much do you know about sunbathing? Complete the table by ticking the correct box.

	True	**False**
A sun tan is healthy		
A tan will protect you from the sun		
You can get burnt on a cloudy day		
You can get burnt if you are in water		
With sunscreen to protect me, I can sunbathe for much longer.		

After carrying out some calculations in 1973, Mario Molina, the research scientist, believed that CFCs could destroy the ozone layer in the stratosphere, and the Earth would no longer be protected from the harmful UV radiation.

$CFCl_3$ is a CFC used in air conditioners and refrigerators.

4. Name the elements in a CFC molecule._____



The booming CFC industry of the early 1970s

5. Give four uses of CFCs.

_____

_____

6. Why do you think the CFC industry was doing so well in the early 1970s?

_____

_____

After Molina made his initial discovery, he knew that, if he was right, then the Earth would be in serious trouble. As a scientist he felt that he had a responsibility to tell the world, and to do something about the ever-growing CFC industry.

7. What did Mario Molina believe CFCs would do to the Earth?

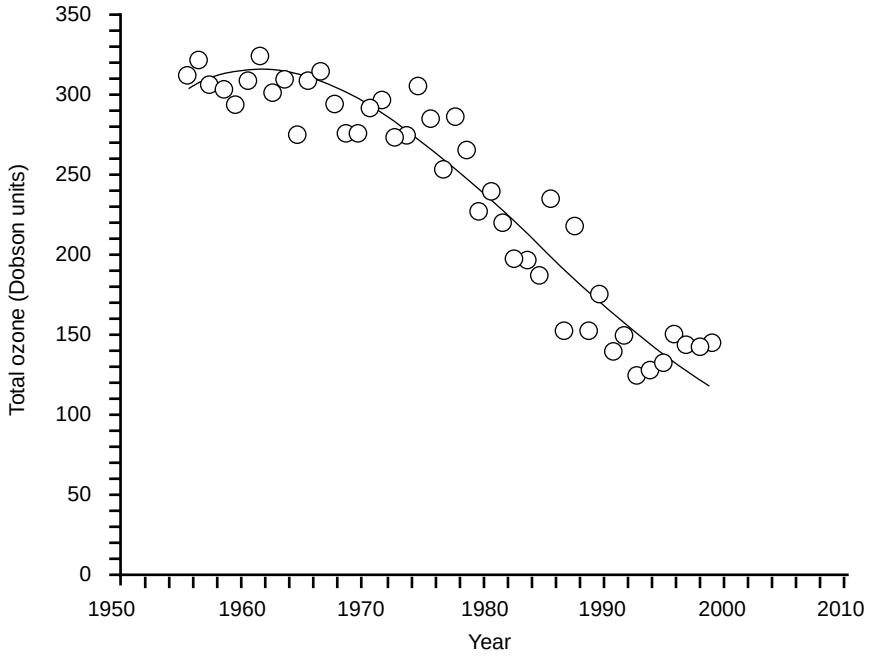
_____

_____

You now could make a timeline, which tells the CFC-ozone story so far. Your teacher will give you the instructions, which are on a separate sheet. It is important to realise that the story is not yet over. Every day scientists record the ozone level and alternative chemicals to CFCs are being researched because it will be a long time before the ozone hole is mended.

Looking at the evidence

The amount of ozone in the stratosphere has been closely monitored since 1956, at the Halley, Rothera and Vernadsky / Faraday stations in Antarctica. Scientists have shown that the amount of chlorine in the stratosphere has rapidly increased since the late 1970s.



The mean October ozone levels recorded at the Halley station
(Reproduced with permission from J. Shanklin, British Antarctic Survey.)

9. In your own words describe what the graph tells us.

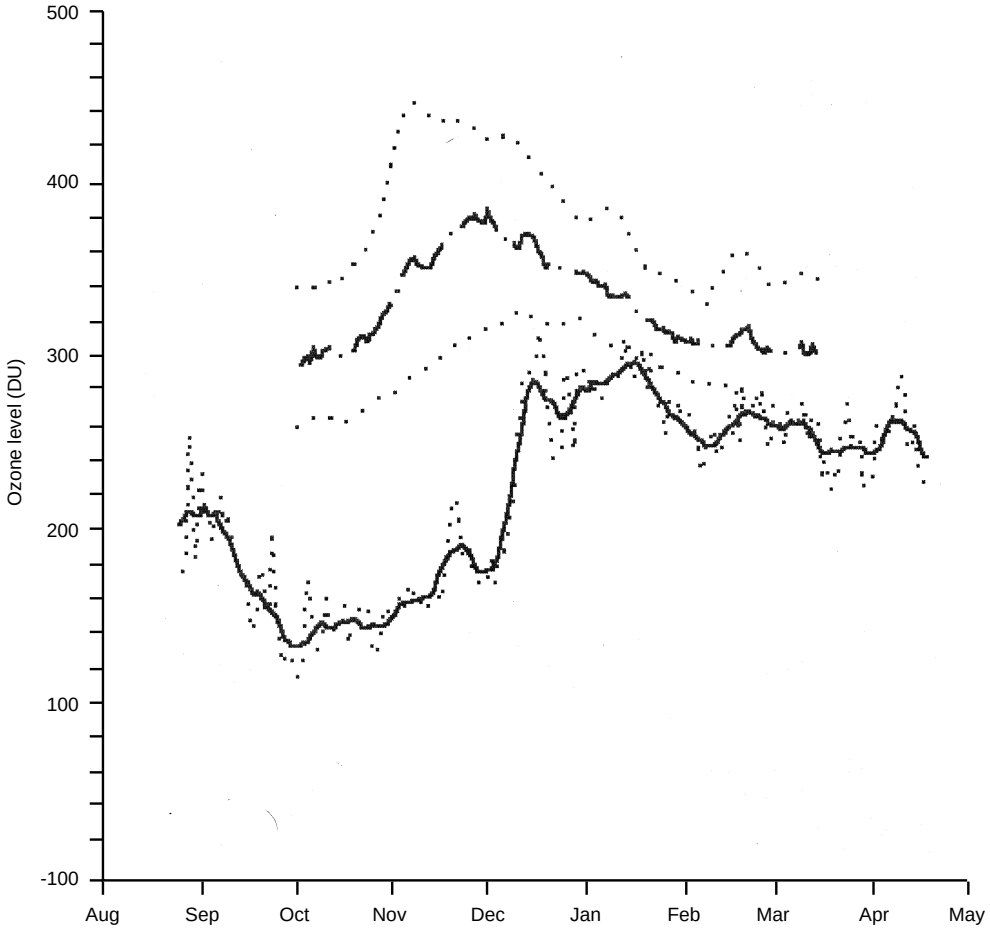
_____

_____

10. In which year did the ozone levels start to decrease?

_____

Constant monitoring in the Antarctic has revealed that ozone levels naturally fluctuate throughout the year.



Real ozone data recorded at the Halley Station, 1999–2000
(Reproduced with permission from J. Shanklin, British Antarctic Survey.)

11. In which month of the year are the ozone levels highest? _____

12 In which month of the year are the ozone levels lowest? _____

13. How much do the ozone levels fluctuate on a daily basis?_____

_____

_____

14. Compare the present ozone level with the level recorded before 1977.

_____

_____

15. Suggest a reason why ozone levels fluctuate.

_____

_____

_____

_____

The story continues…

CFCs and ozone still makes the papers…even with all the data from scientific research, it is still a controversial subject. In developing countries economic reasons have meant that these chemicals are still being used, and even in the developing world there is still controversy. Read the following newspaper extract.

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30 March 1999, The Times, p.15

Answer the following questions

16. Do you support the views of Greenpeace?

17. Research and find out about methods of cooling *ie* refrigerants and air conditioning systems that do not use CFCs.

18. Write a wordprocessed letter to the Sydney 2000 Olympic Games Committee, either supporting Greenpeace or supporting the Olympics Co-ordinating Authority, on the subject of 'Green Games'. You should include scientific / technological evidence to backup your opinion.