

The Air Is Full of Nitrogen, and Almost Nobody Can Eat It

Learning target: I can explain, with evidence from a passage, how nitrogen atoms move from the air into living things and back, and why the same atoms can become a problem when too many arrive at once.

Reading with evidence

About 35 min

Individual

MS-LS2-3 · practice

MS-LS2-4 · supports

reading

writing

Standards connections

MS-LS2-3 (practice): The passage follows nitrogen atoms through nonliving reservoirs (air, soil, water) and living ones (bacteria, plants, animals). Reading and citing it builds the understanding students need to construct a cycling-of-matter model; it does not itself produce a model.

MS-LS2-4 (supports): The final paragraphs describe how a change to a nonliving part of a water ecosystem (extra nitrate) led to a fish die-off. This is background for the evidence argument students build in Worksheet 8.

Purpose: build · **Time:** about 35 minutes · **Format:** individual

Answers with reasoning

The Air Is Full of Nitrogen, and Almost Nobody Can Eat It

[1] Take a breath. About four-fifths of what just entered your lungs was nitrogen gas. Your body needs nitrogen badly: every protein in your muscles and every strand of your DNA contains nitrogen atoms. Yet the nitrogen you breathed in will leave on your next breath exactly as it came. The reason is that nitrogen gas is made of pairs of nitrogen atoms clamped together by one of the strongest bonds in chemistry. Almost no living thing has the tools to pull that pair apart. Animals cannot. Plants cannot. For most of life on Earth, the biggest supply of nitrogen on the planet might as well be locked in a safe.

[2] A few kinds of bacteria hold the key. They carry out nitrogen fixation: using a great deal of energy, they turn nitrogen gas into ammonia, which in damp soil quickly becomes a form called ammonium. Some of these bacteria live on their own in soil and water. Others live inside small lumps, called nodules, on the roots of plants such as peanuts, beans, clover and alfalfa. The partnership is a trade. The plant pumps sugar down to the bacteria; the bacteria hand back fixed nitrogen. Farmers noticed thousands of years ago that fields recover after a season of beans or clover, long before anyone knew bacteria were doing the work.

[3] Lightning is the only other natural process that fixes nitrogen. The heat of a bolt makes nitrogen gas react with oxygen gas in the air. The nitrogen oxides that form dissolve in raindrops and reach the ground as nitrate, a form that plant roots absorb easily. But it is a small contribution: across the whole planet, bacteria fix many times more nitrogen than lightning does.

[4] Once nitrogen is fixed, it begins to travel. Nitrifying bacteria in the soil change ammonium into nitrate. Plant roots take in both ammonium and nitrate and use them to build proteins and other molecules. A rabbit that eats clover digests the clover's proteins into their building blocks, amino acids, and reassembles them into rabbit proteins. When the rabbit produces waste, and when any plant or animal dies, decomposers break the proteins down and release ammonium back into the soil. In wet, oxygen-poor soil, denitrifying bacteria convert nitrate back into nitrogen gas, which drifts up into the air. The safe is locked again.

[5] In 1909, the German chemist Fritz Haber showed that nitrogen gas could be forced to combine with hydrogen in the laboratory, and by 1913 the engineer Carl Bosch had turned the method into a working factory. The process needs very high pressure and temperature, which take a lot of energy. Today fertilizer plants fix more nitrogen than all the lightning on Earth, and scientists estimate that about half of the people alive are fed by crops grown with factory-made nitrogen. The nitrogen atoms in your last meal may well have passed through a steel reactor before they passed through a plant.

[6] There is a catch. Nitrate dissolves completely in water and does not stick to soil particles. When a farmer spreads more fertilizer than the crop can take up, or when a storm arrives soon after spreading, the extra nitrate washes into streams, ponds and the sea. Algae in the water use it the way crops do and multiply into thick green blooms. When the algae die, decomposers feed on them and use up the water's oxygen through cellular respiration. Fish suffocate. Most summers, a 'dead zone' with too little oxygen for fish forms in the Gulf of Mexico near the mouth of the Mississippi River, fed by nitrogen washed off farms upstream.

[7] Notice what did not happen in that story. No nitrogen was destroyed, and none was created. The same atoms that were in the air were fixed by a factory, spread on a field, washed into a river, built into algae, released by decomposers and, eventually, returned to the air by denitrifiers. A nitrogen atom in your muscle right now has probably been part of the air, a bacterium, a plant and an animal, and it will be again. Matter on Earth does not get used up. It gets used again.

Questions: cite the passage

1. According to paragraph 1, why can't you use the nitrogen you breathe in, even though your body needs nitrogen? Quote the phrase that gives the reason.

Answer: Nitrogen gas is made of two nitrogen atoms held together by an extremely strong bond, and animals (and plants) lack the tools to separate them. Quote: 'clamped together by one of the strongest bonds in chemistry' (paragraph 1).

Why: The passage gives the bond strength as the reason; the student should quote or closely paraphrase it and may add that it leaves 'exactly as it came.'

Also acceptable: Accept 'Almost no living thing has the tools to pull that pair apart' as the quoted phrase.

- Names the strong bond between the two atoms
- Quotes or closely paraphrases paragraph 1

2. Paragraph 2 calls the relationship between a bean plant and its root bacteria 'a trade.' What does each partner give, and what does each get?

Answer: The plant gives sugar (made in its leaves) to the bacteria in its root nodules; the bacteria give fixed nitrogen (ammonia/ammonium) to the plant. The plant gets usable nitrogen for proteins; the bacteria get food.

Why: Paragraph 2 states both directions of the trade explicitly.

Also acceptable: Accept 'ammonia' or 'usable nitrogen' for what the bacteria provide.

- Plant gives sugar
- Bacteria give fixed nitrogen

3. Paragraph 3 says lightning fixes nitrogen. In what **form** does that nitrogen reach the ground, and how does the paragraph compare the amount with what bacteria fix?

Answer: It reaches the ground as nitrate, dissolved in raindrops (the nitrogen oxides made by the bolt dissolve in rain). The paragraph says bacteria fix 'many times more nitrogen than lightning does,' so lightning is a small contributor.

Why: This item checks the accurate product of lightning fixation (nitrate, not ammonia) and the relative size of the two natural routes.

Also acceptable: Accept 'nitrogen oxides that become nitrate in rain.'

- Nitrate named as the form
- States that bacteria fix much more than lightning

4. Using paragraph 4, list in order the forms a nitrogen atom takes from ammonium in the soil to ammonium in the soil again, passing through a clover plant and a rabbit. Name the organism or process responsible for each change.

Answer: Ammonium in soil → nitrate (changed by nitrifying bacteria) → clover protein (roots absorb nitrate or ammonium and the plant builds proteins) → amino acids (the rabbit digests the clover proteins) → rabbit protein (the rabbit reassembles the amino acids) → ammonium in soil again (decomposers break down the rabbit's wastes or remains and release ammonium).

Why: The order and the agents are all in paragraph 4. The amino-acid step is the accurate correction to the textbook's claim that animals use nitrates to build protein.

Also acceptable: A student who skips nitrate and has the root absorb ammonium directly is still correct, since the passage says roots take in both.

- Forms listed in the correct order
- An organism or process named for each change
- Includes digestion to amino acids before rabbit protein

5. Paragraph 1 says about four-fifths of air is nitrogen gas. The air in a typical classroom has a mass of about 240 kg. Estimate the mass of nitrogen gas in the room. Then explain in one sentence why a houseplant in that room still needs fertilizer.

Answer: Four-fifths of 240 kg: $240 \text{ kg} \times \frac{4}{5} = 240 \times 0.8 = 192 \text{ kg}$ of nitrogen gas. (Using the exact 78 percent: $240 \times 0.78 \approx 187 \text{ kg}$.) The houseplant still needs fertilizer because it cannot use nitrogen gas; it needs fixed nitrogen (ammonium or nitrate) in the soil, and the room has no nitrogen-fixing bacteria feeding its pot.

Why: The arithmetic is a fraction of a mass; the explanation ties back to paragraphs 1 and 2. Either 192 kg or about 187 kg is acceptable depending on the fraction used.

Also acceptable: Accept 190 kg as a rounded answer with work shown.

6. What problem did Haber and Bosch solve, and what does paragraph 5 say it costs to run their process?

Answer: They found a way to fix nitrogen without bacteria or lightning: forcing nitrogen gas to combine with hydrogen in a factory. Paragraph 5 says the process needs very high pressure and temperature, which take a lot of energy.

Why: The problem is the locked-safe problem from paragraph 1; the cost is energy.

Also acceptable: Accept 'it uses a lot of energy' without the pressure and temperature detail.

- States that the process fixes nitrogen artificially
- Names the energy cost (high pressure and temperature)

7. Paragraph 6 explains why extra nitrate can kill fish. Describe the chain of events in order, and explain why the fish die **after** the algae bloom rather than during it.

Answer: Chain: extra nitrate washes off the field into the water → algae take it up and multiply into a bloom → the algae die → decomposers feed on the dead algae and use up oxygen through cellular respiration → fish suffocate. The fish die after the bloom because the oxygen loss is caused by decomposers breaking down dead algae, which cannot happen until the algae have grown and died; while the algae are alive and growing, they are also making oxygen in sunlight.

Why: The timing explanation is the key insight: the harm comes from decomposition, a later step, not from the nitrate itself.

Also acceptable: Accept an answer that notes algae also use oxygen at night as part of the explanation.

- Steps in the correct order
- Decomposers using oxygen named as the cause of fish death
- Explains the delay

8. The passage ends: 'Matter on Earth does not get used up. It gets used again.' Using evidence from at least two different paragraphs, explain how the dead-zone story supports that claim even though it describes a serious problem.

Answer: The dead-zone story is a problem of nitrogen being in the wrong place, not of nitrogen being used up. Paragraph 6 shows the same atoms moving from fertilizer to water to algae to decomposers; paragraph 7 states that 'No nitrogen was destroyed, and none was created' and lists the atoms returning to the air by denitrifiers. Paragraph 4 gives the same loop in a healthy soil. So the problem is caused by too much nitrogen arriving at once in one reservoir, while the total stays the same and keeps cycling; conservation of matter explains both the normal cycle and the harm.

Why: Full credit requires evidence from two paragraphs and the distinction between 'used up' and 'moved to the wrong place at the wrong rate.'

Also acceptable: A student who argues that the atoms 'return to the air eventually' using paragraph 7 and the denitrifier sentence in paragraph 4 is giving a strong answer.

- Evidence cited from at least two paragraphs
- States that the atoms were moved, not destroyed
- Connects the problem to too much nitrogen in one reservoir rather than loss of matter

Teacher notes

The passage is about 700 words and is deliberately accurate where the textbook simplifies: lightning produces nitrogen oxides that reach the ground as nitrate (the book says ammonia); decomposers release ammonium and nitrifying bacteria make nitrate (the book has decomposers leaving nitrates); animals build proteins from amino acids obtained by digesting food proteins, not from nitrates; and industrial fixation is a

third route the book omits. Historical facts are established: Haber demonstrated laboratory synthesis of ammonia in 1909 and the first industrial plant under Bosch opened in 1913; the estimate that roughly half of the world's population depends on synthetic nitrogen fertilizer is widely cited in the scientific literature; the Gulf of Mexico hypoxic zone forms most summers off Louisiana and is fed largely by Mississippi River nutrients. The extension's budget: $120 - 65 - 18 = 37$ kg reaches the river; good practice changes are splitting applications to match crop uptake or avoiding spreading before forecast rain (timing) and rotating with a legume such as clover (biological fixation reduces the fertilizer needed).

Scaffold offered to students: Track the forms

On scrap paper, draw six boxes in a row and label them: nitrogen gas, ammonium, nitrate, plant protein, animal protein, ammonium again. As you read the second time, write above each arrow between boxes the organism or event that causes the change (for example, 'nitrifying bacteria' between ammonium and nitrate). Questions 3, 4, 7 and 8 can all be answered from this strip.

Extension: A nitrogen budget for one field

Suppose a farmer spreads 120 kg of nitrogen on a field. The crop takes up 65 kg, denitrifying bacteria return 18 kg to the air, and the rest washes toward a river. Calculate how much nitrogen reaches the river. Then design two changes to the farmer's practice that would shrink that number, and explain for each which process or reservoir in the passage it works on. One change should involve timing and one should involve a plant from paragraph 2.