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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

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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.

$O_2 + hv \rightarrow O + O$

$O + O_2 \rightarrow O_3$

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.

$O_3 + hv \rightarrow O_2 + O$

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.

$CFCl_3(g) + hv \rightarrow CFCl_2(g) + Cl(g)$

$CF_2Cl_2(g) + hv \rightarrow CF_2Cl(g) + Cl(g)$

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

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

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

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:

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

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

$Cl_2(g) + hv \rightarrow 2Cl(g)$

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

$Cl_2O_2(g) + hv \rightarrow ClO_2(g) + Cl(g)$

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

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.

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!

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

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