HSC Chemistry

Research and Open Ended Investigation

Increase and Effects of oxides in the atmosphere (Part A)

Oxides

Oxides are compounds which contain oxygen and display acidic or basic properties. These oxides exist in the atmosphere as a result of both natural occurrences and human activities.

Three oxides which exist in the atmosphere are:

- Carbon Dioxide (CO_2)
- Sulfur Dioxide (SO_2)
- Nitric oxide and nitrogen dioxide (NO_x)

Sources

Carbon Dioxide

Carbon dioxide is produced naturally as a component of the carbon cycle, by which carbon moves through plants, animals, oceans, rocks and the atmosphere. This is the main natural cause of carbon dioxide in the atmosphere. However, in recent times the amount of carbon dioxide sourced from human activities has increased. The combustion of fossil fuel is the single most human contributor of carbon dioxide and is the cause of increasing levels of carbon dioxide in the atmosphere. Other human causes include the blasting of iron in a furnace, and the fermentation of ethanol from glucose, however these sources are less significant. Carbon dioxide is the main contributor to the "greenhouse effect".

Sulfur dioxide

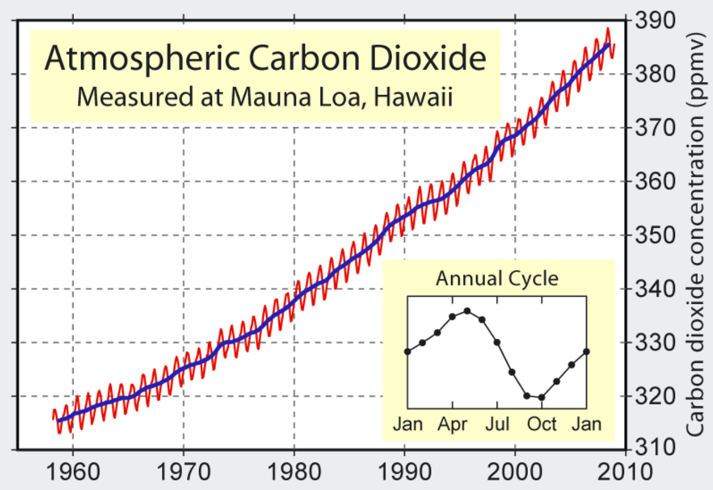
Sulfur dioxide is naturally produced from volcanoes and hot springs. About two thirds is produced this way; however the level can vary with volcanic conditions. Human sources including the combustion of fossil fuels, extracting sulfur from its ores and the burning of coal and oil in power stations are also sources of sulfur dioxide, although the human sources are not as significant, especially since coal in Australia has low sulfur content.

Nitrogen dioxide and nitric oxide

The major source of nitrogen oxides is lightning (natural), which produces nitric oxide and then reacts with oxygen in the air to produce nitrogen dioxide. Other natural sources include bushfires and decomposition of organic matter. Human sources include combustion in power stations and emissions from cars and trucks. Nitrogen dioxide is predominantly produced from sources of nitric oxide which combine with oxygen in the atmosphere.

Evidence of increase in oxides[1]

In recent times, the level of oxides in the atmosphere has increased, primarily due to human sources such as the combustion of fossil fuel. This has had implications for the environment and also has negative health effects.



The oxide which has had the most increasing levels of concentration in the last 150 years is carbon dioxide, and is mainly due to the combustion of fossil fuels and emissions that contribute to the greenhouse effect. The graph shows the change in carbon dioxide levels. From the period 1960-2009, the carbon dioxide in the atmosphere has increased from about 310ppm to 385ppm. This is an increase of approximately 30%.

The concentration for sulfur dioxide varies from country to country. For example, China has seen a 27% increase in emissions since 2000, whereas the United States has seen a 33% decrease. (Statistics from the United States EPA). This is probably due to the changing structure of the economies in those countries. The concentration of sulfur dioxide in the earth's atmosphere is approximately 0.001ppm.

The concentration for nitric oxide and nitrogen dioxide has been fairly constant as the sources mainly originate from natural occurrences. However, since the development of electricity and widespread use of cars, the concentration of nitrogen dioxide has slightly increased, but has been countered with emission controls. The concentration of nitric oxide and nitrogen dioxide in the atmosphere are less than 0.001 and 0.001 respectively.

Assessment of evidence

It can be seen that the levels of oxides in the atmosphere has been increasing recently. Predominantly, the oxides which have an increasing level of concentration are sourced from human activities, such as the combustion of fossil fuels, which has been increasing rapidly. Carbon dioxide, the oxide which has seen the most significant increase in concentration is the major contributor to the greenhouse effect, and as such the climate change observations can back up the increasing concentration. The evidence in the graph is reliable as it was sourced from the US Government project. Carbon dioxide levels have been monitored for over 200 years, so the data acquired is reliable, and has been sourced by quantitative analysis from various sources such as ice and analysis of calcium carbonate content in coral.

[1] Image from en.wikipedia.org/Carbon_dioxide

The evidence for the increase in sulfur dioxide concentrations is mainly associated with structure of the economies. At the industrial revolution, sulfur dioxide levels had increased due to the increased combustion of fossil fuels. It can be said that in the developing and emerging markets such as India and China, the concentrations have increased, whereas in developed countries such as the USA and Japan, the levels have gone down due to reduced emissions from factories. Also, geographical factors affect the concentration of sulfur dioxide in the atmosphere, due to natural occurrences such as volcanoes and hot springs. In areas with high volcanic activity, the concentration was found to be higher. Generally, the concentration of sulfur dioxide has been quite low (around 0.001 ppm), and the increases have generally been isolated to certain geographical locations. The instruments for measuring these levels have only been available in recent times, and as such a detailed, accurate history is not available.

However, the evidence available for concentrations of nitric oxide and nitrogen dioxide is quite inconclusive and does not sufficiently show that levels of these oxides have been increasing. This is because the concentration is very low (about 0.001ppm), so it doesn't show much evidence in the increase. Also, there are limitations to the equipment being used to monitor these levels, and may not be able to show these low concentrations. However, indications of increasing levels of photochemical smog (mixture of air and organic compounds to form ozone, reduces visibility) and acid rain do provide some evidence of increasing levels of nitric oxide and nitrogen dioxide, but this data would not be entirely accurate as there was no trend in the levels, the conditions were fluctuating.

Formation and effects of acid rain

Formation

Acid rain is rain that has a higher hydrogen ion concentration than normal, higher than about 10^{-5} mol/L. (definition from textbook). It has a pH of lower than 7. Generally this pH lies between 5 and 6, although there have been instances where the pH level has been as low as 3.

Acid rain is formed when sulfur dioxide and nitrogen dioxide released into the atmosphere from sources such as combustion of fossil fuels and industrial emissions combine with water vapour in the clouds to form sulfuric acid and nitric acid. When the rain falls it is acidic.

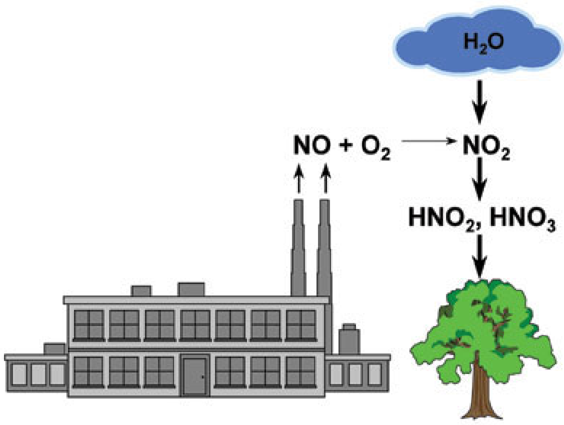


Figure 1: Diagram showing formation of acid rain. (http://www.metalfinishing.com/editors_choice/articles/images/051108_JohnFig1HiRes.jpg)

The reasons for the formation of acid rain relate to natural occurrences such as volcanoes and biological process, and human impacts such as vehicle emissions, production of electricity and emissions from factories, which are the most significant contributors.

Equations

$SO_{2\,(g)} + H_2O_{\,(l)} \rightarrow H_2SO_{3\,(aq)}$ (sulfur dioxide reacting with water vapour, produces sulfurous acid. This then combines with water droplets when rain falls)

$2H_2SO_{3\,(aq)} + O_2 \rightarrow 2H_2SO_4$ (the sulfurous acid produced reacts with oxygen in the air to produce sulfuric acid. This also combines with water droplets.)

$2NO_{2\,(g)} + H_2O_{\,(l)} \rightarrow HNO_{3\,(aq)} + HNO_{2\,(aq)}$ (nitrogen dioxide reacts with water to produce nitric and nitrous acids. These acids then combine with water droplets when rain falls)

$2HNO_{2\,(aq)} + O_{2\,(g)} \rightarrow 2HNO_{3\,(aq)}$ (the nitrous acid reacts with oxygen in the air to produce more nitric acid. This also combines with water droplets)

Effects of acid rain

There are many effects of acid rain, which have negative effects on the environment and the overall health of the ecosystem. It can also affect human elements such as buildings, visibility and cause respiratory problems. Environmental consequences of acid rain include damage to soils and vegetation, a reduction in air quality and increase the acidity of lakes.

Acid rain increases the acidity of soils, damaging the effectiveness of growing crops. Also, the sulfuric acid from the acid rain damages nutrients in the soil. This causes aluminium to be released, which can deprive plants and trees from nutrients such as calcium and eventually they die. Some of the sulfur dioxide which is released can affect the photosynthesis process in plants.

Acid rain can have adverse effects on lakes and aquatic species. It increases the acidity of lakes and concentration of aluminium (released from the soil when sulfuric acid damages nutrients), which can damage aquatic species, potentially causing them to die as the sulfuric acid affects the intake of oxygen. The lower pH levels can damage the offspring and eggs of aquatic species, causing birth deformities.

It also affects air quality, especially in urban areas where the concentration of sulfur dioxide and nitrogen dioxide in the atmosphere is higher. This in turn increases the chance of acid rain to develop.

Acid rain also affects human society as it can affect buildings. Acid drops can fall onto buildings which cause them to corrode.

Figure 2: Acid rain has caused damage to buildings such as the Taj Mahal as it contains marble. (science.howstuffworks.com)

In particular it affects buildings made of limestone and marble as the acid rain reacts with carbonates present in those buildings. This has implications on some industries, as they need to invest in materials which withstand the effects of acid rain.

Respiratory problems and visibility are increasing problems of acid rain in urban areas. Respiratory problems such as asthma and can cause irritations. Acid rain has been indirectly linked to brain damage and kidney damage (through the release of aluminium in soil which is used to grow food). It also reduces visibility in urban areas as a result of sulfate particles in the air. This can cause issues for the aviation sector.

Decarbonisation of soft drink (Part B)

Aim: to decarbonise soft drink and gather data to calculate mass changes and volume of gas produced

Equipment: 300mL soft drink, sodium chloride (40g), spatula, beaker, electronic balance, filter funnel, stirring rod

Method:

1. Record mass of soft drink and bottle.

2. Place 300mL soft drink in beaker.

3. Add 10g of sodium chloride into beaker with soft drink. Agitate using stirring rod to ensure mixing of sodium chloride.

4. Record observations.

5. Repeat (3-4) until no bubbles appear when sodium chloride is added.

6. Pour soft drink and sodium chloride mixture back into bottle using filter funnel.

7. Record mass of soft drink/sodium chloride mixture and bottle.

8. Calculate mass change and hence calculate volume of gas produced.

Results:

Items	**Mass (g)**
Mass bottle	30.25
Mass soft drink + bottle	345.88
Mass salt (total amount used)	9.97 + 10.01+9.94+10.00 = 39.92
Mass soft drink + bottle + salt + carbon dioxide (initial)	385.80
Mass soft drink+ bottle + salt (final)	382.84
Mass carbon dioxide (final – initial)	2.96

Observations

When the bottle was opened initially, a fizzing sound was heard and bubbles of gas started moving up the bottle.

When salt was added, it had started fizzing and foaming up and after a short time most of the salt had dissolved and fizzing had stopped. Also, after each addition of salt, the amount of fizzing had decreased, until on the 4th trial there was no evidence of fizzing.

Calculations

Moles of Carbon dioxide

$$\boldsymbol{moles = \frac{mass}{molar\ mass}}$$

Mass Carbon dioxide = 2.96g

Molar mass carbon dioxide = (12.01) + (16 x 2) = 44.01

Moles Carbon dioxide = $\frac{2.96}{44.01}$

= 0.07 mol

Volume of carbon dioxide

$$\boldsymbol{volume\ of\ gas = moles\ of\ gas\ x\ molar\ volume\ (24.79L\ at\ RTP)}$$

Moles carbon dioxide = 0.07

Molar volume = 24.79L

Volume of gas (L) = 0.07 x 24.79

= 1.67 L

<u>Discussion:</u>

In this experiment, the volume of carbon dioxide was calculated and the mass change was found to be 2.96g, which resulted in a volume of 1.67L for a 300mL bottle. This is compared to the theoretical value of approximately 1.12L/300mL soft drink**.** The independent variable in this experiment was the type of drink used (Coca-Cola) and the amount of salt added (39.92g). The dependent variable was the mass and volume of carbon dioxide which was produced, after observing mass changes and through calculation. The constants were the volume of drink used (300mL) and laboratory conditions (29^{o}C, 100.8kPa). The method had several advantages, although there were some errors and limitations associated which resulted in variations from the theoretical result.

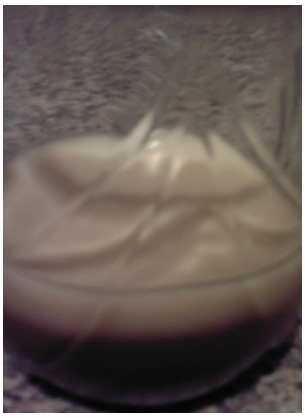


Figure 3: Fizzing after addition of salt. (Note: photo not taken on day of experiment)

The method can be justified as there are several chemical and physical advantages to using it. Firstly, the mass was measured whilst the drink was still in the bottle to ensure that the exact amount of gas was taken into account to ensure accuracy. It also prevented gas from escaping as compared to measuring it in a beaker. However, after measuring the mass in the bottle, it was placed in the beaker to reduce the tendency of liquid spilling over. At the end after the salt was added it was poured back into the bottle as it complies with the initial readings, as they were done in the bottle. The method of adding salt was chosen as it was more effective as compared to shaking (which would have let gas both go in and out) and heating (some water would have evaporated). Salt was added due to its chemical nature. It has a greater force of attraction to the water molecules as compared to carbon dioxide (H^+ attracts to Cl^- and O_2^- attracts to Na^+). It also decreases the solubility of carbon dioxide, which forces gas to be released and fizzing to be observed. The solution was stirred to allow more attraction of ions, and also to dissolve all the salt so that when it was poured back, none remained in the beaker.

There were also some limitations and errors associated with this experiment. Firstly, the lab conditions were not standard (25^OC, 100kPa). This means that the gas produced may not act like an ideal gas and would have altered the volume of gas produced, and reduced accuracy. However, the main error in this experiment was human error, which resulted in a volume which was higher than expected. When solution was being poured back into the bottle, a small amount had spilt out, which resulted in a greater mass change. A very small amount had also remained behind on the stirring rod. These errors would have resulted in reduced reliability and accuracy of the results. Also, some of the gas may have been left over even after the soft drink stopped fizzing, which would have reduced the accuracy of the results (not taking into account spillages). Also, the salt may not have been 100% pure, which may have affected the reaction and mass change. Another factor was that the electronic balance may not have been entirely accurate as it only displayed to 2 decimal places, possibly causing a small error.

There were many methods by which the accuracy and reliability of the experiment could be improved. Firstly, the experiment should be repeated to improve the reliability of results to minimise experimental error. Repeating the experiment would ensure that human error such as spillages are minimised. Human error can also be avoided by not pouring the solution back into the bottle; instead the mass of the beaker and bottle could be recorded. Also, a variety of methods could be used such as shaking (to alter pressure), heating, adding an acid (to increase concentration and shift equilibrium to the left) as well as adding salt. This would allow the effectiveness of each method to be compared. Also, the effect of pressure and temperature changes on the equilibrium position can be analysed. Soft drink at various temperatures should be used as changes in temperature affects equilibrium. Also, a cover should be placed to collect the gas (using a closed system), along with using the calculation method as this would increase reliability.

Conclusion: Soft drink was decarbonised and the mass change and volume of gas produced was calculated. The mass change was found to be 2.96g, which resulted in 1.67L of gas (for a 300mL bottle).

Equation and chemical explanation:

$$CO_{2\,(g)} + H_2O_{\,(l)} \rightleftharpoons H_2CO_{3\,(aq)}$$

The opening of the bottle and the addition of salt had resulted in the equilibrium to shift towards the left. It was an exothermic reaction.

When the soft drink is in a closed system such as the bottle, the pressure allows for the carbon dioxide to dissolve in water. When the bottle was opened, the pressure of the whole system reduces, allowing for the gas to escape. This follows Le Chatelier's principle, when the pressure is decreased; it seeks to restore the pressure level by forcing the CO_2 out, by increasing the pressure when carbonic acid changes back into water and carbon dioxide. Therefore the reverse reaction is favoured as it is the side which favours the increase in pressure (Decrease in pressure favours the side with the most gaseous molecules, in this case the reactants). Hence, equilibrium shifts to the left. The fizzing observed and decarbonisation of water is a result of the carbon dioxide gas being released.

The addition of salt increases the rate of reaction; the salt has a greater force of attraction to the water molecules (Na^+ is attracted to O^- and Cl^- is attracted to H^+ ions). This polar bond is stronger than the bond between water and carbon dioxide, hence reducing the solubility of carbon dioxide, forcing it to escape.