Cyan: You're listening to Brains On, where we're serious about being curious.

<Brains On is supported in part by a grant from the National Science Foundation>

Molly: Cyan! Welcome to Brains On headquarters! The studio is right this way.

Cyan: I'm so excited to be here!

Molly: Ok -- so…

Marc: (yelling down hallway from a short distance) Make sure you follow the traffic signal for direction!

Molly: Traffic signal?

Marc: Yeah! I installed this new hallway traffic signal to keep things flowing smoothly at Brains On headquarters.

Cyan: Whoa. That is NOT the usual green, yellow, red traffic signal.

Marc: Good eyes, Cyan! I made a few small tweaks. Nothing too complicated.

Molly: Small tweaks? Marc -- there are now…(counting softly) TWELVE different color lights?

Marc: Well, yeah! Green means go. Red means stop. Obviously. And yellow as we know means slow down. And then blue means sit on the floor and think for a second. Orange means do cartwheels....purple means dance in a funky manner...turquoise means wave to the adoring imaginary crowd ...oh yeah, this magenta one means (hums a little) start humming...chartreuse means you should pretend to be either riding a unicorn or you are a unicorn yourself, I haven't decided which is better. And then this pink one here means...um. Oh no..what does this pink one mean? I can't possibly have too many different colored lights, can I?

Molly: No way! I like it!

Cyan: I bet pink means… give Marc a high five!

Marc: Sure! Hold on (flipping switch) pink light!

Cyan: High five Marc!

Molly: My man!

Marc: Now... (flipping switch) Purple light! Go ahead and dance yourselves to the studio!

Molly: In a funky manner!

(music plays)

Cyan: See ya, Marc!

Molly: You're listening to Brains On from American Public Media. I'm Molly Bloom and I'm here with Cyan from Victoria, British Columbia. Hi Cyan!

Cyan: Hi Molly!

Molly: This episode is a celebration of color. And Cyan, your name itself is a color! Can you describe what Cyan looks like?

Cyan: Sure. Cyan is similar to the color of the sky when it's sunny out. It's a really nice blue.

Molly: Oh, I love that description. So, how did your parents pick that name for you?

Cyan: My dad is an artist and my mom also really likes art so they picked my name because they wanted something original and kind of related to colors.

Molly: Have you met another Cyan before?

Cyan: I have never met another Cyan before.

Molly: So do you like being named after a color?

Cyan: Yeah, it's pretty cool to have a unique name.

Molly: Do you do a lot of explaining about what your name means?

Cyan: Yeah, it's funny because some people don't understand that I'm named after a color and it's funny because a lot of people don't understand how to say my name too.

Molly: What are some of the ways they say it?

Cyan: Sometimes people will be like -- see-an or kye-ann or sye-ann.

Molly: We should probably say how it's spelled. It's spelled: C Y A N.

Cyan: Yes.

Molly: So, do you have a favorite place where you see Cyan in your life?

Cyan: Sometimes just laying in the grass and just looking at the sky because it's really similar to the color cyan.

Molly: Sounds lovely. Do you have other favorite colors besides cyan?

Cyan: I really like the color lavender. It's like a light purple. It's just really calming and nice.

Molly: So this episode was inspired by one particular question that we found super fascinating.

Maximilian: My name is from Maximillian. I come from Germany. And my question is: why is green the go color?

Molly: That is a great question!

Cyan: Yeah! Like, why isn't it purple? Or orange?

Molly: As we were researching and working on answering this question we found fascinating stories about other colors too! We don't have time to delve into every color in this one episode, so we're focusing on three:

Cyan: Red, blue, and of course green.

Molly: Why these three? You might have heard about primary colors — the colors you can mix together to get other colors.

Cyan: Those are red, yellow, and blue, when you're thinking of paint.

Molly: But red, green and blue are a different kind of primary color — if you have light from these three shades -- red, green and blue -- you can mix them together to get all the colors of light.

Cyan: In fact, TVs and phones and computers all use red, green and blue to make all the images you see on a screen.

Molly: Right. So we're going to dig into these three very important colors.

Cyan: But first, we have to make a pitstop to answer this question:

Finn: Hi Brains On, my name is Finn and my question is how does everything get its color?

Molly: Well, let us illuminate you. Color starts with light.

Cyan: The main source of light in our galaxy is -- our friend and yours -- THE SUN!

Molly: Our pal the sun beams out light we can see.

Cyan: That's called visible light. It's what colors our world.

Molly: And this visible light has a range of energy levels in it -- we see these different energy levels as different colors.

Cyan: So when light hits something, some of these specific energies of light are reflected. Those are the colors we see.

Molly: Other energies of light get absorbed by the object. So we don't see those colors. So when you see a bright orange salamander, for example, it means that light in that orange color range is bouncing off of your amphibian pal. And reaching your eyes -- making you see it as orange.

Cyan: The salamander's skin absorbs the other colors of light, so you don't see those colors.

Molly: If you stop to think about it this is a mind blowing fact: sunlight and the white light from lightbulbs -- actually contain all the colors at once! <SFX Kaboom>

Cyan: All the colors are shining down all the time, but you only see certain ones when they get bounced back to the cells in your eyes.

Molly: More on those cells in a second, but first, Cyan, are you ready to bounce around some ideas about the ...mystery sound!

Cyan: Yes.

Molly: Here it is.

<<sound>>

Molly: Ok, Cyan, what is your guess?

Cyan: There's like a beeping and it also sounded like it was raining.

Molly: Interesting. So, any thoughts about what could possibly be beeping and some kind of rain sound?

Cyan: Uh...I don't know.

Molly: Ok, well, we're going to give you another chance to hear it and guess again a little later in the show.

<Stinger: Brains On!>

Molly: Another big piece of how color works is our eyeball machinery. Brains On producer Menaka Wilhelm is here to tell us more about that.

Menaka: Hi Molly, Hi Cyan! I talked to a physicist named Pupa Gilbert about this. And, Cyan, she's actually one of your fans!

<Pupa: My very favorite color is cyan, or turquoise as I call it.>

Menaka: Besides telling me how much she likes the color behind your name, she helped sketch out how we see all the colors. Which, prepare yourselves, is going to take us to the very back of the eyeball, or the retina. Molly, do you have the zoom ray ready?

Molly: Ready.

<SFX zoom>

Cyan: To the retinaaaaa! <zoom zoom zoom zoom>

Molly: Wow, there's a whole tiny world back here.

Cyan: < faded background jazz >There's even a jazz club!

Menaka: Yeah, we're headed there soon actually! But first, the lay of the land. When light bounces off things in the world, and into your eyeballs, cells back here notice that light, and send messages to your brain.

<Pupa: So these are specific type of brain cells that are sensitive to light.>

Menaka: We have a couple different kinds of these cells. There are rod cells and cone cells. Rod cells help us see in low light situations -- they're basically black-and-white vision. Cone cells on the other hand, they sense colors. These are the ones we're talking about today. And get this: There are just three different kinds of cone cells that help us see the whole entire rainbow.

<Pupa: So we see color through three different types of cones that are, for simplicity, called the red, green and blue cones in the back of our eye.>

Menaka: Our eyes have millions of these cone cells, and each one is either a red cone, a blue cone, or a green cone.

Molly: So, with just those three types of cones -- the red, the green and the blue -- we can see all the colors?

Menaka: Exactly. They actually help you see other colors too - like yellow, and purple, and orange.

Cyan: How does that work?

Menaka: Well, to explain it, let's step into that jazz club you mentioned.<SFX door open to full sound jazz> you can think of the three cones as a little like a Jazz trio.

Long Red: <piano> Looooooong Red, here on the keys! Reds get my jets goin'!

Mezzo Greeno: <saxophone> And, Mezzo Greeno is my name, this saxophone is my game! that's mezzo like middle, since I'm into greens — the inbetweens of the rainbow!

Blue shorty: <bass> Plucking this bass, Blue Shorty here — blues hit me right in my feels!

Cyan: So those are cone cells?

Menaka: Yep. We sometimes call these the red, green and blue cones, but each cone really senses a whole range of colors.

<Pupa: It's not as if the red cones are only sensitive to red light, they're actually sensitive to a very broad range. >

Menaka: That's important, because there are a lot of colors to see!

Mezzo Greeno: Sure are! This rainbow trio wants you to see them all!

Long Red: So when the light hits us, we <piano> play the brain a tune describing what we see.

Blue Shorty: <bass comes in on top of piano> Your brain makes our beautiful signals into your mental picture of the world!

Menaka: Since each cone signals for a range of colors, you can think of Long Red, that red cone, playing reds and oranges and yellows and even some greens. So most colors set off more than one cone at once.

Blue Shorty: Right, we're just not that big on solos.

Menaka: When two cones respond to the same color, their signals will be at different levels. For this trio, you can think about different cones playing together, but at a different volume.

Blue shorty: When you're looking at a deep purple plum, I play nice and loud <loud bass> — 'cause remember, I don't just play blues — also purples, too!

Long Red: And I join in, <quiet piano> hit a couple of notes, quietly, — even though that might surprise you! I may be Long Red, but I sense some purple light as well.

Mezzo Greeno: So do I -- even though my forte is green. But I just pick up a little purple, so it's just, like, a quiet, little ditty. <quiet saxophone>

Menaka: So that purple plum is a mix of signals from each cone! Same with orange, even though none of these cones ever get called orange cones.

Blue shorty: Orange cones belong on the road, directing traffic! Not in the eye. We handle orange just fine on our own.

Long Red: Like, say you're looking at an orange cat, I play the loudest <loud piano>, Mezzo Greeno backs me up <medium saxophone>, and Blue Shorty keeps his volume real low <very low bass>

Menaka: These different signals from all three cones are almost a little code. The brain can decode it, and each translation becomes a color you see! <jazz sting finale> And these multi-talented cones sound just great.

<music and applause>

Menaka: It seems like this jazz trio is taking a break. Molly, can you zoom us out to our normal sizes.

Molly: Absolutely!

<zoom zoom zoom zoom>

Menaka: Alright! Nice shrinky dinking with you all, but I've got to scoot — see you soon!

Cyan: Thanks Menaka!

Menaka: Anytime! Bye!

<STING: Brains On!>

Molly: Now that we've explored how we see colors -- let's get to know those three main ones a little better — red, blue, and green.

Cyan: And red is up first!

Molly: We thought red would be a good place to start -- because it's a powerful color that can stir up a lot of feelings.

Cyan: Which is something Brains On listeners have wondered about.

<My name is Inya and I live in Houston, Texas and my question is: Why are certain colors associated with certain moods or emotions?
<Hi my name is Viola, I'm nine years old and my question is Why do people like certain colors?>
<My name is Zoey from Manheim, Pennsylvania and I want to know: Do different colors affect how we feel?>

Kassia: So this is a really interesting one. There are essentially a few different reasons why colors can really affect people.

Cyan: That's Kassia St. Clair.

Molly: She's a writer and color expert, who wrote the book, "The Secret Lives of Color."

Kassia: Some of it is cultural. For example, in the West, if you think of royalty -- and you are asked to associate a color with royalty, most people will often say purple. And that is, in part because in the ancient world, there was a very expensive purple dye that was actually made from sea snails that was purple and was reserved almost exclusively for royalty.

Molly: Oh, your royal cape is so divine.

Cyan: Why thank you, it's made from the finest sea snails.

Kassia: But if you would ask someone in China what color they associated with royalty, they would most likely say yellow because in China, a yellow dye was reserved for royalty.

Molly: Kassia told us that colors can have personal associations too.

Cyan: For example, if your bedroom is painted green, and you do fun stuff in there… read stories, play with toys,listen to podcasts...You might associate the color green with feeling happy.

Molly: And green might bring on the same feelings as you get older, even if you have a new room in a different color.

Cyan: But we're here to talk about red.

Molly: Right! Cyan - when you think of red, what comes to mind?

Cyan: I think of red fruit adn vegetables like apples and strawberries and then I think of dragons.

Molly: I like that. Well, Kassia says that throughout history, people have been interested in red.

Kassia: Red has always had this really important place in human culture. It's very often associated with burials, you very often find red pigments or red-dyed cloth in graves, all over the world, from China to South America, to Europe. In ancient Egypt, there's a God of the afterlife, who's also known by the name, “Lord of the Red Cloth,” and very often in Egyptian burials mummies were often found with cloth that had been dyed red with a pigment, or colorant, called hematite.

Cyan: Hematite is a pigment that comes from iron in the earth. It can be used as a dye or paint.

Molly: You’ve probably seen that red-orange color a rusty nail has when it’s been left outside. If you took that nail and wiped it on your shirt, then you’d basically be doing the same thing as the ancient Egyptians.

Cyan: Kassia says that people found other natural ways to make red too.

Kassi: You also get red dyes, that is that are produced by insects, believe it or not. Tiny, tiny insects that are so small that they almost look like grains of rice. But when you squish them they produce a very powerful read colorant and this is called cochineal. The best types of cochineal come from South and Central America and are in fact still used today as a food coloring and as a coloring in cosmetics.

Molly: Nobody can really say why people have been drawn to red for so long, but its popularity is clear. Even to this day.

Kassia: it seems to be near universal that red has a power over us tha tcan be seen throughout all cultures and over a vast range of time. And so it's very difficult to tell because we do have all these personal feelings, and it's very difficult to untangle what colors mean to us. But there's no denying that color has the power to influence our mood and to make us feel happy or sad or to remember certain people or friends and in that way, color has a real power over us and is incredibly important in our lives, even if we don't always know exactly why.

<music>

Molly: Clearly colors can inspire a lot of feelings -- but they can inspire other things too.

Cyan: Like superheroes!

Molly: Aw yeah. We asked you to dream up a color hero for this episode -- and you sent us some super-creative ideas.

<music>

<Hi, my name is Ellie and I am from Fulsom, California. My color superhero is Super Silver. She can give silver to people in need.
Hello my name is Max from Basel, Switzerland. My color superhero would be Aqua Ninja. He can control water and stand on water.
Hi Brains On, my name is Matthew and I am from New Westminster, BC. My superhero's name is Mr Planto and he is the color green. He can fight pollution and grow any plants in the world. And his sidekick's name is Planty. He can destroy pollution or anything he wants and he can make a plant wall. Thank you!
My name is Tupelo. I am from Minneapolis, Minnesota. My superhero's name is Rainbow Star. Her powers are she can shoot rainbows from her hands and she spreads lots of color all around the world.>

Molly: We've got more color heroes coming up.

Cyan: Plus - we're diving into deep blue and gorgeous green -- right after this.

<MUSIC>

Molly: Do you have a mystery sound you want to share with us?

Cyan: A question you want answered on the show?

Molly: Or maybe a drawing of your fabulous color superhero?

Cyan: Send those all to us at brains on dot org slash contact.

Molly: That's what this listener did.

<<My name is Gabe from Brighton, Michigan. My question is: Why are bees black and yellow?>>

Cyan: We'll be back with the answer to that question at the end of the show…

Molly: That's our Moment of Um…

Cyan: And we'll have the most recent group of listeners to be added to the Brains Honor Roll.

Molly: We also want to hear from you for an episode we're working on right now about tiny robots. We want to know -- if you could invent a tiny robot, what would it do and what noise would it make? My tiny robot would vacuum up pollen before it could get to my nose. And it would sound like this: <<noises>> Share your tiny robot jobs and noises with us at brains on dot org slash contact. Can't wait to hear from you.

<Hi Brains On, my name is Andrew and I live in New Westminster, BC, Canada. My color superhero is red and he is called Oxygenist. His superpower is he breathes in carbon dioxide and breathes out oxygen. I gave him this superpower because he will stop climate change and global warming.
Hi, I'm Summer and my color superhero's color is blue. It's name is Sea Blue and its superpowers are to control the sea.
Hi Brains On, my name is Jack from San Antonio, Texas and my color superhero is Red Fire. He shoots fire out of his eyes.
Hi, my name is Amir and I am a 10 year old from Zionsville, Indiana. My color inspired superhero is named Purple Petite. Her superpower is that she can squeeze through tiny spaces. She lives in Color Kingdom and her enemies are the Jasper Junkfood Bandits. They try to convince Color Kingdom into only eating junk food. Dun dun dun!>

Molly: You're listening to Brains On from American Public Media. I'm Molly.

Kid: And I'm Cyan

Ruby: And I'm Ruby.

Molly: Hey it's our friend Ruby Guthrie! She's here with a story about blue.

Ruby: Hi Molly! Hi Cyan! So far, we've talked a lot about how we see colors and what different colors mean. But have you ever wondered how you make a color?

Cyan: I have a rough idea. Usually I think of paint and just mixing the primary colors together.

Molly: Yeah, you can create so many colors that way. Listeners Jonah and Kayla also had some colorful questions.

<Hi, my name is Kayla and I live in Davis, California. Hi, I'm Jonah from Ventura, California. My question is: how do people make color? How are colors created?>

Ruby: Great questions. I was curious too. So I talked to Mas Subramanian, he's a chemistry professor at Oregon State University. About 10 years ago, Mas created a color in his lab-- but it happened all by accident.

<music>

Ruby: One day Mas was in his lab, and he was mixing different chemicals, trying to create a new material for computers. He told his grad student to mix three compounds containing three elements: yttrium, that's white, indium, which is yellow, and manganese, that's black. They took these materials and heated them up in a super hot oven. This way all the elements could mix together to form a new compound-- kinda like when you bake a cake! But when they took it out, they were shocked.

Mas: I noticed that they came out stunningly blue, which I did not expect. Now imagine my surprise because I started with materials that were white, yellow and black in color. And out came this brilliant blue.

Ruby: Mas named it YInMn Blue, after the three elements yttrium, indium, and manganese. Now YInMn Blue isn't a new color per se, but rather a new blue pigment. A pigment is usually a powder, that you use to add color to other things -- like paint, ink, or cloth.

And civilizations have struggled for centuries trying to make blue pigments -- mostly because it's such rare color. There aren't many things that are naturally blue, and if you try to create blue with chemistry, it can be tricky to get it right.

For example, in the Renaissance period, painters used ultramarine, a pigment made from the gemstone lapis lazuli. Ultramarine was ultra expensive because not only was it made from a rare material, but it also took weeks to extract the color. Since this took so much work, sometimes ultramarine cost more than gold!

So when Mas realized he made such a vivid blue, he put his computer work on hold to look more into his new discovery.

Mas: Immediately I recognized these components may have potential to be useful as blue pigment as they are very stable and no change in color when exposed to very high temperatures.

Ruby: Mas just said that this blue is really stable. That means it doesn't change much when it comes in contact with things like heat, water, or even acid. That makes it super tough and long-lasting, which is great for painting things like cars and buildings.

It's so cool--literally! Not only is blue a cool toned color, but YInMn blue actually deflects heat, meaning heat bounces off of it. So it stays cool even if it's exposed to really hot temperatures.

Mas: So if you coat a building or a car with YinMn blue, it can keep the building cooler or the car cooler during summertime. So otherwise we call this as a cool pigment. So that makes it very special because no other blue pigment actually deflects heat.

Ruby: Now that's chilling in a freezer with sunglasses kind of cool! And to think -- it all started with an accident!

Mas: Most of the amazing discoveries come by accident. Not everything can be predicted, not everything can be discovered by planning. I tell my students don't think too much. Just do it in the lab and you may well create something interesting, actually.

Ruby: Mas is totally right. A lot of times I think we think of accidents as bad things, but they can

actually be a really good chance for us to learn and explore. And his accident is leading to even more exploring. Mas is now trying to make a red pigment that's as stable as YInMn Blue. So keep experimenting! You never know what you might discover.

Molly: Thanks Ruby!

Ruby: Thank you! And I'm off to the kitchen -- I'm really craving some blueberries.

Molly: Alright Cyan, are you ready to hear the Mystery Sound one more time?

Cyan: Yes.

Molly: Ok, here it is.

<sound>

Molly: Ok, any new thoughts?

Cyan: Maybe a car backing up in the rain?

Molly: Oh good thought. Sometime when car's back up they make that beeping sound? Excellent thought. Well, we're going to hear it again and this time there's a hint in the sound.

<sound>

Molly: Ok, what do you think now that you heard that more complete sound?

Cyan: Huh. Maybe a plane landing?

Molly: Oh yeah. Because I heard the word California in there.

Cyan: Yeah.

Molly: That's an excellent guest. Well, that is the sound of a signal at a crosswalk!

Cyan: Oh!

Molly: You know sometimes they have those voices that talk to you while you're waiting for the crosswalk?

Cyan: Yeah.

Molly: At some traffic intersections, the signals beep one way to tell you to wait, and change to a different beep when it's time to go. And that brings us back to that very important color question:

<Why is Green the Go Color?>

Molly: We asked our resident plant lover and general green-thing enthusiast -- Sanden Totten to look into this.

Sanden: Oh I love talking about green. Did you know George Washington loved the color? He called it “grateful to the eye!” And studies suggest just looking at green boosts your creativity. And right -- one of its most important roles is being the “go” color. But why? I asked historian Megan Kate Nelson to weigh in.

<Megan: The green for go and the red for stop came from the railroad industry>

Sanden: Turns out, stoplight inventors picked green since it worked so well for trains! But get this. Originally, for trains, white was the go color! What?! I know. Check it out.

This was before lights ran on electricity. Back then, you didn’t flick a switch, or press a button to turn on a light -- oh no. You lit a match to light a lamp! Lamps were basically teeny tiny fires in a container — picture a metal cylinder, with a light from a fire shining through a glass window. That’s a lamp.

Megan Kate Nelson — our historian friend — says back then, train stations lit a plain white lamp to mean go. To mean stop, they covered the same lantern with a red glass cover.

<Megan: They ran into some problems when they were using white as go, because sometimes the red glass would break and then it would be all white. >

Sanden: Oof, yeah. Mixing up stop and go — Very bad news.

<Megan: They changed it to green. So that you had a very clear difference.>

Sanden: That way, if the green glass broke — which happened from time to time -- conductors would know something was up! Because the light was white -- not green or red. But wait, so why did railroads pick green for go? Why not purple or blue? Well it seems like railroads chose it because factories used it!

<Megan: The very first factories that created all kinds of different objects had really big machines and you know, you could tell that they were on or off from the noise, but you also flipped a switch to turn them on, and that switch was often green. >

Sanden: It’s hard to find an explanation for why green was used in early factories. My friends, it’s a secret lost to the green mists of time. But maybe it was because green things rule! These factory people could’ve been inspired by green ferns! Or green emeralds! Probably not green boogers, but maybe green parakeets? or green algae? Or grasshoppers? Ooh, praying

mantises. Four-leaf clovers, three-leaf clovers, five-leaf clovers, green mold on bread. Probably not green mold on bread. Ninja turtles... <more and more green as fades down>

<THEME>

Molly: Colors happen because of bouncing light.

Cyan: The light that bounces off of something is the color you see.

Molly: Eyes take in colors with special cells called cone cells.

Cyan: Then the brain builds a picture of what the world looks like.

Molly: Red has been used as a powerful symbol in many cultures throughout history.

Cyan: People associate different colors with different feelings depending on where they might have first experienced that color.

Molly: Blue was once a really rare color pigment -- but scientists are finding new ways to create it!

Cyan: Green first started to mean Go in factories, then railroads, and eventually stop lights.

Molly: That's it for this episode of Brains On!

Cyan: It was produced by Menaka Wilhelm, Marc Sanchez, Sanden Totten and Molly Bloom.

Molly: We had production help from Sabby Robinson, Ruby Guthrie and Kristina Lopez.
And engineering help from John Miller. Special thanks to Ladena Racine, Olivia Kuzio, Luke Burbank, Andrew Walsh, Rosie Dupont, and Libby Denkmann.

Cyan: Now, before we go, it's time for our Moment of Ummmmmmm.

<My question is why are bees black and yellow?

Dan: There's a fancy term for that. It's called aposematic coloration. And what that does that is it tells predators not to eat it. My name is Dan Cariveau. In MN I'm an assistant professor of entomology. Entomology by the way is the study of insects and I look at native bees. So when we think of bees we can think of things like a honeybee but in reality there are 20,000 or more species of bees on earth and so we kind of study those other bees. If you think about it, the black and the yellow -- they're very high contrast in color. So you have this very dark black and then a very bright yellow. And what that does it makes it very easy to see opposed to something that might be green and drab. What that does is it helps tell predators that in fact this is something you don't want to eat, you don't want to touch, that very bright coloration. There are a

number of other animals that do this. Things like coral snakes or poison arrow frogs. There are butterflies that are poisonous that all look alike. And that helps predators realize they shouldn't eat them. As I mentioned, there are 20,000 species of bees on earth and actually most of them are not yellow and black. We have all different colors of bees. There are greens, and blues and all sorts of browns and blacks so go ahead and look at all the different species that are out there. It's fascinating.>

Molly: Brains On will be back soon with more answers to your questions.

Cyan: Thanks for listening!