Chemistry, Climate Change, and Collision Theory

Using bacteria to decrease greenhouse gasses

Introduction

What do you do when there's no oxygen? Humans (and all other animals and plants and, well, a lot of other things!) would be in pretty big trouble if they found themselves without it, but it's not a big deal for many kinds of bacteria. Animals tend to avoid environments without oxygen, but many types of bacteria live in environments that are at least some of the time, **anoxic** ("no oxygen"), such as deep in the soil or near hydrothermal vents along the ocean floor. Bacteria living in these environments can't always use **aerobic** ("with air") metabolism, where oxygen (O_2) is used to produce chemical energy for growth and cell division. Instead, when there isn't any oxygen to be had, the bacteria switch to **anaerobic** ("without air") methods that produce energy without O_2.

The energy-generating anaerobic reactions used by some bacteria involve starting compounds made of nitrogen and oxygen atoms such as nitrate (NO_3^-). The ultimate product of the reactions is nitrogen gas (N_2). The overall process is called **denitrification** and involves four major steps, as shown in **Figure 1**.

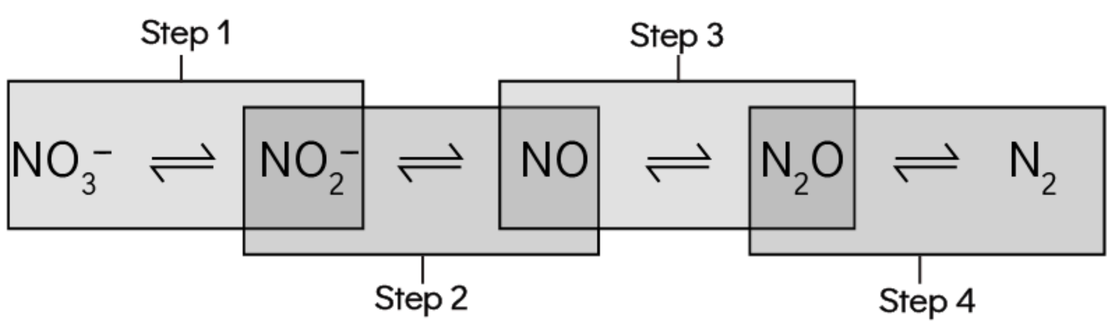

Figure 1. Denitrification. The denitrification process converts nitrate (NO_3^-) to nitrogen gas (N_2) in four stages. Each step in the process is catalyzed by reaction-specific enzymes. **Important!** The reactions shown are **not** balanced.

Each of the four major steps in the denitrification process take place within the bacteria and requires an enzyme. **Enzymes** are proteins that speed up a chemical reaction without being used up in the process. One way enzymes work is by "catching" reactant molecules and rearranging them so that they are aligned in a way that favors the reaction. Without an enzyme, the chances of the molecules colliding with enough energy and with the right orientation to react is so low that the reaction is unlikely to occur. In this lesson, you'll learn about how scientists are studying anaerobic energy-producing reactions in bacteria, hoping that maybe they can help solve...climate change. Yep. Climate change. Curious how? Read on!

What To Do

Answer the analysis questions, reading the Bite when instructed.

Analysis Questions

1. Under what conditions does denitrification typically occur in bacteria? Under what conditions does it not typically occur?

2. What do enzymes do and why are they important to denitrification?

While all of the nitrogen compounds involved in the denitrification process might seem similar at first glance, one of the intermediates is very important to scientists. An **intermediate** is a compound produced in one step and consumed in a later step. The denitrification intermediate N_2O, or nitrous oxide, is a common pollutant generated by human activities, and it is also a greenhouse gas. Greenhouse gasses absorb and reradiate energy in the form of heat in the atmosphere. Extra greenhouse gasses in our atmosphere contribute to global warming.

Examine **Figure 1** again. Nitrous oxide is produced in Step 3, but consumed in Step 4. Unfortunately, some nitrous oxide produced in Step 3 can escape into the atmosphere before it is used up in Step 4, contributing to greenhouse gas emissions.

3. As noted above, N_2O is one of the intermediates in denitrification.

    a. What are the two other intermediates shown in **Figure 1**?

    b. How do you know they are intermediates?

The data below is from scientists studying the denitrification process. They observed how much nitrogen gas (N_2) was produced at two different temperatures. Recall that N_2 is the final product of the denitrification process.

Percent of Reaction Time	Micromoles N_2 Produced at 17°C	Micromoles N_2 Produced at 30°C
0%	0	0
18%	1	1
34%	4	6
50%	9	16
66%	15	30
84%	38	52
100%	54	54

Table 1. Nitrogen Produced in a Denitrification Reaction. Scientists measured the amount of nitrogen gas, N_2, a group of bacteria produced over time at two different temperatures. *Source:* Lycus, Pawel, et al. 2018.

4. Use **Table 1** to answer the following questions.

a. Graph the data. Be sure to label and scale your axes appropriately, and include a key for the two temperatures.

b. At which of the two temperatures is there more N_2 …

- at 10% of reaction time?
- At 30% of reaction time?
- At 70% of reaction time?

c. Does the denitrification reaction happen at a greater initial rate at 30°C or 17°C? Use evidence from your graph. Support your evidence with reasoning in your response.

d. Does the observed difference in the rate of the denitrification reaction at the two temperatures agree with our understanding of how temperature affects reaction rate? Be sure to discuss principles of collision theory in your response.

STOP & read Science Bite:

Who Needs Oxygen?

5. Examine **Figure 2** in the Bite. This figure shows the changes in NO and N_2 while denitrification was occuring at 30°C.

   a. When did NO reach its maximum amount?

   b. When did N_2 reach its maximum amount?

   c. Which compound, NO or N_2, was produced more quickly at first? (Hint: look at the slopes of the two graphs!)

   d. What happened to NO production as the amount of N_2 peaked? Why do you think that is?

6. Consider the rate of NO production at 30°C and 17°C by comparing the scale of the *x*-axes in **Figures 2** and **3** in the Bite.

   a. How are the *x*-axes scales different?

   b. A combination of enzyme activity and collision theory can explain this difference. Explain how each one could contribute to the different results noted in part a.

   c. When differences in the *x*-axis are this big, scientists will often divide hours by the total number of hours, measuring reaction time as a percent of total time elapsed. Why did it make sense to present the data you used to make your graph with time in % reaction time rather than in hours?

These surprising results can be explained if you know that the full denitrification pathway we have been exploring so far is **not** the only way bacteria can produce N_2. Two pathways are shown in **Figure 2** on the next page**:** The full denitrification process (Pathway 1) and N_2 production from N_2O in the environment (Pathway 2).

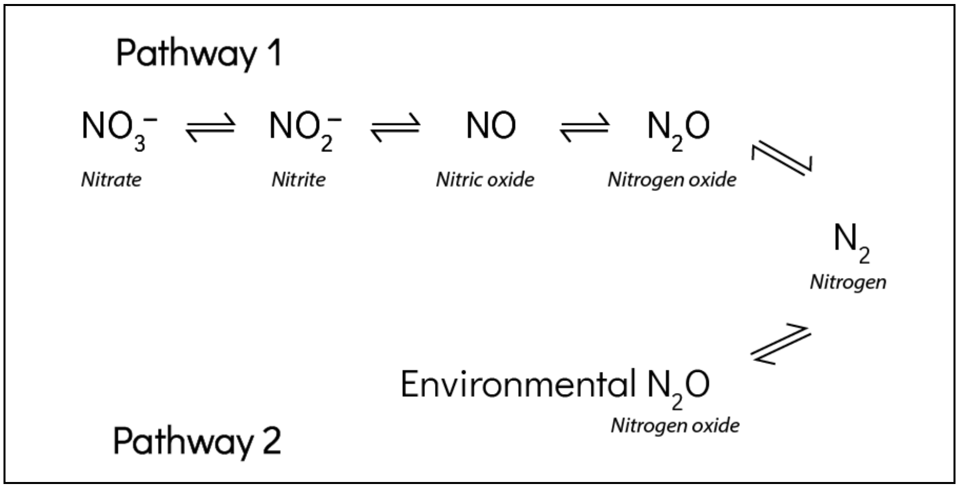

Figure 2. Two Pathways for Producing Nitrogen Gas. At 17 °C, the soil bacteria cells were all able to grow, even though only some were performing Step 2 in the denitrification process (Pathway 1). This led the scientists to hypothesize that *P. denitrificans* could also use N_2O from the environment to make N_2 (Pathway 2), which would provide energy for growth, without going through all the other steps in denitrification.

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7. At 17°C which pathway do you think is happening: Pathway 1, Pathway 2, or some combination of both? Explain your answer.

8. Imagine that you are a scientist that wants to develop a way to use this bacteria to remove as much N_2O as possible from the environment in order to combat climate change.

a. What is one reason that you might decide that you should place the bacteria in a warm environment where the average temperature is near 30°C? Use your understanding of kinetics to support your answer.

b. What is one reason that you might decide that you should place the bacteria in a cool environment where the average temperature is near 17°C? Use evidence from the Bite to support your answer.

9. **Connect to the Big Question**. The first life forms that evolved on Earth used anaerobic respiration to generate energy.

a. What does that suggest about early Earth conditions in terms of oxygen availability?

b. What likely happened to these earliest life forms when photosynthetic organisms evolved? What does this suggest about how life and the environment are connected?

c. Humans are just about as different from anaerobic bacteria as you can get. Are humans today dependent on anaerobic bacteria? What does your answer suggest about the interconnectedness of all life?

d. Some people think that only biologists and ecologists care about climate change. Explain why it is important for all scientists to consider climate change in their work.