[QUIRKY MUSIC PLAYING]

MOLLY BLOOM: Hi, *Brains On!* listeners. It's Molly.

SANDEN TOTTEN: And Sanden.

MARC SANCHEZ: And Marc!

MOLLY BLOOM: And as you know, *Brains On!* is powered by your questions, ideas, and mystery sounds. But we're also powered by your support.

SANDEN TOTTEN: *Brains On!* is listener-driven, meaning listeners-- you-- help us do what we do.

MARC SANCHEZ: And since you love the show, we're asking you to help us keep it going. Just go to BrainsOn.Org/Donate to find out how.

MOLLY BLOOM: Here are some fans who have already helped out.

GAVIN: My name is Gavin, and I'm from Portland, Oregon.

MAX: And I'm Max, Gavin's brother.

GAVIN: We donated to *Brains On!* because we really enjoy listening to it.

MAX: If *Brains On!* Is something you like too, consider giving like we did.

GAVIN: Thanks for the great program.

MAX: Yeah, thanks, *Brains On!*

SANDEN TOTTEN: We love making this show. It's our favorite job ever. And when you support the show, it totally makes our day.

MARC SANCHEZ: And to thank you, we've got some really rad gifts, like Brains On! headphones, color-changing water bottles, and a coloring book.

SANDEN TOTTEN: Oh, don't forget the cool new electric blue shirt we just had made.

MARC SANCHEZ: Oh, Sanden, I think it's more of a teal.

MOLLY BLOOM: It's kind of more like blue raspberry. Anyway, you can see it for yourself at BrainsOn.Org/Donate. Thanks for the support and--

ALL: (IN UNISON) Stay curious!

SANDEN TOTTEN: Is that weird?

MOLLY BLOOM: It's OK, we'll edit it. we'll edit it.

SANDEN TOTTEN: OK.

HABTE MARTONE: You're listening to *Brains On!,* where we're serious about being curious.

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

MOLLY BLOOM: This is the fourth episode of our series on electricity. And that means it's time for another stop at

(ECHOING) the electric games!

SPEAKER 2: Welcome back to this broadcast of the Electric Games! We've seen feats of daring, leaps of knowledge, and bracing moments of insight. But it's time to take a moment to meet one of the game's unsung heroes, Scribonius Largus, team doctor extraordinaire.

SCRIBONIUS LARGUS: Happy to be here.

SPEAKER 2: Tell us, Scribonius, what is the key to success in these games?

SCRIBONIUS LARGUS: Well, you know, it's all about drive, giving 110%.

SPEAKER 2: That's mathematically impossible! Your support of the team is inspiring, but we want to know more about you. Just who is Scribonius Largus?

SCRIBONIUS LARGUS: I don't like talking about myself, but here goes. I was the court physician of the Roman emperor, and I think I got recruited to be team doctor here thanks to a fish.

SPEAKER 2: A fish? Do tell.

SCRIBONIUS LARGUS: Well, one of my patients was having some pain, so I sent him to walk in the cool waters of the Mediterranean. It sometimes helps. Well, in doing so, he stepped on a fish. And not just any fish, a torpedo ray.

[GASP]

It sent a tingling sensation up his leg, and his pain was gone. Remarkable. I started keeping tanks of these fish in my office, and you can guess the rest. Elbow pain? Stick it in the tank. Foot pain? Stick it in the tank. Headache? That's right, dunk that whole head in there.

SPEAKER 2: Incredible.

SCRIBONIUS LARGUS: It is. And actually, electric stimulation is still used to treat pain today. You know--

THOMAS EDISON: Hey, Doc!

SPEAKER 2: How exciting. It's Thomas Edison, a competitor here at the games.

SCRIBONIUS LARGUS: Yeah, Eddie?

THOMAS EDISON: My knee is killing me after that race. Your tank free?

SCRIBONIUS LARGUS: Sure is, champ. Got to run, thanks. Great talking to you.

SPEAKER 2: No, no. Thank you, Scribonius Largus. Thank you. That's it for these Electric Games. Thanks for tuning in!

MOLLY BLOOM: You're listening to *Brains On!* From American Public Media. I'm Molly Bloom, and this is the fourth and final installment of our electricity series.

HABTE MARTONE: It's been electrifying!

MOLLY BLOOM: And that's Habte Martone, he's been my co-host for this series. Hi again, Habte.

HABTE MARTONE: Hello!

MOLLY BLOOM: During our last episode, we heard the tale of Luigi Galvani and Alessandro Volta.

HABTE MARTONE: Volta invented the battery, and changed the world.

MOLLY BLOOM: And pushed Galvani's ideas about animal electricity aside in the process.

HABTE MARTONE: But Galvani was onto something. And his nephew, Giovanni Aldini, wanted to prove it.

MOLLY BLOOM: Thanks to the invention of his uncle's rival, Alessandro Volta's battery, Giovanni Aldini traveled around doing public exhibitions of what an application of electricity could do to dead tissue. Now, this is all a little creepy, but he would take an ox head and make it stick out its tongue. Or he would take dead bodies, designated for scientific research, and make them wave to the crowd, or open their eyes, all by strategically applying charge.

HABTE MARTONE: So, while Aldini's experiments were definitely disturbing, they were also memorable and captured attention.

MOLLY BLOOM: Aldini was not the only scientist doing this sort of gruesome puppeteering, and it was these displays that partly inspired the book *Frankenstein.* And about 50 years after his Uncle Galvani's death, the technology had advanced enough that scientists could actually measure the electricity in a frog's nerve or muscles.

HABTE MARTONE: Frogs-- the real heroes of electricity research.

MOLLY BLOOM: And thanks to frogs, and many, many scientists working over many years, we know a lot about the electricity that makes our bodies work.

HABTE MARTONE: Electricity makes our hearts beat.

MOLLY BLOOM: It makes our muscles move.

HABTE MARTONE: It flows through our nerves.

MOLLY BLOOM: Which leads to this excellent question.

DORIAN: My name is Dorian. I would like to know how your brain could make electricity.

HABTE MARTONE: Right. How do our cells make electricity?

MOLLY BLOOM: Your body is made up of lots and lots of atoms.

HABTE MARTONE: And atoms are made of protons, neutrons, and electrons.

MOLLY BLOOM: Protons have positive charges, and electrons have negative charges.

HABTE MARTONE: Some atoms have a negative charge, some have a positive charge, and some are neutral.

MOLLY BLOOM: The cells in your body have more positively charged atoms outside them than they do inside them. So the inside of your cell is slightly negatively charged, and the outside is slightly positively charged.

HABTE MARTONE: And when a tiny opening, called a pore, opens in the cell--

[ELECTRICITY BUZZES]

Zap! A charge is created.

MOLLY BLOOM: This happens because the positively charged atoms and negatively charged atoms move toward each other, creating a quick change in charge.

HABTE MARTONE: And these pores open up thanks to chemical signals.

MOLLY BLOOM: So it's a little chemical-electrical chain.

HABTE MARTONE: Neurologist Jerrold Vitek explained that that's what happened with neurons, for example.

MOLLY BLOOM: Those are nerve cells.

DR. JERROLD VITEK: At the end of the neurons is what releases the chemical. That chemical flows across to the next neuron, and it causes a chemical change there that leads to electricity, and on down the line.

HABTE MARTONE: And this happened really fast.

DR. VITEK: Milliseconds.

HABTE MARTONE: There's 1,000 milliseconds in a second.

MOLLY BLOOM: So, yeah, that's fast.

DR. VITEK: But the way the body-- the way the nerve, the brain, helps to make conduction faster is by insulating the nerve. So if you take a wire, for example, that doesn't have an insulator on it, it's going to conduct slower than a wire that does. And that's called myelin. It's a fatty deposition that goes around the nerve, and it keeps it kind of snug so the electricity can't leak out, and that's how they move faster. So, some cells are faster than others.

MOLLY BLOOM: When your brain sends a signal to another part of your body, it travels down a chain of neurons.

HABTE MARTONE: And in your brain is a huge web of neurons.

MOLLY BLOOM: Electricity is important to most cells in your body.

HABTE MARTONE: But some areas use it more actively than others.

MOLLY BLOOM: Your brain and nerves are a hotbed of electrical activity.

HABTE MARTONE: And so is your heart.

MOLLY BLOOM: *Brains On!* producer Marc Sanchez is here to tell us how, and answer this question.

MATTHEW KING: Hi, my name is Matthew King. I live in Oak Point, Texas. My question is, how does your heart beat to keep you alive?

MARC SANCHEZ: You probably know the sound of a heartbeat.

[HEARTBEAT]

But what's making that sound? Your heart is made of four chambers. Two on the right, and two on the left. There's a right atrium and a left atrium. These are where the blood comes into the heart. And then, there's a right ventricle and a left ventricle. Those are where the blood leaves the heart. One of the jobs of your blood is to transport oxygen all around your body. And where does your blood get this oxygen?

The lungs. So, blood stops by the lungs and gets filled up with oxygen. It then travels from your lungs and goes to the left side of your heart. The left side of your heart then pumps it out to the rest of your body. Then, once its oxygen delivering duties are complete, the blood comes back into the right side of the heart, and gets pumped into the lungs to get some more oxygen. And this cycle keeps happening over and over and over again.

[IMITATES HEARTBEAT]

That "lub-dub" sound is the valves between the different chambers in your heart as they open and close. It's the valves' job to make sure blood is going where it's supposed to go. The first sound, that "lub," it's quieter, and is made by the valves that sit between the bottom and the top chambers on each side of the heart. The second sound, the "dub," that's coming from the valves that open to the rest of the body.

[IMITATES HEARTBEAT]

And this cycle I just described is electric.

DR. DAVID BENNETT: Well, electricity is the main driver of all components of heart, and, in fact, of all muscles everywhere in the body.

MARC SANCHEZ: Dr. David Bennett is a cardiologist at the University of Minnesota. So he knows about hearts.

DR. BENNETT: In the heart, in particular, there are special cells. These cells, that start each heartbeat, are located in the right atrium. And these particular cells are called sinus node cells, and they fire-- in healthy people-- on a regular basis.

[HEARTBEAT]

So, that set of cells then signals the rest of the heart muscle to operate in like fashion.

MARC SANCHEZ: And this electrical signal starts in one part of the heart and travels to the rest of the heart through a network of fibers.

DR. BENNETT: You'll see this net-- it's visible to the eye. If you look inside a heart chamber, you'll see a net of these lighter colored fibers. The heart muscle is a brownish-red color. But inside of these special conduction fibers which tend to be a little whitish-red. And so it's a network, kind of like a massive telephone network. And this electricity goes through to get to all parts of the heart muscle at roughly the same time. So, the whole electrical network is designed to make the mechanical contraction as efficient as possible.

[MUSIC PLAYING]

MOLLY BLOOM: OK, Habte. I know my heart is beating faster, and that's because it's time for the mystery sound.

[MYSTERIOUS MUSIC PLAYS]

SPEAKER 3: (WHISPERING) Mystery sound.

Here it is.

[MYSTERY SOUND PLAYS]

OK, any guesses?

HABTE MARTONE: I-- there's a low note and a high note.

MOLLY BLOOM: Mm-hm.

HABTE MARTONE: And it-- is it-- it can be an animal that could make very low and loud notes and very high notes.

MOLLY BLOOM: That is an--

HABTE MARTONE: I don't know.

MOLLY BLOOM: That is an excellent guess. We're going to be back with the answer in just a little bit.

[QUIRKY MUSIC PLAYING]

SANDEN TOTTEN: Did you know that some dolphins create their own names? They actually make up signature whistles that they sing, so others know it's them.

MARC SANCHEZ: That's not interesting. What is interesting is that octopuses have super intelligent limbs. Most of their neurons are in their tentacles, not in their head, so their arms can solve problems while the rest of them are doing something else.

SANDEN TOTTEN: Boring. Dolphins are so smart, they even use tools. Bottlenose dolphins put sea sponges on their noses to help them dig fish out of the sandy seafloor.

MARC SANCHEZ: Seafloor? Octopuses are the kings of the seafloor. Fossils show that they've been roaming the ocean bottom for 296 million years.

SANDEN TOTTEN: Well, they can't match a dolphin's speed. These animals can swim up to 20 miles per hour.

MARC SANCHEZ: Octopuses have actual blue blood!

MOLLY BLOOM: OK, settle, settle. As you've probably guessed, Marc and Sanden are busy prepping for our next debate.

SANDEN TOTTEN: Dolphins--

MARC SANCHEZ: Or octopuses.

MOLLY BLOOM: And they could use your help. Send either side your best arguments and facts. We'll play our favorites during the show.

SANDEN TOTTEN: And you can tweet or Instagram drawings, either side, just tag @brains_on, and go #TeamDolphin.

MARC SANCHEZ: Or if you want to be on the winning side, #TeamOctopus.

MOLLY BLOOM: We're excited to hear your thoughts on this epic debate.

HABTE MARTONE: You're listening to *Brains On!* from American Public Media. I'm Habte Arthur Martone.

MOLLY BLOOM: And I'm Molly Bloom. OK, Habte, are you ready for that mystery sound again?

HABTE MARTONE: Yep, definitely.

MOLLY BLOOM: Here it is one more time.

[MYSTERY SOUND PLAYS]

OK so these are two different sounds put together into one file, but they're made by basically the same kind of thing. So what--

HABTE MARTONE: Two different types of flies.

MOLLY BLOOM: Ooh, two different types of flies? I like that guess. Let's call a scientist to find out the answer.

[DIAL TONE]

GRACIELA UNGUEZ: OK, so, my name is Graciela Unguez, and I am a professor in the Department of Biology at New Mexico State University, here in Las Cruces, New Mexico.

MOLLY BLOOM: So, Graciela, can you tell us what did we just hear.

GRACIELA UNGUEZ: OK, so, you thought they were different types of flies, huh?

HABTE MARTONE: Yep.

GRACIELA UNGUEZ: OK, so, they're actually two different types of electric fish.

MOLLY BLOOM: So, what was that sound that we heard?

GRACIELA UNGUEZ: So, the sound was-- what I did is, I have these two completely different types of electric fish in their tank, and they're just swimming along. And I inserted an electrode into the tank that I connected to a speaker, just something that you can get at any shop. And, basically, what I was hearing was their discharge of their electric organ.

HABTE MARTONE: That is amazing. That-- I did not know that fish made sound.

GRACIELA UNGUEZ: Yes.

MOLLY BLOOM: We have a lot more questions for you about electric fish, so we are very glad you're here.

HABTE MARTONE: What are electric fish, and where do they get the electricity?

GRACIELA UNGUEZ: OK, so, first of all, let me tell you, Habte, that this is the most nervous I've ever been for an interview. I'm so used to talking to my peers, older people. But the most unexpected questions come from people your age. OK, so, what are the electric fish and where do they get electricity. So, electric fish are just like any fish, like salmon, but they are the only ones that have very, very specialized structures, sometimes in their tails, sometimes in their chest, sometimes where the stomach is. And what they are are these thousands and hundreds of tiny cells that basically produce electricity. So, all the cells together are called an electric organ. And only electric fish-- that's why they are called electric fish-- only these fish have those specialized cells, no other fish have them.

HABTE MARTONE: Nice.

[GRACIELA CHUCKLES]

Are these fish similar to electric eels?

GRACIELA UNGUEZ: Well, an electric eel, even though it's called an eel, it's actually a fish. So, the electric eel is very famous and is very popular because it generates up to 500-600 volts.

HABTE MARTONE: Whoa.

GRACIELA UNGUEZ: That's 50 to 60 times more than what your car battery generates. And so--

HABTE MARTONE: What?

GRACIELA UNGUEZ: Yes. So, it generates a lot of electrical power.

HABTE MARTONE: Why don't electric fish electrocute themselves?

GRACIELA UNGUEZ: It's a really fascinating question, and it's a really good question. Everybody wants to know, including myself. You have this electric fish, in the same tank with other fish. They're in the same water. The electric eel can generate 600 volts of electricity and it can totally immobilize a small fish. And, in fact, that's how they eat. They deliver a huge shock, and the fish, basically, becomes immobilized, and then they can eat them alive.

Now, we do know that when the electric eels deliver their shock, they actually twitch. You can actually see that they twitch. So, we know that they can feel it, but they don't kill themselves, and they don't hurt themselves. We think that because their brain, and their heart, and their more essential organs are very close together, they may be protected by, maybe, some tissues, so that they don't kill themselves. That is what most people think. There are other ideas that are out there, but we still don't know.

HABTE MARTONE: Why are some animals electric and some not?

GRACIELA UNGUEZ: Actually, one little secret is that all of us, including you, you generate electricity. It's just that it's very small, so your heart generates electricity, your brain generates electricity, your spinal cord generates electricity. The difference of these fish is that they have, in addition to that, they also have these very, very specialized cells, the electric organ that no other animal has.

HABTE MARTONE: How do animals use electricity for navigation?

GRACIELA UNGUEZ: That's one of the specialties of these electric fish. Basically, it's a field of electricity that surrounds them. So, imagine, you walking around, say, with a hula hoop, or inside a ball. That is your field, and you're walking around. If you bump into anything, that ball will get distorted, and so you know, ah, there's something there.

And it's a great way for them to navigate, because the water that they live in, they get very little light, so it's hard to see. And so, they now generate this field that, any time it's distorted, they know where things are. And they can also detect electricity from other fish, so they know if it's a live animal, or if it's a rock, or if it's a plant.

HABTE MARTONE: Can sharks sense humans from miles away with electricity?

GRACIELA UNGUEZ: So, sharks are awesome animals. And, unfortunately, we tend to be very afraid of them. But they also have these specialized receptors that we call electroreceptors, all around their skin, along the sides of their face, and down their body. So, they can detect electricity. However, they actually-- sharks-- have an amazing, acute sense of vision and smell. So, they can see up to 100 feet away, they can smell also very far. So, what we think is that, it's a combination of all their receptors that make them so good, not just their electric receptors.

MOLLY BLOOM: Fish and sharks aren't the only animals that use electricity. In fact, you can find electric animals all over the tree of life. The platypus, an egg-laying Australian mammal, has a duck-like bill that's full of electroreceptors. It swings its bill back and forth in muddy waters, sort of like a metal detector, to find prey. And the Oriental hornet actually makes its own electricity from the sun. It has specialized pigments in its stripe that convert sunlight into electrical energy, which they can then use to help them dig their nests in the ground.

HABTE MARTONE: Electricity is very important to our bodies.

MOLLY BLOOM: It sends messages through our neurons.

HABTE MARTONE: Makes our hearts beat.

MOLLY BLOOM: And our muscles move.

HABTE MARTONE: And animals have some pretty amazing electrical skills.

MOLLY BLOOM: From sensing prey from far away to defending themselves from an attack.

HABTE MARTONE: That's it for this episode of *Brains On!*

MOLLY BLOOM: And for our series on electricity.

HABTE MARTONE: *Brains On!* is produced by Marc Sanchez, Sanden Totten, and Molly Bloom.

MOLLY BLOOM: We had production help this week from Jon Lambert, Lauren Dee, and Emily Allen, and engineering help from Cameron [? Wylie, ?] Corey Schreppel, Edmundo [? Resmendes, ?] and Ryan Roberts. Many thanks to [? Racquel ?] [? Hiley, ?] Liam Martone, Robert Martone, Crystal Barber, [? Juliet ?] [? Berba, ?] [? Stephen ?] Smith, and Bob Collins.

HABTE MARTONE: *Brains On!* doesn't need turbines, wind, or battery to power the show.

MOLLY BLOOM: We are fully charged by the questions, mystery sounds, and drawings sent in by you, our listeners.

HABTE MARTONE: And because of your fabulous curiosity, we give you a little shout out.

MOLLY BLOOM: Here's the latest list to join the Brains Honor Roll.

[LISTING HONOR ROLL]

HABTE MARTONE: Thanks for listening.

[MUSIC PLAYING]

SUBJECT 2: E-L-E-C-T-R-I-C-I-T-Y. Electricity, my oh my. It's an exchange of charge from electrons you'll see. And it's a form of energy.

Static is a charge with potential. Current is a charge when it's in the flow. Batteries can take the charge on the go via electric bodies of charged animals.

Whoa. Zap. E-L-E-C-T-R-I-C-I-T-Y. Electricity, my oh my. E-L-E-C-T-R-I-C-I-T-Y.

SUBJECT 3: (SINGING) Electricity. Electricity. Electricity. Electricity.

SUBJECT 2: And atoms and electrons will leap and will fly, sharing negative charges. Hello and goodbye. Hello. Goodbye.

Hello. Goodbye. Hello. Goodbye. Hello. Goodbye.

Hello. Goodbye. Hello. Goodbye.

Hello. Goodbye. Hello. Goodbye.