Mixing Ratios or Parts per Million, Billion

In this serial dilution activity, connections are made to atmospheric mixing ratios.

Background

Certain gases such as ozone occur in the atmosphere in very tiny amounts. In the stratosphere, for instance, you may find only one to ten ozone molecules for every one million molecules of other gases. This amount is called one to ten parts per million (ppm). Measurements such as parts per million can be expressed in terms of volume or mass. With gases in the atmosphere, we usually think in terms of volume and may express this as parts per million by volume (ppmv). You can also use the units parts per billion by volume (ppbv), and parts per trillion by volume (pptv). Measurements such as ppmv, ppbv, and pptv are called mixing ratios.

Learning Goals

1. Students will understand that a mixing ratio is the concentration of a certain substance expressed in parts per million or parts per billion by volume.
2. Students will be able to explain that some substances, such as ozone, have profound effects even when they occur in very small concentrations or mixing ratios.
3. Students will be able to work with exponential notation and unit conversions to express results numerically.

Alignment to National Standards

National Science Education Standards

- Earth and Space Science, Structure of the Earth System, Grades 5 to 8, pg. 160, Item #8: "The atmosphere is a mixture of nitrogen, oxygen, and trace gases that include water vapor. The atmosphere has different properties at different elevation."
- Unifying Concepts and Processes, Grades K to 12, pg. 118, paragraph #5: "Scale includes understanding that different characteristics, properties, or relationships within a system might change as its dimensions are increased or decreased."

Benchmarks for Science Literacy, Project 2061, AAAS

- Common Themes, Scale, Grades 9 to 12, pg. 279, Item #1: "Representing large numbers in terms of powers of ten makes it easier to think about them and to compare things that are greatly different."
- Common Themes, Models, Grades 6 to 8, pg. 269, Item #1: "Models are often used to think about processes that happen too slowly, too quickly, or on too small a scale to observe directly, or that are too vast to be changed deliberately, or that are potentially dangerous."

Grade Level/Time

- **Grade level:** 6 to 9
- **Time:**
    - Instructions and dilution activity: 30 minutes
    - Questions and discussion: 30 minutes

Materials

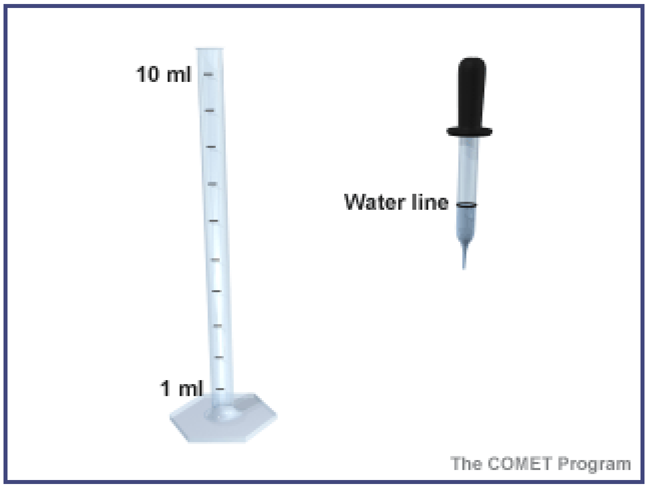
For each team of students:

- 10 ml graduated cylinder
- Test tube rack
- 10 test tubes
- Masking tape
- Markers
- Pipette or eyedropper
- Pitcher or jug of water
- A colored liquid (a very strong color such as carmine red or indigo blue is most desirable. Food coloring will work, but is not quite as good.)

Procedure

1. Using masking tape and markers, label the test tubes 1 through 10.
2. Put 9 ml water in test tubes 2 through 10.
3. Put 10 ml colored liquid in test tube 1.

4. Draw 1 ml of water into the pipette or eyedropper and mark the level using a marker pen. After marking the water level, you may empty the pipette or eyedropper.



5. Using the pipette or eyedropper with the measure for 1 ml, draw 1 ml of the colored liquid from test tube 1 into the pipette or eyedropper and transfer it to test tube 2. Shake the test tube to mix the colored liquid and the water.

6. Draw 1 ml of the liquid in test tube 2 into the pipette or eyedropper and transfer it to test tube 3. Shake the test tube to mix the colored liquid and the water.

7. Continue this process with all test tubes.

8. Next fill out the mixing ratio in the chart provided. Test tube 1 contains pure color, so its mixing ratio is one part in one = 1/1 = 1. Write this down for the mixing ratio in the parts by volume column in Table 1.

9. Test tube 2 has one part coloring for ten parts liquid. What is this mixing ratio? (1/10 or 10-1) Write it on your chart and translate it into exponential notation. A mixing ratio of 1/10 is written 10^{-1}, 1/100 is 10^{-2}, etc. Continue this process for all ten containers.

10. Now convert into parts per million by volume by multiplying the parts by volume (the second column) by 10^6. This will tell you how many parts per million by volume you have in each test tube.

11. Convert to ppbv.

Observations and Questions

1. Which containers have the highest concentration? (# 1) The lowest concentration? (# 10)

2. Which container has the highest mixing ratio? (# 1) Which has the lowest mixing ratio? (# 10)

3. What happens to the color of the liquid as the mixing ratio decreases? (becomes lighter) Why does this happen? (The number of dye molecules becomes diluted ten times by water in each progression of the serial dilution.)

4. Does the liquid ever become colorless? (yes). If so, at what mixing ratios is the liquid colorless? (Answers will vary depending upon the strength of the initial solution.) Why do you think it is colorless? (So few dye molecules are present that they are not visible.)

5. Which test tube contains one ppmv of coloring? (7) Which test tube contains one ppbv of coloring? (10)

6. Ozone in the stratosphere has a mixing ratio in the range of one to ten ppmv. Which containers represent one and ten ppmv? (7 and 6)

7. A typical mixing ratio for ozone in the troposphere is 10 to 100 ppbv. Which test tubes represent this range of mixing ratios? (8 and 9)

8. Your teacher will provide you with a chart showing the major gases that make up the atmosphere, along with their mixing ratios in the atmosphere. Note that some of the mixing ratios are given in ppmv, others in ppbv. Look at the table and at your dilution chart. See if you can find gases on the table that have mixing ratios similar to those of the 10 tubes in the dilution chart. Write the name of the gas next to the dilution chart values.

Table 1. Dilution Chart

Container number	Parts by volume	Parts per million by volume (ppmv)	Parts per billion by volume (ppbv)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Table 2. Major and Selected Trace Gases in the Atmosphere

Gases	Concentration
Nitrogen (N_2)	**78.08% by volume (equivalent to 780,800 ppmv)**
Oxygen (O_2)	**20.95% by volume (209,500 ppmv)**
Argon (Ar)	**0.93% by volume (9,300 ppmv)**
Water Vapor (H_2O)	**0 to 1 or 2% by volume (up to 20,000 ppmv)**

Carbon dioxide (CO_2)	**365 ppmv**
Hydrogen (H_2)	**500 ppbv**
Helium (He)	**524 ppbv**
Neon (Ne)	**1818 ppmv**
Ozone (O_3) **in troposhere**	**0.02 to 0.1 ppmv**
Ozone (O_3) **in stratosphere**	**0.1 to 10 ppmv**
Methane (CH_4)	**1.7 ppmv**
Nitrous oxide (N_2O)	**0.31 ppmv**
CFC-12 (CF_2Cl_2)	**0.5 ppbv**
CFC-11 ($CFCl_3$)	**0.3 ppbv**

Assessment Ideas

- Have students calculate how much a part per million or billion represents in terms of common objects (e.g., how much chlorine in a swimming pool makes one part per billion, how much lemon in a pitcher of iced tea is a part per million, etc.). Perhaps have students express the answers in common units such as one teaspoon in a swimming pool, or have them become familiar with metric units of volume, such as liters and milliliters.
- Let students think of their own common objects and have them guess reasonable dimensions for these objects and calculate their volume. Have them write down their work so that their guesses and assumptions are recorded. Scientists and engineers frequently have to guess at approximate answers to problems they are considering and then justify their assumptions. This is an important skill to learn.

Modifications for Alternative Learners

English Language Limited students may have fewer problems with mathematics than with language, so few modifications may be needed. Where language issues might interfere with following the instructions, pairing with a language-skilled student might be helpful. Be aware that some students will find the mixing ratio calculations challenging, and will need extra time to puzzle it through. Have a follow-up assignment ready for the fastest students.

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