Module 1: Activity 3

Investigating Parts Per Million, Drop by Drop

IT'S OUR AIR

SUMMARY

Students will develop an understanding of the terms parts per million (ppm) and parts per billion (ppb) by systematically diluting a solution of food coloring and water. They will convert ratios to percentages to ppm to ppb. They will correlate the ratios they've created in the classroom to the ratios of various gases in our atmosphere. As another option, the class can do a similar activity using milk and water. In this case, students can demonstrate the Tyndall effect in which a beam of light is visible in a mixture of water and milk, even when the mixture appears clear to the naked eye.

ESSENTIAL QUESTIONS

- What does parts per million mean?
- How different is 1 part per million from 1 part per billion?
- Relatively speaking, how much nitrogen, oxygen, and argon are in the atmosphere?

TIME NEEDED

45 minutes if one option is done, 1 hour if both options are done (including warm up and wrap up).

North Carolina ESSENTIAL STANDARDS FOR EARTH/ENVIRONMENTAL SCIENCE

- EEn.2.5.1 Summarize the structure and composition of our atmosphere.

A product of the NC Air Awareness Program 2014.

MAKING CONNECTIONS

Most humans have trouble imagining numbers as big as a million and a billion, whether the subject is science or the federal deficit. It's correspondingly difficult to comprehend the meaning of such tiny concentrations as one part per million or one part per billion. This activity gives students a hands-on understanding of these difficult concepts within the context of learning about the structure and composition of our atmosphere.

Measurements such as parts per million (ppm) and parts per billion (ppb) are used in many different arenas besides the study of the atmosphere and air pollution. For example, some contaminants in drinking water such as arsenic are measured in ppb. In the study of air quality, ground-level ozone is measured in ppb as well.

BACKGROUND

There are many different ways of measuring amounts: mass/weight (ounces, grams), area (square feet), volume (cubic meters). In the study of the atmosphere and air pollution, however, we are often more interested in concentrations than amounts. That's because an amount of a pollutant is meaningless unless you know the total amount of air that contains the pollutant. If you have 1,000 cubic feet of carbon dioxide in a room, will it kill you? It depends on the size of the room. If the room is 10 feet by 10 feet by 10 feet (1,000 cubic feet), then yes! If the room is 10 feet by 100 feet by 100 feet (100,000 cubic feet), then no. (You will not die because the percentage of carbon dioxide in that room would be 1,000/100,000 which equals 1%. A person loses consciousness after 5-10 minutes breathing 8% carbon dioxide.)

"PERCENT (%)" MEANS:
"for every hundred" in Latin.

SO 1% MEANS:
1 part per hundred.

Parts per million and parts per billion are ways of talking about concentrations that are much smaller than 1%.

THE TYNDALL EFFECT

If you use milk for this activity, you can demonstrate the Tyndall effect in which a beam of light from a laser pointer or pen light is visible in a mixture of water and milk, but not visible in plain water. The particles of milk in the water scatter the light, making it possible for us to see the light beam. In fact, you can use the Tyndall effect to tell the difference between a beaker of plain water and a beaker that appears to be plain water, but actually contains a small amount of milk – which will be the case for the last several beakers in this activity.

To illustrate the Tyndall effect, use a small focused light, such as a laser pointer or pen light, rather than a large flashlight. Hold it close to the side of the beaker and shine it through the mixture. You should be able to see a beam of light in the mixture by looking down at the beaker from above, or looking at it from the side. It may help to have the room slightly darkened, particularly for the mixtures with very little milk.

You may wish to make the connection that air pollution often isn't visible – just as the milk is not visible in some of the very dilute mixtures. However, just because we can't see it doesn't mean it isn't there.

MATERIALS

OPTION 1: Food Coloring and Ice Cube Tray

Per group

- Food coloring (darker colors work best)
- White ice cube tray with cells labeled 1-10
- 2 eyedroppers or pipettes
- Stirring stick
- Several cups of water for rinsing out eyedropper or pipette
- Permanent marker or masking tape/sticky notes with marker to label outside of cells
- Rubber gloves (to avoid staining hands)
- Coffee filter or paintbrush

OPTION 2: Milk with Beakers

Per group

- Ten 100-ml beakers
- 100 ml of milk
- Graduated pipette (optional)
- Stirring stick
- Water
- Laser pointer, pen light (small LED flashlight), or other small focused light beam
- Method of labeling beakers (masking tape or sticky notes)

WARM**UP**

Discuss with the class the meaning of "1 part per," using a few illustrations. For example, you could use 1 red marble and 9 blue marbles in a jar to illustrate 1 part red marbles per 10 marbles. A collection of 10 red marbles and 90 blue marbles would also illustrate 1 part per 10. Similarly, use 1 red marble and 99 blue marbles to illustrate 1 part per 100.

Suggest a few different ways of visualizing 1 part per 1,000,000 (ppm) and 1 part per 1,000,000,000 (ppb). For example, 1 ppm can be illustrated like this:

- 1 second in about 11 days or
- 1 minute in about two years or
- 1 day in about 2,740 years or
- 1 inch in about 16 miles.

As a class, practice converting equivalent ways of expressing the same concentration:

- 1 part per 10 = 10 parts per 100 = 10,000 parts per 100,000
- 1 part per 100 = 0.1 part per 10 = 0.01 parts per 1

Also review the relationship between ratios and percentages, and make sure students understand the difference between the concepts of water and solution. In the food coloring activity, solution refers to the combination of food coloring and water. For example these three are equivalent:

- 10% food coloring
- 10 parts food coloring to 100 parts solution
- 10 parts food coloring to 90 parts water.

NOTE: If you do this activity with milk and beakers, the resulting liquid is technically not a solution because the milk solids do not dissolve. For that reason, we call it a mixture.

Teacher Tips

Set-up Time: 10 Mins.

Activity Time: 45 Mins. – 1 Hour

Either option works well – choose one depending on what materials you have available in the classroom. Using the milk-and-water mixture in clear beakers allows the additional benefit of demonstrating the Tyndall Effect, which your students might find intriguing. If you don't have ice cube trays, you could use well plates instead.

One of my favorite ways to teach this activity is to do both set ups at the same time. Use groups of four students each and have two students set up the food coloring activity while the other two set up the milk activity. Then have each group demonstrate the activity they set up to the other group. I assess their understanding of the demonstration by having the students answer the questions from the opposite group's demonstration.

If you don't have graduated pipettes, you can still do the activity – simply pour out 10 ml each time rather than measuring it out with a pipette. If you do have graduated pipettes, it's a good opportunity for the students to practice using them with precision.

– Mark Townley

THE ACTIVITY

OPTION 1: Food Coloring and Ice Cube Tray

NOTE: Use one eyedropper for clean water and the other one for food coloring and water with food coloring in it.

1. Use an eyedropper or pipette to place 10 drops of food coloring in cell 1 of the ice cube tray.
2. Using the same eyedropper or pipette, remove 1 drop of food coloring from cell 1 and place it in cell 2.
3. Use a clean eyedropper or pipette to add 9 drops of clean water to cell 2. Stir.
4. Fill out the second row of the table provided.
5. Remove 1 drop from cell 2 and place it in cell 3.
6. Using the clean eyedropper or pipette, add 9 drops of clean water to cell 3.
7. Fill out the third row of the table.
8. Remove one drop from cell 3 and place it in cell 4.
9. Using the clean eyedropper or pipette, add 9 drops of clean water to cell 4.
10. Fill out the fourth row of the table.
11. Continue in this manner until you've finished 10 cells in the ice cube tray and all 10 rows of the table.
12. Label a coffee filter with the numbers 1-10 along the circumference, then place one drop from each cell in the appropriately numbered space on the filter. (Do this after you have prepared all of the solutions.) This lets you compare the appearance of each of the 10 solutions. Or if you don't have a coffee filter, you can use a paintbrush to brush a sample from each solution onto your table, next to the number of the cell. In either case, clean the eyedropper or paintbrush between each use.

Ratio of Food Coloring to Solution Expressed as. . . .

Cell Name	...a fraction	...parts per hundred (%)	...parts per million (ppm)	...parts per billion (ppb)
1.	10/10 (= 1/1)	100%	1,000,000 ppm	1,000,000,000 ppb
2.	1/10	10%		
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				

THE ACTIVITY continued…

OPTION 2: Milk and Beakers

1. Label beakers 1-10 (label beaker at top or bottom to leave room for shining a light through the beaker in step 10)
2. Pour 100 ml of milk in Beaker 1.
3. Remove 10 ml of liquid from Beaker 1 with a graduated pipette and pour it into Beaker 2.
4. Add 90 ml of water to Beaker 2 and stir.
5. Fill out Row 2 of the table provided.
6. Remove 10 ml of the liquid from Beaker 2 and pour it into Beaker 3.
7. Add 90 ml of water to Beaker 3 and stir.
8. Fill out Row 3 of the table.
9. Continue in this manner until you have filled all 10 beakers and all 10 rows of the table.
10. Demonstrating the Tyndall effect: Point a laser pointer or pen light so that the light shines through beaker 2. You should be able to see the beam of light illuminated in the beaker, as the light bounces off particles of milk in the mixture. Try this for each beaker, noticing that the light beam is illuminated even in the beakers that look like plain water. Try doing this with a beaker of clear water to compare – you won't be able to see the beam of light because there are no solid particles.

Ratio of Milk to Mixture Expressed as. . . .

Beaker Number	...a fraction	...parts per hundred (%)	...parts per million (ppm)	...parts per billion (ppb)
1.	100/100 (= 1/1)	100%	1,000,000 ppm	1,000,000,000ppb
2.	10/100 (=1/10)	10%		
3.				
4.				
5.				
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8.				
9.				
10.				

WRAP UP AND ACTION

Answer the following questions:

OPTION 1: Food Coloring and Ice Cube Tray

1. Does the solution in the any of the cells appear colorless? Is there any food coloring in them? How do you know? [Answer: Yes, because we know that each cell contains a little bit of solution from the very first cell, which is full of food coloring.]
2. When there is only a tiny amount of food coloring in the solution, what is the benefit of expressing ratios as ppm or ppb instead of as a percent? [Answer: The percentages are hard to read when there are so many zeroes in them.]
3. Nitrogen is 78% of our atmosphere, or 78/100. How many ppm is that? Hint: Solve for x in the following equation: 78/100 = x/1,000,000 [Answer: 780,000 ppm.]
4. Which of the cells is closest to representing the ppm of nitrogen in our atmosphere? [Answer: Cell 1]
5. Oxygen is 21% of our atmosphere. How many ppm is that? Which of the cells of is closest to representing the ppm of oxygen in our atmosphere? [Answer: 210,000 ppm. Cell 2]
6. Argon is less than one percent (0.9%) of our atmosphere. How many ppm is that? Which of the cells is closest to representing the ppm of argon in our atmosphere? [Answer: 9,000 ppm. Cell 3.]
7. Ground-level ozone pollution in the air is measured in ppb. A measurement of 86 ppb is considered unhealthy for sensitive groups. Which of the cells is closest to representing that level of ppb? [Answer: Cell 8.]

OPTION 2: Milk and Beakers

1. Does the mixture in the any of the beakers appear colorless? Is there any milk in them? How do you know? [Answer: Yes, because each beaker contains a little of the mixture from the first beaker, which was 100% milk.]
2. When there is only a tiny amount of milk in the mixture, what is the benefit of expressing ratios as ppm or ppb instead of as a percent? [Answer: The percentages are hard to read when there are so many zeroes in them.]
3. Nitrogen is 78% of our atmosphere, or 78/100. How many ppm is that? **HINT:** Solve for x in the following equation: 78/100 = x/1,000,000 [Answer: 780,000 ppm.]
4. Which of the beakers is closest to representing the ppm of nitrogen in our atmosphere? [Answer: Beaker 1.]
5. Oxygen is 21% of our atmosphere. How many ppm is that? Which of the beakers is closest to representing the ppm of oxygen in our atmosphere? [Answer: 210,000 ppm. Beaker 2.]
6. Argon is less than one percent (0.9%) of our atmosphere. How many ppm is that? Which of the beakers is closest to representing the ppm of argon in our atmosphere? [Answer: 9,000 ppm. Beaker 3.]
7. Ground-level ozone pollution in the air is measured in ppb. A measurement of 86 ppb is considered unhealthy for sensitive groups. Which of the beakers is closest to representing that level of ppb? [Answer: Beaker 8.]

ASSESSMENT

HAVE STUDENTS:

- Turn in their completed worksheets for grading.
- Draw a picture or make a 3D model that demonstrates the relative concentrations of nitrogen, oxygen, and argon in our atmosphere. Encourage your students to be creative with materials you have on hand in the classroom or that they can find at home. For example, students could make a collage, construct a building of Lego bricks, or make cookies using the appropriate proportions.

EXTENSIONS

Challenge your students to come up with other ways of illustrating 1 ppm or 1 ppb.

RESOURCES

The food coloring activity is based on one on the UCAR (University Corporation for Atmospheric Research) website: http://www.ucar.edu/learn/1_4_2_14s.htm

Teacher's Answer Key

Cell/Beaker Number	% food coloring/ milk	...parts per million (ppm)	...parts per billion (ppb)	Analogous to what gas in the atmosphere?
1.	10/10 or 100%	1,000,000 ppm	1,000,000,000 ppb	Nitrogen(N_2)=780,000 ppm
2.	1/10 or 10%	100,000 ppm	100,000,000 ppb	Oxygen (O_2)=210,000 ppm
3.	1/100 or 1%	10,000 ppm	10,000,000 ppb	Argon=9,000 ppm
4.	1/1,0000 or 0.1%	1,000 ppm	1,000,000 ppb	
5.	1/10,0000 or 0.01%	100 ppm	100,000 ppb	
6.	1/100,0000 or 0.001%	10 ppm	10,000 ppb	
7.	1/1,000,0000 or 0.0001%	1 ppm	1,000 ppb	
8.	1/10,000,0000 or 0.00001%	0.1 ppm	100 ppb	Ground level ozone of 86 ppb (unhealthy for sensitive groups)
9.	1/100,000,0000 or 0.000001%	0.01 ppm	10 ppb	Ground level ozone of 15 ppb (no health effects expected)
10.	1/1,000,000,0000 or 0.0000001%	0.001 ppm	1 ppb	

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Food Coloring Student Page #1

THE ACTIVITY

Food Coloring and Ice Cube Tray

INSTRUCTIONS

NOTE: Use one eyedropper for clean water and the other one for food coloring and water with food coloring in it.

1. Use an eyedropper or pipette to place 10 drops of food coloring in cell 1 of the ice cube tray.
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Food Coloring and Ice Cube Tray

WORKSHEET

1. Does the solution in the any of the cells appear colorless? Is there any food coloring in them? How do you know?

2. When there is only a tiny amount of food coloring in the solution, what is the benefit of expressing ratios as ppm or ppb instead of as a percent?

3. Nitrogen is 78% of our atmosphere, or 78/100. How many ppm is that? **HINT:** Solve for x in the following equation: $78/100 = x/1,000,000$

4. Which of the cells is closest to representing the ppm of nitrogen in our atmosphere?

5. Oxygen is 21% of our atmosphere. How many ppm is that? Which of the cells of is closest to representing the ppm of oxygen in our atmosphere?

6. Argon is less than one percent (0.9%) of our atmosphere. How many ppm is that? Which of the cells is closest to representing the ppm of argon in our atmosphere?

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Milk Student Page #1

THE ACTIVITY

Milk and Beakers

INSTRUCTIONS

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4. Add 90 ml of water to Beaker 2 and stir.
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6.				
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8.				
9.				
10.				

IT'S OUR AIR

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Milk Student Page #2

Milk and Beakers

WORKSHEET

1. Does the mixture in the any of the beakers appear colorless? Is there any milk in them? How do you know?

2. When there is only a tiny amount of milk in the mixture, what is the benefit of expressing ratios as ppm or ppb instead of as a percent?

3. Nitrogen is 78% of our atmosphere, or 78/100. How many ppm is that? Hint: Solve for x in the following equation: $78/100 = x/1{,}000{,}000$.

4. Which of the beakers is closest to representing the ppm of nitrogen in our atmosphere?

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