The Production of Nitrogen Dioxide from Nitrogen (II) Oxide (Precursors of Ozone)

by Mary Beth Leavitt

Purpose

Demonstrate the production of nitrogen(II) oxide from copper and nitric acid by water displacement.
Demonstrate the production of nitrogen dioxide from nitrogen (II) oxide.
Enhance the understanding of ozone by studying the precursors of ozone, nitrogen (II) oxide and nitrogen dioxide (NO_x).
Create an investigative report on ozone.

Student Learning goals

Facilitate a discussion on the precursors of ozone, N_xO
Facilitate a discussion on the sources of ozone, both man made and natural.
Experience the production of NO_x and observe their properties.
Research a topic on ozone.
Develop technical writing skills.

Time

Preparation of 8M HNO_3: 5 minutes
Setup of demonstration apparatus: 15 minutes
Demonstration: 15 minutes
Discussion: open-ended
Selection of research topics: 30-40 minutes
Report: open-ended

Level

Middle school and High school, grades 7-12

Educational Outcomes

Identify and comprehend what produces surface ozone.
Generate and understand the equation of the formation of ozone from oxygen.
Generate and understand the equation of the formation of nitrogen dioxide from nitrogen(II) oxide.
Observe the production of NO_x.
Identify two properties (solubility and color) that distinguish nitrogen(II) oxide from nitrogen dioxide.
Research a topic on ozone.
Collate facts about ozone into an investigative report.

Skills

Observing the production of nitrogen(II) oxide and nitrogen dioxide
Writing the chemical equations
Comparing the properties of nitrogen (II) oxide to nitrogen dioxide
Discussing the sources of NO_x
Discussing the sources of ozone
Researching and writingan investigative report

Materials and Tools

35g of copper turnings or small copper shot

250 mL of 8M HNO_3
1000 mL gas generator or:
1000 mL Erlenmeyer flask
thistle tube
8 2-holed rubber stopper
12 cm right angle glass tube (7 mm) to insert into a 2-holed stopper
pneumatic trough
2 lengths of rubber tubing to connect the gas generator to the pneumatic trough and from the trough into a sink
2-1000 mL Florence flasks
2-solid #8 rubber stoppers that fit the Florence flasks
glass plate
fume hood
chemical resistant gloves
500 mL beaker
sink

Preparation

Prepare nitric acid solution
Weigh 35g of copper and place in Erlenmeyer flask
Assemble gas generator
Connect gas generator to pneumatic trough
Fill the Florence flask with water and cover with glass plate

Prerequisites

Able to understand and/or write chemical equations
Able to research a topic
Able to report results of research

Introduction

It is important that students understand ozone can be found in two distinct locations in the earth's atmosphere. Its effect on us can be either beneficial or harmful depending on which location the ozone is found. The troposphere is the lower band of atmosphere around the earth. It is the region that extends from the earth's crust to between 8 and 18 km above the earth's surface. The stratosphere lies in the region directly above the troposphere between 10 and 50 km above the earth's surface.

Stratospheric ozone is considered to be the "good ozone" that protects us from harmful ultraviolet (UV) radiation. It acts as a shield, absorbing harmful UV radiation. In recent decades, scientists have observed that there has been a reduction in ozone in the stratosphere due to the introduction of manmade pollutants. The largest contributors to this pollution are chlorofluorocarbons (CFCs), which were and to some extent are still used in refrigerants, aerosols, and cleaning solutions. These compounds are unusually stable in the troposphere and are not harmful to man. The problem with the CFCs begins as they migrate up into the stratosphere where the high energy UV radiation breaks them down and releases atomic chlorine. The atomic chlorine, which is very reactive, then attacks the ozone and starts a chain reaction of ozone destruction. We are very dependent on the ozone in the stratosphere to protect us. With a reduction in stratospheric ozone we are vulnerable to an increase in skin cancers, weakened immune systems, cataracts and damage to all plants and trees due to an increase in the UV radiation.

Tropospheric ozone or surface ozone is considered to be the "bad" ozone and is an air pollutant. It is a main ingredient in photochemical smog. The ozone is produced as a secondary reaction to the exhaust from fossil fuels. For example, in the extreme high heat and pressure in a car engine, diatomic oxygen (O_2) and nitrogen (N_2) molecules break down into atomic nitrogen and oxygen and reform as nitrogen(II) oxide or nitric oxide (NO).

$$N_{2(g)} + O_{2(g)} + \text{high temperature and pressure} \rightarrow 2NO_{(g)}$$

This nitric oxide reacts with oxygen in the atmosphere to produce nitrogen dioxide. These are both referred to as NO_x (nocks).

$$2NO_{(g)} + O_{2(g)} \rightarrow 2NO_{2(g)}$$

When nitrogen dioxide is in the presence of UV radiation (from sunlight) it breaks down into nitric oxide and atomic oxygen. The atomic oxygen is very reactive and attaches to diatomic oxygen in the air to produce ozone.

$$NO_{2(g)} + \text{sunlight} \rightarrow NO_{(g)} + O_{(g)}$$

$$O_{(g)} + O_{2(g)} \rightarrow O_{3(g)}$$

This reaction is especially prevalent in the summer when there is a lot of car exhaust, sunshine and slow moving high-pressure systems that trap the air and prevent it from mixing and removing the pollutants. These pollutants can rise to dangerous levels and cause severe health problems. The most dangerous pollutant is the ozone. Ozone is a strong oxidant. It is responsible for respiratory distress, damage to rubber and paint, and is the most important cause of plant destruction and loss. Besides automobile exhaust, biomass burning also produces a significant increase in ozone that threatens the tropics. Additionally ozone is produced during lighting or anytime there is an electrical arc in the presence of oxygen.

$$3O_{2(g)} + \text{electricity} \rightarrow 2O_{3(g)}$$

It is essential that the students understand that we have too much of the tropospheric ozone and not enough of the stratospheric ozone. Also it is vital for them to realize that ozone produced in photochemical smog stays in the troposphere and does not transfer into the stratosphere where it would be beneficial.

In the demonstration, nitrogen (II) oxide is produced from the reaction of copper(Cu) with nitric acid(HNO_3) and is collected by water displacement. About 100mL of water is left remaining in the flask. As the stopper of the flask is opened to expose the nitrogen(II) oxide to the air, brown nitrogen dioxide is immediately produced. After the brown nitrogen dioxide is produced, the flask is quickly stoppered and then swirled in the remaining water. The water dissolves the nitrogen dioxide and the brown color disappears. Each time the stopper is removed the reaction takes place faster due to the partial vacuum created when the nitrogen dioxide dissolves. Nitrogen (II) oxide is colorless and is not soluble in water. This can be repeated until all the nitrogen (II) oxide is used up.

$$3Cu(s) + 8HNO_3(aq) \rightarrow 3Cu(NO_3)_2(aq) + 2NO(g) + 4H_2O(l)$$

Lesson Design

The lesson is designed to facilitate:

1) **the demonstration of the production of nitrogen(II) oxide and nitrogen dioxide**
2) **the demonstration of the differences in color and solubility of nitrogen(II) oxide and nitrogen dioxide**
3) **the basic understanding of NO_x as precursors to ozone**
4) **a discussion of the causes and effects of ozone in our world**
5) **brainstorming on research topics by using clustering**
6) **an internet research project on ozone**

How to Do It

Use gloves when handling the acid. The day before the demonstration, prepare the 8M HNO_3 by carefully pouring 125mL of concentrated (16M) HNO_3 into 125mL of distilled water. Store the solution in a brown bottle and label. Assemble the gas generator if one is not available by inserting a 7 mm right angle glass tubing into a #8 2-holed stopper. Use glycerine as a lubricant, twist the tube slowly into the stopper. Do not put any pressure on the side arm or it will break. Also insert the thistle tube (or a long-stemmed funnel) into the #8 2-holed stopper so that it will be about 5 mm from the bottom of the gas generator. Place 35g of copper turnings into the flask and place the 2-holed stopper assembly on the flask. Connect the gas generator from the right angle tubing to the bottom of the pneumatic trough with rubber tubing. Also, connect another length of rubber tubing from the end of the pneumatic trough into a sink for the overflow of water. Set out a 1000 mL florence flask, a #8 solid rubber stopper that fits the flask and a glass plate.

Right before the demonstration, fill the pneumatic trough about half full with water and place under a fume hood. Also fill the 1000 mL florence flask completely with water so that it mounds over the top. Slide the glass plate over the top of the flask so that no air is trapped inside. Holding the plate tightly on the flask, invert the flask and place in the pneumatic trough so that the mouth of the flask is under the water. Slide the glass plate away from the flask and carefully balance the flask so that it remains upside down.

To start the demonstration, turn on the fume hood and pour 100mL of 8M HNO_3 slowly into the thistle tube of the assembled gas generator. Allow the reaction to proceed for about a minute to remove air from the assembly and the tubing. The gas will be bubbling out of the hole in the bottom of the pneumatic trough. After a minute, slide the water-filled florence flask over the hole in the bottom of the pneumatic trough to collect the nitrogen(II) oxide. Any nitrogen dioxide that is produced from the nitrogen(II) oxide and the air will dissolve in the water. Nitrogen dioxide is soluble in water while nitrogen(II) oxide is not. Collect the nitrogen(II) oxide by the water displacement until only about 100mL of water is left in the flask. Slide the flask over and carefully insert a solid rubber stopper in the flask. Another bottle of gas can be collected by repeating the water displacement procedure. To stop the reaction, disassemble the gas generator and carefully pour the acid/copper(II) nitrate solution into 500mL beaker half-filled with water. Rinse the remaining copper with several portions of water and save for another time.

To show the production of the reddish-brown nitrogen dioxide gas from the colorless nitrogen(II) oxide, remove the rubber stopper briefly. The reddish-brown gas will form immediately in the neck of the flask from the reaction of the nitrogen(II) oxide with oxygen in the air. After replacing the rubber stopper, shake the colored gas with the 100mL of water left in the flask until all of the color is gone. The colored gas will disappear as it dissolves in the water. The procedure can be repeated many times until the nitrogen(II) oxide is depleted. Each time it will be more impressive because of a partial vacuum created, when the gas dissolves, sucks more air deeper into the flask. Note that, the increase in the vacuum makes it harder to remove the stopper.

Student Assessment

Rubric for investigative report on ozone

Procedure

Introduce the topic of ozone by explaining the difference in stratospheric and tropospheric ozone. Explain the cause and effect of the depletion of the protective ozone in the stratosphere verses the production of harmful ozone in the troposphere. Discuss all of the ramifications on health, agriculture and quality of life by too little ozone in the stratosphere and too much ozone in the troposphere. Lead into the demonstration by discussing the precursors of surface ozone, NO_x.

Demonstrate the production of nitrogen(II) oxide from copper and nitric acid. Remove the stopper to demonstrate the production of nitrogen dioxide. Discuss the chemical reaction and have the students write a chemical equation to represent the reaction of nitrogen(II) oxide with oxygen to form nitrogen dioxide. ($2NO + O_2 \rightarrow 2NO_2$) Show the other chemical equations in the production of photochemical ozone and discuss each step.

Assign a research project on ozone. In teams of three or four, have the students brainstorm on ozone related research topics, by using clustering. Have them pick a recorder and allow them about 10 minutes. After 10 minutes, list on the board all of the different topics developed by the students. After the class reviews the topics, allow for more spontaneous brainstorming and record those topics. Have the students draw a number to determine the order in picking their research topic from the board. Cross out a topic as a student selects it. The assignment is to report the results of their research as if they were an investigative reporter. They should utilize at least five references listed in their bibliography (preferably from the Internet sources).

Helpful Hints

Great care should be given when handling the nitric acid. Gloves should be used at all times. Concentrated nitric acid is a strong acid and will cause severe skin burns. Any contact with skin should be flushed with large amounts of water and neutralized immediately with a paste of sodium bicarbonate and water. It is also a respiratory irritant and should be handled under a fume hood. Nitrogen dioxide gas is extremely toxic and a severe respiratory irritant and should also be kept under the fume hood. Students should not be allowed to come in contact with either of these chemicals. The demonstration should be done by an experienced teacher.

If time or space does not allow for the actual production of the nitrogen(II) oxide by water displacement in class, it can be prepared ahead of time and stored in the stoppered flask. At your convenience you can show the rapid conversion of nitrogen(II) oxide to nitrogen dioxide by just removing the stopper.

When the students are brainstorming, walk around to keep them on task and offer some suggested topics if they are having trouble.

Tell the students to be as creative as possible with their investigative report as long as they adhere to the facts. If they have the capability, tell them to use a newspaper format just as if they were a reporter. This should be fun for the students.

Educational Advantages of using this Activity

1. **Enlightens students on the precursors of ozone**
2. **Provides students an opportunity to see the production and properties of NO_x**
3. **Utilizes an activity designed to meet the educational needs of multiple cognitive levels and different learning styles:**
    a) **Interpersonal learner through cooperative group activity;**
    b) **Linguistic learner through reading, researching, collating and writing a report**
    c) **Visual learner through observations during the NO_x demonstration;**

d) Logical learner through interpreting research and generating chemical equations;
e) Naturalist learner through learning more about the problems of his or her own world.
f) Autistic learner through hearing explanation and discussion of the topic

INVESTIGATIVE REPORT ON OZONE OR RELATED TOPIC
Student Rubric for Assessing Report

Imagine that you are a reporter investigating an aspect of ozone. As a good investigative reporter, you must tell the "who", "what", "when", and "how" on your topic. Try to be as creative with your report while sticking to the scientific facts. You will be graded on content, thoroughness, and creativity. The report should be 2 single-spaced typewritten pages long with a complete bibliography attached. Information reflected in a quality report:

- Headline/byline
- Written in 3rd person
- Written in columns
- Reveals scientific information in a clever way
- Topic sentence hooks reader
- Typed
- Correct spelling, grammar and sentence structure
- Content rich, and thorough
- Illustrates the investigative method
- Impact on society and mankind with possible solutions
- Graphs, data tables, clip art if applicable
- One paragraph editorial on student's personal views
- Complete bibliography with at least five sources

Investigative Report on Ozone- Rubric for Assessment
4 <u>EXPERIENCED REPORTER</u> · Creative report that reveals information in a clever manner · Written in 3rd person · Uses columns · Has a headline and a byline · Typed with correct spelling, grammar and sentence structure · Good use of graphs or data table to clarify information · Content rich, and thorough · Shows impact on society and mankind with possible solutions · Interesting report that is enjoyable to read · Insightful editorial that demonstrates an understanding of the topic · Illustrates the investigative method · Complete bibliography with five or more sources
3 <u>COMPETENT REPORTER</u> · Not as creative, clever or insightful as an experienced reporter · Written in 3rd person · Has a headline and a byline · Typed with correct spelling, grammar and sentence structure · Good use of graphs or data table to clarify information · Content rich and thorough · Shows impact on society and mankind with possible solutions · Editorial demonstrates an understanding of the topic · Illustrates the investigative method · Complete bibliography with four or five sources

2 INTERMEDIATE REPORTER

- **Written in 3rd person**
- **Has a headline and a byline**
- **Typed with correct spelling, but has some trouble with grammar and sentence structure**
- **No graphs or data tables, or labeled incorrectly or not at all**
- **Not as thorough as a competent reporter**
- **Shows some impact on society and mankind with possible solutions**
- **Editorial is weak and shows poor understanding of the topic**
- **Bibliography only has two or three sources**

1 BEGINNING REPORTER

- **Not in 3rd person, and poor organization**
- **Incorrect spelling, grammar and poor sentence structure**
- **Shows a lack of research**
- **Minimum effort**
- **No information on impact, possible solutions or editorial**
- **Bibliography only has one source**

0 FIRED REPORTER

- **Not in 3rd person, and no apparent organization**
- **Incorrect spelling, grammar and poor sentence structure**
- **Shows a total lack of effort**
- **No information on impact, possible solutions, editorial or bibliography**