LIBBY: You're listening to *BrainsOnwhere* we're serious about being curious.

SPEAKER 1: *Brains On* is supported in part by a grant from the National Science Foundation.

SANDEN TOTTEN: All right, Marc. Deep breath in.

MARC SANCHEZ: [INHALES]

SANDEN TOTTEN: And deep breath out.

MARC SANCHEZ: [EXHALES]

SANDEN TOTTEN: Deep breath in.

MARC SANCHEZ: [INHALES]

SANDEN TOTTEN: And a little deep breath out.

MARC SANCHEZ: [EXHALES]

SANDEN TOTTEN: Awesome work.

MARC SANCHEZ: Oh, oh. Hang on a second, Sanden. It's Molly. What's up, Bloomers?

MOLLY BLOOM: Hey, I'm with Libby.

LIBBY: Hi.

MARC SANCHEZ: Hey, hang on a second. I'm going to put you on speaker because Sanden's here, and you know, we're on vacation.

MOLLY BLOOM: How are things going in the desert?

MARC SANCHEZ: Oh, so good. The desert is amazing. And Sanden is teaching me how to meditate, so I'm totally in my zen zone. [CLEARS THROAT]

SANDEN TOTTEN: More om, less phone, Marc. Total self-enlightenment and complete inner peace isn't going to find itself.

MOLLY BLOOM: All right. We'll let you get back to that.

LIBBY: Yeah, we've got a tape our episode on where oxygen comes from anyway.

SANDEN TOTTEN: Now that's easy. Oxygen comes from plants. Thank you, next.

MOLLY BLOOM: Well, I think, actually--

MARC SANCHEZ: Yeah, all this fresh air. [INHALES] It comes from the plants around. Wait. Why are there so few plants around?

SANDEN TOTTEN: Because it's the desert.

MARC SANCHEZ: Then where is the oxygen coming from?

SANDEN TOTTEN: Wait. No plants equals no oxygen. We're running out of air.

MARC SANCHEZ: Why were we taking such big breaths before?

MOLLY BLOOM: Guys, I don't think it works like that.

MARC SANCHEZ: This could be my last breath. Oh, wait. That could have been my last breath. Oh, wait. This is my last breath.

MOLLY BLOOM: You guys, trust me. You are going to be fine.

MARC SANCHEZ: That lizard is hogging all the air. Hey, lizard. Stop hogging all the air.

LIBBY: Calm down. Take a deep breath and just listen to the episode.

[THEME MUSIC]

MOLLY BLOOM: You're listening to *Brains On* for American Public Media. I'm Molly Bloom. And with me today is Libby from Chelmsford, Massachusetts. Hi, Libby.

LIBBY: Hi, Molly.

MOLLY BLOOM: So Libby, you inspired today's episode with a really interesting question about the air that we breathe. What was that question?

LIBBY: How do people in the desert breathe if there is no trees? Is there any way to track where the air we're breathing has been before? Am I breathing air from Japan?

MOLLY BLOOM: [CHUCKLES] That is a really, really good question. So how did you come up with that thought?

LIBBY: I don't know. I was sitting in the car, and there was a lot of trees outside my window, and I guess I was thinking about the desert.

MOLLY BLOOM: Do you often come up with questions and ideas?

LIBBY: I think a lot. And then I get curious. And then I-- and then I have questions.

MOLLY BLOOM: Is there a topic that you think about more than others, would you say?

LIBBY: Sometimes I find myself randomly thinking about socks.

MOLLY BLOOM: [LAUGHS]

LIBBY: I think socks were dancing or something.

MOLLY BLOOM: Oh, interesting.

LIBBY: And now it's happening right now again because I'm thinking about it.

MOLLY BLOOM: I really like the way your mind works.

LIBBY: Thanks.

KIDS: *B-B-B-Brains On!*

MOLLY BLOOM: So we are going to answer your very curious question about how air travels around the world in just a bit. But we should start with the basics, like this question from Jude in Portland, Oregon.

JUDE: My question is, how is oxygen formed?

LIBBY: Jude, good question.

MOLLY BLOOM: So the oxygen in the air we breathe mostly comes from plants and also algae and bacteria.

LIBBY: You know, algae and bacteria don't get enough credit for all the oxygen they make.

MOLLY BLOOM: Totally. They need a better PR team. Anyway, those three have this amazing superpower. They can take water, sunlight, and carbon dioxide and turn it into oxygen gas and sugar.

LIBBY: Oxygen and sugar, two of my favorite things. We call this awesome ability photosynthesis.

MOLLY BLOOM: It is very fun to say. It makes you sound like a robot. (ROBOTIC) Photosynthesis.

LIBBY: (ROBOTIC) Photosynthesis.

MOLLY BLOOM: So a lot of the oxygen in our air comes from photosynthesis. And guess what that oxygen is made up of?

LIBBY: Atoms?

MOLLY BLOOM: Exactly.

LIBBY: I mean, literally everything is made of atoms. They're the building blocks of the universe.

MOLLY BLOOM: So the oxygen gas we breathe is made of oxygen molecules. Molecule just means some atoms are bonded together like they're in a group. In this case, it's two oxygen atoms bonded together.

LIBBY: Because oxygen atoms hate being alone.

OXYGEN 1: I got to bond. I need a friend.

OXYGEN 2: I need a friend too. Let's be friends, friend.

OXYGEN 1: OK, friend.

OXYGEN 2: Yay, friend!

OXYGEN 1: Yay!

MOLLY BLOOM: When there are two oxygen atoms bonded together, we call these molecules O2.

OXYGEN 1: We're pals now.

OXYGEN 2: And we're flying as a gas.

OXYGEN 1: So fun. Yay!

OXYGEN 2: Woohoo!

[MUSIC PLAYING]

MOLLY BLOOM: So oxygen gas is made from oxygen atoms bonded into molecules. But when you have just one, single, solitary oxygen atom, we call it elemental oxygen.

LIBBY: But where did all this elemental oxygen come from in the first place?

MOLLY BLOOM: For that, we turn to Alicia Johnson. She studies oxygen at Arizona State University.

[FAINT RINGING]

ALICIA JOHNSON: So originally, elemental oxygen is created like all other elements in stars. And then when those stars explode-- it's called the supernova-- more elements are created. And so the elements created from that old star all distributed in the planets in our current solar system. And so that's where the oxygen originally comes from.

LIBBY: Did you catch that? The oxygen atoms and the oxygen gas that we breathe got made when the solar system did in the giant star explosion. Ka-blam!

[EXPLOSION]

MOLLY BLOOM: [CHUCKLES] Right. So when Earth formed, it had plenty of oxygen. But early on, that oxygen was trapped in rocks, water, and other gases. You couldn't find much O2 around.

LIBBY: We'll tell you how it got into the air in a minute.

MOLLY BLOOM: But first, Libby, get ready. Here comes the mystery sound.

SPEAKER 2: (WHISPERS) Mystery sound.

[MYSTERY SOUND]

MOLLY BLOOM: So Libby, you heard the sound. What is your guess?

LIBBY: It sounds sort of like a smoke alarm.

MOLLY BLOOM: Mm, very good guess. Well, we're going to get back to the answer a little bit later in the show. But first, we're going to go back to the story of oxygen.

LIBBY: When last we left off, so much of Earth's oxygen was trapped in rocks and stuff.

MOLLY BLOOM: So how did it get out and end up filling our atmosphere? Producer Menaka Wilhelm is here with answers. Welcome, Menaka.

MENAKA WILHELM: Hi, Libby. Hi, Molly. I'm here to talk about the great oxygenation event. It's got a lot of names actually. The Great Oxidation Event, the GOE, or my personal favorite, the Oxygen Revolution. It sounds like a bunch of oxygen atoms getting feisty and taking over the sky. And in a way, that's what happened. It was the first time that oxygen gas really got big in Earth's atmosphere. And it was 2.5 billion years ago. So if we go back to that time, we're on Earth, but it's almost like a different planet.

[RUMBLING AND SPLASHING]

There are some small continents, but they aren't the continents that we know today. The ocean and a bunch of underwater volcanoes do exist. And there's probably a little bit of oxygen in the atmosphere at this point. But mostly, the air has more carbon dioxide and also more methane and ammonia, so probably kind of smelly. And there aren't any plants or animals around, but there are bacteria.

BACTERIUM 1: We're hanging out in the ocean.

BACTERIUM 2: I mean, like, some of us are on the land.

BACTERIUM 3: Yeah, but a lot of us are in the ocean.

MENAKA WILHELM: And this one bacteria, a kind of bacteria called cyanobacteria, figures out how to do something special. Cyanobacteria starts taking water, carbon dioxide, and sunlight and turning it into oxygen gas and sugar.

CYANOBACTERIA: I feel really weird.

[BUBBLES]

Oh. Oh.

[PASSES GAS]

Ah, excuse me. Sorry. Is that what I should say? I've never done that before.

BACTERIUM 4: Did you just pass oxygen gas?

CYANOBACTERIA: Well, yeah. I had to get rid of the oxygen gas molecules I made somehow.

BACTERIUM 5: Wait, wait, wait. You're making O2 gas?

CYANOBACTERIA: Yes. And I shall call it--

BACTERIUM 5: A fart. [CHUCKLES]

CYANOBACTERIA: Photosynthesis.

BACTERIUM 5: How did you pull that off?

CYANOBACTERIA: Well, I found, like, this water in the ocean. And then with sunlight, I sort of, like, transferred some electrons around and split this water molecule apart and then.

BACTERIUM 5: [LIP TRILLS]

CYANOBACTERIA: Yeah, it gave me oxygen gas? But then I can also take this carbon dioxide and store energy as sugar and--

BACTERIUM 5: Do it again!

CYANOBACTERIA: OK.

[BUBBLES]

[PASSES GAS]

BACTERIUM 4: Wait, wait, wait, wait, wait. Can I do it too? Um.

[BUBBLES]

[PASSES GAS]

Yes!

BACTERIUM 5: Hey, I can do it too. Pull my finger.

CYANOBACTERIA: We're bacteria. We don't have fingers.

[BUBBLES]

[PASSES GAS]

BACTERIUM 5: Too late. [LAUGHS]

[PASSES GAS REPEATEDLY]

MENAKA WILHELM: They were doing photosynthesis. Plants today also do photosynthesis. But back then, the rise of oxygen actually wasn't good for the atmosphere on early Earth

MICROBE 1: Wow, you guys, this is going to be huge!

MICROBE 2: Ugh, speak for yourself. Blech. I do not appreciate this oxygen gas.

MENAKA WILHELM: As oxygen slowly infiltrated the atmosphere, it changed life on Earth.

MICROBE 1: Ugh, quit whining. Photosynthesis is like a superpower. It's the future.

MICROBE 2: Ugh, oxygen gas is poisonous to me, me and many of my microbe pals. We aren't going to be able to live in your pollution. Ugh. Gah, what a world! What a world! What a world!

MENAKA WILHELM: So some microbes died out. Or they migrated underground or deep into the ocean, places where they could hide from this oxygen gas. Over billions of years, the photosynthesizing cyanobacteria eventually evolved into the plants that do photosynthesis today, making even more oxygen gas. Other microbes evolved to breathe in oxygen, setting the stage for life forms like us.

So scientists are pretty sure that cyanobacteria and the Great Oxygenation Event is where much of the oxygen gas on Earth first came from. Thanks, cyanobacteria.

CYANOBACTERIA: You're welcome.

MENAKA WILHELM: Yep. [INHALES] And we're still breathing in the benefits of photosynthesis today. All right. Bye, you guys!

LIBBY: Bye!

MOLLY BLOOM: Bye, Menaka.

[MUSIC PLAYING]

OK. Libby, are you ready to find out what the mystery sound was? Let's hear it one more time.

[MYSTERY SOUND]

OK. Libby, any final guesses? Last time, you thought maybe it was a fire alarm.

LIBBY: I still kind of think it sounds like a fire alarm. I don't really know.

MOLLY BLOOM: What kind of sound-- so you think it's something like a mechanical thing?

LIBBY: It went like, beep, beep, beep, beep, beep, beep, beep!

MOLLY BLOOM: Well, here with the answer is marine scientist Allison Coe.

ALLISON COE: The sound you just heard was a xenon lamp on a fluorometer that we use to measure chlorophyll a on our prochlorococcus cultures.

MOLLY BLOOM: So that was a very hard mystery sound. It was--

LIBBY: I didn't know what, like, what most of those words meant. I didn't know.

MOLLY BLOOM: Yep, with very good reason because that was a lot of big words. And I didn't really know what any of them meant either, but we're going to find out right now. That sound is part of a machine that Allison uses to measure chlorophyll a, and that is a type of chlorophyll. And Libby, do you know where chlorophyll connects back to oxygen? Have you heard the word chlorophyll before?

LIBBY: I don't know what chlorophyll is.

MOLLY BLOOM: Well, chlorophyll is a chemical that plants and cyanobacteria make. They use it for photosynthesis, and it's actually what makes plants green.

ALLISON COE: Chlorophyll is basically like an antennae, and it collects light energy that the cells use to convert carbon dioxide and water into carbohydrates and oxygen.

MOLLY BLOOM: So chlorophyll is really key to how plants are able to take the carbon dioxide that we breathe out and turn it into the oxygen that we can breathe in. So in the lab Allison works in at MIT, she does experiments on a type of bacteria called prochlorococcus.

LIBBY: Huh?

MOLLY BLOOM: I know, right? But let me guess-- let me say that again. Prochlorococcus.

LIBBY: OK.

MOLLY BLOOM: So she wants to understand more about how they make oxygen. And that's really important for us because we need oxygen to breathe. The lamp in the mystery sound helps her measure how much chlorophyll the prochlorococcus have.

ALLISON COE: And we'll measure that amount of chlorophyll over time. So if the cells are happy, and they're dividing, the chlorophyll is going to increase.

MOLLY BLOOM: Marine scientists like Allison are curious about prochlorococcus bacteria because there's a lot of them on Earth, like a lot, a lot.

ALLISON COE: There's three octillion at any given time. And that's three billion, billion, billion cells. [LAUGHS] Yeah, they collectively weigh more than the human population and lives in the open ocean all around the world.

MOLLY BLOOM: Today, about half of our oxygen comes from plants like trees and grasses and shrubs. But the other half comes from microscopic photosynthesizers like this prochlorococcus and green algaes and others. Sure, they are microscopic, but collectively, they make a big difference in the air we breathe.

LIBBY: Thanks, tiny things.

MOLLY BLOOM: Coming up, are we breathing the same air the dinosaurs breathed?

LIBBY: We'll tell you in a sec, but don't hold your breath because breathing is good. Just stay tuned.

[MUSIC PLAYING]

MOLLY BLOOM: There are two kinds of wormholes, actual holes that worms live in--

LIBBY: --and theoretical tunnels in space that take you from one place to another.

MOLLY BLOOM: We're doing an episode about the second kind. But since they are theoretical, we have no idea if they exist or what they are like.

LIBBY: That's why we want you to fill in the gaps with your brainpower.

MOLLY BLOOM: Send us a recording describing what you think it's like inside a wormhole. What do you see? What does it sound like? What smells are there? Libby, what do you think you see?

LIBBY: I think you see stars and maybe a whole new galaxy and maybe worms that live on the planet, alien worms.

MOLLY BLOOM: [LAUGHS] That is very cool. Record your answer and send it to us at brainson.org/contact. Your response could end up in the episode.

LIBBY: While you're there, you could also send us a question.

MOLLY BLOOM: Like Carly did.

CARLY: Hi. My name is Carly, and I'm from Woodstock, Georgia. And my question is, would a poisonous snake die if it bit itself? Thank you.

LIBBY: We'll answer that during our *Moment of Um* at the end of the show.

MOLLY BLOOM: Plus, we'll have the latest group to become elite members of the Brains Honor Roll.

LIBBY: So keep listening.

[MUSIC PLAYING]

MOLLY BLOOM: This is *Brains On.* I'm Molly.

LIBBY: I'm Libby.

OXYGEN 1: And I'm an atom of oxygen. Will you be my friend?

MOLLY BLOOM: So far, we've talked about how Earth's air went from having almost zero oxygen to being full of the stuff.

LIBBY: Our atmosphere today is 20% oxygen. And lots of plants and bacteria are still out there photosynthesizing, making more of O2 all the time.

MOLLY BLOOM: So you might wonder if oxygen levels are still increasing.

LIBBY: Or you might wonder if oxygen levels change with the seasons, like Gus from Minneapolis did.

GUS: My question is, how do trees clean the air in the wintertime if they do not have any leaves? Is there less oxygen in the air?

MOLLY BLOOM: Here's our pal Alicia Johnson again.

ALICIA JOHNSON: The oxygen in the atmosphere is probably not increasing right now. It's probably pretty stable. We see small fluctuations every year in very, very small amounts. Every time it's summer, and all the trees grow, that produces a lot of oxygen. But there's so much oxygen that those tiny variations don't make a big difference.

MOLLY BLOOM: Even though plants and algae and bacteria are making a ton of oxygen every year, humans and animals are also-- [INHALES] --breathing a lot of oxygen in. So the total amount of oxygen stays roughly the same. Other things like fires burning, volcanoes erupting, and even lightning striking also use up a little bit of O2 gas from the atmosphere. That helps keep oxygen levels in check.

LIBBY: We also asked Alicia a question that our listeners sent to us.

ANNABELLE: My name is Annabelle from Michigan. My question is, do we breathe in the same oxygen as the dinosaurs?

ALICIA JOHNSON: When you calculate how long one oxygen molecule exists in the atmosphere, it's about six million years, which is a really long time, but it's not as long as the dinosaurs live ago. So the last dinosaur was 65 million years ago, and so the atmosphere, at least in terms of oxygen, has probably turned over 10 times since then.

MOLLY BLOOM: So yes, the oxygen atoms from the dinosaurs' time are still around, but those atoms have probably bonded to other elements by now because there are lots of different ways for an oxygen atom to react and bond. Sometimes, oxygen is friends with two hydrogen atoms.

LIBBY: That makes H2O or water.

OXYGEN 2: Hey, hydrogens. You guys want to hear a joke? Why don't scientists trust atoms?

HYDROGENS: Uh, we don't know.

OXYGEN 2: Because they make up everything.

HYDROGENS: [LAUGH]

HYDROGEN 1: Relatable content.

HYDROGEN 2: Oh, oxygen. You're so funny. Let's be friends.

MOLLY BLOOM: But other times, an oxygen atom will bond to more than one element. Calcium carbonate is a good example. That's what white chalk is made of. The formula for calcium carbonate is three oxygen atoms, one calcium atom, and one carbon atom.

LIBBY: And chalk is made of millions and millions of those little groups.

OXYGEN 3: Calcium and carbon, I think I speak for all three of us oxygens when I say, you rock!

OXYGEN 4: Yeah, you're the best friends any atom could ask for.

OXYGEN 5: Totally.

CARBON: Oh, oxygens. We love you too.

CALCIUM: Oxygen, carbon, you two are so mushy. But sure, we're friends.

MOLLY BLOOM: In the end, an oxygen atom just wants pals. It's a friendly element.

LIBBY: And oxygen likes to travel, especially when it's in the air.

MOLLY BLOOM: Which brings us back around to your question.

LIBBY: How does oxygen travel around the world? Here to help us answer that is Deanna Hence.

MOLLY BLOOM: She's an atmospheric scientist at the University of Illinois. Hi, Deanna.

DEANNA HENCE: Hi. How are you all doing today?

MOLLY BLOOM: We're great. Thank you for being here.

LIBBY: Is there a way to tell where the oxygen I'm breathing right now came from?

DEANNA HENCE: The answer to that is a bit yes and mostly no. [LAUGHS] Um, it's a little bit complicated because of a few reasons. One, I mean, oxygen comes from so many places on our planet. You know, we get oxygen from plants, we get oxygen from plankton in the oceans and algae. The wind will pick up the oxygen, mix it with all the other gases in our atmosphere, and mix it all around.

Now, what we can do and the reason why I say sort of is that we do have complex computer models that actually trace where the air goes. You know, like if you take water and you drop dye in it, and you swirl it around, you can kind of see where the dye swirls around? Well, we can effectively do something very similar in a computer model where we would place tracers into the model and then run the model either forward or backward in time to see where those tracers go.

The only thing about it is that after a certain amount of time, it becomes so well mixed with everything else that's in the atmosphere, it's hard to trace after too long.

LIBBY: How does oxygen travel around the world?

DEANNA HENCE: Well, oxygen travels around the world with all the other gases in our atmosphere with the wind. And it can get lifted up in the atmosphere through our big weather systems like thunderstorms and our big cyclones, things like that. If it gets higher up in the atmosphere, then it can race around the world with the jet stream that's really high up in our atmosphere.

LIBBY: What is the jet stream?

DEANNA HENCE: The jet stream is this river of air that's many, many miles up in the atmosphere. And it's what brings a lot of our storms to the United States. It's actually the movement of that jet stream-- if it moves north, if it moves south-- is that movement of that river of air that can really change our weather here in the United States.

LIBBY: Cool. When you were in the desert, where did most of that oxygen come from?

DEANNA HENCE: There aren't a lot of plants, right? I mean, there are some, but there's not a lot. And so we talked about, it's like, air moves around. And so a lot of that oxygen is probably coming from somewhere else. And so it's moving with the wind and those bigger air patterns that we talked about.

LIBBY: Are there places on Earth that don't have much oxygen? Like maybe the North or South Pole?

DEANNA HENCE: Well, as long as you're close to the ground, like the surface of the Earth, then you pretty much have the same amount of oxygen, except-- and this is except-- if you're going up high in altitude. So if you go up on top of a mountain, for example, that's where the air starts to get very thin. And that's because you're going higher and higher up into the atmosphere where there's less and less air actually around. So there, the air itself is thinner, so there's actually just less oxygen molecules in the air for you to breathe. And that's just because you're higher up in the atmosphere.

LIBBY: I learned a lot. Thank you.

DEANNA HENCE: Thank you all for having me. It was fun.

LIBBY: Goodbye!

[THEME MUSIC]

MOLLY BLOOM: The oxygen gas we breathe is a molecule made up of two oxygen atoms bonded together. We call it O2.

LIBBY: Early Earth got a lot of its O2 from microscopic bacteria called cyanobacteria.

MOLLY BLOOM: Those cyanobacteria used a process called photosynthesis to make O2.

LIBBY: Lots of plants, algae, and bacteria are still doing that today.

MOLLY BLOOM: Wind, weather, and the jet stream all help move oxygen around the world. That's it for this episode of *Brains On.*

LIBBY: *Brains On* is made by Sanden Totten, Marc Sanchez, and Molly Bloom.

MOLLY BLOOM: Menaka Wilhelm is our very talented fellow. We had production help this week from Jacqueline Kim, Cameron Wiley, Jason Croft, Mike [? Garth, ?] and Veronica Rodriguez. Special thanks to Danielle [? Okudah, ?] [? Misha ?] [? Youssef, ?] Jonathan [? Shifflett, ?] [? Elissa ?] Dudley, Austin Cross, Lori [INAUDIBLE], Annie Gilbertson, and Aaron Mendelsohn.

LIBBY: You can support brains on by going to brainson.org/donate. We can't do this without you, so please give.

MOLLY BLOOM: Now before we go, it's time for our*Moment of Um!*

[CHORUS OF UMS]

CARLY: Would a poisonous snake die if it bit itself?

[MUSIC PLAYING]

LAURIE AARONS: My name is Laurie Aarons. I'm a reptile keeper here at the San Diego Zoo. I primarily take care of crocodiles, large snakes, and some cool monitor lizards but working with all the reptiles here at the zoo. It's kind of a tough question to answer. There is a bit of yes and a whole lot of no. So if a snake bites itself, they do have fangs that can cause some damage. So if they happen to bite themselves in an important organ or a very sensitive area, they could make enough damage that they could die.

But generally speaking, it's not from venom. They tend to have an immunity to their own venom. It's made more specifically for capturing and eating prey or to protect themselves from predators that are trying to get a hold of them. There are some snakes out there that do, in fact, have venom, but they don't use it for eating. So things like king cobras will have really strong jaws that they use to capture their prey as opposed to envenomating.

I have myself seen venomous snakes that have bitten themselves, but they don't show any signs of envenomation or any issues afterwards. And most of the time, when we have seen snakes bite themselves, it's on accident. They're defending themselves for some reason, and they're biting at whatever is nearby. And that could potentially be themselves.

[MUSIC PLAYING]

[CHORUS OF UMS]

MOLLY BLOOM: I'm going to sink my fangs into this list. It's time for the Brains Honor Roll. These are the amazing listeners who send their questions, mystery sounds, and ideas to us.

[LISTING HONOR ROLL]

[MUSIC PLAYING]

We'll be back soon with more answers to your questions.

LIBBY: Thanks for listening.