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APPENDIX

TRANSVAAL EDUCATION DEPARTMENT SYLLABUS STATEMENT

MODULE 9: AI. . POLLUTION (CHEMISTRY: OPTIONAL)

Weighting: 10 units — Time: 10 hours

9.1 The composition of unpolluted air

9.2 Refer briefly to the most important functions of some of the main constituents of the atmosphere : O_2, N_2, CO_2 *and the ozone layer*

9.3 Some substances which play an important role in air pollution in South Africa, their origin and effects:

- 9.3.1 Solid particles eg soot, smoke, dust.
- 9.3.2 Oxides of sulphur and sulphuric acid
  Equations for their formation
  Refer to acid rain
- 9.3.3 Lead in petrol
- 9.3.4 Carbon monoxide
  Simple equation for its formation during incomplete combustion of carbon:
  $2C + O_2 = 2CO$
- 9.3.5 Propellants and their effects on the ozone layer

9.4 Measures to combat air pollution:

- 9.4.1 Smoke-free zones, alternative fuels, smoke-free-stoves, electrification, tar roads, establishment of a plant cover, filters, electrostatic precipitators
- 9.4.2 *Liberation of gases high in the atmosphere* by tall chimneys
- 9.4.3 Prevention of incomplete combustion
- 9.4.4 Chemical removal of oxides of sulphur and sulphuric acid
- 9.4.5 Reduction in the lead content of petrol
- 9.4.6 Role of legislation, state institutions, ESKOM, *mines, chemical and other* industries.

SOE/025H10SY (PhyScience)

Let Us Talk About Air Pollution

1. What is "air pollution"?

2. What are "air pollutants"?

3. Make a list of "air pollutants" that you know.

4. How are you aware that air pollution is occurring?

5. What are the causes (sources) of air pollution?

6. Is Air pollution of concern to you?
   Explain your answer.

7. Explain the meaning of the terms
   a. "Greenhouse effect"

   b. "Hole in the ozone layer"

   c. "CFCs"

8. Why do you think air pollution is often discussed nowadays in newspapers, on radio and TV?

9. Do you think air pollution can be controlled?
   Explain your answer.

SURVEY ON AIR POLLUTION

Survey for Research on Optional Topic

For 1 - 4, please rate the following environmental issues according to of how much concern they are to you. For each issue, choose your response from the following responses (a), (b), (c) or (d). Mark the appropriate letter (a), (b), (c) or (d) on the response sheet next to the number of the environmental issue.

a) of great concern
b) of concern
c) of little concern
d) of no concern

1. soil erosion

2. air pollution

3. water pollution

4. exposure to nuclear radiation

5. Air pollution
   i) can occur when the concentration of a substance occurring naturally in the atmosphere is increased.
   ii) can occur when the concentration of a substance occurring naturally in the atmosphere is decreased.
   iii) only occurs when substances that do not naturally occur in the atmosphere enter the atmosphere.
   iv) is only caused by substances in a gaseous state.

   The correct answer(s) is/are
   a) (i) only
   b) (i) and (ii)
   c) (iii) only
   d) (iii) and (iv)
   e) (i) and (iv)

6. The percentage of the atmosphere that air pollution affects is:
   a) more than 50%
   b) about 10%
   c) about 20%
   d) about 5%
   e) less than 0,05%

7. Air pollution is a result of the activities of
   (i) Industry
   (ii) The rich
   (iii) The poor
   (iv) Science and technology

My answer is
a) (i) only
b) (i) and (iv)
c) (i), (ii), (iii) and (iv)
d) (i), (iii) and (iv)
e) (ii) only

8. With regard to the term "greenhouse effect"
   a) I have not heard of the term.
   b) I have heard of it but do not understand what it means.
   c) I have heard of it and I think I know what it means.
   d) I have heard of it and I am sure I understand its meaning correctly.

9. With regard to the term "CFCs"
   a) I have not heard of the term.
   b) I have heard of it but do not understand what it means.
   c) I have heard of it and think I know what it means.
   d) I have heard of it and I am sure I understand its meaning correctly.

10. With regard to the phrase "hole in the ozone layer"
   a) I have not heard of the phrase.
   b) I have heard of it but do not understand what it means.
   c) I have heard of it before and think I know what it means.
   d) I have heard of it before and am sure I understand its meaning correctly.

In the next section (11 - 24) you are asked to respond to certain statements. For each of these statements choose your response from the following responses (a), (b), (c), (d) or (e) and mark the appropriate letter (a), (b), (c), (d) or (e) on your card next to the number of the statement.

(a) I agree strongly with this statement
(b) I agree with this statement
(c) I have no opinion about this statement
(d) I disagree with this statement
(e) I disagree strongly with this statement

11. "Economic and political issues are more important to me than the issue of air pollution"

12. "There is no air pollution where I live"

13. "Air pollution is not a problem in the Republic of South Africa"

14. "It is only the forms of air pollution that can be seen or smelled that are important"

15. "Once pollutants have entered the atmosphere they remain there for ever"

16. "The media always report air pollution issues accurately"

17. "Environmentalists are able to predict with certainty the consequences of air pollution"

18. "Industry is not concerned about air pollution"

19. "Technological/industrial development should be stopped in order to preserve the atmosphere"

20. "Air pollution is uncontrollable and will increase steadily until life is destroyed"

21. "Air pollution can be controlled, using science and technology, but it will need a constant monitoring of the risks and benefits of our activities"

22. "I contribute very little to air pollution and thus have no role to play in its control"

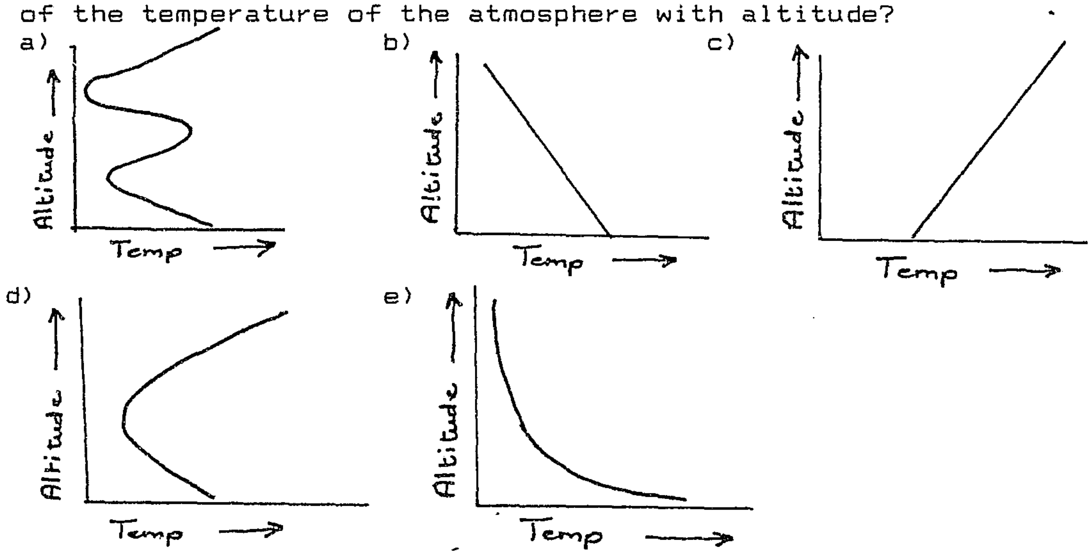
23. "To improve air pollution control we must be prepared to pay more for things"

24. "If the topic "Air Pollution" were offered in the Physical Science syllabus in the future, my interest in the study of science would increase greatly."

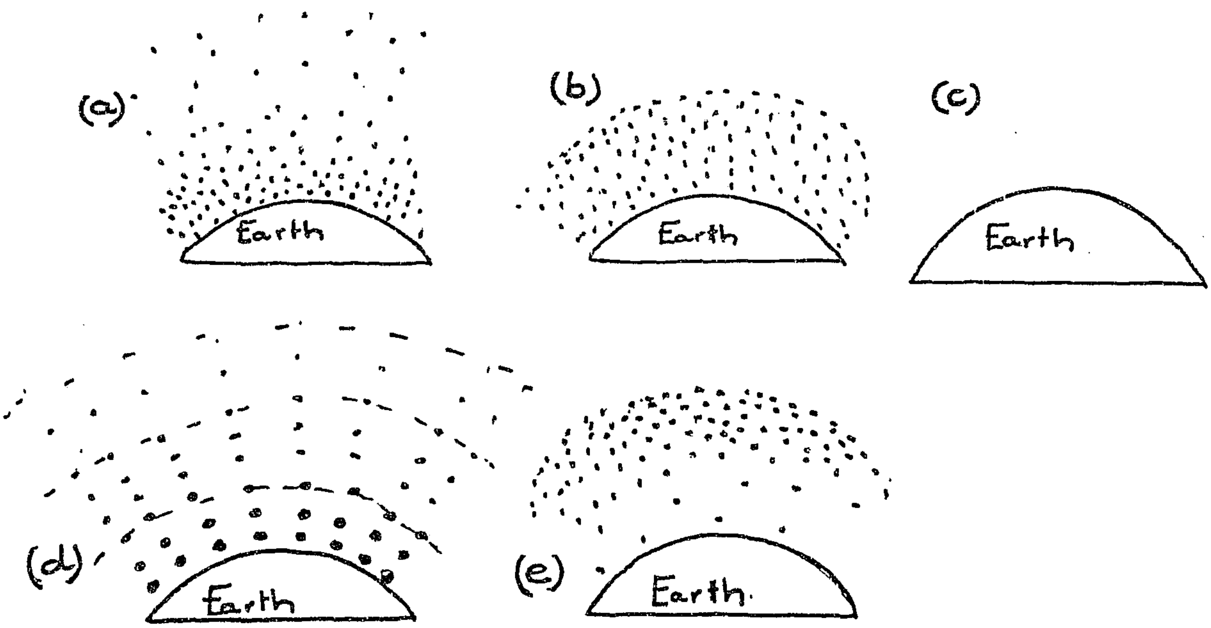
25. The atmosphere extends to an altitude of approximately

    a) 10 km b) 20 km
    c) 1 km d) 500 km
    e) 2 000 km

26. Which graph is a correct representation of the variation of the temperature of the atmosphere with altitude?



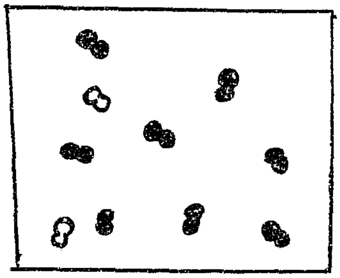
27. Which diagram is a correct representation of the distribution of particles in the atmosphere?

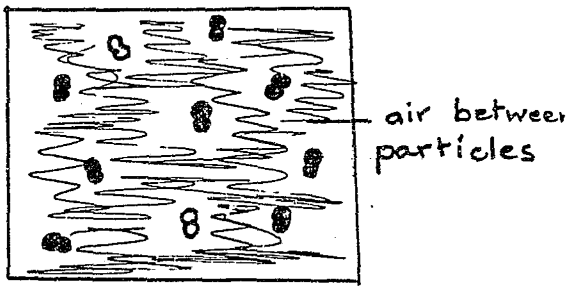


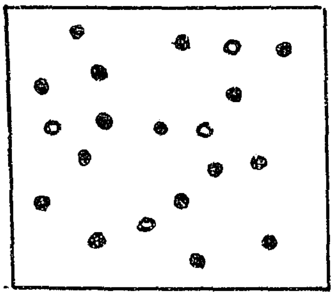
28. The approximate percentage of carbon dioxide present in the lowest region of the atmosphere (troposphere) is
a) 50%   b) 0,03%   c) 30%   d) 25%   e) 1%

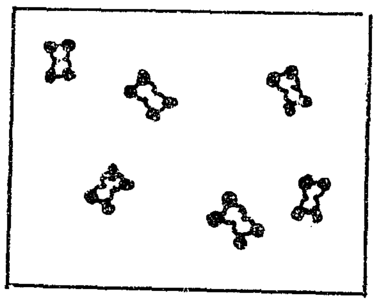
29. Which statement is <u>incorrect</u>?
a) The atmosphere protects life from harmful solar radiation.
b) The "greenhouse" or energy trapping effect of the atmosphere is harmful to life.
c) The properties and composition of the atmosphere are not the same throughout.
d) Scientists believe that the composition of the atmosphere has changed over the billions of years since the "birth " of the planet.
e) The atmosphere is naturally reactive.

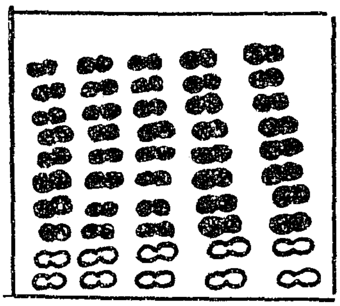
30. Which diagram is a correct representation of the microscopic nature of the air in the lowest region of the atmosphere?
(● = nitrogen atom)   (o = oxygen atom)

(a)


(b)


(c)


(d)


(e)


For 31 - 45 please rate the following statements as true or false. Use (a) for true
(b) for false
(c) for I do not know
Mark the letter of your response, (a), (b) or (c) next to the number of the statement.
Please do not guess. If you do not know the answer, mark (c).

31. Approximately 90% of the world's energy needs comes from the combustion of coal and oil.

32. Both coal and oil are classified as fossil fuels.

33. Coal is only composed of carbon.

34. The only products formed when coal is burned are: ash, soot, carbon dioxide and carbon monoxide.

35. The ash, produced by burning coal, does not present any air pollution problems because it is solid and can easily be removed.

36. South African coal has a low sulphur content. Therefore the release of sulphur dioxide from coal combustion is neglible.

37. The burning of coal in households, can produce worse air pollution than that produced by power stations.

38. In South Africa, coal-fired power stations burn more coal than industries such as ISCOR.

39. Nitrogen oxides (which contribute to air pollution problems) are only produced by industrial processes.

40. The total contribution to air pollution by motor vehicles, is very small compared to industry.

41. The temperature in parts of a running motor car engine is sufficient to bring about a reaction between nitrogen and oxygen in the air.

42. Petrol sold in South Africa contains lead compounds.

43. The only products formed when petrol is burned in engines of motor vehicles are: carbon dioxide, carbon monoxide and lead compounds.

44. Natural gas is mostly methane.

45. In South Africa, natural gas deposits have been discovered near Mossel Bay.

Thank you for your co-operation.

For 31 - 45 please rate the following statements as <u>true</u> or <u>false</u>. Use

(a) for <u>true</u>,
(b) for <u>false</u>
(c) for <u>I do not know</u>

Write the letter of your response, (a), (b) or (c) next to the number of the statement.
Please do not guess. If you do not know the answer, mark (c).

31. The chemical formula of ozone is O_3.

32. The concentration of ozone is the same throughout the atmosphere.

33. Once ozone is destroyed in the stratosphere, it can never be reformed.

34. The sky is blue because ozone is a blue gas.

35. CFCs are compounds whose molecules consist of chlorine, fluorine and carbon atoms.

36. Both CFCs and nitrous oxide (N_2O) destroy ozone in the stratosphere.

37. One chlorine atom released from a CFC molecule, is capable of destroying approximately 100 000 ozone molecules.

38. CFCs are only used in industrial processes.

39. CFCs occur naturally in the atmosphere.

40. CFCs are unreactive in the troposphere but become reactive in the stratosphere.

41. All solar radiation that enters the atmosphere, reaches the surface of the Earth.

42. Ozone is the only substance in the atmosphere capable of absorbing radiation of wavelength 220 -330 nm.

43. Solar radiation of wavelength 220 - 330 nm is harmful to life.

44. A photochemical reaction can only be brought about by visible light.

45. With modern day technology, scientists never make mistakes.

Thank you for your co-operation.

Unit 5 - Smog

For 31 - 45 please rate the following statements as true or false. Use

(a) for true
(b) for false
(c) for I do not know

Write the letter of your response, (a), (b) or (c) next to the number of the statement.
Please do not guess. If you do not know the answer, mark (c).

31. Smog is always a combination of smoke and fog.

32. Smog is mainly an urban problem.

33. Smog only forms on a cold, wet day.

34. Smog is only the result of burning coal.

35. Smog is not a problem in South Africa.

36. Weather plays an important role in the formation of smog.

37. Smog can have a detrimental effect on health.

38. Smog is only caused by industrial activity.

39. Ozone only has beneficial effects in the atmosphere.

40. Ozone is not present in the lowest region (the troposphere) of the atmosphere.

41. Sunlight and some of the gases released from motor car exhausts, can result in smog formation.

42. Nitrogen oxides are formed when nitrogen and oxygen in the air combine in the very hot parts of the motor car engine.

43. Hydrocarbon compounds, released from motor car exhausts, are involved in chemical reactions which produce photochemical smog.

44. Ozone accumulates during the formation of photochemical smog.

45. Science and technology have no methods for controlling photochemical smog.

Thank you for your co-operation.

For 31 - 45 please rate the following statements as true or false. Use (a) for true
(b) for false
(c) for I do not know
Mark the letter of your response, (a), (b) or (c) next to the number of the statement.
Please do not guess. If you do not know the answer, mark (c).

31. The "greenhouse effect" of the atmosphere is beneficial.

32. The possible global warming (that scientists are concerned about) is a result of the Sun getting hotter.

33. Approximately 45% of the Sun's energy that enters the Earth's atmosphere, reaches the surface of the Earth.

34. The atmosphere is warmed directly by the Sun's energy as it passes through the atmosphere.

35. The atmosphere is warmed by energy being radiated from the Earth's surface.

36. All gases in the atmosphere are capable of absorbing infrared radiation (heat).

37. Gases that contribute to the problem of an enhanced "greenhouse effect" include: carbon dioxide, ozone, nitrous oxide, methane and CFCs.

38. Human activities such as agriculture and cattle farming do not contribute to air pollution problems.

39. The burning of coal and oil, is a major contributor to the problem of an enhanced "greenhouse effect".

40. Scientists can predict with certainty, the consequences of an enhanced "greenhouse effect".

41. Once carbon dioxide has been released into the atmosphere, it remains there forever.

42. The atmosphere prevents the Earth having scorching hot days and freezing cold nights.

43. Carbon dioxide concentrations in the atmosphere have increased rapidly since the Industrial Revolution.

44. Cutting down trees has no effect on carbon dioxide concentrations in the atmosphere.

45. If the average surface temperature of the Earth were to increase, the only effect would be the rising of the level of the seas.

Thank you for your co-operation.

For 31 - 45 please rate the following statements as true or false. Use (a) for true
(b) for false
(c) for I do not know
Mark the letter of your response, (a), (b) or (c) next to the number of the statement.
Please do not guess. If you do not know the answer, mark (c).

31. Rain is naturally neutral with a pH of 7.

32. "Acid rain" is a consequence of increased concentrations of carbon dioxide in the atmosphere.

33. Rain and snow with a pH = 2,1 has fallen in Britain.

34. Acids such as sulphuric acid, nitric acid and hydrochloric acid have been detected in rain.

35. "Acid rain" is not a problem in South Africa.

36. The rate of release of sulphur dioxide into the atmosphere as a result of human activities, exceeds the rate of release of sulphur dioxide from natural sources.

37. CFCs contribute to the problem of "acid rain".

38. Combustion of fossil fuels (coal and oil) is a major contributor to the problem of "acid rain".

39. Some gases released from vehicle exhausts contribute to the problem of "acid rain".

40. Industries contribute more than coal-fired power stations to the problem of "acid rain".

41. The contribution of industry to the total concentration of nitrogen oxides in the atmosphere, is greater than the contribution of transportation.

42. The death of fish in lakes in Europe and America, has been a consequence of "acid rain".

43. It is a fact that "acid rain" alone is responsible for the death of large numbers of trees in the forests of Europe and America.

44. The use of tall chimney stacks (which dilute air pollutants) has overcome the problem of "acid rain".

45. Damage by "acid rain" only occurs close to the source of gases causing this air pollution problem.

Thankyou for your co-operation.

For 31 - 45 please rate the following statements as true or false. Use

(a) for true
(b) for false
(c) for I do not know

Write the letter of your response, (a), (b) or (c) next to the number of the statement.
Please do not guess. If you do not know the answer, mark (c).

31. There are natural processes which remove air pollutants from the atmosphere.

32. All air pollutants remain in the atmosphere for the same length of time.

33. For the concentrations of substances in the atmosphere to remain constant, the rates at which they are released into the atmosphere should be equal to the rates at which they are removed from the atmosphere.

34. Air pollution results when the rates at which air pollutants are released into the atmosphere, exceeds the rates at which natural processes remove air pollutants from the atmosphere.

35. There is no law in South Africa to control air pollution.

36. In South Africa, no research is conducted into air pollution problems.

37. International agreements have been reached concerning some air pollution problems.

38. South Africa has never manufactured CFCs.

39. CFCs are compounds that do not occur naturally.

40. The production of CFCs in South Africa has been reduced.

41. It is proposed that no CFCs will be produced by the year 2 000.

42. If the production of CFCs is stopped, the air pollution problems associated with them will be immediately solved.

43. The destruction of ozone in the stratosphere is a global air pollution problem.

44. The Montreal Protocol is an international agreement to reduce CFC production.

45. All nations of the world have signed an agreement to reduce CFC production.

Thank you for your co-operation.

For 31 - 45 plea‑ rate the following statements as <u>true</u> or <u>false</u>. Use (a) fo <u>true</u>
(b) for <u>false</u>
(c) for <u>I do not know</u>

Mark the letter of your response, (a), (b) or (c) next to the number of the statement.
Please do not guess. If you do not know the answer, mark (c).

31. There are no methods available for controlling the release of particulates into the atmosphere.

32. Cyclones are very efficient devises for reducing air pollution.

33. At present, there are no techniques available for reducing the release of sulphur dioxide into the atmosphere.

34. Industry could make use of technology which would eliminate air pollution completely.

35. The cost of installing and using technology to reduce air pollution, is small compared with other costs faced by industry.

36. The use of tall chimney stacks by industry is always a solution to air pollution problems.

37. Catalytic convertors cannot be used in South Africa because there are lead compounds in our petrol.

38. ESKOM does not use technology to reduce the release of sulphur dioxide into the atmosphere.

39. Fly-ash from coal-fired power stations can reduce the quantity of fertilisers farmers need to use.

40. Supplying electricity to towns in South Africa, has totally reduced air pollution from coal fires.

41. In some areas in South Africa, the air pollution from domestic coal fires exceeds air pollution from coal-fired power stations.

42. SASOL only produces petrol from coal.

43. The only use for coal is to su‑ ly us with energy when the coal is burnt.

44. If power stations use improved technology to control air pollution, electricity could become too expensive for many people.

45. Industry never monitors the quantity and nature of the air pollutants produced by its activities.

Thank you for your co-operation.

Copy of Letter Sent to Experts Asking for Their Evaluation of the Package

November, 1991

Dear...,

For the last 11 months, I have been writing the first draft of a teaching resource package on AIR POLLUTION, which accompanies this letter. In your capacity as

....

I would value your comments on this package as a teaching resource to be used in South African schools in std 9 in 1993. Please comment on any content you feel may be incorrect and/or on any issues that are misrepresented. Any other comments with regard to the package will be most welcome.

At the moment I am attempting to consolidate and analyse the evaluations from a number of schools that have implemented parts of the package. Towards the end of January 1992 I'll be correcting the package and so I would appreciate your comments by then. Please send the (corrected package) and any comments back to me in the Chemistry Dept, Wits. If you prefer to telephone me it will probably be easier to contact me at home (782 8778) towards evening.

I would like to thank you (in anticipation) for the time you will be spending in assessing the package. I look forward to hearing from you.

With kind regards,

Instructions Given to Teachers at Workshops

Notes to Teacher

1. Thank you very much for agreeing to take part in this evaluation - it is much appreciated.
2. You have been provided with:

   Unit 1 - Introduction
   - A Copy of the Worksheets + Copies for students
   - Answers to the Worksheets

   Unit 2 - Introduction
   - A Copy of the Worksheets + Copies for students
   - Answers to the Worksheets

   Unit 3 - Introduction
   - A Copy of the Worksheets + Copies for students
   - Answers to the Worksheets

   Three evaluation forms for each unit.
   One overall evaluation sheet for the part of the package you have taught.

   A Survey to test attitudes/knowledge of the students.

3. Please administer this as a <u>pretest</u> before you start teaching and then as a <u>post-test</u> after you have taught your portion of the package. You will need <u>two</u> computer cards per pupil for each test. The first card is for questions 1 - 25, the second card is for 26 - 50. Both cards are needed as there are 45 questions. Please collect the printed sheets of questions so that you can use them again for the post-test. Please ask the students not to write on the question paper.
   When the students fill in the cards, please ask them to fill in their names, the name of their school and the date. They must use a pencil to mark the answers. A line is drawn across the letter as shown.

   eg. 1. ~~(a)~~ (b) (c) (d) (e)

   Not all the options, (a), (b), (c), (d), (e) will be used for every question. For example question 1 uses only options (a), (b), (c) and (d). Question 31 - 45 uses only three options (a), (b), (c).

4. When you have completed teaching and testing, please send me the computer cards for the pre- and post-tests, the three evaluation sheets for the units and the evaluation sheet for the package. If you have any problems, please don't hesitate to contact me.
   Telephone : 782-8778 (H)   716-2004 (W)

FEEDBACK ON COMPLETION OF EACH UNIT

Please complete a copy of this form for EACH unit which you have tested.

SCHOOL : ....

NAME OF TEACHER : ....

NUMBER OF YEARS TEACHING EXPERIENCE : ....

NUMBER OF YEARS TEACHING STD.9 : ....

CLASS : .... DATE: .... UNIT NUMBER: ....

TITLE OF UNIT: ....

Approximate time taken to teach this unit : ....

We would appreciate any feedback on how you approached this unit. Therefore, please describe how you taught this unit in the space below .

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Tick any of the following strategies used in each of the activities / worksheets. Every unit does not have as many activities as listed. Please ignore those columns which are irrelevant.

Teaching Strategy	Activity / Worksheet						
	a	b	c	d	e	f	g
Teacher "chalk and talk"							
Students working individually							
Students working in groups							
Number in each group							
Teacher demonstration							

If you did not use all the activities provided, please give a reason for your choice.

....

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....

Please tick the appropriate blocks:

	Yes	Average	Not really
I am confident teaching this material			
The students were enthusiastic			
The students understand the content			
I would like more content information			

General comment on this unit : ....

....

My rating of this unit in terms of suitability for use in Std. 9

excellent	good	average	poor	very poor

FINAL EVALUATION OF THE PACKAGE

Please complete this form once you have tested all the units supplied to you.

SCHOOL : ....

NAME OF TEACHER : ....

TITLES OF UNITS TESTED :

a. ....

b. ....

c. ....

I was unable to do everything suggested in my part of the package because:-

	Yes	No
Lack of time		
Students not at school		
Material too difficult for the students		
Equipment not available (give details below)		
Other reasons (please state why)		

....

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Please comment on the language demand of the package for:-

a. the teacher ....

....

b. the students ....

....

PTO --->

Please indicate how useful you found the following:

	Very useful	Useful	Not so useful	Useless
Learning Objectives				
Background Information				
Prepared worksheets				
Experiments				
Games / Models				
Teacher notes				

I have the following suggestions for improving the package:

....

....

....

Please post this form immediately on completion together with:-

a. the feedback on each unit
b. the multiple choice pre-test responses of the students
c. the multiple choice post-test responses of the students

to:-

Mrs M.D. White,
13 Sanguine Street,
Montroux,
Johannesburg. 2195   Telephone: (011) 782 8778 (H)
(011) 716 2004 (W)

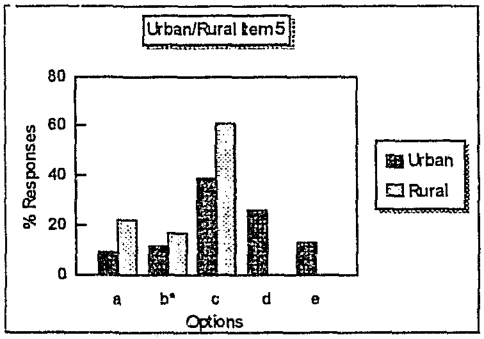
Thank you for your help. I hope that your participation was of benefit to you and your students.

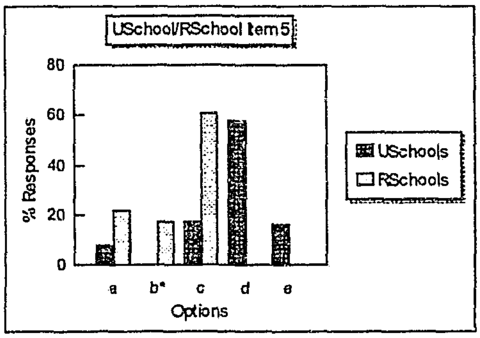
Comparison of Pre-test Outcomes for Some Survey Items for Urban Schools (UI_4 and UI_6) and Rural Schools (RS_1 and RS_2)

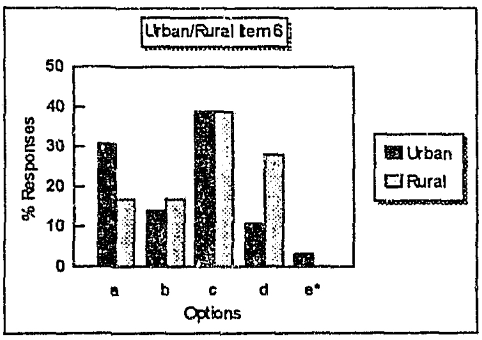
The barcharts on the left represent responses from the urban sample of students (N = 204) and rural sample of students (N = 18) for some knowledge and attitudinal items in the pre-test of the Survey. They are identical to the barcharts presented in Chapter 6, section 6.2.

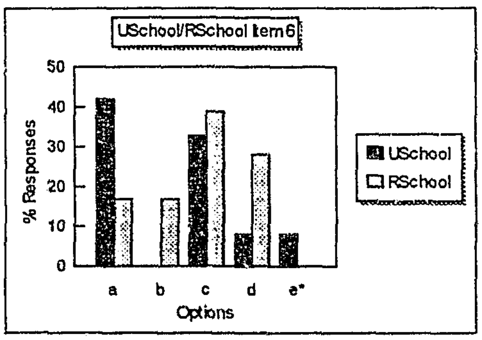
The bar charts on the right represent the outcomes of two samples of urban and rural students that are similar in size. The urban sample is from schools UI_6 and UI_4 (N = 12). The rural sample is from schools RS_1 and RS_2 (N = 18). The urban sample is very similar to the rural sample in language profile. None of the urban or rural students had English as their mother tongue. In addition both the urban teachers and the rural teachers did not have English as their mother tongue. The rural teachers were both underqualified. One of the urban teachers was under qualified.

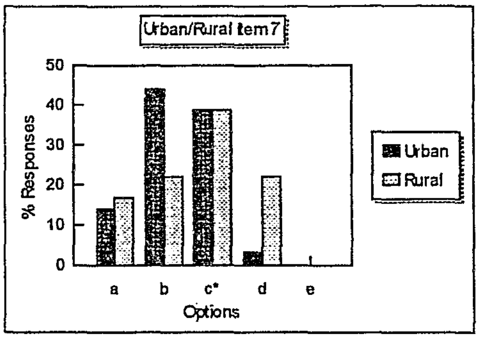
Outcomes for Some Knowledge Items

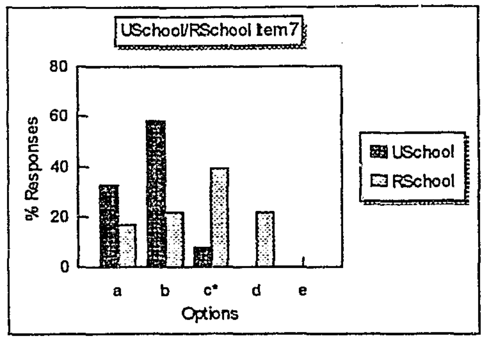


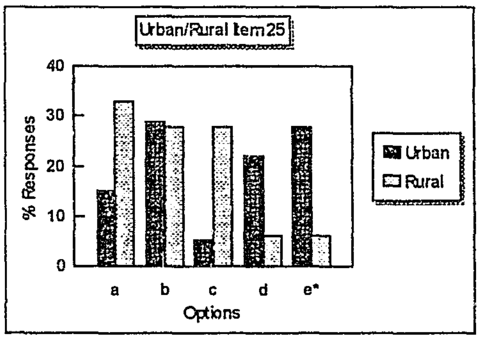


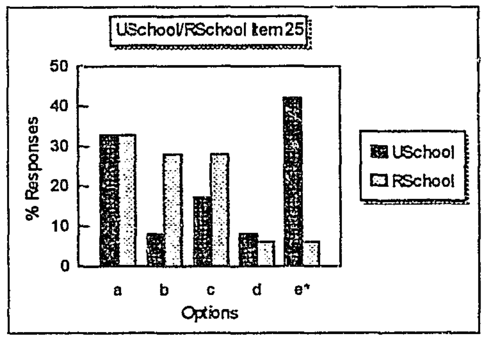








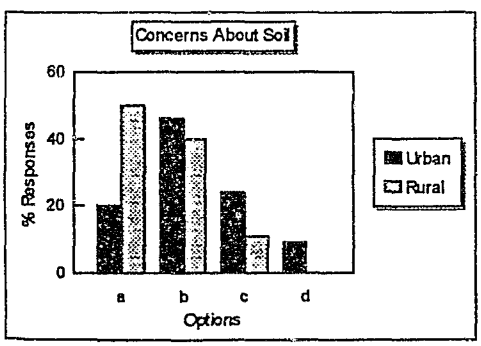


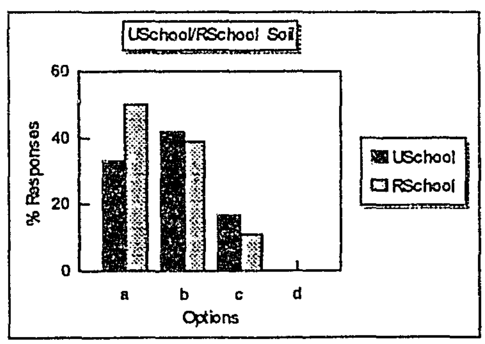


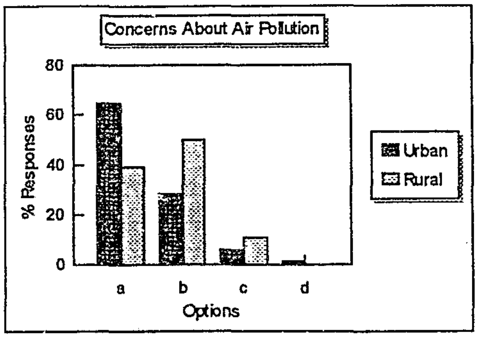
Comments on Knowledge Items

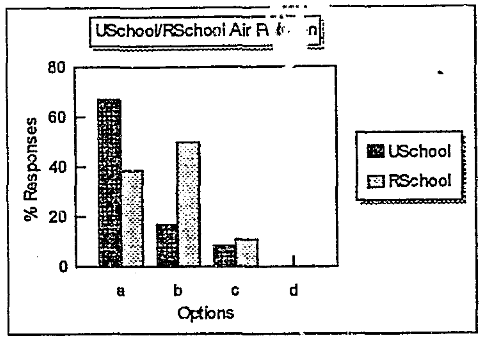
In general the outcomes in the barcharts on the right are not that different from the outcomes in the barcharts on the left. Relatively few students from both groups chose the correct options.

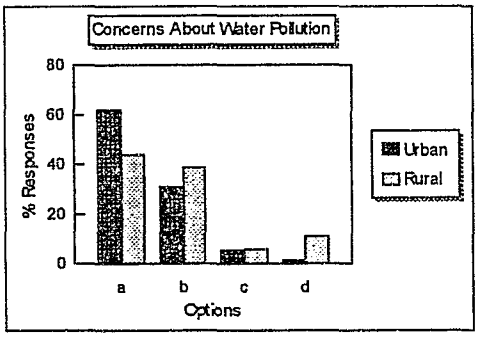
Outcomes for the Attitudinal Items

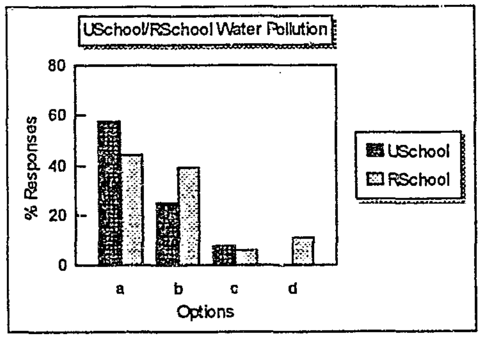


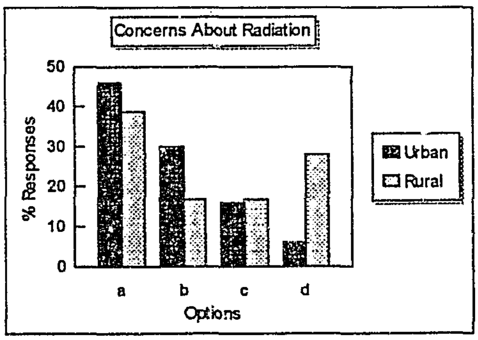


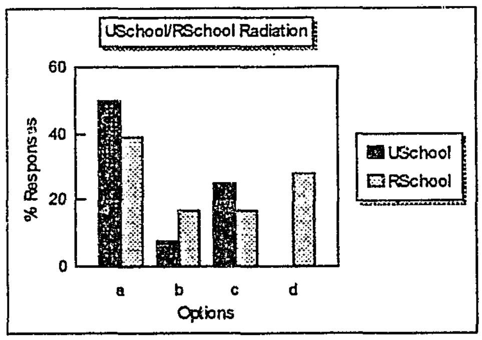






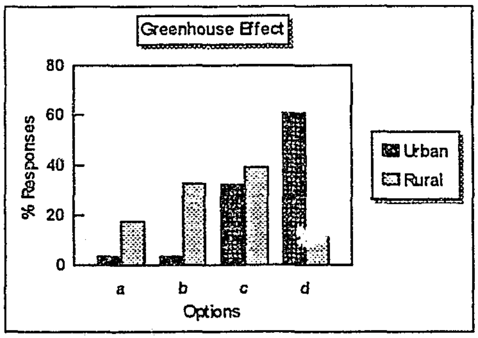


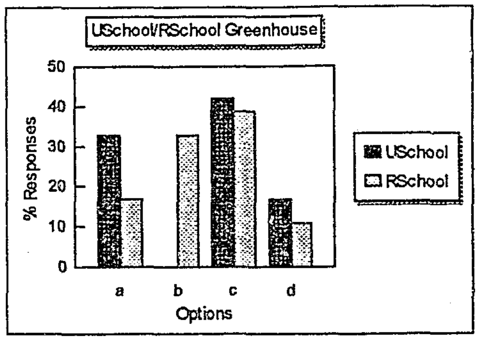


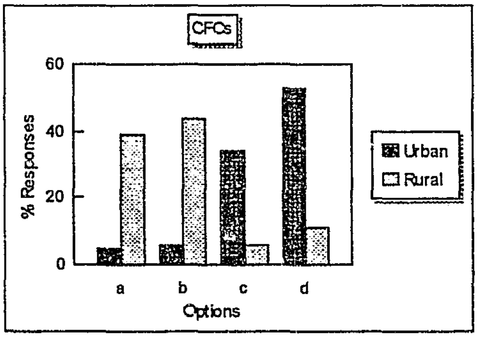


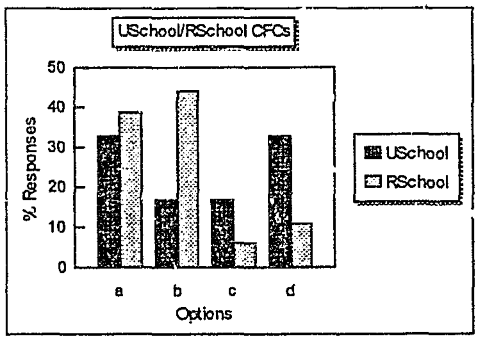
Comments on Concerns

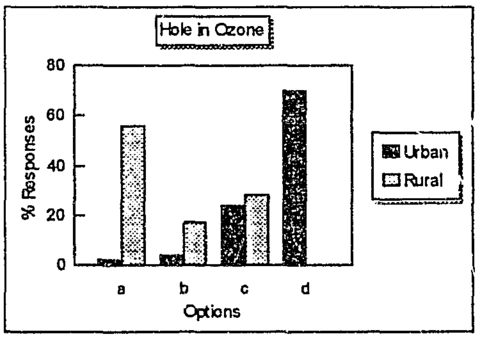
For each of the "concerns", the trends in outcomes as shown in bar charts on the left and on the right are very similar. Both sets of barcharts indicate that rural students were more concerned about soil erosion than urban students. In both sets of bar charts, urban students appeared more concerned than rural students about air and water pollution and exposure to nuclear radiation.

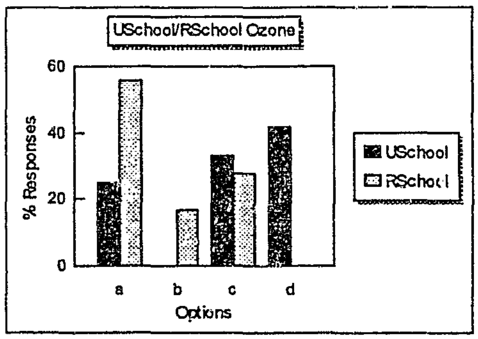






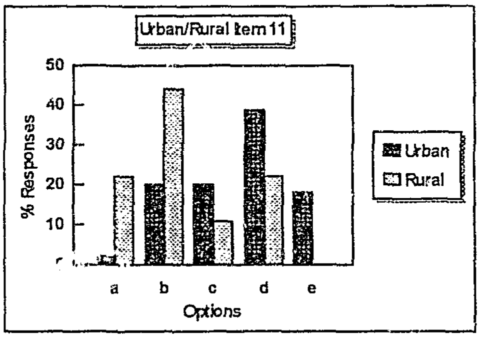


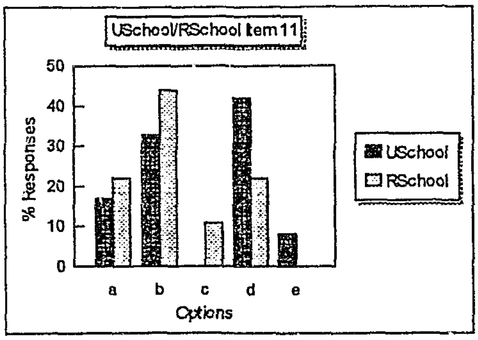




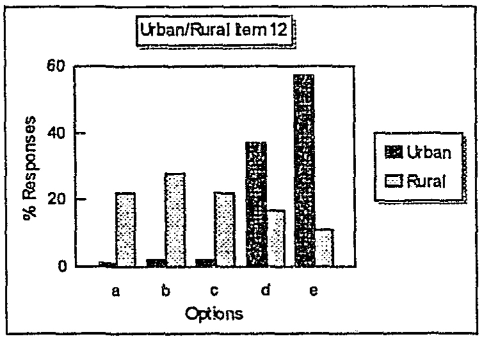
Comments on Understanding of Terms

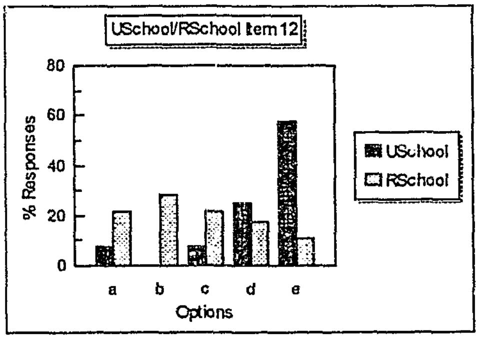
Again the trends in the two sets of barcharts are not that different. The rural students in both comparisons did not appear as well-informed as the urban students. This was particularly so for "CFCS" and "the hole in the ozone layer".



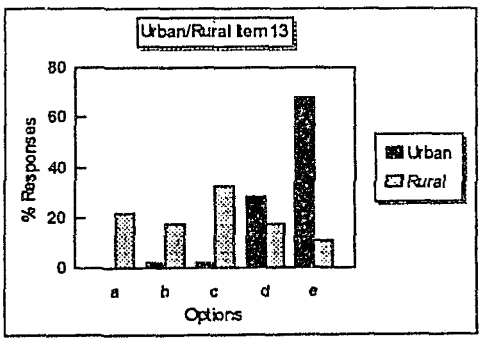


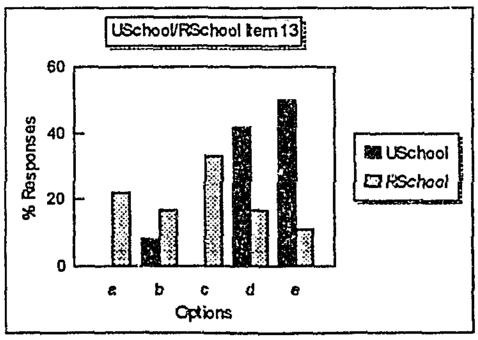
Comments
Both sets of bar charts reveal that rural students are more concerned than urban students about economic and political issues.



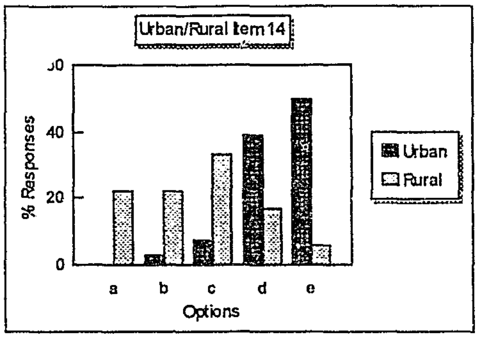


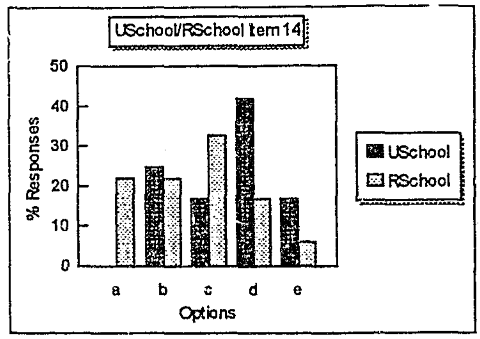
Comments
Both sets of barcharts show that urban students were more aware than rural students of air pollution where they lived.





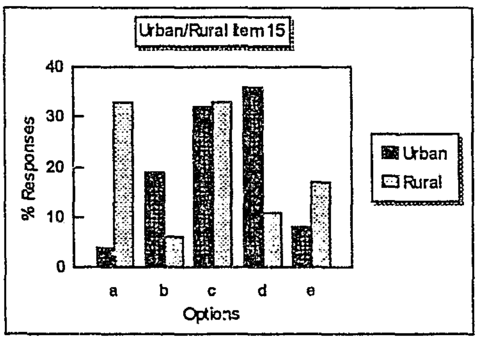
Comments
Both sets of bar charts show that urban students felt more strongly than rural students that air pollution was a problem in South Africa.

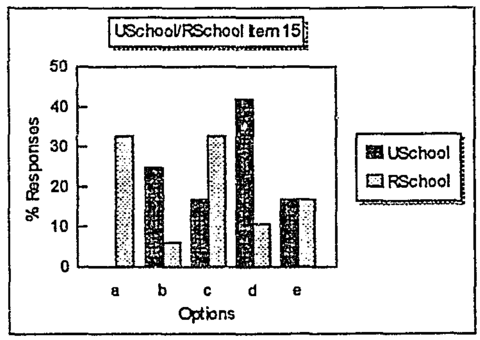




Comments

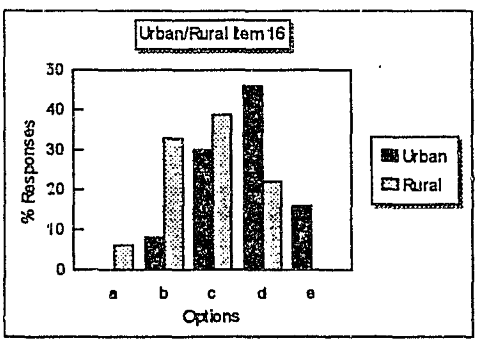
Both sets of bar charts show that urban students understood better than rural students that air pollutants were not necessarily seen and smelled.

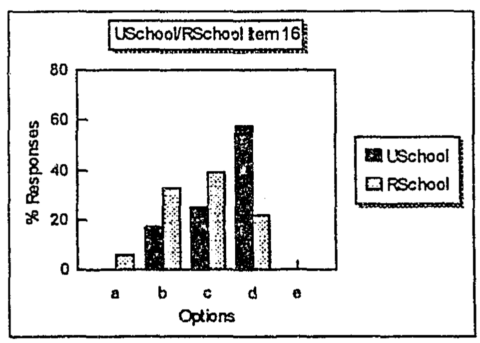




Comments

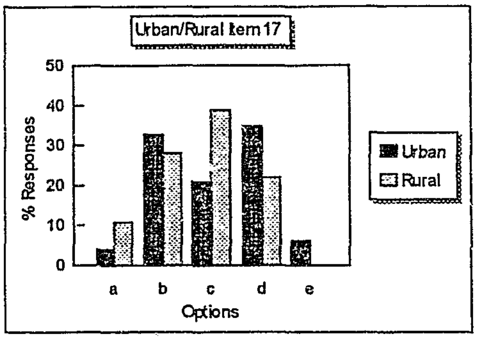
Both sets of bar charts show that urban and rural students had mixed feelings about the issue as to whether air pollutants remained in the atmosphere forever.

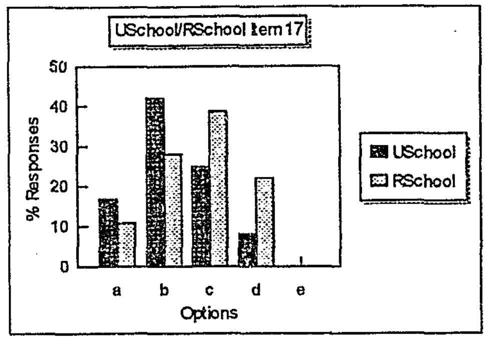




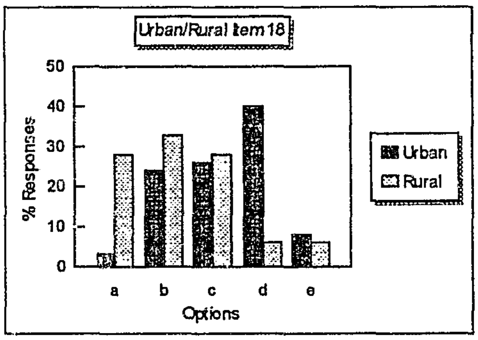
Comments

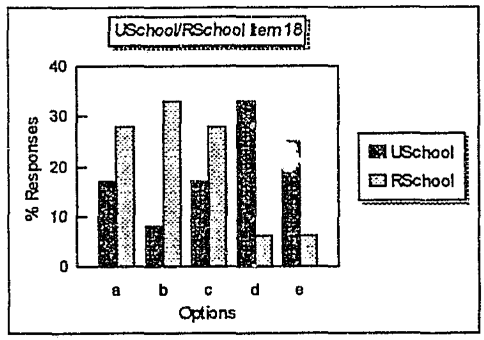
Both sets of bar charts show that urban students were more critical of the media than rural students.



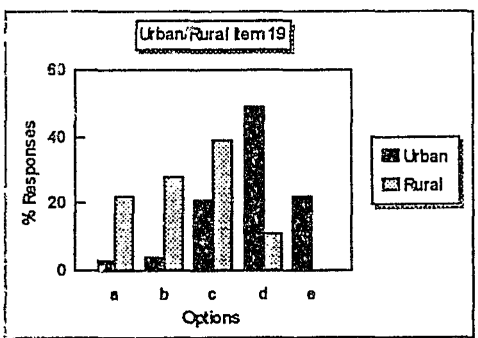


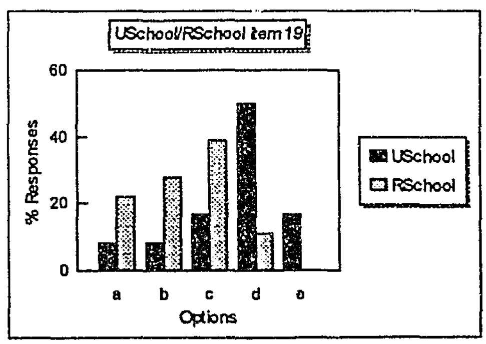
Comments
Both sets of graphs show that students had rather mixed feelings about environmentalists' ability to predict the consequences of air pollution.



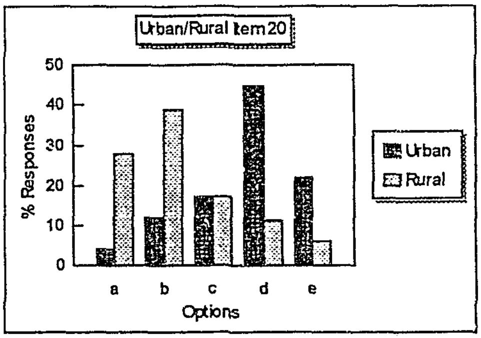


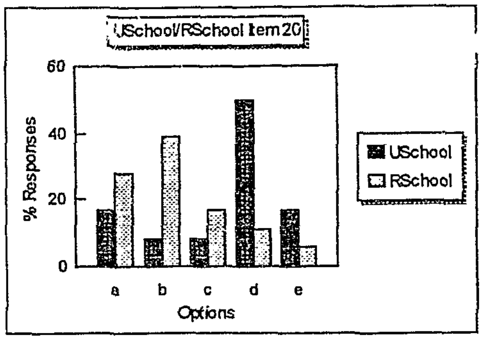
Comments
Both sets of bar charts show that rural students feel more strongly than urban students that industry is not concerned about air pollution.



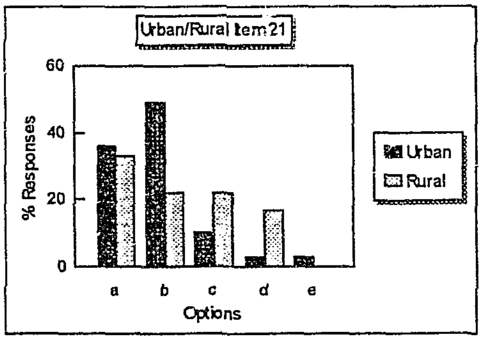


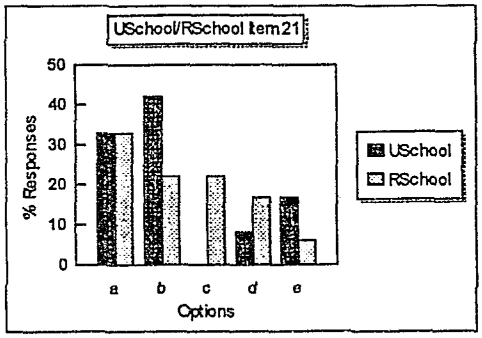
Comments
Both sets of bar charts show that urban students felt more strongly than rural students that technological development should not be stopped to preserve the environment.



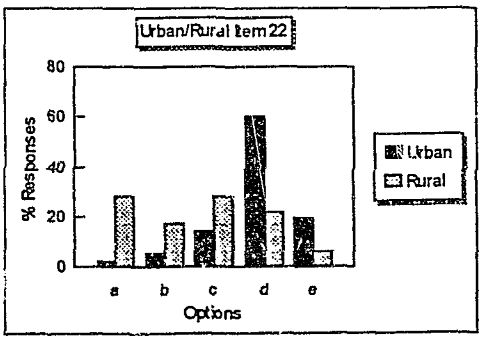


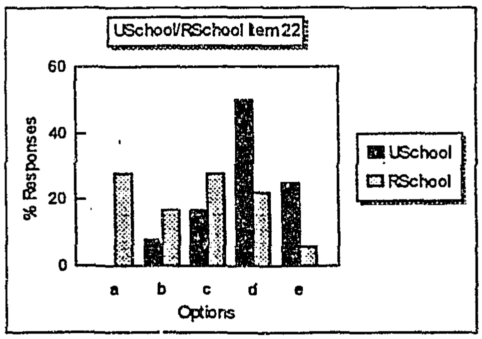
Comments
Both sets of bar charts show that in contrast to rural students, majority of urban students felt that air pollution is not uncontrollable.



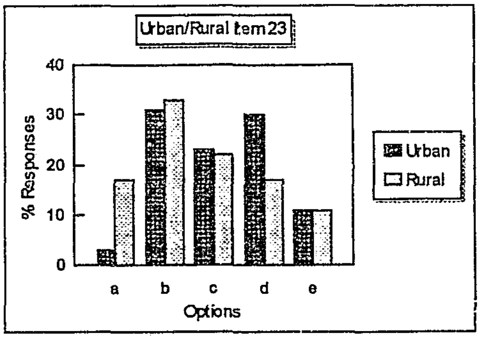


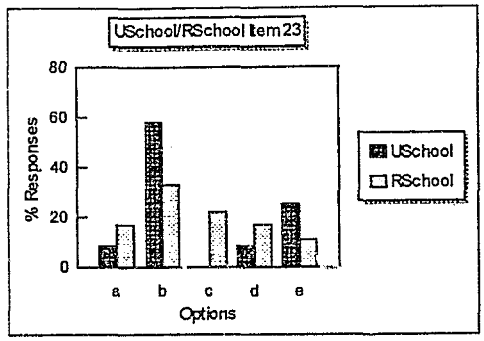
Comments
In both sets of bar charts urban students and rural appeared to feel that air pollution could be controlled. The responses from the urban students in this item are consisitent with their responses in item 20 (above). However the response from the rural students contradicts their response in item 20 (above). This is indicates that language could have been a problem for the rural students.





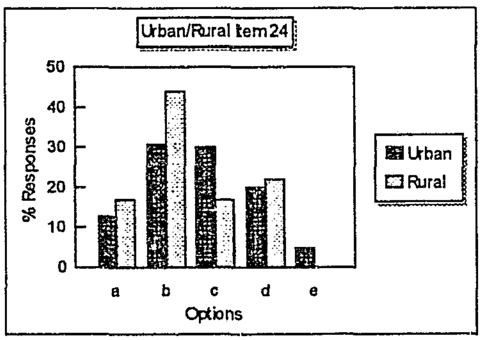
Comments
Again the trend in both sets of bar charts is similar. Urban students felt more strongly than rural students that they contribute to air pollution and have a role to play in its control.

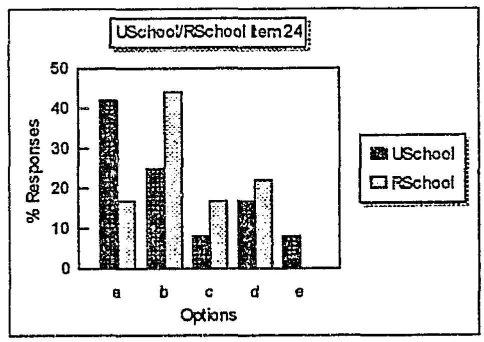




Comments

There is a slight difference in the two sets of bar charts. The bar chart on the right, reveals that the urban students seemed a little more agreeable to paying more for commodities. The bar chart on the left reveals more ambivalence amongst the urban students. Both sets of bar charts reveal that rural students felt reasonably agreeable to paying more for commodities to improve the control of air pollution.





Comments

There is a small difference in the two sets of bar charts. The barcharts on the right show that urban students were slightly more positive than the rural students about the possible inclusion of the topic air pollution in the syllabus.

The bar charts on the right reveal a general tendency on the part of the rural students to agree with the statements in items 11 - 24. The same tendency was revealed in the bar charts on the left. These outcomes were highlighted in Chapter 6, section 6.2.

Overall Comments

Thus the trends shown in the urban/rural samples discussed in Chapter 6, section 6.2. are largely substantiated in the comparison of urban and rural samples that are similar in size.

Inventory of Unit Specific Items in Survey

Good Prior Knowledge Items

Unit 3 Combustion

Item 32	Both coal and oil are classified as fossil fuels. [1](T) [2] **4%**
Item 33	Coal is composed of only carbon.(F) **0%**
Item 40	The total contribution to air pollution by motor vehicles is very small compared to industry. (F) **-19%**
Item 42	Petrol sold in South Africa contains lead compounds. (T) **4%**

Unit 4 The Depletion of Ozone in the Stratosphere

Item 32	The concentration of ozone is the same throughout the atmosphere. (F) **31%**
Item 34	The sky is blue because ozone is a blue gas. (F) **-6%**
Item 38	CFCs are only used in industrial processes. (F) **0%**
Item 41	All solar radiation that enters the atmosphere, reaches the Earth. (F) **-7%**
Item 45	With modern day technology, scientists never make mistakes. (F) **-2%**

Unit 5 Smog

Item 32	Smog is mainly an urban problem. (T) **-15%**
Item 33	Smog only forms on a cold, wet day. (F) **-38%**
Item34	Smog is only the result of burning coal. (F) **15%**
Item 35	Smog is not a problem in South Africa. (F) **4%**
Item 36	Weather plays an important role in the formation of smog. (T) **20%**
Item 37	Smog can have a detrimental effect on health. (T) **4%**
Item 38	Smog is only caused by industrial activity. (F) **7%**

Unit 6 The Enhanced Greenhouse Effect (Outcomes for urban schools only)

Item 32	The possible global warming (that scientists are worried about) is the result of the Sun getting hotter. (F) **5%**
Item 35	The atmosphere is being warmed by energy from the Earth's surface. (T) **-1%**

---

1 Correct response shown in brackets.

2 Knowledge gains shown in bold as a percentage.

Item 37 Gases that contribute to the problem of an enhanced "greenhouse effect" include: carbon dioxide, ozone, nitrous oxide, methane and CFCs. (T) **13%**

Item 39 The burning of coal is a major contributor to the problem of an enhanced greenhouse effect. (T) **17%**

Item 42 The atmosphere prevents the Earth from having scorching hot days and freezing cold nights. (T) **15%**

Item 43 Carbon dioxide concentrations in the atmosphere have increased rapidly since the Industrial Revolution. (T) **23%**

Item 44 Cutting down trees has no effect on the carbon dioxide in the atmosphere. (F) **0%**

Item 45 If the average temperature of the Earth were to increase, the only effect would be the rising of the seas. (F) **6%**

Unit 7 Acid Rain

Item 34 Acids such as sulphuric acid and hydrochloric acid have been detected in rain. (T) **32%**

Item 35 "Acid rain" is not a problem in South Africa (F) **14%**

Item 36 The rate of release of sulphur dioxide into the atmosphere as a result of human activities, exceeds the rate of release of sulphur dioxide from natural sources. (T) **0%**

Item 39 Some gases released from vehicle exhausts contribute to the problem of "acid rain". (T) **14%**

Item 45 Damage by "acid rain" only occurs close to the source of gases causing this air pollution (F) **9%**

Unit 8 The Control of Air Pollution

Item 31 There are natural processes which remove air pollutants from the atmosphere (T) **10%**

Item 32 All air pollutants remain in the atmosphere for the same length of time. (F) **0%**

Item 33 For the concentrations of substances in the atmosphere to remain constant, the rates at which air pollutants are released into the atmosphere should be equal to the rates they are removed from the atmosphere. (T) **0%**

Item 34 Air pollution results when the rates at which air pollutants are released into the atmosphere exceeds the rates at which natural processes remove air pollutants from the atmosphere. (T) **0%**

Item 36 In South Africa, no research is conducted into air pollution problems. (F) **0%**

Item 37 International agreements have been reached concerning some air pollution problems (T) **20%**

Item 38 South Africa has never manufacured CFCs. (F) **20%**

Item 39 CFCs are compounds that do not occur naturally. (T) **10%**

Item 40 The production of CFCs in South Africa has been reduced. (T) **-10%**

Item 42 If the production CFCs is stopped, the air pollution problems associated with them will be immediately solved. (F) **0%**

Item 43 The destruction of ozone in the stratosphere is a global air pollution problem. (T) **-10%**

<u>Unit 9 Response by Industry</u>

Item 33 At present there are no techniques available for reducing the release of sulphur dioxide into the atmosphere. (F) **0%**

Item 36 The use of tall chimney stacks by industry is always a solution to air pollution problems. (F) **12%**

Fair Prior Knowledge Items

<u>Unit 3 Combustion</u>

Item 31 Approximately 90% of the world's energy comes from the combustion of coal. (T) **24%**

Item 34 The only products formed when coal is burned are: ash, soot, carbon dioxide and carbon monoxide. (F) **10%**

<u>Unit 4 The depletion of Ozone in the Stratosphere</u>

Item 36 Both CFCs and nitrous oxide (N_2O) destroy ozone in the atmosphere. (T) **16%**

Item 39 CFCs occur naturally in the atmosphere. (F) **19%**

<u>Unit 5 Smog</u>

Item 41 Sunlight and some of the gases from motor car exhausts can result in smog formation (T) **-4%**

Item 45 Science and technology have no methods for c ... photochemical smog. (F) **-4%**

Unit 6 The Enhanced Greenhouse Effect

Item 34 The atmosphere is warmed directly by the Sun's energy as it passes through the atmosphere. (F) **0%**

Unit 7 Acid Rain

Item 32 " Acid rain" is a consequence of increased concentrations of carbon dioxide in the atmosphere. (F) **14%**

Item 38 Combustion of fossil fuels (coal and oil) is a major contributor to the problem of "acid rain". (T) **36%**

Unit 8 The Control of Air Pollution

No items in ths category

Unit 9 The Response by Industry

Item 31 There are no methods available for controlling the release of particulates into the atmosphere. (F) **25%**

Item 39 Fly-ash from coal-fired power stations can reduce the quantity of fertilisers farmers need to use. (T) **25%**

Item 41 In some areas of South Africa, the air pollution from domestic fires exceeds air pollution from coal-fired power stations. (T) **38%**

Item 42 SASOL only produces petrol from coal. (F) **-50%**

Item 43 The only use for coal is to supply us with energy when the coal is burnt. (F) **0%**

Poor Prior Knowledge Items

Unit 3 Combustion

Item 35 The ash produced by burning coal does not present any pollution problems because it is solid and can be easily removed. (F) **38%**

Item 36 South African coal has a low sulphur content. Therefore the release of sulphur dioxide from coal combustion is negligible. (F) **-14%**

Item 37 The burning of coal in households can produce worse air pollution than that produced by power stations. (T) **38%**

Item 38	In South Africa, coal-fired power stations burn more coal than industries such as ISCOR. (T) **29%**
Item 39	Nitrogen oxides which contribute to air pollution problems are only produced by industrial processes. (F) **28%**
Item 41	The temperature in parts of the running motor car engine is sufficient to bring about a reaction between nitrogen and oxygen in the air. (T) **19%**
Item 43	The only products formed when petrol is burnt in the engines of motor vehicles are: carbon dioxide, carbon monoxide and lead compounds. (F) **19%**
Item 44	Natural gas is methane. (T) **33%**
Item 45	In South Africa, natural gas deposits have been discovered near Mossel Bay. (T) **14%**

Unit 4 The Depletion of Ozone in the Stratosphere

Item 31	The chemical formula for ozone is O_3. (T) **48%**
Item 33	Once ozone is destroyed in the stratosphere, it can never be reformed. (F) **36%**
Item 35	CFCs are compounds whose molecules consist of chlorine, fluorine and carbon atoms. (T) **51%**
Item 37	One chlorine atom released from a CFC molecule is capable of destroying approximately 100 000 ozone molecules. (T) **26%**
Item 40	CFCs are unreactive in the troposphere but become reactive in the stratosphere. (T) **22%**
Item 42	Ozone is the only substance in the atmosphere capable of absorbing radiation of wavelength 220- 330 nm. (T) **40%**
Item 43	Solar radiation of wavelength 220-330 nm is harmful to life. (T) **26%**
Item 44	A photochemical reaction can only be brought about by visible light. (F) **8%**

Unit 5 Smog

Item 31	Smog is always a combination of smoke and fog. (F) **-20%**
Item 39	Ozone only has beneficial effects in the stratosphere. (F) **18%**
Item 40	Ozone is not present in the lowest region (the troposphere) of the atmosphere.(F) **18%**

Item 42 Nitrogen oxides are formed when nitrogen and oxygen in the air combine in the very hot parts of the motor car engine. (T) **18%**

Item 43 Hydrocarbon compounds released from car exhausts, are involved in the chemical reactions which produce photochemical smog. (T) **19%**

Item 44 Ozone accumulates during the formation of photochemical smog. (T) **-7%**

Unit 6 The Enhanced Greenhouse Effect

Item 31 The "greenhouse effect" of the atmosphere is beneficial. (T) **58%**

Item 33 Approximately 45% of the Sun's energy that enters the Earth's atmosphere, reaches the Earth. (T) **38%**

Item 36 All gases in the atmosphere are capable of absorbing infrared radiation (heat). (F) **18%**

Item38 Human activities such as agriculture and farming do not contribute to air pollution problems. (F) **46%**

Item 40 Scientists can predict with certainty the consequences of an enhanced "greenhouse effect". (F) **50%**

Item 41 Once carbon dioxide has been released into the atmosphere, it remains there forever. (F) **25%**

Unit 7 Acid Rain

Item 31 Rain is naturally neutral with a pH of 7. (F) **45%**

Item 33 Rain with a pH = 2.1 has fallen in Britain. (T) **36%**

Item 37 CFCs contribute to the problem of "acid rain". (T) **37%**

Item 40 Industries contribute more than coal-fired power stations to the problem of "acid rain". (F) **18%**

Item 41 The contribution of industry to the total concentration of nitrogen oxides in the atmosphere, is greater than the contribution of transportation. (F) **36%**

Item 42 The death of fish in the lakes of Europe and America has been a consequence of "acid rain". (T) **45%**

Item 43 It is a fact that "acid rain" alone is responsible for the death of large numbers of trees in the forests of Europe and America. (F) **32%**

Item 44	The use of tall chimney stacks (which dilute air pollutants) has overcome the problem of acid rain. (F) **23%**

Unit 8 The Control of Air Pollution

Item 35	There is no law in South Africa to control air pollution. (F) **40%**
Item 41	It is proposed that no CFCs will be produced by the year 2000. (T) **10%**
Item 44	The Montreal Protocol is an international agreement to reduce CFC production. (T) **50%**
Item 45	All the nations of the world have signed an agreement to reduce CFC production. (F) **30%**

Unit 9 The Response by Industry

Item 32	Cyclones are very effcient devices for reducing air pollution. (F) **0%**
Item 34	Industry could make use of technology which would eliminate air pollution completely. (F) **13%**
Item35	The cost of installing and using technology to reduce air pollution, is small compared with other costs faced by industry. (F) **25%**
Item 37	Catalytic convertors cannot be used in South Africa because there are lead compounds in our petrol. (T) **76%**
Item 38	ESKOM does not use technology to reduce the release of sulphur dioxide into the atmosphere. (T) **0%**
Item 40	Supplying electricity to towns in South Africa, has totally reduced air pollution from coal fires.(F) **-26%**
Item 44	If power stations use improved technology to control air pollution, electricity could become too expensive for many people. (T) **12%**
Item 45	Industry never monitors the quantity and nature of the air pollution produced by its activities. (F) **50%**

DESIGNING, IMPLEMENTING AND EVALUATING
A
SCIENCE-TECHNOLOGY-SOCIETY (STS)
TEACHING RESOURCE PACKAGE
ON
AIR POLLUTION

VOLUME 2

Margaret Dawn White

A thesis submitted to the Faculty of Science, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Doctor of Philosophy.

October, 1998.

A SCIENCE-TECHNOLOGY-SOCIETY (STS) TEACHING RESOURCE PACKAGE ON AIR POLLUTION

Completed by M D White
as part of the degree of
Doctor of Philosophy

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University of the Witwatersrand

1998

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An Introduction to the Package

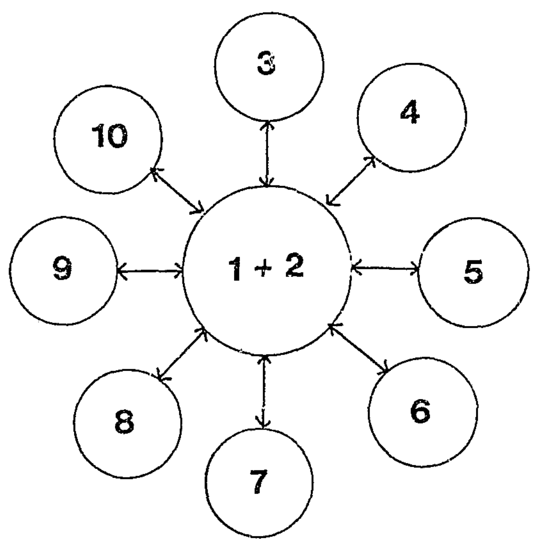
This package has been designed to provide a resource of background information and student activities for teachers of Std 9 classes. However it may be suitable for teaching at a tertiary level eg. in Colleges of Education, or for use in resource centres. Selected parts of the package may be suitable for Stds 6-8 or for other disciplines eg. Geography.

The Design of the Package

The resource package comprises 10 units which are:

1. The Atmosphere
2. What is Air Pollution?
3. Combustion
4. The Depletion of Ozone in the Stratosphere
5. Smog
6. The Enhanced Greenhouse Effect
7. Acid Rain
8. The Control of Air Pollution
9. The Response by Industry
10. What are Our Alternatives?

Units 1 and 2 form the core of the package. The other units are related to the core as illustrated in the diagram.



Each unit consists of:

a) An Introduction
This provides background information for the teacher. It informs and enriches and goes beyond the requirements of the lesson.

b) A List of Learning Objectives
These summarise the essential aspects of each lesson.

c) <u>Worksheets</u>
They provide a variety of activities. There are opportunities for small group discussions, practical activities, long-term projects, problem solving, reading and comprehension, creative writing, role-play, graphical representation of data and interpretation of data.
The resource package does not aim to be prescriptive. It is proposed that teachers will make their own choices as to lesson plan and suitability of activities for the context in which they teach. The worksheets provided could be used as classroom activities, homework exercises, projects or test questions.

d) <u>Solutions</u>
Comprehensive solutions for the worksheets are to be found at the end of each unit.

A <u>glossary</u> of terms has been included. It explains much of the terminology used in the package. A few other terms which have not been used in the package but which may be encountered in other sources, have also been included.

Examples of <u>multiple choice</u> questions, <u>True/False</u> statements and statements to which students <u>agree/disagree</u> are to be found at the end of the package. These questions probe conceptual understanding of and attitudes towards air pollution. These questions could be used as follows:

i) <u>To Introduce the Topic of Air Pollution</u>
The questions/statements sensitise students to the issues. Some questions/statements aim to make students more aware of their attitudes towards the problems of air pollution. It makes an interesting study to assess how students' attitudes and understanding change after studying the topic. To do this some of the questions/statements could be administered as a pre-test before teaching and then as a post-test after teaching a topic.

ii) <u>To Stimulate Debate</u>
Questions or statements could be used singly to stimulate a lively classroom debate.

iii) <u>To test/examine</u>
Many of the questions could be used to assess students' understanding of a topic after teaching.

The Aims of the Package

Two broad aims of the package are:

A. To study the concepts and principles of air pollution.

B. To address the attitudes of students
  i) towards science and technology
  ii) towards issues concerning air pollution

The more specific aims of the package are that students should:

1. gain an accurate and balanced understanding of the issues and complexity of air pollution.
2. understand and effectively use the terminology associated with the topic.
3. relate the concepts studied to the "real world"
4. perceive science as a human activity, involving team work, where errors are sometimes made and some outcomes remain uncertain.
5. become aware of the role played by science, technology and society in the problems of air pollution and in the search for solutions.
6. understand and apply fundamental chemical principles, previously learnt, to this topic.
7. become aware of the interrelationship of knowledge from different disciplines in the study of air pollution.
8. realise the importance of a risk/benefit approach to finding solutions to the problem of air pollution.
9. develop a critical approach to the presentation of information on air pollution by the media.

Parts of this package will become outdated as our understanding of air pollution increases. Nevertheless, the package will form a basis for the topic. New worksheets may be devised by the teachers themselves or included from other sources as they become available.

This project has been generously sponsored by SASOL.

UNIT 1

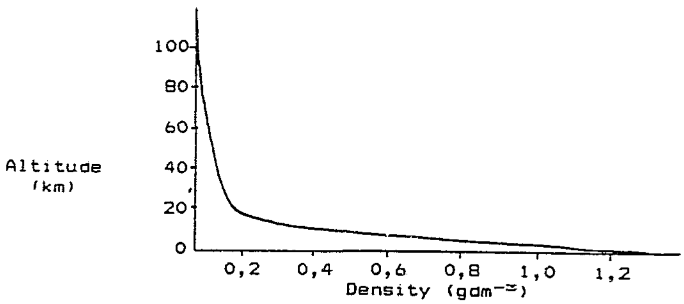
The Atmosphere

Introduction to Unit 1

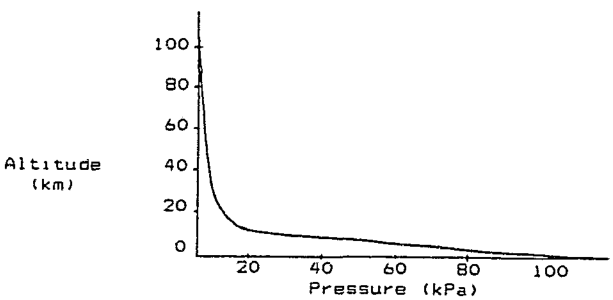
As it hurtles through space, Planet Earth can be compared with a spaceship. This "spaceship" consists of three states of matter: solid, liquid and gas. The solid state is the land or lithosphere; the liquid state is composed of the seas, lakes, rivers, glaciers, polar ice caps, underground water and is called the hydrosphere. The gaseous state is the air or atmosphere. We shall concentrate on the atmosphere (from Greek words: 'atmos' meaning 'vapour' and 'sphaira' meaning 'ball').

The atmosphere is a mixture of gases in which solid particles and droplets of liquid may be dispersed. The atmosphere is naturally reactive. This is apparent, for example, in its involvement in combustion and the rusting of iron. The atmosphere extends to an altitude of more than 2 000 km above the surface of the Earth. However the atmosphere is not uniform: the density of the atmosphere decreases sharply with increasing altitude as a consequence of gravity. Thus 50% of the total mass of the atmosphere is found lower than an altitude of 5 km, 90% is found within 15 km and 99,9% is within 60 km of the Earth's surface. (The total mass of the atmosphere is about 5×10^{18} kg.) The pressure of the atmosphere shows a similar variation with altitude.

Graph of Altitude versus Density in the Atmosphere



Graph of Altitude versus Pressure in the Atmosphere



The temperature of the atmosphere also varies with altitude - sometimes in a surprising way! This has led to the classification of different layers of the atmosphere according to altitude, temperature and other properties such as composition and air movements. The main layers or regions are the troposphere, the stratosphere, the mesosphere and the thermosphere or ionosphere. The regions are not separate from one another but continuous. The classification is simply made to assist in the study of the atmosphere. Our study will focus mainly on the troposphere and the stratosphere.

<u>Graph of Altitude versus Temperature in the Atmosphere</u>

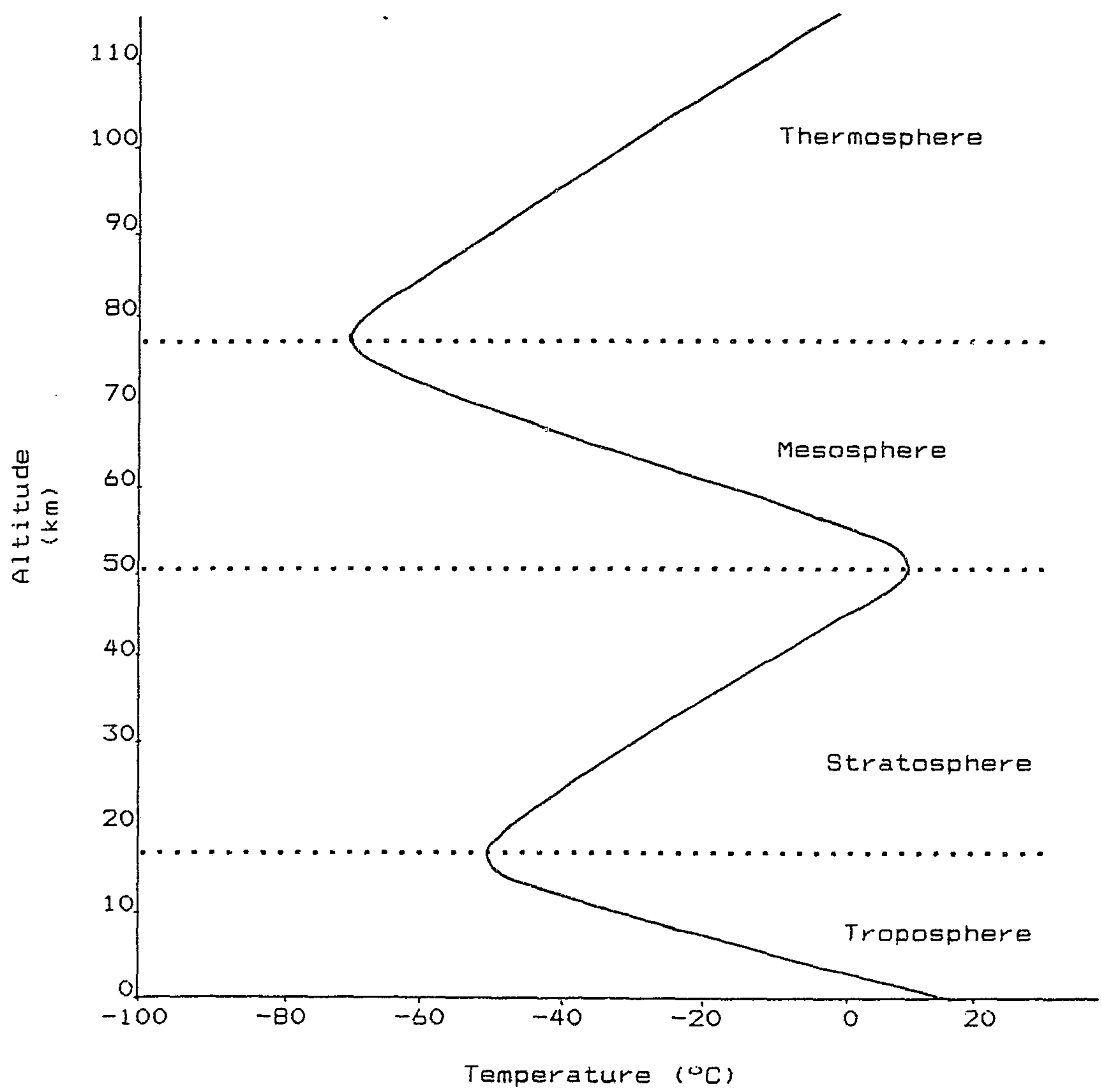
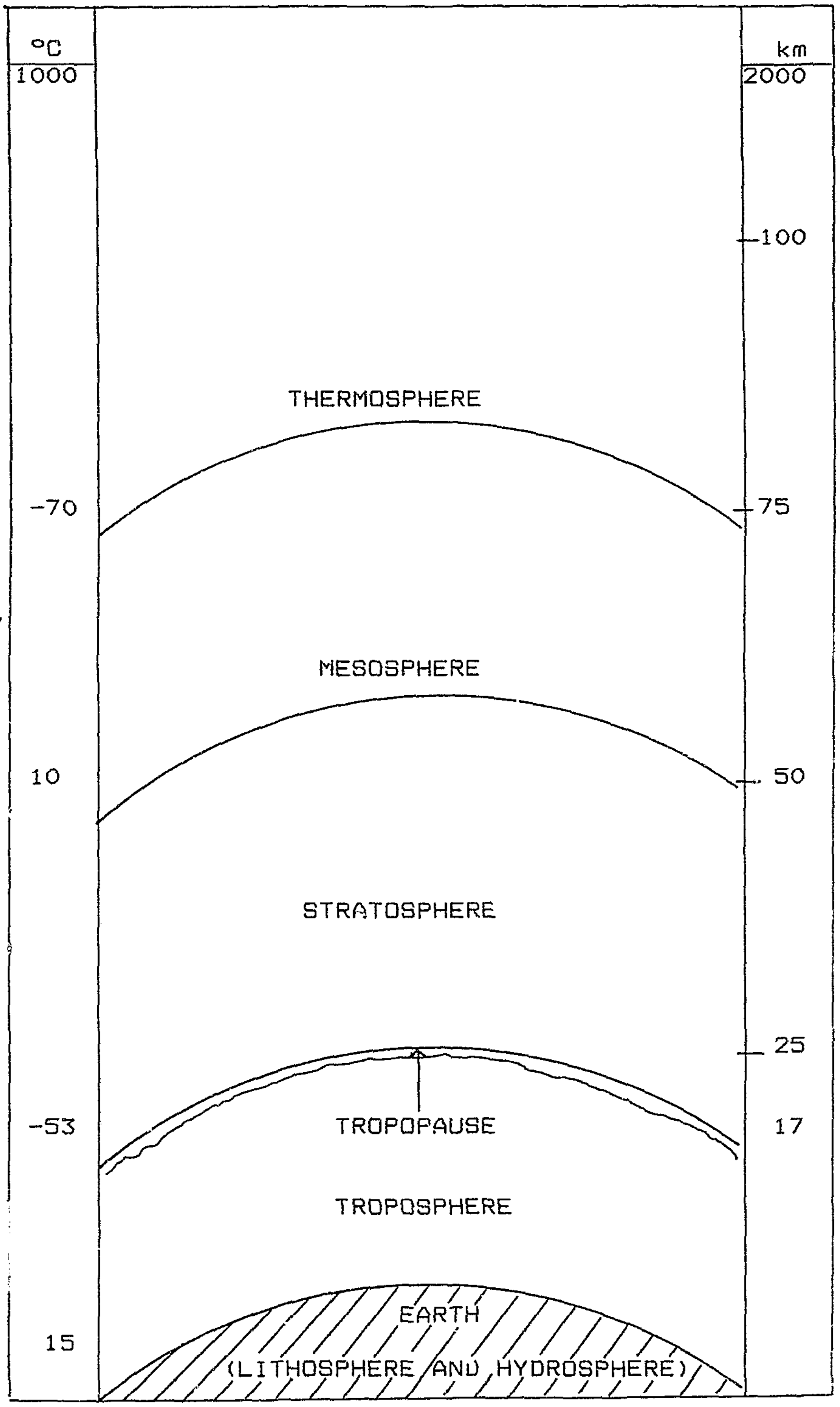


Diagram Showing the Major Regions of the Atmosphere



The troposphere extends up to about 17 km above the Earth's surface. There is a steady decrease in temperature from an average temperature of 15°C at the surface of the Earth to approximately −53°C at an altitude of 17 km above the Earth's surface. This decrease in temperature with increasing altitude is a consequence of the absorption of most of the longwave (infrared) radiation from the Earth's surface. This absorption is greatest at lowest altitudes, so it is warmest near the surface. The troposphere contains the gases for respiration and photosynthesis. The clouds and winds that are a part of the weather are found in the troposphere too. Convection currents due to the warming and rising of air cause turbulence. The air in the troposphere is in constant motion in both the horizontal and vertical directions. The name troposphere (from a Greek word tropos meaning "to turnover") is apt. Most of the activities of humans take place in the lowest 2 km of this region. Some of these activities are affecting both the troposphere and the stratosphere.

The tropopause is a relatively thin layer in between the troposphere and the stratosphere. Its height varies according to latitude and season. At the tropopause the temperature begins to increase: here ozone molecules absorb some of the Sun's high energy ultraviolet radiation and decompose exothermically. The tropopause is a region of temperature inversion as the trend in temperature change with altitude becomes inverted or reversed. The type of temperature inversion found in the tropopause is always relatively stable because the hotter air above has a lower density than the underlying colder air. Thus exchange between the troposphere and stratosphere (across the tropopause) is slow and does not occur to a large extent. The low temperature found at the start of the tropopause plays an important role. It prevents most of the water vapour present in the atmosphere from reaching altitudes where it would decompose into hydrogen and oxygen under the influence of high energy ultraviolet solar radiation. (This decomposition is initiated by solar radiation entering the atmosphere. It is an example of a photochemical reaction. Photochemical reactions play an important role in the chemistry of the atmosphere.) If water were to decompose at high altitudes in the atmosphere, the hydrogen produced would escape from the Earth's atmosphere. Thus the tropopause prevents the loss of hydrogen from the Earth's atmosphere because the water vapour freezes sometimes resulting in cirrus cloud formations. These cloud formations act as a "marker" of the position of the start of the tropopause. Most commercial aircraft fly just below the tropopause.

Extending about 30 km above the tropopause is the stratosphere (from a Latin word, stratum meaning "layer"). In this region, temperature increases with altitude until the temperature reaches a maximum of approximately 10°C at 40 to

50 km above the Earth's surface. The stratosphere is an important region because here the concentration of ozone (present in the tropopause as mentioned earlier) increases to a maximum of about 10 parts per billion or 10 ppb. Although this is a small concentration, ozone plays a very important role in protecting life on Earth from the Sun's high energy ultraviolet radiation. The ozone molecules absorb some of this high energy radiation and are decomposed by it. The decomposition is exothermic. This causes the increase of temperature which is observed in the stratosphere. While some vertical movement of the air occurs in the stratosphere, strong, fast moving, horizontal air currents predominate. (It was hoped that aeroplanes such as the Concorde would make use of these horizontal currents, sometimes called "jet streams". Because of concern about the consequences of exhaust fumes on the atmosphere in this region, it has been decided to fly the Concorde at a lower altitude.) Very little water vapour is present in the stratosphere for the reasons discussed in the description of the tropopause.

The temperature in the <u>mesosphere</u> falls steadily with increasing altitude reaching -70°C at approximately 80 km above the Earth's surface. Meteors, sometimes called "shooting stars" burn out in this region.

The <u>thermosphere</u> (also known as the ionosphere) is characterised by a steady increase in temperature with altitude. For example the temperature exceeds 1 000°C at an altitude of 700-800 km. The air in the thermosphere is ionised by the high energy ultra-violet part of the solar radiation.

The composition of the troposphere (if unpolluted) varies very little near the surface of the Earth. (With the exception of water vapour which may be present in quantities up to 4% in some regions or be totally absent in others.)

<u>Composition of Dry Tropospheric Air</u>

	Substance	Formula	Percent of Gas Particles
Major Components	nitrogen	N_2	78,08
	oxygen	O_2	20,95
Minor Components	argon	Ar	0,934
	carbon dioxide	CO_2	0,0314
Trace Components	neon	Ne	0,00182
	ammonia	NH_3	0,00100
	helium	He	0,000524
	methane	CH_4	0,000200
	krypton	Kr	0,000114

Other gases are present in concentrations below 0,0001% for example hydrogen (H_2), xenon (Xe), ozone (O_3), two nitrogen oxides - nitrogen monoxide (NO) and nitrogen dioxide (NO_2), which are often given the collective formula NO_x, carbon monoxide (CO), sulphur dioxide (SO_2).

The table on page 11 gives the composition of the tropospheric air in terms of percentage of gas particles. The composition of tropospheric air can also be expressed in a number of other ways of which <u>percentage by volume</u> is probably one of the most important. The values of volume percentages will be identical to those of molecular percentages. This is because equal volumes of gases at the same temperature and pressure contain the same number of molecules. Thus the volumes of gases at the same temperature and pressure are directly proportional to the number of molecules they contain.

For the minor constituents because the percentages are so small, the concentrations are quoted in parts per million (ppm) or parts per billion (ppb). Thus the concentration of carbon dioxide is 0,0314% or 314/1 000 000 or 314 parts out of a million ie. 314 ppm. The percentages quoted are really averages for the lower atmosphere (troposphere) because, as mentioned earlier 99% of the mass of the atmosphere lies below an altitude of 30 km.

The composition of the troposphere varies very little. However the composition of the atmosphere does vary with altitude. Between 120 km and 1 000 km above the Earth's surface, oxygen atoms (not molecules) are a major component. Helium is a major component from 1 000 km to 2 500 km whilst above 2 500 km hydrogen atoms (not molecules) predominate.

The concentrations of the major components of the atmosphere remain constant over relatively "short" periods of time (say 100 000 years!). However circumstantial evidence seems to suggest that since our planet first formed, the composition and temperature of the atmosphere have changed. Some researchers have suggested that the early atmosphere contained 1 000 times as much carbon dioxide as it does today and that there was very little oxygen present. Much of the carbon dioxide may have formed carbonates in sedimentary rocks and the concentration of oxygen may have increased as life began to proliferate.

Ice samples from a 2 km core drilled from the Antarctic ice sheet contain trapped bubbles of air from ancient times and this allows scientists (geologists and geophysicists) to reconstruct a 160 000 year record of atmospheric gases and temperatures. Their findings suggest that during the past two centuries the concentrations of some of the minor and trace components (see table on page 11 for composition of air) have changed faster than at any time in human history.

These changes may have consequences for the nature of the benign climate the atmosphere provides for us to live in. If it were not for the atmosphere the average temperature of the bare Earth would be -1°C with scorching hot days and freezing nights. This situation exists on the Moon which is not enveloped by an atmosphere. The interaction of the atmosphere with radiation from the Sun and radiation from the Earth raises the average surface temperature of the Earth to 15°C - a beneficial "greenhouse" effect.

In addition the atmosphere protects us from harmful high energy radiation of the Sun for example ultraviolet and cosmic radiation.

A chemist's study of the atmosphere focuses on the molecules and atoms it contains. These are in constant motion. Molecules are vibrating and molecules and atoms are moving rapidly in all directions in straight lines colliding with one another from time to time. The average speeds of these particles will be greater at higher temperatures and less at lower temperatures. There are spaces between the particles of gases. The speeds with which the particles move and the spaces between the particles account for the rapid mixing and diffusion of gases. The microscopic behaviour of these particles, if it involves sufficiently large numbers, determines the macroscopic properties of the atmosphere that we observe or detect.

Learning Objectives for Unit 1

On completing this unit students should be able to:

1.1 Describe the composition of the Earth as being solid (the land) or lithosphere, liquid (seas, lakes and rivers) or hydrosphere and gas (the air) or atmosphere.
1.2 Describe qualitatively how the density of the atmosphere changes with increasing altitude.
1.3 Describe qualitatively how the temperature of the atmosphere varies with increasing altitude.
1.4 Explain what is meant by a temperature inversion.
1.5 Explain what is meant by a photochemical reaction.
1.6 Describe the classification of the atmosphere into regions - the troposphere, the stratosphere, the mesosphere and the thermosphere with respect to altitude and temperature.
1.7 Describe the main features of the troposphere and the stratosphere.
1.8 Name and write the chemical formulae for the major, minor and trace components of the atmosphere.
1.9 Express the concentrations of gases in the atmosphere in terms of percentage of molecules and percentage by volume.
1.10 Express the concentration of the minor and trace gases as parts per million (ppm) or parts per billion (ppb).
1.11 Explain how the atmosphere provides a benign climate for life (the biosphere) on Earth.
1.12 Describe the natural reactivity of the atmosphere.
1.13 Describe briefly the theories which describe changes in the composition of the atmosphere since the birth of the planet and during the past two centuries.
1.14 Interpret the macroscopic atmosphere in terms of a microscopic model of a mixture of gases - using terms such as element, compound, mixture, atom and molecule.
1.15 Explain the phenomena of miscibility and diffusion in terms of the microscopic model of the atmosphere.

Worksheet 1(a) "Planet Earth"

i) Planet Earth is like a manned space-ship hurtling through space. Earth carries with it the physical features that support life (the biosphere). Try to name some of these physical features or life-support systems.

ii) Astronauts often comment on the beauty of Earth encircled by the atmosphere which is marked by its pattern of clouds. What would planet Earth be like if there were no atmosphere?

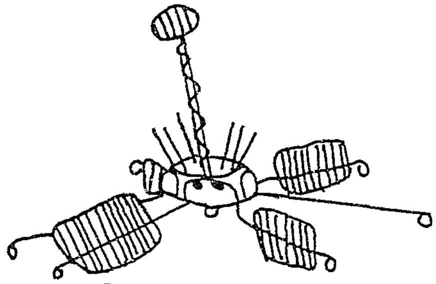
iii) Why do the gases that comprise the atmosphere not leave the Earth and escape into interplanetary space?

iv) Is the atmosphere naturally unreactive? Explain your answer.

Worksheet 1(b) "Lift-off!"

Scientists monitor the atmosphere using sophisticated devices on the surface of the Earth that can "look" into the atmosphere up to a height of approximately 2 km. They can also measure its temperature, pressure and chemical composition, by sending up instruments aboard balloons, rockets and satellites.

Let's suppose that you are aboard an imaginary craft "Beetle-Bob II" designed to travel to a height of 200 km above the Earth's surface. Instruments record altitude, temperature and pressure. You will also be collecting 1 dm^3 samples of air at certain altitudes.



Beetle-Bob II

Task 1

Look at the data given below on temperature and altitude for the atmosphere. Before plotting a graph of this data, convert the temperature readings from the Celcius scale to the absolute (Kelvin) scale of temperature. (You will be adding information to the graph and it will be clearer if the curve you draw does not cut across the vertical axis). Now plot a graph of altitude versus absolute temperature using the vertical axis to represent altitude and the horizontal axis to represent temperature. Use as large a scale as possible.

Altitude/km	0	15	25	50	75	100	150
Temperature/°C	20	-35	-20	10	-100	-40	230
Temperature/K							

When you have the points on your graph paper, join them with a smooth curve. Now use your graph to answer the following questions:

i) At what altitude is the temperature the lowest?

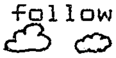
ii) What is the lowest temperature?

iii) At what altitude(s) is the temperature the same as that at the surface of the Earth?

iv) Mark the position of the temperature inversion (the tropopause) on your graph. You may notice other temperature inversions on the graph: label them (in this sequence) stratopause and mesopause.

v) Now mark the positions of the stratosphere, mesosphere and thermosphere on your graph.

Exercise is based on an idea from
ChemCom - Chemistry in the Community by the American Chemical Society.

Task 2
Using your graph as a flight record chart, mark off the positions of the following:
cumulus clouds  , cirrus clouds  , rain, Mount Kilimanjaro (5760 m), aeroplanes, "shooting stars", directions of wind movements/air currents.

Task 3
Imagine that you took a 1 litre (1 dm^3) sample of air at ground level, then at an altitude of 10 km and then at regular intervals of 10 km as the craft rises. What will happen to the mass readings of the samples of air you are collecting as the altitude of the craft increases?

Can you explain this?

Represent this in some way on your graph.

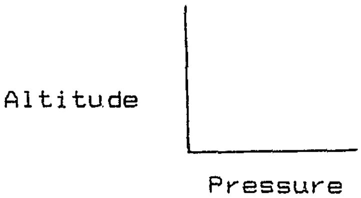
At an altitude of 8 km in the atmosphere would there be less/the same/more oxygen in a litre of air than in a litre of air at the surface of the Earth?

Would the composition (% particles) of the air at an altitude of 8 km be the same as that of the air just above the Earth's surface?

Can you explain your answer?

Task 4
"Beetle-Bob II" will be recording atmospheric pressure readings. What will happen to the magnitude of the pressure readings as the craft rises higher and higher above the Earth's surface?

Without marking actual altitude and pressure values, sketch a graph showing how you think the pressure would change with altitude.



Worksheet 1(c) " A Small View of Air"

In this exercise we consider and discuss the microscopic nature of air. Although we use the word "microscopic", the atoms and molecules that make up air cannot be seen under a microscope. They are in fact far too small to be seen even under the most powerful microscope.

Work in small groups (approximately 4 students in a group) to complete the tasks that follow. Discuss your answers with each other and try to agree on an answer. However if you fail to reach agreement, agree to differ and maybe a solution can be found when you discuss your answers with your teacher and the rest of the class at the end of the exercise.

Task 1
On a macroscopic scale (ie. using our eyes) air appears uniform and it looks as if nothing is there! However we know air is a mixture of substances.

Composition of Pollution-Free, Dry Tropospheric Air

	Substance	Concentration(% particles)
Major Components	nitrogen	78,08
	oxygen	20,95
Minor Components	argon	0,934
	carbon dioxide	0,0314
Trace Components	neon	0,00182
	ammonia	0,00100
	helium	0,000524
	methane	0,000200
	krypton	0,000114

i) Paying no attention to proportions, can you draw a diagram in which you represent air as a mixture of these gases? Use symbols such as and for atoms and molecules respectively. Label the atoms/molecules you have drawn.

ii) When the concentration of a gas in the atmosphere is very small, we express its concentration as parts per million (ppm) or parts per billion (ppb).
For example, from the table, we see that the concentration of carbon dioxide in the atmosphere is given as 0,0314 % of particles.
This means that the fraction of particles in the atmosphere that are carbon dioxide is $\frac{0,0314}{100}$

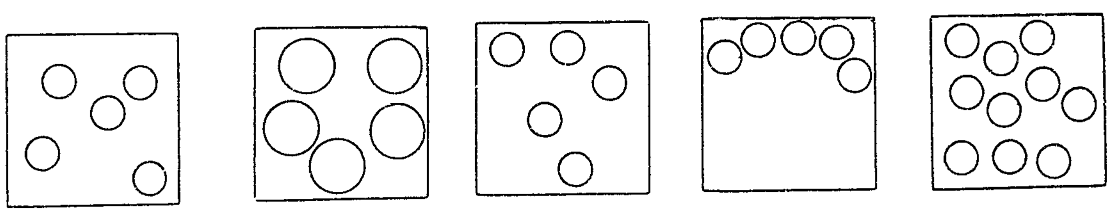
or $\frac{314}{1\ 000\ 000}$

ie. out of 1 million particles in the atmosphere, 314 particles are carbon dioxide molecules. Therefore the particle concentration of carbon dioxide in the atmosphere is 314 parts per million or 314 ppm.

Now try to express the particle concentration of methane in parts per million (ppm).

Task 2

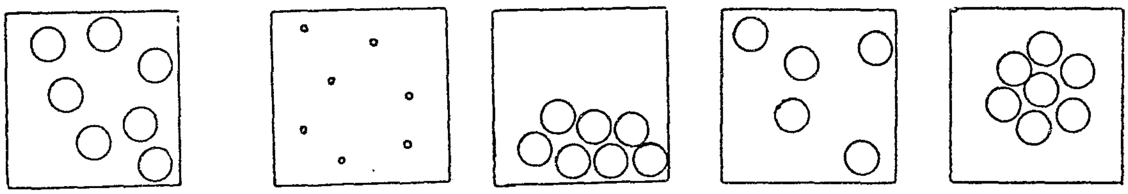
i) Diagram I is a microscopic representation of a sample of air in a rigid container (a container that cannot expand). The symbol  is used to represent an air particle.
Which diagram (a, b, c or d) is the correct microscopic representation of the sample of air when it has been warmed?



I a b c d

Answer:
Explanation:

ii) If you climb a high mountain, you may start to feel breathless and gasp for air. (We describe this by saying "the air is becoming thinner".)
Diagram II is a microscopic representation of 1 dm^3 air at the base of a very high mountain. Which diagram (e, f, g or h) is a correct microscopic representation of 1 dm^3 air at the top of the very high mountain?



II e f g h

<u>Answer:</u>
<u>Explanation:</u>

<u>Task 3</u>
Light the candle that has been given to you. Let it burn for about a minute and then blow it out.
Carefully watch the movements of the smoke produced.
a) Describe the movements and explain what is happening.
b) Why does the smoke disappear?

Worksheet 1 (d) "Take a Deep Breath!"

Task 1

i) Every day we breathe approximately 16 kg of air. That is six times the mass of food we eat in a day! If the air has a density of 1,28 g dm^{-3}, calculate the total number of air particles you breathe every day. (Disregard the solid and liquid particles and calculate only the particles of gas.) Assume a constant temperature of 25 °C and a pressure of 101,3 kPa.

ii) Calculate the number of oxygen molecules inhaled in a day. (Remember only a fraction of these molecules is involved in the reaction which produces energy from the food we have eaten and so the mixture of gases we exhale will contain some oxygen as well).

iii) Calculate the number of argon atoms we inhale in a day.

Task 2

Read the following passage based on an article appearing in a journal, the "American Scientist" (1967), and then answer the questions that follow.

"There was a time when little argon existed in the Earth's atmosphere, and practically no free oxygen at all. That was billions of years ago. The oxygen has built up to its present abundance by the photosynthetic processes of green plants. The argon has over millions of years grown to its present percentage as a result of the radioactivity of one of the isotopes of potassium atoms found in rocks. That radioactive decay steadily goes on. In 5 billion years our atmosphere will contain about twice as much argon as it does now.

In your next breath you are taking in, besides the oxygen and nitrogen, 3×10^{19} atoms of argon. A few seconds later you exhale those argon atoms along with billions and billions of molecules of carbon dioxide, oxygen and nitrogen.

Now let us follow the "career" of one argon-rich breath. We shall call it Breath X. It quickly spreads. Its argon, exhaled this morning, by night fall is all over the neighbourhood in which you live. In a month, it is all over the country. By the end of the year, the 3×10^{19} argon atoms of Breath X will be evenly distributed throughout all the air of the lower atmosphere. You will then be breathing some of those same argon atoms again. A year from now, wherever you are on the Earth's surface, in a day's breathing you will inhale at least 15 of those argon atoms of today's Breath X.

This rebreathing of argon atoms of past breaths, your own and others' has some picturesque implications. The argon atoms associate us, with an airy bond, with the past and future. Every saint and every sinner of earlier days, and every common man and beast have inhaled the argon atoms in the atmosphere. Your next breath will contain more than 400 000 of the argon atoms that Gandhi breathed in his long life. Argon atoms are here from the conversations of the Last Supper, from sighs and pledges of ancient lovers, from the recitations of the classic poets and from the battle cries at Waterloo. Our next breaths, yours and mine, will share the snorts, bellows, shrieks, cheers and prayers of the prehistoric and historic past.

There ought to be a moral to this story of argon. We do not want the atmosphere corrupted, polluted, poisoned. The moral could be: Respect your breath! Keep it decent!"

<u>Questions</u>

i) Why does the writer talk about argon <u>atoms</u> but about oxygen and nitrogen <u>molecules</u> ?

ii) Why does the argon in the atmosphere not escape into outer space?

iii) Explain how it is possible that the argon atoms you have exhaled spread so quickly - "by night fall they are all over the neighbourhood....by the end of the year they are distributed throughout the air of the lower atmosphere."

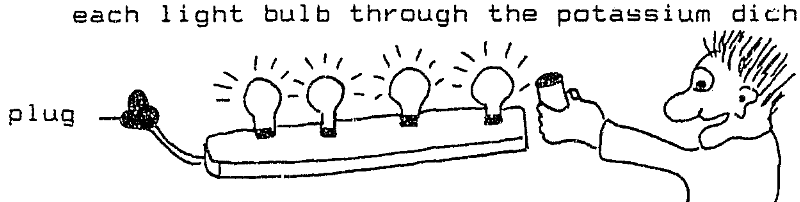
iv) Why does the writer highlight the constancy of argon and not nitrogen and oxygen in the atmosphere?

v) Discuss the statement "The composition of the atmosphere has remained constant since the birth of planet Earth. It is only the activities of humans that are changing the composition of the atmosphere". (Passages in the article quoted above may help you in your answer.)

Worksheet 1(e) "Fun in the Sun"
This activity could also be performed by the students when studying Unit 4: The Depletion of Ozone or Unit 5: Smog

Requirements
Potassium dichromate (or ammonium dichromate)
Measuring cylinder
Spatula
2 watch glasses
2 pieces of filter paper
2 coins or other objects to place on filter paper
4 coloured light bulbs (red, blue, yellow, green) connected to plug
1 small clear glass container (a sample bottle is ideal)

Method
1. Dissolve approximately half a spatula of potassium dichromate in about 20 ml water.
2. Dip the two pieces of filter paper into the solution and drain of the excess solution.
3. Spread the coloured filter paper on the two watch glasses.
4. Place a coin (or other small object) at the centre of each piece of filter paper.
5. Place one of the watch glasses and filter paper, in the direct sunlight (at an open window or outside).
6. Leave the other watch glass and filter paper indoors out of the direct sunlight.
7. Leave the watch glasses in these positions for about 20 minutes.
8. While you are waiting, fill the small container with some of the remaining potassium dichromate solution.
9. Plug in and switch on the coloured light bulbs. Observe each light bulb through the potassium dichromate solution.



10. Record your observations.
11. Bring in the watch glass and filter paper that was placed in the direct sunlight.
12. Remove the coins from both pieces of filter paper and compare the two pieces of filter paper.
13. Record your observations.

Observations

1. Colour of light bulbs observed through the potassium dichromate solution.

Red Bulb	Yellow Bulb	Green Bulb	Blue Bulb

2. Comparison of two pieces of filter paper

Filter Paper Exposed to Sun	Filter Paper Indoors

Questions

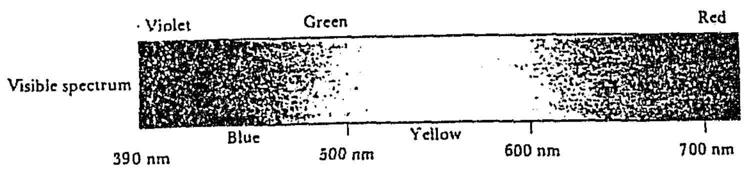
1. What do you conclude from your observation of the light bulbs through the potassium dichromate solution?

2. Explain any observed differences in
   i) the filter paper (exposed to direct sunlight) and the filter paper kept indoors.

   ii) the areas covered by the coins and the areas left uncovered.

3. Using the information shown below, calculate the approximate energy (per photon) necessary for the phenomenon you have observed in this exercise.

Diagram Showing the Wavelengths of the Visible Electromagnetic Spectrum



Solutions to Worksheets for Unit 1

Worksheet 1(a) "Planet Earth"

i) *Atmosphere, Water (the Hydrosphere), Land or Soil (the Lithosphere).*

ii) *No life (the Biosphere) present because of the lack of oxygen.*
Days would be extremely hot and nights freezing cold. All solar radiation (including high energy harmful radiation) would reach the surface of the Earth during the day. At night all radiation from the Earth's surface, would travel out into space.

iii) *The Earth's gravitational force keeps these gases close to the Earth.*

iv) *No. The atmosphere is naturally reactive. This is apparent in the rusting of iron, the deterioration of materials, eg. rubber, paint, on exposure to the atmosphere. The process of burning or combustion is also evidence of the atmosphere's reactivity.*

Worksheet 1(b) "Lift-off!"

Task 1

Temperature /K 293 238 253 283 173 233 503

i) 75 km
ii) $-100°C$ (173 K)
iii) 115 km
iv) and v) on graph on next page

Task 2
On graph on next page

Task 3
The mass readings of the samples will decrease.

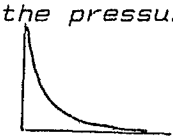
Explanation: Air becomes less dense as one moves up from the Earth's surface. The higher the sample is taken, the smaller the mass of air in the same volume (1 dm^3).

(Representation of dots ● on graph)

At an altitude of 8 km in the atmosphere, there would be less oxygen in a litre of air than in a litre of air at the surface of the Earth.

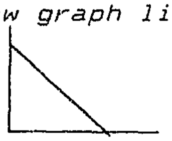
Yes, the composition of the air at an altitude of 8 km in the atmosphere would be the same as that of the air just above the Earth's surface.
Explanation: There would be fewer particles of all gases. Therefore the fraction (percentage) of each gas would be the same. The composition of the troposphere (up to 15 km) is more or less uniform.

Task 4
The magnitude of the pressure readings will decrease.

Altitude  (a)

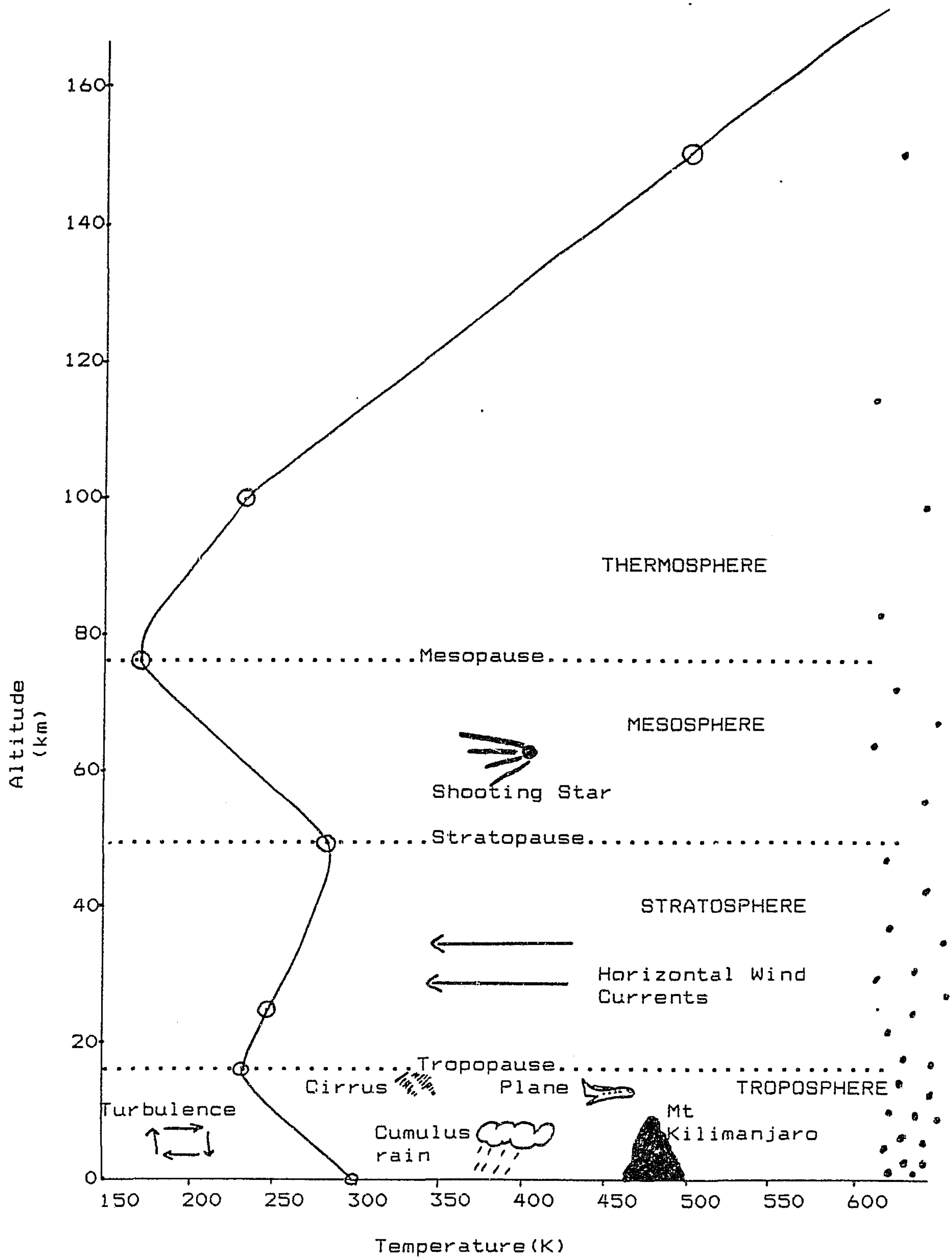
Pressure

Students may draw graph like this

Altitude 

Pressure

Teacher should mention that graph has shape as shown in (a) because gravitational force follows an "inverse square law".



Altitude (km)
160
140
120
100
80
60
40
20
0
THERMOSPHERE
Mesopause
MESOSPHERE
Shooting Star
Stratopause
STRATOSPHERE
Horizontal Wind Currents
Tropopause
Cirrus
Plane
TROPOSPHERE
Turbulence
Mt Kilimanjaro
Cumulus rain
150
200
250
300
350
400
450
500
550
600
Temperature (K)

Worksheet 1(c) "A Small View of Air"

Task 1

i) Example of Representation

Key:

helium atom

neon atom

argon atom

krypton atom

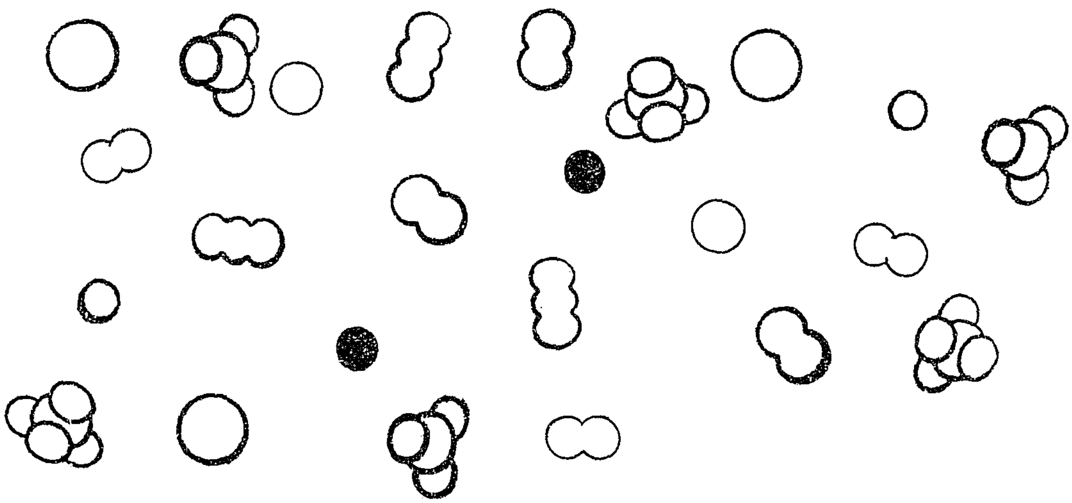
oxygen molecule

nitrogen molecule

carbon dioxide molecule

ammonia molecule

methane molecule



ii) % methane = 0,0002 (from the table given)

$$\text{Particle concentration of methane} = \frac{0{,}0002}{100}$$

$$= \frac{2}{1\ 000\ 000}$$

= 2 molecules (particles) of methane per million particles of air

= 2 ppm

Task 2

i) Answer: b
Explanation: Particles of air will be moving faster. This cannot be shown so representation for warmer air will be very similar to I . Particles themselves will remain the same size and will remain evenly dispersed throughout the container.

ii) Answer: g
Explanation: At the top of the mountain the air is less dense than at the foot of the mountain. There are fewer particles of air in the same volume (1 dm^3) and these particles are dispersed throughout the volume of 1 dm^3. The size of the particles remains the same, but the spaces between them are larger.

Task 3

a) Rising of smoke is caused by the warm air rising above the hot flame and the smoke particles being carried along too. The "curling" of the smoke is caused by interference of other air movements such as draughts and wind.

b) Particles of smoke move from a region of high concentration (visible cloud of smoke) to regions where the smoke particles are less concentrated (smoke is no longer visible). This process of diffusion occurs because of the constant movement of the air particles which "bump" and move the smoke particles. The spaces between the air particles allow the smoke particles to disperse and we say they "disappear".

Worksheet 1(d) "Take a Deep Breath!"

Task 1

(i)

Mass air = 16 kg = 16×10^3 g

Density of air = $\frac{\text{mass}}{\text{volume}}$

$1{,}28 \text{ g dm}^{-3} = \frac{16 \times 10^3 \text{ g}}{\text{volume}}$

$\therefore$Volume of air breathed per day = 12 500 dm^3

$PV = nRT$

$101{,}3 \text{ kPa} \times 12\ 500 \text{ dm}^3 = n \times 8{,}314 \text{ JK}^{-1}\text{mol} \times 298 \text{ K}$

n = 511 mol particles of air

No. of particles inhaled per day = $3{,}1 \times 10^{26}$ per day

(ii)

Percentage of oxygen in the atmosphere = 21%

No. of oxygen molecules inhaled per day

$= \frac{21}{100} \times 3{,}1 \times 10^{26}$

$= 6{,}5 \times 10^{25}$ molecules

(iii)

Percentage of argon in the atmosphere = 1%

No. of argon atoms = $\frac{1}{100} \times 3{,}1 \times 10^{26}$

$= 3{,}1 \times 10^{24}$ argon atoms

Task 2

i) Argon is a gas which consists of separate, unbonded atoms.

ii) Argon atoms have a relatively large mass. The force of gravitational attraction between the Earth and the argon atoms, keeps the argon atoms encircling the Earth.

iii) The argon atoms quickly move amongst the other rapidly moving particles (atoms or molecules) of gases in the atmosphere.
The argon atoms are also carried by the turbulence of the troposphere. This turbulence gives rise to the air currents and winds characteristic of the lower region

of the atmosphere.

iv) Argon is an unreactive gas (a "noble gas"). Argon does not react with other substances in the atmosphere, hydrosphere, lithosphere and biosphere. Argon remains unreacted in the atmosphere. Nitrogen and oxygen can react with other substances in the atmosphere, hydrosphere, lithosphere and biosphere. The nitrogen and oxygen can thus be "removed" from the atmosphere. (See Unit 6 and Unit 9 for some cycles)

v) The article indicates that the composition of the atmosphere has changed since the birth of the planet. Quote, "There was a time when little argon existed... and practically no free oxygen at all." The article states that the concentration of argon is increasing: "in 5 billion years our atmosphere will contain about twice as much argon as it does now." Thus the changes in the atmosphere are not only caused by human activities - natural phenomena also cause changes in the composition of the atmosphere.

Worksheet 1(e) "Fun in the Sun"

Observations

1.

Red Bulb	Yellow Bulb	Green Bulb	Blue Bulb
Red	Yellow	Yellowish	Dark - no colour

2.

Filter Paper Exposed to Sun	Filter Paper Indoors
Dark Brown with orange-yellow coin shape in centre	Orange Yellow with little difference in colour of the coin shape

Questions

1. The potassium dichromate solution absorbs blue light (and some green as well).

2. i) A change occurred in the filter paper exposed to the Sun. A chemical reaction occurred which must have been initiated by the energy from the Sun - a photochemical reaction.

   ii) The areas covered by the coins were not changed. No energy from the Sun reached this part of the paper and so no reaction occurred. The parts of the paper exposed to the Sun's energy changed as described in (i) above.

3. Wavelength blue light is approximately 445 nm (from diagram).

$$\text{Energy per photon} = \frac{hc}{\lambda}$$

$$= \frac{6{,}62 \times 10^{-34}\ \text{J s} \times 3{,}00 \times 10^{8}\ \text{m s}^{-1}}{445 \times 10^{-9}\ \text{m}}$$

$$= 4{,}47 \times 10^{-19}\ \text{J per photon}$$

UNIT 2

What is Air Pollution?

Air is a natural resource that is freely available to all. It is essential to almost all forms of life and most industrial processes. Only when problems of air pollution exist, does the quality of air become important. Only then does the value of clean, unpolluted air become apparent.

What is air pollution? For many of us, our initial knowledge of air pollution is gained via the media; we read reports in newspapers, magazines or hear/see reports on the radio and T.V. Sometimes these are accurate reports written by scientists who are experts in their fields. However sometimes articles are written by journalists who are not experts but who are reporting on information they have read in scientific articles. Errors and misinterpretations may occur. Reports in the media can influence our knowledge and attitudes to the problem of air pollution. We should therefore read such articles critically with a view to checking information in other sources before simply accepting ideas or views put forward.

In our search for an answer to the question, "What is air pollution?", a glance at some definitions given in dictionaries may provide initial ideas. For example:

"Pollution - Term applied to any environmental state or manifestation which is harmful or unpleasant to life, resulting from man's failure to achieve or maintain control over the chemical, physical or biological consequences or side-effects of his scientific, industrial and social habits."

(Chambers Dictionary of Science and Technology)

"Air Pollution - The presence in the outdoor atmosphere of one or more contaminants such as dust, fumes, gas, mist, odour, smoke or vapour in quantities and of characteristics and duration such as to be injurious to human, plant or animal life or to property, or to interfere unreasonably with the comfortable enjoyment of life."

(McGraw-Hill Dictionary of Scientific and Technical Terms)

These are complex definitions. More simply stated, air pollution is the presence in the atmosphere of substances which may be a nuisance or may cause damage to life or materials. Air pollution manifests itself in many ways: for example odour, smoke plumes, reduced visibility, damage to humans, plants and animals, damage to buildings, damage to materials eg rubber.

The substances giving rise to the air pollution are termed air pollutants. Air pollutants can be solids (dust, soot or ash), gases (eg. sulphur dioxide or carbon monoxide) and aerosols (solid or liquid particles which are mixed with the air and are too small to drop out of the air). Gaseous pollutants may travel large distances and their effects may be directly or indirectly felt. Such pollutants remain in the atmosphere until they are chemically changed or are dissolved in droplets of water in the atmosphere and precipitated in rain or snow. Gaseous pollutants are potentially more harmful than particulates because they are usually invisible and odourless and it may take considerable time before their effects manifest themselves. Large solid particles or droplets of liquid settle out of the atmosphere fairly quickly under the influence of gravity. Smaller solid particles or droplets of liquid remain in the atmosphere for longer periods of time and can travel further. Particulate pollution can give rise to the visible forms of air pollution; smoke or haze and dust or dirt deposits on surfaces etc.

Air pollutants may be classified as primary air pollutants or secondary air pollutants. Primary air pollutants are found and cause air pollution problems in the same chemical form in which they were released from the source eg. carbon monoxide. Secondary air pollutants are formed as a result of chemical reactions involving primary air pollutants and other components in the atmosphere eg. H_2SO_3 is formed when SO_2 emitted from the burning of coal reacts with water in the atmosphere.

When air pollutants cause the quality of air to deteriorate close to their source, this is termed local air pollution. Some air pollutants are more widely dispersed within the troposphere and cause regional air pollution. If the entire atmosphere is affected, eg. the accumulation of carbon dioxide, then global air pollution results.

In many cases, the atmosphere is able to render air pollutants less harmful by dispersing and diluting them. (However, as we shall see in later Units, dilution is not always a means of overcoming the problem of air pollution.) Dilution and dispersal of air pollutants take place by means of diffusion, or by horizontal air movements (wind) or vertical air movements (convection currents). In addition some pollutants may be changed to less harmful substances by chemical reactions in the atmosphere. Some pollutants dissolve in droplets of water in the atmosphere and are then removed from the atmosphere in precipitation such as rain or snow. (Of course this can then cause problems in the soil, lakes and rivers!) The biosphere may also play a role in removing air pollutants. For example, trees absorb carbon dioxide from the atmosphere during the process of photosythesis. Air pollution becomes a problem when the introduction of air pollutants into the atmosphere takes place at such a large rate and/or for such long periods of time that the capacity of the atmosphere to render these pollutants harmless, is exceeded.

From these descriptions of the dispersal and/or removal of air pollutants from the atmosphere, it is apparent that the weather and climatic conditions play an important role in air pollution. Carried by winds, air pollutants can cause problems hundreds of kilometres from where they originated. Temperature inversions can lead to a layer of warm (less dense) air "trapping" colder (more dense) air below. This results in air pollutants present in the colder air not being dispersed and diluted. This is a common phenomenon, for example, in the Transvaal Highveld in winter. Climatic conditions such as the absence of rain in the dry Transvaal Highveld winters, can result in air pollutants (which would normally be dissolved and precipitated in the rain) remaining in the atmosphere for long periods of time. Thus air pollution is much more evident for example in the Witwatersrand in winter than in summer.

To attempt to control air pollution, it is necessary to understand what the sources of air pollution are. Human activities are sources of air pollution. (Air pollution is a feature of "life at work".) Many of these activities require the burning of coal and oil. This combustion produces substantial amounts of sulphur dioxide (SO_2), nitrogen oxides (NO_x), carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbons (termed non-methane hydrocarbons or NMHCs) and soot particles. Tetraethyl lead is added to petrol to prevent "knocking" in engines. As a consequence, lead compounds are emitted from vehicle exhausts. Other industrial processes release dust, chlorofluorocarbons (termed CFCs) or toxic metal compounds into the atmosphere. Agricultural activities can also lead to pollution. Fields spread with nitrogen-rich fertilisers emit dinitrogen oxide (N_2O). Burning forests yield large amounts of carbon monoxide. (The loss of forests can also lead to accumulation of carbon dioxide in the atmosphere.) Rice-paddies and ruminants, such as cattle, contribute significantly to methane (CH_4) concentrations in the atmosphere. Particles such as soot, dust and ash get into the air as a result of activities such as burning fossil fuels, agriculture, construction, mining.

Nature, too can cause an increase in the concentrations of many of these gases. Lightning and the bacterial action in soils result in the formation of nitrogen oxides. Biological decay produces ammonia and methane. Volcanic eruptions produce sulphur dioxide, hydrogen sulphide and dust. Soil erosion by wind can produce dust particles. Over the years, these natural emissions of pollutants, with the exception of volcanoes, do not fluctuate significantly. (Volcanoes can have significant effects on the atmosphere. Volcanic eruptions can thrust volcanic dust and other air pollutants into the stratosphere where they are widely distributed by the horizontal winds that move from the equator to the poles. The dust decreases the solar radiation reaching the Earth and chlorine compounds can deplete the ozone in the stratosphere.)

he table, at the end of this introduction, lists some of the gaseous pollutants and compares the quantities emitted annually by human and natural sources. You will notice that the gases listed are the minor or trace components of the atmosphere. The concentrations of the major components nitrogen and oxygen which together with argon make up 99,95% of the atmosphere, remain constant. Air pollution, at present, is causing rapid variation in the concentration of gases that make up only the remaining 0,05% of the atmosphere. Air pollution may occur when the concentration of a trace component of the atmosphere eg. carbon dioxide, is increased. Air pollution may occur when the concentration of a trace component in the atmosphere eg. ozone in the stratosphere, is decreased. Air pollution may also occur when a substance which does not occur naturally in the atmosphere is released into the atmosphere, eg. chlorofluorocarbons (CFCs).

The study and constant monitoring of the atmosphere involves people from many disciplines (for example chemists, physicists, geographers, geophysicists, climatologists, nuclear physicists, biologists, etc). Much information with regard to the origin, nature and consequences of pollutants is being provided by the investigations and research of such scientists.

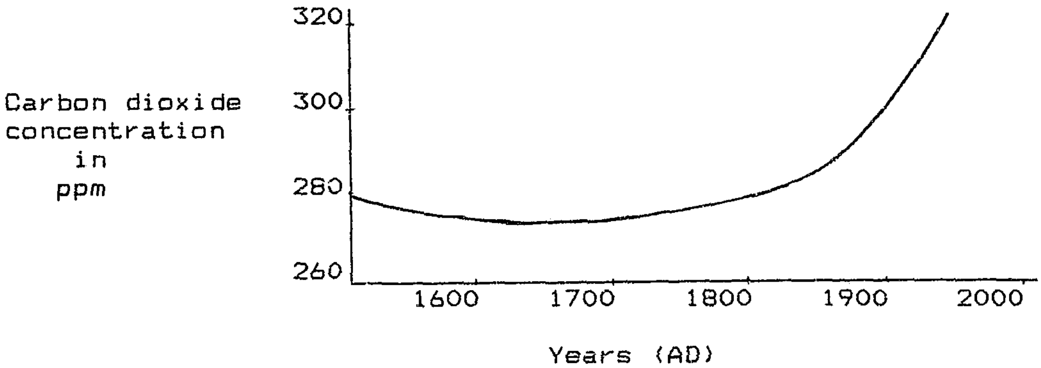
Scientists believe that since the birth of the planet Earth billions of years ago the atmosphere has been changing. However over "shorter" periods of time (approximately 100 000 years) the composition of the atmosphere has remained the same. The analysis of air bubbles trapped in the ice sheets of Antarctica has revealed that there has been relatively rapid change in the concentrations of some of the components of the atmosphere over the last two centuries. It is this greater pace of change that is a matter of great concern.

For the concentration of an air pollutant in the atmosphere to remain constant (a "steady state"), the rate at which the pollutant is released into the atmosphere should equal the rate at which the pollutant is removed from the atmosphere. If the rate at which the air pollutant is released into the atmosphere exceeds the rate at which it is removed then the concentration of the pollutant in the atmosphere will increase. This appears to be the case with the rapid increase in the concentration of carbon dioxide in the atmosphere. In the case of the ozone in the stratosphere, the rate at which ozon is being depleted by air pollutants such as CFCs and nitrous oxide, exceeds the rate at which it is being generated by a photochemical reaction from oxygen. This is resulting in a decrease in the concentration of ozone in the stratosphere which could be detrimental to life on

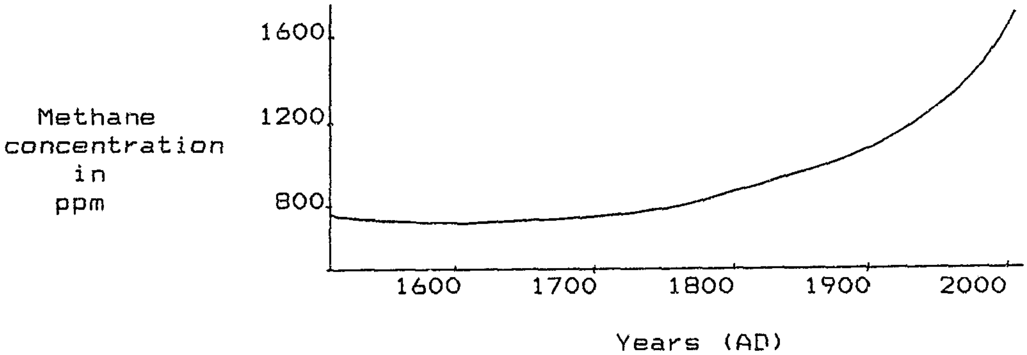
Earth.

Graphs showing changes in the Concentrations of Some Trace Gases

A. Changes in the Concentration of Carbon dioxide in the Atmosphere since 1600



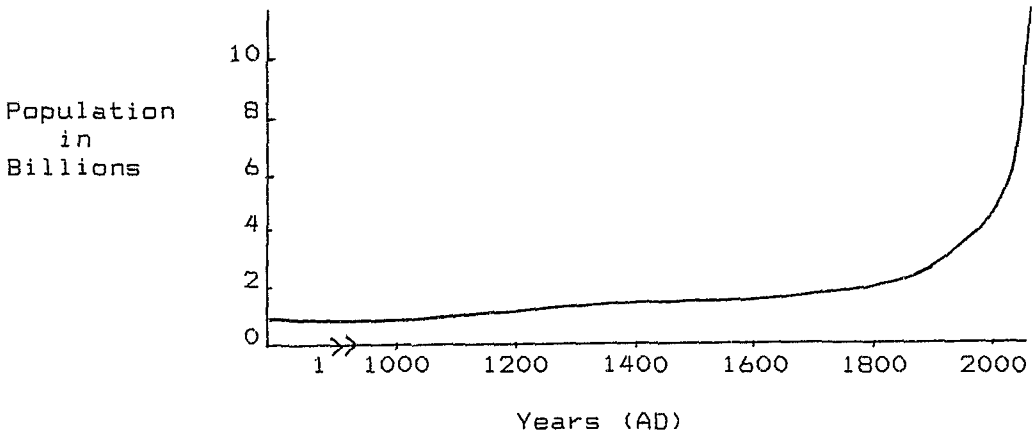
B. Changes in the Concentration of Methane in the Atmosphere since 1600



Who is to blame for air pollution? Technological development is often portrayed as the culprit. However the role of technology in the problem is complex. Technological development contributes to changes in the concentrations of minor and trace gases in the atmosphere. However, it is also science and technology that have provided the techniques and instruments for detecting and measuring the concentrations of the gases in the atmosphere. Without these skills we would not be as well-informed about air pollution as we are. In addition to being one source of pollution, technology provides the solutions to pollution problems. We must also bear in mind the positive contributions of science and technology to our quality of life. Every benefit of life carries with it a risk. The solutions we find to the problems of pollution will require a delicate balance between the aspects of benefit and risk. We make this kind of decision every time we use a motor car rather than walking!

The alarming growth in the world population must also play a significant role in the problem of air pollution. The graph of population plotted against time correlates extremely well with those showing the increase in the concentrations of carbon dioxide and methane shown earlier.

Graph showing the Growth of the Human Population



Both poor and rich people contribute to air pollution. During winter the coal fires of the poorer communities contribute more than industry does to the smoke and sulphur dioxide concentrations in the air in the Witwatersrand area. The emissions of privately owned motor cars in affluent Los Angeles in the United States of America can result in health-threatening smog.

Political and social problems also have an impact on pollution. After the recent 1991 war in the Middle East, the smoke from burning oil wells in Kuwait blotted out the sunlight and lowered the temperature of the Earth in that region. Details of severe air pollution in Eastern European countries such as Hungary, Czechoslovakia and Poland are emerging. Old, poorly-maintained factories belch out fumes into greasy brown air so that "In this part of the world, nobody takes breathing for granted" (words of someone waiting at a clinic in Hungary.)

Some consequences of air pollution are becoming apparent, for example acid rain, the depletion of ozone and the formation of smog. However it is not possible to predict with certainty the outcomes of these consequences: thus it is not clear whether increased concentrations of carbon dioxide in the atmosphere will lead to global warming. Nor is it possible to state with certainty that acid rain is destroying trees in Europe.

Recognition of the fact that air pollution is a problem is a step along the path to finding a solution. Human ingenuity coupled with a willingness to change our lifestyles (eg. using motor vehicles less or paying more for electricity that uses additional technology to reduce pollutants from stacks) will be required in finding a solution to the problem of air pollution.

Note: Table showing annual world-wide emissions of some air pollutants, follows on the next page.

Annual Worldwide Emissions of Some Air Pollutants (10^9 kg yr^{-1})

Pollutant	Human Activity	Quantity	Natural Phenomena	Quantity.
CO_2	Combustion of wood and fossil fuels	20 000	Biological decay, release from oceans, forest fires and respiration	1 000 000
CO	Incomplete Combustion	600	Forest fires	2 500
SO_2	Combustion of coal and oil, smelting of ores	207	Volcanoes and biological processes	10
CH_4	Rice fields, cattle, fossil-fuel production, rubbish dumps	188	Anaerobic biological decay and termites	1 800
NO_x	High-temperature combustion	90	Lightning, bacterial action in soil	180
NMHC*	Incomplete combustion	40	Biological processes	20 000
NH_3	Sewage treatment and fertilisers	6	Anaerobic biological decay	260
H_2S	Petroleum refining and sewage treatment	3	Volcanoes and anaerobic biological decay in soil and water	84
CFCs#	Spray cans, refrigerants, foams	1	-	-

* NMHC = non-methane hydrocarbons, ie. all hydrocarbons other than methane.

\# CFCs = chlorofluorocarbons

The sources of information for the table on the previous page are:

1. "ChemCom" by the American Chemical Society (1988), page 374.

2. "Chemistry of the Atmosphere" by Richard Wayne (1985) pages 194 and 195.

Learning Objectives for Unit 2

On completing this unit students should be able to:

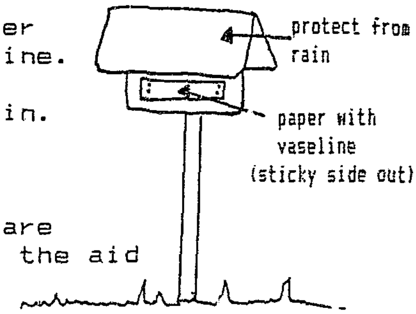
2.1 Explain the meaning of air pollution and air pollutants.
2.2 List some of the ways in which air pollution manifests itself eg. odour, smoke, reduced visibility, damage to plant and animal life, damage to buildings, damage to materials etc.
2.3 Explain that air pollutants can be classified as solids, aerosols, gases.
2.4 Explain what is meant by primary air pollutants and secondary air pollutants.
2.5 List some of the major human activities that are sources of air pollution.
2.6 List the names (and formulae if applicable) of air pollutants produced by the activities listed in 2.5.
2.7 List some of the natural sources of air pollution.
2.8 List the names and formulae (if applicable) of air pollutants produced by the natural sources in 2.7
2.9 Explain that air pollution affects the concentrations of some of the minor and trace components in the atmosphere ie. approximately 0,05% of the atmosphere.
2.10 Describe the natural ways in which air pollutants are rendered harmless or removed from the atmosphere eg. by chemical conversion to other compounds or through precipitation in rain.
2.11 Discuss the role played by science and technology in the problem of air pollution.
2.12 Discuss the role played by world population and social conditions in the problem of air pollution.
2.13 Describe the role played by the weather and climatic conditions in air pollution.
2.14 Assess more critically reports of air pollution in the media.

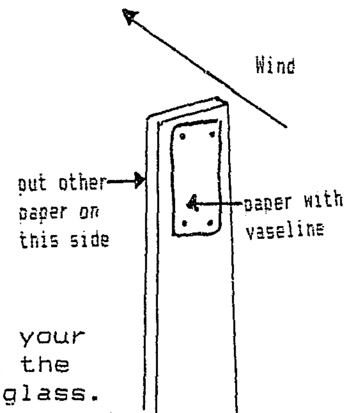
Worksheet 2(a) Particulates (Solid Particles)

Particulate matter suspended in the atmosphere gives rise to visible air pollution. Particulate matter in the atmosphere is sometimes referred to as TSP or Total Suspended Particles. Some particles are large enough to settle out of the atmosphere fairly quickly. Smaller particles may remain in the air for several hours and, carried by wind, may travel consicerable distances. Very small particles may remain suspended in the atmosphere for long periods of time.

In this activity, for a period of 1 - 2 weeks you will attempt to detect and collect some of these particles. Keep your results and bring them to class to discuss them with your teacher.

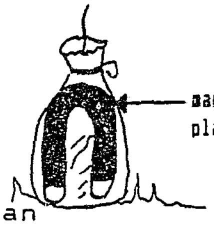
i) Cut two identical strips of stiff paper and smear one side of each with Vaseline. Fix one strip outside well exposed to the air but protect it from the rain. Fix the other strip indoors. Record their positions and the number of days for which you conduct your investigation. After 1 - 2 weeks compare the appearance of the two strips with the aid of a magnifying glass. Summarise your findings:



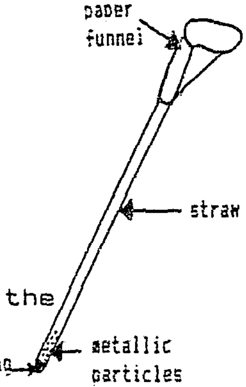


ii) Smear another two strips of stiff paper with Vaseline. Fix the strips to each side of a piece of wood that is driven into the ground. Face one of the strips towards the prevailing wind. Record the position of the plank and the length of time for which you conduct your investigation. After 1 - 2 weeks compare the two strips with the aid of a magnifying glass. Summarise you findings: (Remember to make a note of the direction in which the two sides of the wood were facing.)

iii) To collect magnetic particles, place a small magnet in a thin, plastic bag. Attach a string to the bag and drag it over the ground. You can collect material from a number of different areas eg. next to a road, near an industrial area. etc. To store the magnetic materials you have collected use a drinking straw. Plug one end of the straw and insert a paper funnel in the other end. Use different straws for the different areas in which you have collected magnetic particles. Compare the material you have collected from different areas. (Remember that not all metals are magnetic. Only certain metals will be picked up this way.)



Summarise your findings:



Now try to list sources of particulates in the atmosphere.

Suggest the effects of particulates in the atmosphere.

Exercise is adapted from
International Show - and - Do Conservation Project Kit
by the World Scout Bureau and World Wildlife Fund.

Worksheet 2(b) "What is Air Pollution?"

i) What is air pollution?

ii) What are air pollutants?

iii) Complete the table below, listing some of the air pollutants you are aware of in the area in which you live. If possible identify the source of the air pollution and any effects you are aware of. (List only what you have experienced yourself, not what you may have only read about.)

Air Pollutant	Source	Effect

iv) Name an activity that does not cause air pollution.

v) Discuss the role of science and technology in the problem of air pollution.

vi) Discuss the role of world population in air pollution.

vii) Is air pollution only a feature of modern day living? Explain your answer.

viii) Do air pollutants remain in the atmosphere for ever? Explain your answer.

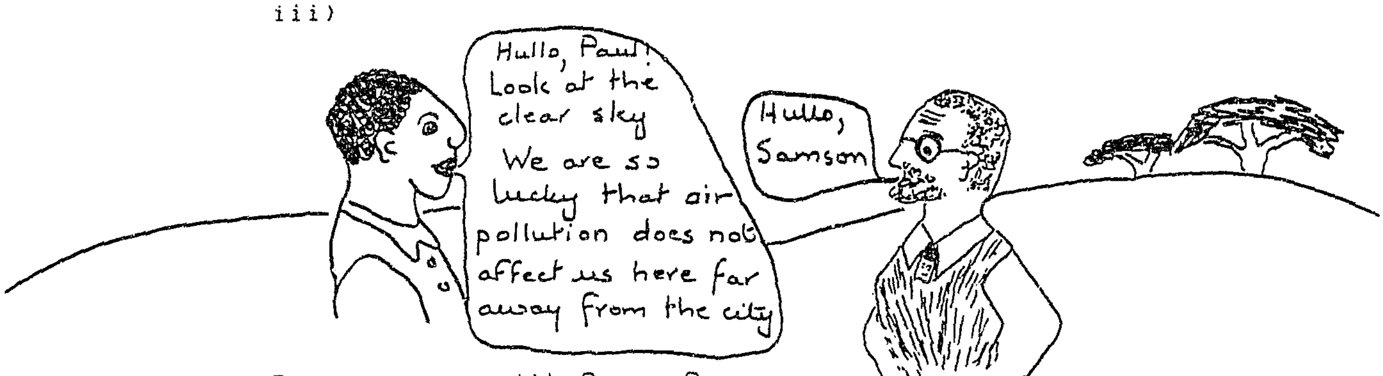
Worksheet 2(c) Don't Let the Smoke Get in Your Eyes!

i) The picture of a nemical factory at the start of the century shows smoke billowing from chimneys.

Why do you think the smoke was so clearly depicted?

ii) What is your attitude to smoke?

iii)



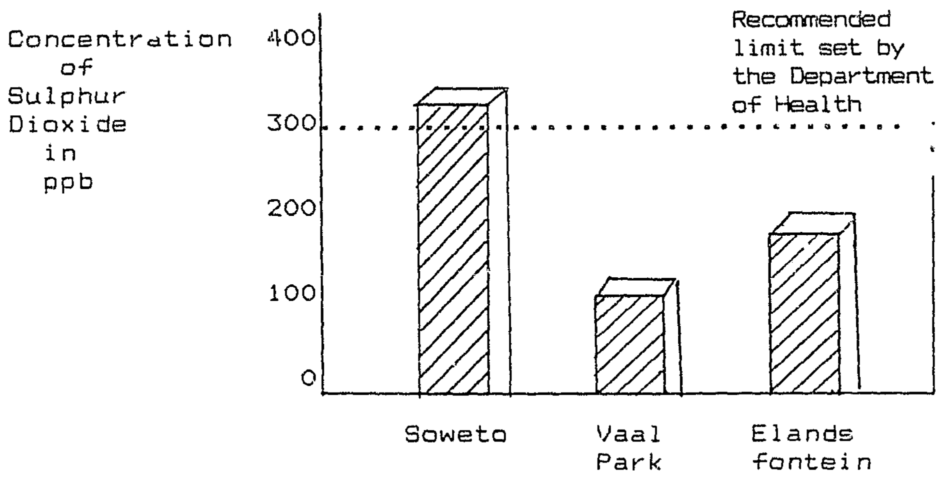
Do you agree with Samson?
Explain your answer.

iv) Areas of Natal appear to be affected by sulphur dioxide and nitrogen dioxide although there are no large industries in the areas concerned. Explain w y you think this is happening.

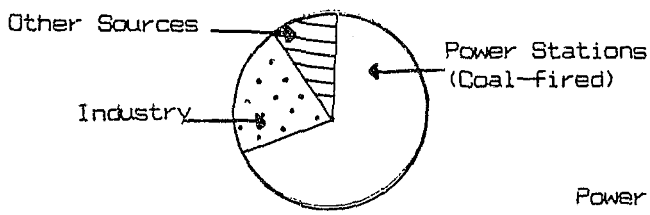
v) In the Witwatersrand air pollution is more apparent during winter. Discuss the reasons for this.

vi) Look at the information given in figures A and B. Interpret these results.

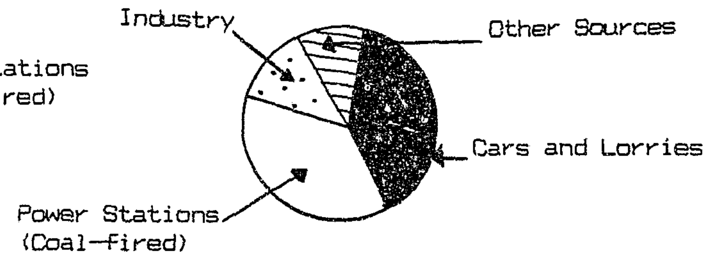
A. <u>The Average Concentration of Sulphur Dioxide in the Atmosphere in Soweto and Two Rural Power Stations (Vaalpark and Elandsfontein) during Winter 1984</u>



B. Contributions of Different Sources to Sulphur Dioxide and Nitrogen Dioxide Production in Britain in 1984



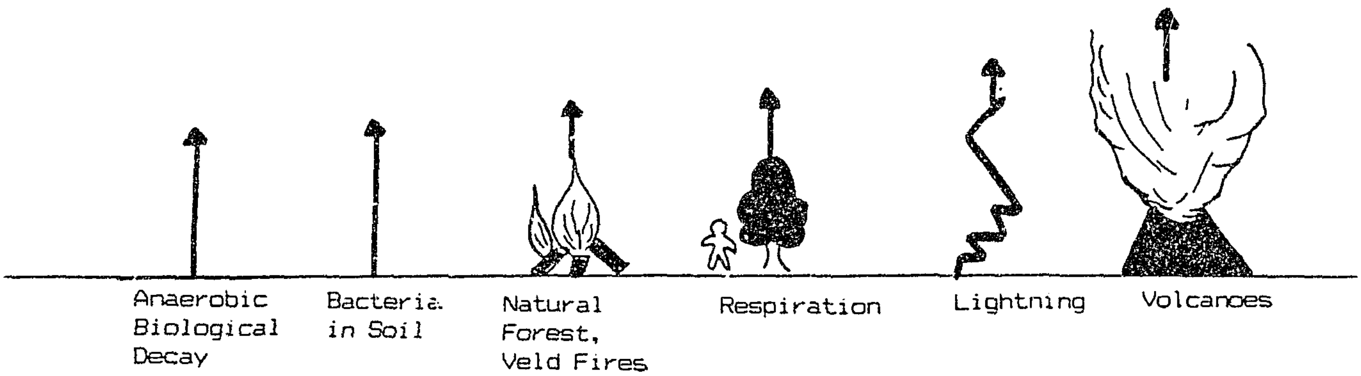
Sulphur dioxide



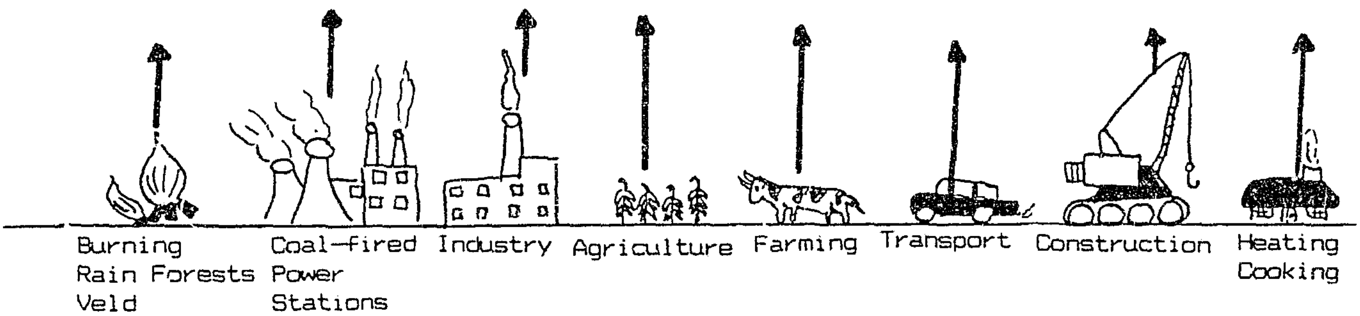
Nitrogen dioxide

Worksheet 2(d) "Steady State"

i) Label the arrows with the names or chemical formulae (if you know them) of some of the minor and trace components of the atmosphere that may be produced by natural sources shown in the diagram below.



ii) Label the arrows with the names of some of the trace components in the atmosphere that are produced by human activities.



iii) Comment on the statement:
"I'm confused; most of the trace components in the atmosphere produced by human activities are also produced by natural sources. What is air pollution - can natural sources cause air pollution too?"

iv) Using the container provided and running water from a tap (or other larger container), try to maintain the level of the water at the mark on the container.

Explain what you did.

Under what conditions does the water in the container rise above the mark?

This maintenance of a constant quantity of water in the container is referred to as a "steady state". A steady state is an open system in which there is an exchange of matter; matter will enter the system (the input) and matter can leave the system (the output). In a steady state, the exchange of matter will be such that the input will be equal to the output.

The analysis of air bubbles trapped in the ice in Antarctica, has led scientists to believe that the concentration of gases in the atmosphere has remained more or less constant for approximately 160 000 years - a steady state.

If the the container represents the atmosphere and the water represents one of the components in the atmosphere, suggest what the flow of water into the container might represent.

What does the flow of water out of the container represent in terms of the atmosphere?

Try to explain how the composition of the atmosphere remained constant during the past 160 000 years.

Scientists are constantly monitoring the concentrations of the components of the atmosphere. They believe that the composition of the atmosphere is now changing more rapidly than it has before.

The concentration of some components in the atmosphere, eg. CO_2 is increasing. Explain this in terms of a steady state model.

The concentration of some components in the stratosphere, eg. ozone, is decreasing.
Explain this in terms of a steady state model.

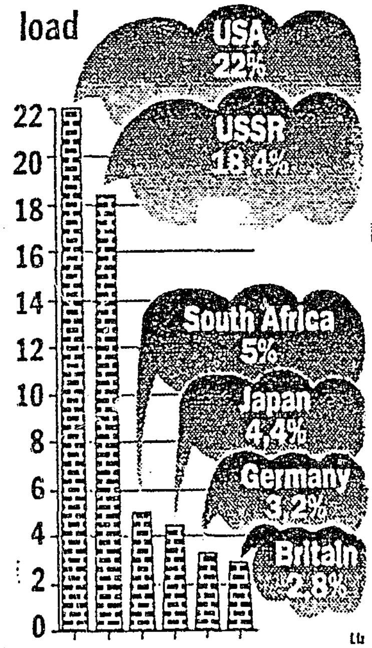
Worksheet 2(e) "Hot News! Read All About It!"
Read the two newspaper articles,
I "Pumping Out Gas - Putting on the Heat" which appeared in The Star newspaper, March 27, 1991
and
II "Carbon dioxide output is 1,6 pc" (on the next page), which appeared in The Star newspaper, April 22nd. 1991.

Then answer the questions that follow.

I

Pumping out gas – putting on the heat

The biggest contributors to the carbon-dioxide load



South Africa is emerging as possibly the third largest contributor to global levels of carbon dioxide gas — the major greenhouse gas — even though its industry is currently in recession and many power stations are mothballed.

Man could soon be forced to come down off the clouds, and stop fiddling about with the atmosphere, causing freak global weather, especially the unprecedented heat- waves experienced in various regions recently.

An *international law of the* atmosphere — which is bound to affect South Africa — is likely to move a stage further next month when the United Nations holds a conference in Rotterdam.

The week-long conference — the Second World Industry Conference on Environmental Management — is a forerunner to an even bigger world environment conference in Rio de Janeiro next year.

South Africa is sending delegates to both. The subject of the greenhouse effect, a result of industrial air pollution, will loom large on the agenda at Rotterdam.

South Africa is emerging as possibly the third largest contributor to global levels of carbon dioxide gas even though its industry is currently in recession and many power stations are mothballed.

According to a recent survey published in New Scientist (which did not assess South Africa) the US is the worst offender — it contributes 22 percent of global carbon dioxide emissions — Russia is second with 19 percent and Japan is third with 4,4 percent.

World output of carbon dioxide is 5700 million tons a year.

South Africa's present carbon dioxide output — from coal burning alone — is 280 million a year. This is about 5 percent of the world total, putting South Africa ahead of Japan.

It is more than Britain and France produce between them — judging by New Scientist's figures for those countries.

Once the South African economy has picked up and Eskom is going full bore, output could reach 400 million tons or more.

On a per capita basis South Africa produces almost 10 tons a year — 10 times the world average and twice that of the US.

Fear of the consequences of the greenhouse effect are causing industrial nations to look, once again, towards nuclear power.

Most atmospheric scientists now believe the freak global weather lately — especially the unprecedented heatwaves in various regions — is because man has changed the nature of the atmosphere.

Jonathan Weiner, author of a just-published book for the layman — "The Next 100 Years" — compares what is happening to a worst case geological event.

He says the biggest eruption in historical times was that of Mount Tambora in Java in 1815. One third of the 3 000 metre high mountains was blown to smithereens and the dust cloud girdled the Earth producing "the year without a summer".

Weiner says Tambora put 100 million tons of carbon dioxide into the atmosphere — yet annually, South Africa puts 2,5 times that into the sky.

Weiner is pessimistic about man acting in time to avert widespread weather chaos.

JAMES CLARKE

II

Carbon dioxide output is 1,6 pc

The article, "Pumping out gas — putting on the heat" (The Star, March 27), is misleading, because it has been based on a confusion between carbon and carbon dioxide emissions.

James Clarke states that the world output of carbon dioxide is 5 700 million tons a year, but it is in fact 18 300 million tons, according to reliable sources. (The figure quoted by Clarke equates closely with carbon emissions.)

Current estimates of industrial carbon dioxide emissions in South Africa of 295 million tons a year agree closely with Clarke's figure.

Thus South Africa's contribution to global carbon dioxide production is about 1,6 percent, not 5 percent as stated by Clarke; this would position South Africa at the bottom of the graph used in his article.

According to a New Scientist survey (October 27 1990) this would also place South Africa (although not mentioned) on a par with Australia and below the USA (22 percent), Japan (4,4 percent), Germany (3,2 percent), and Britain (2,8 percent).

The fact that South Africa is not considered a major industrial nation also reinforces this positioning, as carbon dioxide emissions are an indication of the level of industrialisation.

We trust that this resolves the confusion between carbon and carbon dioxide emissions, and places South Africa's carbon dioxide emission levels in perspective in terms of the global situation.

A J Dickson,
Power Station Engineering Manager, Eskom
Megawatt Park

<u>Questions</u> (Write your answers on a separate sheet of paper.)

1. In article I, explain the use of the title, "Pumping out gas - putting on the heat".

2. Is it a <u>fact</u> that carbon dioxide is causing changes in the global weather? Explain your answer.

3. Explain the meanings of the words, <u>global</u> and <u>levels</u> in the phrase, "global levels of carbon dioxide".

4. i) According to article I, what percentage does South Africa contribute to the global release of carbon dioxide into the atmosphere?
   ii) In article I, where does South Africa rank as a contributor to the global release of carbon dioxide?

5. i) According to article II, what percentage does South Africa contribute to the global release of carbon dioxide into the atmosphere?
   ii) In article II, where does South Africa rank as a contributor to the global release of carbon dioxide?

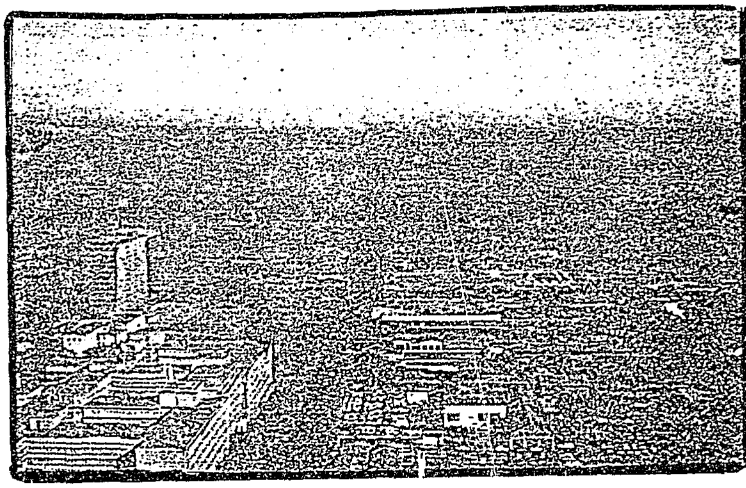
6. The writer of article II suggests that an error was made in article I. What was this error?

7. Show the working out of the calculation that arrived at the wrong answer of 5% in article I. Then show the working out for the answer of 1,6% as arrived at in article II.

8. Why does the writer of article II suggest that an output of 1,6% is realistic for South Africa's contribution to the global release of carbon dioxide into the atmosphere?

9. If you had not read the second article, what impressions would the first article have left you with?

Worksheet 2 (f) A Winter Scene in the Transvaal Highveld.



The picture shows a typical scene on a winter's morning in the Highveld. Let's try and copy or simulate the conditions in the atmosphere that give rise to the dispersion of smoke seen in the picture.

Requirements

2 glass tubes (approximately 500 cm in length) open at both ends
2 retort stands and clamps
2 crucibles or 2 small open tins
2 pieces of string
Ice or cooler bags from the freezer
2 large beakers or other containers
4 thermometers and string or cotton to suspend them in tubes
Matches
Long piece of black paper

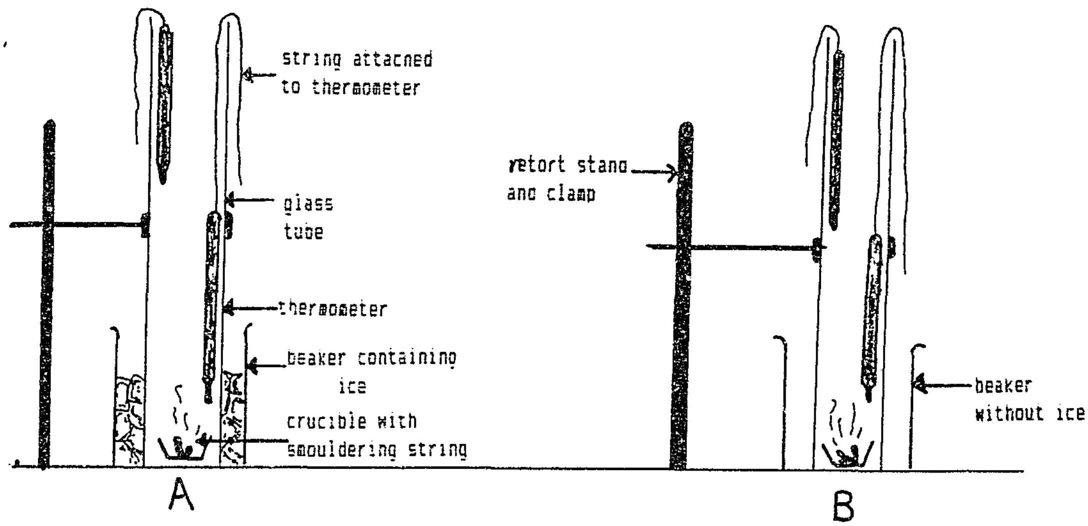
Method

1. Clamp the two glass tubes upright in the large beakers.
2. Pack ice (or the cooler bags) into the beaker around the base of one of the tubes (A) and leave for 15 - 20 minutes.
   If you place the ice in plastic bags you can easily pack it and lift it out when necessary.
3. Suspend two thermometers in tube A and two in tube B so that one registers the temperature near the top of the tube. The other registers the temperature in the lower half of each tube.
4. Light a piece of string so that it smoulders and place it in one of the crucibles. Carefully remove the ice or

cooler bags from the base of tube A. Lift tube A just enough to slip the crucible inside the base of tube A. Quickly pack the ice or cooler bags around the base of tube A.

5. After a few minutes, observe the dispersion of smoke in tube A. If you hold the piece of black paper behind the tube, you might see the smoke more clearly. Record the temperatures registered on the two thermometers in tube A.
6. Light the second piece of string so that it smoulders. Place it in the second crucible. Carefully lift tube B and place the crucible inside the base of tube B. Observe the dispersion of smoke in tube B. Record the temperatures on the two thermometers suspended in tube B.

Diagram of Apparatus

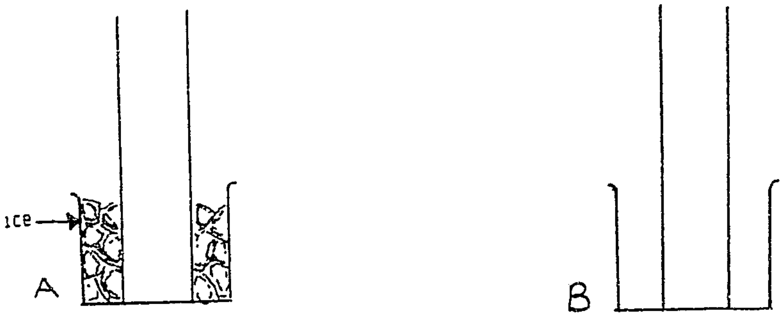


Observations

Tube	Temperature in upper half	Temperature in lower half	Dispersion of Smoke
A			
B			

Questions

1. In the diagrams below, illustrate the density of the air in the tubes just before the smoke was introduced. Use the symbol • for a particle of air.



2. Explain the dispersion of smoke in tubes A and B.

3. Now try to explain the dispersion of smoke seen in the picture at the beginning of this worksheet.

Solutions to Worksheets for Unit 2

Worksheet 2(a) Particulates (Solid Particles)

This investigation could be coupled with the study of the acidity of rain (Unit 7) as an assignment.

Sources of Particulates

Road building; construction of buildings; wind lifting dust from the dry soil; from mine dumps; from industry; from power stations; from indoor fires; from motor vehicles etc.

Effects of Particulates in the Atmosphere

Reduce visibility.
Reduce sunlight causing lower temperatures.
Cause irritation to eyes, throat, chest.
Make interiors of buildings dirty.
Make washing dirty.

Worksheet 2(b) "What is Air Pollution?

i) Air pollution is the release of substances into the atmosphere, which are harmful to life and the environment (including natural surroundings and man-made structures, eg. buildings and materials).

ii) Air pollutants are the substances which, when released into the atmosphere, cause damage to life and the environment.

iii)

Air Pollutant	Source	Effect
Particulates: Smoke	Fires Industrial processes Power stations	Reduces visibility Irritates eyes, chest etc. Dirties interior of buildings
Dust	Agriculture Construction Dirt roads Mine dumps	Reduces visibility Irritates eyes, chest etc. Dirties interior of buildings. Covers leaves of plants
CFCs	Aerosols Fridges	Destroys ozone
SO_2	Power stations	Damages vegetation, materials. Kills fish in lakes.
Lead Compounds	Car exhausts	Causes brain damage
Smog	Car exhausts	Damages materials. Causes health problems.

Note: These are examples of some responses. Students may have many ideas from Geography or the media. This exercise could be used to find out what the students know.

iv) Difficult to name one! Even "living" and respiring produces carbon dioxide which could be considered an air pollutant! However this may be debatable - students may argue that carbon dioxide is removed from the atmosphere during photosynthesis.

v) *Science and technology have contributed to the problem of air pollution but in response to demands for improved standards of living.*
However science and technology provide the sophisticated methods whereby the detection of air pollution and its consequences are possible.
Science and technology will play an increasingly important role in the search for solutions to the problem of air pollution.

vi) *The alarming increase in the world's population contributes greatly to air pollution. The increased demand for energy, transport, food and other commodities results in an increase in the release of air pollutants.*
The rich contribute eg. by the excessive use of cars in Los Angeles. The poor also contribute eg. by the removal of trees (burning of the rain forests) or by the use of coal-fires.

vii) *Air pollution episodes have been recorded in the past, eg. the fires of smelting works in Seneca in 3 A.D. blanketed the city with smoke. In the past, large cities, eg. London, suffered with hazardous smog episodes.*

viii) *Air pollutants are removed eventually from the atmosphere. This can be simply by settling down on surfaces, eg. dust, particulates. The removal of pollutants can also take place by precipitation (or depositing) of air pollutants in rain, snow, dew etc.*
Chemical reactions involving air pollutants and the biosphere, hydrosphere and lithosphere also occur and remove air pollutants,eg. carbon dioxide in photosynthesis.

Worksheet 2(c) Don't Let the Smoke get in Your Eyes!

i) *The smoke was proudly displayed as a symbol of progress, wealth and industrial development.*

ii) *Many students will feel that the emission of smoke is unacceptable.*
However in some cultures, and in some, instances, smoke is regarded as having "cleansing" or "healing" properties. (This needs to be discussed.)

iii) *Not entirely.*
It is true that some air pollution problems are local and cause problems close to their source. However other air pollution problems are regional (eg. acid rain) or global (eg.ozone depletion) and the effects of such pollution are felt far from the source. In addition, it is not only the visible forms of air pollution that cause damage.

iv) *Some air pollutants are carried hundreds of kilometres from their source before their effects become apparent, eg. SO_2 and NO_x. Wind direction and weather patterns play an important role.*

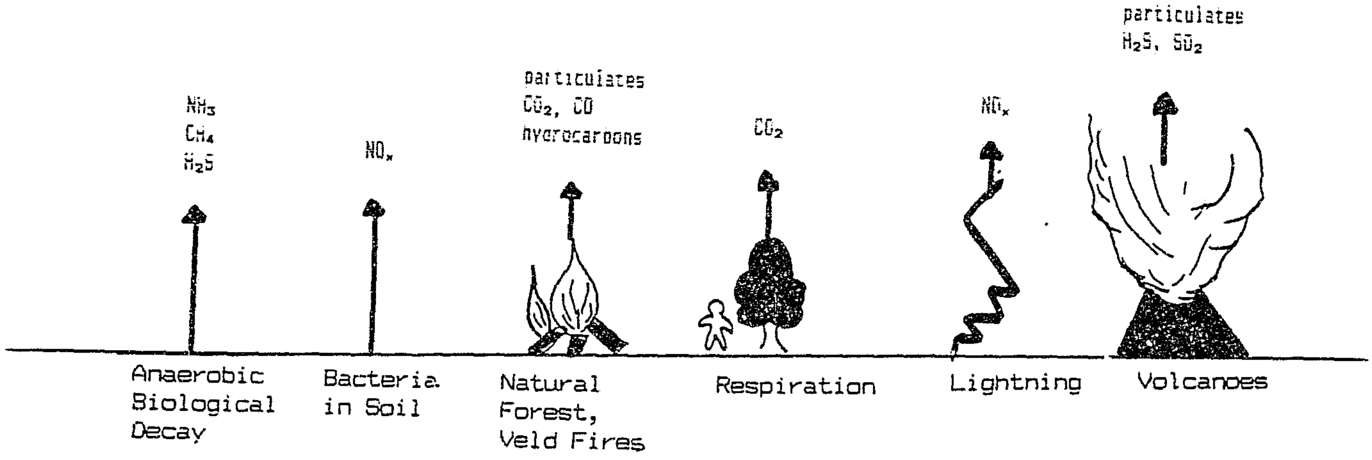
v) *In winter there is little or no rain to precipitate or deposit some air pollutants. Temperature inversions occur frequently on winter mornings. The air is stable with little turbulence to disperse air pollutants.*

vi) *Figure A*
In winter, domestic coal fires (used for cooking, heating water and providing additional warmth) contribute more sulphur dioxide than large power stations. The concentration of sulphur dioxide in Soweto exceeded the recommended limits and so could have caused health problems.
Figure B
Sulphur dioxide
In Britain in 1984, power stations produced the largest contributions to sulphur dioxide when compared to industry and other sources. (In fact industry's contribution was less than half that of the power station's.) This is an important observation as the electricity generated by these power stations meets our energy needs with regard to "everyday activities" such as cooking, heating, lighting and the use of all electrical appliances etc.
Nitrogen dioxide
The contributions to nitrogen dioxide concentrations in 1984, in Britain, by transportation and power stations were approximately the same. These two sources contributed the most to nitrogen dioxide concentrations. Once again industry's (and other sources) contributions were less than half that of "transport" and power stations.

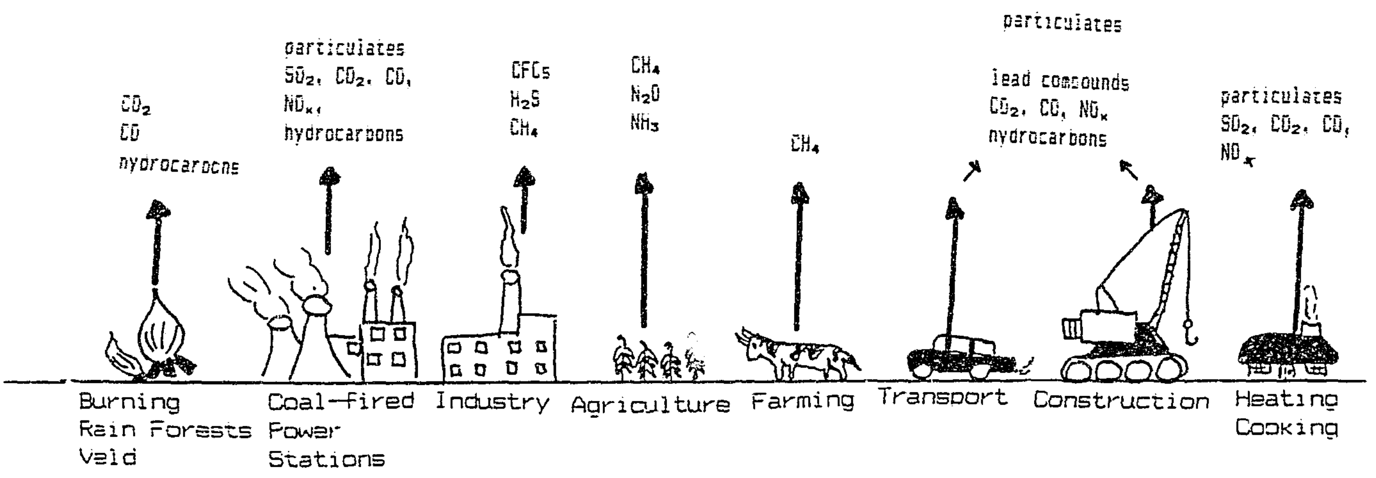
Worksheet 2(d) "Steady State"

Students should be given data from the table at the end of the introduction to Unit 2, to assist them with this exercise.

i)

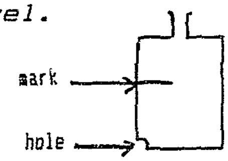


ii)



iii) All substances that can cause air pollution are also produced by natural processes (with the exception of CFCs). Nature can also cause air pollution if this release of substances exceeds the atmosphere's capacity to remove these substances or render them harmless.

iv) Students must be provided with a container (eg. a plastic bottle) with a hole cut in its base. A mark should be drawn with a waterproof pen on the bottle to show the required level.



To maintain the level of water at the mark on the container, water was run into the container so that,

Rate of water running in = Rate of water running out

The water rises above the mark when,

Rate of water running in > Rate of water running out

Flow of water into container $\equiv$ Rate of release of gases into atmosphere

Flow of water out of container $\equiv$ Rate of removal of gases from atmosphere

The composition of the atmosphere remained constant over this period because the rate of release of substances into the atmosphere was equal to the rate at which these substances were removed from the atmosphere.
ie. a <u>steady state existed</u>.

<u>Note</u>: <u>Steady state</u> is <u>not</u> the same as <u>chemical equilibrium</u>. <u>Chemical equilibrium</u> refers to a <u>closed</u> system; <u>steady state</u> refers to an <u>open</u> system.

<u>Increase in Concentration of Carbon dioxide</u>
At present the rate at which carbon dioxide is being released into the atmosphere is greater than the rate at which carbon dioxide is being removed from the atmosphere.

<u>Decrease in the Concentration of Ozone in the Stratosphere</u>
The rate at which ozone is being formed ("released") in the stratosphere is less than the rate at which ozone is being destroyed ("removed") from the stratosphere.

Worksheet 2(e) "Hot News! Read All About It!"

1. *The title of article I, indicates that a gas is being released into the atmosphere, which is contributing to an "enhanced greenhouse effect" or global warming. This gas is carbon dioxide.*

2. *It is not yet certain (ie. it is not a fact) what the consequences of the increased carbon dioxide concentration in the atmosphere will be. The passage, "Most atmospheric scientists now believe..."etc. indicates that global warming is not a certainty.*

3. *"Global" means "world-wide", or involving the entire planet Earth.*
   "Levels" means "the concentration of carbon dioxide in the atmosphere".

4. *i) 5%* *ii) S.A. ranks 3rd in the world (above Japan)*

5. *i) 1,6%* *ii) Below Britain (S.A. ranks the same as Australia - not shown on the graph)*

6. *The error made by the writer of article I was that he stated that the world output (release) of carbon dioxide is 5700 million tons annually. It should be 18300 million tons annually. (Writer of article I incorrectly used total carbon release into the atmosphere instead of the total carbon dioxide release.)*

7. *Article I Calculation (Error)*
   $\%CO_2$ *contributed by S.A. annually* $= \frac{280 \times 100}{5700} = 4,9\%$

   Article II Calculation (Correction)
   $\%CO_2$ *contributed by S.A. annually* $= \frac{{}^*295 \times 100}{18300} = 1,6\%$

   (295 million tons is quoted in article II as being S.A.'s annual release of* CO_2*. This is slightly different from the first article but it is not the main error.)*

8. *Writer of article II says 1,6% is a more realistic figure as S.A. is not considered a major industrial nation like Japan or the U.S.A.*

9. *The impression would have been gained that S.A.'s contribution to global carbon dioxide concentrations is one of the worst in the world. This impression would have been incorrect, being based on erroneous data.*

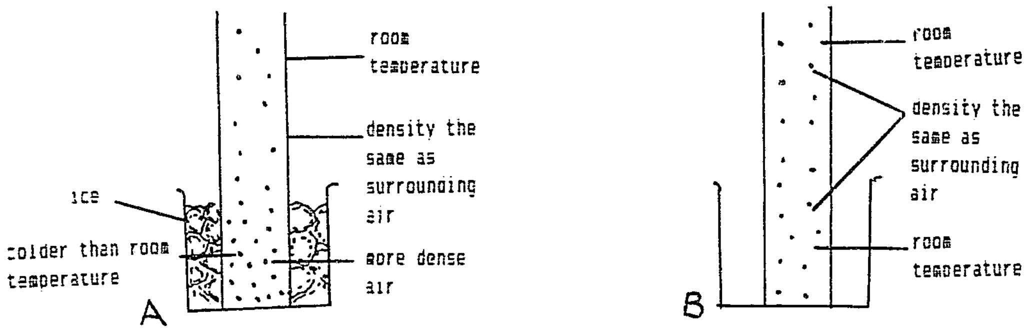
Worksheet 2(f) A Winter Scene in the Transvaal Highveld.

Observations

Tube	Temperature in upper half	Temperature in lower half	Dispersion of Smoke
A	Approx. room temperature	2° or 3° lower than room temperature	Smoke accumulates towards bottom of tube
B	Approx. room temperature	Approx. room temperature	Smoke evenly dispersed in tube and leaves from the top of the tube

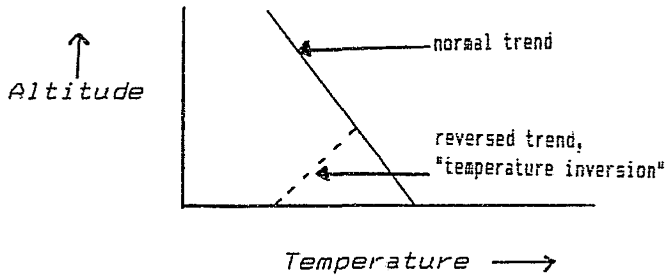
Answers to Questions

1.



2. *The air in A is stable because the arrangement of particles with the denser air lower down in the tube is in agreement with the principle of gravitational force. Therefore the air does not move throughout the tube (stable air). Thus the smoke particles are not dispersed throughout the tube but remain close to where they are formed.*
   In B, smoke is released into "normal" air which is unstable tropospheric air. Smoke is moved along with the movement of air in the tube.

3. *Normally the temperature of the air decreases with altitude (see Unit 1). This leads to the instability or turbulence of air, characteristic of the troposphere. Therefore visible pollution in the atmosphere should be quickly and evenly dispersed in the troposphere.*
However, during winter in the Highveld, the normal temperature trend becomes reversed in the early morning. Colder, more dense air is found nearer the surface of the Earth. Air is stable with little or no turbulence. Smoke (visible pollution) becomes "trapped" (ie. remains close to where it is formed) in this stable region of the atmosphere and is not dispersed.



UNIT 3

Combustion

Introduction to Unit 3

As the world population increases and as living standards rise, the demand for energy increases. As energy availability grows to meet this demand so, too, do the problems of air pollution.

Burning or combustion is a reaction during which the reactive element, oxygen, reacts with another substance forming various oxides. Energy is released. The availability of oxygen in the atmosphere and renewable fuels such as wood and the fossil fuels (coal, oil and natural gas) at or near the Earth's surface, has resulted in these fuels being burnt on a large scale. In fact approximately 90% of the energy used in the world comes from the combustion of these fuels - the remainder is derived from hydro-electric sources or nuclear sources.

Coal

The combustion of coal contributes approximately 30% of our energy needs. Coal, the solid black or dark brown substance found in many places in layers in the earth, is a complex mixture of many substances. It is the fossilised remains of forests that grew 250 million years ago. Materials such as stone, sand and other inorganic substances, were included as the buried vegetation hardened. Because it is the remains of living systems, coal is composed of, among others, carbon, hydrogen, nitrogen, sulphur and oxygen. A diagram, showing the partial and complex structure of a certain type of coal, is shown at the end of this introduction.

When coal burns many complex reactions take place. A summary of these reactions follows. In the equations, the symbols for the different elements (C,H,N,S,) present in the coal are used. The atoms of these elements form part of the very complex molecules that make up coal. These atoms do not occur free (unbonded) as the equations suggest.

a) If oxygen is plentiful, the complete combustion of carbon occurs and carbon dioxide is formed.

$$C(\text{in coal}) + O_2 \longrightarrow CO_2$$

Carbon dioxide is a colourless, odourless, tasteless gas. The concentration of carbon dioxide has increased rapidly since the Industrial Revolution. This may lead to an enhanced greenhouse effect causing greater global warming.

b) If oxygen is in short supply, incomplete combustion of carbon occurs and carbon monoxide is formed.

$$2C(\text{in coal}) + O_2 \longrightarrow 2CO$$

Carbon monoxide is a colourless, odourless, tasteless gas. If inhaled it passes directly into the blood stream where it reduces the ability of the red blood cells to carry oxygen to the tissues of the body. It can cause headaches and drowsiness. At concentrations of 1000 ppm or more death can result.
Carbon monoxide is not known to have any effects on vegetation, visibility or materials.

c) Hydrogen in the coal combines with oxygen in the air to form water.

$$4H(\text{in coal}) + O_2 \longrightarrow 4H_2O$$

d) At high temperatures nitrogen from the coal reacts with oxygen to form nitrogen monoxide.

$$2N(\text{in coal}) + O_2 \longrightarrow 2NO$$

In addition at high temperatures, nitrogen and oxygen in the air can react to form nitrogen monoxide.

$$N_2 + O_2 \longrightarrow 2NO$$

The nitrogen monoxide can react further with oxygen to produce nitrogen dioxide, NO_2. NO and NO_2 are collectively given the formula NO_x in some discussions of air pollution.
Both nitrogen oxides are toxic if their concentration is sufficiently high. (NO_2 is four times more toxic than NO). Nitrogen oxides cause dyes to fade and fabrics to deteriorate.
Nitrogen oxides may undergo a number of photochemical reactions in the atmosphere. Visibility can be reduced by the products (secondary pollutants) of such reactions.

e) The sulphur in the coal reacts with oxygen in the air to produce sulphur dioxide.

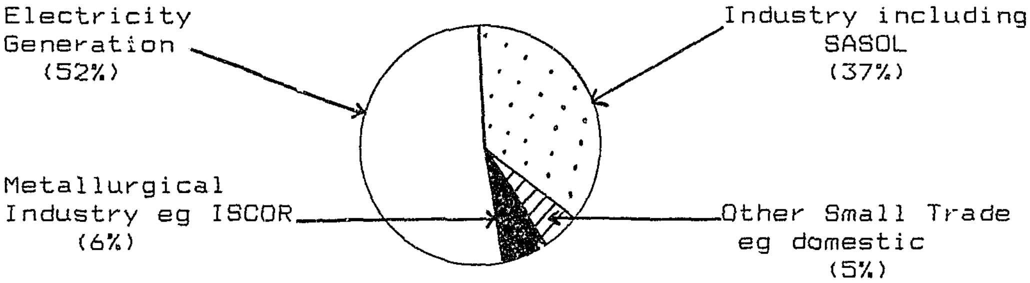
$$S(\text{in coal}) + O_2 \longrightarrow SO_2$$

Sulphur dioxide can react with oxygen and moisture in the air to form secondary pollutants which mark the leaves of plants, damage buildings and corrode metals. At high concentrations sulphur dioxide can irritate or damage lung tissue.

In addition particulates are emitted during the combustion process. This gives rise to the visible forms of air pollution, smoke and haze. This smoke consists of soot and fly-ash. The mineral impurities in the fuel are incombustible and form ash. Part of this ash is very finely powdered and is carried out of the chimney stacks with gaseous products of combustion (carbon dioxide, carbon monoxide, water vapour, nitrogen oxides and sulphur dioxide) and becomes airborne. It is termed 'fly-ash'. The formation and release of these particulates as well as the gases carbon dioxide, carbon monoxide, nitric oxide, nitrogen dioxide and sulphur dioxide, are all partly responsible for the air pollution problems associated with the combustion of coal.

South Africa is a land rich in coal. In our local market almost half of the coal sold is used for generating electricity; power stations burn vast amounts of coal to make high pressure steam which drives the turbines which generate electricity. The diagram below shows the composition of the local coal market.

South African Local Coal Usage, 1987

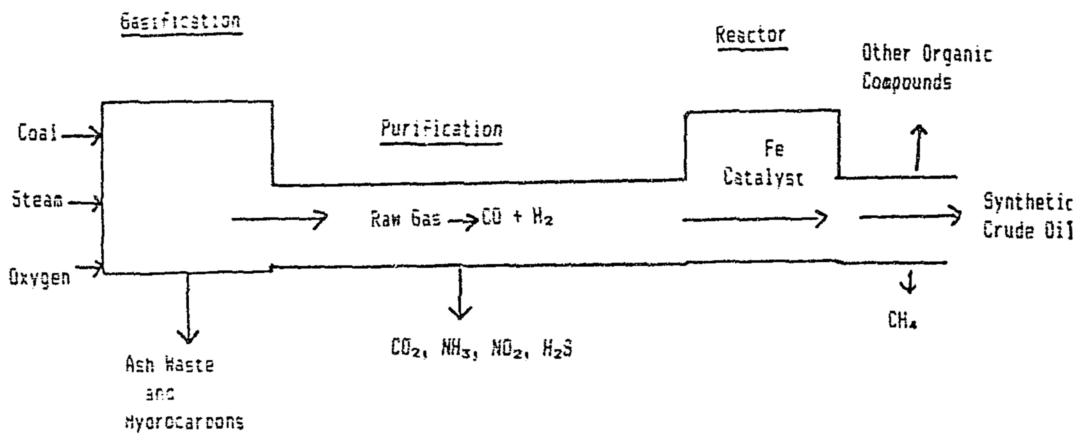


Because of our large coal reserves and to avoid a total dependence on imported oil, SASOL plants were developed to produce petrol and diesel fuels from coal. The coal is converted to synthetic crude oil in two stages:

1. The crushed coal, in the presence of steam and oxygen, is gasified at temperatures of more than 1 100°C and converted into an initial impure mixture of gases called "raw gas".
   The waste is ash which is removed to ash dumps.
2. The raw gas is then cooled and purified. The gaseous mixture, carbon monoxide and hydrogen, is passed through a second stage reactor where the crude oil is produced.
   Substances removed during the purification process include carbon dioxide, ammonia, methane and sulphur

compounds such hydrogen sulphide. Some of these substances are used in further synthesis, eg ammonia is used in the synthesis of fertilisers.

Summary of SASOL Process



In many ways the emissions from the SASOL process resemble those from the combustion of coal. These include:

i) Particulates produced during the grinding and pulverising of coal before gasification. Volatile hydrocarbons (substances whose molecules contain only hydrogen and carbon atoms) are released from the coal during the gasification.

ii) Carbon monoxide, carbon dioxide, and the nitrogen oxides produced during the purification and processing of the raw gas. Hydrogen sulphide is produced (and not sulphur dioxide as when coal is burned). The sulphur is recovered from the hydrogen sulphide and used in the manufacture of other chemicals.

Natural Crude Oil

Natural crude oil is found in underground deposits in many regions of the world and was probably formed about 300 million years ago. Oil is thought to be the remains of marine life which over time, through the action of heat, pressure and movements in the earth yielded a thick, dark, foul-smelling liquid, oil. Being the remains of living systems, oil is also a complex mixture of compounds containing mainly carbon, hydrogen, sulphur and nitrogen. Impurities similar to those in coal are also present.

Petrol and diesel fuels, made from the synthetic crude oil produced by SASOL or natural crude oil, are complex mixtures of different hydrocarbons. In the combustion engines of vehicles these hydrocarbons are mixed with air and burned. The energy released does the work of moving the pistons in the engine and turning the heels of the vehicle. Exhaust gases very similar to those produced by the combustion of coal, are produced. If the petrol burns well, carbon dioxide and water vapour are produced. But engines do not burn the fuel 100% efficiently and so produce carbon monoxide as we''. Some of the sulphur in the petrol is removed during the processing of the crude oil but some sulphur compounds still remain. Sulphur dioxide will be produced when the fuel is combusted. So much petrol is burnt nowadays that even with the removal of some of the sulphur, the mass of sulphur dioxide produced is many billions of kg per year.

The sparkplugs of a petrol-driven engine produce temperatures sufficiently high to cause nitrogen and oxygen (in the air) to combine to form nitrogen dioxide. It is an irritant and a toxic substance. It dissolves in water and may contribute to the problem of acid rain (see Unit 7). Nitrogen dioxide can be dangerous in sunny countries as it is involved in the formation of photochemical smog (a subject to be studied later in Unit 5).

Most petrols contain additives to make them burn more efficiently. An example is the lead compound, tetraethyl lead or TEL. High octane petrol has in the past contained as much as $1cm^3$ of tetraethyl lead per litre of fuel. During the combustion of such a petrol, a white powder, lead oxide, is deposited on the sparkplugs of the car stopping them from working. Ethyl bromide is added with the tetraethyl lead to prevent this happening. On burning such a fuel, tetraethyl lead is converted to gaseous lead bromide. This is released into the atmosphere with the other exhaust gases. Lead compounds are dangerous and can cause permanent brain damage, especially in small children whose brains are still developing. The lead compound concentration of petrol is being reduced because of this.

Hydrocarbons and particulates are also emitted from the exhausts of motor vehicles.

Natural Gas

Natural gas is often found above oil deposits but it is also found in some places in the Earth where there is no oil. Natural gas consists of approximately 75% methane (CH_4), 15% ethane (C_2H_6), 5% propane (C_3H_8) and 5% more complex hydrocarbons. It is the cleanest fuel that can be burned. It does not give rise to the pollution problems associated with sulphur dioxide and fly-ash experienced when burning coal. Natural gas has been found in off-shore deposits for instance near Mossel Bay.

Combustion of natural gas also produces less carbon dioxide per unit of energy than coal or oil when burned.

Fuel	Number of Moles CO_2 Formed per MJ of Energy Produced
Coal	2,54
Oil	1,46
Natural Gas	1,12

A change to using natural gas in power stations is occurring in some parts of the world. Natural gas is also used in some homes for cooking and heating.

Wood

When wood is burned on a large scale (as with the destruction of the rain forests), it also causes air pollution problems: carbon dioxide, carbon monoxide and particulates are emitted.

The table at the end of this introduction may help to summarise the types of air pollutants (and their effects) formed as a result of the combustion of coal, oil, wood and natural gas. We shall study many of their effects in later units.

So who is to blame for this air pollution? The blame is often levelled at industry, oil companies and factories. It is true that they do contribute to these air pollutants. But we have to ask ourselves the questions:

Who drives the cars?
Who uses the buses, trains, aeroplanes?
Who burns coal to keep warm?
Who cuts wood and burns it to keep warm?
Who uses the electricity to heat, cook, provide light, heat water?
Who works in the factories?

When we attempt to answer these questions we see how deeply we all are involved in these problems of air pollution.

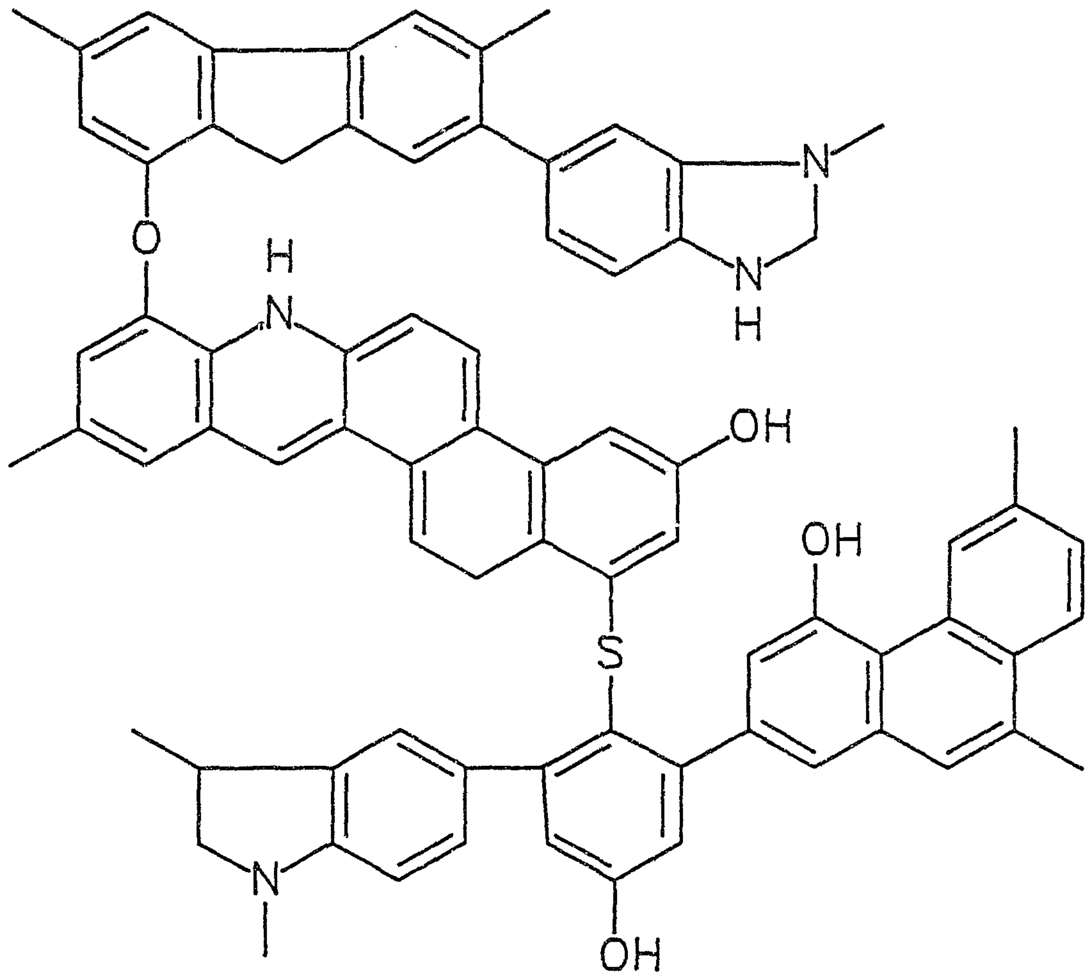
Summary of Air Pollutants formed as a Result of Combustion

Pollutant	Major Source	Effects
Carbon dioxide	Burning of coal, oil, wood, gas	Could contribute to global warming
Carbon monoxide	Incomplete combustion of coal, wood, oil, gas	Drowsiness, nausea, death if too much is inhaled
Sulphur dioxide	Fuels which contain sulphur eg coal and oil	Forms acid rain which affects soil, kills plants and fish. Corrodes metals, brick, plastic, rubber
Nitrogen oxides	High temperature combustion eg in power stations, car engines	Forms acid rain and involved in the formation of smog
*Hydrocarbons	Combustion of wood, coal and oil.	Involved in smog formation. Can cause cancer
Lead compounds	Petrol to which lead compounds have been added	Destroys nerve tissue
Particulates	Combustion of wood, coal and oil	Scatter and absorb sunlight causing temperature to drop, reduce visibility

* Volatile hydrocarbons eg. methane, are released from wood, coal and oil at the high temperatures produced during combustion. Volatile hydrocarbons also escape from car exhausts because of incomplete combustion in the motor engines.

A diagram Showing Part of the Proposed Molecular Structure of Coal

This diagram indicates the complexity of the molecular structure of coal. It also shows the presence of carbon, hydrogen, oxygen, nitrogen and sulphur in coal.



Learning Objectives for Unit 3

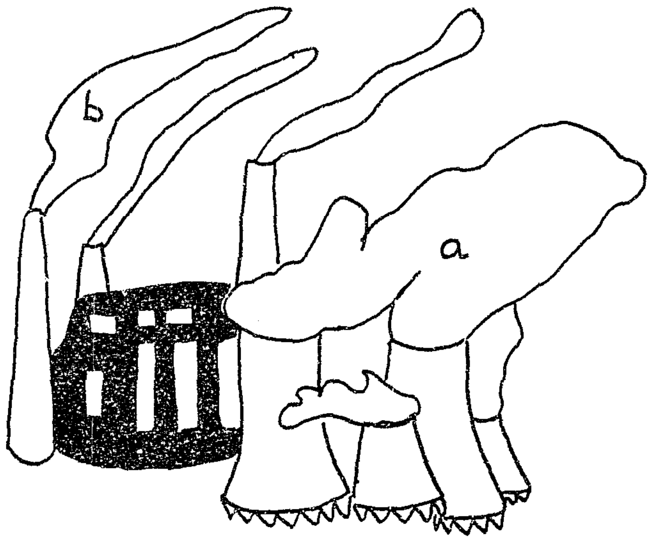
On completing this unit students should be able to:

3.1 Describe combustion as a reaction during which oxygen reacts with other substances forming oxides.
3.2 Explain that energy becomes available as a result of combustion.
3.3 Describe briefly the formation and nature of coal.
3.4 Name and give the formulae of the gaseous pollutants produced when coal is burnt.
3.5 Describe the origin of the fly-ash that results from burning coal.
3.6 Explain briefly the process used by SASOL whereby petrol and diesel oil is produced from coal.
3.7 Name and give the formulae (where applicable) of some of the air pollutants from the SASOL process.
3.8 Describe briefly the origin and nature of natural crude oil.
3.9 Name and give the formulae (where applicable) of the pollutants produced by burning petrol and diesel fuel.
3.10 Explain the addition of lead compounds to improve the efficiency of burning petrol and the emission of lead compounds from the exhausts of cars.
3.11 Describe the effects of the following pollutants: particulates, carbon dioxide, carbon monoxide, nitrogen monoxide, nitrogen dioxide, sulphur dioxide, hydrocarbons, lead compounds.

Worksheet 3(a) Combustion

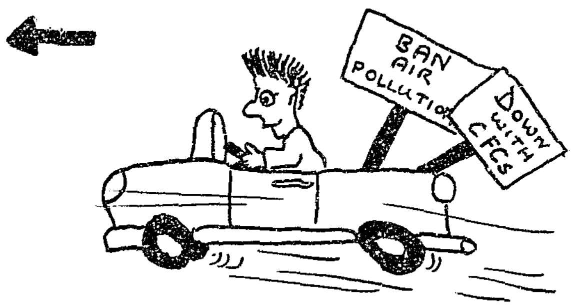
This worksheet could be used for small group discussions.

1. Discuss the emissions (a) and (b) from the coal-fired power station shown in the diagram.
   Make a list of the air pollutants produced by the power station. Describe the effects of these air pollutants.

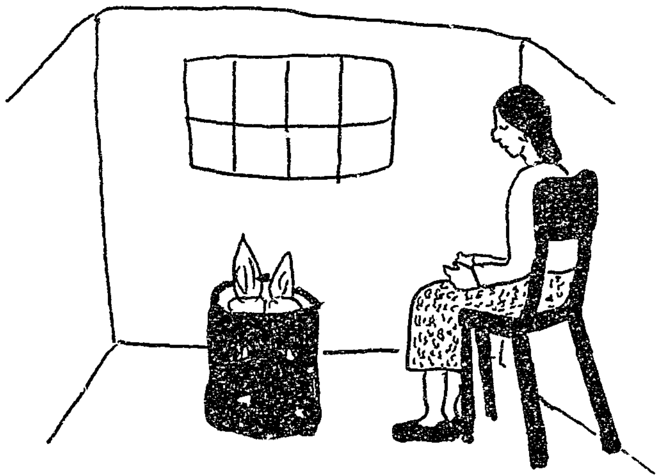


2. Comment on this scene.

To Air Pollution Protest March



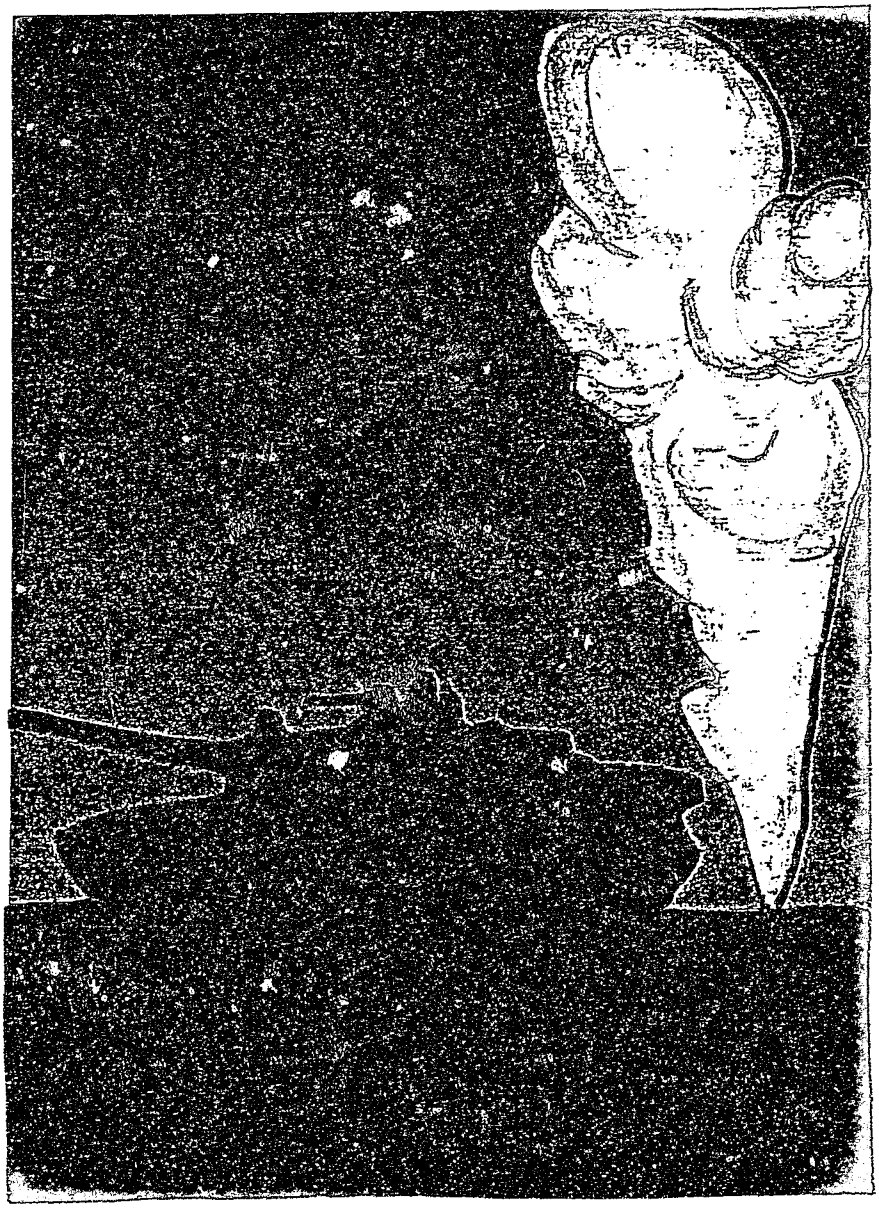
3. An indoor fire can be dangerous because of some of the air pollutants formed. Discuss the dangers and possible measures that should be taken when using such a fire.



4. Make a list of the activities of members of your group since you woke up this morning, that involve the energy provided by combustion.

Worksheet 3(b) "Gulf War"

This is a picture of a burning oil well during the war in 1991 in Kuwait. Imagine that you are a news reporter who is witnessing this scene. Write a newspaper article which includes a description of the air pollutants formed during the cumbustion of the oil and the possible consequences of the large scale burning of these oil wells.



Worksheet 3(c) Burning Coal

Let's try to detect some of the air pollutants produced when we burn coal.

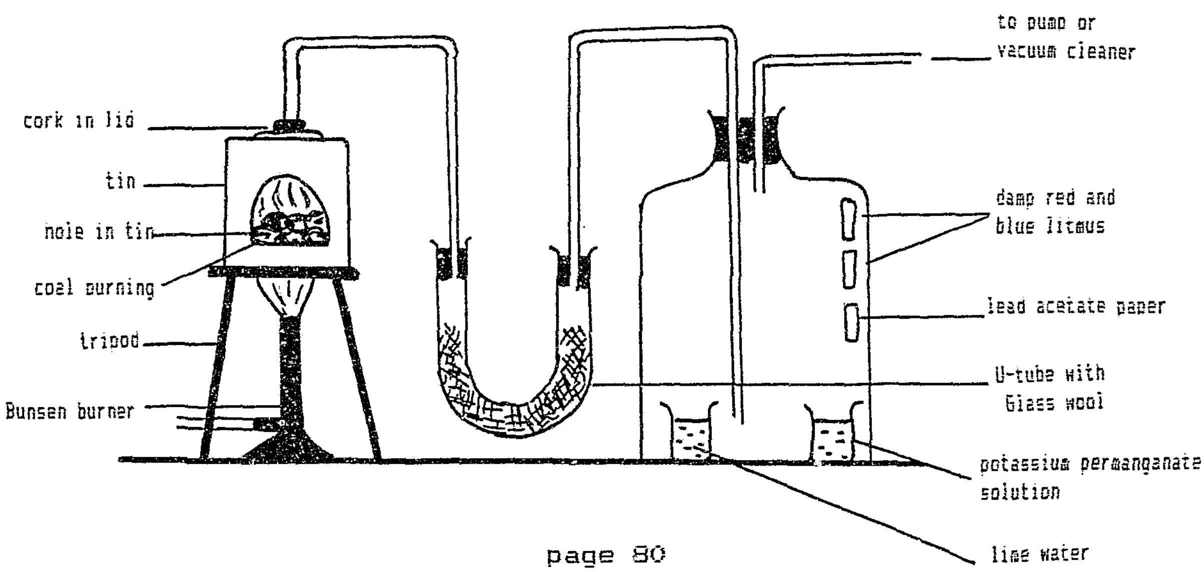
Requirements

an empty tin with a push-on lid eg. a syrup tin
a bell jar or other similar container
a Bunsen burner
a pair of tin snips
a U-tube
two rubber corks (one must fit into the top of the belljar, the other fits into a hole in the lid of the tin.)
two one-holed rubber bungs to fit the U-tube
some litmus paper and lead acetate paper
some glass wool
some coal
a pump attached to the water taps (or a vacuum cleaner to draw air through the apparatus)
a small beaker containing some lime water
a small beaker containing some potassium permanganate solution

Method:

1. Punch several holes in the bottom of the tin using a large nail.
2. Using the tin snips cut a flap in one side of the tin.
3. Make a hole in the lid large enough to fit one of the bungs. (The tin looks like a fireplace.)
4. Set up the rest of the apparatus as shown in the diagram.

Apparatus for Detecting the Products formed when Coal is Burned



5. You will have to draw the air through the U-tube and into the bell jar. The pump at the water taps may be used. If this is not available, hold the end of the cleaning pipe of a vacuum cleaner near the outlet pipe from the belljar. (As shown in the diagram)
6. Complete the table of observations that follows.

Observations

	Change	Explanation
Contents of Tin		
Glass Wool		
Litmus Paper		
Lead acetate paper		
Lime water		
Potassium permanganate solution		

Discussion:
During this activity you observed or detected the presence of some of the air pollutants produced when we burn coal. Comment on the consequences of these products being released into the atmosphere.

Experiment is adapted from
Experiments on Air Pollution
by D.I. Williams, D. Anglesea.

Worksheet 3(d) Sparkplugs

In this exercise we will study the changes that occur in the air surrounding a sparkplug of a motor car, while it functions.

Requirements
1 spark plug
two lengths of insulated copper wire
small bottle, $250cm^{-3}$, with a bakelite top (or a small spice bottle and its lid and a little Prestik)
an induction coil (free standing or car induction coil)
damp litmus paper

Method
1. Place a piece of damp blue litmus paper and a piece of damp red litmus paper in the small jar (or spice bottle).
2. Make a small circular hole in the bakelite top of the jar, so that the plug can be screwed into it.
2. Screw the bakelite top and plug back onto the jar.
* (If you are using a small spice jar, cut a hole in the plastic lid and insert the plug. Use the Prestik to seal any spaces around the plug where it fits the hole in the lid.)
3. Attach the plug to the induction coil using the wires and switch on.
4. A tiny spark will jump across the gap in the sparking plug.
5. Continue to spark for about 5 minutes.
6. Record any changes you observe in the contents of the jar and in the colour of the damp litmus paper.

(Note:
The high tension lead of the car can also be used.
Attach this lead to the plug in the jar. An earth wire from the body of the car to the side of the plug is also required.)

Diagram of Bottle

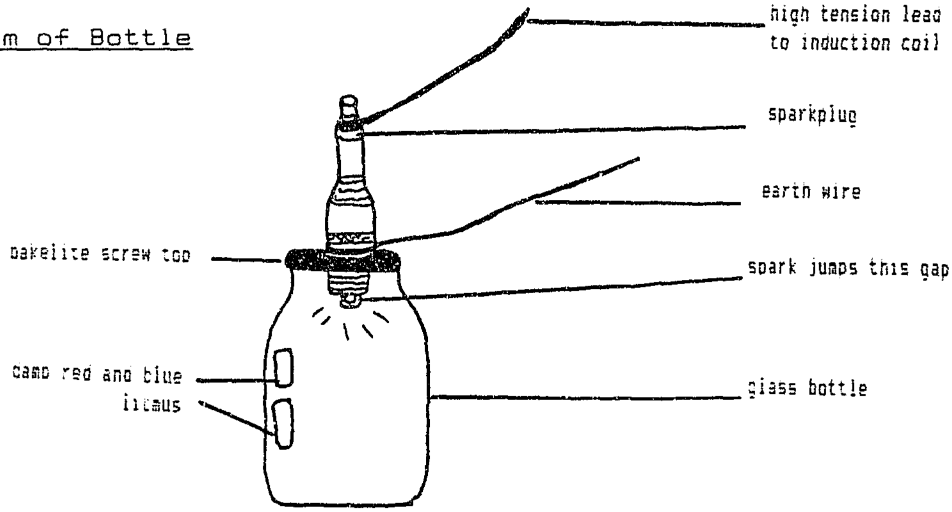
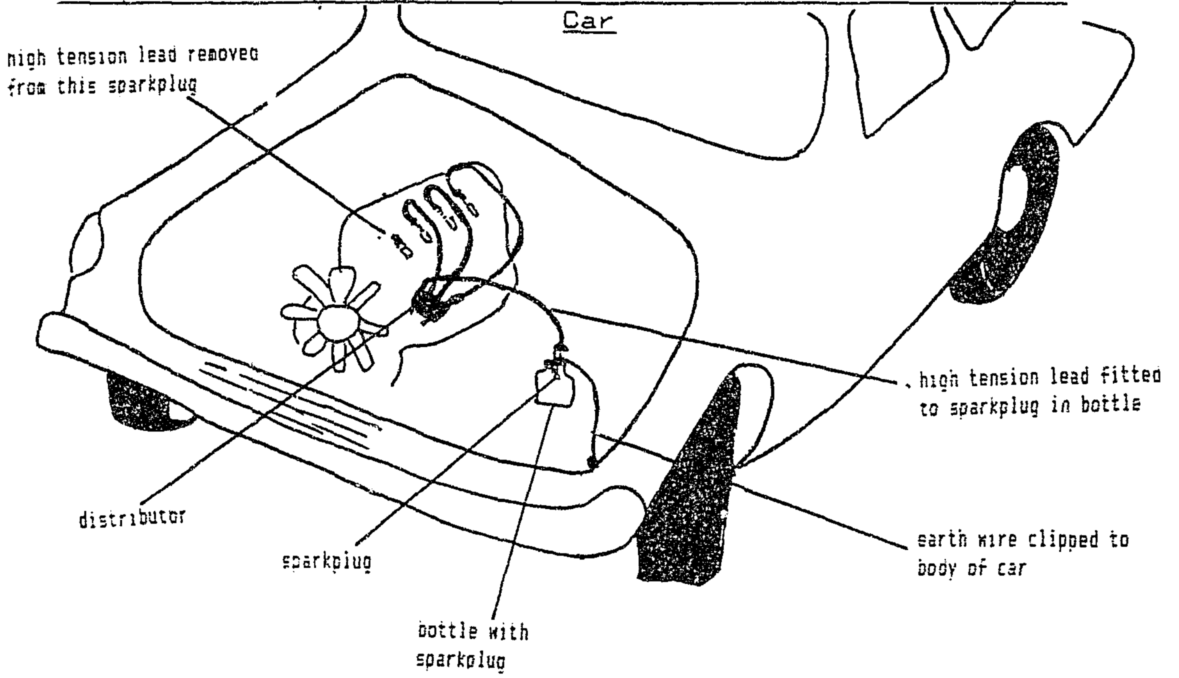


Diagram Showing How to Use the Induction Coil of the Motor Car



Observations

Changes in contents of jar	Changes in Litmus Paper

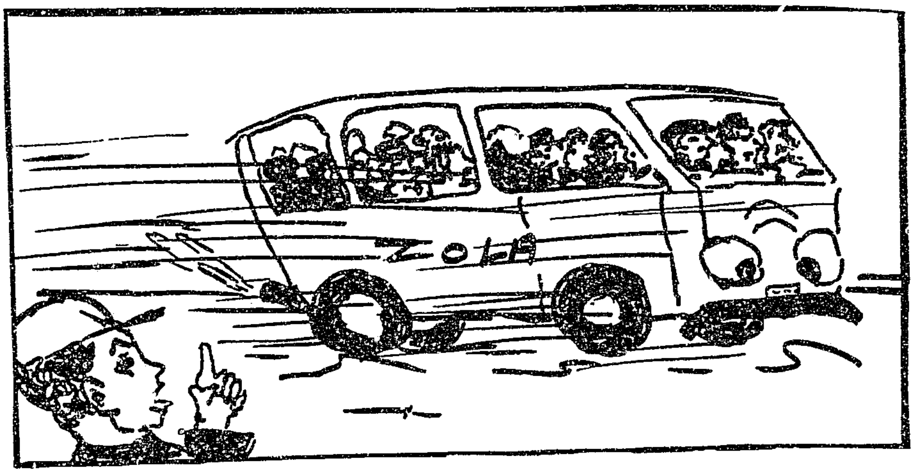
Explanations

i) Explain the changes you have observed in the jar.
(Include any relevant equations in your answer.)

Experiment is adapted from
Experiments on Air Pollution
by D.I. Williams, D. Anglesea.

ii) What may be the consequences for the atmosphere, of the phenomenon observed in this investigation.

<u>Worksheet</u> 3(e) TAXI!



<u>Questions</u>
Please use a separate sheet of paper for your answers.

1. What provides the energy to make the engine of the taxi work and turn the wheels?

2. i) Draw three columns and head them:

   SUBSTANCE ORIGIN EFFECT

   ii) Under the column "SUBSTANCE" list the names of the substances released into the atmosphere from the exhaust pipe of the taxi.
   iii) Under the column "ORIGIN" describe how these substances are formed in the engine of the taxi.
   iv) Under the column "EFFECT" describe the effects of each substance when it is released into the atmosphere.

3. In question 2 you described some of the air pollution problems arising from the use of the taxi. Now write a few sentences describing the benefits of the use of this form of transport with regard to the problem of air pollution.

Solutions to Worksheets for Unit 3

Worksheet 3(a) Combustion

1. (a) Steam (water vapour) from the cooling towers
   Therefore not air pollutants.
   (b) Products of combustion of coal released from chimney stacks:
   carbon dioxide - possible enhanced greenhouse effect
   carbon monoxide - toxic to humans
   sulphur dioxide - "acid rain"
   sulphur trioxide - "acid rain"
   nitrogen oxides - "acid rain" and smog
   hydrocarbons - smog
   - carcinogenic
   particulates - reduce visibility
   - cause irritation to eyes, chest
   - makes surfaces, materials dirty

2. Driver is possibly overlooking the contribution of motor vehicles to air pollution. Released from the exhaust pipe are the following air pollutants:
   nitrogen monoxide, nitrogen dioxide - contributes to "acid rain" and smog
   lead compounds - poisonous, cause damage to nervous system
   hydrocarbons - carcinogenic and give rise to smog
   carbon dioxide - possible enhanced greenhouse effect
   carbon monoxide - toxic and contributes to smog

3. If there is no ventilation, carbon monoxide forms and accumulates. This compound reacts with haemoglobin in the blood, preventing the haemoglobin from transporting oxygen to the cells of the body. Headaches and drowsiness result. If the concentration of carbon monoxide is sufficiently high, death results.
   WINDOWS SHOULD BE LEFT OPEN.

4. *For example*

Switching on light Switching on radio/TV * Washing in warm water * Cooking food	Energy provided by the combustion of coal at coal-fired power station * These may also be provided by the combustion of coal/gas/paraffin
Travelling to school -	Energy provided by combustion of petrol
Sitting in heated classroom -	Energy provided by the combustion of coal at power station or in heating system of school

4. *(continued)*

Using computers, overhead projectors	–	*Energy provided by the combustion of coal at power station*
Eating food	–	*transport of food requires energy provided by the combustion of coal*
	–	*processing of food often requires energy provided by coal-fired power stations*

Worksheet 3(b) "Gulf War"

Suggested outline for newspaper article, "Gulf War"

Article should mention:

Combustion of oil produces:

Particulates
Blot out the sun, reduce visibility
Reduce the temperature
Cause irritation of lungs, eyes
Make surroundings dirty

Hydrocarbons
Are carcinogenic
Are involved in reaction producing photochemical smog which gives rise to health problems and damages materials eg rubber tyres

Carbon dioxide
Contributes to the possibility of an enhanced greenhouse effect and probable global warming

Carbon monoxide
Toxic, causes headaches, drowsiness and death (if concentration is sufficiently high)

Sulphur dioxide
Reacts with materials eg cement, paint
Damages vegetation
Causes health problems eg chest ailments
Contributes to the problem of "acid rain"

Nitrogen oxides
Involved in the production of photochemical smog (in reaction with hydrocarbons and carbon monoxide in the presence of sunlight)
Contributes to the problem of "acid rain"
Can damage vegetation
Causes respiratory problems

Worksheet 3(c) Burning Coal

Observations

	Change	Explanation
Contents of tin	Ash forms	The inorganic compounds in coal eg sand, stone, which have not been combusted
Glass Wool	Soot, pieces of ash, tar, blacken the wool	Formed during the combustion of the coal. They are some of the particulates normally released.
Litmus Paper	Blue piece turns red. Red piece remains red.	Some acidic gases are produced. eg SO_2, SO_3, NO_x, H_2S
Lead acetate Paper	May turn black	H_2S produced during combustion of coal
Lime water	Turns milky	CO_2 produced during combustion
Potassium permanganate solution	Purple colour becomes paler	SO_2 produced reacts with $KMnO_4$ decolourising solution

Discussion

Particulates (ash, soot)	:	Can become airborne. Reduce visibilty, dirty surfaces, irritate eyes, chest.
Acidic gases (SO_2, SO_3, H_2S, NO_x)	:	Contribute to "acid rain" problems H_2S is toxic
Carbon dioxide	:	Contributes to possible enhanced greenhouse effect.

Worksheet 3(d) Sparkplugs

Observations

Changes in contents of jar	Changes in Litmus Paper
Brown gas produced close to region of sparking	Blue litmus turns red Red litmus remains red

Explanations

i) High temperatures reached during sparking causes the nitrogen in the air to react with the oxygen.

$$N_2 + O_2 \longrightarrow 2NO$$

$$2NO + O_2 \longrightarrow 2NO_2 \quad \text{(brown gas)}$$

ii) a. NO and NO_2 (collectively termed NO_x) contribute to the problem of "acid rain".

b. NO_2 decomposes in the sunlight (a photochemical reaction) and reacts with other gases released from the car exhaust (eg hydrocarbons, carbon monoxide) to form photochemical smog.
This is a problem in cities such as Los Angeles, Tokyo, Johannesburg and Cape Town.
The photochemical smog contains substances which are harmful to life and damage materials.

Worksheet 3(e) TAXI!

1. The combustion of petrol provides the energy to make the engine work and turn the wheels.

2.

SUBSTANCE	ORIGIN	EFFECT
carbon dioxide	Complete combustion hydrocarbons in petrol	Causes an increase in the concentration of carbon dioxide in the atmosphere. This may lead to an enhanced greenhouse effect.
carbon monoxide	Incomplete combustion of hydrocarbons in petrol	Causes drowsiness, headaches. Death can result if concentration is too large. Is one of the substances forming photochemical smog.
sulphur dioxide	A very small percentage of sulphur is present in petrol. Sulphur reacts with oxygen during the combustion of petrol.	Causes "acid rain" which damages materials eg cement, metal. Also damages vegetation and causes health problems eg chest ailments.
nitrogen dioxide	A very small percentage of nitrogen is present in petrol. The nitrogen reacts with oxygen during the combustion of petrol. Also temperatures in the engine are high enough to cause nitrogen in the air to combine with oxygen.	Causes "acid rain" which damages vegetation and materials. Also one of the substances forming photochemical smog.
lead compounds	Are added to petrol to make it burn better. During combustion these lead compounds are converted to different lead compounds.	Can cause health problems by damaging the nervous system.

2. (continued)

SUBSTANCE	ORIGIN	EFFECT
hydrocarbons	Some hydrocarbons in the petrol are not combusted due to the inefficiency of the engine. These hydrocarbons are volatile and are released from the exhaust.	Combine with carbon monoxide and nitrogen to form smog.
water	Hydrogen present in compounds in petrol, reacts with oxygen during the combustion of the petrol.	Not involved in air pollution problems.

3. The taxi contributes to the problems of air pollution because of the air pollutants released from the exhaust. However, the taxi transports <u>several people at the same time.</u> This reduces the number of motor vehicles on the road. It is the large number of motor vehicles (often with one or two people inside) that contributes significantly to the problems of air pollution.

UNIT 4

The Depletion of Ozone in the Stratosphere

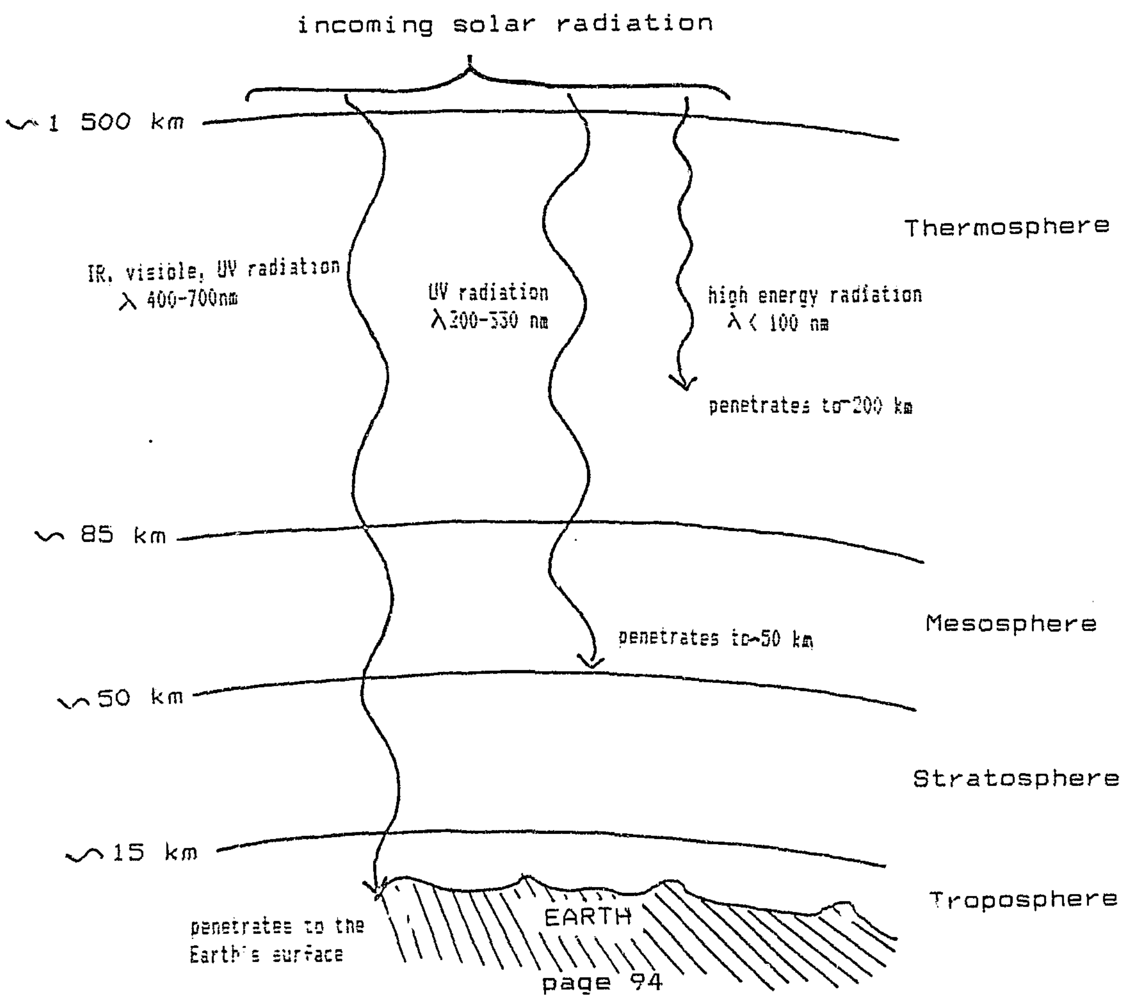
Introduction to Unit 4

The solar radiation that reaches the Earth's atmosphere includes ultraviolet radiation of wavelengths that are harmful to life on Earth. For example ultraviolet radiation with a wavelength < 200 nm, has sufficient energy to break some of the bonds in the molecules of nucleic acids, RNA and DNA, which are essential to life. Exposure to ultraviolet radiation with a wavelength 280 – 320 nm, can result in cancer.

The Absorbing Action of the Atmosphere

The atmosphere acts as an absorber of some solar radiation, so that most of the harmful radiation does not penetrate the troposphere. The diagram below shows the extent to which solar radiation of different wavelengths penetrates the atmosphere.

Penetration of Solar Radiation into the Atmosphere



Adapted from
Environmental Chemistry 3rd ed.
by S.E. Manahan.

The absorption of some solar radiation is due to some of the components of the atmosphere. The absorption of the radiation initiates chemical reactions termed photochemical reactions.

Looking at the diagram, we see that in the thermosphere (ionosphere) high energy ultraviolet radiation with wavelengths less than 100 nm is absorbed. It is this absorption of energy by the molecules that ionises them in the ionosphere resulting in species such as O_2^+, O^+ and NO^+. The high temperatures in the ionosphere (reaching a maximum of 1200°C) are the result of the distribution of some of this energy by collisions between the molecules.

Oxygen, a major component of the atmosphere, is one of the gases that absorbs high energy radiation with a wavelength < 230nm.

eg. $$O_2 \xrightarrow{UV,\ \lambda < 103\ nm} O_2^+ + e^- \quad (i)$$

and $$O_2 \xrightarrow{UV,\ \lambda < 230\ nm} 2O \quad (ii)$$

(You may remember that in Unit 1: The Atmosphere, it was mentioned that oxygen atoms are a major component of the atmosphere 120-1000 km above the Earth's surface.)

The oxygen atoms, generated as shown in (ii), can collide with molecules of oxygen to produce ozone molecules, O_3.

$$O + O_2 + M \longrightarrow O_3 + M \quad (iii)$$

A third molecule, M, which is usually N_2 or O_2 because they are plentiful, assists with the distribution of energy resulting from bond formation in reaction (iii).

Ozone is the only substance in the atmosphere capable of absorbing solar ultraviolet radiation with a wavelength longer than approximately 230 nm. Ozone absorbs particularly strongly radiation of wavelength 220 - 330nm. If most of this radiation were not absorbed, it would cause severe damage to life on Earth. (However some ultraviolet radiation is necessary to ensure healthy bone development.)

$$O_3 \xrightarrow{UV,\ \lambda\ 220\text{-}330\ nm} O + O_2 \quad (iv)$$

$$O + O_3 \longrightarrow 2O_2 \quad (v)$$

The absorption of the ultraviolet radiation by ozone molecules leads to their destruction.

In our study of the atmosphere in Unit 1, we noted that the temperature increased steadily from an altitude of approximately 17 - 50 km in the atmosphere. We can now see that in the stratosphere, energy is absorbed by the ozone from the solar ultraviolet radiation. The subsequent decomposition of ozone and formation of oxygen is exothermic. Hence the temperature increase in this region.

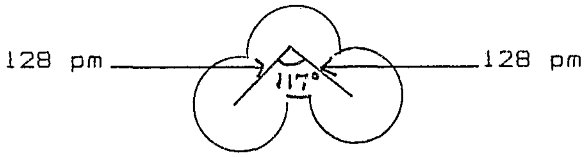
As the diagram on page 94 shows, it is the photochemical reactions involving species such as oxygen and ozone molecules that result in high energy ultraviolet radiation being absorbed. Hence the solar radiation that penetrates the troposphere is mostly of wavelengths > 330nm. In fact most of this radiation is visible light with wavelengths 400—700 nm.

(In unit 6, dealing with the "greenhouse effect", we will see that ozone also absorbs some radiation with wavelengths > 700 nm. This is infrared radiation.)

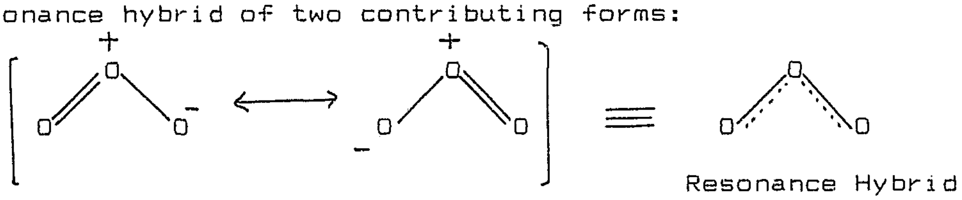
Properties and Structure of Ozone

Pure, gaseous ozone is blue and has an odour rather like that of garlic - hence the name "ozone" from the Greek, ozo, I smell. However in low concentrations, for example when mixed with other gases in the atmosphere, it appears colourless. (It is not ozone that gives the sky its blue colour! The blue colour is due to scattering of some blue-violet light as it passes through the atmosphere.)

A molecule of ozone has an angular shape:



It is not possible to write a unique Lewis structure for the ozone molecule so the molecule is represented as a resonance hybrid of two contributing forms:

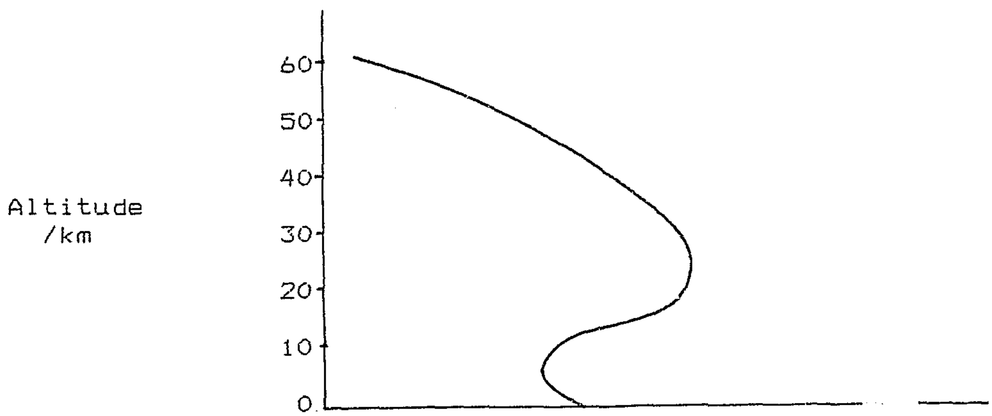


The bonds in the molecule are of equal length (128 pm) which is intermediate between a typical O-O single bond (148 pm) and O=O double bond (120 pm). The ability of the ozone molecule to absorb certain energies of solar radiation is closely related to the nature of the bonds in the ozone molecule.

The Distribution of Ozone in the Atmosphere

The formation of ozone occurs most commonly in the stratosphere where the concentration of oxygen molecules is still relatively high. The highest concentrations of ozone (approximately 10 ppm) occur 20 - 50 km above the Earth's surface. This is the so-called "ozone layer". This phrase is misleading as it implies a well-defined region where the ozone concentration is very high. In fact in this region of the atmosphere there is a mixture of gases of which ozone is still a trace component! (If all the atmospheric ozone were concentrated into a shell of pure gaseous ozone at atmospheric pressure, it would measure about 3 mm in thickness. That's about the thickness of the cover of a hardcovered book!) In the stratosphere, the ozone is produced mostly over the tropics because the intensity of ultraviolet radiation penetrating the atmosphere is greatest there. The ozone is carried towards the poles by the horizontal air circulation which is a feature of the stratosphere. Thus although less ozone is generated in polar regions, the concentration actually increases towards the poles. Fluctuations in the ozone concentration occur with the seasons and between day and night because of the fluctuations in the intensity of the ultraviolet radiation reaching the stratosphere.

Variation of Ozone Concentration with Altitude

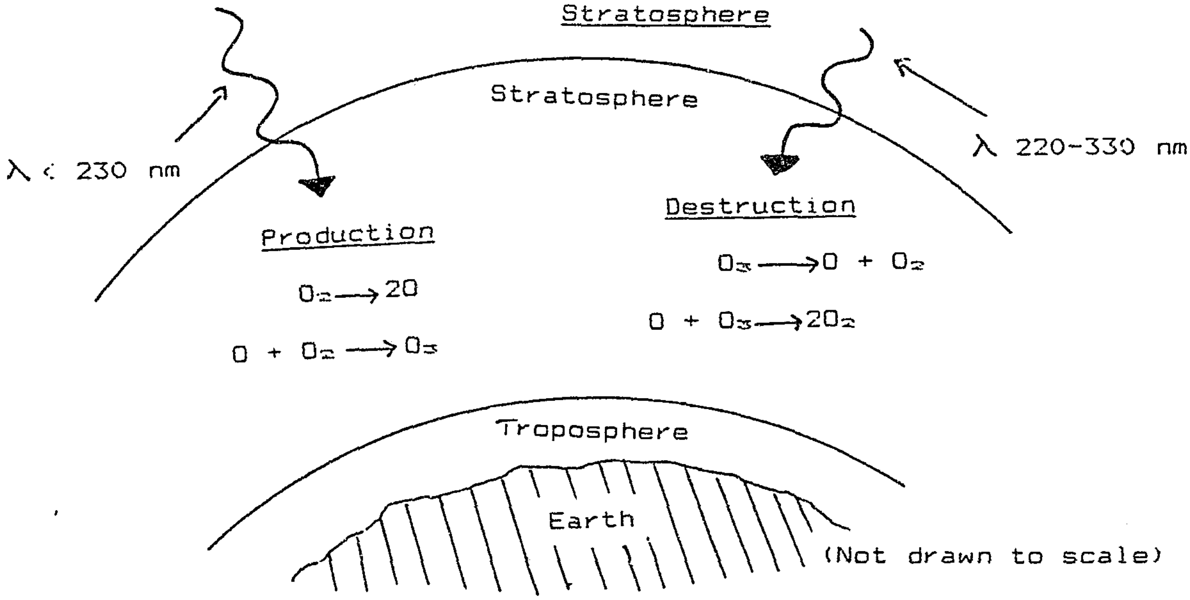


Increasing Ozone Concentration

In the troposphere, the ozone concentration is lower, (approximately 0,04 ppm). Some ozone in the troposphere arises from a slow downward exchange between the stratosphere and troposphere across the tropopause. It also arises from reactions involving hydrocarbons emitted from vegetation and motor vehicles. The ozone concentration in the troposphere is currently increasing as a result of the exhaust gases produced by vehicles. We shall study this later in Unit 5 when dealing with smog.

In our study of present day concern about ozone depletion we shall focus on the ozone in the stratosphere. It may be helpful to summarise the reactions taking place in the stratosphere that result in the formation of ozone and its destruction when it absorbs ultraviolet radiation. The reactions (ii), (iii), (iv) and (v) were all given earlier.

Production and Destruction of Ozone in the Stratosphere



There is another way in which ozone is destroyed. A reactive species (X) can react with ozone molecules to produce oxygen molecules ;

$$O_3 + X \longrightarrow XO + O_2 \qquad \text{(vi)}$$

$$XO + O \longrightarrow O_2 + X \qquad \text{(vii)}$$

$$O_3 + O \longrightarrow 2O_2 \qquad \text{Overall Reaction}$$

X could be hydrogen atoms (H), or hydroxyl radicals(OH), nitrogen oxides (NO_x) or chlorine atoms (Cl). For millions of years reactions involving all these species and the ozone in the stratosphere maintained a steady state. On average the rate at which ozone was being produced was equal to the rate at which it was being destroyed. However in recent times, as a result of increased and changing human activities. the concentration of some of these reactive species (X) in the stratosphere is increasing. The result is that the stratospheric ozone may be being destroyed faster than it is being produced. Concentrations of ozone in the atmosphere have been monitored during recent years and the results seem to indicate that the ozone concentration in the stratosphere is decreasing.

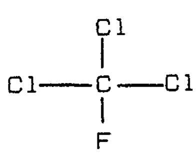
<u>The Historical Development of a Theory of Stratospheric Ozone Depletion Caused by CFCs</u>

Thomas Midgley, born in 1889, was a prolific inventor and contributor to the fields of science and technology. One of his achievements was the discovery that the addition of tetraethyllead to petrol improved the efficiency of its combustion. (We have studied the air pollution problems associated with the addition of lead compounds to petrol in Unit 3.)

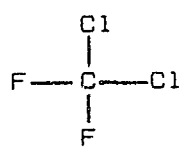
In the 1920's there was a large increase in the use of refrigerators in the USA. The gases used in refrigerators were ammonia (NH_3), sulphur dioxide (SO_2) and chloromethane (CH_3Cl) which were toxic, corrosive or flammable gases. Midgley suggested the use of alternative compounds as refrigerants. These compounds were:

non-toxic,
non-corrosive,
non-flammable,
stable or unreactive
odourless
made at affordable prices
safe to use
ideal as refrigerant gases because they boiled between 0°C and -40°C at atmospheric pressure

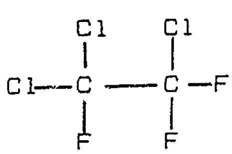
These alternative compounds were chlorofluorocarbon compounds or as we call them today, CFCs. They are compounds whose molecules consist of chlorine, fluorine and carbon atoms. There are many different compounds which were developed but the five most important CFC compounds are represented below:



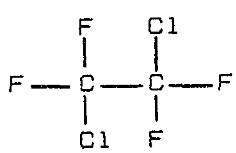
<u>CFC-11</u>



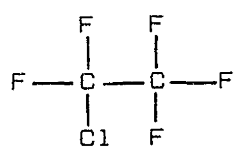
<u>CFC-12</u>



<u>CFC-113</u>



<u>CFC-114</u>



<u>CFC-115</u>

Of these CFC-11 (trichlorofluoromethane) and CFC-12 (dichlorodifluoromethane) have been produced most abundantly.

Until very recently, these were regarded as "wonder chemicals". They have been widely used as refrigerant gases in refrigerators and airconditioners, propellants in aerosol cans, solvents to clean electronic equipment and blowing agents during the production of foam rubber and polystyrene. Yet today CFCs are recognised as air pollutants contributing to stratospheric ozone depletion, the "*greenhouse effect*" (Unit 6) and acid rain (Unit 7). Now the manufacture and use of CFCs is being carefully reviewed; the Montreal Protocol (Unit 10) is an agreement between 39 nations which seek to reduce CFC usage by 50% by 1999.

The first indications that CFCs could cause air pollution problems came when James Lovelock, a British chemist, detected the presence of CFCs in the atmosphere in the Southern Hemisphere - far from the major release points in the Northern Hemisphere. This finding seemed to indicate the molecules of CFCs did not react in the atmosphere and were dispersed over the globe.

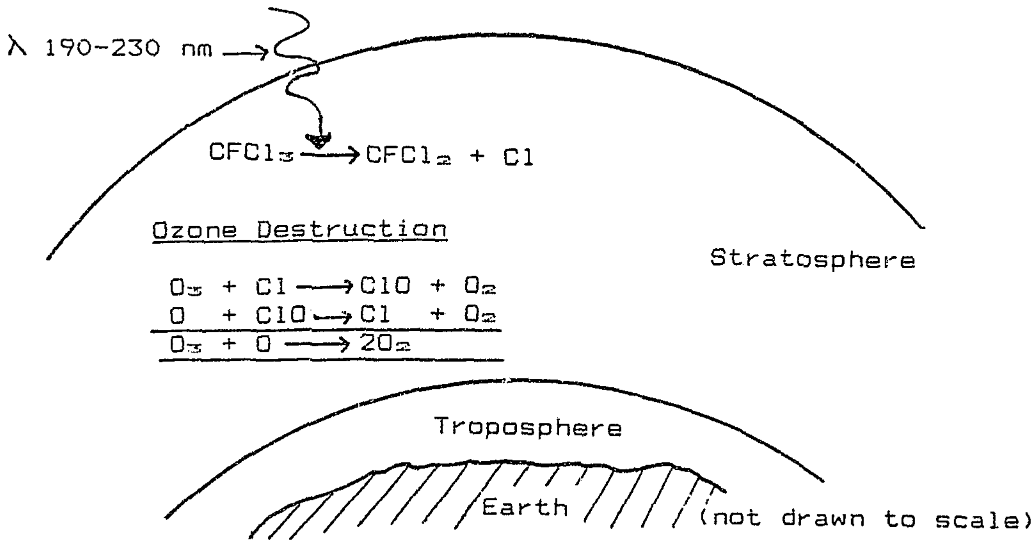
Rowland and Molina, at the University of California, also studied the behaviour of CFCs in the atmosphere. In 1974 they published a paper suggesting that CFCs were destroying ozone in the stratosphere. The chemical inertness of the CFCs (one of the most attractive features of these compounds) allows them to remain unreacted in the atmosphere for a long time (up to 150 years). They are carried by upward movements of the troposphere and slowly (it can take 10 years!) drift through the tropopause into the stratosphere. Once in the stratosphere the CFCs can be rapidly spread around the globe by the strong horizontal winds in the stratosphere. There these normally unreactive CFC molecules become exposed to high energy ultraviolet radiation. A photochemical reaction takes place in which absorption of high energy ultraviolet radiation breaks C-Cl bonds in the molecules releasing chlorine atoms.

eg. $$CFCl_3 \xrightarrow{UV,\ \lambda\ 190-230\ nm} CFCl_2 + Cl$$

$$CF_2Cl_2 \xrightarrow{UV,\ \lambda\ 190-230\ nm} CF_2Cl + Cl$$

The chlorine atoms (radicals) are highly reactive. They can enter into a chain reaction in which a single chlorine atom destroys 100 000 molecules of ozone before being removed from the atmosphere for example as HCl.

Diagram Showing Stratospheric Ozone Depletion by CFCs eg $CFCl_3$



In this chain reaction, Cl atoms and ClO radicals are not used up since each species is remade in a complete cycle.

The work of Rowland and Molina was regarded as contraversial as there was no experimental evidence to support it. However in 1985 reports of a "hole" in the ozone layer over the South Pole revived interest in this theory. Since 1977, a British team of researchers, in Antarctica, under the leadership of Joseph Farman, had been monitoring the ozone concentration in the stratosphere using instruments raised by balloons. In the spring of 1982 readings taken from a balloon showed an alarming decrease in the ozone concentrations in the stratophere over Antarctica. However these findings were not substantiated by readings taken by the American Nimbus 7 space satellite that had also been monitoring the ozone concentrations since 1978. Initially Farman ascribed his findings to experimental error but readings taken at another station 1600 km away confirmed his results. Farman felt sure he was correct and published his findings in 1985. His paper caused the American scientists to re-examine the data from the Nimbus satellite with some embarrassing results! The Nimbus had recorded figures matching those of the British team, but the computers had been programmed to reject any findings that "fell out of the parameters of credibility" and so these readings of low ozone concentration had been stored by the computers aboard the Nimbus as "erroneous data"! This is now regarded as one of the greatest "scientific misses" of recent times.

The phrase "Antarctic ozone hole" became much used as a result of these experimental findings. The term "hole" is misleading as the "hole" is not really a hole but rather an area of very reduced concentration of ozone.

The Impact of Geographical Features on Ozone Depletion

Observations made by scientists seem to suggest that the reduction in ozone concentration is worse over the South pole than over the North Pole and that this reduction is more pronounced every second year. Explanations for these findings can be found in the geographical features of the Antarctic. It is a roughly circular continent and a system of extremely strong winds, called the "polar vortex", circles this continent each winter sealing off the Antarctic stratosphere. Ice crystals form in the stratosphere forming a catalytic surface for the reaction of ozone with CFCs which have accumulated during the previous summer.

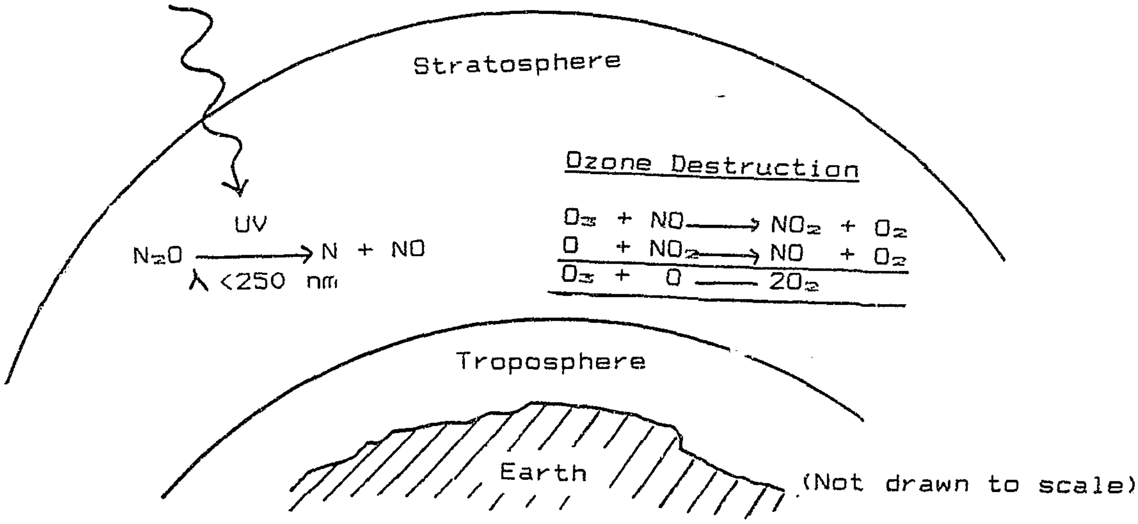
Greatest ozone depletions have been reported over Antarctica for 1987 and 1989. An explanation offered for this is that a delayed breakdown of the polar vortex in the Spring, following a winter of great ozone depletion, results in a reduced inflow of CFCs. Thus the destruction of ozone the following winter will not be so great.

A similar reduction of ozone over the Arctic does not occur because the continental structure is not the same as that of the Antarctic. (The Antarctic continent is roughly circular. The continents that make up the Arctic are not so regularly shaped.) The northern winter polar vortex is not as well-developed as that of the South Pole. It is more easily disrupted by warm air masses and so does not seal off the Arctic stratosphere as effectively as does the polar vortex in the south.

Other Species causing Ozone Depletion

Dinitrogen oxide (also termed nitrous oxide), N_2O, is a gas generated naturally by bacteria in the sea and soil. However the concentration of this gas in the atmosphere is increasing because of the increasing use of nitrogen-rich fertilisers. It is a relatively inert gas with a life-span of approximately 100 years in the atmosphere. Dinitrogen oxide, too, slowly moves from the troposphere into the stratosphere. There, in a similar way to that of the CFCs, it is decomposed. A photochemical reaction occurs because the N_2O molecules absorb ultraviolet radiation with a wavelength $<$ 250 nm. They dissociate to produce a nitrogen atom and a nitrogen monoxide, NO molecule. The nitrogen monoxide becomes involved in a chain reaction with ozone in a very similar way to the CFCs.

Diagram Showing Stratospheric Ozone Depletion by Dinitrogen Oxide



In the chain reaction NO is not used up in the reaction as it is remade in a complete cycle.

Supersonic aircraft, such as the Concorde, were designed to fly in the stratosphere. The exhaust gases of these aircraft contain nitrogen oxides, NO_x. If we look at the reactions represented above we can appreciate the dangers of introducing nitrogen oxides directly into the stratosphere. For this reason the Concorde flies at a lower altitude and measures have been taken to reduce the nitrogen oxide emissions in the exhaust gases.

Consequences of Reducing the Concentration of Ozone in the Stratosphere

The depletion of stratospheric ozone could result in an increased intensity of high energy ultraviolet radiation with wavelengths 220 - 330 nm reaching the surface of the Earth. This could result in the following:

a) An increase in skin cancer.
People with black skins should not be affected but those with lighter skins could be affected. The reduced ozone concentration, detected in the stratosphere over southern Australia and New Zealand in recent years, has resulted in people being warned at times not to remain in the sunlight for periods longer than 15 minutes without protection.

b) An increase in the incidence of cataracts of the eye.

c) A disruption in the processes of photosynthesis and a consequent reduction in crop yields.

d) Damage to the plankton in the sea, thus disrupting important food chains and destroying a means of removing carbon dioxide from the atmosphere.

The Montreal Protocol and the changes in the use of supersonic jets are representative of measures being taken to curb some of the air pollutants that could contribute to the depletion of stratospheric ozone. Our awareness of the problem is only possible because of the scientific and technological skills which have been developed enabling trace components of the atmosphere to be monitored and their concentrations measured. Chemists are able to identify the species involved in and the mechanisms of reactions taking place in the atmosphere. Physicists and space scientists, by means of instruments raised aboard balloons and satellites, are able to study the complex problems in an increasingly accurate manner. The pooling of findings from these disciplines, and those of geography and climatology etc, should result in a deeper understanding of these problems and the creation of improved solutions in the future.

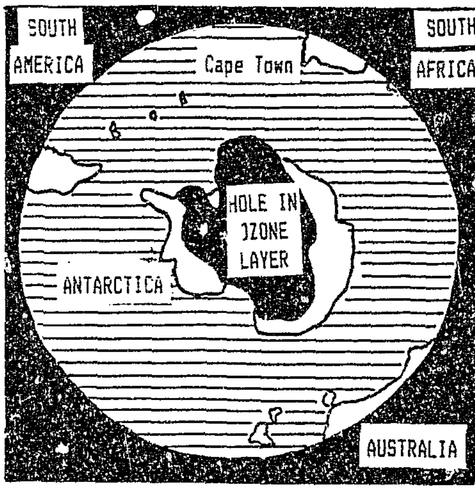
Learning Objectives for Unit 4

On completion of this unit students should be able to:

4.1 Briefly describe the absorption by the atmosphere of most of the harmful, high energy, solar radiation reaching the atmosphere.
4.2 Explain the phrase a photochemical reaction.
4.3 Write equations showing the formation of ozone in the stratosphere.
4.4 Sketch a graph showing the variation of ozone concentration with altitude in the atmosphere.
4.5 Briefly explain the origin of ozone in the troposphere.
4.6 Write an equation showing the photochemical reaction which occurs when ozone absorbs solar radiation.
4.7 Explain the significance of the reaction given in 4.6 in relation to the absorption of solar radiation of wavelengths 220 - 330 nm.
4.8 Describe the maintenance of a steady state concentration of ozone in the stratosphere for millions of years in the past.
4.9 Explain the effect of air pollutants such as chlorofluorocarbons (CFCs) and dinitrogen oxide (N_2O) when they reach the stratosphere.
4.10 Write equations showing the photochemical chain reactions of CFCs and dinitrogen oxide with ozone in the stratosphere.
4.11 Explain the threat these chain reactions pose for the ozone in the stratosphere.
4.12 Describe briefly the properties of CFCs that have made their use as refrigerant gases, solvents, propellants and blowing agents so widespread.
4.13 Describe briefly some of the consequences of ozone depletion in the stratosphere.
4.14 Explain the meaning of the phrases "hole in the ozone" and "ozone layer".
4.15 Discuss the view that science is a human activity - errors can be made and progress is achieved through communication of ideas.
4.16 Describe briefly the roles of the scientific, industrial and technological sectors in monitoring air pollutants and adopting measures to address the problem of stratospheric ozone depletion.

Worksheet 4(a) "Is there a Hole in the Sky?"

Diagram showing "Ozone Hole" over Antarctica



Read the following passage (which is an adaptation of an article appearing in the "Femina", January 1991). Then answer the questions that follow: (You will not find the answers in the passage)

"When the hole in the ozone is largest over Antarctica, South Africa has its highest concentrations of ozone present. As the hole over Antarctica decreases in size, the concentration of ozone over South Africa decreases. This is the opposite of what we would expect!" These are statements made by Greg Bodeker, a researcher at the University of Natal's Space Physics Research Unit.

Most of the world's ozone is produced in the atmosphere above the equator, after which it flows southward towards the South Pole and northwards towards the North Pole. But during winter, climatic conditions at the South Pole produce a polar vortex over the Antarctica which stops the ozone from reaching it. As a result, a ridge of ozone rich air builds up around this vortex - and spills over onto South Africa. Cape Town is closer to this ozone ridge than Durban, which is closer than Pretoria, and so on.

Ozone concentration in the ridge is highest during October but begins to break down during November, until it reaches its lowest concentration in May. Spring is then the best time for South Africans to indulge in outdoor activities. By late summer ozone concentrations are dangerously low and only begin to pick up in midwinter.

Countries further south don't have the benefit of this ozone ridge. Australia, New Zealand and parts of South

America are suffering visible effects of the widening ozone hole, and lifestyles are being drastically altered. In Chile, fish, rabbits and sheep are being blinded by the effects of the hole. Tree buds are showing deformed growth and certain types of marine algae are secreting a red pigment never seen before. Already Australia has the highest rate of skin cancer in the world and South Africa is not far behind.

Industry is usually targeted whenever environmental foot dragging occurs, but local manufacturers are to be commended. Ian Macdonald, chairman of the Wildlife Society of Southern Africa's Ozone Assessment Board, says that South African industry has been exemplary in the way in which it's responding to the problem."

Questions

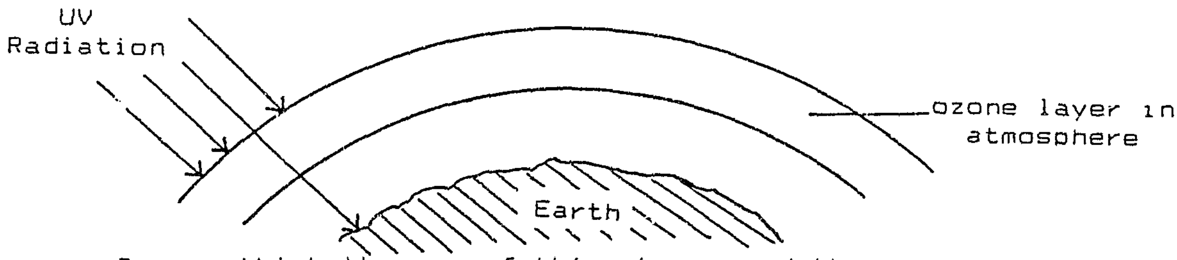
Please answer on a separate sheet of paper.

1. What is ozone?

2. In which region of the atmosphere is the ozone referred to in the diagram (and discussed in the article) to be found?

3. (i) How is the ozone produced in the region of the atmosphere identified in 2 (above)? (Include any equations you think are relevant.)
   (ii) Why is "most of the ozone produced in the atmosphere above the equator"?

4. The phrase "ozone layer" is used in the diagram at the start of this worksheet.
   Sometimes this "ozone layer" is shown like this:



   Do you think the use of this phrase and the representation as shown in the diagram could be misleading?
   Explain your answer and if you agree that the use of this phrase and representation are misleading suggest alternative descriptions.

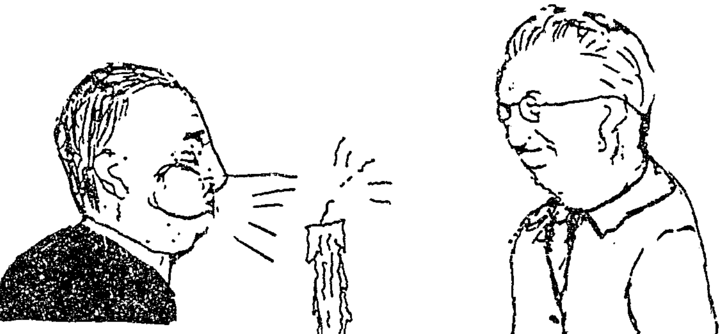
5. Is there "a hole in the sky"?
   Explain your answer fully.
   (Include a discussion of human activities and substances that are contributing to the"hole", in your answer.)

6. (i) What is the "polar vortex" mentioned in the passage?
   (ii) What is the "ozone ridge" discussed in the article?

7. Why is the "hole in the sky" producing the effects such as blindness in animals, damage to vegetation and changes in algae found in the sea?

8. How has industry responded to the problem of the "hole in the sky"?

Worksheet 4(b) "Saint or Serpent?"

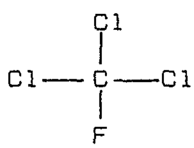


Thomas Midgley discovered ways of using CFCs. At a meeting of the Society of Chemical Industry in 1937, he dramatically demonstrated his faith in CFCs. He filled his lungs with a gaseous CFC, exhaled and extinguished a burning candle!

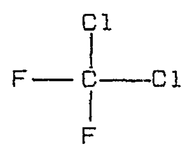
Questions

Please answer on a separate sheet of paper.

1. (i) What are CFCs?
   (ii) Write the *molecular* formulae of two of the most commonly used CFCs:



CFC-11



CFC-12

2. What properties of these compounds was Midgley demonstrating by his actions?

3. What use did Midgley foresee for these compounds?

4. What was the problem with the refrigerant gases used at that time?

5. Why are CFCs posing serious problems as air pollutants?

6. A scientific author has posed the question:
   "Was Midgley a saint or serpent?"
   Discuss this question.

Worksheet 4(c) Science as a Human Activity.

Read the following passage:

The first indications that CFCs could cause air pollution problems came when James Lovelock, a British chemist, detected the presence of CFCs in the atmosphere in the Southern Hemisphere - far from the major release points in the Northern Hemisphere. This finding seemed to indicate the molecules of CFCs did not react in the atmosphere and were dispersed over the globe.

Rowland and Molina, at the University of California, also studied the behaviour of CFCs in the atmosphere. In 1974 they published a paper suggesting that CFCs were destroying ozone in the stratosphere. The chemical inertness of the CFCs (one of the most attractive features of these compounds) allows them to remain unreacted in the atmosphere for a long time (up to 150 years). They are carried by upward movements of the troposphere and slowly (it can take 10 years!) drift through the tropopause into the stratosphere. Once in the stratosphere the CFCs can be rapidly spread around the globe by the strong horizontal winds in the stratosphere. There these normally unreactive CFC molecules become exposed to high energy ultraviolet radiation. A photochemical reaction takes place in which absorption of high energy ultraviolet radiation breaks C-Cl bonds in the molecules forming chlorine atoms.

eg.
$$CFCl_3 \xrightarrow{UV,\ \lambda\ 190-230\ nm} CFCl_2 + Cl$$

$$CF_2Cl_2 \xrightarrow{UV,\ \lambda\ 190-230\ nm} CF_2Cl + Cl$$

The chlorine atoms (radicals) are highly reactive. They can enter into a chain reaction in which a single chlorine atom destroys 100 000 molecules of ozone before being removed from the atmosphere for example as HCl.

The work of Rowland and Molina was regarded as controversial as there was no experimental evidence to support it. However in 1985 reports of a "hole" in the ozone layer over the South Pole revived interest in this theory. Since 1977, a British team of researchers, in Antarctica, under the leadership of Joseph Farman, had been monitoring the ozone concentration in the stratosphere using instruments raised by balloons. In the spring of 1982 readings taken from a balloon showed an alarming decrease in the ozone concentrations in the stratosphere over Antarctica. However these findings were not substantiated by readings taken by the American Nimbus 7 space satellite that had also been monitoring the ozone concentrations since 1978. Initially Farman ascribed his findings to experimental error but readings taken at another station 1600 km away confirmed his results. Farman felt sure he was correct and published his findings in 1985. His paper caused the American scientists to re-examine the data from the Nimbus satellite with some embarrassing results! The Nimbus had recorded figures matching those of the British team, but the computers had been programmed to reject any findings that "fell out of the parameters of credibility" and so these readings of low ozone concentration had been stored by the computers aboard the Nimbus as "erroneous data"! This is now regarded as one of the greatest "scientific misses" of recent times.

Instructions

Discuss the statements given below using information from the passage to illustrate your answers.
Please write your answers on a separate sheet of paper.

1. "Scientific theories are based on the work of one scientist".

2. "The significance of ideas proposed by scientists is always immediately apparent".

3. "Scientists studying the same problem always reach the same conclusions."

4. "Scientists know instinctively what observations will be important."

5. "With modern highly developed instruments errors do not occur."

Solutions to Worksheets for Unit 4

Worksheet 4(a) "Is there a Hole in the Sky?"

1. Ozone is a gas found in small quantities in the atmosphere (particularly the stratosphere). Its chemical formula is O_3.

2. Stratosphere.

3. (i) Oxygen absorbs high energy solar radiation penetrating the stratosphere, and causes oxygen atoms to form.

$$O_2 \xrightarrow{hv,\ \lambda < 230\ nm} 2O$$

(A photochemical reaction)

The oxygen atoms react with oxygen molecules to form ozone molecules.

$$O + O_2 \longrightarrow O_3$$

(ii) This is the region of the atmosphere where the intensity of the Sun's radiation (necessary for the photochemical reaction given in (i) above) is the greatest.

4. It could be a misleading representation. The diagram implies that the layer is composed only of ozone. The representation almost implies the layer is solid. However the "layer" is simply a region of the atmosphere where the ozone concentration is its greatest. This is still a very small concentration ($\backsim$10 ppm) and ozone is mixed with other atmospheric gases found in the stratosphere.

5. There is not a hole in the sky! The ozone in the stratosphere is being destroyed faster than it is being produced. This is causing a reduction in the concentration of ozone in the stratosphere. CFCs (used in aerosols, fridges, as blowing agents in polystyrene and foam) and dinitrogen oxide, N_2O (generated by fertilisers used in agriculture) are causing the reduction in the ozone concentration in this region of the atmosphere. CFCs and dinitrogen oxide are normally unreactive in the troposphere but become reactive in the stratosphere in the presence of high energy solar radiation (λ < 230 nm) which penetrates this region.

Equations follow on next page.

eg.

$$CFCl_3 \xrightarrow{hv,\ \lambda < 230\ nm} CFCl_2 + Cl$$
$$O_3 + Cl \longrightarrow ClO + O_2$$
$$O + ClO \longrightarrow Cl + O_2$$
$$\overline{O_3 + O \longrightarrow 2O_2}$$

OR

$$N_2O \xrightarrow{hv,\ \lambda < 250\ nm} N + NO$$
$$O_3 + NO \longrightarrow NO_2 + O_2$$
$$O + NO_2 \longrightarrow NO + O_2$$
$$\overline{O_3 + O \longrightarrow 2O_2}$$

6. (i) This refers to the extremely strong winds which encircle Antarctica and prevent mixing of the atmosphere above Antarctica and the surrounding atmosphere.
   (ii) The "ozone ridge" is a region of increased ozone concentration in the stratosphere.

7. Ozone absorbs radiation in the region λ 220-330 nm. This radiation (called UV or ultraviolet radiation) is harmful to life. Ozone in the stratosphere absorbs and prevents most of this solar radiation reaching the troposphere. The reduced concentration of ozone in the stratosphere is resulting in more of this radiation reaching the Earth's surface. This radiation damages life eg vegetation, algae etc.

8. Many of the world's producers of CFCs (including RSA). have signed an agreement, "The Montreal Agreement". This agreement plans to reduce and finally stop manufacturing CFCs. These substances will and are being replaced by other substances which do not react with ozone.
   The Concorde, a supersonic jet, does not fly at the altitude intended because of the damaging effects of NO_x gases released from its exhaust. These NO_x gases would react with the ozone.

Worksheet 4(b) "Saint or Serpent?"

1. (i) CFCs are compounds whose molecules contain carbon, fluorine and chlorine atoms.
   (ii) CFC-11, $CFCl_3$ CFC-12, CF_2Cl_2

2. He demonstrated that CFCs extinguished flames (or were unreactive) and that CFCs were non-toxic.

3. He foresaw their use as refrigerant gases.

4. They were toxic and caused serious hazards when they leaked from refrigerators. They corroded (reacted with) the material used for the pipes in the refrigerators. Gases eg ammonia and sulphur were used.

5. CFCs are unreactive in the troposphere. They slowly drift up to the stratosphere. There, in the presence of high energy solar radiation, they react (a photochemical reaction). A chlorine atom is released from a CFC molecule and this chlorine atom is capable of destroying 100 000 ozone molecules.

6. Midgley discovered the use of lead compounds in petrol to improve the combustibility of petrol. He also discovered the use of CFCs as refrigerant gases. These seemed excellent ideas at the time. Hence Midgley can be called a "saint". However with time, the air pollution consequences of the lead compounds in petrol and the CFCs have become apparent. Therefore Midgley can be called a "serpent"!

Worksheet 4(c) Science as a Human Activity.

1. This statement is not necessarily true.
   Scientific theories represent "team work" (or the work of a number of people). For example, in this article, Lovelock, Rowland, Molina, Farman and scientists using the Nimbus satellite, were all involved in developing the theory of ozone destruction.

2. No.
   Sometimes the work of scientists does not seem immediately significant. Its importance only becomes apparent later. For example, the work of Rowland and Molina was not immediately recognised as being significant.

3. This statement is not necessarily true.
   Farman and the scientists working with the Nimbus satellite did not come to the same conclusions when monitoring ozone concentrations in the stratosphere over Antarctica.

4. This statement is not necessarily true.
   The Amercian scientists decided to ignore readings of very small ozone concentrations taken by the Nimbus satellite and regarded them as "erroneous data".

5. This is not true.
   Errors (caused by the "human factor") were made with the Nimbus satellite.

UNIT 5

Smog

Introduction to Unit 5

Aerosols are solid particles or droplets of liquid which are too small to drop out of the air. In the atmosphere they may reduce visibility and create hazards for air, water and land traffic. Some of these aerosols form as a result of weather conditions. For example <u>mist</u> consists of very small droplets of water (radius of less than 1μm or 1 x 10^{-6} m) suspended in the air. <u>Fog</u> is a suspension of larger droplets of water (radius 1μm - 10μm) in the air.

However some aerosols not only reduce visibility but also present health hazards and damage vegetation and materials. Air pollutants, sometimes in combination with mist or fog, may give rise to these aerosols. The term <u>smog</u> was coined in 1905, to describe the combination of smoke and fog. Nowadays this term is used to describe any smoky or hazy pollution of the atmosphere. The composition of smog and its effects depend on the type of activity causing the air pollution. Smog is an urban problem. In addition the weather and geography of the area play significant roles. Broadly speaking there are two main categories of smog. These two types of smog are named after the cities in which they were first experienced and studied. They are:

A. The London-type Smog or Classical Smog.
B. The Los Angeles-type Smog or Photochemical Smog.

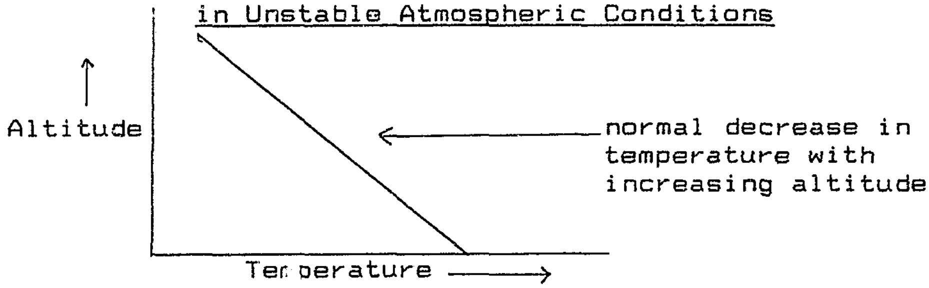
A. <u>The London-type Smog or Classical Smog</u>

In 1952 a tragic air pollution episode occurred in London. A thick smog hung over the city for 5 days. People coughed, tears streamed down their faces from irritated eyes. Traffic came to a standstill because drivers could not see. Large particles of ash, soot and other pollutants fell to the streets or into houses. People poured into hospital - in particular the elderly or those with pre-existing heart and respiratory problems. More than 4 000 people died and many more became seriously ill. This episode probably resulted because of the size of the city and the scale of industrialisation at a time when no air pollution control measures were in operation. Large quantites of smoke and soot had been released into still, moist, foggy air over the city. The smoke had a high sulphur dioxide content. (British coal has a high sulphur content.) Sulphur dioxide is itself a respiratory irritant. Below concentrations of 25 ppm the irritation is confined to the upper respiratory tract. If soot particles are present the sulphur dioxide is absorbed onto soot particles. The lower respiratory tract becomes affected if these particles are inhaled.

The weather conditions played an important role in the formation of this smog. In normal conditions the air near the surface of the Earth is warmer than the air above it. The warmer air is less dense and rises to higher altitudes.

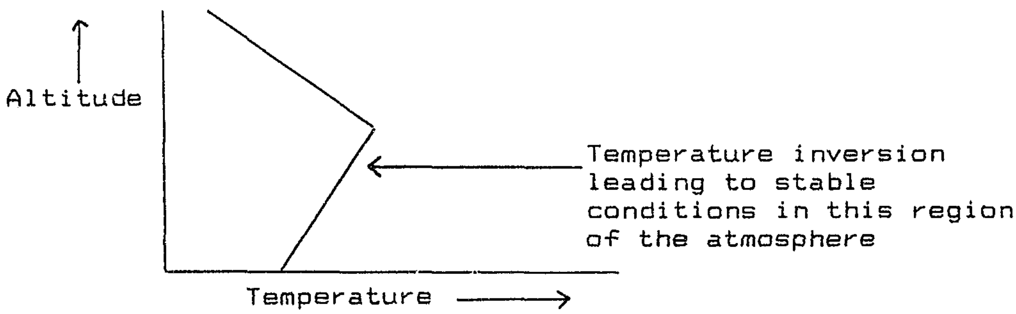
Cooler more dense air replaces it. These convection currents cause the turbulence that is a feature of the troposphere. Under these conditions the air is referred to as being unstable. Air pollutants emitted into unstable atmospheric conditions are rapidly dispersed and diluted in the troposphere.

Graph showing the Variation of Temperature with Altitude in Unstable Atmospheric Conditions



Sometimes, however, a layer of cold air occurs near the surface of the Earth and the temperature of the troposphere increases with altitude. (This is called a temperature inversion, as the trend is the reverse of the normal one.) The cold air near the ground is more dense than the warm air above. Thus very little up and down movement of the air occurs. Under these conditions the air is referred to as being stable. Air pollutants released into stable atmospheric conditions are not dispersed.

Graph showing a Variation in Temperature with Altitude Leading to Stable Atmospheric Conditions



The smog in London formed under these stable atmospheric conditions, brought about by a temperature inversion as shown in the graph above.

London-type smog is likely to occur on a cold (temperature below 10 °C), foggy day or during cold nights. This type of smog clears as the temperature of the troposphere increases.

To control the air pollution giving rise to this smog, strict measures were introduced. Controls were placed on the type of fuel burnt, and the smoke emitted. Only "smokeless" fuels were allowed to be burnt in urban areas. These measures have avoided similar serious episodes of such air pollution occurring again in London.

B. Los Angeles-type or Photochemical Smog

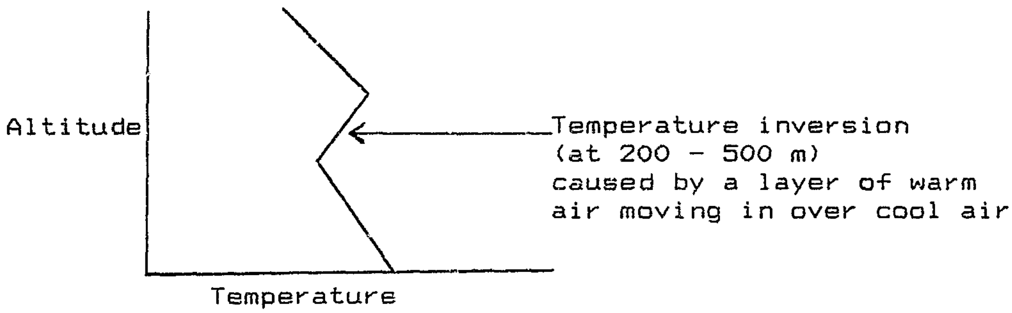
The ill effects of air pollution were first noted in Los Angeles in the 1940s. A brown haze that irritated the eyes, nose and throat appeared in the air. Crops and materials such as rubber were damaged. The occurrence of this haze (smog) was puzzling as Los Angeles has no major industries. However it does have many motor vehicles and lots of sunshine!

The brown haze (smog) was a suspension of small solid particles and small droplets of liquid in the air - an aerosol. This aerosol reduced visibility. The explanation for the formation of this smog was provided in 1952 by a chemist, A.J. Haagen-Smit. He was attempting to isolate the main ingredient of pineapple odour. Working on a smoggy day he detected a greater concentration of ozone in his experiment than is normally found in unpolluted tropospheric air. (The natural concentration of ozone in the troposphere is approximately 0,04 ppm. This ozone originates in the stratosphere (Unit 4) and is slowly transferred across the tropopause and into the troposphere. Ozone cannot be formed in the troposphere in the same way in which it is formed in the stratosphere, because most of the solar radiation with wavelengths less than 290 nm does not reach the troposphere (Unit 4)).

Haagen-Smit delayed his research to find the reason for this increase in ozone concentration. His study led him to realise the significance of the role played by sunlight (with a wavelength greater than 290 nm) in the formation of this type of smog. He coined the term photochemical smog. The energy from solar radiation initiates a series of reactions which lead to the formation of this type of smog. (Refer to Unit 1 for background on photochemical reactions). Thus in contrast to London-type smog, photochemical smog forms on sunny days with a temperature of more than 24°C. The formation of the smog ceases when the sun sets and the temperature decreases.

In addition the geographic and the climatic conditions of Los Angeles play their role. The geography of the Los Angeles district is such that the region can be compared to a giant "reaction vessel". The floor of the valley, and the mountains on three sides form most of the walls of the "vessel". The valley is open to the sea and a prevailing wind blowing in from the sea provides the remaining "wall" of the "vessel". Frequent temperature inversions, at an altitude of 200-500 m, effectively "trap" the polluted air in this "vessel". These temperature inversions form when a layer of warm (less dense) air blows in and overlies a layer of cooler air. This gives rise to stable atmospheric conditions with very little mixing of the air. Thus air pollutants are not dispersed and diluted. In Los Angeles such temperature inversions occur approximately 320 days a year!

<u>Graph showing the Variation of Temperature with Altitude in Temperature Inversions in Los Angeles</u>



Some of the components of exhaust gases (primary air pollutants) released into the atmosphere by the large number of motor vehicles are the reactants in the photochemical reaction. The reaction gives a complex mixture of products (secondary air pollutants) which in turn form the smog.

Although the situation in Los Angeles has been discussed in detail, photochemical smog is becoming an increasing problem in many cities throughout the world. In South Africa with our plentiful sunshine, increasing numbers of motor vehicles and frequent temperature inversions (for example during the Highveld winters), photochemical smog is of growing concern.

Let us take a closer look at the chemistry involved in the formation of photochemical smog. The reactions taking place are complex. (For example more than 100 different hydrocarbon compounds may be detected in a sample of polluted city air.) We will attempt to simplify the reactions taking place and highlight some of the main features. The reactions may be summarised as follows:

Some components of car exhaust gases + oxygen

$\downarrow$ sunlight

photochemical smog

ie. $C_aH_b(g) + CO(g) + NO_x(g) + O_2 \xrightarrow{\text{sunlight}} C_aH_yO_z(g) + O_3(g) + CO_2(g) + H_2O(g) + NO_x(g)$

(This equation is not balanced)

The exhaust gases (primary air pollutants) contain many of the products of combustion of petrol (Unit 3). Hydrocarbon compounds (C_aH_b) are released as a result of incomplete combustion and leakages from the fuel systems of motor vehicles. Carbon monoxide is also a product of incomplete combustion. At the high temperatures present in parts of the engine, the nitrogen and oxygen in the atmosphere combine to form nitrogen oxides, NO_x. One of these oxides is a brown gas, nitrogen dioxide, NO_2.

Organic compounds (eg.$C_aH_yO_z$), ozone and nitrogen oxides are secondary air pollutants which form the smog. These secondary pollutants cause the irritation, health hazards and damage to vegetation and materials.

The photochemical smog reaction begins when some of the photons from the sunlight initiate the dissociation of nitrogen dioxide molecules into nitrogen monoxide molecules and oxygen atoms. Nitrogen dioxide molecules absorb a wide range of wavelengths of visible and ultraviolet radiation penetrating the lower atmosphere.

$$NO_2 \xrightarrow[\lambda < 430 \text{ nm}]{\text{sunlight}} NO + O$$

The oxygen atoms produced react with the oxygen molecules in the atmosphere to produce ozone.

$$O_2 + O \longrightarrow O_3$$

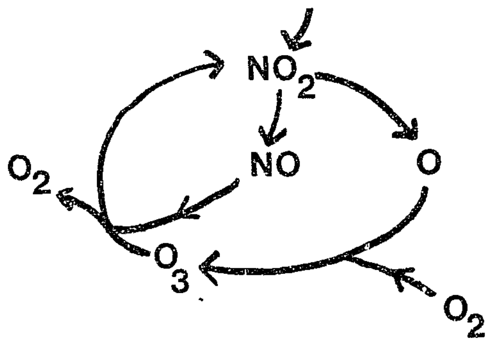
The nitrogen monoxide molecules formed can react with ozone molecules to reform NO_2 molecules.

$$NO + O_3 \longrightarrow NO_2 + O_2$$

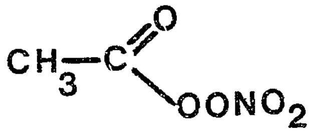
Thus nitrogen dioxide can participate in both the production and destruction of ozone.

These reactions collectively form a cycle. The net effect of this cycle is the recycling of NO_2 and, were it not for competing reactions which interfere with this cycle the concentrations of NO, NO_2 and ozone would not change. A steady state would be reached in which they would form at the same rate as they are destroyed.

Cycle



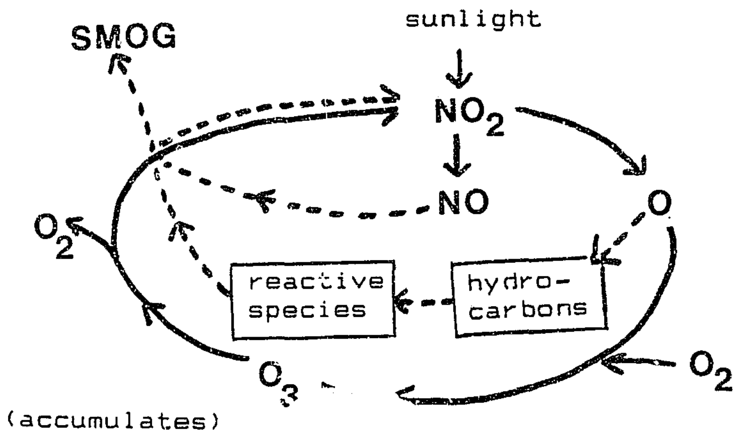
However competing reactions occur involving the hydrocarbons which are emitted from the same source (the exhaust) as NO_x. The cycle is disrupted because hydrocarbons readily react with the oxygen atoms produced. In addition the hydrocarbons can react with the ozone. The products of such reactions are very reactive and react with the nitrogen monoxide giving rise to compounds such as



These compounds are collectively called PAN. The structural formula above represents peroxyacetylnitrate.

The consequence of this is that with NO removed from the cycle the normal mechanism for the destruction of ozone has been eliminated and the concentration of ozone in the air increases.

Diagram Showing the Involvement of Hydrocarbon Compounds in the Nitrogen Dioxide Cycle



As a result of the complex series of reactions that take place in the formation of photochemical smog, many other organic compounds such as aldehydes and ketones are formed. Many of these are irritants and health hazards. The composition of photochemical smog formed in different regions of the world, varies. This is because of differences in concentrations of air pollutants, differences in climatic conditions and differences in the duration of the smog.

In the discussion of photochemical smog, motor vehicles have been highlighted as a source of hydrocarbon compounds which when released into the atmosphere are air pollutants. However there are other sources which also release these compounds into the atmosphere:

a) Petroleum
During the refining of petroleum a complex mixture of hydrocarbons may be released into the atmosphere. Hydrocarbons are also released during transport and storage processes.
b) Combustion
Hydrocarbons are produced during the combustion of coal for heating or power generation and during the combustion of wood as a fuel or in forest fires.
c) Household Products
Hydrocarbons are found in many volatile household products eg. hair spray, spray paint, cigarette lighters, oil-based paints, paint thinners and solvents etc.

The Effects of the Components of Photochemical Smog

a) Ozone
Ozone in the stratosphere is beneficial as it absorbs solar radiation that would be harmful to life (Unit 4). We don't have any direct contact with that ozone. However we do have contact with ozone in the troposphere. Ozone is a very reactive substance - it is an oxidising agent and is toxic.
Ozone can affect:
   i) Human Health
   Ozone can cause a variety of symptoms depending on the exposure time, the concentration of the ozone and the health of the individual. Asthmatics are adversely affected by ozone concentrations of 0,25 ppm. At concentrations of between 0,25 and 0,3 ppm healthy individuals develop headaches, chest pains and coughs. Concentrations of more than 50 ppm for an hour, may prove fatal.
   ii) Vegetation
   Plants are more sensitive than humans to increased ozone concentrations. Concentrations as low as 40 ppb can cause damage. In fact damage to plants was one of the earliest observed effects of photochemical smog. Ozone bleaches leaves and burns the tips of trees such

as pine. It is believed that reaction with ozone removes calcium and magnesium ions from dissolved salts in the leaves of plants. This has far reaching effects on plant metabolism and can lead to the death of the plant. It is now thought that damage to trees in parts of America and Europe is caused by increased tropospheric ozone concentrations and not only acid rain as previously thought. However the problem is complex and not yet fully understood. Factors such as climate, acid rain, fog, ozone and loss of soil nutrients all contribute to tree damage. It may be factors like this which are causing the observed damage to pine plantations in the Eastern Transvaal. (It should be noted, however, that over densely forested areas, on warm, sunny days a haze is observed. This is the result of a reaction between terpenes (a type of hydrocarbon compound) which are released naturally from vegetation and the naturally low concentrations of ozone in the troposphere.)

iii) Materials

Ozone causes large economic costs because of the damage it causes to materials such as plastics, dyes, paints and rubber. This "damage" is a chemical reaction between ozone and these materials. The damage to rubber was an early technique used by Haagen-Smit to estimate the concentration of ozone in the air in Los Angeles. In regions regularly experiencing photochemical smog, damage to car tyres is more significant than mechanical wear.

iv) Global Warming

Ozone absorbs infrared radiation and is termed a "greenhouse" gas (Unit 6). Increased concentrations of this gas in the troposphere contribute to the possible problem of global warming.

b) Organic Components of Photochemical Smog

PANs cause respiratory irritation and intense irritation of the eyes. They also damage the leaves of plants causing "bronzing" of the leaves. This can lead to significant loss in crop yields.

Other organic compounds present in photochemical smog are carcinogenic.

The Control of Photochemical Smog

Photochemical smog consists largely of secondary air pollutants and so control measures seek to restrict the release into the atmosphere of the primary air pollutants which give rise to the smog. These measures include the following:

1. Stricter controls on the industrial emissions of hydrocarbons and nitrogen oxides.
2. Improvements in the combustion efficiency of motor vehicle engines.

3. Reducing the numbers of motor vehicles on the road by encouraging the use of public transport.
4. The use of devices such as catalytic converters to reduce some exhaust gases from motor vehicles. The situation is complex, however, as this also reduces the concentration of nitrogen oxide which plays an important role in reducing ozone concentrations.

The problem of smog is complex. An increase in the public awareness of the nature of the problem could result in a willingness to co-operate in finding solutions to this issue.

Learning Objectives for Unit 5

On completing this unit students should be able to:

5.1 Explain the meaning of the terms aerosol, mist, fog and smog.
5.2 Describe the origin of London-type or classical smog.
5.3 Describe the role played by weather conditions in the formation of classical smog.
5.4 Describe the composition and effects of classical smog.
5.5 Describe the measures taken to prevent classical smog from occurring.
5.6 Describe the origin of Los Angeles-type or photochemical smog.
5.7 Describe the role played by weather conditions in the formation of photochemical smog.
5.8 Describe the composition and effects of photochemical smog.
5.9 Describe measures taken to reduce the formation of photochemical smog.
5.10 Compare and contrast classical and photochemical smog with regard to origin, role played by the weather, composition and effects.
5.11 Explain that a component of the atmosphere eg, ozone, beneficial in the stratosphere is an air pollutant in the troposphere.

Worksheet 5(a) Looking into the Smog.

Task 1
Using the table given below, compare and contrast classical (London-type) smog and photochemical smog with respect to the headings given.

	Classical Smog	Photochemical Smog
Type of Environment Where it Occurs		
Physical Description		
Weather Conditions for Formation		
Weather Conditions for Clearing		
Source of Smog		
Components of Smog		
Effects		
Control Measures		

Task 2
Clarify this "confusion".

Worksheet 5 (b) "It's nice from far and far from nice."
Read this article which [illegible]ed in the Star in August 1991. Answer the questions that [illegible]:

Perilous highveld ozone trends

By Julienne du Toit

Ozone on the ground has tripled in the Johannesburg and Pretoria regions since the 1960s, but it is decreasing steadily 20 km up, according to a meteorologist at the Pretoria Weather Bureau.

Both trends are dangerous. Ozone high in the stratosphere protects the Earth from solar radiation, but at ground level it threatens health and crops — and ozone on the ground will never rise and replace the ozone in the stratosphere.

Mark Zunckel, who has been measuring the ozone in Irene, near Pretoria, for 2½ years, said he had found levels had risen to about 40 parts per billion.

International standards, which are used as guidelines in SA, state that above 120 parts per billion, ozone can cause respiratory ailments.

Ozone has a sweetish smell, and although it is present at ground level in minute quantities it is so corrosive that a whiff of pure ozone could kill almostly instantly.

In the Vaal Triangle, the ozone pollution levels have approached 120 parts per billion. And these levels were measured in winter, when ozone levels are usually low.

The levels would probably increase in summer, said Dr Petro Terblanche of the Medical Research Council, who is to release a report on the subject soon.

Greg Bodeker, who is doing his Masters thesis on global ozone depletion at the University of Natal, explained that an increase of ozone on the ground is caused by anything electrical — car spark plugs, electrical substations, even appliances with high voltages — which split up oxygen atoms. As free oxygen radicals they join up in unstable sets of three to form ozone.

Ozone is also produced by burning fossil fuels, which give off nitrogen oxides, and unburnt hydrocarbons. These react with each other to produce ozone.

Ozone damages lungs, and makes eyes itch, burn and water. It also lowers resistance to colds and pneumonia.

Ozone may be the main pollutant that damages plants and weakens some materials such as rubber.

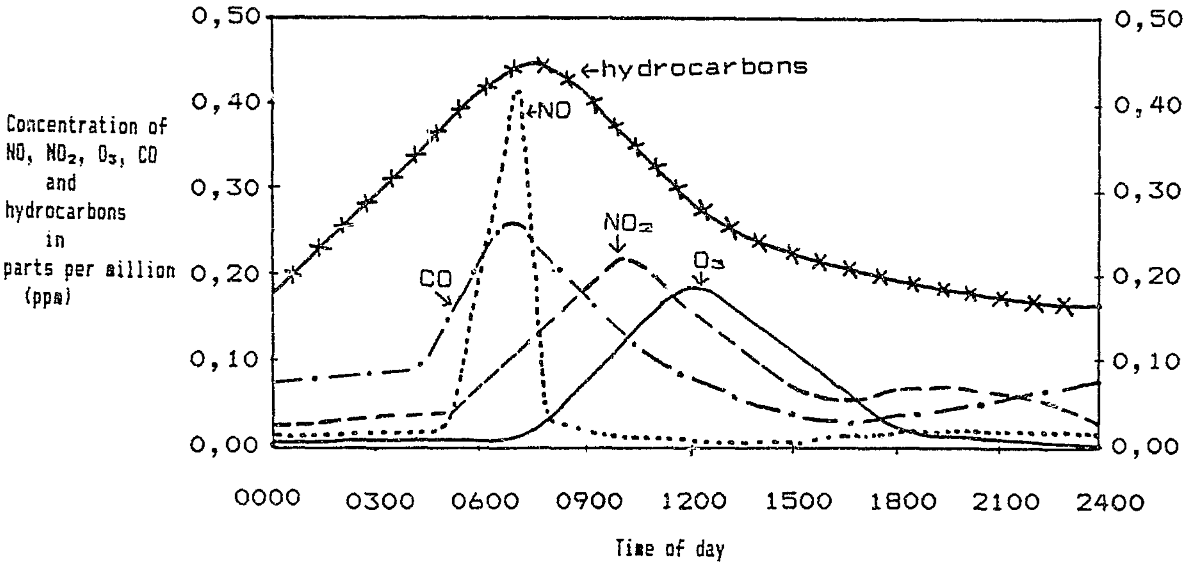
"It's nice from far and far from nice," said Mr Bodeker.

Questions
(Write your answers on a separate sheet of paper)

1. Explain the phrase "ozone on the ground".
2. Why does the author state that "ozone on the ground will never rise and replace ozone in the stratosphere"?
3. Why will the "level (concentration) of ozone probably increase in summer"?
4. A Masters student, Greg Bodeker, has identified many sources of "ozone on the ground". Describe these sources.
5. What is wrong with the phrase "....which split up oxygen atoms"?
6. The article states, "As free oxygen radicals they join up in unstable sets of three to form ozone"
   i) What are "free oxygen radicals"?
   ii) Replace the phrase "they join up in unstable sets of three" with a more scientifically correct description.
   iii) Represent the sentence quoted above, with a chemical equation or equations. (You may need to use ideas you gained while studying Unit 4: Ozone Depletion.)
7. Describe the effects of "ozone on the ground" as mentioned in the article.

Worksheet 5 (c) Interpreting Graphical Data

Look at the graph and then answer the questions posed.



Questions

Please write your answers on a separate sheet of paper.

1. i) At what time of day do the concentrations of hydrocarbons and nitrogen monoxide (NO) reach a maximum?
   ii) Explain why you think this happens.

2. Why does the concentration of NO reach a minimum when the the concentration of NO_2 reaches a maximum?

3. i) At what time of day does the concentration of ozone reach a maximum?
   ii) Why is this?

4. What substances are at mimimum concentrations when ozone is at a maximum concentration?

5. Which substances appear to be involved in the production of ozone in the polluted air?

6. Why do the NO and NO_2 concentrations increase towards evening?

7. Why does the ozone concentration decrease towards evening?

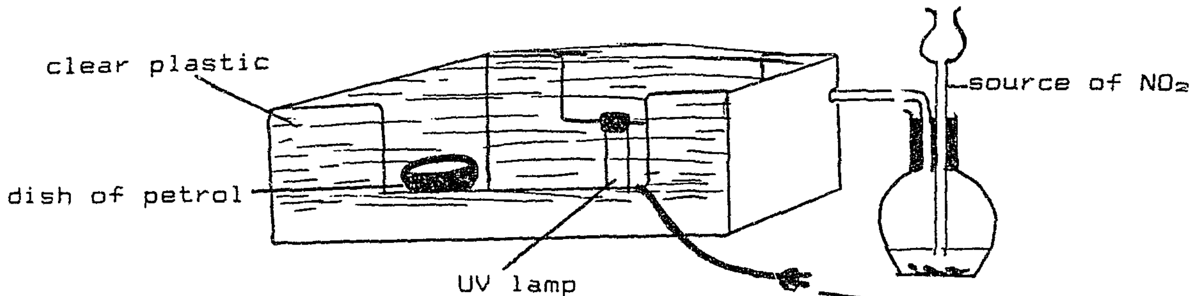
8. Reduced lung function can occur in normally healthy individuals at ozone concentrations of 0,1-0,3 ppm. Explain why many people would suffer respiratory problems on a day as shown in the graph.

Adapted from
Environmental Chemistry
by H.S. Stoker, S.L.Seager.

Worksheet 5 (d) Smog in a Box

Requirements
1 box (a bit bigger than a shoe box)
sheets of plastic
1 flat dish
1 tablespoon of petrol
1 ultraviolet lamp
source of NO_2 (copper filings and concentrated nitric acid)
A small amount of black paint and a paint brush (or line the inside of the box with black paper)
1 torch
2 inflated balloons
2 pieces of brightly coloured fabric

Diagram of Apparatus



Method
1. Cut out the sides of the box as shown.
2. Paint the insides of the box and its lid with black paint. (Or line the inside of the box with black paper.)
3. Place the ultraviolet lamp in the box.
4. Place clear plastic sheets over the sides of the box.
5. Put a tablespoon of petrol into the flat dish and place dish inside the box.
6. Place one inflated balloon in the box. Leave the other inflated balloon outside (and not close to) the box as a control.
7. Place one piece of fabric in the box. Leave the other outside the box as a control.
8. Introduce some nitrogen dioxide (NO_2) into the box as shown in the diagram.
9. Place the lid on the box and switch on the ultraviolet lamp. Avoid looking at the ultraviolet lamp.
10. Observe the air inside the box. If you shine the torch on the black sides of the box it might make this observation easier.
11. Observe any changes in the balloon and fabric you have placed in the box. (You will have to compare them with the controls you kept outside the box.)
12. Some changes may only be observed after several hours.
13. Avoid inhaling air near the box.
    It would be better to perform this experiment in a fume cupboard if one is available.

Observations

1. After the ultraviolet lamp has been switched on.

2. When the torchlight is shone on a black side of the box.

3. Compare the inflated balloon in the box with the control balloon.

4. Compare the coloured fabric in the box with the control fabric.

Explanations

1. In this simulation, what does the dish of petrol represent?

2. In this simulation, what does the ultraviolet lamp represent?

3. In this simulation what does the source of nitrogen dioxide represent?

4. Using the terms such as "aerosol" and "photochemical change" explain the observations you noted in the air inside the box and in the materials (rubber balloon and fabric) you placed in the box.

Experiment is adapted from
Air Pollution
by C.W. Lavaroni, P.A. onnell.

Solutions to Worksheets for Unit 5

Worksheet 5(a) Looking into the Smog

Task 1

	Classical Smog	Photochemical Smog
Type of Environment Where it Occurs	Mainly urban environment	Mainly urban environment
Physical Description	Thick haze which is a combination of smoke and fog	Brownish haze
Weather Conditions for Formation	Cold wet day or night Temperature < 10°C Temperature inversion present	Sunny, warm day Temperature > 24°C Temperature inversion present
Weather Conditions for Clearing	Clears as the temperature increases and the sun rises	Clears as the temperature drops and the sun sets
Source of Smog	Burning of coal and presence of fog	Mostly release of exhaust gases from motor vehicles (hydrocarbons, NO_x, CO) and sunlight
Components of Smog	Sulphur dioxide, soot, droplets of water (aerosol)	Ozone, NO_x, aerosol consisting of droplets of organic compounds
Effects	Irritates eyes, chests, dirties homes Causes serious health problems for frail people	Irritates eyes, chests, damages materials eg. rubber, damages plants
Control Measures	Only "smokeless" fuels allowed to be burnt eg. anthracite, gas ie. reduction in burning of coal in urban areas	Control of release of hydrocarbons from industrial sources Reduction in number of vehicles in cities Improvement in combustion efficiency of motor vehicles. Catalytic converters fitted to motor vehicles

Task 2

Ozone <u>in the stratosphere is being destroyed</u>. This is a serious problem because ozone is the only substance in the atmosphere that absorbs solar radiation with a wavelength 220 - 330 nm. This radiation is harmful to living cells. We do not come into contact with ozone in the stratosphere.

However, ozone <u>is being produced in the troposphere</u> during the formation of photochemical smog in urban areas. Ozone is a very reactive substance. In the troposphere it comes into contact with the biosphere causing damage to vegetation and health problems. Ozone damages materials such as rubber.

The ozone produced in the troposphere does not rise to the stratosphere and thus solve the problem of the ozone depletion in the stratosphere. This is because ozone is very reactive and reacts with many other substances in the troposphere. In addition the exchange of substances across the tropopause is very slow. (See Unit 1)

Worksheet 5(b) *"It's nice from far and far from nice."*

Questions

1. *The phrase "ozone on the ground" refers to ozone in the troposphere.*
2. *Ozone in the troposphere will not rise and replace ozone in the stratopsphere because ozone is very reactive and will react with other substances in the troposphere and form new compounds.*
3. *Concentrations of ozone will probably increase in the summer because the intensity of solar radiation will increase in summer. The solar radiation plays a very important role in the formation of photochemical smog.*
4. *According to Greg Bodeker, ozone can be produced by electrical devices eg. sparkplugs. Ozone is also produced by some of the gases released during the combustion of fossil fuels.*
5. *The oxygen atoms are not split. The bond between the atoms is broken.*
6. (i) *Free oxygen atoms radicals are unbonded oxygen atoms. They could be represented by means of a Lewis diagram eg.*

(ii) *A more scientifically correct statement would be:*
" Oxygen atoms (radicals) combine with oxygen molecules to form ozone molecules (composed of three oxygen atoms). The ozone molecules are very reactive."

(iii)

$$O_2 \xrightarrow[\text{electrical spark}]{\text{eg. by}} 2O \text{ (radical)}$$

$$\underset{\text{(radical)}}{O} + \underset{\text{(molecule)}}{O_2} \longrightarrow \underset{\text{ozone}}{O_3} \text{ (reactive)}$$

7. *The effects of ozone, as mentioned in the article, are:*

Damages lungs.
Irritates eyes.
Lowers resistance of body.
Damages plants.
Weakens some materials.

<u>Worksheet</u> 5(c) Interpreting Graphical Data.

1. (i) 08.00 h
   (ii) At this time of day, there are many motor vehicles driving in Los Angeles - as people drive to work.

2. NO reacts with oxygen in the air to produce NO_2.

3. (i) 12.00 h (noon)
   (ii) At this time of day, the sunlight is most intense. It is the sunlight which iniates chemical reactions which produce the smog.

4. Hydrocarbons, CO, NO_2, NO.

5. Hydrocarbons, CO, NO_2, NO.

6. The intensity of the sunlight is decreasing. The photochemical reaction involving the dissociation of NO_2 does not occur to the same extent.

7. The production of photochemical smog decreases towards evening because of the decrease in the sunlight. Ozone is a component of photochemical smog.

8. Between 10.00 h and 15.00 h, the ozone concentration in the air in Los Angeles, is greater than 0,1 ppm. Therefore many people will suffer respiratory problems.

Worksheet 5(d) Smog in a Box

Observations

1. A haze forms in the box.

2. Tiny droplets of liquid which form the haze can be seen.

3. *The inflated balloon may appear more deflated than the control balloon - the rubber of the balloon is damaged by the haze, and some air escapes.

4. *Fabric may appear faded when compared with the control fabric.

(* These changes may be observed after several hours)

Explanation

1. The dish of petrol represents hydrocarbon compounds released mainly from exhausts of motor vehicles.

2. The UV lamp represents the solar radiation which is necessary for the photochemical reaction to occur during the formation of photochemical smog.

3. The source of NO_2 represents the NO_x gases released from the motor vehicle exhausts.

4. A reaction is initiated by the UV lamp. This reaction is the photochemical decomposition of nitrogen dioxide molecules into nitrogen monoxide molecules and oxygen atoms. The oxygen atoms react with oxygen molecules in the air to form ozone molecules.
The hydrocarbons (from the petrol) compete with this reaction. Ozone accumulates and liquid droplets of organic compounds eg. PAN, form. This gives rise to the haze or photochemical smog. The components of this smog react with the rubber balloon and the fabric, changing these materials.

UNIT 6

The Enhanced Greenhouse Effect

Introduction to Unit 6

Scientists have long been aware of the "greenhouse" or radiation-trapping and warming effect of the atmosphere; Svante Arrhenius, in 1896, described the relationship between the concentration of carbon dioxide in the atmosphere and atmospheric temperature. He was concerned about the effects that the coal-dependent Industrial Revolution would have on global climates. He predicted that a doubling of the concentration of carbon dioxide in the atmosphere could increase the Earth's average temperature by approximately 5°C - something which is closely borne out by modern day estimates using sophisticated computer programmes.

Recently the phrase "greenhouse effect" has received popular usage in a way that indicates it is something undesirable. However the greenhouse effect is something good! Without it, life on Earth might not exist. Without the atmosphere and certain gases in it, we might well be like the Moon with scorching hot days and freezing nights and an average surface temperature of -1°C . Instead the average surface temperature of the Earth is 15°C - a comfortable temperature for life to exist.

In our study of the greenhouse effect we shall concentrate on the troposphere - that part of the atmosphere that stretches approximately 15 km above the surface of the Earth. The troposphere receives energy from the Sun in the form of electromagnetic radiation with a range of wavelengths (400 - 700nm) covering the ultraviolet, visible and infra-red regions of the spectrum. However most of the radiation occurs as visible light. The diagram below shows the fate of the energy as it reaches the troposphere.

The Distribution of Incoming Solar Energy

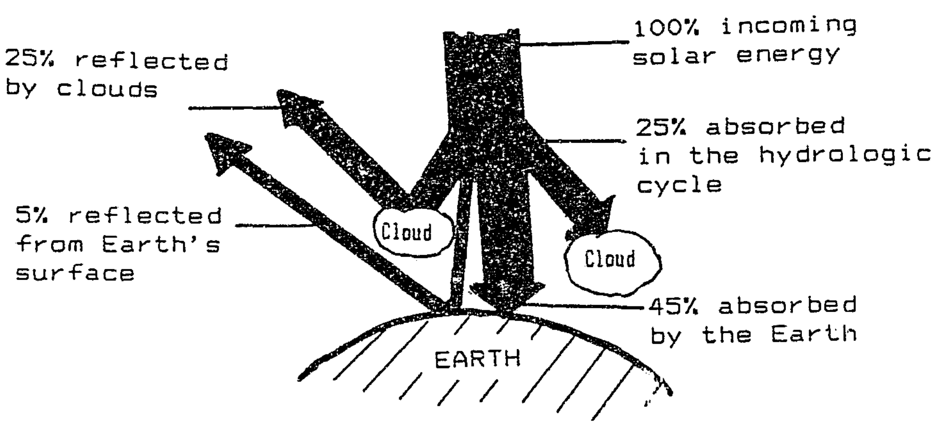


Diagram adapted from
Changing the Climate (Scientific American 261 (3), 1989)
by S.H. Schneider.

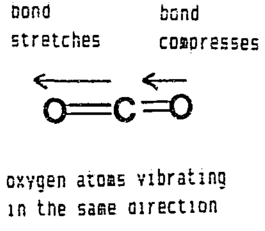
About 30% of the incoming solar radiation is reflected by clouds, particles in the atmosphere or by snow, sand or concrete on the Earth's surface. The remaining 70% is absorbed: 25% is absorbed and used in the hydrologic cycle (the continuous cycling of water in to and out of the atmosphere by evaporation and condensation) and 45% is absorbed by the Earth and converted into thermal energy, warming the atmosphere, oceans and continents.

People often think that the Sun's energy warms the atmosphere directly. However this occurs only to a very small extent - most of the heating of the atmosphere occurs because of its contact with the warmed Earth. It could be concluded that because the Earth is absorbing solar radiation 24 hours a day the Earth should be getting hotter and hotter. This is not so because the Earth itself radiates energy at infrared wavelengths (larger wavelengths than the radiant energy received from the Sun). Spacecraft above the atmosphere analyse the radiation emitted by the Earth and find that it represents the type of radiation that is emitted by a body with a temperature of −18°C. Yet the Earth's surface temperature when measured with thermometers on Earth is an average 15°C. This difference is not because of an error in calculation by the instruments aboard the spacecraft but because some of the energy emitted by the Earth does not leave the atmosphere but is in fact absorbed in the atmosphere. This absorption of energy is the origin of the so-called greenhouse effect of the atmosphere.

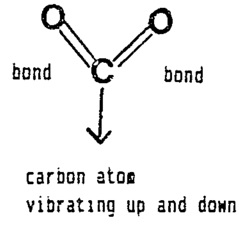
If the atmosphere were composed only of nitrogen and oxygen the temperature of the Earth would be well below the freezing point of water. Nitrogen and oxygen do not absorb the infrared radiation emitted by the Earth. (We say nitrogen and oxygen are <u>transparent</u> to the infrared radiation.) However there are some 30 trace gases which absorb some of this infrared radiation. (We say these gases are <u>opaque</u> to the infrared radiation.) Of these 30 trace gases, the most important are carbon dioxide (CO_2), water vapour, methane (CH_4), CFCs, dinitrogen oxide (N_2O) and ozone (O_3). Absorption of infrared radiation by molecules increases their vibrational energy.

<u>Diagram Showing (for example) Modes of Vibration of a Carbon dioxide Molecule</u>

(i)



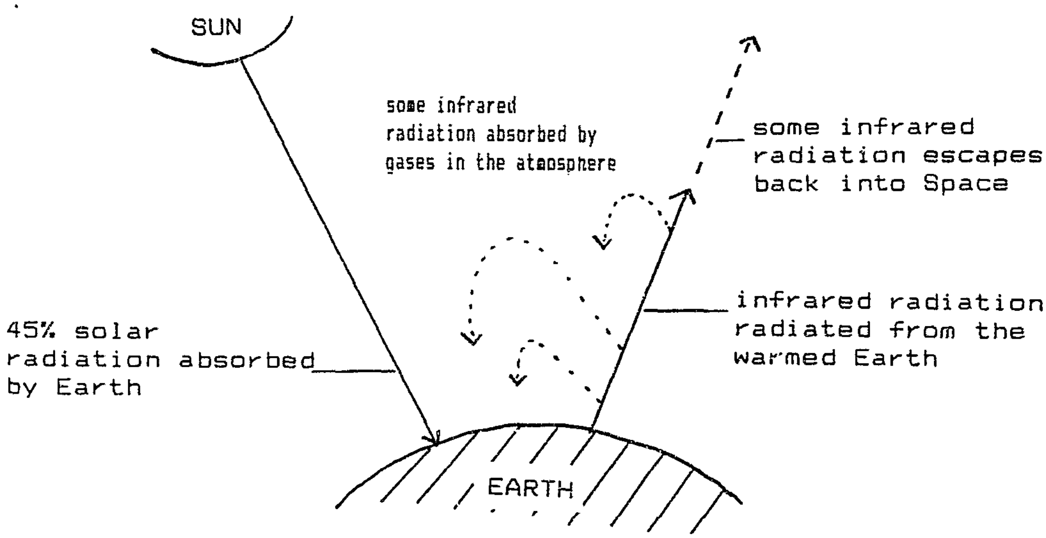
(ii)



Since the vibrational energy of a molecule is quantised, only certain wavelengths of infrared radiation can be absorbed by the molecule. For example, carbon dioxide absorbs at 1200 nm and 1800 nm, N_2O at 700 nm and CH_4 at 1300 nm.

Once the energy has been absorbed by the molecules of these trace gases they have a higher kinetic energy than other molecules around them. Through collisions with these other molecules, they distribute this kinetic energy. As kinetic energy is proportional to absolute temperature, we observe a warming of the atmosphere - the greenhouse effect. The temperature of the Earth's surface is determined by the interrelationship between the rate of absorption, by the Earth, of energy from the Sun, the rate of absorption of energy by the greenhouse gases and the rate of emission of energy into space.

Diagram Illustrating the Greenhouse Effect

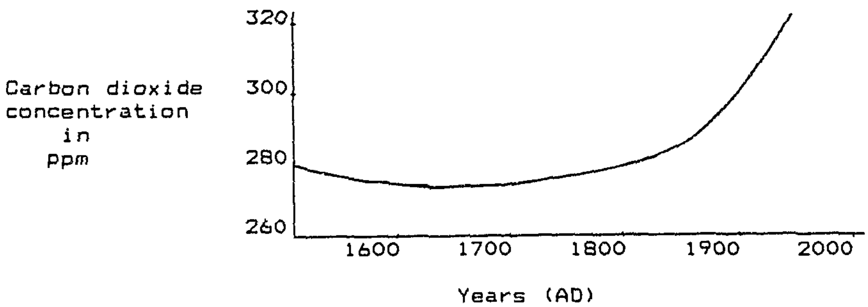


The analogy of the atmospheric "greenhouse effect" to the way in which a greenhouse functions must not be followed too closely. The warmth provided by a greenhouse is largely due to the physical barrier of the glass which prevents energy being transferred from the greenhouse by convection. For this reason some people prefer to use the term "global warming" rather than "greenhouse effect".

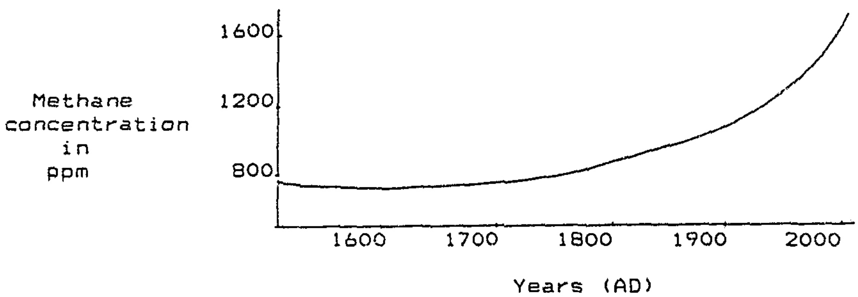
Over the centuries, the average temperature of the Earth's surface has stayed about the same because the difference between the rate of energy absorption by the Earth and the rate of energy leaving the atmosphere and escaping into space, has remained more or less constant. This was because the concentration of the trace gases capable of absorbing some of the infrared radiation emitted by the Earth's surface, remained more or less constant. However analysis of the air bubbles trapped in the ice in Antarctica, indicates that since the time of the Industrial Revolution, the concentrations of some of these trace "greenhouse" gases has increased very rapidly.

Graphs Showing Some Results of Analysis of Air Trapped in Ice

A. Changes in the Concentration of Carbon dioxide in the Atmosphere since 1600



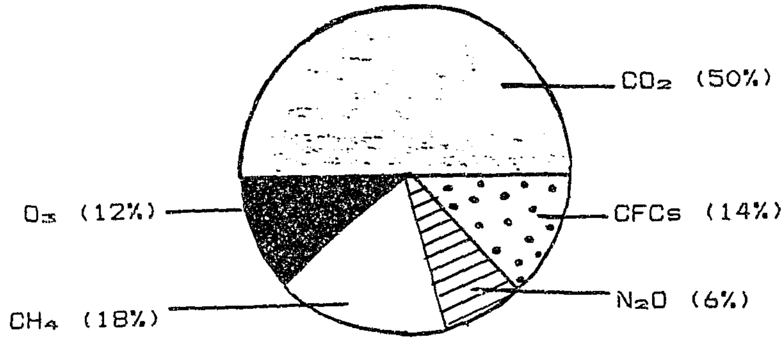
B. Changes in the Concentration of Methane in the Atmosphere since 1600



As the concentration of these gases greenhouse gases increases, less of the infrared radiation emitted by the Earth escapes into space. The result could be global warming of the atmosphere. Many scientists believe that this warming has already begun. Thus it is not the greenhouse effect but the enhanced or exaggerated greenhouse effect that is causing concern.

Ignoring the contributions of water vapour to the greenhouse effect, the present contributions of carbon dioxide, methane, dinitrogen oxide, CFCs and ozone can be shown as follows:

Diagram Showing Overall Contribution to the Greenhouse Effect



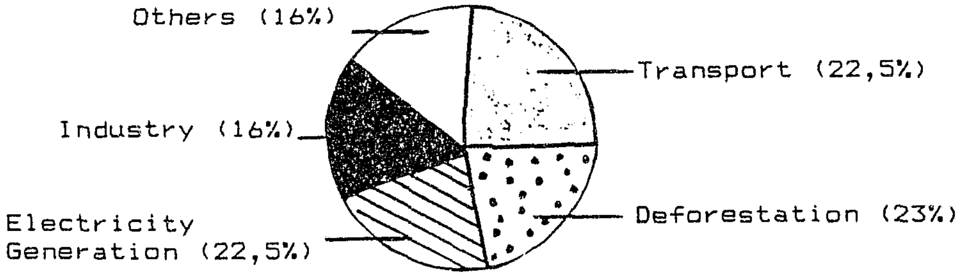
We shall consider each of these gases in turn:

1. Carbon dioxide

The concentration of carbon dioxide has increased from 283 ppm in 1880 to 356 ppm at present and is increasing at a rate of 0,4% per annum. Many of our activities require the burning of fossil fuels (coal, oil and natural gas) for electricity, for transport and for domestic and industrial purposes. It is estimated that the use of these fossil fuels contributes 1,8 x 10^{16} g of carbon dioxide per year to the atmosphere. The increasing demand for the energy provided by burning these fossil fuels is closely related to the rapid growth in world population.

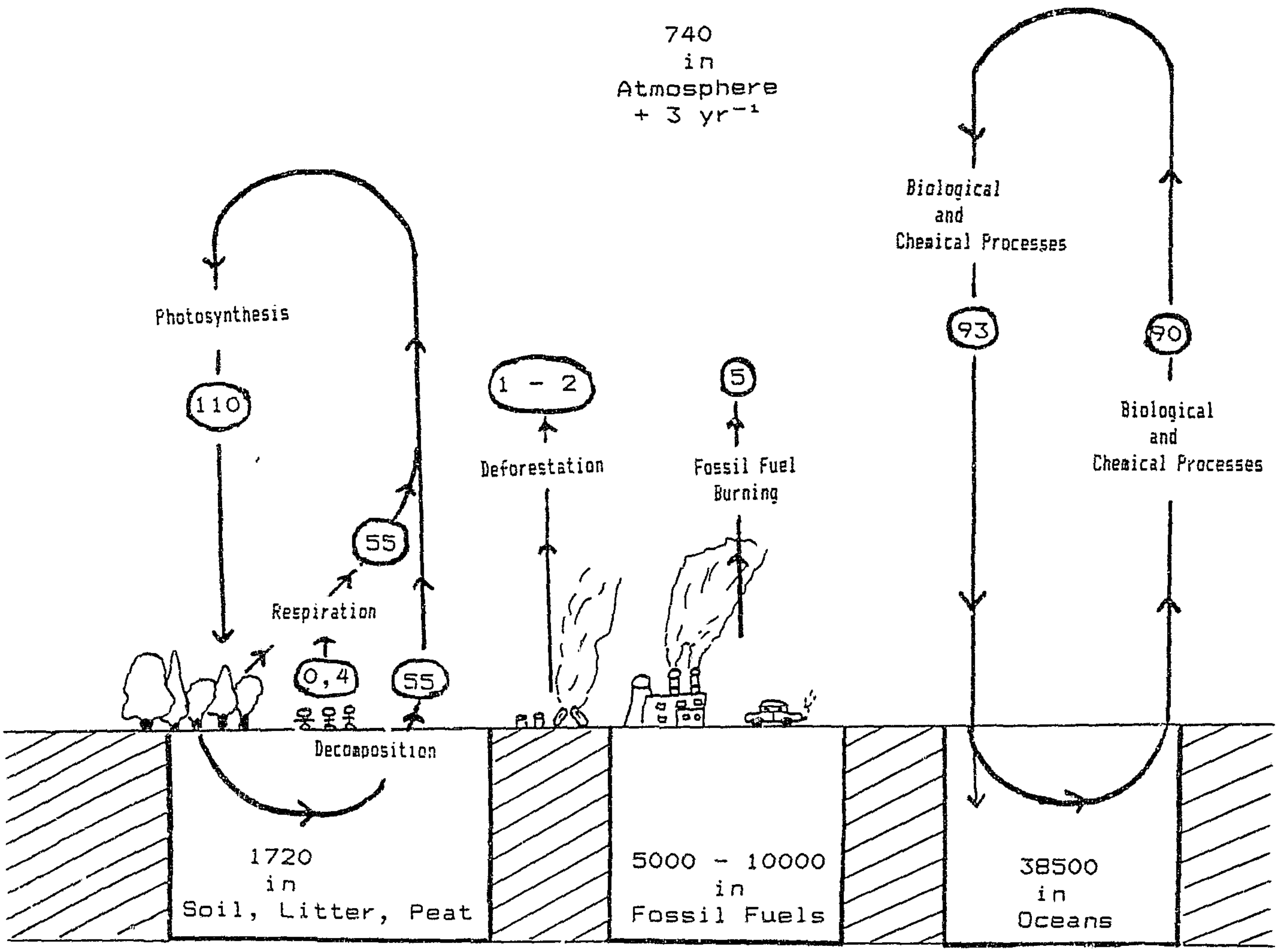
The chopping down of trees also effectively increases the carbon dioxide concentration as trees (and other plants) absorb carbon dioxide during photosynthesis. The destruction and burning of natural forests thus contributes to the accumulation of carbon dioxide in two ways - as a result of the combustion and as a result of the destruction of a means of removal of carbon dioxide from the atmosphere.

Diagram Showing Worldwide Contributions to Carbon dioxide Concentrations in the Atmosphere



Carbon dioxide forms part of the natural cycle of carbon between the atmosphere, oceans, land and plants and animals. (See diagram of the carbon cycle on the next page.) In this cycle, carbon is exchanged between the atmosphere, the biosphere, the soil and oceans. The existing cycles on land and in the oceans remove about as much carbon from the atmosphere as they add. However deforestation and the burning of fossil fuels is increasing the concentration of carbon (mostly in the form of carbon dioxide) in the atmosphere by approximately 3 x 10^{15} g per year.

Diagram of the Carbon Cycle (as in 1988)



* All figures given as 10^{15} g of carbon
eg. 38500 means 38500 x 10^{15} g C

* Circled figures show the exchange of carbon into or out of the atmosphere. Units for exchange are given as 10^{15} g C yr^{-1}
eg. 110 means 110 x 10^{15} g C yr^{-1} are removed from the atmosphere by photosynthesis.

Diagram adapted from
Changing the Climate (Scientific American 261 (3), 1989)
by S.H. Schneider.

As we shall see later, carbon dioxide does not absorb as great a proportion of infrared radiation as the other "greenhouse gases" but it poses more of a problem than they do at present because the concentration of carbon dioxide is higher than that of the other "greenhouse " gases.

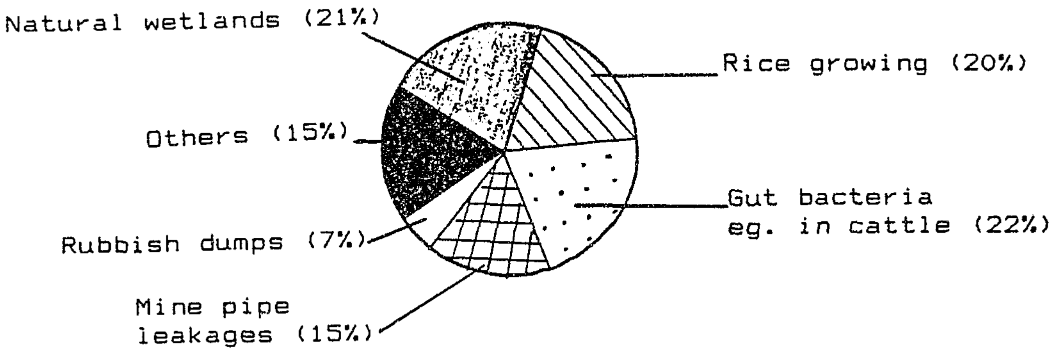
2. Methane (CH_4)

This gas is produced naturally by bacteria acting on decaying biological matter in swampy areas in the absence of oxygen. It is also produced by bacteria in rice-growing paddy fields, rubbish dumps and in the guts of ruminants such as cattle. Leakages from coal mines and natural gas pipelines also contribute to the concentration of this gas in the atmosphere.

Once again the increase in the concentration of this gas in the atmosphere can be closely related to the the growth in the world population. The world population of cattle doubled between 1960 and 1980. Each of these animals can produce 73 000 litres (at 15°C and 1 atmosphere pressure) of methane per year!)

At present the concentration of methane is 1,7 ppm and is increasing at 1% per year. Methane is 30 times more effective than carbon dioxide at absorbing infrared radiation.

Diagram Showing Contributions to Methane Concentrations



3. Chlorofluorocarbons (CFCs)

These compounds have been studied with regard to the depletion of stratospheric ozone. Their contribution to the greenhouse effect is significant because some of these compounds exist for a long time in the atmosphere (up to 150 years!). CFCs are not part of a natural global cycle. Some

CFCs are 25 000 times more efficient at absorbing infrared radiation than carbon dioxide. At present the concentration of CFCs is 0,0005 ppm and it is increasing at 5% per year.

4. Ozone (O_3)

Ozone has been studied previously as being beneficial in the stratosphere but harmful in the troposphere. In addition ozone is a greenhouse gas. It is 2 000 times more efficient at absorbing infrared radiation than carbon dioxide and its concentration in the troposphere is increasing by 1,5% per year.

5. Dinitrogen oxide (N_2O)

This compound has also been encountered in our study of ozone depletion in the stratosphere. It is being produced in increasing quantities from the use of nitrogen-containing fertilisers. At present its concentration is 0,3 ppm and its concentration is increasing by 0,3% per year. It can exist in the atmosphere for up to 150 years and is 150 times more efficient than carbon dioxide at absorbing infrared radiation.

Summary of the Main Greenhouse Gases Showing Energy trapping Effectiveness, Concentration at Present and Increase per Year

Compound	Energy-trapping Effectiveness Compared to CO_2	Concentration /ppm	Increase % per year
CO_2	1	356	0,4
CH_4	30	1,7	1,0
CFCs	10 - 25000	0,0005	4,0
O_3	2000	0,04	1,5
N_2O	150	0,3	0,3

Possible Consequences of the Increase in the Concentration of the Greenhouse Gases

The effects of the increased absorption of radiation from the surface of the Earth, by these gases is the subject of an ongoing debate. The consequences are complex issues with many factors at work. Some of the predictions are as follows:

a) <u>A General Temperature Rise</u>

A temperature rise of between 0,5°C and 7°C during a period of 50 - 100 years has been predicted on the basis of some calculations. The sea levels could rise due to expansion of the sea water and melting of ice in the North and South Pole regions. This would endanger coastal cities and change the main sea currents in the ocean. This in turn would lead to climatic changes. Such a rapid climatic change could cause extinction of many species of plants and animals, and changes in the quantity and distribution of rain. Because agricultural crops are sensitive to climatic change this would have drastic effects on the production of food and on the economy of countries. (In South Africa, in the south west Cape, for instance, it has been suggested that belts of warm weather would move further south with the result that the cold fronts which usually bring rain to the Cape in winter would miss the tip of Africa. The south west Cape would in time change from a winter-rainfall area to a summer-rainfall area. The unique flora found in this area and its wine-producing industry would be threatened and possibly even replaced by mealie and pineapple fields!)

b) <u>A Reduction in Solar Radiation</u>

Some predictions suggest that if global warming occurred, it would be accompanied by more evaporation of water which would lead to increased cloud formation. These clouds would reflect or block out more of the solar radiation. This would counteract the effect of the increasing concentration of the greenhouse gases.

c) <u>Increase in the Ice-Caps</u>

Some predictions suggest that global warming would cause more precipitation of snow on the Ice-caps which would thus grow in size.

d) <u>The Counteracting of Another Ice-Age</u>

The Earth could experience another Ice-age caused by the tilting of the Earth on its axis. The warming effect produced by the increased concentrations of greenhouse gases could thus be beneficial!

These are a few of the predictions rather simply stated. There are others. We must remember that all these predictions are marked by uncertainty; at present it is difficult to assess and predict accurately the outcomes of an enhanced greenhouse effect. This emphasises the need for internationally coordinated scientific research to reduce the uncertainty. At present, the possiblity of an enhanced greenhouse effect remains one of the most disturbing problems of air pollution.

Learning Objectives for Unit 6

On completion of this lesson students should be able to:

6.1 Describe the meaning of the term "greenhouse effect".
6.2 Describe briefly the distribution of incoming solar energy as it reaches the atmosphere; reflection by clouds, absorption by the hydrologic cycle, absorption by the Earth and reflection from the Earth's surface.
6.3 Name, and if applicable, give the formula of the major greenhouse gases; carbon dioxide (CO_2), water vapour(H_2O), methane (CH_4), CFCs, dinitrogen oxide (N_2O) and ozone (O_3).
6.4 Describe briefly the role played by these gases in absorbing some of the energy radiated by the Earth.
6.5 Explain why the analogy of the greenhouse effect to the functioning of a greenhouse is misleading.
6.6 Explain why the average surface temperature of the Earth has remained more or less constant over the past centuries.
6.7 Discuss the trends in the concentrations of the greenhouse gases over the last three centuries.
6.8 Explain the effects these trends may have on the average surface temperature of the Earth in the future.
6.9 Draw a pie chart to represent the contributions of greenhouse gases to the greenhouse effect.
6.10 List some of the main sources of carbon dioxide, methane and dinitrogen oxide in the atmosphere.
6.11 Interpret a diagram of the carbon cycle explaining that it is deforestation and the burning of fossil fuels that are increasing the concentration of carbon dioxide in the atmosphere.
6.12 Quote some of the predictions concerning the consequences of an enhanced greenhouse effect.
6.13 Describe the uncertainty surrounding these predictions about future global atmospheric change.

Worksheet 6(a) "The Science Boffins"

Read the newspaper article below and then answer the questions that follow.

Nobody's more confused than the boffins of science

JUST when you'd got your tongue around the "green house effect" and "global warming" it seems that scientists have got it all wrong. A controversial new study says that global warming might in fact be global cooling. Confused? So are the scientists!

Before this study, conducted by the Geography Department of Edinburgh University, it was believed that global warming would melt the ice caps of the north and south poles, making the oceans swell and flooding some waterfront towns and countries.

However the findings of this new study of the east Antarctic and Greenland show that the ice caps may get thicker as the temperature gets hotter, causing the sea levels to fall.

Snowfalls

The team of researchers were amazed to discover that on days when the temperature was warmer the ice actually got thicker, and not thinner as they had expected. This is due to increased snowfalls when temperatures are slightly warmer.

What is likely to happen is that although the caps might decrease slightly in size, they will get far thicker. This is good news indeed for threatened countries, but they can't relax completely because far more evidence is needed to prove the theories of the Scottish research team.

This study has certainly highlighted the fact that scientific answers based on what seems sound logic, still require evidence from that master of magic — Nature.

The Star, February, 1991

1. Explain the meaning of the term "greenhouse effect".
2. Distinguish between the terms "greenhouse effect" and "enhanced greenhouse effect".
3. Why do some people prefer the term "global warming" to "greenhouse effect"?
4. The contributions to the greenhouse effect can be summarised as follows:

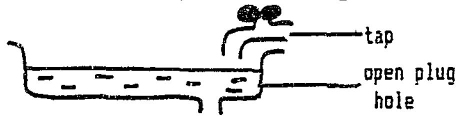
CO_2	50%
CFCs	14%
N_2O	6%
CH_4	18%
O_3	12%

   i) Draw a pie chart to represent this data.
   ii) List as many sources of these gases as you can.

5. Why is global warming of such concern these days?
6. What are some of the underlying social factors that are causing this problem?
7. In what way are the boffins of science confused?
8. Do you know of other predictions of the outcomes of global warming? If so, briefly describe them.

Worksheet 6(b) Does the Concentration of Carbon dioxide in the Atmosphere Represent a Steady State?

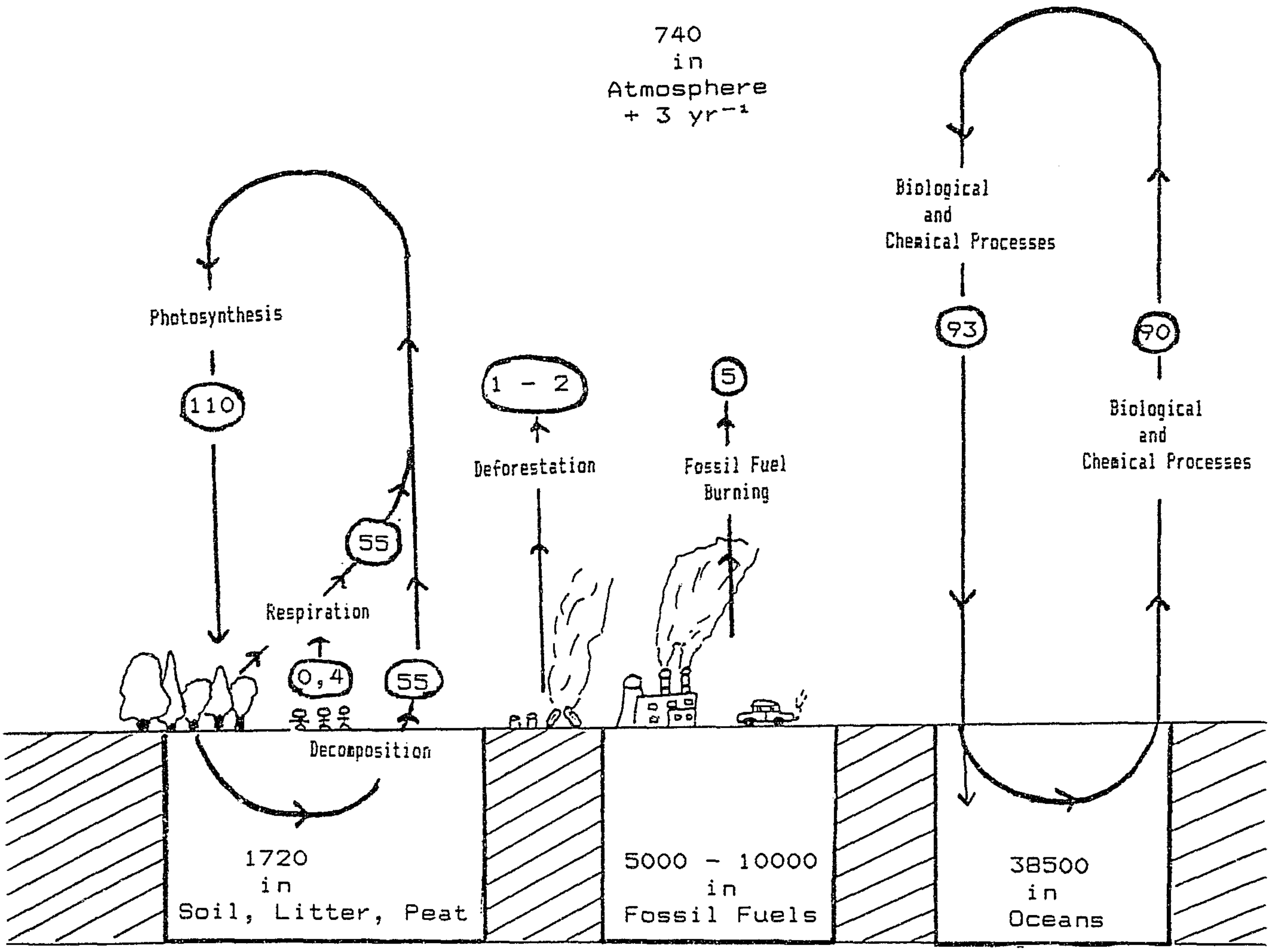
How can we keep the quantity of water in the bathtub constant (if there is no plug being used)?



We describe the maintenance of a constant quantity of water in the bath tub as a steady state.

In the exercise that follows, you will make use of the following diagram:

Diagram of the Carbon Cycle (as in 1988)



* All figures given as 10^{15} g of carbon
eg. 38500 means 38500 x 10^{15} g C

* Circled figures show the exchange of carbon into or out of the atmosphere. Units for exchange are given as 10^{15} g C yr^{-1}
eg. 110 means 110 x 10^{15} g C yr^{-1} are removed from the atmosphere by photosynthesis.

We shall use the diagram on the previous page to determine whether or not the quantity of carbon dioxide in the atmosphere represents a steady state. Carbon dioxide is a very important "greenhouse gas". At present scientists are unsure as to how much carbon dioxide will accumulate in the atmosphere. The carbon cycle is the exchange of carbon (mostly in the form of carbon dioxide) between the atmosphere, the biosphere, the soil and the oceans. The soil, fossil fuels and oceans are sometimes referred to as "reservoirs of carbon". These are parts of the Earth where matter may be found whose molecules contain carbon atoms. As a result of certain processes, these carbon atoms may be exchanged with the atmosphere.

Now perform the following tasks:

1. Make a list of the processes shown in the diagram that result in carbon (in the form of carbon dioxide) being released into the atmosphere. Make a note of the mass of carbon contributed by each process per annum. Use this information to complete the table that follows.

Process Releasing Carbon (as CO_2) in the atmosphere	Input in 10^{15} g C yr^{-1}
Total Input	

2. In a similar way make a list of the processes as shown in the diagram that result in carbon dioxide being removed from the atmosphere. Make a note of the mass of carbon (as CO_2) being removed from the atmosphere during each process. Use this information to complete the table given below.

Process Removing Carbon (as CO_2) from the Atmosphere	Output in 10^{15} g C yr^{-1}
	Total Output

3. Compare the magnitude of the total input and output of carbon (mostly in the form of carbon dioxide) in the atmosphere. Does this represent a steady state with regard to carbon (mostly in the form of carbon dioxide) in the atmosphere? Explain you answer.

4. What is the net result for the atmosphere of the input and output processes for carbon (as CO_2) during one year?

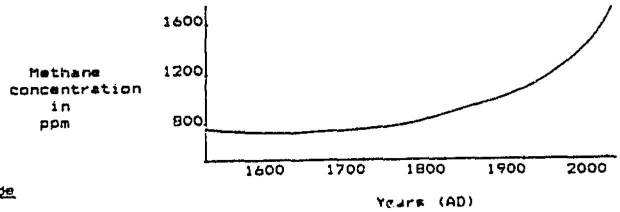
5. Which process/processes could be identified as the main cause of the result you described in (4)?

6. Which reservoir is involved in the exchange of carbon (in the form of carbon dioxide) in which more carbon is removed from the atmosphere than is released into the atmosphere?

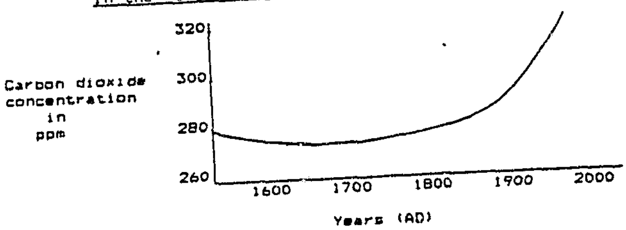
(It is the role of this reservoir that contributes to some of the uncertainty surrounding the consequences of an enhanced greenhouse effect.)

Worksheet 6(c) "WOW!!!"

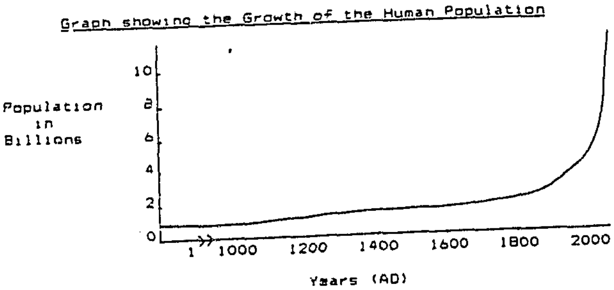
Changes in the Concentration of Methane in the Atmosphere since 1600



Changes in the Concentration of Carbon dioxide in the Atmosphere since 1600



Graph showing the Growth of the Human Population



Questions

(Answer on a separate sheet of paper.)

1. Discuss the trends shown by these graphs.
2. Explain the trends shown by these graphs.
3. Data is provided for changes in the concentrations of carbon dioxide and methane in the atmosphere.
   a) Is the percentage composition of these gases
      (i) 20% or more of atmosphere?
         (ie major components of the atmosphere)
      (ii) 0,01 - 1,0% of the atmosphere?
         (ie minor components of the atmosphere)
      (iii) 0,0001 - 0,01% of the atmosphere?
         (ie trace components of the atmosphere)
4. What percentage of the atmosphere (in total) does air pollution affect?

Worksheet 6(d) Comparing carbon dioxide concentrations in samples of gases taken from different sources.

In this investigation, we shall compare carbon dioxide concentrations in the following samples (collected in small plastic bags)

1. air
2. exhaled gases during respiration
3. exhaust gases from a motor car
4. almost pure carbon dioxide prepared from vinegar and baking soda (sodium hydrogen carbonate)

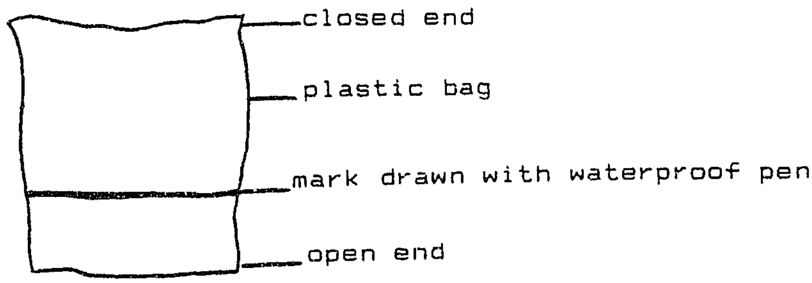
In our comparison, we shall use a standard solution (the colour of bromothymol blue indicator in water).
When we pass the gas samples (containing different concentrations of carbon dioxide) through solutions of water and bromothymol blue indicator (in 4 different, labelled test tubes), we may observe colour changes in the indicator solutions. A solution of household ammonia will be added dropwise to the test tubes until the colour of each solution returns to the same colour as that of the standard.

Requirements for Each Group of Students

5 test tubes
a test tube rack
a measuring cylinder
a metal or hard plastic funnel
a small glass funnel
2 oven gloves
a straw
4 small "Jiffy" plastic bags
4 "twisties" to seal plastic bags
a narrow-necked bottle eg an empty wine bottle
a dropping bottle of household ammonia (1 part ammonia to 100 parts water)
100ml vinegar
5ml baking soda
bromothymol blue indicator solution
labels
a water-proof marking pen
a bicycle pump

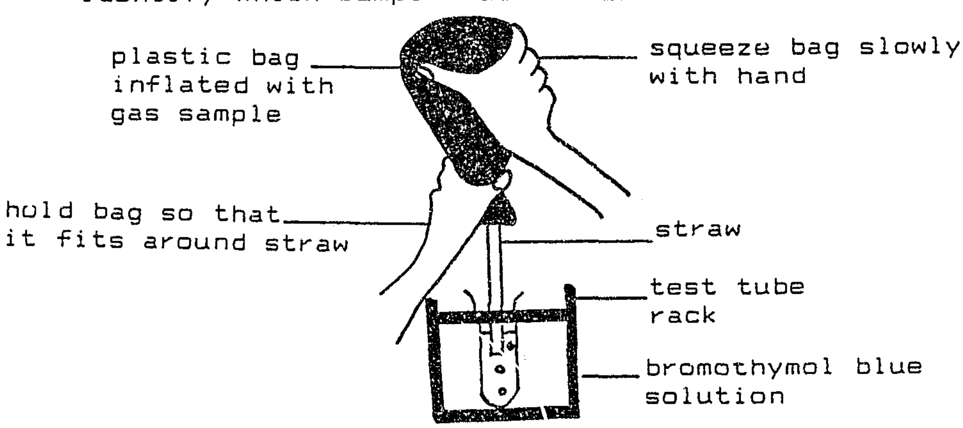
Method

1. Draw lines on 4 plastic bags in the same position using the waterproof pen.
   eg.



When the bags are filled with the gas samples, the bags will be sealed with the "twisties" at these marks. This is to ensure that the volume of gases collected in each plastic bag, will be the same.

2. Fit a p stic bag to the narrow end of the funnel. Place the wide end of the funnel over the exhaust pipe of a motor-car that has been running for a few minutes. Thick gloves should be worn to avoid burning your hands. <u>Care should be taken not to inhale the fumes.</u>
2. Fill the plastic bag with gases from the exhaust pipe. Seal the bag, at the mark drawn on the bag, with a "twistie". Label the plastic bag.
3. Fill another plastic bag with <u>air</u> using a bicycle pump. Seal the bag at the mark drawn on it and label the bag.
4. Fill a plastic bag with <u>exhaled air</u> by letting a member of the group blow it up. Seal it at the mark drawn on it, with a "twistie". Label the bag.
5. Fill a plastic bag with with <u>almost pure carbon dioxide</u> as follows:
   Pour 100ml of vinegar into a narrow-necked bottle.
   Using a funnel add 5 ml of baking soda.
   Let the mixture bubble for about 3 seconds to drive out the air.
   Slip a plastic bag over the neck of the bottle and collect carbon dioxide in the bag. When the bag is full, seal it at the mark drawn on it and label it.
6. Add 15 ml of water and 10 drops of bromothymol blue indicator to each of 5 testtubes in a test tube rack.
7. Carefully insert the straw, in turn, into each plastic bag while releasing the "twistie". Bubble gas from each bag through the bromothymol blue solution in a test tube (as shown in the diagram). Label the test tubes to identify which sample was used.



8. Keep one of the test tubes as a standard for comparison.
9. Using the dropper bottle of ammonia solution, add drops of ammonia solution to each test tube until the solution returns to the same colour as the standard.
10. Keep a record of the number of drops used.

Results

Gas Sample	Number of Drops of Ammonia Solution Added
Exhaust Gases	
Air	
Exhaled Gases	
Pure CO_2	

Explanations

1. i) What happens to the bromothymol blue solution in each test tube when the gas from each balloon is bubbled through it?

   ii) Why does this happen?

2. i) What happens when the ammonia solution is added to the indicator solutions?

   ii) Why does this happen?

3. Which solution required the largest number of drops of ammonia solution to return its colour to that of the standard?

Explain why you think this is.

4. Now arrange the other samples of gas in sequence according to the concentration of carbon dioxide they contained. Start with the sample with the largest concentration of carbon dioxide and end with the sample with the smallest carbon dioxide concentration.

5. Discuss the implications of your findings in terms of the impact of some of our activities on the composition of the atmosphere.

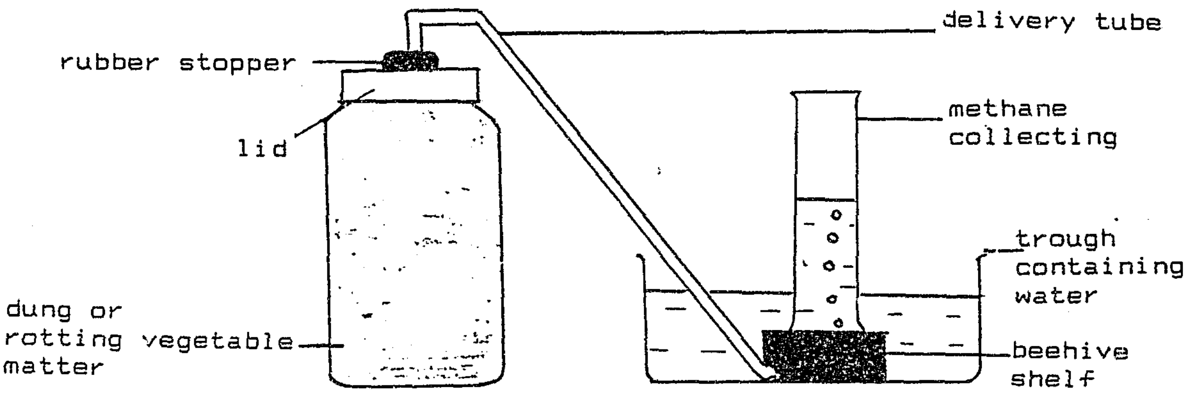
Adapted from
The Greenhouse Effect in a Vial
(The Science Teacher 56 (5), 1989)
by R. Golden, C. Sneider.

Worksheet 6(e) Making Methane

Requirements

A large plastic bottle with a tight fitting lid
A one-holed rubber stopper fitted with glass tubing
Some horse or cattle dung (or rotting vegetable matter)
A beehive shelf
A trough
A gas jar
Water

Diagram of Apparatus



Method

1. Fill the jar with the dung. Press it down to remove as much air as possible.
2. Make sure the dung is kept moist through out the experiment.
3. Insert the stopper with a glass tube. Make sure the glass tube is clear of the top of the dung. Leave the end of the tube open.
4. Place the bottle in a warm place. (The best temperature is $\sim 36°C$.)
5. Leave for approximately 12 days. At the end of this time, methane starts to be given off.
6. Collect the gas by setting up the apparatus as shown in the diagram.
7. Keep the gas jar of methane well-sealed so that you can use it for Worksheet 6(f).

Explanation

Please answer on a separate sheet of paper.

1. Make a list of human activities that are leading to the increase in the concentration of methane in the atmosphere.
2. Why is there concern about this increase in the concentration of methane in the atmosphere?
3. Discuss the role of the world population in this air pollution problem.

Experiment is adapted from
Experiments on Air Pollution
by D.I. Williams, D. Anglesea.

Worksheet 6(f) To Compare the Extent to which Some Gases absorb Infrared Radiation

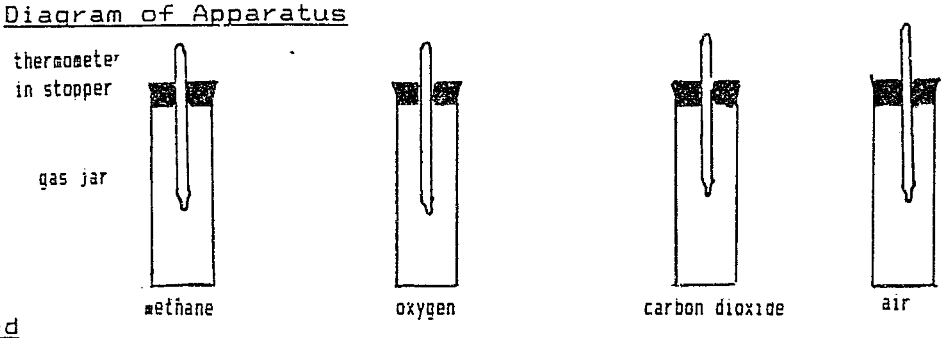
Requirements

Prepare the following:

A gas jar of methane
A gas jar of carbon dioxide
A gas jar of oxygen
A gas jar of air

4 stoppers (each fitted with a thermometer) to fit the gas jars

Diagram of Apparatus



Method

1. Prepare a gas jar of each of the gases named above.
2. Record the temperature on each of the four thermometers. (The initial temperature)
3. Quickly fit the stoppers and thermometers into the gas jars as shown in the diagram.
4. Place the four gas jars in the sunlight for about half an hour.
5. Record the temperature in each gas jar. (The final temperature)

Observations

Gas	Initial Temperature	Final Temperature	Increase in Temperature
CH_4			
O_2			
CO_2			
Air			

Explanation

Note If you do not wish to make methane from dung, the following preparation of methane may be used instead.

1. Grind together in a mortar anhydrous sodium acetate and an excess of sodium hydroxide.
2. Put the mixture into a hard glass test tube fitted with a delivery tube and heat.
3. The methane can be collected over water in a similar manner to that shown on page 159.

   The reaction is:

$$CH_3CO_2Na \quad + \quad NaOH \longrightarrow Na_2CO_3 \quad + \quad CH_4$$

Solutions to Worksheets for Unit 6

Worksheet 6(a) "The Science Boffins"

1. The "greenhouse effect" is the ability of some gases in the atmosphere to absorb some infrared radiation. This leads to a warming of the atmosphere.
2. The "greenhouse effect" is beneficial and has been responsible for the maintenance of a constant average temperature ($\sim 15^\circ C$) of the Earth's surface. Without it there would be very hot days and freezing nights.
   Some "greenhouse gases" are increasing in concentration. The infrared absorption will increase and the temperature of the atmosphere (and the Earth's surface) could increase. This is the "enhanced greenhouse effect". This could be detrimental.
3. Some people prefer the term "global warming" because the "greenhouse effect" of the atmosphere does not operate the same way as the functioning of a greenhouse. A greenhouse functions by preventing the warmed air from leaving because of the glass barrier. Thus the energy cannot be transferred by convection.
   In the atmosphere, the "greenhouse gases" absorb some of the infrared radiation. The molecules of these gases have a higher kinetic energy than the other molecules around them. This excess energy is distributed to other molecules in the atmosphere through collisions between the molecules of the "greenhouse gases" and molecules of other substances present in the atmosphere.
4. (i)

   CO_2 : 50% of 360° = 180°

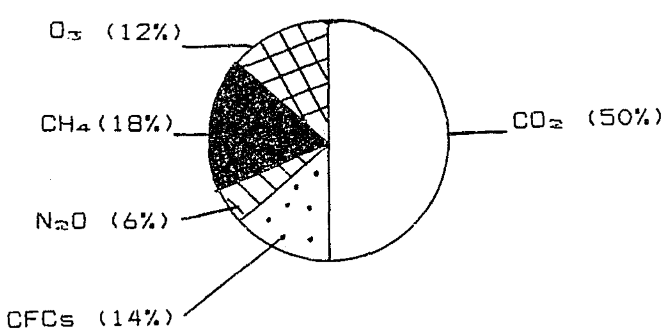
   CFCs : 14% of 360° = 50,4°

   N_2O : 6% of 360° = 21,6°

   CH_4 : 18% of 360° = 65°

   O_3 : 12% of 360° = 43°

   Pie Chart



(ii) Sources

CO_2: comoustion cf fossil fuels, respiration
CFCs: propellants in aerosols, refrigerant gases
N_2O: fertilisers
CH_4: rotting carbage, rice-paddies, cattle
O_3: (in troposphere) photochemical smog

5. The concentrations of the "greenhouse gases" are increasing very rapidly (ie. more rapidly than ever before.)
6. Some of the underlying factors causing this problem: the rapidly increasing world population and its demand for energy, food and transport.
7. The "boffins" of science are confused because the consequences of increased concentrations of these "greenhouse gases" are not certain.
8. Other predictions are for example:
   Global warming may be beneficial if the Earth experiences another Ice Age.
   Global warming may cause more cloud formation. These clouds would block out the sun resulting in cooler temperatures.

<u>Worksheet</u> 6(b) Does the Concentration of Carbon dioxide in the Atmosphere Represent a <u>Steady State</u>?

The quantity of water in the bath tub could be kept constant by running in water at the same rate as the water is running out through the open plug hole.

1.

Process Releasing Carbon (as CO_2) in the atmosphere	Input in 10^{15} g C yr^{-1}
Respiration	55,4
Decomposition	55
Deforestation	1 - 2
Fossil fuel burning	5
Biological/chemical processes from ocean	90
Total Input	206,4 - 207,4

2.

Process Removing Carbon (as CO_2) in the atmosphere	Output in 10^{15} g C yr^{-1}
Photosynthesis	110
Biological/chemical processes involving the Ocean	93
Total Output	203

3. No this does not represent a steady state. The rate of release (input) of carbon (mostly as carbon dioxide) into the atmosphere does not equal the rate at which carbon (as CO_2) is removed from the atmosphere (output of carbon).

4. The net result is the increase in the concentration of carbon (mostly as CO_2). This increase is approximately $3 \rightarrow 4 \times 10^{15}$ g C yr^{-1}

5. The processes identified as the main causes are:
   Fossil fuel burning
   Deforestation

6. The oceans appear to remove more carbon (as CO_2) from the atmosphere than is released into the atmosphere.

Worksheet 6(c) "WOW!!!"

1. All three graphs show rapid increases: the first in concentration of carbon dioxide in the atmosphere; the second in concentration of methane in the atmosphere; the third in the world population. There appears to be a good "fit" (or correlation) of the graphs. This correlation suggests that there could be an inter-relationship between the three graphs.

2. The trends can be explained as follows:

   a) The concentration of carbon dioxide began to increase rapidly from ~1850 (about the time of the Industrial Revolution). Increased industrial activity from this time, lead to an increase in the combustion of fossil fuels (coal and oil) to provide energy to drive engines and other machinery. Since the Industrial Revolution, technological and industrial development has increased rapidly.

   b) Methane concentrations in the atmosphere have increased rapidly since ~1850. Methane is released into the atmosphere from rotting garbage, herds of cattle, some forms of mining. These sources of methane-release increase as the world population increases and the demand for food increases. The disposal of increasing waste from growing populations also increases the methane concentrations.

   c) The world population increased rapidly since ~1850. (It is worth noting that it took ~ 4 million years for the world population to reach 1000 million or 1 billion by ~1850. The population doubled by 1925. Now the world population increases every by 1 billion every 12 years!)
   The rapid growth in the world population can be attributed to improved quality of life: scientific and technological development has led to improved health care. Improved methods of transport have led to better ways of dispersing food, medicine, expertise. The rapidly growing population places demands on industry for commodities. It places demands on the provision of energy and food. The population also places demands on the environment. Thus the interrelationship between the graphs becomes apparent.

3. Percentage composition of:

   a) carbon dioxide is ~ 0,03% of the atmosphere (a minor component)
   b) methane is ~ 0,0002% of the atmosphere (a trace component)

4. $\sim$ 0,05% of the atmosphere is affected by the changes in the concentration of substances that give rise to the problems of air pollution.

NB Question 3 and 4 emphasise the point that changes in the concentration of minor and trace components of the atmosphere may have significant impact on the chemistry of the atmosphere and on the environment.

Worksheet 6(d) Comparin: carbon dioxide concentrations in samples ' gases taken from different sources.

Results

Gas Sample	Number of Drops of Ammonia Solution Added
Exhaust Gases	(After pure CO_2, this sample needs the most drops)
Air	(Needs the least number of drops)
Exhaled Gases	(Needs less drops than exhaust gases but more than sample of air)
Pure CO_2	(Needs the largest number of drops)

Explanations

1. (i) Colour changes for samples of exhaust gases, exhaled air and pure carbon dioxide. Almost no change for air sample.
   (ii) Carbon dioxide in the sample dissolves in the bromothymol blue solution making it more acidic.

2. (i) Solutions change colour and return to the original colour of the solution before the gas sample was bubbled through.
   (ii) Ammonia solution neutralises the acidic solution.

3. "Pure" carbon dioxide sample required the largest number of drops of ammonia solution.

   This is because the concentration of carbonic acid (from the CO_2 dissolving in the water) is greatest in this sample. Therefore this solution needed more ammonia solution to neutralise the acidic solution.

4. "pure CO_2" (from the wine bottle), exhaust gases, exhaled air, air sample.

5. The burning of fossil fuels (eg petrol) produces a large quantity of carbon dioxide. This is one of the main reasons for the rapid increase of the :rbon dioxide in the atmosphere.

Note: Students may suggest that nitrogen dioxide is also present in the exhaust gas sample. This gas will also dissolve in water to produce an acidic solution. This is true. However the concentration of nitrogen dioxide will be very small in relation to the concentration of carbon dioxide in the exhaust gas sample.

Worksheet 6(e) Making Methane

Explanation

1. Some of these activities are:

   growing rice in rice paddies
   cattle farming
   dumping rotting carbage
   coal mining activities
   gas exploration

2. Methane is a "greenhouse gas". It is 30 times better than carbon dioxide at absorbing infrared radiation.
   The release of methane into the atmosphere as a result of these activities is increasing rapidly.
   It could cause global warming or an "enhanced greenhouse" effect.

3. The increasing world population needs ever increasing supplies of food, energy. The production of waste or carbage also increases.

Worksheet *6 (f) To Compare the Extent to which Some Gases Absorb Infrared radiation.*

Observations

The order of increase of temperature for the gases in the gas jars should be

methane > carbon dioxide > air > oxygen

Explanation

Methane and carbon dioxide are "greenhouse gases". Molecules of these gases absorb infrared radiation. This results in molecules of methane and carbon dioxide having more kinetic energy than molecules of substances in the other gas jars.
Temperature is proportional to average kinetic energy. Therefore the temperature of the methane and the carbon dioxide will be higher than the temperature in the gas jar of air and in the gas jar of oxygen.
Methane is approximately 30 times better than carbon dioxide at absorbing infrared radiation. This is the reason the temperature increase in the gas jar of methane is the greatest.

UNIT 7

Acid Rain

Introduction to Unit 7

The term "acid rain" was first coined in 1858 by a chemist, Robert Angus Smith when he presented a paper on air pollution to the Chemical Society in Britain. In this paper he reported how "the stones and bricks of buildings ....crumble more readily in large towns, where much coal is burnt, than elsewhere" and he attributed this to "the slow, but constant, action of the acid rain". This report and the term "acid rain" was forgotten until the 1960's. Nowadays, a hundred years later, the term has popular usage in describing the detrimental effects of some air pollutants.

The term acid rain is misleading because rain is not a neutral substance; rain is naturally acidic. Carbon dioxide present in the atmosphere reacts with droplets of water in the atmosphere to form carbonic acid; the natural pH of rain is actually 5,6.

$$CO_2(g) + H_2O(l) \longrightarrow H_2CO_3(aq)$$

Carbonic acid is a weak acid and partially dissociates in the water:

$$H_2CO_3(aq) + H_2O(l) \longrightarrow H_3O^+(aq) + HCO_3^-(aq)$$

Over the last few decades rain of a greater acidity (lower pH) has been of widespread occurrence. Other precipitations such as snow and hail have also become affected. The increased acidity of these precipitations can cause damage to plants, animals and materials. Analysis by chemists of these precipitations reveals that strong acids such as sulphuric acid (H_2SO_4), nitric acid (HNO_3) and hydrochloric acid (HCl) are present.

In the Northern Hemisphere, two regions have been particularly affected by this problem; north-eastern United States of America (and neighbouring parts of Canada) and the Scandinavian countries (particularly Sweden and parts of Norway). A "frozen record" of the acidic properties of some precipitations has been preserved as glacial ice. Analysis of this ice reveals that in some parts of Scandinavia, the H_3O^+ concentration in precipitation has increased by a factor of more than 200 over the last two decades. The average pH in precipitation over the north-eastern United States is now between 4,0 and 4,2 with values as low as 2,1 being recorded in individual storms. Problems associated with the increased acidity of rain were detected in industrial parts of Britain almost a hundred years ago. However, it is the frequent occurrence and widespread nature (even in regions remote from industry) of this phenomenon in recent years that is of growing concern.

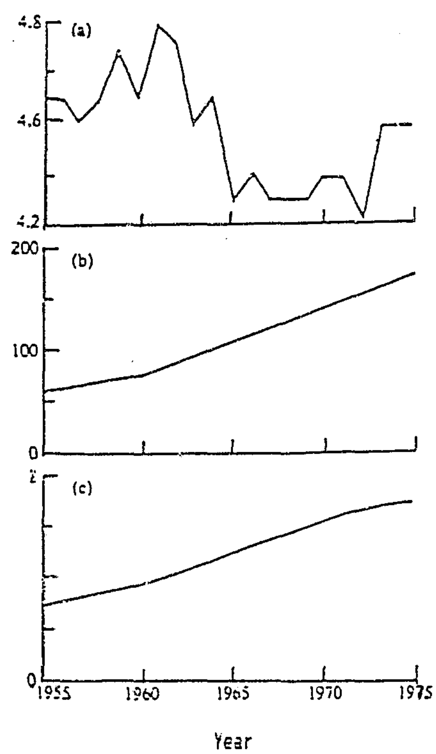
Combustion-related activities appear to be at the root of the problem, in particular the combustion of fossil fuels. If we look back at the table at the end of the introduction to Unit 2, we see that globally, human activities contribute more sulphur dioxide than natural phenomena. Oil companies are required by law to remove most of the sulphur from petroleum, so the chief culprit must be the combustion of coal. Although globally, human activities contribute little to the nitrogen oxides (NOx) in comparison to natural phenomena, when emissions of nitrogen oxides occur in industrial areas they are also involved in the problem of air pollution. Some effects of these air pollutants occur close to their source but other effects are noted hundreds of kilometres away. Thus, for example, winds carry air pollutants hundreds of kilometres from highly industrialised regions of Britain and Europe to parts of Scandinavia, where they are precipitated and deposited in the soil and lakes. In the same way air pollutants from industrialised regions in the United States are carried by winds and may cause damage to lakes and forests further north, eg in Canada. The damage to fish in lakes in these regions was the first indication of the detrimental effects of this type of air pollution. Freshwater fish are particularly sensitive to changes in the acidity of water.

<u>Graphs Showing (a) Rain Water Acidity (Norway), (b) Barren Lakes (Norway) and (c) Increases in European Fossil Fuel Combustion, over the period 1955 - 1975</u>

(a)
Annual Average
pH of Rain
in Lista, Norway

(b)
Number of Lakes
with No Fish
(in Norway)

(c)
Fossil Fuel
Consumption in
Europe
(10^{12} kg yr^{-1})



Taken from
<u>Chemistry of the Atmospheres</u>
by R.P. Wayne.

In the Transvaal Highveld we have a high density industrial region whose air pollution compares with air pollution in the Northern Hemisphere. Air pollutants are also transported many kilometres from their source and cause problems of increased acidity in precipitations in other regions of South Africa. Increased acidity in rain, fog and mist is suspected of contributing to damage to pine forests in the Eastern Transvaal. A CSIR survey of streams and forests in the Drakensberg indicates that precipitation with increased acidity is having an effect on streams and forests in this area. The most affected streams (with increased acidity and reduced aquatic life) are found near Golden Gate, the Natal/OFS boundary and the Transvaal/Swaziland border. These are all regions that are far removed from urban and industrial activities.

The primary air pollutants contributing to the increased acidity of precipitations of rain, snow and hail are mainly sulphur dioxide (SO_2) and the nitrogen oxides,(NO_x). CFCs are also primary pollutants. Hydrogen chloride is a product of CFC decomposition in the stratosphere (Unit 4). This is eventually precipitated as hydrochloric acid.

Sources of Sulphur Dioxide

Natural phenomena can be a source of sulphur dioxide. For example the recent eruption of Mount Pinatuba volcano in the Philippines caused a cloud of sulphur dioxide 6 400 km long in the atmosphere. However as mentioned earlier, human activities are releasing larger quantities of sulphur dioxide into the atmosphere than natural phenomena. Some of these sources are:

1. Coal- fired Power Stations
   In South Africa, the sulphur content of coal used in power stations is approximately 1,2% by mass. This is less than the mass % of sulphur in coal used in the Northern Hemisphere. However the low-grade quality of the coal results in comparatively larger quantities being burnt. Ultimately the rate of production of sulphur dioxide is very similar to that in the Northern Hemisphere.

2. Roasting of Metal Ores containing Sulphur
   The production of some metals requires the heating in air to very high temperatures ("roasting") of metal ores (rock material containing minerals). Some of these minerals are metal sulphides eg. copper(I) sulphide and lead(II) sulphide.
   In copper production the roasting of copper(I) sulphide results in the formation of copper metal.

$$Cu_2S + O_2 \longrightarrow 2Cu + SO_2$$

During the production of lead, lead(II) sulphide is roasted to form lead oxide.

$$2PbS + 3O_2 \longrightarrow 2PbO + 2SO_2$$

In general, roasting of sulphides produces sulphur dioxide, as the above examples show.

3. Coal Mining Operations
Emissions of sulphur dioxide result from the spontaneous combustion of coal in underground coal-seams and in mine dumps.

4. Domestic Combustion of Coal
The domestic combustion of coal (for cooking and heating purposes) contributes significantly to the release of sulphur dioxide into the atmosphere. In winter in the High veld, domestic emissions of sulphur dioxide exceed those of industry (Unit 3). Electrification of homes does not always solve the problem. For example in Soweto, all of the 83 200 formal houses have electricity, yet in two thirds of these houses, coal is still used for heating water and to provide warmth.

5. Other Industries
Sulphur dioxide is also formed as a result of processes in paper and pulp production, and in brickworks.

Sources of Nitrogen Oxides (NO_x)

Natural phenomena such as lightning and the action of bacteria in soil, are sources of nitrogen oxides in the atmosphere. The contributions by natural sources outweigh those produced by human activities. Nevertheless, the nitrogen oxides from human sources contribute to the increased acidity of precipitations. The major source of nitrogen oxides from human activities is high temperature combustion (Unit 3). High temperature combustion is a feature of:

1. Coal-fired Power Stations
Nitrogen, which is a component of coal can react with oxygen in the air to produce nitrogen oxides. In addition, because of the high temperatures involved, nitrogen present in the air can also react with oxygen in the air.

2. Motor Vehicles
The high temperatures found in internal combustion engines, result in the nitrogen in the air reacting with the oxygen of the air to produce nitrogen oxides.

These primary air pollutants, sulphur dioxide (SO_2) and nitrogen oxides (NO_x), are then involved in a series of reactions during which secondary air pollutants are formed.

Reactions of Sulphur Dioxide

Sulphur dioxide reacts with oxygen in the air to produce sulphur trioxide (a secondary air pollutant).

$$2SO_2 \quad + \quad O_2 \longrightarrow 2SO_3$$

Sulphur trioxide reacts with water in the atmosphere to form sulphuric acid (a secondary air pollutant).

$$SO_3 \quad + \quad H_2O \longrightarrow H_2SO_4$$

In addition, sulphur dioxide reacts with water in the atmosphere to form sulphurous acid, H_2SO_3 (a secondary air pollutant).

$$SO_3 \quad + \quad H_2O \longrightarrow H_2SO_3$$

Reactions of Nitrogen Oxides, NO_x

The two major nitrogen oxides are nitrogen monoxide, NO, and nitrogen dioxide, NO_2. Since most nitrogen monoxide is ultimately converted to nitrogen dioxide we shall only consider the reaction of nitrogen dioxide.
Nitrogen dioxide reacts with water in the atmosphere to produce nitric acid (HNO_3) and nitrous acid (HNO_2). Nitric acid and nitrous acid are secondary air pollutants.

$$2NO_2 \quad + \quad H_2O \longrightarrow HNO_3 \quad + \quad HNO_2$$

Nitric acid is a strong acid, similar in strength to sulphuric acid.

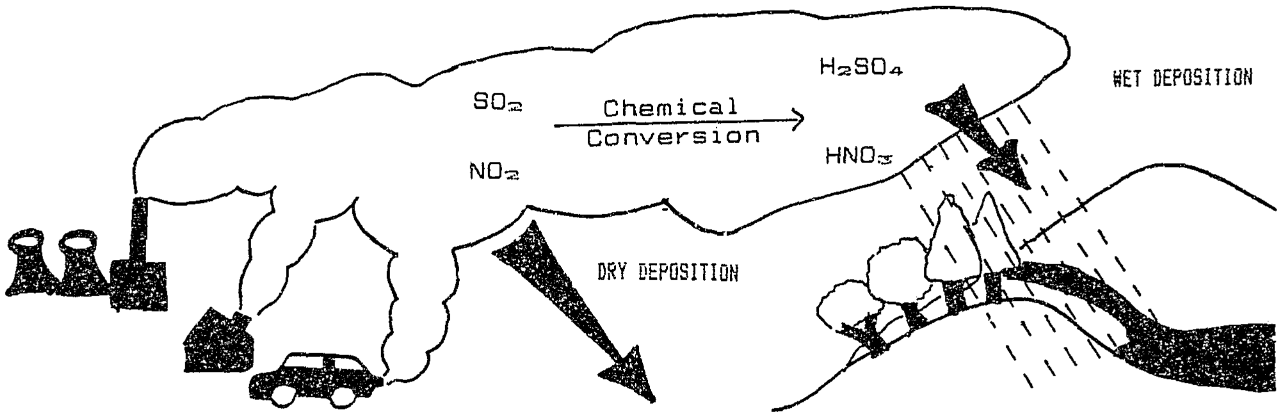
(Other more complex reactions can take place involving ozone, the hydroxyl radical and the solar radiation from the sun, but we shall not study those reactions here.)

The Effects of Primary Air Pollutants (SO_2, NO_x) and Secondary Air Pollutants (H_2SO_4 and HNO_3)

Sulphur dioxide, soot and fog combined to produce the episode of classical smog described in Unit 5. Although measures were taken to reduce the effects of these air pollutants and prevent such an episode from occurring again, sulphur dioxide still contributes to damage on life, the environment and materials.

Primary air pollutants, sulphur dioxide and nitrogen oxides released into the atmosphere, may react with the surfaces of materials and vegetation, close to the source. This is termed dry deposition. Weather conditions giving rise to stable atmospheric conditions (eg temperature inversions) can result in the accumulation of these pollutants. Tall chimney stacks were introduced to reduce this type of deposition by allowing winds and turbulence to dilute and disperse these pollutants. However they do not always provide the anticipated solutions: gases such as sulphur dioxide and nitrogen oxides may be transported hundreds of kilometres before reacting with water in the atmosphere and being deposited in rain, snow or hail. This is termed wet deposition.

Diagram Showing the Dry and Wet Deposition of SO_2 and NO_x



Let us study the effects of dry depositions:

1. Dry Depositions of SO_2

   Plants and trees may be affected by sulphur dioxide. Bleaching of leaves termed chlorosis, occurs during long periods of exposure. Sulphur dioxide may supress growth and thus reduce crop yields. Some plants eg lichens are very sensitive to sulphur dioxide concentrations. In fact, observation of the abundance of lichens is used to estimate sulphur dioxide concentrations.
   Respiratory problems may occur in humans.
   Sulphur dioxide can cause paints to dry and harden and metals such as iron and zinc, to corrode. Nylon is damaged by sulphur dioxide.

2. Dry Depositions of NO_x

   Nitrogen oxides do lead to plant damage. However it is difficult to assess which effects are directly from the

nitrogen oxides and which are the effects of secondary pollutants formed by photochemical reactions of nitrogen dioxide. At low concentrations nitrogen dioxide appears to stimulate growth.
Nitrogen oxides are potential health hazards.
Nitrogen oxides can cause fading of some textile dyes.

Wet depositions of SO_2 and NO_x lead to increased acidity of precipitations which have the following effects on:

1. Lakes

In Scandinavia, lakes are often found on beds of granite rocks. These lakes are very sensitive to increased acidity of precipitation as there are very low concentrations of dissolved substances which could counteract (neutralise) it. Freshwater fish are very sensitive to increases in acidity and this has resulted in many lakes in Scandinavia, having no fish populations. Lakes containing slaked lime (calcium hydroxide) are able to neutralise the acids and fish populations have not been so seriously depleted. Lime (calcium oxide) is added to some lakes to prevent the damage associated with increased acidity.

2. Soils

Low concentrations of nitrates and sulphates resulting from reactions of the sulphuric and nitric acids in rain and compounds in the soil, may initially improve the quality of soils.(They are fertilisers). However the accumulation of such compounds may cause the quality of the soil to deteriorate. Farmers are able to control the quality of soils for their crops by adding compounds such as lime to the soil. Problems arise in natural environments where the quality of the soil is not continuously monitored and adjusted.

3. Vegetation

It is reported that many forests in America and Europe are dying because of the adverse effects of the increased acidity of precipitations. It has been suggested that this leads to the dissolving and subsequent washing away of salts of magnesium and calcium which are essential plant nutrients. However the damage to vegetation is difficult to assess; trees seem to be affected by a combination of increased acidity, increased ozone concentrations, soil types, forestry methods, pests and drought. Forests themselves contribute to the acidity of the soil in which they grow. Thus the damage to vegetation is not yet fully understood.

4. Materials

Materials (eg. marble, limestone, slate and cement) which contain carbonate compounds are affected by increased acidity in precipitations. This is because the acids convert the insoluble carbonates into soluble compounds which are then washed away.

eg. $CaCO_3 + H_2SO_4 \longrightarrow CaSO_4 + CO_2 + H_2O$

(insoluble) (soluble)

To control this form of air pollution measures are being taken. These measures involve reducing the quantities of primary pollutants, sulphur dioxide and nitrogen oxides, that are released into the atmosphere. We shall study some of these measures in Units 9 and 10.

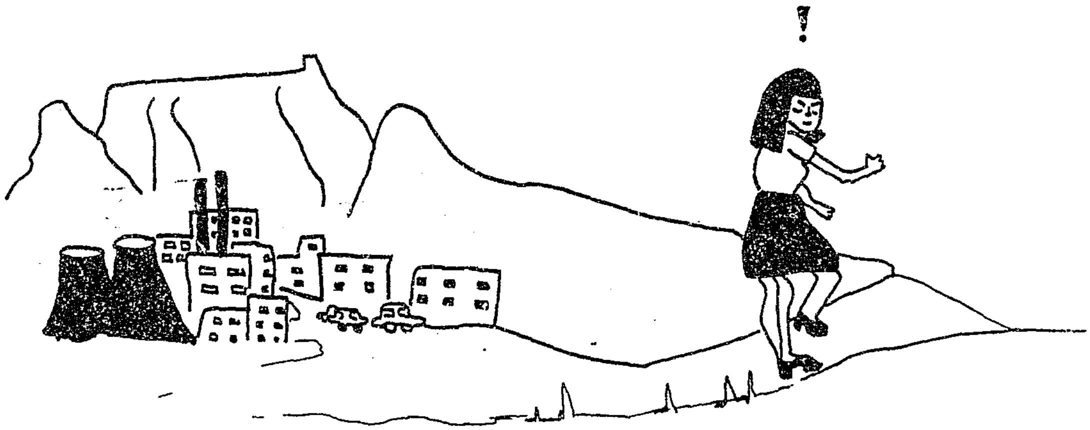
Learning Objectives for Unit 7

On completing this section students should be able to:

7.1 Explain that rain is naturally acidic.
7.2 Explain the terms "precipitation" and "acid rain".
7.3 Name the substances that give rise to the increased acidity of rain.
7.4 Name the gases (primary air pollutants) which are being released into the atmosphere and which contribute to the problem of increased acidity.
7.5 Describe the origin of these gases from natural sources.
7.6 Describe the origin of these gases from human activities.
7.7 Compare the contributions of natural sources and human activities to the total global release of these gases.
7.8 Explain the terms dry deposition and wet deposition.
7.9 Describe the effects of both dry and wet depositions of these gases on vegetation, the environment, health and materials.
7.10 Interpret graphical data showing contributions of human activities to the total releases of these primary pollutants.

Worksheet 7(a) "Petronella van Stinkblaar's Pantihose"

Read this passage and then answer the questions that follow on the next page.



"Acid rain made the news headlines in Cape Town as early as April 1973. Female office workers in the vicinity of downtown Table Bay power station complained of pollution-laddered stockings and pantihose. It was reported that one woman claimed she lost one new pair of pantihose in this way each day! Another worker received mild acid burns to her face, neck and arms from pollution fall-out while she walked through the city.

A daily plume of dense white smoke would pour forth from the stacks of the oil-fired electricity plant in Dock road and then descend on the lower slopes of Table Mountain, near the prestigious Disa Park flats complex. Burglar-bars and steel railings corroded, plants wilted and residents suffered from obvious eye, nose and throat irritation. At the new BP centre, close to this source of air pollution, the air conditioning system was severely corroded after only two years in use.

Cape Town is situated in a bowl-like setting, surrounded by mountains on one side and the ocean on the other. This setting produces a notorious "inversion effect" in which air pollutants are trapped over the city. However under different wind conditions, chemical emissions from local power plants, factories and motor vehicles can travel as far as the Hex River Valley before acid rain falls.

Operations at the Table Bay power station were phased out over 1973-74 as a result of the escalation of oil prices and local environmentalist pressure."

(An adaptation of an article in "Rotating the Cube"- Indicator Project South Africa)

Questions

Please answer on a separate sheet of paper.

1. Explain the meaning of the term "acid rain".
2. What does the phrase "chemical emissions" (from power plants, factories and motor vehicles) mean?
3. Make a list of the effects of the air pollutants as noted in this article.
4. Name (and give the formulae) of the air pollutants you believe are the main contributors to these effects.
5. What activities in the city were contributing to these air pollution problems?
6. Why was oil combusted in the Dock road (Table Bay) power station?
7. i) Explain what is meant by the notorious "inversion effect"?
   ii) Discuss the role played by this effect in the problems of air pollution discussed in this article.
8. Describe the ways in which the air pollutants giving rise to "acid rain" in the city and neighbouring regions, are deposited. (Quote passages from the article to substantiate your answer.)
9. Explain why the deposition of "acid rain" over the Hex River valley is a matter of concern?
10. The Dock road (Table Bay) power station is no longer in operation. How does ESKOM generate electricity in this region now?
11. Although the Dock road (Table Bay) power plant is no longer in operation, air pollution problems still persist in this region. In July 1991, the concentrations of some air pollutants were as much as 30% higher than the recommended limits suggested by international standards. Explain why you think this is so.

Worksheet 7(b) Lichens as Indicators of Sulphur Dioxide Concentrations.

Lichens are plants which respond readily to air pollution. They are found in urban and rural environments. They grow on walls, buildings, roofs, trees, rocks etc. The less the pollution of the air in which they are growing, the greater the variety of lichens you will find. Polluted air supports a smaller variety of lichens although there may be many lichens of the same variety. In rural, unpolluted areas, 12 or more types of lichen may be identified. In urban, polluted areas, only one or two (if any) species may be found.

The table below may help you identify some of these varieties (forms) of lichen:

Variety/Form	Description
Powdery	Bright green or yellow, easily rubbed off (in fact this form is not a lichen)
Crusty	Flat, cracked. Very difficult to rub off. Grey or green.
Leafy	Flat with small, crinkly leaves. Easy to remove. Can put fingernail beneath them. Many colours including yellow, orange, green, grey, white and black.
Shrubby	Bushy, or long and straggly with circular and flat branches. Grey and green.

Method

1. Select a surface such as a tree or a concrete wall.
2. In a number of different environments count the numbers of different forms of lichen found on such a surface.
3. Make a record of the type of surface you selected for your observations and the types of environment in which you were able to find this surface.
4. The abundance of lichen forms has been related to concentrations of sulphur dioxide present in the air as shown in the table below:

POLLUTION	LICHEN FORMS	CONCENTRATION SO_2 IN $\mu g\ m^{-3}$
Very polluted	No lichens	170
Polluted	Powdery and crusty	125 - 150
Slightly Polluted	Powdery, crusty and leafy	40 - 70
Unpolluted	Powdery, crusty, leafy and shrubby	30

Use this table to estimate the sulphur dioxide concentrations in the environments you studied.

Observations

Surface Studied.......................................

Type of Environment	Estimated concentration of $SO_2/\mu gm^{-3}$

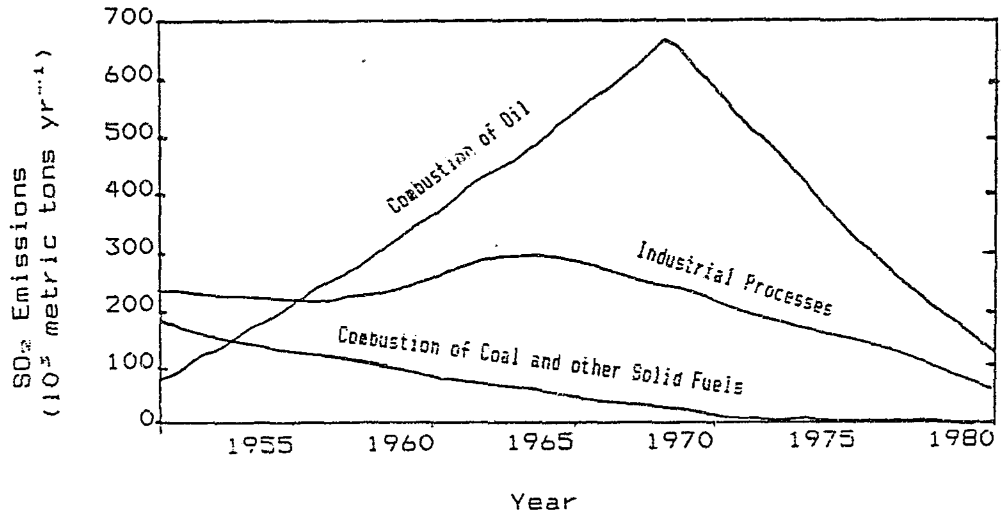
Adapted from
Testing the Air (Junior Projects No 53, 1990)
by B. Chambers.

Worksheet 7(c) Graphical Interpretation

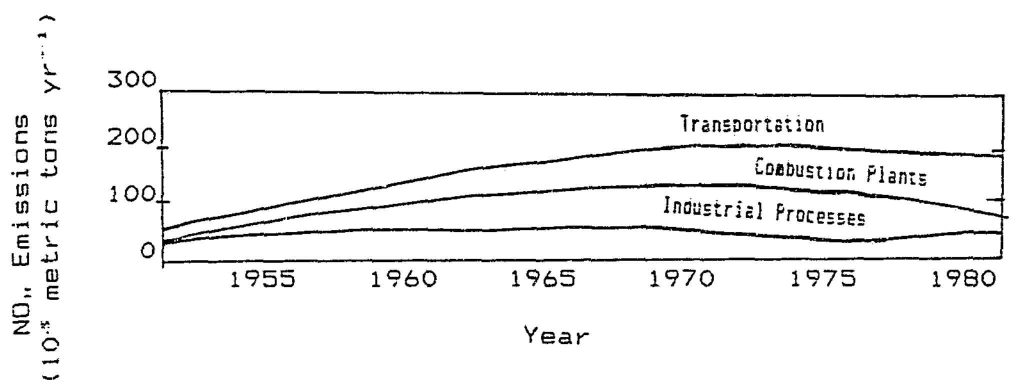
The increased acidity of rain in Europe and America has been researched for a longer time than that in South Africa. Data from Europe (Sweden) is presented in this exercise. The contributions are shown of various activities to the primary air pollutants that give rise to the increased acidity in precipitations.

Look at the graphical data and then write a paragraph in which you discuss the activities and their contribution to the problem of increased acidity in precipitations. Comment, as well, on the trend in quantities of the gases formed and released into the atmosphere.

Graphical Data for the Release of SO_2 into the Atmosphere in Sweden



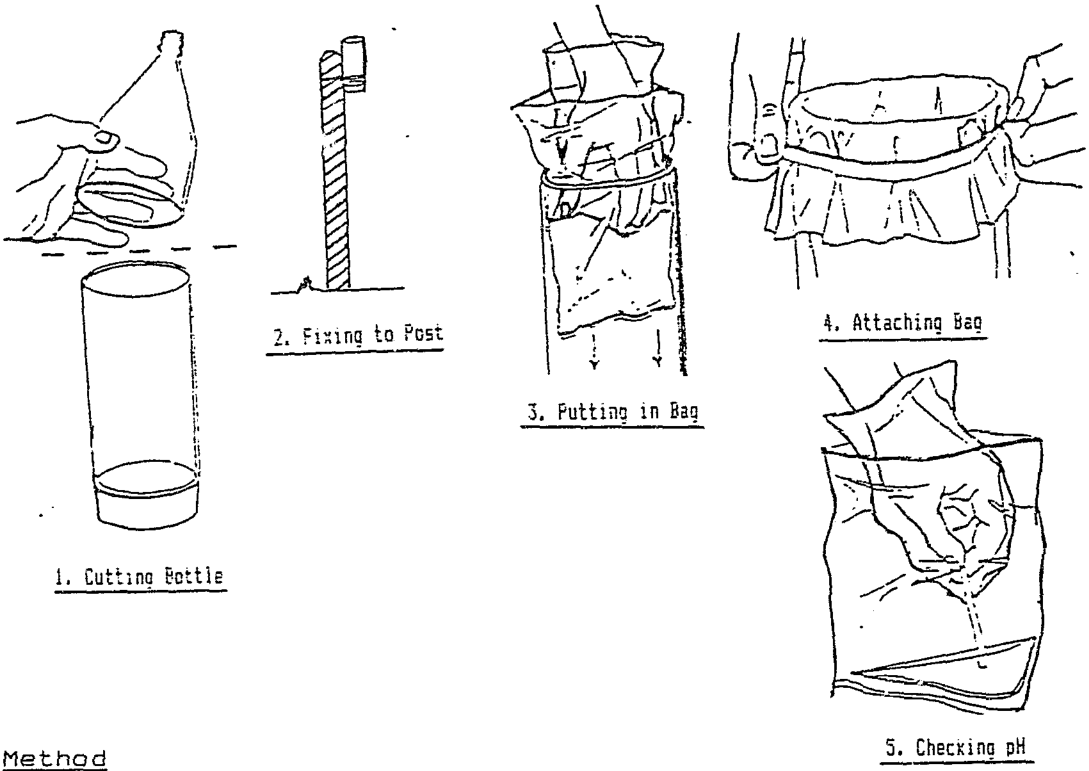
Graphical Data for the Release of NO_x into the Atmosphere in Sweden



Taken from
Acid Rain (unpublished notes)
Schools Information Centre on Chemical Industry,
Polytechnic of North London.

Worksheet 7(d) Monitoring Rain

Requirements
1 empty 2 litre plastic cooldrink bottle
40 - 50 plastic bags (these can be washed and re-used)
elastic bands
Universal pH indicator paper and colour chart
1 plastic spoon
1 compass
1 flag or piece of material
A map of your area.



Method
1. Cut the plastic bottle open as shown in the diagram.
2. Fix the bottle to a post with a strong elastic band. Choose a site out in the open, away from overhanging trees or buildings (and away from inquisitive people and animals!)
3. Every morning, at the same time, put a clean plastic bag into your collecting bottle. (Use another plastic bag as a glove - you must not touch the inside of the collecting bag as the sweat on your hands is acidic.) Use an elastic band to fix the collecting bag to the bottle.
4. Check the wind direction using the flag and compass.
5. Every evening, test the pH as shown in the diagram.
6. Keep a record for a period of about 20 days.

Record of Results

Keep a record of your results under the headings:

Date	pH	Wind Direction	Contamination eg. dirt, leaves, bird droppings.

Analysis of Results

1. Use eight wind direction categories:
   N, NE, E, SE, S, SW, W, NW.
2. List the pH values for the rain under a wind direction category and then find the average pH of the rain in each wind direction category.
3. Plot a graph of average pH (on the vertical axis) against the wind direction categories.
4. Analyse your results bearing in mind the following questions: (You will probably need to look at a map of your area to assist you in your analysis.)
   i) Are there any local sources of air pollution which may affect the acidity of the rain water? (eg. busy roads, power stations, industries, large town etc.)
   ii) Do your results indicate long distance pollution from known industrial sites?
5. Write a short report of not more than a page, on the analysis of your results from this investigation.

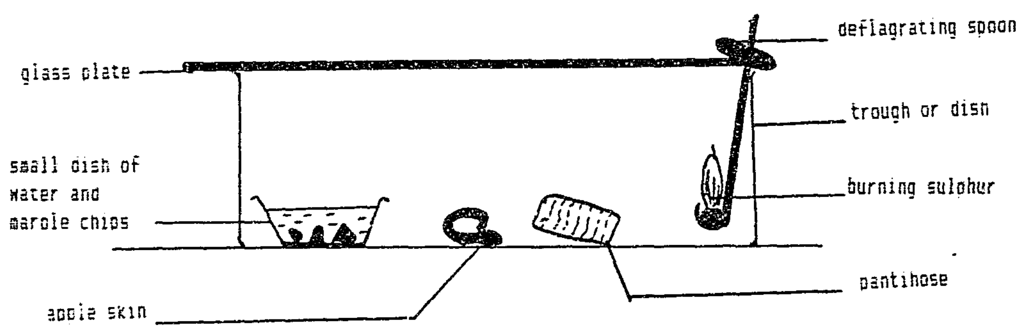
Adapted from
WATCH. Acid Drops Project
by N. Cape, J. Baker.

Worksheet 7(e) Simulating "Dry Deposition"

Be careful not to inhale the gas made during this simulation. Use a fume cupboard if there is one available or perform the experiment in the open air outside the classroom.

Requirements
1 glass trough (or a large dish)
1 glass plate
1 small dish
1 deflagrating spoon
powdered sulphur
some apple skin
a piece of pantihose
a few marble chips
matches
pH paper
Bunsen burner

Diagram of Apparatus



Method
1. Observe the condition of the apple skin and piece of panti-hose and place them inside the trough. (Stretch the pantihose over a small metal frame for better exposure.)
2. Fill the small dish with some tap water. Place the marble chips in the dish of water and observe their appearance. Measure and record the pH of the water using some pH paper.
3. Place the dish of water (and the marble chips) inside the trough.
4. Half-fill the deflagrating spoon with some powdered sulphur.
5. Light the Bunsen burner and ignite the sulphur by holding the spoon over the burner until you observe a blue flame.
6. Quickly insert the spoon into the trough and cover as much of the trough as possible with the glass plate.
7. After 2 minutes, remove the spoon and quickly cover the trough with the glass plate. Extinguish the flame under a

dripping tap.

8. Leave the contents of the jar for approximately half an hour
9. Remove the glass plate and measure and record the pH of the water in the dish using the pH paper.
10. Remove the apple skin, pantihose and marble chips from the trough. Observe and note any changes in their appearance.

Observations

1.

	Before SO_2 formation	After SO_2 formation
pH of water		

2.

Object	Changes in Appearance
Apple Skin Panti- hose Marble Chips	

Explanations
Please write your answers on a separate sheet of paper.

1. Write a balanced equation to represent the combustion of the sulphur.

2. Explain why the pH of the water in the dish changed. (Include any chemical equations you feel are important in your explanation.)

3. Explain the changes you observed in the marble cnips. (Include any equation(s) you feel are important)

4. Relate your answer to (3) to the damage shown in the picture on the next page.

Appearance of a Sculpture in Germany built in 1702:

a) in 1908 b) in 1969

Taken from
Inside Chemistry
by C. Compton.

5. Explain the changes you observed in the apple skin and the pantihose.

6. Name four activities that give rise to this primary air pollutant, SO_2.

Experiment is adapted from
Air Pollution
by C.P. Lavaroni, P.A. O'Donnell.

Worksheet 7(a) "Petronella van Stinkblaar's Pantihose"

1. "Acid rain" is any precipitation (rain, snow, hail, dew, frost) that has a pH value less than 5,6.

2. The phrase "chemical emissions" means the substances which are released into the atmosphere as a result of chemical reactions taking place during the combustion process in the power stations, during industrial processes and during the combustion of petrol in motor vehicles. Most of these chemical substances which are released are air pollutants.

3. Laddered stockings
   Mild acid burns to the face, arms neck
   Corrosion of burglar-bars, steel railings
   Plants wilted
   Eye, nose, throat irritation
   Corrosion of air conditioning system after 2 years

4. SO_2 and NO_x (NO and NO_2)
   ie. sulphur dioxide and nitrogen oxides (nitrogen monoxide and nitrogen dioxide)

5. The combustion of oil at the power station
   Industrial processes at factories
   Combustion of petrol in motor vehicles

6. Oil was combusted because Cape Town is far from the coal fields and the large power stations in the Transvaal. It was more economical to use oil (transported to Cape Town by oil tankers.)

7. (i) The notorious "inversion effect" is a temperature inversion which gives rise to stable air conditions.
   (ii) Air pollutants are not dispersed and accumulate in the atmosphere above Cape Town.

8. "Worker received mild acid burns.....from <u>pollution fall-out</u> " is a sentence used in the passage.
   "<u>Pollution fall-out</u>" is usually termed <u>dry deposition</u>. In this deposition, $SO_2(g)$ and $NO_x(g)$ react directly with the surfaces of substances that these gase come into contact with.
   "Chemical emissions.........Hex River Valley before <u>acid rain f-lls</u>", is a sentence in the passage.
   "<u>Acid rain falls</u>" refers to wet deposition of SO_2 and NO_x . SO_2 and NO_x react with water droplets to form H_2SO_4 and HNO_3 and are deposited in the rain.

9. *This valley is a wine-producing region. Acid rain damages the vines and the grapes. This affects the quality of the wine produced. This has economic consequences.*

10. *ESKOM generates electricity from the Koeberg nuclear power station, situated 40 km from Cape Town.*

11. *Air pollution is still caused by other industries and the ever-increasing numbers of motor vehicles in the city. Increased urbanisation and population growth contribute to the air pollution. Photochemical smog remains a serious problem in the city.*

Worksheet 7 (c) Graphical Interpretation

Release of SO_2

Combustion of oil (since 1953) releases more SO_2 than the combustion of coal. Since ~1957, the combustion of oil released more SO_2 than industrial processes. The combustion of oil is used in power stations and for transportation. Since 1973, the release of SO_2 by the combustion of oil and industrial processes has been steadily reduced. This is most probably due to improved technology to reduce SO_2 emissions.
Emissions of SO_2 from coal have been steadily declining since 1950 - possibly because of a reduction in the use of coal as a fuel.

Release of NO_x

Transportation produces more NO_x than does the combustion of coal and industrial processes. Industry produces the smallest quantities.
After the steady increase to 1970 – 1975, emissions of NO_x have remained more or less constant (although the use of processes which release NO_x has probably increased). Catalytic converters have probably been used on motor vehicles to reduce the release of NO_x. Improved methods of combustion in power plants (power stations) and improved technology have probably reduced the release of NO_x.

Worksheet 7(e) Simulating "Dry Deposition"

Observations

1. pH should decrease after the formation of SO_2 in the trough.

2.

Object	Changes in Appearance
Apple Skin	Pale (white) marks appear on the skin
Panti-hose	Holes develop
Marble Chips	Surface changes and crumbles

Explanation

1. $S(s) + O_2(g) \longrightarrow SO_2(g)$

2. (i) SO_2 reacts with O_2 to form SO_3

$2SO_2(g) + O_2(g) \longrightarrow 2SO_3(g)$

$SO_3(g)$ reacts with water to form sulphuric acid

$SO_3(g) + H_2O(l) \longrightarrow H_2SO_4(aq)$

(ii) In addition $SO_2(g)$ can also react with water to form sulphurous acid

$SO_2(g) + H_2O(g) \longrightarrow H_2SO_3(g)$

Because of the formation of these acids, the pH is less.

3. The sulphuric acid formed reacts with the marble to form another compound, $CaSO_4$, which crumbles away.

$$CaCO_3(s) + H_2SO_4(aq) \longrightarrow CaSO_4(aq) + H_2O$$

marble calcium carbonate — sulphuric acid — calcium sulphate

4. The damage shown in the picture is caused by the reaction quoted in (3). The calcium sulphate formed is soluble in water and is washed away in the rain.

5. SO_2 reacts with compounds making up the skin of the apple and making up the nylon of the pantihose.

6. (a) Combustion of coal
   (b) Coal mining operations
   (c) "Roasting" of ores containing sulphur

UNIT 8

The Control of Air Pollution

Introduction to Unit 8

In this Unit we shall study the control of air pollution by the following means:

A. The Natural Removal of Air Pollutants from the Atmosphere

B. The Law

C. International Agreements

D. Research Organisations

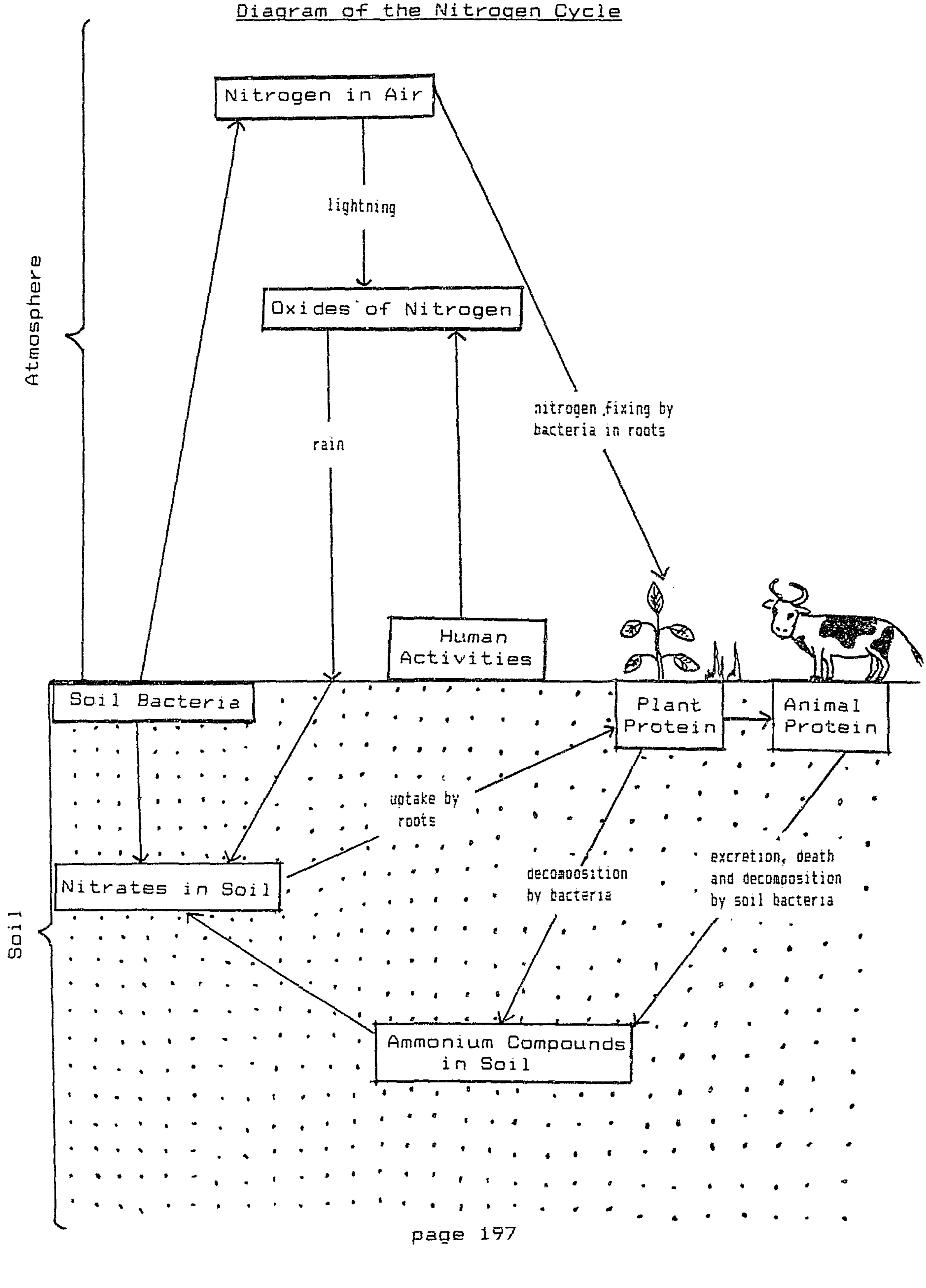
E. Environmental Groups

A. The Natural Removal of Air Pollutants from the Atmosphere

To maintain the constant concentration of substances in the atmosphere (a steady state), the rate at which these substances are released into the atmosphere should equal the rate at which they are removed from the atmosphere. (See Unit 2). Solid and liquid air pollutants may eventually drop out of the atmosphere and be deposited on surfaces. Gaseous pollutants may dissolve in droplets of water in the atmosphere and be deposited in rain, snow, hail, frost and dew. Air pollutants may also undergo chemical reactions with other substances present in the atmosphere and be converted to less harmful substances.

During these processes of change and removal, there is often an interaction between the atmosphere, the land (lithosphere), the oceans, rivers, lakes etc (hydrosphere) and living systems (biosphere). A change occurs in the distribution of substances from the atmosphere by means of chemical and/or physical processes. This redistribution of substances can manifest itself in cycles, for example carbon cycle (Unit 6). Other cycles involving elements such as nitrogen, oxygen and sulphur occur. Air pollutants are trace components of the atmosphere and form a part of these cycles. On the next page is a diagram of one of these cycles, for example the nitrogen cycle.

Diagram of the Nitrogen Cycle



In the troposphere, the hydroxyl radical, (OH) is a very important species that takes part in the chemical conversion of some air pollutants (eg. methane, carbon monoxide, sulphur dioxide, nitrogen oxides, etc). Its concentration in the troposphere is approximately 0,00001 ppb. This concentration is very small but the hydroxyl radical is very reactive. The hydroxyl radical is formed mainly by the following processes:

i) A small amount of ozone drifts across the tropopause and enters the troposphere. Ozone absorbs solar energy with a wavelength less than 310 nm, and reacts to form oxygen molecules and highly reactive oxygen atoms.

$$O_3 \xrightarrow[\lambda < 310\ nm]{hv} O_2 + O$$ (See Unit 4)

ii) The oxygen atoms produced react with water molecules present in the troposphere to form hydroxyl radicals.

$$O + H_2O \longrightarrow 2OH$$

Some examples of reactions of this radical are the following:

a) <u>Reaction with methane</u>

$$CH_4 + OH \longrightarrow CH_3 + H_2O$$

The methyl radical produced reacts with oxygen in the air to form organic compounds which may ultimately be converted into carbon monoxide. The hydroxyl radical is able to react readily with any compound containing a carbon-hydrogen bond.

b) <u>Reaction with carbon monoxide</u>
The carbon monoxide generated in (a) and the carbon monoxide released directly into the atmosphere, reacts with the hydroxyl radical to form carbon dioxide and water.

$$CO + 2OH \longrightarrow CO_2 + H_2O$$

c) <u>Reaction with sulphur dioxide</u>
Sulphur dioxide reacts with the hydroxyl radical to form a reactive sulphur containing radical, $HOSO_2$.

$$SO_2 + OH \longrightarrow HOSO_2$$

This sulphur-radical further undergoes a series of complex reactions to form sulphuric acid, H_2SO_4.

The sulphuric acid produced may be removed from the atmosphere when it dissolves in precipitations such as rain, snow etc.

d) Reaction with nitrogen dioxide

Nitrogen dioxide can react with the hydroxyl radical to form nitric acid.

$$NO_2 + OH \longrightarrow HNO_3$$

The nitric acid produced may be precipitated in rain etc.

The ease with which substances can be removed from the atmosphere is reflected in the results of calculations of average times that substances remain in the atmosphere.

Table showing the Average Times Some Substances remain in the Atmosphere

Substance	Average Residence Time in the Atmosphere
CO	months
CO_2	$\sim$100 years
CH_4	$\sim$10 years
NO_x	days
SO_2	days - weeks
CFCs	60 - 100 years
N_2O	$\sim$170 years

Since the Industrial Revolution in the 19th Century, the rates at which some substances are being released into the atmosphere have exceeded their rates of removal from the atmosphere, by natural processes. The result is that some substances are accumulating in the atmosphere. For example, at present the concentration of carbon dioxide is increasing by 2,3% per year. The concentration of methane is increasing by 1,7% per year. (See graphs Unit 2.) Human activities are a major source of the substances giving rise to the problem of air pollution. It is necessary for humanity to control the release of air pollutants into the atmosphere. Some aspects of this control are enforced by the Law.

B. The Law

We shall focus on the legal air pollution policy for the Republic of South Africa. An official investigation into the desirability of air pollution control was conducted in 1955. This led to the promulgation of the Air Pollution Prevention Act in 1965. Air pollution control became the responsibility of a number of officials in the Department of Health and Population Development under the guidance of the Chief Air Pollution Officer. The aim of this legislation is to prevent the concentrations of air pollutants exceeding those that are safe for humans and the environment.

To achieve this, control is exercised over:

1. Industrial Pollution
   The extent of air pollution is monitored. The release of sulphur dioxide, nitrogen oxides, volatile hydrocarbons, visible particles and other poisonous gases is limited. This is achieved by the installation of air cleaning equipment and regular inspections of industries. New plants are fitted with the latest air cleaning equipment. Research is conducted into problems and possible solutions.

2. Smoke Pollution
   Legally acceptable concentrations of smoke in residential areas have been established.

3. Dust Control
   Measures for controlling dust from mining operations and mine dumps, are stipulated.

4. Vehicle Emissions
   Visible smoke from vehicles is not allowed. The concentrations of lead compounds in petrol are being reduced. The release of hydrocarbons from exhausts is controlled.

To control air pollution, guide lines for acceptable concentrations of air pollutants (for example sulphur dioxide, nitrogen oxides and ozone) are given.

Table of Acceptable Concentrations of Some Air Pollutants (RSA)

Pollutant	Concentration ($\mu g\ m^{-3}$)		
	Period		
	1 hour	24 hour	1 year
SO_2	780	265	80
NO_x	1080	540	270
O_3	240	100	-

Equipment for reducing air pollution is very expensive to install and operate. A recent survey has shown that, in the Republic of South Africa, the industrial sector has installed air cleaning equipment costing more than R2500 million over the last decade. Annual operation costs more than R100 million. Therefore, in finding solutions to air pollution problems, a balance has to be found between what is essential for a safe and healthy environment and what can be afforded by industry. This method of control is referred to as control by the best practicable means. This flexible and adaptable method is found to be most suitable for a developing country like South Africa.

Some areas in South Africa present bigger air pollution problems than others. Such areas have greater priority with respect to air pollution control. These areas are:

The Pretoria-Witwatersrand area.
The Eastern Highveld.
The Greater Durban Area.
The Western Cape.

The South African Air Pollution policy allows for participation in international treaties and agreements.

C. International Agreements

Global air pollution problems have arisen because of the production and use of CFCs. These CFCs are used as propellants in spray cans, as blowing agents in foam plastics, as refrigerants in refrigerators, freezers and air-conditioners and as solvents for cleaning electronic equipment. (See Unit 4.) In 1985, research findings were released which indicated that CFCs are largely responsible for stratospheric ozone depletion. In 1987, 39 nations signed an agreement, the Montreal Protocol, to reduce their use of CFCs by 50% by 1999. At a United Nations conference in

Helsinki in 1989, 89 nations signed an agreement calling for an end to the production and use of CFCs by the year 2 000. South Africa signed this agreement. AECI is the sole producer of CFCs in South Africa but its products are used by a large number of other industries.

The cost of finding and manufacturing alternative products, has resulted in some nations eg. China, refusing to comply with these conditions. We shall study some of the alternative products in Unit 10.

The possibility of an enhanced greenhouse effect, is also a global air pollution problem. The problem of increased acidity in precipitations such as rain and snow is leading to regional air pollution problems often crossing the borders of countries. It has been suggested that an International Law of the Atmosphere should be formulated to control the release of gases which contribute to these problems.

D. Research Organisations

In many countries around the world, the atmosphere is being carefully monitored and researched. Research teams use sophisticated technology which can identify and measure the concentrations of the components of the atmosphere. In South Africa, a monitoring station at Cape Point provides valuable information on the composition of the atmosphere in the Southern Hemisphere. The Council for Scientific and Industrial Research (CSIR), in Pretoria has a division for Atmospheric Research. Some South African universities are also conducting research into air pollution problems.

The pooling of research findings from many disciplines such as biology, geography, geology, chemistry, physics, results in a deeper understanding of the problems of air pollution. With this understanding comes the search for and development of solutions to the problem.

E. Environmental Groups

In the 1960's, Rachel Carson wrote a book, "The Silent Spring". This book emphasised the problems of environmental damage. During the 1980's, public awareness of global environmental problems began to grow. The protection and preservation of the environment became the aim of many groups and societies, for example the "Greenpeace movement". Pressure is exerted by these groups/societies at local, national and international levels. Emphasis is placed on the participation of the community in decision making.

"Green" politics emerged in countries like West Germany. Green political parties give prominence to environmental issues.

The contribution of many of these "green" pressure groups has been very valuable in the control of environmental issues such as air pollution. However the response of some groups to environmental problems has been emotional and inaccurate. Solutions offered by such groups are sometimes unrealistic and too idealistic.

The emergence of "green" movements indicates that communities and the public at large will become more deeply involved in the formulation of solutions to the problem of air pollution in the future.

In Units 9 and 10 we shall study some of the measures being taken to control air pollution.

Learning Objectives for Unit 8

On completing this unit students should be able to:

8.1 Describe the role played by natural processes in the removal of air pollutants from the atmosphere. (Details of the carbon and nitrogen cycle need not be recalled.)
8.2 Explain the difference between the hydroxyl radical and the hydroxyl (hydroxide) ion.
8.3 Explain (with the aid of equations), the formation of the hydroxyl radical in the atmosphere.
8.4 Quote equations showing the reaction of the hydroxyl radical a) with carbon monoxide and
b) with nitrogen dioxide
8.5 Explain why some trace components of the atmosphere are accumulating and giving rise to problems of air pollution.
8.6 Briefly discuss the control of air pollution in South Africa by legislation.
8.7 Discuss the control of global air pollution by international agreement eg. the Montreal Protocol.
8.8 Discuss the role played by technology and research in controlling air pollution.
8.9 Discuss the role played by environmental groups in the control of air pollution.

Worksheet 8(a) The Natural Removal of Air Pollutants from the Atmosphere

Please write your answers on a separate sheet of paper.

Task 1

The concentration of the hydroxyl radical in the atmosphere is very small (0,00001 ppb !). Yet the hydroxyl radical plays a very important role in the chemistry of the troposphere.

i) With the aid of Lewis diagrams, explain the difference between the hydroxyl radical and the hydroxyl (hydroxide) ion.

ii) Why is the hydroxyl radical so reactive?

Task 2

With the aid of equations show how the hydroxyl radical is produced in the atmosphere.

Task 3

Nitrogen oxides may be removed from the atmosphere by a number of natural processes. Discuss two of these processes. (Make use of chemical equations to clarify your answer.)

Task 4

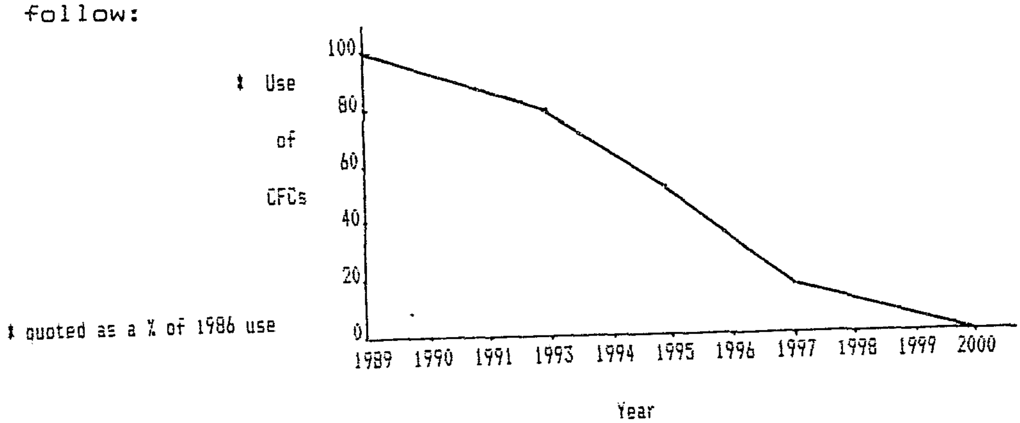
Explain the removal of carbon monoxide by natural processes from the atmosphere. (Make use of chemical equations to clarify your answer.)

Task 5

If air pollutants are able to be removed from the atmosphere by natural processes, why is air pollution a problem?

Worksheet 8(b) Controlling the Use of CFCs

Look at the data given below and answer the questions that follow:



Questions

Please write your answers on a separate sheet of paper.

1. What are CFCs?

2. What are the uses of CFCs?

3. Name articles in your household that require the use of CFCs in their manufacture.

4. Briefly describe the proposed trend in usage of CFCs from 1986 to 2000.

5. Why is it believed that this trend in CFC usage should be closely adhered to?

6. By what means are some nations of the world committed to this trend in CFC usage?

7. Why have some nations not committed themselves to this proposed trend?

8. Has South Africa committed itself to this proposed trend in CFC usage?

9. Name the company that is the sole producer of CFCs in South Africa.

10. Discuss some of the implications and possible problems this company is facing with regard to CFC manufacture.

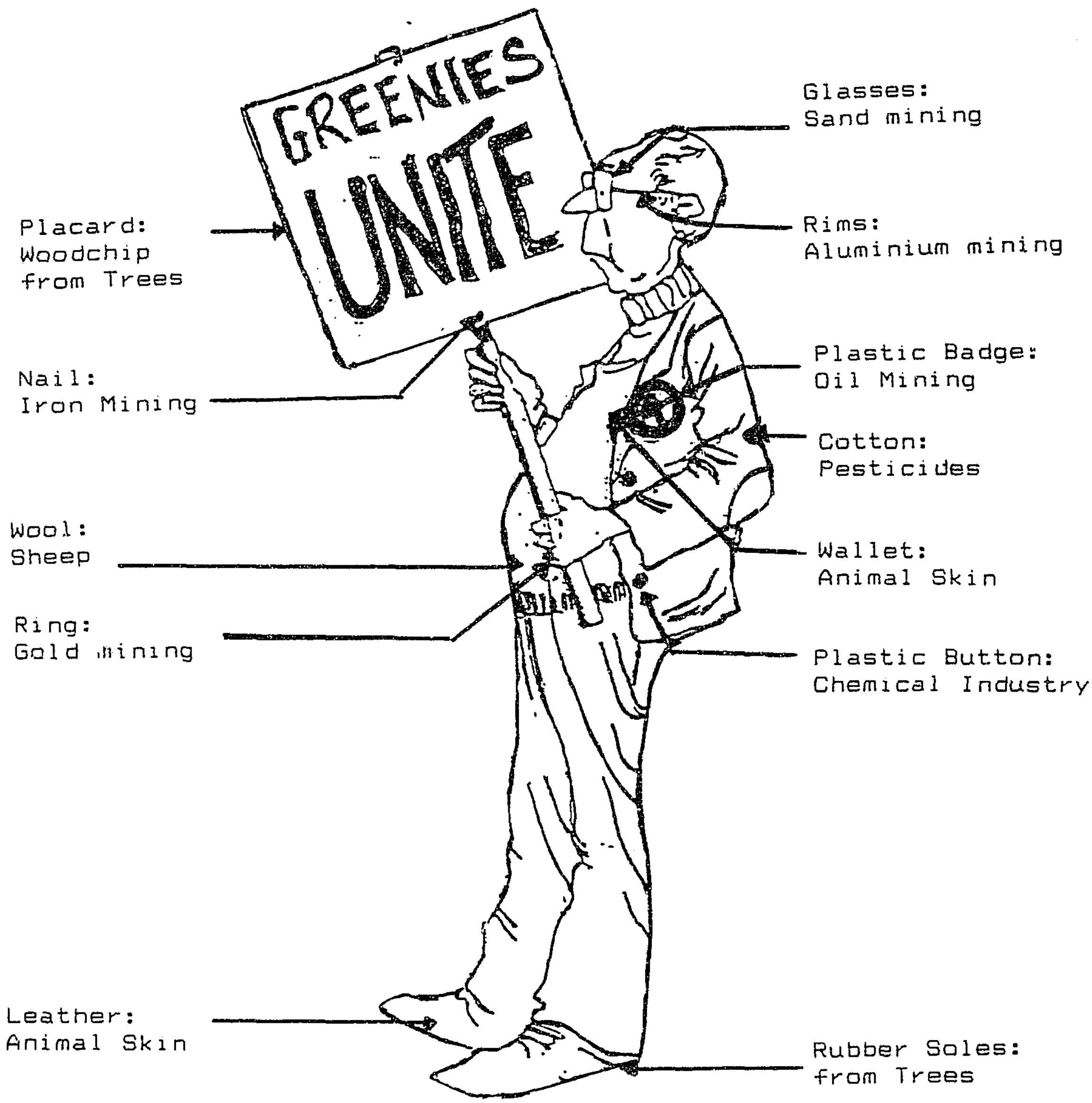
11. Will the environmental problems linked to the use of CFCs be immediately solved if the manufacture of CFCs is stopped? Explain.

Worksheet 8(c) "Greenies"

This man cooked some porridge on the electric stove. He ate it with milk from the fridge. Then he washed his hands with some soap and hot water. He left his heated home and drove to the protest meeting in his car.

Instructions
Write a short comment (not more than 1 page) entitled:

"The Involvement of Green Movements in the Problem of Air Pollution"

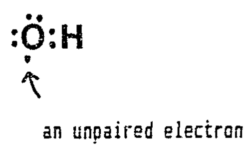


<u>Solutions to Worksheets for Unit 8</u>

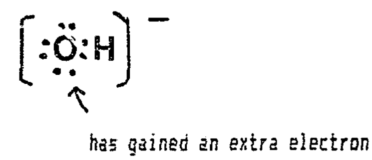
<u>Worksheet</u> 8(a) The natural Removal of Air Pollutants from the Atmosphere

<u>Task 1</u>

(i) <u>Hydroxyl Radical</u>



<u>Hydroxyl (hydroxide) ion</u>



(ii) The presence of the unpaired electron makes the hydroxyl radical very reactive.

<u>Task 2</u>

(i) A small quantity of ozone slowly drifts down into the troposphere and is dissociated into molecular oxygen and atomic oxygen.

$$O_3 \xrightarrow[\lambda\ <\ 310\ nm]{hv} O_2 \quad + \quad O$$

(ii) Oxygen atoms react with water molecules to form hydroxyl radicals.

$$O \quad + \quad H_2O \longrightarrow 2OH$$

<u>Task 3</u>

(i) $$2NO_2 \quad + \quad H_2O \longrightarrow HNO_3 \quad + \quad HNO_2$$

This is the formation of acid rain. The nitrogen dioxide reacts with droplets of water in the atmosphere. The nitric acid (HNO_3) and the nitrous acid (HNO_2) are removed from the atmosphere by the precipitation of rain, snow etc.

(ii) $$NO_2 \quad + \quad OH \longrightarrow HNO_3$$

Nitrogen dioxide reacts with the hydroxyl radical to form nitric acid. The nitric acid is removed from the atmosphere by the precipitation of rain, snow etc.

Task 4

Carbon monoxide reacts with the hydroxyl radical to form CO_2 and water.

$$CO + OH \longrightarrow CO_2 + H_2O$$

The carbon dioxide may be removed from the atmosphere by the precipitation of rain. (Carbon dioxide reacts with water to form carbonic acid.)

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

The carbon dioxide could also be removed from the atmosphere by plants using carbon dioxide during photosynthesis.

Task 5

The rate of removal of air pollutants by natural processes, is less than the rate of release of air pollutants into the atmosphere. This leads to increases in the concentrations of these substances (air pollutants) in the atmosphere.

Worksheet 8(b) Controlling the Use of CFCs

1. Compounds whose molecules consist of carbon, fluorine and chlorine atoms.

2. Used (i) as refrigerant gases
   (ii) to blow tiny bubbles into foam rubber
   (iii) to blow bubbles into polystyrene
   (iv) as solvents to clean electronic equipment
   (v) as propellants in aerosols

3. Fridges, air conditioners, electronic equipment (eg. calculators), computers, foam rubber (eg. for mattresses), aerosols (eg.deodorants), polystyrene (eg. cups).

4. CFC usage should be reduced as follows:
   (Percentages quoted are % of 1986 usage.)
   By 1993 CFC usage reduced to 80%
   By 1995 CFC usage reduced to 50%
   By 1997 CFC usage reduced to 15%
   By 2000 CFCs should no longer be in use

5. CFCs are causing serious depletion of ozone in the stratosphere.

6. Some nations have signed the Montreal Protocol agreeing to reduce CFC production.

7. It is very expensive to find and produce alternative products.

8. Yes

9. AECI (Previously known as African Explosive and Chemical Industry)

10. This industry is having to build new production plants and provide new technology to produce alternative products. The costs are tremendous.

11. No. CFCs will remain in the atmosphere for a long time - Some of them for ~150 years! Therefore although the production and use of CFCs are stopped, the depletion of ozone in the stratosphere will continue until well into the next century.

<u>Worksheet</u> 8(c) "Greenies"

** This worksheet could also be used to initiate a classroom debate.*

Some comments on this exercise:

1. *It seeks to stress that we are <u>all</u> involved in the problems of air pollution. We contribute to air pollution by the <u>products we buy</u>. For example, those products shown in the diagram involving mining, industry, cutting down of trees etc.*
   We also contribute to air pollution by <u>our activities</u>. For example, using cars, using fridges, using electricity for heating and cooking etc.

2. *Some students may feel the cartoon "pokes fun at the environmental ("green") movements. The exercise may stir up some lively discussions!*
   The cartoon is not used to mock the green movements. (Cartoons are used throughout this teaching package.)
   It is very important that we become aware of the environmental consequences of our lifestyles.
   Green movements have and are playing very valuable roles in the preservation of the environment. Sometimes, however, the response of some groups to environmental problems is emotional and inaccurate. For example, a leading pharmaceutical company in Germany finds that it is very restricted by limitations placed on its functioning by "green politics". It is almost no longer economically viable for the company to function. Consideration is being given to moving the company to another country. This would have serious employment and economic implications.
   A <u>balance</u> must be found between the <u>benefits</u> offered by the processes we use and the <u>risk</u> they pose to the environment. It is not a solution to stop or slow down technological development. We must use our ingenuity to reduce any negative impact this technology presents for the environment. The public, the "green" movements, scientists, industrialists, governments must all be involved in the search for ways for us to live in harmony with our environment.

UNIT 9

The Response by Industry

Introduction to Unit 9

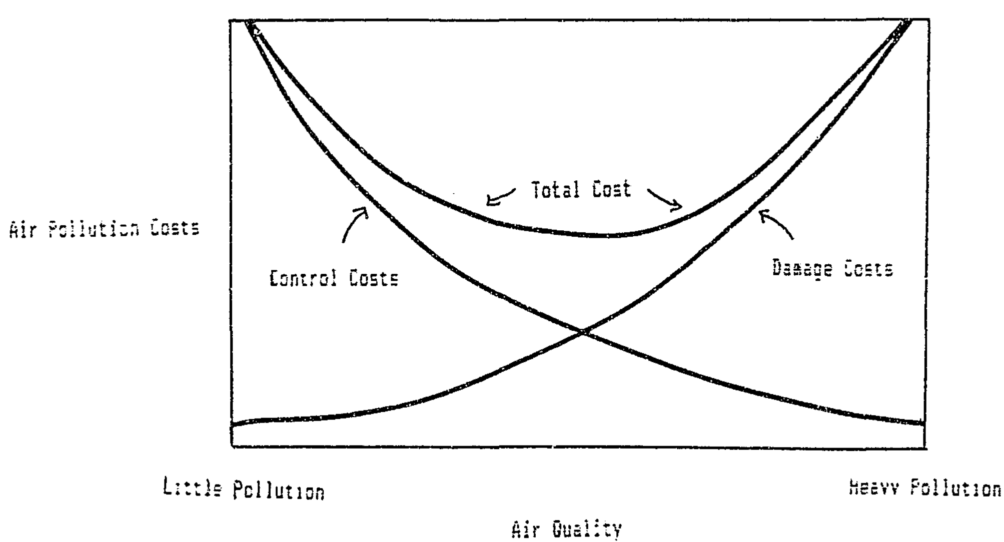
Public awareness and concern for the environment is growing. This is motivating industry and the business sector to regard environmental issues, such as air pollution, more seriously. The environmental impact of industrial processes is playing an ever increasing role in the decision-making of companies.

This is not only happening because of concern of companies about their image but also because industry realises that serious degradation of the environment will ultimately have a detrimental effect on the viability of industry itself.

Air pollution is costly. Firstly because of <u>damage</u>; damage to the health of members of society, damage to crops and damage to materials etc. Secondly, air pollution is costly in terms of <u>control</u>; the development and installation of technology to reduce air pollution increases the running costs of industry and ultimately the price of commodities being produced. Thus in terms of the cost of damage or control we all pay a price for the quality of the air we breathe.

The graph below shows, qualitatively, the costs of air pollution in terms of damage and control. The total cost to society is the sum of the two curves. Ideally, the best balance between costs in terms of damage and costs in terms of control occurs where the two curves intersect or where the total costs to society reach a minimum.

Diagram Showing Air Pollution Costs in Terms of Damage and Control



Adapted from
<u>ChemCom - Chemistry in the Community</u> by the American
Chemical Society.

The control measures adopted by industry must maintain a balance between the interests of the public who want clean air, the industrialist who wants to make a profit, the employees who want to keep their jobs and the government who wants national prosperity as well as healthy and contented citizens. This should lead to an open-ness on the part of industry to the nature of the air pollution problems incurred by industrial processes. The search for solutions should involve industrialists, experts from scientific disciplines, members of the public and government representatives.

The damage to life and the environment by air pollution, has been dealt with in previous Units. In this Unit we shall study some of the measures developed and used by industry to control air pollution. At present most air pollution control measures are employed <u>at the end of processes</u>, just before the air pollutants are released into the atmosphere. Some air pollution control measures involve techniques which are <u>integrated with the industrial process</u>.

A. <u>Measures to Control the Release of Particulates into the Atmosphere</u>

These measures involve th. use of electrostatic precipitators, baghouse filters, cyclones and scrubbing techniques.

1. <u>Electrostatic Precipitators</u>

Electrostatic precipitators operate by imparting a charge to the particulates as they move through a strong electrical field. The charged particles collect on plates of opposite charge from where the particulates can be collected. This technique can remove up to 99% of particulates. Electrostatic precipitators are used on a large scale for removal of

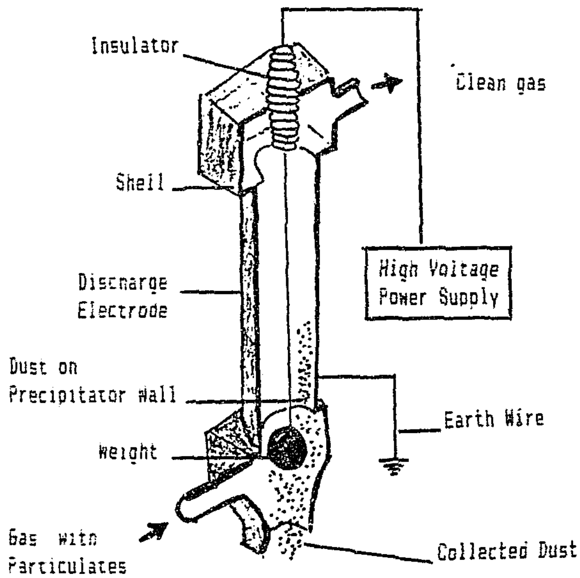
dust, eg. from cement kilns,

smoke, eg. processes involving the combustion of coal

fly-ash, eg. from power stations.

a small amount of droplets of sulphuric acid mist, eg. in acid manufacturing plants

Diagram of an Electrostatic Precipitator



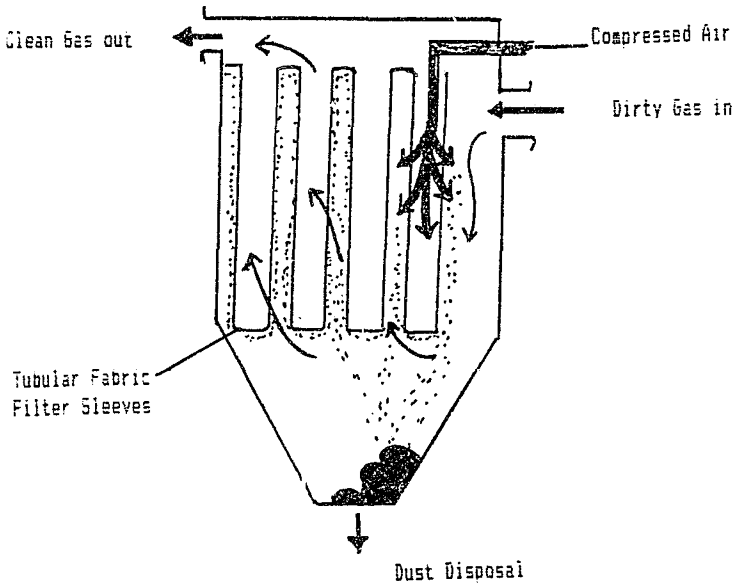
The electrostatic precipitator works as follows. The thin central wire (suspended by the weight) is charged negatively to a very high voltage (40 - 60 kV). The air immediately surrounding the wire is bombarded by electrons released from the wire. Some molecules in the air gain negative charges. Some of these ions collect on the surface of particulates in the gas stream passing through the precipitator. These negatively charged particulates move towards the positive (earthed) sections where they are discharged. A layer of particulates several millimetres thick collects on the wall of the precipitator. This layer is removed by tapping the tubes.

2. Baghouse Filters

The baghouse filter is a large scale version of the house hold vacuum cleaner. The substances released are passed through a cleaning room (baghouse) where huge filters made of fabric trap up to 90% of particulates. The choice of fabric determines the efficiency of the filters. A simple filter housed in a steel casing is shown in the diagram.

The fabric is arranged in tubes (or sleeves) supported on wire frames. The gas containing the particulates, passes through the fabric sleeves. The particulates adhere to the fabric. In due course, a layer of particulates builds up on the fabric thus reducing the flow. To remove this layer, compressed air can be used which causes the layer of particulates to fall to the bottom of the filter from where the solid material is removed.

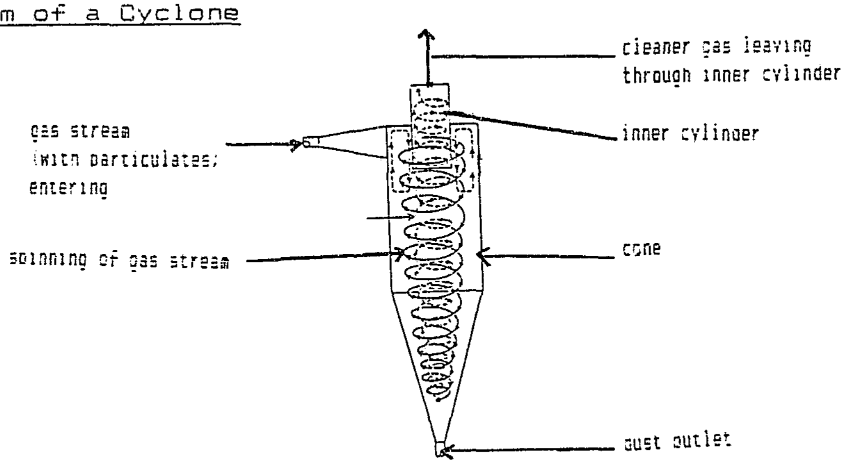
Diagram of a Baghouse Filter



3. Cyclones

In a cyclone, the particulate matter is separated from the gas stream, by forces (centrifugal forces) caused by the rapid spinning motion of the gas stream in a cone. The particulates are spun outwards to the walls of the cone. The particulates then fall to the base of the cone where they are removed. The cleaner gas rises upwards through the inner cylinder. This technique removes 50 - 90% of larger, visible particulates but few of the smaller particulates.

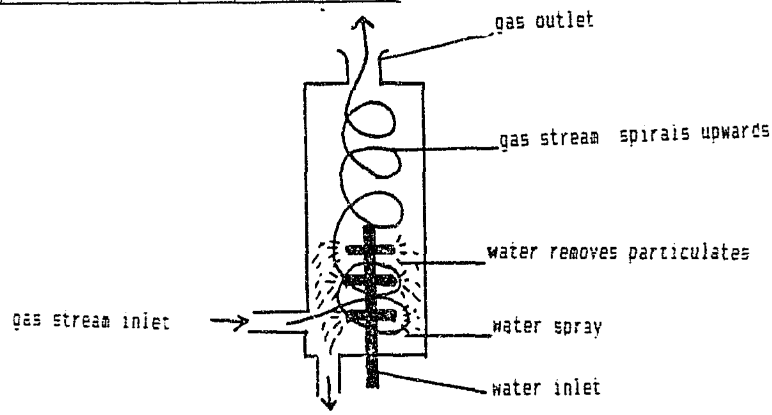
Diagram of a Cyclone



4. Scrubbing

Scrubbing methods for the removal of particulates, work on the same principle as rain when it removes particulates from the atmosphere. The gas stream enters a spray tower where falling droplets of water from a spray, collect the particulates. This method is only effective for relatively large particulates. (Note: The term "scrubbing" is also used for other techniques used in the removal of sulphur dioxide. These techniques are different from the technique described above. They involve the use of water and/or other substances.)

Diagram of a Spray Scrubber



B. Measures to Control the Release of Gaseous Pollutants into the Atmosphere

The most widely used techniques for removing gaseous air pollutants involve the reaction of these gases with other compounds to form substances which can be removed and are non-polluting. Many industrial processes involve the combustion of coal. We have seen in earlier Units that the gaseous sulphur dioxide and nitrogen oxides produced during this combustion, cause serious air pollution problems. We shall study measures taken by industry to control these and other gases.

1. Measures to Control the Release of Sulphur Dioxide
   When coal is burned, about 90% of the sulphur it contains, is converted into sulphur dioxide. Most of the rest of the sulphur combines with minerals in the coal to form part of the fly ash (See Unit 3). A small quantity of sulphur trioxide is also produced. The release of sulphur dioxide (and sulphur trioxide) into the atmosphere can be reduced by two techniques:

   a) Dry Scrubbing or coal cleaning
   b) Wet Scrubbing or flue gas desulphurisation

a) <u>Dry Scrubbing or Coal Cleaning</u>

Calcium carbonate (limestone) is blown into the furnace or combustion chamber where the coal is being burned. (If the coal is pulverised, there is better contact between the calcium carbonate and the coal. This causes the reactions described below to occur more frequently and the removal of sulphur dioxide and sulphur trioxide will be improved.)

The calcium carbonate decomposes on heating to form calcium oxide (lime).

$$\underset{\text{limestone}}{CaCO_3(s)} \xrightarrow{\text{heat}} \underset{\text{lime}}{CaO(s)} + CO_2(g)$$

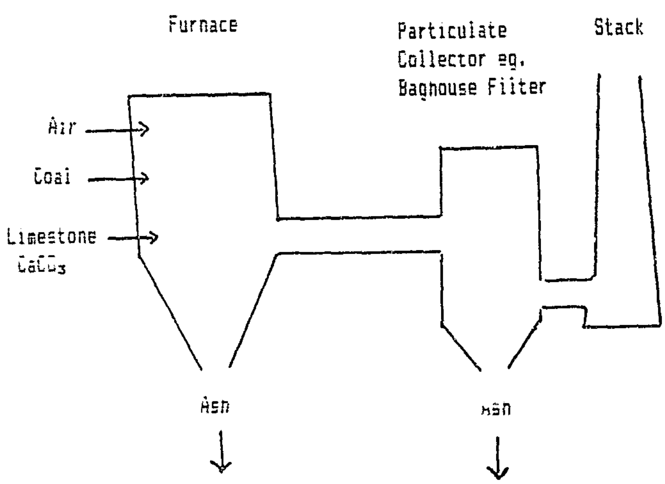
The calcium oxide (lime) reacts with sulphur oxides produced by the combustion of the coal to form calcium sulphite and calcium sulphate.

$$\underset{\text{lime}}{CaO(s)} + \underset{\text{sulphur dioxide}}{SO_2(g)} \longrightarrow \underset{\text{calcium sulphite}}{CaSO_3(s)}$$

$$\underset{\text{lime}}{CaO(s)} + \underset{\text{sulphur trioxide}}{SO_3(g)} \longrightarrow \underset{\text{calcium sulphate}}{CaSO_4(s)}$$

The calcium sulphite and calcium sulphate are removed with the ash and by means of particulate collectors, eg. electrostatic precipitators or baghouse filters.

<u>Diagram showing Implementation of Dry Scrubbing</u>



b) Wet Scrubbing or Flue Gas Desulphurisation

Calcium oxide (lime) and water are injected into the gas stream after the combustion of coal. The calcium oxide reacts with water to form calcium hydroxide

$$\underset{\text{lime}}{CaO(s)} + H_2O(l) \longrightarrow \underset{\text{calcium hydroxide}}{Ca(OH)_2\ (aq)}$$

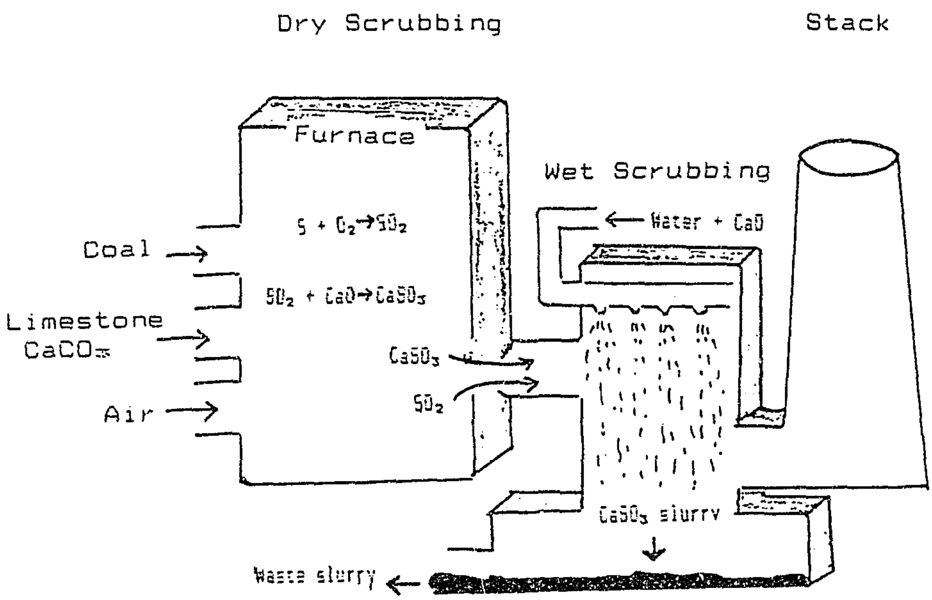
The calcium hydroxide reacts with the sulphur dioxide (produced during the combustion of coal) to produce calcium sulphite and water.

$$\underset{\text{calcium hydroxide}}{Ca(OH)_2(aq)} + SO_2(g) \longrightarrow \underset{\text{calcium sulphite}}{CaSO_3(s)} + H_2O(l)$$

The calcium sulphite is removed as a slurry (a mixture of solid and waste).

Very often dry and wet scrubbing techniques are used together. This is because the scrubbing techniques are not 100% effective. A combination of the techniques leads to the removal of more sulphur dioxide and sulphur trioxide.

Diagram Showing Dry and Wet Scrubbing Techniques used Together in a Power Station



Adapted from
ChemCom - Chemistry in the Community by the American Chemical Society.

2. The Control of the Release of Nitrogen Oxides

When coal is burnt, nitrogen oxides are formed both from the nitrogen in the coal and from the nitrogen in the air.(See Unit 3). Any high temperature combustion (often a feature of industry) will produce nitrogen oxides from the nitrogen and oxygen in the air (See Unit 3). The production of nitrogen oxides can be reduced by the following techniques:

a) Low NO_x Burners and Staged Combustion

The formation of nitrogen oxides can be minimised if combustion begins in a region where the air supply is restricted. More air is added as the combustion proceeds. This type of combustion proceeds at relatively lower temperatures than those usually used. In this way the production of nitrogen oxides is kept to a minimum.

b) Ammonia Injection

Another technique for NO_x reduction is the injection of ammonia into the combustion chamber where it reacts with the NO_x and oxygen in the air. Nitrogen and water are produced.

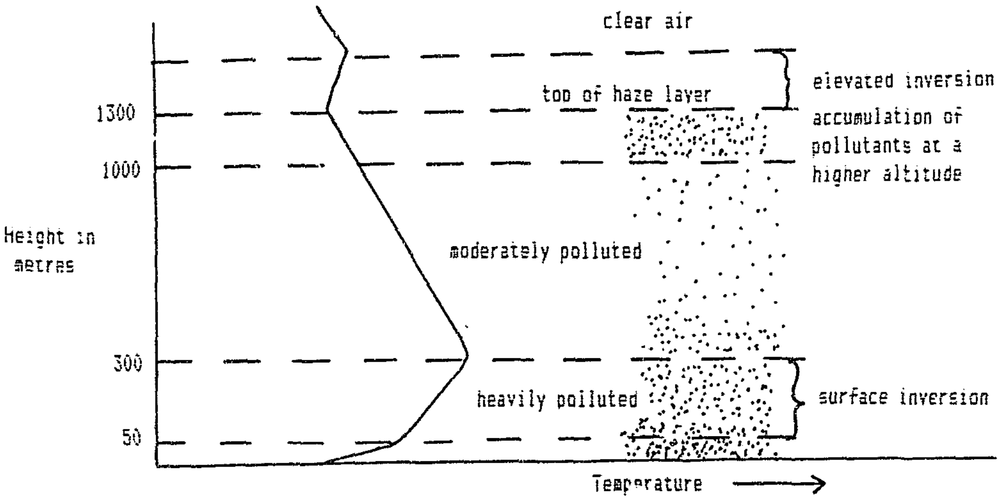
$$4NH_3(g) + 4NO(g) + O_2(g) \longrightarrow 4N_2(g) + 6H_2O(l)$$

3. The Control of the Release of H_2S

Oil refineries and petrochemical industries such as SASOL, face the problem of the production of hydrogen sulphide as a consequence of their processes. Hydrogen sulphide is converted to sulphur which is separated and extracted. The sulphur is used in the fertiliser industry.

No control system will remove all air pollutants from industrial emissions. Approximately 0,1 - 10% of pollutant materials remain in the waste emissions released into the atmosphere. Industry makes use of tall chimney stacks for emissions into the atmosphere. In this way it is hoped to bring about some dilution of air pollutants before ground level contact occurs. As we have seen (Unit 4,Unit 7) this dilution is not always a solution to the problems of air pollution! In addition, sometimes a second temperature inversion occurs at higher altitudes and air pollutants are not readily diluted and dispersed. This is a common problem in the eastern Transvaal highveld.

Diagram Showing The Effect of Second Temperature Inversions on the Dispersion of Air Pollutants



The techniques described so far are used by industry to control air pollutants formed during industrial processes. (These techniques may be used in combination with each other and sometimes in a different sequence from that described.) Industry also plays a role in the design and development of technologies to reduce air pollutants produced by some of our everyday activities such as:

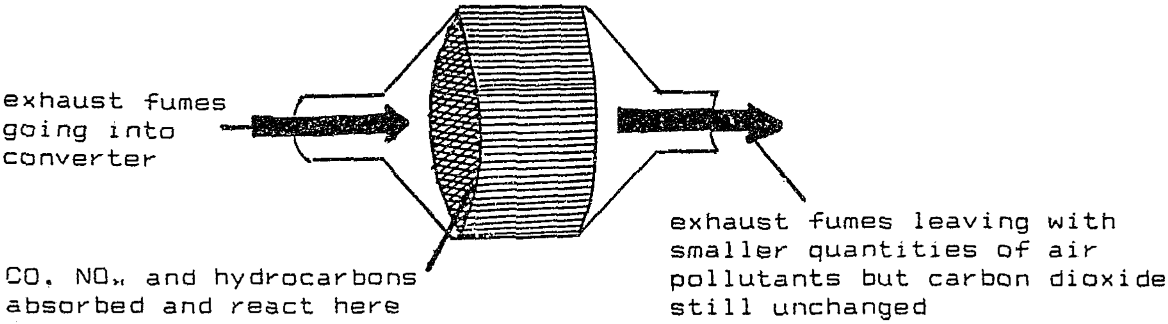
a) Burning petrol in motor vehicles

The emissions from the exhausts of motor vehicles, contain air pollutants namely lead compounds, carbon monoxide, hydrocarbons, and nitrogen oxides and carbon dioxide.

In some countries, petrol that does not contain lead compounds is sold. (Normally at a higher price!) The motor industry is involved in the production of new types of motor engines that run efficiently on "lead-free" petrol. In South Africa, lead-free petrol is not yet on sale although more than half of all new cars are designed to tolerate unleaded petrol. However the lead-content of petrol is being reduced; prior to 1986 the lead halide content of petrol was approximately 0,84g per litre. By 1989 this had been reduced to 0,4g per litre. If the lead-content of petrol is to be reduced further, the oil refineries will have to undergo considerable modifications and this will lead to price increases which will have to be borne by the consumer.

The motor industry has also developed catalytic converters to reduce the release of hydrocarbons, carbon monoxide and nitrogen oxides into the atmosphere from vehicle exhausts. The converter is attached to the vehicle exhaust.

Diagram of a Catalytic Converter



The exhaust gases pass over catalysts such as platinum, palladium and rhodium. These catalysts bring about the conversion of nitrogen oxides and carbon monoxide to nitrogen and carbon dioxide.

eg. $2NO(g) + CO(g) \longrightarrow N_2(g) + 2CO_2(g)$

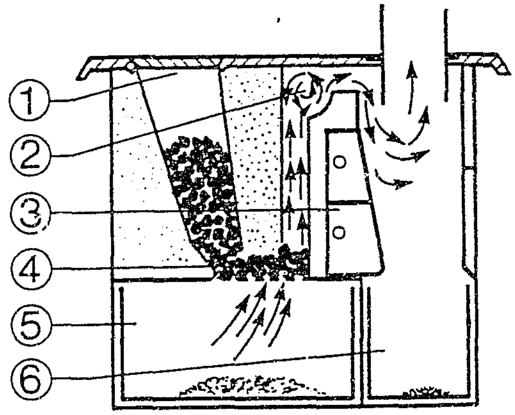
Hydrocarbons are also converted to carbon dioxide and water. South Africa is the world's largest supplier of platinum, palladium and rhodium. Catalytic converters are being manufactured in South Africa and are exported to countries overseas. However these catalytic converters cannot be used in South Africa because the lead compounds in our petrol damage the catalytic converters.

b) The Combustion of Coal for Domestic Purposes such as Warmth and Cooking

In South Africa the use of domestic fires causes many air pollution problems because of the release of smoke, hydrocarbons and sulphur dioxide into the atmosphere. Many areas in large cities in South Africa have been declared "smoke-free" zones. Fires for heating purposes must be made with smoke-less fuels such as anthracite or coke. (Many householders use electricity or gas for heating and cooking purposes.)

A solution to the problem of smoky stoves has been the development of the minimum-smoke stoves sometimes called "smoke-less stoves". These stoves were researched and developed by the Transvaal Coal Owners Association, the National Instititute for Coal Research, CSIR and the Department of National Health. The improved combustion techniques in these stoves, has resulted in better combustion of the coal and a reduction in the quantities of hydrocarbons and smoke produced.

Diagram and Explanation of a "Smoke-less" Stove
(taken from the booklet:
"Air Pollution in South Africa"
issued by the Department of Health and Welfare)



PRINCIPLE OF THE SMOKELESS STOVE

Paper and wood are placed on grate through OPENING 1 in hopper. This is ignited and the cover of OPENING 2 left open until the burning wood has reached incandescence. The hopper is now filled with coal and the cover replaced. Slide ASH PAN 5 out about 25 mm (1") to allow for the introduction of primary air. The COAL 4 will now start burning and the gases become thoroughly burnt in COMBUSTION CHAMBER 2. The hot gases which are released are first deflected downwards which allows the gases to be circulated within the heating chamber before being released through the chimney. BOILER 3 is an optional extra. The GRIT PAN 6 accumulates "Fly Ash" and must be emptied every six months.

Outlook for the Future

It has been suggested by some people, that society return to a more austere life-style brought about by a reduction in industry and a return to some of the more "primitive" or basic methods of the past. While an adjustment in our life-style is necessary, the role of industrial development in the problem of air pollution is complex. Industry provides the commodities society uses to improve the quality of life. The ever increasing world population places an increasing demand on sources of energy, food production and materials. Technology and industry provide the means for meeting these demands. Industry provides the employment and economic growth necessary for the development of the country and the upliftment of its people.

The increasing concern about the environment should lead to the development of better techniques for controlling air pollution. A balance will have to be sought between our demands, as consumers, and the preservation of our environment.

Learning Objectives for Unit 9

On completing this unit, students should be able to:

9.1 Briefly describe the costs of air pollution in terms of damage and control.

9.2 Briefly decribe why it is becoming increasingly important for industry to control air pollution.

9.3 Explain the use of electrostatic precipitators, baghouse filters, cyclones and spray scrubbers to control the release of particulates into the atmosphere.

9.4 Explain the processes of dry and wet scrubbing for the removal of sulphur dioxide and sulphur trioxide from gaseous emissions by industry.

9.5 Describe the removal of nitrogen oxides by:
i) low NOx burners and staged combustion
ii) ammonia injection.

9.6 Explain the use of tall stacks and the problems encountered in the release of emissions from tall stacks.

9.7 Describe measures taken to deal with the problem of air pollution by lead compounds from vehicle exhausts.

9.8 Explain the use of catalytic converters in the control of air pollution by emissions from vehicle exhausts.

9.9 Describe the use of "smokeless" stoves in controlling smoke from domestic sources.

9.10 Briefly describe the complex role played by industry by contributing to the problem of air pollution and yet providing employment and commodities which improve the quality of life.

9.11 Describe briefly the approaches of (for example) ESKOM, SASOL and AECI to air pollution.

Worksheet 9(a) "Cleaning Up Coal"

This exercise is based on an article appearing in Scientific American May 1991.

Until about 20 years ago, coal-fired power stations were regarded as a triumph of modern technology for bringing light and heat into homes and businesses at affordable prices. Burning coal now generates about 56% of America's electricity. However recently, environmental concerns have highlighted the problems associated with this form of energy generation: coal-fired power stations release into the atmosphere gases that give rise to acid rain or may contribute to an enhanced greenhouse effect. Yet coal-fired power stations cannot be abandoned because coal forms 85% of potential fossil-fuel reserves in the United States of America.

In this exercise we will take a "peep" into the working of a modern coal-fired power station in America. In particular we will study the modern technology being used in an attempt to reduce the release of air pollutants into the atmosphere. In some power stations the technology to control air pollution occupies a greater area of the site than the structures which are involved in the production of electricity!

Look at the diagram on page 227. Don't be put off by the detail! You may be surprised at how many of the processes or technologies you understand. Your teacher will assist you if you get lost among the pipes but let's see how much you can work out for yourself!

Questions

Please write your answers on a separate sheet of paper.

1. The main aspects of the power station technology are:
   a. The burning of coal to heat water and produce the steam.
   b. The use of high pressure steam to drive the turbines. These turbines drive the generator (dynamo) which produces the electricity for our homes etc.
   c. The removal of the products formed during the combustion of coal.

   Using the headings COAL COMBUSTION, ELECTRICTY GENERATION and REMOVAL OF PRODUCTS OF COMBUSTION, list the parts of the technology associated with these three aspects (as shown in the diagram).

2. a. Indicate which parts of the technology shown are used in an attempt to reduce the problems of air pollution.
   b. Explain the processes involved, giving the chemical equations involved (if applicable).

3. What parts of the technology, shown in the diagram, are used in coal-fired power stations in South Africa to reduce air pollution?

4. What parts of the technology, shown in the diagram, are at present <u>not</u> used in South Africa to reduce air pollution?

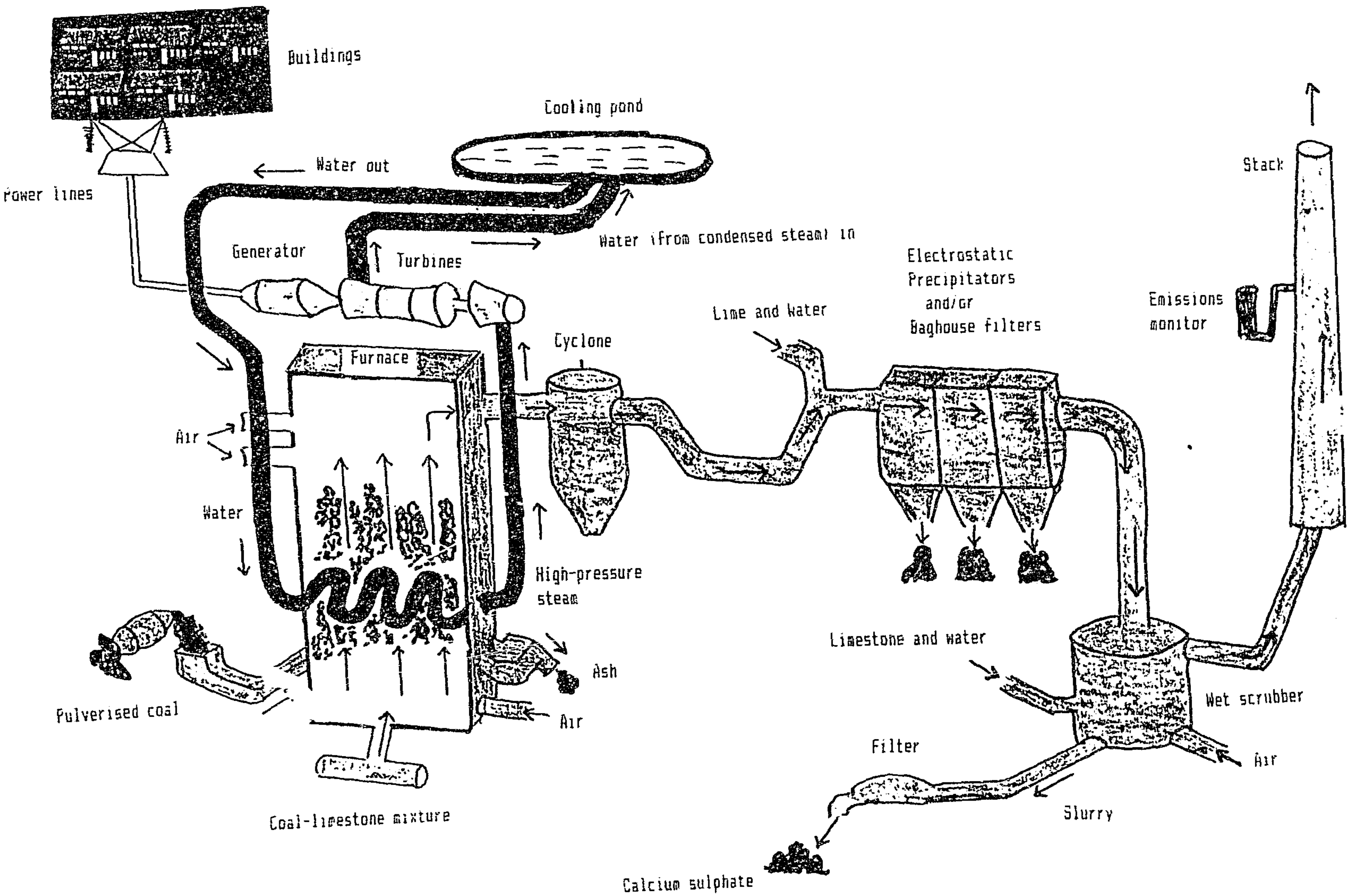
5. Why is ESKOM not using this technology at present?

6. $1,0 \times 10^6$ mol of sulphur dioxide is released per hour from the combustion of coal in a power station. The process of dry scrubbing is used to remove the sulphur dioxide. What mass of limestone, $CaCO_3$, per hour, is necessary to remove the sulphur dioxide? (Assume 100% efficiency for this method.)

7. You will notice that in the technology shown, there is nothing to control the release of carbon dioxide into the atmosphere. This is a very serious problem. It is felt that soon there will be an International Agreement similar to the Montreal Protocol to control the release of carbon dioxide. We must still use our ingenuity to find practical ways of controlling the release of carbon dioxide. Some preliminary ideas were put forward in Unit 6.
   List as many ways as you can think of, to control the release of carbon dioxide.

<u>Footnote</u>:
Air pollution technology similar to that discussed in this exercise, has been installed in four major power stations in the vicinity of the Grand Canyon in America. (In fact most coal-fired power stations in America are equipped with similar technology.) This was done to reduce air pollution in the Grand Canyon and to improve visibility. The Grand Canyon is a major tourist attraction. Recent research seems to indicate that cities in California (eg. Los Angeles) and cities in Mexico contribute more air pollution (which reduces visibility) to the region of the Grand Canyon than do the power stations.

TECHNOLOGY INSIDE A COAL-FIRED POWER STATION IN AMERICA

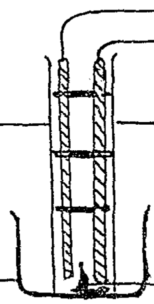


Worksheet 9(b) Controlling Smoke

Requirements

1 Glass tube
2 strips of copper mesh
retort stand and clamp
2 strips of copper screen
a piece of string
matches
dish
induction coil
2 tooth picks

Diagram of Apparatus



Method

1. Set up the apparatus as shown in the diagram.
   The toothpicks are used to prevent the pieces of copper mesh from touching each other.
2. Light the string and place it inside the glass tube.
3. Record your observations.
4. Switch on the induction coil and observe what happens.

Observations

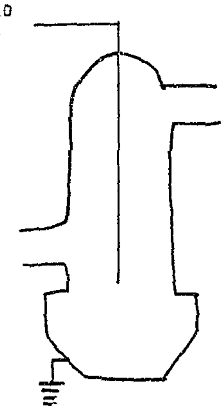
1. Before induction coil is switched on.

2. After induction coil is switched on.

Explanation

Application

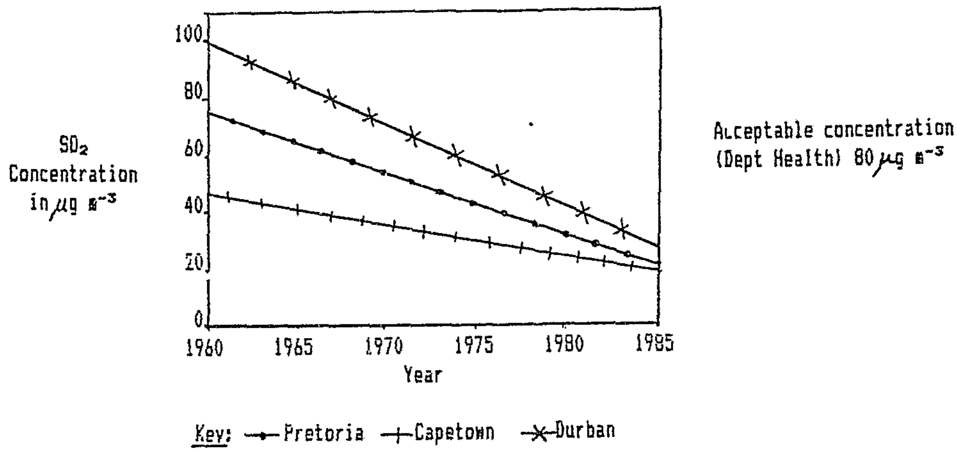
A scientist, Cottrell, developed this technique to control air pollution . Name the device shown in the diagram and explain how it functions in the removal of air pollutants. Label the diagram to clarify your answer.
(Explanation on a separate sheet of paper)



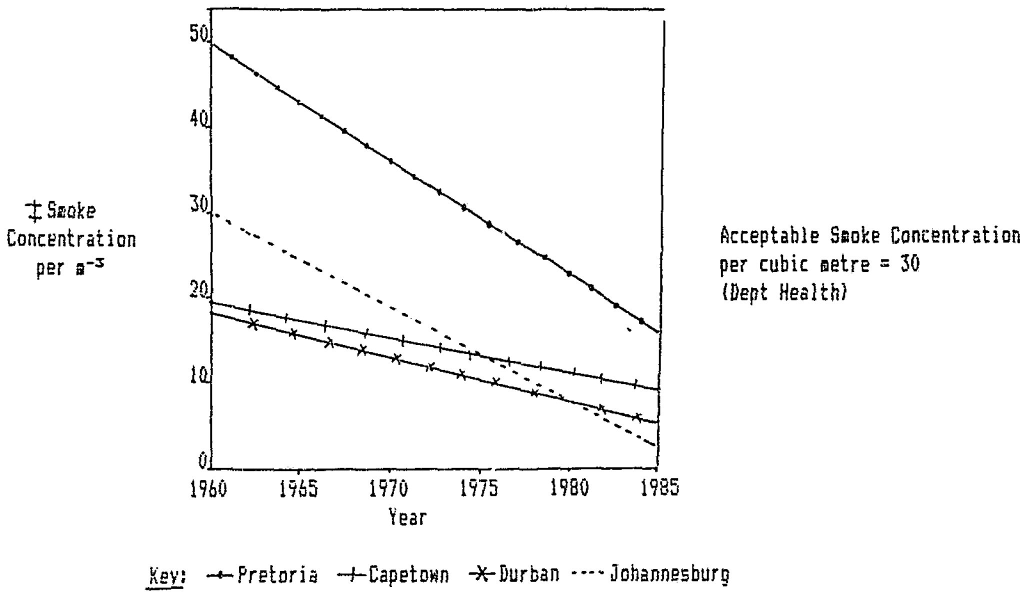
Worksheet 9(c) Trends in Air Pollution

The data below show the trends in sulphur dioxide and smoke concentrations in some South African cities from 1960 to 1985.

a) Sulphur Dioxide Trends for 1960 - 1985



b) Smoke Trends for 1960 - 1985



Instructions

On a separate sheet of paper, discuss the trends shown. Include in your answer the names of techniques which have contributed to these trends.

‡ (Smoke concentration is measured in unit called Soiling Index Unit determined by drawing air through filter paper and comparing with a standard)

Worksheet 9(d) "A Press Conference" (A Role Play)

Instructions

This worksheet contains information on ESKOM, SASOL and AECI. It could be used as a role play.
Choose three students as representatives of the respective companies. Provide each representative with the information for his/her company as given on the pages that follow. The company representatives must be well prepared - charts or diagrams of information they would like to include in their answers should be brought along to the "press conference". The company representatives should be given the questions beforehand that will be posed by the reporters. In this way they will be adequately prepared for the conference.
Choose a chair person to control the discussion.
The role play could simulate, for example, a press conference. The rest of the students in the class are the newspaper reporters. They pose the questions to be answered by the company representatives.

Examples of Questions to be Posed by Newspaper Reporters

1. What commodities does your company produce?

2. How important are these commodities for our society?

3. What air pollution problems does your company encounter?

4. How does your company attempt to solve these problems?

5. Are there any specific problems/dilemmas facing your company? If so, how have you attempted to solve these problems?

6. What are the implications, for society, of air pollution control measures adopted by your company?

7. Predict what your air pollution policy will be in the future.

(These are examples of some possible questions. Teachers may like to include others. The students could follow-up this exercise by writing newspaper articles based on this "news conference".)

If the teacher does not wish to use this material as a role play, the information and questions could be given as a comprehension exercise.

Background information on Three Industries

i) ESKOM Representative

ESKOM is the tenth largest supplier of electricity in the world. Electricity is one of the cleanest forms of energy but its generation can pose serious air pollution problems. South Africa is a land rich in coal with the result that 83% of our electricity comes from coal-fired power stations. 10% comes from hydro-electric plants, 6% from a nuclear plant and 1% from natural gas. These power stations run 24 hours a day, 365 days a year to meet some of the energy demands of the country.

It is the coal-fired power stations which present serious air pollution problems. ESKOM burns 70 million tons of coal a year. The coal is burnt to heat water which produces steam. The steam drives turbines which generate electricity. When the coal is burnt the major air pollutants formed are fly-ash, sulphur dioxide, nitrogen oxides, hydrocarbons and carbon dioxide. The sulphur content of our coal averages 1,2%. This is low in comparison to coal used in the Northern Hemisphere, but the quantity of coal burned in our large power stations makes them a significant source of sulphur dioxide.

Eight of our coal-fired power stations are situated in a relatively small area between the East Rand, Swaziland and the northern border of the Orange Free State.

Control of Air Pollution using Electrostatic Precipitators

On earlier power stations, ESKOM made use of cyclones to control the release of particulates (mostly fly-ash). By 1978 it was recognised that these cyclones were inadequate. Electrostatic precipitators were introduced. The precipitators cost R20 million each. (The replacement value of all ESKOM's precipitators in the country is R1 billion). The installation of precipitators significantly improved the air quality near these power stations. However some farmers in the Komati area, complained. The fly-ash had helped condition their soil. They now have to purchase lime and fertilisers to do this!

Control of Air Pollution Using Tall Stacks

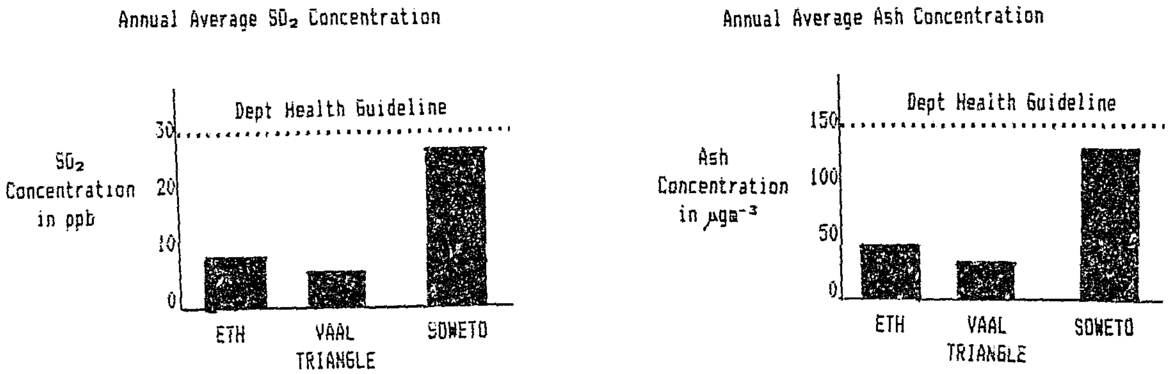
Tall stacks (some as high as 300 m) are used to release the smoke and other emissions above the temperature inversion. It is hoped in this way to dilute and disperse air pollutants.

Control of SO_2 and NO_x

To remove the oxides of sulphur and nitrogen from coal-fired power station emissions, would cost about R1 000 million for each of our large power stations. This would increase the cost of electricity by 33%. The quality of the air would improve and it is believed that the sulphur dioxide concentrations would decrease by 6,9%. However the increased cost of electricity would reduce the number of people who could afford electricity. ESKOM has decided not to make use of technology to control these gases for the time being.

With R1 000 million it is possible to bring electricity to many people who do not have electricity; this sum could electrify 420 000 homes. At present there are approximately 20 million homes in South Africa which do not have electricity. More than 12 million people use wood as a primary source of energy. This results in deforestation with large areas in the country having no trees. The loss of trees contributes to serious erosion problems and destroys an important way in which carbon dioxide can be removed from the atmosphere. Thus the loss of trees contributes to the problem of the enhanced greenhouse effect.

Domestic coal fires contribute significantly to particulates (such as fly-ash) and sulphur dioxide in the air.



ETH (Eastern Transvaal High Veld) and Vaal Triangle are two highly industrial regions.

If 420 000 homes were electrified, it is estimated that the sulphur dioxide concentrations in a town could be reduced by as much as 64%.

Thus providing electricity for more South Africans would have a very good effect on the preservation of our environment. Environmental issues are complex and ESKOM believes that the solutions to such issues should involve the nation as a whole. ESKOM is one of the few industries to agree to the international "green" movement request for an annual audit. Such audits would be similar to a financial audit. Enrichment and damage to the environment by ESKOM would be assessed.

ESKOM has established an Air Quality Research Group. A network of monitoring stations has been established in the vicinity of major power stations. These monitor the concentrations of sulphur dioxide, nitrogen oxides, ozone and hydrocarbons. A light aircraft has been fitted with air quality measuring instruments.

ESKOM is looking ahead well into the next century. At present ESKOM has a surplus of generating capacity. It may in fact not be necessary to build another power station in South Africa. Zaire is currently investigating a massive hydro-electric power station. Such a scheme could provide enough electricity for the whole African continent until well into the next century.

ii) SASOL Representative

South Africa is a land rich in coal but lacking oil. SASOL technology is the response of a country concerned about the implications of a total dependence on imported oil.

SASOL plants manufacture oil from coal and are the only oil-from-coal plants in operation in the world. The first SASOL plant was built in 1955 in Sasolburg. (This plant no longer produces oil; it only produces chemicals.) Two SASOL plants were built later at Secunda. The SASOL plants in Secunda have their own power stations and coal mines. In fact these coal mines form the largest underground mining complex in the world.

During the SASOL Synthol process, coal, in the presence of steam and oxygen, is gasified at temperatures of more than 1100°C. The raw gas formed is purified: carbon dioxide, nitrogen oxides, ammonia, organic compounds, sulphur compounds, and tar are removed. Many of these "impurities" are put to very good use:

a) The nitrogen oxides are converted into ammonia.
b) The ammonia is used for fertilisers and explosives.
c) Some of the organic compounds are used in the manufacture of plastics. Other organic compounds are used as solvents such as lacquer thinners and benzene.
d) Some of the sulphur in the coal is converted into sulphur dioxide. However the SASOL process results in the production of many other sulphur compounds eg. H_2S and CS_2. Secunda plants have been equipped with process units which remove 90% of the hydrogen sulphide, H_2S. During this process elemental sulphur is produced and sold to the paper industry or used in the manufacture of sulphuric acid or fertilisers.
e) The tar products are also used eg.to preserve wood.

After purification the gas mixture of carbon monoxide and hydrogen is passed over an iron catalyst in a reactor where crude oil is produced. A wide range of very pure waxes are also derived from the SASOL process. These are used in polishes, printing inks and lubricants.

Air Pollutants Produced by the SASOL Process

It is interesting to compare a power station and a SASOL plant with respect to the products and air pollutants formed. A power station consuming 10 million tons of coal produces 200 000 tons of sulphur dioxide, 70 000 tons of nitrogen oxides, over 28 million tons of carbon dioxide and 1000 tons of fly-ash. By contrast a SASOL fuel plant converts 10 million tons of coal into petrol, many other chemical by-products and 70 000 tons of sulphur and 120 000 tons of ammonia. 17,5 million tons of carbon dioxide would be produced. There is almost no emission of sulphur compounds, nitrogen oxides or ash. However SASOL plants require power and steam. This is provided on site by a power station using a further 5 million tons of coal. This power station produces 100 000 tons of sulphur dioxide, 35 000 tons of nitrogen oxides, 500 tons of ash and 14 million tons of carbon dioxide.

The table below shows the comparison between a power station and a SASOL fuel plant (both using 10 million tons of coal) with respect to products and total air pollutants formed.

	Power Station	SASOL Plant
Coal Consumption	10 million tons	10 million tons
Product	Power	Petrol and a Variety of By-Products Sulphur 70 000 tons Ammonia 120 000 tons
Air Pollutants SO_2 NO_x CO_2 Fly-ash	 200 000 tons 70 000 tons 28 million tons 1 000 tons	Mostly From SASOL Power Station 100 000 tons 35 000 tons 31,5 million tons 500 tons

<u>SASOL's Air Pollution Policy</u>

SASOL acknowledges that industrial activities have a negative effect on the environment. SASOL takes the possible influence of activities into account at the planning phase of operations. SASOL ensures that products and processes are environmentally compatible. SASOL applies the best available and most cost effective technology to control air pollution. It co-operates with the authorities and research and environmental organisations in the search for solutions to the problem of air pollution. Some of the major air pollution control measures taken are:

a) The development and installation of process units at Secunda, to remove hydrogen sulphide from gas streams. Hydrogen sulphide is the gas that gives the "bad egg" smell sometimes detected in the Vaal Triangle. The SASOL plant at Sasolburg has had problems with hydrogen sulphide removal. At times this gas has been released into the atmosphere. The latest sulphur recovery technology will be used when this plant undergoes updating.

b) Electrostatic precipitators have been installed to prevent fly-ash from being released into the atmosphere. Most of the ash is removed at the gasification stage.

The SASOL fuels produced from the crude oil are very close to "clean-burning". The petrol produced is free of sulphur and nitrogen. Some international companies have recently released details of their <u>future</u> targets for "green" petrol - petrol whose combustion will result in more acceptable exhaust emissions. SASOL petrol already complies with all but one of these targets that of the lead-compound content. SASOL adds lead compounds to its petrol in compliance with government regulations.

iii) <u>AECI Representative</u>

AECI is South Africa's largest chemical company. It manufactures a wide range of chemicals, plastics, explosives, fertilisers, paints and synthetic yarns such as nylon. The company employs 27 000 people.

AECI feels a commitment to the preservation of the environment. The chemical industry has a potential for much damage to the environment.To preserve the environment, industrial activities have to be very carefully managed and controlled. Managers must be trained to be aware of the impact of industrial processes on the environment. The planning of new projects must take the environmental implications into account. Scientists and engineers who design production plants must include in their design the most cost-effective technology to control air pollution. AECI hopes to achieve an openness about air pollution issues. Local communities are invited to become involved in our activities. The local community should be involved in monitoring the impact our company has on the environment. An understanding of our problems by the public is vital. Some of our plants are old and cannot operate at the same standards as a new plant. Efforts are being made to update these plants but this is costly and takes time.

<u>Air Pollution Control</u>

Our explosives and chemical plants burn 1,7 million tons of coal a year. This combustion releases air pollutants such as particulates, sulphur dioxide, nitrogen oxides, hydro carbons, carbon monoxide and carbon dioxide. Other gaseous air pollutants such as chlorine, hydrogen chloride, and ammonia are produced.

<u>The Control of Particulates</u>

Electrostatic precipitators and cyclones are used to remove particulates from the gas stream. Baghouse filters are used to control dust from the raw materials and at the product handling systems.

The Control of Gaseous Pollutants

Scrubbers are used to remove gaseous pollutants such as chlorine, hydrogen chloride and ammonia. The concentrations of sulphur dioxide and nitrogen oxides are being monitored and so far these have been found to be within nationally and internationally acceptable limits.

In fact some interesting data are available with regard to nitrogen oxide emission from our nitric acid plants in comparison to that from coal combustion and vehicle emissions.

National NO_x Emissions	% Contribution to Total
From Nitric Acid Plants	0,5%
From Coal Combustion for S.A.	74,4%
From Motor Vehicles	25,1%

The Use of Tall Stacks

Stacks are designed to give as much dispersal and dilution as possible.

Other Contributions to Air Pollution Control

a) AECI is the only producer of CFCs in South Africa. AECI is totally committed to the Montreal Protocol. By 1990 CFC production was reduced by 50%. It is proposed to cease the production of CFCs by the year 2000. Alternative products have been found for use as aerosol propellants, foam blowing agents and solvents. However, at present, difficulty is being found in developing an alternative product for refrigeration and air conditioning purposes. The mining industry would not function without the use of this gas in its cooling systems. If reasonable care is taken to repair faulty equipment or retrieve the CFC gas in old discarded equipment, CFCs would be prevented from escaping into the atmosphere. A worldwide attempt is being made to find suitable alternatives for these purposes. However some of these alternative products used, at present, may contribute to the problem of an enhanced greenhouse effect. (See Unit 10)

b) AECI is involved in a methane recovery scheme at the Robinson Deep disposal landfill. The methane is used in the production of other chemicals eg. calcium cyanide. This recovery plant prevents methane, one of the gases contributing to the enhanced greenhouse effect, from escaping into the atmosphere.

In looking at the air pollution problems posed by our industrial activities, one must not forget the impact that population growth has on these activities. An increasing population places an increasing demand on the commodities we produce. The public will have to pay more for commodities if improved air pollution technology is used to cope.with the impact of industry on the atmosphere.

Solutions to Worksheets for Unit 9

Worksheet 9(a) "Cleaning up Coal"

1. Coal Combustion
   Furnace
   Pulverised coal
   Coal-limestone feed
   Air

   Electricity Generation
   Cooling pond
   Water out of pond
   Water pipes in furnace
   Steam pipes out
   Turbines
   Generator
   Power lines to buildings
   Water (from condensed steam) back to pond

   Removal of Combustion Products
   Coal lime-stone feed
   Ash (from furnace)
   Cyclone
   Lime and water injection
   Electrostatic precipitator
   Baghouse filters
   Wet scrubber
   Filter
   Slurry
   Calcium sulphate
   Stack

2. a. Parts used to reduce problems of pollution are the parts listed above under "Removal of Combustion Products". Also the emissions monitor on the stack.

   b. Pulverising Coal
   Coal is ground into small pieces. Physical and chemical cleaning of coal takes place.

   Coal-limestone Feed
   This is the dry scrubbing technique. The limestone (calcium carbonate) is blown into the furnace with the coal. The calcium carbonate decomposes on heating to form calcium oxide (lime). The calcium oxide reacts with the sulphur oxides (produced during the combustion of coal) to form calcium sulphite and calcium sulphate.

Equations

$$CaCO_3(s) \xrightarrow{heat} CaO(s) + CO_2(g)$$

limestone → lime

$$CaO(s) + SO_2(g) \longrightarrow CaSO_3(s)$$

lime + sulphur dioxide → calcium sulphite

$$CaO(s) + SO_3(g) \longrightarrow CaSO_4(s)$$

lime + sulphur trioxide → calcium sulphate

These solid substances will be removed in the ash leaving the furnace or in the cyclone.

NB. The restriction of air supply to the combustion furnace will mean that combustion proceeds at a lower temperature. This reduces the production of nitrogen oxides (whose formation is favoured at high temperatures). In the diagram more air is added when partial combustion has taken place (at the top of the furnace)

Cyclone

Particulate matter is separated from the gas stream, (from the furnace) in the cyclone. As the gas stream enters the cyclone, it spins rapidly in the cone. The particulates spin outwards against the wall of the cone. They then fall to the base of the cone where they are removed. The cleaner air rises through an inner cone and then leaves the cyclone.

Lime and water injection

This is the wet scrubbing technique. Lime (CaO) and water are injected into the gas stream leaving the cyclone. The calcium oxide and water react to form calcium hydroxide, $Ca(OH)_2$.

$$CaO(s) + H_2O(l) \longrightarrow \underbrace{Ca(OH)_2(aq)}_{\text{calcium hydroxide}}$$

The calcium hydroxide reacts with the sulphur dioxide in the gas stream to produce calcium sulphite and water

$$Ca(OH)_2(aq) + SO_2(g) \longrightarrow CaSO_3(s) + H_2O(l)$$

The calcium sulphite is removed with the particulates in the precipitator.

Electrostatic Precipitator

Charged wires in the precipitator produce ions in the air inside the precipitator. Some of these ions collect on the surface of the particulates giving them a charge. These charged particulates move to earthed sections of the precipitator where they are discharged *(neutralised). They collect to form a layer of dust which leaves the precipitator.*

Baghouse Filters
The particulates move through huge fabric filters in the baghouse filters. The particulates stick to the fabric. A thick layer of particulates builds up on the fabric. Compressed air is used to remove this layer which falls to the bottom of the filter. The solid waste is removed from here.

Wet scrubber
The sulphur oxides react with the limestone slurry to form calcium sulphate and calcium sulphite. After filtering, these compounds are dried and removed from the power station.

3. *Cyclones and electrostatic precipitators.*
   Very tall stacks to assist in dispersal of air pollutants.

4. *All the parts of the technology aimed at removing the sulphur oxides, ie. wet and dry scrubbing techniques.*

5. *The estimated cost of installing this technology would reduce the number of people who could afford electricity. Coal fires in townships such as Soweto release more sulphur dioxide and particulates into the atmosphere than a large coal-fired power station. ESKOM has decided to provide more homes in the townships with electricity instead of installing scrubbing technology. It is felt that this will have better impact in improving air quality at present.*

6. *Equations:*

   $CaCO_3 \longrightarrow CaO + CO_2$ $\qquad\qquad$ $CaO + SO_2 \longrightarrow CaSO_3$

   1 mol SO_2 requires 1 mol $CaCO_3$ per hour
   1,0 x 10^6 mol SO_2 requires 1,0 x 10^6 mol $CaCO_3$

   $$\begin{aligned} \text{Mass of } CaCO_3 &= 1{,}0 \times 10^6 \text{ mol} \times \text{molar mass } CaCO_3 \text{ hr}^{-1} \\ &= 1{,}0 \times 10^6 \text{ mol} \times 100{,}09 \text{ g mol}^{-1} \text{ hr}^{-1} \\ &= 1{,}0 \times 10^8 \text{ g hr}^{-1} \\ &= 1.0 \times 10^5 \text{ kg hr}^{-1} = 100 \text{ tons } CaCO_3 \text{ hr}^{-1} \end{aligned}$$

7. *Some preliminary ideas are:*
   i) *Planting trees to remove carbon dioxide from the air.*
   ii) *Pumping the carbon dioxide deep into the oceans. Some animals use this carbon dioxide (probably in the form of H_2CO_3) to build their shells (mostly $CaCO_3$).*
   iii) *Using microalgae to convert carbon dioxide into biomass. This could be liquified and used as transportation fuel.*

Worksheet 9(b) Controlling Smoke

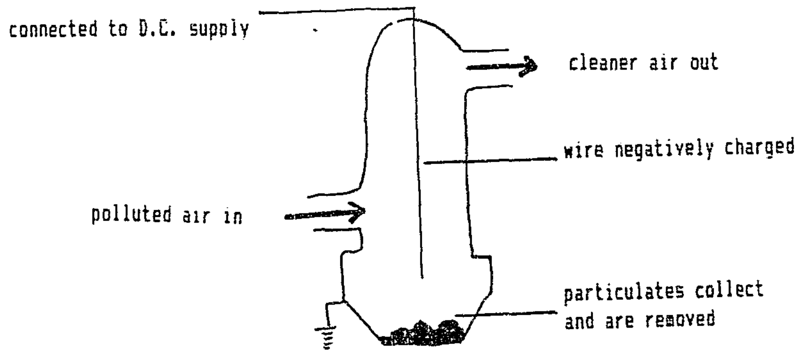
Observations

1. *Smoke goes straight up the tube.*

2. *Smoke moves towards copper mesh (with positive charge).*

Explanation

Air molecules gain electrons from copper mesh. These negatively charged ions attach themselves to smoke particles which are attracted to the postively charged copper wire.



Air molecules around the wire gain electrons from negatively charged wire. These ions attach themselves tp particulates in the smoke. Particulates move towards positive (earthed) sections where they are discharged. The particulates collect on the sides and eventually drop to the base of the precipitator.

Worksheet *9(c) Trends in Air Pollution*

a) SO$_2$ Trends

For all three cities SO$_2$ concentrations have decreased since 1960.

At present wet/dry scrubbing techniques are not used by ESKOM or other industries because of the expense of installing these techniques. However the "tall stacks policy" of ESKOM and other industries has helped in moving and diluting SO$_2$ from ground levels. In addition many cities have been declared "smoke-free zones". Coal may not be burned in these regions. Smokeless stoves or coke and anthracite are used. Thus the rate of release of SO$_2$ into the atmosphere has been reduced.

b) Smoke Trends

In all three cities smoke has been reduced. The effect of the tall stacks, smoke-free zones and smokeless fuels, as discussed above, will also have an effect on reducing smoke concentrations. However smoke contains many particulates. ESKOM and most other industries use cyclones, or electrostatic precipitators, or baghouse filters, or scrubbing (with water) to remove 90% or more particulates from the gases released into the atmosphere. This must have contributed a great deal to reducing smoke pollution in these cities.

Worksheet 9(d) "A Press Conference"

1. Commodities:

   ESKOM - electricity
   SASOL - petrol, fertilisers, solvents, sulphuric acid, tars, waxes, plastics (polyethylene)
   AECI - explosives, plastics, fertilisers, synthetic yarns, paints, refrigerant gases

2. Pupils can discuss the value of each of these commodities. Our lives (standard of living and quality of living) would be seriously affected if we had to do without these commodities.

3. ESKOM - Tall stacks have been successful but second temperature inversions (elevated inversions) can cause air pollutants to accumulate at a higher altitude.
   - Wet/dry scrubbing techniques are not used as yet. Thus SO_2 causes problems of acid rain.

   SASOL - H_2S sometimes escapes and gives rise to "bad egg smell".
   - Our mining operations and power stations contribute to air pollution problems.

   AECI - Wet/dry scrubbing to remove SO_2 has not yet been installed.
   - Trying to synthesise alternatives to CFCs.

4. ESKOM - Tried to solve problems using tall stacks, electrostatic precipitators.

   SASOL - Reconstructing SASOL I plant to prevent H_2S escaping.

5. AECI - Use electrostatic precipitators, cyclones. baghouse filters and some scrubbing techniques.

6. ESKOM - Dilemma: should we install scrubbing techniques? This would put the cost of electricity out of the reach of many people. OR should we use the money to provide electricity for people who do not have electricity?

   AECI - Manufacturing alternatives to CFCs at great cost. However these alternatives appear to give rise to other air pollution problems eg. a possible enhanced greenhouse effect. (See Unit 10) Recovers and uses methane from rubbish dumps.

6. For all these companies, the cost of installing air pollution control measures increases the price of

commodities. This has to be paid by the consumer.

7. *ESKOM - We would like national decisions involving people from all walks of life to help in decision-making.*

   SASOL - Our fuels are very clean-burning.
   Many "green" movements are interested in these fuels.

   AECI - Scientists must design better (more cost-effective) equipment to improve air pollution control.
   AECI hopes to be open about problems.
   The community must be involved in decision-making.
   Managers must be trained to be environmentally aware of the impact of this industry.

UNIT 10

What are our Alternatives?

Introduction to Unit 10

The growth of the world's population and its demands energy and commodities are having detrimental effects o environment. It will not be possible to raise the standa of living of this large population without increasing the impact on the environment further. To control the impact of our activities on the environment, we need to consider our future options and closely study the implications of these options with regard to the environment. We will have to change our use of resources and our life styles. This change will not take place overnight but change is essential. We will focus on alternatives which have an impact on the problem of air pollution. Some of these alternatives are:

A. Alternative Sources of Energy
B. Alternative Products
C. Alternative Behaviour by Society

A. Alternative Sources of Energy

One of the major sources of air pollution is the combustion of fossil fuels. Alternative sources of energy need to be considered and explored. This is not only because of the problems of air pollution, but also because the reserves of these fossil fuels are limited. Fossil fuels took millions of years to form and we are burning them up in a matter of a few centuries! Besides being a source of energy, fossil fuels are the basis of many of the chemicals we require. (See Unit 9). Yet at the moment we are sending this valuable "chemical feedstock" up in smoke!

Although it is a fossil fuel, natural gas provides an alternative to the burning of coal. Natural gas is mostly methane and is cleaner burning than coal. Natural gas does not contain any of the minerals that coal contains that give rise to fly-ash. In addition the combustion of natural gas will not give rise to significant amounts of air pollutants such as sulphur dioxide and particulates. The combustion of natural gas produces fewer moles of carbon dioxide per MJ of energy if compared to the combustion of coal or petrol. (See Unit 3)

In Britain, the use of natural gas has increased. (Although reserves of natural gas are limited.) In South Africa, reserves of natural gas have been discovered off Mossel Bay - the Mossgas project. Natural gas will play a role in South Africa's sources of energy.

The development of technology for the utilisation of alternative sources of energy has been slow probably because of the relatively easy accessibility and short-term lower cost, of energy from fossil fuels. However alternative sources of energy will have to be found. Some of our alternative sources of energy are:

a) Nuclear Energy
b) Hydro-electric Energy
c) Solar Energy
d) Wind Energy

a) <u>Nuclear Energy</u>

Reactions involving the nucleus of an atom release large amounts of energy. For some isotopes of elements eg. uranium, such reactions occur of their own accord. This provides a large source of energy. For example, 1 kg of uranium provides as much energy as the combustion of 3 million kilograms of coal.

This energy can be used to generate electricity. In a nuclear power station, steam which drives the turbines is produced by heating water with the energy from nuclear reactions instead of energy from the chemical reactions taking place in the burning of coal. One of the most attractive features of nuclear power stations, is that under normal operations, the power station does not cause air pollution.

Seventy percent of France's electricity requirements are generated by nuclear power stations. In the period from 1980 to 1986 France reduced the release of sulphur dioxide into the atmosphere by 56%, nitrogen oxides by 9% and particulates by 36%. Yet during this period, France's generation of electricity rose by 40%. The reduction in air pollution can be attributed to the four-fold increase in the generation of electricity using nuclear energy.

Seventeen percent of the world's electricity is generated by nuclear power stations. If these were to be replaced by coal-fired power stations, the total quantity of carbon dioxide released into the atmosphere would have been 2 billion tons higher.

Since the accidents at Three-Mile Island and Chernobyl, public concern about nuclear energy has grown. When accidents occur at nuclear power stations they can have disastrous consequences on life and the environment. This has resulted in a resistance to this source of energy. Pressure from the public has brought the construction of nuclear power stations to a halt. It takes a number of years to plan and build a nuclear power station. Western Europe and the United States of America, face the possibility of serious electricity shortages early in the next century.

In South Africa, there is a nuclear power station in the Western Cape, 40 km from Cape Town. This is the Koeberg power station. South Africa has large reserves of uranium and is one of the world's top uranium producers. Koeberg is approximately 1 500 km from the coal mines and power stations in the Transvaal. The cost of transporting coal to power stations in the Cape Province is very high. So, too, is the cost of conveying electricity from the Transvaal to the Cape. The price of the electrictiy in the Cape Province would thus be much higher. Koeberg only has to be loaded with uranium once a year thus reducing transport costs. The cold waters of the Atlantic ocean are used for cooling at Koeberg. This results in a saving of some of our scarce inland water.

The disadvantages of nuclear power stations, are the risk of radiation escape in the case of an accident. The disposal of nuclear waste material is also a problem. Improved technology is used to reduce these threats. The construction of the building that holds the reactor at Koeberg, is so strong that it can withstand a crash by a Boeing 747. Measures have also been taken to prevent the cracking of this building in the unlikely event of a major earthquake.

b) Hydro-electric Energy

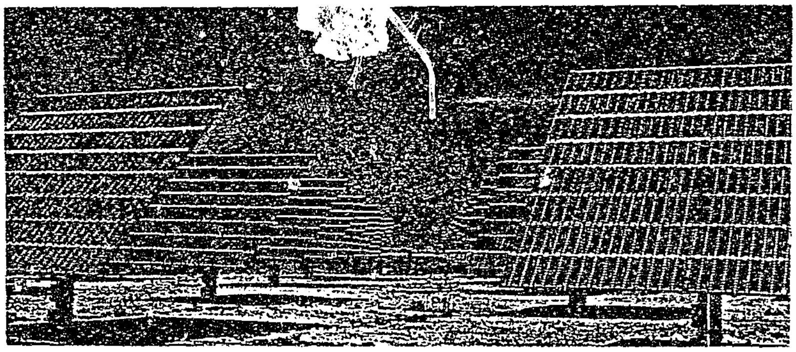
In a hydro-electric plant, the energy of falling water is used to turn the turbines that generate electricity. This method of generating energy is very clean; no air pollution results from this activity. Hydro-electric plants already provide more than 1/5 of the world's energy. If these plants were replaced with coal-fired power stations, 6 billion tons of carbon dioxide would be released into the atmosphere. (Not to mention air pollutants such as sulphur dioxides, nitrogen dioxides etc.) In the Third world only 7% of the energy available for hydro-electric plants, is harnessed. The Zaire river has the potential to generate sufficient electricity for the whole continent of Africa until well in to the next century.

In some parts of the world, waves and tides are also used to generate electricity.

c) Solar energy

The alternative of using solar energy is very attractive because solar energy is so abundant. The energy is constantly being renewed and its use will not produce air pollutants. The quantity of energy from the Sun that strikes the Earth in half an hour is equivalent to all the world's energy needs for one year. However it is difficult to utilise this form of energy. It is dispersed and intermittent. Therefore it needs to be collected, concentrated and stored. Methods of concentrating involve covering areas of land with mirrors. These focus the solar energy on "collectors". Solar cells are used for collecting the energy from the Sun. These cells are expensive. The substances used for the collection of solar energy could pose disposal problems if solar energy is used on a large scale.

<u>Collections of Solar C[illegible] Using Sunlight to make Electricity</u>



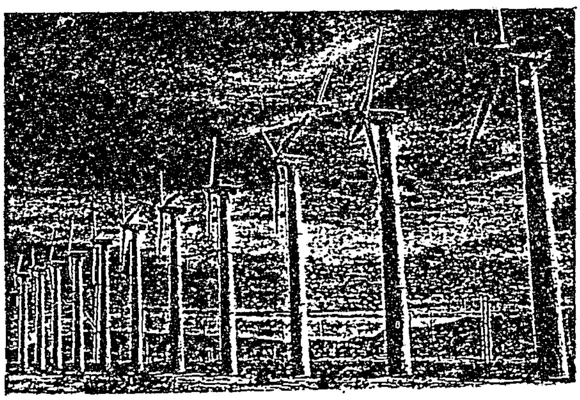
The fact that the Sun's energy is dispersed could also be an advantage; this energy is delivered free! The utilisation of solar energy involves technology which operates on a smaller scale for individual homes or communities. This type of technology can utilise space that is available on rooftops etc. Ninety percent of houses in Cyprus make use of solar heaters for heating water. Two thirds of the homes in Israel make use of similar solar heaters. Israel has one of the few solar power stations.

To produce electricity on a large scale, some scientists have suggested building structures in space that would collect solar energy. However at present, the use of solar energy is too expensive and its collection is too inefficient to produce very large quantities of electricity.

d) <u>Wind</u>

The energy of wind has been utilised in windmills for many centuries. Modern versions of windmills called wind turbines, are used to generate electricity.

<u>Wind Towers which Generate Electricity</u>



Once again the utilisation of this form of energy is difficult beause the energy is dispersed and intermittent. At present 95 countries make use of these wind turbines. Wind energy could generate 1/5 of electricity needs of the United Kingdom by the year 2020.

Alternate Sources of Energy for Motor Vehicles

The combustion of fossil fuel in motor vehicles is a very significant source of air pollution. Some other sources of energy for this purpose are being considered. These include solar energy, energy from the combustion of hydrogen, and electricity provided by batteries. The batteries will have to be recharged using mains electricity. This will add to the burden of coal-fired power stations with resultant air pollution problems. Much research is being conducted to develop new batteries. The disposal of substances used in batteries also poses environmental problems although these will not be air pollution problems.

B. Alternative Products

Some of the products we manufacture, eg.CFCs, create serious air pollution problems. Industry is heavily committed to finding alternatives for these products. Some alternative products developed so far are:

a) Dimethyl ether, CH_3OCH_3 (Systematic Name: methoxymethane)

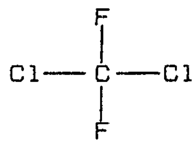
Dimethyl ether (trivial name) was first made in 1835. The Norwegians used it in aerosols in 1939. Its use was replaced by that of CFCs. However, because of the damaging effects of CFCs on ozone, there is increased interest in the use of this compound once again. In South Africa, dimethyl ether (tradename Prozone) is manufactured by a company in Durban, C. G. Smith Chemicals. Vaporised pure methanol is passed over a catalyst and dimethyl ether and water form.

$$\underset{\text{methanol}}{2CH_3OH(g)} \xrightarrow{\text{catalyst}} \underset{\text{dimethyl ether}}{CH_3OCH_3(g)} + H_2O(l)$$

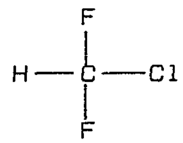
Some of the properties of this compound make it well-suited to its use as a propellant in aerosols. It has a boiling point of -25°C at 1 atm. It is miscible with water. Thus the flammability of dimethyl ether is reduced by mixing it with water. Dimethyl ether is odourless and does not irritate the skin. Once it is expelled into the atmosphere, it degrades fairly rapidly to form carbon dioxide and water. The contribution of dimethyl ether to the carbon dioxide concentrations in the atmosphere is estimated to be small - 0,02% of other sources.

b) HCFCs (hydrochlorofluorocarbons) and HFCs (hydrofluorocarbons)

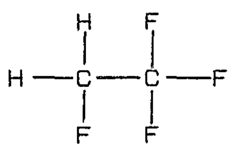
CFCs are compounds whose molecules consist of chlorine, fluorine and carbon atoms. eg CFC-12,



HCFCs are compounds whose molecules consist of hydrogen, chlorine, fluorine and carbon atoms. eg



AECI has announced that HCFCs will be made as an interim measure to phase out the use of CFCs for the refrigeration industry. The presence of a carbon—hydrogen bond makes these compounds more reactive than CFCs. For example in the atmosphere, HCFCs will react with the hydroxyl radical. Thus the period of time that HCFCs remain in the atmosphere will not be as long as that of CFCs. However the presence of chlorine atoms in these compounds is unfavourable; these will also lead to the depletion of the ozone in the stratosphere. In time it is planned to replace HCFCs with HFCs; compounds whose molecules consist of hydrogen, fluorine and carbon atoms (no chlorine). AECI is developing one of these compounds CH_2FCF_3 (tradename Klea).



HFCs will not cause damage to the ozone in the stratosphere. A warning has, however been issued by Joe Farman, the scientist who first detected the depletion of stratospheric ozone. His findings suggest that both HCFCs and HFCs are "greenhouse gases" and could contribute significantly to global warming.

C. Alternative Behaviour by Society

The human population took 4 million years to reach a total population of 1 000 million in 1850. The population doubled by 1925. Now the world population increases by 1 000 million every 12 years! It is the activities of both the rich and the poor sectors of the population that are contributing to the problems of air pollution. The rich consume energy on a large scale. The motor vehicles they drive contribute to the serious problems of air pollutants released from the exhausts. The poor denude the land of trees in their search for fuel for their fires. The poor burn coal for cooking and heating purposes. The air pollutants produced contribute to the smog that shrouds the areas in which they live.

Society will have to curb this growth in population. Science and technology have saved the lives of infants and prolonged the life of the elderly. Now the advances of science and technology in curbing population growth need to contribute to the control of numbers.

As members of society we can contribute to the control of air pollutants by changing our life-style. This change could operate in the following areas:

a) Transport

The exhaust gases released by motor vehicles contribute significantly to the problems of air pollution. We can reduce this contribution by checking the tuning of the engines of our cars so that they burn petrol more efficiently. We can reduce our use of cars by walking or using bicycles for short distances. Sharing lifts or the forming of lift-clubs is better than cars being used for one or two people only. Using public transport will also help in reducing air pollutants. In Johannesburg trams, using electricity, could make their reappearance. This will increase the demand for power from the power stations, but it will help to reduce the formation of smog in urban areas.

b) Homes

Our thoughtful use of electricity could reduce the demands on power stations. This in turn would reduce the quantities of air pollutants produced by these power stations. For example, we can save electricity by:

switching off unnecessary lights.
setting geysers at an efficient temperature.
installing appliances that are not big users of electricity.
insulating homes to avoid the use of air conditioners in summer and excessive heating in winter.
closing doors of heated rooms and sealing draughts.
using smoke-less fuels such as anthracite.
using smokeless stoves
avoiding the use of coal stoves for heating if there is electricity in the home.

When we shop for commodities, we should be aware of their impact on the environment.

These changes look trivial on an individual scale. However when a large number of people change their activities this could have a significant effect on some of our air pollution problems.

Conclusion

The problem of air pollution is serious. This may make us feel our future is bleak and inevitable. It need not be. A study of air pollution increases our awareness and understanding of the problem. This is the first vital step towards finding solutions to the problem. Now we must use our ingenuity and adaptability. With our scientific knowledge and skills of technology, we are well-equipped to find a balance between our needs and the preservation of our environment.

Learning Objectives for Unit 10

On completion of this unit students should be able to:

10.1 Explain that, to control the problem of air pollution, it is necessary to consider
- alternative sources of energy
- alternative compounds to CFCs
- alternative life styles by society.

10.2 Describe the alternative sources of energy: nuclear, hydro-electric, solar and wind.

10.3 List some of the advantages and disadvantages of these forms of energy.

10.4 Name alternative products being used and developed to replace CFCs.

10.5 Describe the production and use of dimethyl ether to replace CFCs in propellants.

10.6 Explain the development of alternatives to CFCs for refrigeration purposes.

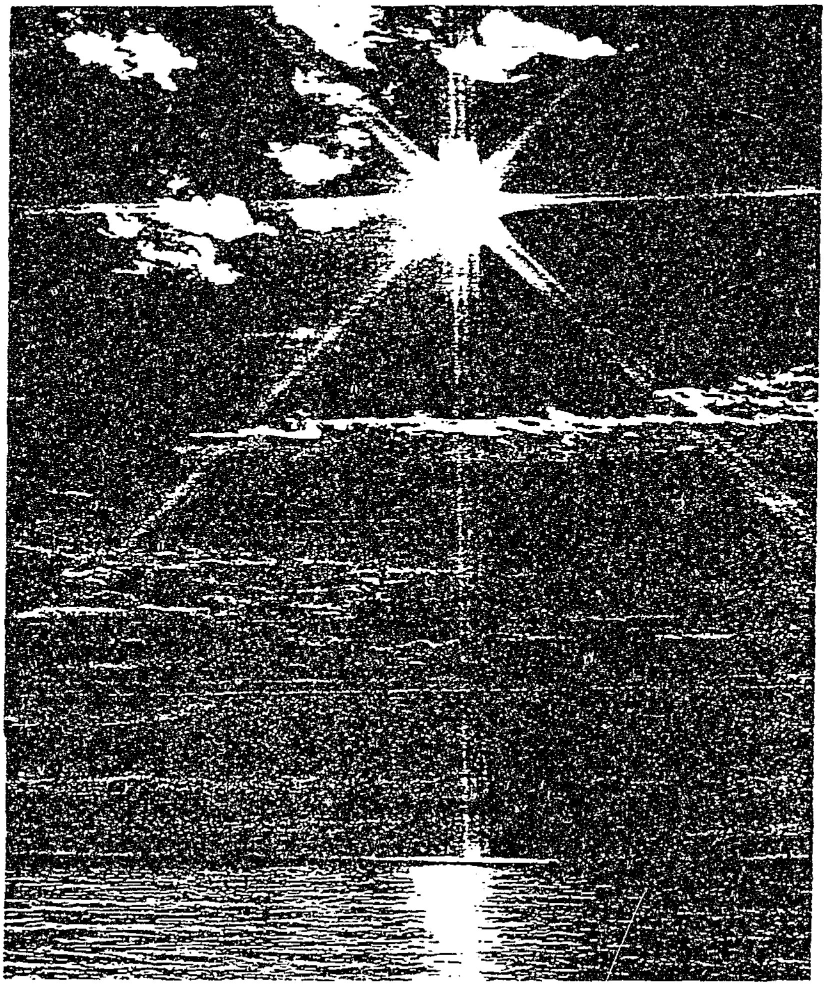
10.7 Explain the meaning of the abbreviations "HCFCs" and "HFCs".

10.8 Describe the impact of increasing population on air pollution.

10.9 Describe ways in which we, as members of society can help in the control of air pollution by changing our life-styles.

Worksheet 10(a) Alternative Sources of Energy

Task 1

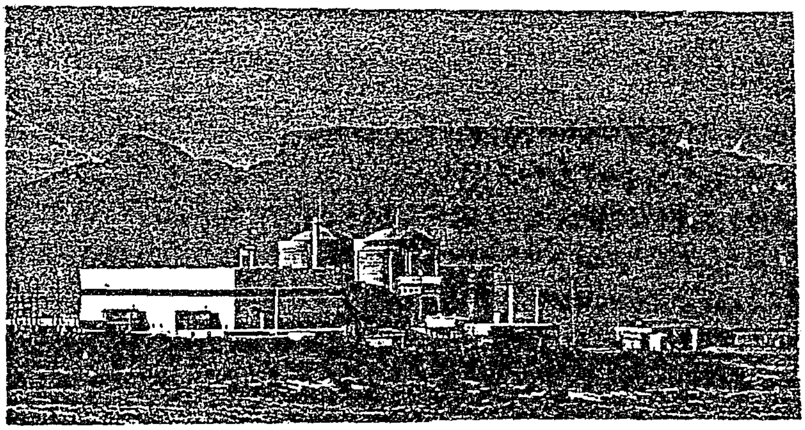


Solar energy is an alternative source of energy.

i) Discuss the advantages and problems of using this source of energy.

ii) Suggest ways of using this source of energy in your home.

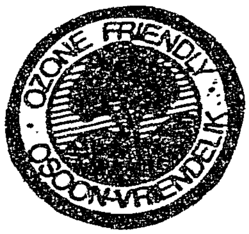
Task 2



Koeberg is a nuclear power station 40 km from Cape Town. Discuss the advantages and disadvantages of this nuclear power station for South Africa.

Worksheet 10(b) Alternative Products
(Please write your answers on a separate sheet of paper)

The phrase "Ozone Friendly", appears on most aerosol cans these days. Symbols similar to the two shown below are displayed on the aerosol cans.

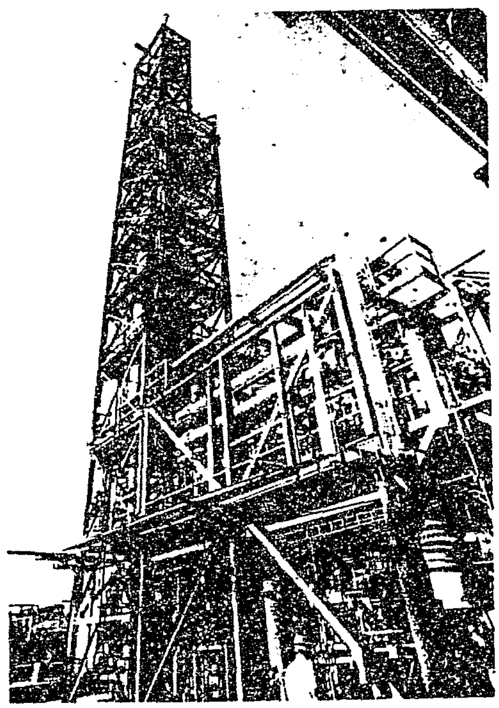


Task 1

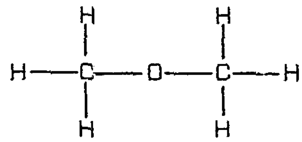
i) What does the term "ozone friendly" mean?

ii) C.G. Smith Chemicals in Durban manufacture a compound which is an alternative to CFCs. The trade name of this compound is Prozone.

The Prozone Plant
of
C.G. Smith Chemicals
in
Durban



ii) *(contin)*
What are the trivial and systematic names of this alternative compound, prozone? (The projection formula of prozone is shown below.)



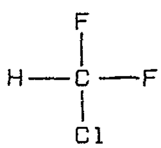
iii) What properties of this compound make it suitable to use as a propellant in aerosols?

iv) This compound is produced by the reaction represented by the equation:

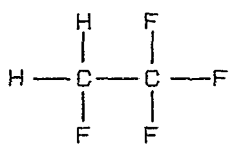
$$2CH_3OH(g) \xrightarrow{\text{catalyst}} CH_3OCH_3(g) + H_2O(l)$$

C.G. Smith is able to supply an annual order of 1 000 tons of CH_3OCH_3 per year for the South African market. What mass of pure methanol, CH_3OH, is required per year to meet this demand?

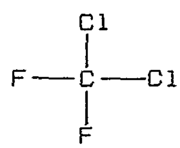
Task 2
AECI is manufacturing alternative products to replace the use of CFCs in refrigerators. Look at the projection formulae and then answer the questions below:



(a)



(b)



(c)

i) Which compound is the CFC?

ii) Which compound is the HCFC?

iii) Which compound is the HFC?

iv) In what way do HCFCs and the HFCs represent an "improvement" on CFCs?

v) Joe Farman (one of the scientists who first discovered ozone depletion in the stratosphere) has issued a warning about CFC substitutes. Read this extract taken from the Star newspaper July, 1991:

Expert warns on CFC substitutes

Star Bureau

LONDON — The British scientist who discovered the ozone hole over the Antarctic has warned that substitutes for the ozone-depleting CFCs (chlorofluorocarbons) will accelerate global warming faster than the chemical industry admits.

Joe Farman, an atmospheric physicist, described the leading substitutes for CFCs as "*powerful greenhouse gases*".

If industry were allowed to release large quantities of the new chemicals — hydrochlorofluorocarbons (HCFCs) and the hydrofluorocarbons (HFCs) — the potential benefits from phasing out CFCs could vanish.

The chemicals industry has spent hundreds of millions developing CFC substitutes.

The largest CFC manufacturer, Du Pont of the US, has, for example, put its investment at about R775 million and talks of spending more than R2,5 billion over the next year.

Chemical companies say that if they are not allowed to produce CFC substitutes for long enough to make a return on investment, users, such as the refrigeration industry, will face a severe crisis when CFC manufacturing stops in the late 1990s in accordance with the Montreal Protocol.

Speaking in Geneva where government officials are meeting to start drafting a similar international convention on climate change, aimed at limiting global warming, Mr Farman said the chemical industry seriously under-estimated the environmental impact of CFC substitutes when it claimed they would add only 1 percent to man-made global warming in coming decades.

Mr Farman's arguments — which are supported by pressure groups such as Friends of the Earth — were rejected by Du Pont's environmental co-ordinator, Mark McFarland.

"You have to look at the big picture when judging what are the best alternatives to CFCs. That means looking at their environmental impact, toxicity and flammability," said Mr McFarland.

<u>Questions</u>

1. What warning is Joe Farman issuing?
2. What are the problems that confront industry in this regard?

Worksheet 10(c) Alternative Behaviour by Society ....
Hot Plates!

Look at the drawing below.
Then answer the questions that follow.
(Use a separate sheet of paper for your answers.)

i) Why do you think the woman still wants to keep her coal stove?

ii) Coal stoves are still used in many homes in the townships, although the houses have electricity. Describe the effects of this use of coal stoves on the quality of the air in the townships.

Worksheet 10(d) Alternative Behaviour by Society......
Wheels, Changes and Predictions!

Task 1

Read this article (from the Star newspaper, September, 1991) and then answer the questions that follow on the next page.

"Have car will travel. Unfortunately, this is what more and more South Africans are doing. They crawl in second and even first gear for minutes on end on clogged highways to get to work. They have even been seen braaing on the side of the road in holiday traffic queues. And the authorities answer to it all? More highways and wider and faster arterials across the suburbs. But now some towns are putting their foot down - on the brake.

Johannesburg is to get a sophisticated seven-route sky-tram and road tram network, after a two year feasibility study concluded by transport consultants, Masstran, for the Department of Transport. One of Masstran's objectives was to reduce the public's dependence on the car.

Sandton last week scrapped all plans to build new highways and widen existing ones. Car commuters were expecting R25 million a year more to be spent on new expanses of tar so that they could get to work faster. The council says it has better uses for the money.

A similar trend is evident in Los Angeles where highways dominate the scenery. Cynics joke about liking to see the sort of air they are inhaling. But they have learned a big lesson: highways have not solved their traffic problems. They have merely spread them.

Throughout the world a new generation of town planners is beginning to turn on King Car. They argue that multiple lane freeways meant to ease traffic actually attract it. In Europe and the US, where more and wider roads have been built to cope with the worsening traffic congestion, experts are now saying the long term solution lies not in wider or extra highways - in fact, it lies in the very opposite: cars must be discouraged.

The public, too, is turning against cars - at least as a commuting vehicle. It recognises cars as a major contributor to global warming (greenhouse gases come out of the exhaust pipe). The public has become aware of the toxic pollutants emitted at ground level which are making people ill and causing crops to wilt.

Athens, one of the three most populated cities in the world, is cutting down on traffic by allowing cars with odd number registration plates to enter the city one day and even numbers the next. Santiago Chile, is implementing a similar system. South Africa is also showing definite trends towards ending its love affair with the car.

Suburban people, especially, perceive highways as threats to the peace of their suburbs. Suddenly "squeeze points" are in: so are speed bumps and traffic islands; anything to slow down traffic and reduce its noise too. The expression "traffic calming" has become a catchphrase.

South Africa is slowly joining the international trend towards ending its love affair with the car. Although we do not have severe congestion yet, most members of the public no longer see new roads as an answer to the problem of increasing traffic.

In Sandton, a proposed network of arterial roads (a six-lane highway was to be built!) created a huge backlash. Sandton management committee chairman Bruce Stewart said that 800 letters which crossed his desk had been unanimously against the major road plan. Mr Stewart, a town planner by profession, believes the public must be offered an alternative to the car as far as getting to work is concerned. His formula for Sandton is to encourage more of the public to use public transport. In addition intersections must be improved and traffic lights synchronised."

Questions
Please answer on a separate sheet of paper:

i) What "behaviour" is discussed in the article?
ii) Discuss the problems being experienced by this "behaviour".
iii) What solutions to these problems have been offered in the past?
iv) What solutions to these problems are being used or planned? Include in your answer solutions in South Africa and in other countries in the world.
v) Why is the "public" expressing concern about this "behaviour"?
vi) Discuss the contribution you and your family make to this problem.
vii) Describe ways in which you think you (and your family) could contribute to solving this problem.

Task 2
On a separate sheet of paper, make a list of your activities (in a typical day) that contribute to air pollution. List the air pollution consequences of these activities and the changes you could make in these activities that would help reduce air pollution. Use these headings for your records:

MY ACTIVITIES   AIR POLLUTANTS PRODUCED   POSSIBLE CHANGES

Task 3
Comment on this prediction.

Solutions to Worksheets for Unit 10

Worksheet 10(a) Alternative Sources of Energy

Task 1

i)

Advantages	Problems in Using this Source
Abundant	Dispersed and intermittent
Renewable	Difficult to use, at present
Distributed "free of Charge"	Substances used to "collect" and store this energy could pose problems in other areas
Very clean - no air pollution	ie. cause other forms of pollution but not air pollution

ii) The space available on the roof of a house could be used to set up solar heaters for heating water. If the house is insulated so that the warmth does not easily leave the house, the Sun's energy could be used to warm the house in winter.

Task 2

Advantages

1. No air pollution during normal operation.
2. In South Africa, Koeberg functions to provide electricity in regions remote from the coal mines. These regions are also remote from our coal-fired power stations. Therefore transporting coal or electricity to these remote regions would make electricity very expensive.
3. Koeberg can use cold Atlantic sea water for cooling. This saves scarce water resources (normally used in coal-fired power stations.
4. Fuel source (uranium oxide) is compact and easily transportable.
5. Nuclear power station only refuelled once a year.
6. South Africa has reserves of uranium.

Disadvantages

1. If accidents occur, there may be very serious consequences.
2. The nuclear wastes pose problems for their disposal.

Worksheet *10(b) Alternative Products*

Task 1

i) The term means that the gas used to disperse the contents of the aerosol (ie the propellant) is <u>not</u> a CFC. Therefore the propellant does not destroy the ozone in the stratosphere.

ii) Trivial name - dimethyl ether
Systematic name - methoxymethane

iii) Prozone is a gas at room temperature and pressure.
Prozone is miscible with water, therefore its flammability can be reduced.
Prozone is odourless and non-irritating to the skin.
Prozone breaks down rapidly in the atmosphere to produce carbon dioxide and water and so does not pose the same air pollution problems as CFCs.

iv) Mass of dimethyl ether needed per year

$$= 1\ 000 \text{ tons}$$
$$= 1\ 000 \times 1\ 000 \text{ kg}$$
$$= 10^3 \times 10^3 \times 10^3 \text{ g} \quad = 10^9 \text{ g}$$

Amount of dimethyl needed per year $= \dfrac{10^9 \text{ g}}{46{,}07\text{g mol}^{-1}}$

$$= 2{,}171 \times 10^7 \text{ mol}$$

From the equation,
The production of 1 mol dimethyl ether requires 2 mol methanol

Therefore the production of $2{,}171 \times 10^7$ mol dimethyl ether requires $2 \times 2{,}171 \times 10^7$ mol methanol

Therefore the mass of methanol $= 2 \times 2{,}171 \times 10^7 \times 32{,}04$ g
$= 1{,}391 \times 10^9$ g
$= 1{,}391$ tons methanol per year

Task 2

i) The CFC is compound (c)

ii) The HCFC is compound (a)

iii) The HFC is compound (b)

iv) HCFCs and HFCs are more reactive than CFCs because of the presence of a C-H bond. The hydroxyl radical (Unit 8) present in the atmosphere reacts with these molecules before they reach the stratosphere.
HCFCs have fewer chlorine atoms (and HFCs have no chlorine atoms). Therefore destruction of ozone in the stratosphere should be reduced.

Questions (from newspaper article)

1. *Joe Farman is warning that HCFCs and HFCs could contribute to possible global warming, as they are "greenhouse gases".*

2. *Companies have invested large amounts of money in the development of alternative products. Therefore a reduction in the production of these alternatives will pose economic problems for the companies.*

Worksheet 10(c) Alternative Behaviour by Society..... Hot Plates!

i) *Some of the student answers may include the following:*
   Coal is cheaper to warm water.
   It is easy to buy coal in the townships.
   Electricity is expensive: when coal is used she knows how much she is spending.
   The coal stove keeps the house warm.
   It is good to sit and talk around the coal stove in the evenings.
   She can use the coal stove if the electricity supply is cut off.

ii) *The use of coal stoves in many houses in the townships causes the following:*
   Visibility is reduced by the pieces of soot (smoke) that settle around the houses. It is sometimes dark even at 10 o'clock in the morning and car lights have to be switched on.
   The soot dirties the outsides of buildings, the insides of houses, the clothes on the washing line.
   The smoke irritates eyes, causes throat and chest irritation and conditions such as bronchitis and asthma.
   In Unit 2 and Unit 9, we learn that coal stoves in townships such as Soweto, release more fly-ash and sulphur dioxide than some of the largest coal-fired power stations in South Africa.

NB. *The purpose of this worksheet is to stimulate a discussion among the students. This activity aims to make students more aware of the problems associated with the use of coal-stoves. This awareness could lead to changed lifestyles in the future.*

Worksheet 10(d) Alternative Behaviour by Society........
Wheels, Changes and Predictions!

Task 1

i) The use of the motor car, is the "behaviour" being discussed in this article.

ii) Problems experienced are:
Slow movement of traffic with vehicles travelling in first or second gear. Roads are "clogged" with traffic. Motor vehicles produce exhaust gases which contribute to possible global warming and photochemical smog. This smog makes people ill and damages vegetation.

iii) Solutions in the past, involved the building of more roads/freeways and the widening of existing roads. However, these solutions simply attracted more cars!

iv) New solutions are:
1. Discouraging the use of the car.
Eg. In Athens, cars with odd numbers are allowed to enter the city on one day and even numbers the next.
Eg. In South Africa, plans are being developed to use a "sky tram" and "road tram" system using electricity.

2. Citizens are being asked to use public transport.

v) The public is expressing concern as they become aware of air pollution problems.

vi) Contributions to the problem by some families are
eg. use of cars for frequent, short trips
eg. trips in car for 1 or 2 people

vii) Contributions to solutions could be
eg. walking or using bicycles for short trips
eg. planning the use of the car so that many tasks can be accomplished in one trip
eg. formation of lift clubs
eg. use of public transport

Task 2

The purpose of this activity is to hightlight the involvement of us all in the problems of air pollution.
Solutions may not always be apparent. However an awareness of the complexity of the problem is the first step towards finding solutions. Some interesting discussions could emerge from this exercise. A few examples are listed on the next page.

MY ACTIVITIES	AIR POLLUTANTS PRODUCED	POSSIBLE CHANGES
Bathed in hot water	CO_2, SO_2, NO_x, fly-ash, CO, hydrocarbons, soot from coal-fired power station	Installation of a solar heater
Washed in water heated on coal stove	CO_2, SO_2, NO_x, fly-ash, CO, hydrocarbons, soot from burning coal Produces smog in suburbs/townships	Use of electricity for heating water (although as we see above this also gives rise to problems. However, at least local air pollution is reduced.)
Ate cereal and milk for breakfast	Fertilisers produce N_2O which can cause ozone depletion Cows (for milk) increase methane concentration which contributes to possible global warming Transport of these products contributes to photochemical smog, air pollution by lead compounds etc.	???????? (Maybe some interesting discussions here!!)

Task 3

The purpose of this task is to stress that we should not despair about the problems of air pollution. Nor should we feel that ultimate destruction is inevitable. Air pollution is a serious problem. However the "alternatives" suggested in this unit are presented to show students that we may be able to find solutions to these serious problems. The solutions will depend on our skills (offered by science and technology), ingenuity and willingness to change our lifestyles. The very rapid growth in world population must be reduced. We will have to find a balance between our activities and the impact they have on the nature of the atmosphere.

Glossary

Glossary

Included in this short glossary are terms/phrases used in the package which may need clarification. Terms/phrases that have been defined in the text are not restated here: a reference to the relevant unit and page number is given. Words that are not used in this resource package but which may be encountered in further reading or via the media, have been marked with an asterisk, *

A

acid rain - Unit 7 page 170.

aerosol - (scientific definition) Unit 5 page 117.
- (popular usage) spray can (aerosol can) in which pressure of a gas is used to scatter liquid contents in a fine spray.

air - mixture of a variety of gases found in Earth's atmosphere. The composition of the mixture varies with altitude.

air pollution - Unit 2 page 33.

* air quality standard - concentration of an atmospheric pollutant permitted during a specific time in a specific area. Standard is set by the Department of Health.

alternatives - choices of a different approach to a problem or situation.

altitude - height above sea level.

AECI - African Explosives and Chemical Industry: one of South Africa's largest manufacturers of chemicals, plastics, explosives, fertilisers.

* ambient air - surrounding air in a particular place.

anaerobic decay - reactions of substances in dead plants or animals (as they decompose) in the absence of oxygen.

atmosphere - Unit 1 page 7.

B

<u>bacterial decay</u> - changing of substances in dead plants or animals (as they decompose) by means of very small organisms living in the air, soil or water.

<u>baghouse filter</u> - Unit 9 page 215.

<u>benign climate</u> - weather conditions that are relatively pleasant and easy to live in.

<u>biosphere</u> - the living part (plants and animals) of Earth.

<u>boffin</u> - a scientist based in scientific research.

C

<u>carbon cycle</u> - Unit 6 page 144.

<u>carbon dioxide (CO_2)</u> - Unit 3 page 69.

<u>carbon monoxide (CO)</u> - Unit 3 page 69.

<u>cataract of the eye</u> - the lens of the eye is clouded (opaque) instead of being clear so the person cannot see properly.

<u>chain reaction</u> - a reaction in which one or more reactive reaction intermediates (often radicals) are continuously reformed by a cycle of repeated reactions.

<u>chemical feedstock</u> - (as used in an industrial context) substances which are used on a large scale in industry as reactants in chemical reactions to produce a variety of other substances.

<u>chlorofluorocarbons (CFCs)</u> - Unit 4 page 99.

<u>clouds</u> - visible aerosols of water in the atmosphere
i) cumulus clouds - dense, dome-shaped clouds with rounded edges.
ii) cirrus - thin, fragile, very high clouds with delicate filaments or narrow bands.

* <u>cleanse</u> - (as used in the context of air pollution) changing and/or removal of air pollutants from the atmosphere by chemical reactions and/or precipitation in rain etc.

coal - Unit 3 page 68.

concentration - the ratio of the mass, volume or amount of a solute in proportion to the volume, mass or amount of solvent or solution.

combustion - the rapid reaction of a substance with oxygen (also called burning). Energy and light are released during this reaction.

commodity - a useful article that is usually sold or traded.

cosmic radiation - electrons and nuclei reaching the Earth from outer space.

CSIR - Council for Scientific and Industrial Research

cyclone - Unit 9 page 216

D

deforestation - the cutting down and destruction (usually by burning) of trees in forests. The cleared land is then used for other purposes eg. building, agriculture.

density - the mass per unit volume, of a substance, at a specified temperature and pressure.

diffusion - spreading of substances from a region of high concentration to regions of low concentration until a uniform concentration is reached.

dinitrogen oxide (N_2O) - Unit 4 page 102.

dry deposition - Unit 7 page 176.

* dump - (used in the context of air pollution) to release substances into the atmosphere.

dust - small, dry, solid particles that may be released into the air by wind, or activities such as grinding.

E

<u>electrostatic precipitator</u> - Unit 9 page 215.

<u>emissions</u> - (as used in the context of air pollution) the release of air pollutants into the atmosphere.

* <u>emission source</u> - source of air pollution eg.
i) point sources such as power stations.
ii) mobile sources eg cars.

<u>enhanced greenhouse effect</u> - Unit 6 page 142.

<u>ESKOM</u> - Electricity Supply Commission ie. the industry supplying electricity to the Republic of South Africa.

F

<u>flammability</u> - the ease with which a substance burns.

* <u>flue gas</u> - waste gas from combustion process.

<u>fly-ash</u> - Unit 3 page 70.

<u>fog</u> - Unit 5 page 117.

<u>fossil fuel</u> - substances such as coal, oil, and natural gas which have formed over millions of years through the anaerobic decomposition of vegetation under extreme pressure in the Earth's crust.

<u>fuel</u> - substance which is burned to make energy available.

* <u>fumes</u> - emissions which are unpleasant or unhealthy.

G

<u>global air pollution</u> - Unit 2 page 34.

<u>greenhouse</u> - a building which has a glass roof and glass walls. Plants, that need to be protected from the cold, are grown in it.

<u>greenhouse effect</u> - Unit 1 page 13.

green politics - politics concerned with the protection of the natural environment.

gut bacteria - bacteria living in the organs of animals where food is digested.

H

haze - reduced visibility caused by the presence of fine dust (particulates) or aerosols in the atmosphere.

height - perpendicular distance from the base to the top of an object.

homogeneous mixture - mixture of substances which appear uniform to the eye ie. only one phase is observable.

hydrocarbons - Unit 3 page 71.

hydro-electric energy - electrical energy made available using the movement of water through turbines.

hydrosphere - Unit 1 page 7.

hydroxyl radical - Unit 8 page 198.

I

Ice-Age - a very cold period of time, lasting many thousands of years, when the Earth's surface was covered with ice.

Industry - work and processes involved in making commodities.

Industrial Revolution - the rapid and widespread change in production methods, in the 19th century, in which commodities were made by machines rather than manual labour.

incomplete combustion - reaction of a substance with oxygen which does not go to completion because there is insufficient oxygen.

infrared radiation - electromagnetic radiation with wavelength ranging from 760 nm to 1×10^6 nm.

inorganic compounds - compounds which do not contain carbon (with the exception of cyanides and carbonates)

L

lead compounds - see Unit 3 page 72

legislation - laws of the state/government.

* level - a misleading term, often used to describe the concentration of a substance.

local air pollution - Unit 2 page 34.

M

macroscopic scale - on a large scale ie. visible with the naked eye.

media - (as used in this resource package) means of spreading the news/ information, eg. television, radio, newspapers etc.

mesopause - Unit 1 page 16, 26 A.

mesosphere - Unit 1 page 11.

microscopic scale - on a very small scale. Not visible with the naked eye nor with a very powerful microscope : an atomic/molecular scale. (The term should strictly be "sub-microscopic".)

* mine - (as used in the context of air pollution) to use substances in the atmosphere.

mist - Unit 5 page 117.

Montreal Protocol - Unit 8 page 201.

methane - Unit 6 page 145.

N

<u>natural gas</u> - Unit 3 page 72.

<u>nitrogen dioxide (NO_2)</u> - Unit 3 page 69.

<u>nitrogen oxides (NO_x)</u> - Unit 3 page 69.

<u>nitrogen monoxide (NO)</u> - Unit 3 page 69.

<u>nuclear energy</u> - energy made available from nuclear reactions.

O

<u>oil</u> - Unit 3 page 71.

<u>ozone</u> - Unit 4 page 96.

<u>ozone hole</u> - Unit 4 page 106, 112.

<u>ozone layer</u> - Unit 4 page 106, 112.

<u>ozone friendly</u> - Unit 10 page 257, 265

P

<u>particulates</u> - small, solid pieces of matter which may be dispersed in the atmosphere.

<u>peat</u> - decaying plant material found in the ground in cool, wet, areas. It can be used for fuel.

<u>peroxyacetylnitrate (PAN)</u> - Unit 5 page 122.

<u>photochemical reaction</u> - Unit 1 page 10.

<u>photochemical smog</u> - Unit 5 page 119.

* <u>plume</u> - (as used in the context of air pollution) visible aerosol, emitted from chimney stacks.

<u>power</u> - rate at which energy is made available or the rate at which work is done.

<u>polar vortex</u> - Unit 4 page 102.

<u>precipitation</u> - (as used in this resource package) deposition of water from the atmosphere in the form of snow, rain, hail, dew etc.

primary air pollutants - Unit 2 page 34.

projection formula - formula showing the sequence of atoms (but not the 3-dimensional structure) of a molecule, ion or radical.

propellant - (as used in this resource package) gas under pressure used in aerosol (spray) cans to carry contents out of the can in a fine spray.

Prozone - Unit 10 page 250.

R

radical - a reactive atom or group of atoms with an unpaired electron.

refrigerant gas - gas used for cooling in air conditioners and refrigerators.

regional air pollution - Unit 2 page 34.

residence time - (as used in the context of air pollution) average time a molecule spends in the atmosphere after it has been released into the atmosphere.

reservoir - (as used in this resource package) part of Earth where large quantities of a substance can be found.

ruminants - animal able to bring food back to the stomach to rechew eg. cows, sheep, deer.

S

SASOL - a large industry in South Africa, which makes oil and other important substances, eg. plastics, solvents, waxes, tars, from coal.

secondary air pollutants - Unit 2 page 34.

simulation - an attempt to copy, or mimic, actual situations/conditions.

* <u>sink</u> - (as used in the context of air pollution) part of Earth where air pollutants are deposited (often in a different form) after they are removed from the atmosphere.

<u>solar radiation</u> - electromagnetic radiation emitted by the Sun.

<u>smoke</u> - a visible aerosol produced during incomplete combustion.

<u>soot</u> - solid, black particles, composed largely of carbon, produced during incomplete combustion.

<u>species</u> - atoms/ molecules/ions/radicals with characteristic structure and composition.

<u>stable air</u> - Unit 1 page 10.

<u>stratopause</u> - Unit 1 page 16, 26A.

<u>stratosphere</u> - Unit 1 page 10.

<u>sulphur dioxide (SO_2)</u> - Unit 3 page 69.

<u>sulphur trioxide</u> - Unit 7 page 175.

<u>systematic name</u> - name of a chemical compound based on a set of rules decided upon by IUPAC (International Union of Pure and Applied Chemistry).

T

<u>technology</u> - activity in which scientific knowledge and approach are used for practical purposes eg. in industry, medicine.

<u>temperature inversion</u> - Unit 1 page 10.

<u>thermosphere</u> - Unit 1 page 11.

<u>toxic</u> - poisonous and may damage health or cause death.

<u>trivial name</u> - name of a chemical compound which is not based on a system of rules and is often related to the source of the substance.

<u>tropopause</u> - Unit 1 page 10.

troposphere - Unit 1 page 10.

turbine - machine which turns when a stream of air, gas, water or steam pushes the blades of a wheel and makes them turn.

U

ultraviolet radiation - electromagnetic radiation with wavelength 40 - 400 nm

V

volatile - evaporates easily under standard conditions (25 °C and 1 atmosphere pressure).

Questions
&
Statements

Examples of Multiple Choice Questions

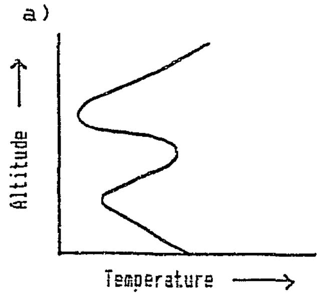
1. The atmosphere extends to an altitude of approximately
   a) 10 km   b) 20 km
   c) 1 km   d) 500 km
   e) 2 000 km

2. The approximate percentage of carbon dioxide present in the lowest region of the atmosphere (troposphere) is
   a) 50%   b) 0,03%   c) 30%   d) 25%   e) 1%

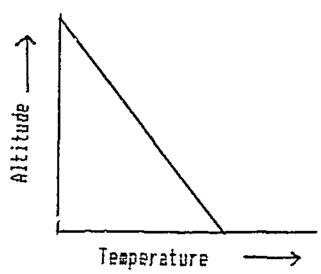
3. Which statement is <u>incorrect</u>?
   a) The atmosphere protects life from harmful solar radiation.
   b) The "greenhouse" or energy trapping effect of the atmosphere is harmful to life.
   c) The properties and composition of the atmosphere are not the same throughout.
   d) Scientists believe that the composition of the atmosphere has cnanged over the billions of years since the "birth " of the planet.
   e) The atmosphere is naturally reactive.

4. Which graph is a correct representation of the variation of the temperature of the atmosphere with altitude?

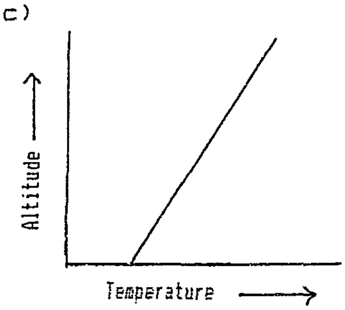
a)



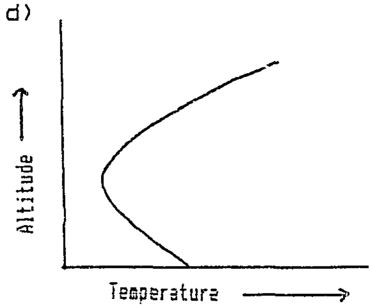
b)



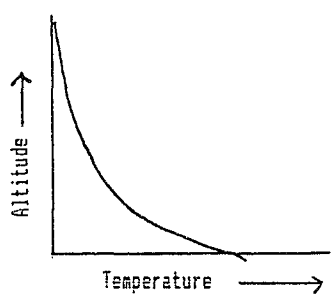
c)



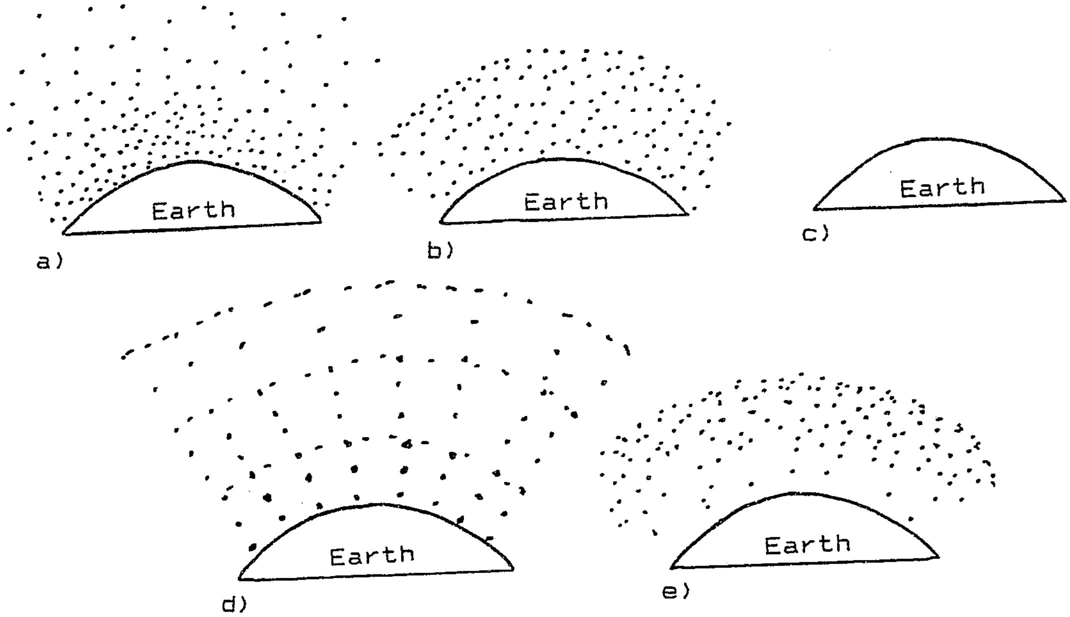
d)



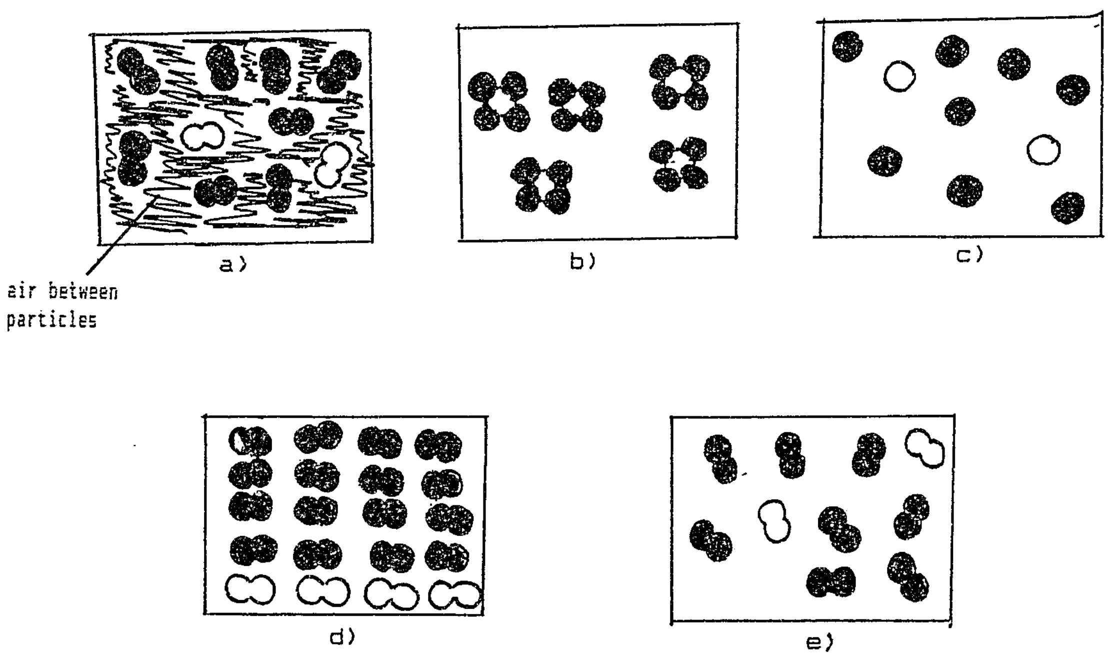
e)



5. Which diagram is a correct representation of the distribution of particles in the atmosphere?



6. Which diagram is a correct representation of the microscopic nature of the air in the lowest region (the troposphere) of the atmosphere?
(= nitrogen atom, = oxygen atom)



7. Air pollution
   i) can occur when the concentration of a substance occurring naturally in the atmosphere is increased.
   ii) can occur when the concentration of a substance occurring naturally in the atmosphere is decreased.
   iii) only occurs when substances that do not naturally occur in the atmosphere enter the atmosphere.
   iv) is only caused by substances in a gaseous state.

   The correct answer(s) is/are
   a) (i) only
   b) (i) and (ii)
   c) (iii) only
   d) (iii) and (iv)
   e) (i) and (iv)

8. The percentage of the atmosphere that air pollution affects (in total) is:
   a) more than 50%
   b) about 10%
   c) about 20%
   d) about 5%
   e) less than 0,05%

9. Air pollution is a result of the activities of
   (i) Industry
   (ii) The rich
   (iii) The poor
   (iv) Science and technology

   My answer is
   a) (i) only
   b) (i) and (iv)
   c) (i), (ii), (iii) and (iv)
   d) (i), (iii) and (iv)
   e) (ii) only

10. Which statement is <u>correct</u>?
   a) CFCs occur naturally.
   b) It is only CFCs that destroy ozone in the stratosphere.
   c) Ozone, produced during the formation of photochemical smog in the troposphere, can drift upwards and replace ozone which is being destroyed in the stratosphere.
   d) Ozone is very unreactive.
   e) The concentration of ozone in the stratosphere is greater than the concentration of ozone in the troposphere.

Answers to the multiple choice questions are:

1. *e*
2. *b*
3. *b*
4. *a*
5. *a*
6. *e*
7. *b*
8. *e*
9. *c*
10. *e*

Examples of True/False statements

1. Approximately 90% of the world's energy comes from the combustion of coal and oil.

2. Both coal and oil are classified as fossil fuels.

3. Coal is composed of carbon only.

4. The only products formed when coal is burned are: ash, soot, carbon dioxide and carbon monoxide.

5. The ash, produced by burning coal, does not present any air pollution problems because it is solid and can easily be removed.

6. South African coal has a low sulphur content. Therefore the release of sulphur dioxide from coal combustion is negligible.

7. The burning of coal in households can produce worse air pollution than that produced by power stations.

8. In South Africa, coal-fired power stations burn more coal than industries such as ISCOR.

9. Nitrogen oxides (which contribute to air pollution problems) are only produced by industrial processes.

10. The total contribution to air pollution by motor vehicles, is very small compared to industry.

11. The temperature in parts of a running car engine is sufficient to bring about a reaction between nitrogen and oxygen in the air.

12. Petrol sold in South Africa contains lead compounds.

13. The only products formed when petrol is burned in engines of motor vehicles are: carbon dioxide, carbon monoxide and lead compounds.

14. Natural gas is mostly methane.

15. In South Africa, natural gas deposits have been discovered near Mossel Bay.

16. The chemical formula of ozone is O_3.

17. The concentration of ozone is the same throughout the atmosphere.

18. Once ozone is destroyed in the stratosphere, it can never be reformed.

19. The sky is blue because ozone is blue gas.

20. CFCs are compoun whose molecules consist of chlorine, fluorine and carbon atoms.

21. Both CFCs and dinitrogen oxide (N_2O) destroy ozone in the stratosphere.

22. One chlorine atom released from a CFC molecule, is capable of destroying approximately 100 000 ozone molecules.

23. CFCs are only used in industrial processes.

24. CFCs occur naturally in the atmosphere.

25. CFCs are unreactive in the troposphere but become reactive in the stratosphere.

26. All solar radiation that enters the atmosphere, reaches the surface of the Earth.

27. Ozone is the only substance in the atmosphere capable of absorbing radiation of wavelength 220 - 330 nm.

28. Solar radiation of wavelength 220 - 330 nm is harmful to life.

29. A photochemical reaction can only be brought about by visible light.

30. With modern technology, scientists never make mistakes.

31. Smog is only a combination of smoke and fog.

32. Smog is mainly an urban problem.

33. Smog only forms on a cold, wet day.

34. Smog only results from the burning of coal.

35. Smog is not a problem in South Africa.

36. Weather plays an important role in the formation of smog.

37. Smog can have a detrimental effect n health.

38. Smog is only caused by industria activity.

39. Ozone has only beneficial effects in the atmosphere.

40. Ozone is not present in the lowest region (the troposphere) of the atmosphere.

41. Sunlight and some of the gases released from motor car exhausts, can result in smog formation.

42. Nitrogen oxides are formed when nitrogen and oxygen combine in the very hot parts of the car.

43. Hydrocarbon compounds, released from motor car exhausts, are involved in chemical reactions which produce photochemical smog.

44. Ozone accumulates during the formation of photochemical smog.

45. Science and technology have no means for controlling photochemical smog.

46. The "greenhouse effect" of the atmosphere is beneficial.

47. The possible global warming (that scientists are concerned about) is a result of the Sun getting hotter.

48. Approximately 45% of the Sun's energy that enters the Earth's atmosphere, reaches the surface of the Earth.

49. The atmosphere is warmed directly by the Sun's energy as it passes through the atmosphere.

50. The atmosphere is warmed by energy being radiated from the Earth's surface.

51. All gases in the atmosphere are capable of absorbing infrared radiation (energy that causes heating).

52. Gases that contribute to the problem of an enhanced "greenhouse effect" include: carbon dioxide, ozone, dinitrogen oxide, methane, CFCs.

53. Human activities such as agriculture and cattle farming, do not contribute to air pollution problems.

54. The burning of coal and oil, is a major contributor to the problem of an enhanced "greenhouse effect".

55. At present, scientists can predict, with certainty, the consequences of an enhanced "greenhouse effect".

56. Once carbon dioxide has been released into the atmosphere, it remains there forever.

57. The atmosphere prevents the Earth having scorching hot days and freezing nights.

58. Carbon dioxide concentrations in the atmosphere have increased rapidly since the Industrial Revolution.

59. Cutting down trees has no effect on the carbon dioxide concentrations in the atmosphere.

60. If the average surface temperature of the Earth were to increase, the only effect would be the rising of the level of the seas.

61. Rain is naturally neutral with a pH of 7.

62. "Acid rain" is a consequence only of increased carbon dioxide concentrations in the atmosphere.

63. Rain and snow with a pH = 2,1 has fallen in Britain.

64. Acids such as sulphuric acid, nitric acid and hydrochloric acid have been detected in rain.

65. "Acid rain" is not a problem in South Africa.

66. The rate of release of sulphur dioxide into the atmosphere as a result of human activities, exceeds the rate of release of sulphur dioxide from natural sources.

67. CFCs contribute to the problem of "acid rain".

68. Combustion of fossil fuels (coal and oil) is a major contributor to the problem of "acid rain".

69. Some gases released from vehicle exhausts contribute to the problem of "acid rain".

70. Industries contribute more than coal-fired power stations, to the problem of "acid rain".

71. The contribution of industry to the total concentration of nitrogen oxides in the atmosphere, is greater than the contribution of transportation.

72. The death of fish in lakes in Europe and America, has been a consequence of "acid rain".

73. It is a fact that "acid rain" alone has been responsible for the death of large numbers of trees in the forests of Europe and America.

74. The use of tall chimney stacks has overcome the problem of "acid rain".

75. Damage by "acid rain" only occurs close to the source of gases causing this air pollution problem.

76. There are natural processes which remove air pollutants from the atmosphere.

77. All air pollutants remain in the atmosphere for the same length of time.

78. For the concentrations of substances in the atmosphere to remain constant, the rates at which they are released into the atmosphere should be equal to the rates at which they are removed from the atmosphere.

79. Air pollution results when the rates at which air pollutants are released into the atmosphere, exceeds the rates at which natural processes remove air pollutants from the atmosphere.

80. There is no law in South Africa to control air pollution.

81. In South Africa, no research is conducted into air pollution problems.

82. International agreements have been reached concerning some air pollution problems.

83. South Africa has never manufactured CFCs.

84. CFCs are compounds that do not occur naturally.

85. The production of CFCs in South Africa has been reduced.

86. It is proposed that no CFCs will be produced by the year 2 000.

87. If the production of CFCs is stopped, the air pollution problems associated with them will be immediately solved.

88. The destruction of ozone in the stratosphere is a global air pollution problem.

89. The Montreal Protocol is an international agreement to reduce CFC production.

90. All nations of the world have signed an agreement to reduce CFC production.

91. There are no methods available for controlling the release of particulates into the atmosphere.

92. Cyclones are very efficient devices for reducing air pollution.

93. At present, there are no techniques available for reducing the release of sulphur dioxide into the atmosphere.

94. Industry could make use of technology which would eliminate air pollution completely.

95. The costs of installing and using technology to reduce air pollution, is small compared with other costs faced by industry.

96. The use of tall chimney stacks by industry solves all air pollution problems.

97. Catalytic converters cannot be used in South Africa because there are lead compounds in our petrol.

98. ESKOM does not use technology to reduce the release of sulphur dioxide into the atmosphere.

99. Fly-ash from coal-fired power stations can reduce the quantity of fertilisers farmers need to use.

100. Supplying electricity to towns in South Africa, has totally reduced air pollution from coal fires.

101. In some areas in South Africa, the air pollution from domestic coal fires exceeds air pollution from coal-fired power stations.

102. Petrol is the only substance that SASOL produces from coal.

103. The only use for coal is to supply us with energy when the coal is burned.

104. If coal-fired power stations in South Africa use improved technology to control air pollution, electricity could become too expensive for many people.

105. Industry never monitors the quantity and nature of the air pollutants produced by its activities.

106. There are no alternative sources of energy which produce less air pollution than coal and oil when burnt.

107. Air pollution has been reduced by the use of nuclear power stations.

108. There are no nuclear power stations in South Africa.

109. Natural gas produces much less air pollution than coal when it is burned.

110. Africa has energy available for hydro-electricity.

111. At present it is easy to use the energy from the Sun for most of our energy needs.

112. It is not possible to use the energy from wind.

113. There are no alternative products to CFCs.

114. South Africa manufactures some alternative products to CFCs.

115. HCFCs are more reactive than CFCs.

116. HFCs are compounds whose molecules are composed of hydrogen, fluorine and carbon atoms only.

117. It has been suggested that HCFCs and HFCs could contribute to global warming.

118. The size of the world population contributes to the problems of air pollution.

119. The use of public transport by more people will help reduce air pollution.

120. Changing some of our everyday activities will help reduce air pollution.

Answers to True/False Statements

1. T	2. T	3. F	4. F
5. F	6. F	7. T	8. T
9. F	10. F	11. T	12. T
13. F	14. T	15. T	16. T
17. F	18. F	19. F	20. T
21. T	22. T	23. F	24. F
25. T	26. F	27. T	28. T
29. F	30. F	31. F	32. T
33. F	34. F	35. F	36. T
37. T	38. F	39. F	40. F
41. T	42. T	43. T	44. T
45. F	46. T	47. F	48. T
49. F	50. T	51. F	52.
53. F	54. T	55. F	56. F
57. T	58. T	59. F	60. F
61. F	62. F	63. T	64. T
65. F	66. T	67. T	68. T
69. T	70. F	71. F	72. T
73. F	74. F	75. F	76. T
77. F	78. T	79. T	80. F
81. F	82. T	83. F	84. T
85. T	86. T	87. F	88. T
89. T	90. T	91. F	92. F
93. F	94. F	95. F	96. F
97. T	98. T	99. T	100. F
101. T	102. F	103. F	104. T
105. F	106. F	107. T	108. F
109. T	110. T	111. F	112. F
113. F	114. T	115. T	116. T
117. T	118. T	119. T	120. T

Statements to which Students Agree/Disagree
(For suggestions on how to use these, refer to introduction to the Package.)

Please respond to these statements. For each of these statements choose your response from the following responses (a), (b), (c), (d) or (e) and mark the appropriate letter (a), (b), (c), (d) or (e) for your response next to the number of the statement.

(a) I agree strongly with this statement
(b) I agree with this statement
(c) I have no opinion about this statement
(d) I disagree with this statement
(e) I disagree strongly with this statement

1. "Economic and political issues are more important to me than the issue of air pollution"

2. "There is no air pollution where I live"

3 "Air pollution is not a problem in the Republic of South Africa"

4. "It is only the forms of air pollution that can be seen or smelled that are important"

5. "Once pollutants have entered the atmosphere they remain there for ever"

6. "The media always report air pollution issues accurately"

7. "Environmentalists are able to predict with certainty the consequences of air pollution"

8. "Industry is not concerned about air pollution"

9. "Technological/industrial development should be stopped in order to preserve the atmosphere"

10. "Air pollution is uncontrollable and will increase steadily until life is destroyed"

11. "Air pollution can be controlled, using science and technology, but it will need a constant monitoring of the risks and benefits of our activities"

12. "I contribute very little to air pollution and thus have no role to play in its control"

13. "To improve air pollution control we must be prepared to pay more for things"

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