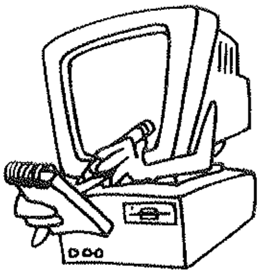


ANSWERS

Chemical Monitoring and Management
Investigation 1

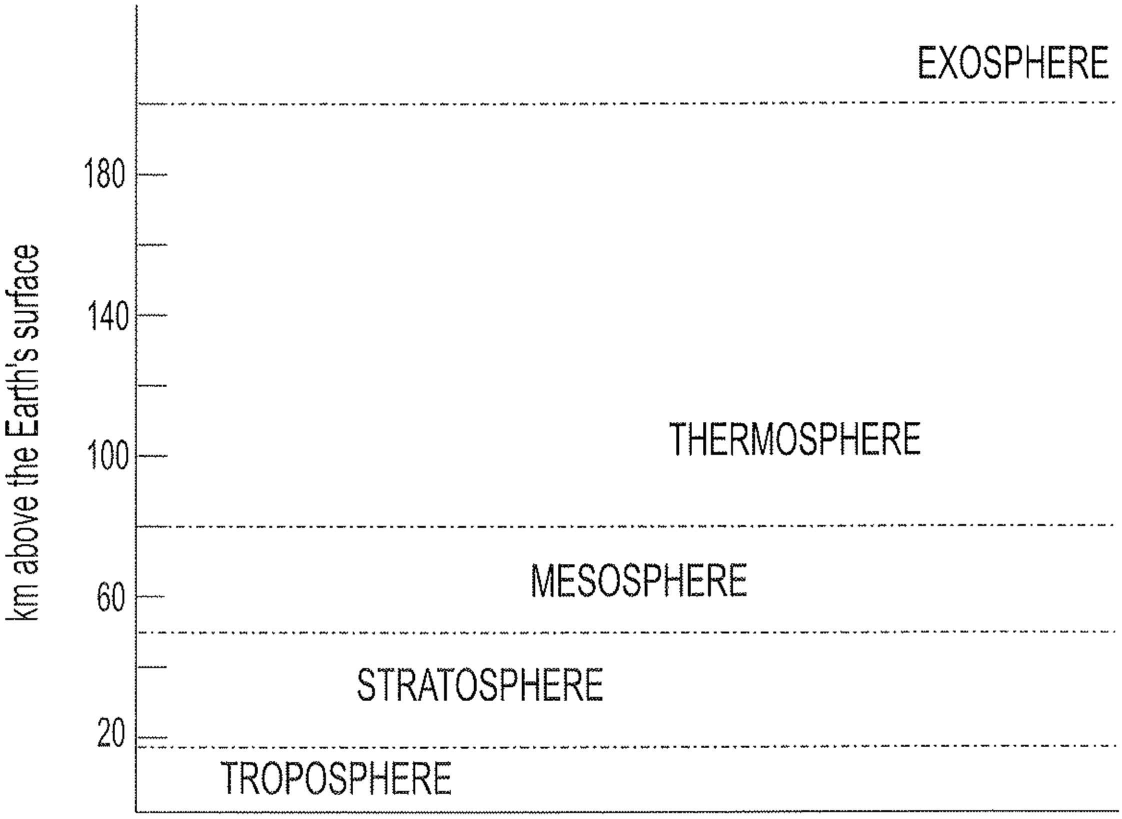
Web research assignment
Ozone in the atmosphere

What is the Earth's atmosphere like?

You can find the information to answer these questions in reference books or at the NASA web site at the following address:

http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/ATM_CHEM/atmospheric_structure.html

1. Draw a diagram to represent the layered structure of the Earth's atmosphere. Make sure you include the names of the different layers and their approximate positions (you don't need to include all the Exosphere in the diagram).



2. Write a short paragraph describing each layer of the atmosphere, in the table below.

troposphere	*Layer closest to the Earth's surface; contains the largest proportion of the mass of the atmosphere; temperature and water vapour content decrease as altitude increases; all weather occurs here; the height of the troposphere varies with the seasons - it is highest in the summer and lowest in the winter.*

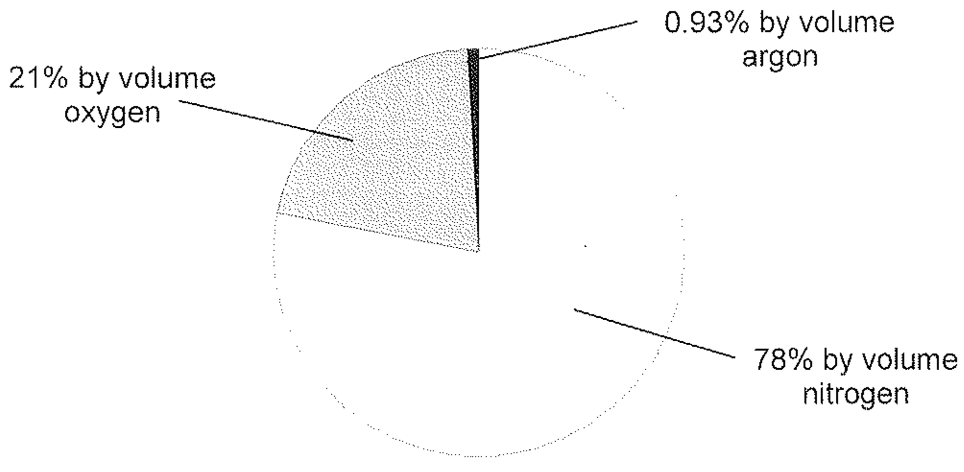
stratosphere	*Air temperature of the stratosphere remains fairly constant up to 25km, then it gradually increases to about 220K. The ozone layer is in the stratosphere. Temperature increases with ozone concentration. The ozone molecules absorb ultraviolet radiation from the sun, converting it to heat.*
mesosphere	*Characterised by decreasing temperatures which reach about 190K at a height of 80km. The temperature decreases because not much ozone or water vapour is present. At very high altitudes, the gases start to form layers according to how heavy they are, due to gravitational separation.*
thermosphere	*The temperature in the thermosphere generally increases with altitude up to 1000-1500K. This increase is due to the absorption of intense solar radiation by the small amounts of molecular oxygen present. At this extreme altitude, gas molecules are relatively far apart.*
exosphere	*This is the transition zone between Earth's atmosphere and interplanetary space. The upper boundary is relatively undefined.*

3. The Earth's atmosphere doesn't really have sharply defined layers - we can't fly to a certain point in the atmosphere and say, for instance, the "troposphere ends exactly at this point". Why then do scientists use the layered model to describe the Earth's atmosphere? Why is it useful?

   It helps us to be able to make sense of our observations and to be better able to communicate these findings to other people.

Measuring the quantities of different gases in the atmosphere

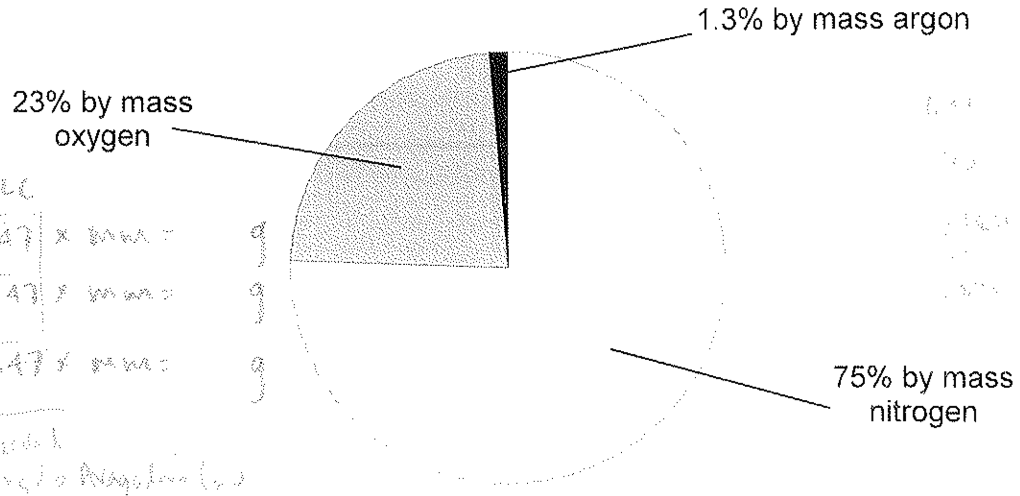
4. The three main gases in the Earth's atmosphere are nitrogen (78% by volume), oxygen (21% by volume) and argon (0.93% by volume). Draw a labelled pie chart to represent the relative proportions of these three gases in the atmosphere by volume. Note: the three percentages don't add up to 100% because there are very small amounts of a number of other gases present as well.



5. Since the atmosphere is 78% by volume nitrogen, what would be the percentage of **moles of nitrogen** in the atmosphere? What would be the percentage composition by moles of oxygen and argon? (Hint - think about Avogadro's hypothesis). Explain your reasoning.

   78% by volume of nitrogen gas, 21% by volume of oxygen gas and 0.93% argon. This follows since equal numbers of molecules of gas (under the same conditions) occupy the same volumes (this is Avogadro's hypothesis).

6. Use your answers to the previous question to calculate the percentage by mass of nitrogen, oxygen and argon in the atmosphere (you will need a list of relative atomic masses to do this). Draw a labelled pie chart to represent the relative proportions of these three gases in the atmosphere by mass.



The three major gases in the atmosphere had been detected there by the end of the 19th century. However, many other gases which were part of the atmosphere in much smaller quantities (called **trace gases**), remained undetected until the necessary equipment, able to detect very small quantities of substances, had been developed.

As very sensitive methods of analysis, such as spectroscopy were developed, new trace gases, at smaller and smaller concentrations were detected. By the 1950's, fourteen gases had been detected in the atmosphere. At present, about 3000 different substances have been detected.

Trace gases, which are only present in very small quantities in the atmosphere are not measured as percentages by volume or mass. Their quantities are given as **parts per million** by volume (or, for even smaller quantities, parts per billion or parts per trillion). If the concentration of a gas is say, 10 parts per million (**ppm**), this means that there are 10 molecules of that gas for every million molecules in the volume of gas which was analysed. 10ppm corresponds to a percentage by volume of 0.001%.

7. The approximate concentrations of some of the trace gases in the atmosphere near the Earth's surface (in the Troposphere) are given in the table below.

   Concentrations which are marked with an asterix * can vary slightly from place to place on the Earth's surface.

Gas	Concentration in ppm
carbon dioxide	318*
neon	18
helium	5.2
methane	1.5*
krypton	1.1
hydrogen	0.5
dinitrogen oxide, N_2O	0.25*
carbon monoxide	0.1*
xenon	0.09
ozone	0.02*
other oxides of nitrogen	0.003*

a. Calculate the percentage of carbon dioxide molecules in the air which corresponds to 318ppm. (Hint - think about the way ppm are defined).

0.0318%

b. Look up the NASA web site again. Find the page entitled "Present Day Atmosphere" at the address:

http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/ATM_CHEM/present_atmosphere.html

Read through the information on the page. Give one reason why the concentrations of the trace gases carbon dioxide, methane and oxides of nitrogen vary from place to place on the Earth's surface.

These vary from place to place because they are produced by processes such as burning fossil fuels and the metabolism of living things. These processes are concentrated in certain parts of the world.

Has the Earth's atmosphere changed over time?

Look up the NASA web site and find the page entitled "Historical Atmosphere" at the address:

http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/ATM_CHEM/historical_atmosphere.html

8. Describe one way in which the modern atmosphere of the Earth differs from the ancient atmosphere it had before about 3.5 billion years ago.

Answers could vary to this question - one obvious difference is that there was no molecular oxygen in the earlier atmosphere.

9. Modern human activity has caused changes in the composition of the atmosphere. Look up the page entitled "Urban and Regional Air Pollution", which is part of the CSIRO web site at the following address

http://www.csiro.au/page.asp?type=faq&id=AirPollutionUrbanAndRegional

What are two of the pollutants which are mentioned in the CSIRO information sheet? What human activities produce them?

Answers will vary - the pollutants could be CO, SO_2, NO_2, O_3, Pb, particles - see the page on the web site for details about what produces these pollutants.

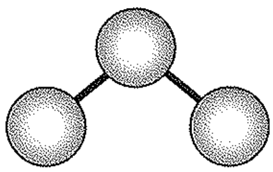
Understanding ozone in the atmosphere

Ozone is a covalent molecular substance which is a gas under normal conditions. Each ozone molecule consists of three oxygen atoms bonded together.

Look up the NASA web site and find the page entitled "Understanding Ozone" at the following address:

http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/ATM_CHEM/understanding_ozone.html

10. Click on the word "ozone" and look at the picture representing the ozone molecule. Draw a diagram to represent the way the oxygen atoms are bonded together in the ozone molecule.



11. Read through the information on the web page. Does ozone seem to be a reactive or non-reactive molecule? On what information do you base your answer?

    Ozone is a reactive molecule - it is a powerful oxidising agent and, as a concentrated gas or a liquid, is highly explosive.

Ozone can be produced from normal oxygen gas, O_2. The O_2 molecule splits apart to form two free oxygen atoms (which are extremely reactive - they are examples of **free radicals**). One of these single oxygen atoms may then combine with another O_2 molecule to form an O_3 or ozone molecule. This series of reactions can be caused by ultraviolet light or by an electric spark (called an electric discharge) passing through oxygen gas.

12. Write a balanced equation to represent the formation of ozone from O_2 molecules (you don't need to include the oxygen atom, O, in your equation - just represent the overall change from O_2 to O_3.)

$$3O_2 \longrightarrow 2O_3$$

13. Ozone has a characteristic sharp smell. This smell sometimes accompanies violent thunderstorms. Why?

Lightning is an electric discharge travelling through the atmosphere - this could cause some O_2 *molecules to react to form* O_3 *molecules.*

Ozone is present in the air which is close to the Earth's surface (the **troposphere**).

Look up the page entitled "Urban and Regional Air Pollution", which is part of the CSIRO web site at the following address

http://www.csiro.au/page.asp?type=faq&id=AirPollutionUrbanAndRegional

14. Read through the section on photochemical smog. How is ozone formed in the lower atmosphere? How does ozone in the air we breathe adversely affect humans?

Ozone is formed from nitrogen oxides and hydrocarbons reacting in sunny conditions. These chemicals are released by motor vehicles and industry. Ozone attacks the tissue of the throat and lungs and irritates the eyes.

Ozone is also present higher up in the atmosphere - in the **stratosphere**. This ozone is not harmful to life - in fact, life on Earth depends on its presence.

15. Ultraviolet radiation from the sun is continually hitting the Earth's atmosphere. How do you think the ozone in the stratosphere may have formed? (Hint - look back at the information just before question 12.)

Ultraviolet light passing through the stratosphere caused some O_2 *to react to produce* O_3.

Look up the NASA web site and find the page entitled "Protective Ozone" at the following address:

http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/ATM_CHEM/protective_ozone.html

16. At about what altitude is most of the ozone in the stratosphere concentrated?

At about 25km above the Earth.

17. Why is the presence of ozone in the stratosphere important for life on Earth?

Ozone in the stratosphere absorbs UV radiation which is harmful for living things.

Why is it important that ultra-violet radiation is absorbed?

Look up the article entitled "Sun and skin - a dangerous combination" (which is part of the web site of the Australian Academy of Science) at the following address:

http://www.science.org.au/nova/008/008key.htm

Read through the article, including the information boxes.

18. What is the most serious effect of ultraviolet radiation on human life?

    UV radiation can generate cancer.

19. Which type of ultraviolet radiation which reaches the Earth is the most harmful? (Box 1)

    UV-B - 280-315 nanometre wavelength

20. Explain how ultraviolet radiation is responsible for both the initiation of cancer and enhancing its growth (Box 3)

    UV radiation can initiate cancerous growth by altering the DNA responsible for the p53 protein. The normal p53 protein causes a cell to self destruct if it is exposed to too much UV light. This means that the cancerous cell does not die when it is exposed to too much UV radiation. Instead these cells can reproduce quickly because all the normal cells around them have died.

21. Why is the rate of skin cancer so high in Australia?

    Because Australia has higher UV levels than Europe and most of Australia's population is of European descent (and therefore have fair skin).

A chemical story about chlorofluorohydrocarbons

Look up and read through the "Beyond Discovery" article entitled "The Ozone Depletion Phenomenon" (which is part of the American science academy web site) at the following address:

http://www.beyonddiscovery.org/beyond/beyonddiscovery.nsf/web/ozone

22. Which part of the story told in the article did you find the most interesting and why?

    Answers to this question will vary.

23. Why were chlorofluorocarbons (CFCs) invented?

These chemicals were developed as safe refrigerants.

24. What were two other ways in which CFCs were used?

They were also used as coolants in car air conditioners, propellants is aerosol sprays, in manufacturing plastics and as cleaning solvents.

25. Who was the first person to detect CFCs in the air and in what year did he do so for the first time?

James Lovelock in 1970.

26. What did the scientists Rowland and Molina find out?

CFC's will decompose at high altitudes when they come into contact with high energy UV radiation. They decompose, releasing chlorine atoms and molecular fragments. The free chlorine was most likely to react with ozone in the stratosphere.

27. Find and write down the chemical equations which represent:

   a. the decomposition of a CFC (use trichlorofluoromethane, CCl_3F, as an example) by ultraviolet radiation, which releases a chlorine atom.

$$CCl_3F \longrightarrow Cl + CCl_2F$$

   b. the reaction between a chlorine atom and an ozone molecule to produce the free radical chlorine oxide, ClO, and oxygen gas, O_2.

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

   c. the reaction between chlorine oxide, ClO, and oxygen atoms which releases chlorine atoms and oxygen gas, O_2.

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

(If you would like to see an **animation** of the series of reactions by which chlorine decomposes ozone, you can find one on the page about Stratospheric Ozone which is part of the Learn web site at the following address http://www.ucar.edu/learn/1_6_1.htm)

28. Explain why a single chlorine atom can decompose many thousands of molecules of ozone.

The chlorine atoms react with ozone to produce ClO, but are then released again when the ClO reacts with the O atom. The chlorine atoms are continually released again to react with more ozone molecules.

29. In what year did British researchers in Antarctica report that levels of ozone over the South Pole were decreasing?

The British reported their findings in 1984.

How do we know what is happening to the ozone layer?

Information about the concentration of ozone in the stratosphere can come from three sources:

- instruments which are on the ground - these can measure the concentration of ozone in the air above them.
- instruments which are on aircraft or balloons
- instruments which are on satellites.

The type of instrument which is now placed on satellites in order to measure ozone concentrations in the atmosphere is called a Total Ozone Mapping Spectrometer (or TOMS). There is a fact sheet about TOMS on the NASA web site which can be found at the following address:

http://pao.gsfc.nasa.gov/gsfc/service/gallery/fact_sheets/earthsci/toms.htm

Read through the fact sheet quickly - don't worry too much about the details.

30. What are the two "crucial problems" in ozone studies?
    - *finding a slow, long term trend among a variety of short term trends*
    - *working out how much of the changes in ozone levels is due to human activity and how much is due to natural processes.*

Why are Antarctica and the surrounding areas so badly affected?

Look up the article entitled "Earth's sunscreen - the ozone layer" (which is part of the web site of the Australian Academy of Science) at the following address:

http://www.science.org.au/nova/004/004key.htm

Read through the article - including the boxes.

31. Why is the ozone layer most seriously depleted above Antarctica and why is this worst in October each year? (See Box 3)

Antarctica is badly affected because of the presence of polar stratospheric clouds which form in the winter. These provide a surface on which the ozone decomposition reactions can take place. The reactions speed up considerably in the Spring (September/October) as sunlight returns to the region supplying the required UV radiation.

Leave this web site open to answer the question in the next section.

What is being done? A disaster averted.

32. What is the "Montreal Protocol"? When was it signed by participating countries?

This was an international agreement which limits the production and use of ozone depleting substances. It was signed in 1987.

The amendment made to the Montreal Protocol at the London meeting in 1990 stated that production of CFCs and several other ozone depleting substances would be completely phased out by the year 2000. The phase-out schedule for other compounds was accelerated by 4 years by the 1992 Copenhagen agreement.

33. Is it likely that the concentrations of ozone in the stratosphere will eventually increase again? On what does this depend?

If all the countries involved keep to the agreements and the ozone depleting substances are phased out, it is likely that the concentrations of ozone in the stratosphere will increase again.

34. Draw a concept map linking the following ideas and processes:

tropospheric ozone	stratospheric ozone	ultraviolet radiation
life on Earth	chlorofluorocarbons	industry
motor vehicles	chlorine	decomposition