Small things can have a big impact.

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Quick hits on diverse discoveries powered by magnets.

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With a little imagination, these high-field data look like high art.

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Scientists have been chasing superconductivity for more than a century. It’s the ideal form of electricity, a state in which electrons travel through a material with perfect efficiency. The more materials that researchers discover with this amazing property and the better they understand how they work, the closer we come to a long dreamed of superconducting revolution that could dramatically lower energy costs worldwide and liberate us from fossil fuels.

Physicist Nick Butch of the National Institute of Standards and Technology has been studying one such material: uranium ditelluride or UTe₂. Last fall, in papers published in Science and Nature Physics, Butch and his colleagues revealed intriguing and promising properties of UTe₂.

“This is a very recently discovered superconductor with a host of other unconventional behaviors,” said Butch. “There’s something different going on in there.”

In Science they reported that UTe₂’s superconductivity involved an unusual electron configuration called spin triplets, in which pairs of electrons are aligned in the same direction. Eager to dig deeper, Butch brought UTe₂ to the National High Magnetic Field Laboratory, where he pushed it even further.

Generally, magnetic fields are an enemy of superconductivity: When strong enough, they bust apart the electron pairs that are responsible for superconductivity. At the MagLab, the team tested UTe₂ in gradually stronger fields to see at which point the magnet would crush superconductivity. They also adjusted the angle at which the UTe₂ crystals were positioned vis-à-vis the direction of magnetic field.

In addition to the superconductivity they had previously observed at lower fields, the team observed that higher fields did indeed kill that superconductivity. But as the researchers ramped the field even higher while continuing to fiddle with angles, they found that a different orientation of the crystal to the field yielded yet another superconducting phase, one that persisted to at least 65 teslas, the maximum field tested. It was a record-busting performance for a superconductor and an unprecedented finding: the first time two field-induced superconducting phases have been found in the same compound. Instead of killing superconductivity, high fields appeared to stabilize it.

While it’s not yet clear exactly what is happening at the atomic level, Butch said the evidence points to a phenomenon fundamentally different than anything scientists have seen to date. Said Butch, “It is sufficiently different, I think, to expect it will take a while to figure out what’s going on.” — KC

Malisa Sarntinoranont is a mechanical engineer at the University of Florida (UF), so you might be surprised to learn that one of her recent research trips took her deep into the center of the brain.

MRI images of the perivascular networks in the brains of four rats. Vessels with perivascular spaces (PVS) that appear to be common in different rats are highlighted using colored arrows.

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“There’s a big physiological question about what is the role of the ventricles,” said Sarntinoranont, an associate professor in UF’s Department of Mechanical & Aerospace Engineering. “Why do you have these big fluid spaces in your head?”

Some scientists suspect they play a role in flushing waste out of the brain, and Sarntinoranont and her research team, using powerful magnetic resonance imaging (MRI) magnets, are mapping out that system in amazing detail.

It’s an important topic. The lymphatic system, which removes bacteria, damaged cells and other waste from the body, doesn’t extend to the brain. So, the brain must use some other tool to stay fresh and clean. Some scientists believe the malfunction of that tool may play a role in diseases like Alzheimer’s and type 2 diabetes.

To better understand what happens under our skulls, Sarntinoranont’s team injected a tracer, a compound that would show up clearly in an MRI scan, into the ventricles of rodents. Then, one cross-section at a time, they meticulously scanned the brains to see where the tracer flowed, accumulating hundreds of two-dimensional images.

Each of these scans showed countless pathways crisscrossing the brain. The pathways are the peri-vascular space, or PVS, which are tubelike spaces that surround some of the brain’s blood vessels, like a straw around a pipe cleaner.

Although scientists knew about the PVS network, they had never seen it in the detail revealed by the 17.6-tesla* magnet used by the team, located at the National High Magnetic Field Laboratory’s UF branch. And the scientists are now translating that data into something truly extraordinary: a three-dimensional map that will show how all these pathways interconnect throughout the brain. Sarntinoranont said that map should be completed by the end of the year.

“Think of it as spaghetti,” she said. “There’s a lot of spaghetti in there that we have to connect.”

The group’s work sheds new light on the PVS puzzle because it delves deeper than the brain’s better-understood surface, revealing links between the ventricles and the PVS.

“One of the beautiful things about MRI is it gives you the ability to look at interior structures,” Sarntinoranont said.

There is still plenty to learn — exactly what fluids are transported and in what direction, for example. Sarntinoranont said the completed 3D map will help her develop computational fluid dynamic models of the brain that could predict flow patterns and waste clearance.

In the meantime, she enjoys watching the 3D map come together.

“It’s like, ‘Oh my goodness, there is so much hidden information in these scans,’” she said. “It’s really gratifying.”

Also contributing to this research were UF graduate students Julian Rey and Kalman Magdorom and Tom Mareci, associate director of the MagLab’s Advanced Magnetic Resonance Imaging and Spectroscopy Facility at UF. — KC

Scientists from Urban Mining Company (UMC) recently visited the National High Magnetic Field Laboratory to test samples of the neodymium iron boride magnets (also referred to as NdFeB, or neo magnets) that they manufacture at their facility near Austin using magnets recovered from recycled electronic devices.

Why recycle old magnets? There’s a high demand and low supply for neodymium, a rare earth element that, when mixed with iron and boron, makes a strongly magnetic alloy used in everything from hard-disk drives to electric motors to smartphone speakers. Most of the world’s neodymium is mined in China, and the extraction process takes a toll on the environment.

So UMC harvests neo magnets from obsolete products, grinds them up, and uses the powder to make new neo magnets, according to their own special recipe.

How do their products stack up? It depends, explained Miha Zakotnik, chief technology officer and chief operating officer of UMC, which was cited as a company to watch by Fortune magazine’s “2019 Change the World List.”

“When we start to become interesting is motor applications,” such as cars and planes, Zakotnik said. “Those environments are up to 240 degrees Celsius (464 degrees Fahrenheit).”

Another type of rare earth magnet, samarium cobalt, has historically been used in high-temperature environments. But neo magnets are stronger, so if they could be engineered to take the heat, they could offer higher performance.

Zakotnik knew that, in conditions such as high heat, UMC’s recycled magnets performed better than both used and new neo magnets. But he needed to understand why, in part by better understanding magnetic properties like remanence (the magnetization left behind after an external magnetic field is removed) and coercivity (the material’s ability to withstand an external magnetic field without becoming demagnetized).

Although Zakotnik had studied his products using special microscopes, he had never tried putting his little permanent magnets inside big electromagnets.

“In order to do this characterization of materials, you must have access to something like this,” Zakotnik said of the MagLab, where he used a 16-tesla* magnet to make his measurements.

“Magnets are engineered products,” Zakotnik said. “Each of them is unique, tailored for the application. It’s a very complex thing to make.”

Scientists in Japan hold the world record for neo magnets in terms of the work they can do (measured in kilojoule per cubic meter), explained Zakotnik. But that is just one measure of performance: Those magnets don’t necessarily perform well in high-heat environments, a niche that UMC is targeting with its special manufacturing process. — KC

* A tesla is a unit of magnetic field strength.

When most people think of magnets, they think of the cute vacation mementos that secure lists and pics to a fridge. This leads to the first misconception tour guides at magnet labs tackle when showing the public around their facilities: Research magnets aren’t like those small, permanent magnets. Rather, they’re enormous electromagnets made of entirely different materials that generate a very high field when you pump lots of current through them.

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A team tackling some gnarly physics using tricky techniques rounds a critical corner. Joy ensues. Then, back to work.

By Kristen Coyne

**THE INCREDIBLE LIGHTNESS OF LITHIUM**

Deemyad is everything you want in a captain. She’s smart, enthusiastic and super positive. An associate professor of physics at the University of Utah, she’s a former recipient of the prestigious National Science Foundation Early Career Award. She specializes in high-pressure physics, and specializes even further in the element lithium.

Used widely in everything from batteries to medicine, lithium is highly reactive and has to be stored in mineral oil to prevent it from interacting with neighboring atoms and molecules. It’s also the third lightest element on the periodic table.

This story is about one such mini milestone. One of those little triumphs that motivates you to keep trudging down the grueling, boring stretches. It’s not a eureka moment, not even an “Aha!” moment. It’s more like a “Phew!” moment, a reassurance you’re slogging up the right path. It’s just enough to keep you keeping on.

If you’re picturing a lone scientist schlepping valiantly uphill, imagine this instead: A whole squad of them. Science is, after all, a team sport. Every good team has a captain, and the one in this story is no exception. Meet Shanti Deemyad, captain of Team Lithium.

**THE BIG SQUEEZE**

The more you compress, the more you can discover. In her own lab, Deemyad is able to put samples under pressures as high as what exists at Earth’s core. But working under pressure while in high magnetic fields is a very different challenge. For that, Deemyad needs to come to the MagLab, which has the expertise and equipment for those experiments. MagLab scientists have developed tiny, specialized pressure cells that tolerate high magnetic fields and fit into the small space inside the magnets; they have also developed sophisticated techniques to measure the signals they are looking for under those extreme conditions.

“It would not be feasible to develop those techniques myself,” Deemyad says.

With a team comprising her students, MagLab specialists and a theory group led by Neil Ashcroft and Roald Hoffmann of Cornell University, Deemyad has been experimenting on lithium at the MagLab for more than five years. They have labored through the science grunt work, gradually reaching higher pressures in the challenging environment of a high-field magnet. Last year, the group hit a mini milestone, successfully creating pressures of 1 gigapascal (GPa) and observing promising data. (As a comparison, 0.5 GPa is the pressure at 5,000 meters below the sea.) It wasn’t the holy grail. It wasn’t science Shangri-La. But it was an affirmation they were on the right track and enough to earn them access to a stronger MagLab magnet for future experiments.

**THE AMAZING DISAPPEARING SAMPLE**

So, one of the great things about lithium, from a science perspective, is it’s light. But one of the worst things about lithium, from a technical perspective, is… well, that it’s light.

Lithium has caused Audrey Grockowiak no end of grief. Grockowiak is a physicist in the research group of Stan Tzotz at the National MagLab, which specializes in high-pressure physics. That means she spends a lot of time at the microscope designing, building and loading tiny pressure cells, which compress samples between two diamonds. It’s a tricky technique with the easiest of samples. Finagling lithium in a pressure cell, however, is exceptionally vexing.

“You try to put this in your pressure cell and — pffft — there it goes. It floats away,” Grockowiak says. “It’s really a pain.” And that’s just one hurdle. The team has also struggled with how to distribute the pressure from the two diamond tips evenly around the entire lithium sample, which is very soft at high pressures. They tried coating the sample in mineral oil but, after months of trial and error, the team still wasn’t sure that was the right technique.

If exposed to air, lithium degrades within seconds and its nice, metallic shine turns dark and dull. So while cutting the sample to the right size (just 40 microns thick, roughly the width of a human hair), Grockowiak had to keep it in oil on the microscope slide, then transfer it into the pressure cell as fast as possible.

“Those samples are the most challenging I’ve had to work with,” Grockowiak says.

Physicist William Coniglio faced his own challenges on the experiments. His job was to connect Grockowiak’s tiny pressure cell to another teensy device (called a tunnel diode oscillator) so they could run electricity through the lithium and measure the resistance.

“Sometimes you get lucky and you have a really good day, and sometimes you get unlucky and things are misbehaving,” explains Coniglio. “And then sometimes, even if you are having a good day, the sample decides how good it is. There are all these factors that are out of your control.”

**Get real.** Scientists get precious few of those. Most of the time, they’re wading through the salty, smelly perspiration that makes up 99% of what they do.

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**THE “PHEW” MOMENT**

A team tackling some gnarly physics using tricky techniques rounds a critical corner. Joy ensues. Then, back to work.

By Kristen Coyne

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Shanti Deemyad has been experimenting on lithium for many years.

(after hydrogen and helium) and (under normal conditions) the lightest of all the solids and metals.

That’s what draws Deemyad to lithium. For someone interested in probing the subatomic realm, the lighter the element, the better. Lighter, Deemyad explains, means more quantum: As you subject atoms of light elements to weird experimental conditions, they are more likely to do curious things, like transform into a different phase of matter or quantum state.

“In stuff that is very light, each particle behaves more like a wave,” Deemyad explains. “Everything is more unstable.”

Deemyad, petite and with a ready smile, wants to make lithium even more unstable to unlock more quantum magic. So she compresses it. Pressurizing materials is one trick scientists use to tease out interesting behaviors like superconductivity — 100% efficient electricity in which current-carrying electrons encounter zero friction.

Under pressure, Deemyad says, “Everything starts changing. The homogeneity of everything goes away.”

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WHAT ARE ELECTRONS TRYING TO TELL US?

All of which begs the question: Why go to all that trouble?

Team Captain Deemyad knows: In science as in sports, no pain, no gain.

Imagine an astronomer obsessed with the idea of life on other planets. She spends countless nights at the observatory operating her telescope, endless days mining the data for the good bits, hoping for a signal from deep in the universe, something whispering, “Yoo-hoo! Over here!”

Deemyad is straining to hear little signals, too, but hers are from electrons in lithium — the lightest subatomic particles in one of the lightest atoms. These signals are called quantum oscillations, which are wavelike undulations measured in the electrical resistance of the electrons. Scientists use them to generate a kind of map of the material known as the Fermi surface, which can only be measured using high magnetic fields. The Fermi surface is a kind of Rosetta Stone for the material, just waiting to be decoded, containing a motherlode of information about how its active electrons behave and interact.

“Seeing the quantum oscillations gives us a lot of information about both the electronic and crystal structures of lithium that is otherwise hard to understand,” Deemyad said.

Ultimately, physicists like Deemyad are looking for the underlying principles behind the behaviors they create in extreme conditions, knowledge that could one day help scientists design new materials for the underlying principles behind the behaviors they create in extreme conditions, knowledge that could one day help scientists design new materials that exhibit those same behaviors under the normal conditions in which we all live.

A BAD WEEK ENDS ON A HIGH-FIELD NOTE

Typically, scientists who come to the MagLab use a magnet for a week. After inserting their small sample into the middle of the magnet coil, they tweak different parameters — the magnetic field, pressure and temperature around their sample — then compare how it behaves under varying conditions.

One Friday evening in February, Tushar Bhowmick, a graduate student in Deemyad’s group, was at the end of an exhausting week at the MagLab. Because Deemyad had other obligations, Bhowmick was working without his advisor, alongside the MagLab team. Earlier that week, they had had some successes — they got a pressure cell to operate at 1.7 GPa, and observed quantum oscillations — as well as some setbacks. One day they struggled with a bad pressure cell, ending their shift with nothing to show for it. Then a freak storm closed all of Florida State University, where the MagLab is headquartered: Another day with no data.

Late that Friday, in his last hours with the magnet, Bhowmick was analyzing the most recent data from a lithium sample under a whopping 2.8 GPa of pressure in magnetic fields of 33 to 35 teslas. He finally saw what may have been the signal they’d been waiting for — a peak in the data that suggested quantum oscillations. But he needed to try again: Some extraneous information, called noise, made the data unclear. So he asked for another 33-to-35 tesla run, hoping for a stronger signal.

And he got it: Not only did he see another peak, but it was much more distinct than the previous one.

“I saw a very clear peak, and I realized we have quantum oscillations,” Bhowmick says. “That was an enormous joy for me.”

Bhowmick threw his arms up in victory; Grockowiak captured his elation on her cell phone.

She was beaming too.

Small Things Can Have a Big Impact

Small things add up. As you’ll read in the stories on the following pages, that goes for the good as well as the bad.

This spring marks the 50th anniversary of Earth Day. In honor of that semicentennial, we’ve created a special section in this issue that highlights how high magnetic fields are tackling environmental challenges.

These challenges involve very small things, including PFAS (turn the page for our story on these so-called “forever chemicals”) and potentially poisonous petroleum molecules found in asphalt roads (p. 20). Though tiny, these compounds are found far and wide, from the North Pole to your driveway. High-field magnets are shedding light on many other environmental issues, too, including better batteries and solar cells, more efficient conductors, microplastics, fracking fluids, climate change and more.

In the face of all these problems, one person can feel powerless. But even small acts adds up. Take inspiration from the scientists we interviewed (p. 16) who work hard every day to make the planet better — on their off time. As scientists, they feel a special call to make a difference, and they challenge each of us to step up in whatever ways we can.

So, Happy Earth Day. Whether you’re a scientist at an office, a lab or at heart, we hope these stories spur you to help our planet, in ways big and small, on April 22 — and on every other day of the year.

Can you find the trash lurking in the beauty of this issue’s cover? Go to fieldsmagazine.org/cover to find out.

* A tesla is a unit of magnetic field strength.
‘Til Death Do They Part?

By Bennett McIntosh

Some manmade chemicals feature bonds so strong they could last forever. And that’s a life-threatening problem.

As she relaxed at home one Saturday in late 2016, Nasim Pica didn’t expect the National Geographic documentary she decided to watch to end up redirecting her research. “I was just browsing,” she recalls, taking a break from finishing her Ph.D. in environmental engineering at Colorado State University (CSU). When the documentary turned its focus to polar bears, however, Pica, who studies water contamination, learned something alarmingly relevant to her work: Scientists had found long-lasting, toxic chemicals in the blood of the largest bears on Earth, despite the fact that they lived so far from where those chemicals are made or used.

Following the trail of PFAS (per- and polyfluoroalkyl substances) would lead Pica to the National High Magnetic Field Laboratory (National MagLab), whose powerful instruments help scientists like her understand the environmental threat PFAS pose.

“I started looking at the [scientific] literature,” on PFAS, Pica recalls, “and I learned nearly all humans have them in their blood plasma too.” The chemicals are attracting increased attention as more scientists find them in drinking water and cow’s milk and as government officials struggle to understand and address the compounds. “Dark Waters,” a 2019 film about the chemicals starring Mark Ruffalo, also drew widespread scrutiny to the issue.

PFAS are a diverse family of molecules, all of which have many fluorine atoms (thus “Pfluoridated” or “Polyfluoridated,” accounting for the “PF” in the acronym) attached to a string of carbon atoms called an alkyl chain (thus “Alkylated Substances,” the “AS”). The fluorine-carbon (FC) bond is exceptionally strong, making these molecules useful for engineering slick surfaces, from nonstick pans to pizza boxes and compostable food containers. And since the molecules disrupt water’s surface tension, helping it foam up, they’re a common component of firefighting foams, which smoother burning surfaces more effectively than water alone. But the strength of the FC bond means very little can break PFAS down, earning them the foreboding moniker, “forever chemicals.”

PFAS enter groundwater or the ocean from many sources, including chemical plants, firefighting training on military bases and consumer disposables. It may take a while for humans or other animals to ingest them, but...
The fluorine-carbon bond in PFAS molecules are exceptionally strong, keeping the manmade molecule from breaking down.

![Diagram of fluorine-carbon bond](image)

forever chemicals can last, well, forever. As they build up in and interact with our bodies, they can, according to studies, cause immune problems, birth defects and cancer.

As Pica read up on PFAS, she decided she needed to do something about them. So after completing her Ph.D., she joined forces with environmental engineers Jens Blotevogel at CSU and Shaily Mahendra at the University of California, Los Angeles, to find ways of removing or destroying PFAS from firefighting foam in water and soil.

The team members wouldn’t be able to tell if their treatments worked, however, without knowing which specific PFAS were in their samples in the first place. Two such compounds, called PFOS and PFOA, are particularly well known, but firefighting foams contain many other compounds, both PFAS and otherwise. Understanding these complex mixtures is where the MagLab comes in.

The lab’s headquarters houses several special instruments called mass spectrometers. Molecules have different masses, depending on their chemical formulas, and mass spectrometers help scientists identify which chemicals are in their sample by breaking them into fragments and weighing the pieces. But where a scale might use Earth’s gravity to measure mass in pounds and ounces, mass spectrometers use powerful electric and magnetic fields to distinguish individual molecules, which weigh in at less than a trillionth of a trillionth of an ounce.

The type of tools at the MagLab, called ion cyclotron resonance (ICR) mass spectrometers, are particularly good at analyzing molecules of very similar mass, since they excel both at resolving the difference between similarly massed compounds and accurately measuring their actual mass. Inside these instruments is a magnet and, the more powerful the magnet, the better the machine’s resolving power and mass accuracy.

Working with MagLab scientists Amy McKenna and Huan Chen, Pica measured her samples on a 9.4-tesla* spectrometer. The output looks like a jagged mountain range, with peaks representing differently massed fragments of different molecules. Pica’s samples are extraordinarily complex mixtures, containing not just PFAS but other additives to the foam and contaminants from the environment. “The first time Amy sent me the list,” she recalls, “there were over 20,000 peaks.”

Normally this wouldn’t be a problem for the ICR machine, which has software to automatically label all of the different peaks in a mixture. After all, the facility routinely analyzes the makeup of petroleum samples containing tens of thousands of different kinds of molecules. But PFAS, explains Chen, “are a newly recognized contaminant, so the detection and characterization methods are not fully developed yet.” The instrument’s software could match the peaks with many other molecules in Pica’s samples, but not PFAS. So she would have to write the software to do that herself.

“I had no coding experience,” recalls Pica. “But I really wanted to look at the data, so I had to learn to do it myself.” As Pica wrote the software (using an open access tool called UltraMassExplorer) and supplied the samples, Chen and McKenna helped run the experiments and interpret the data. It took about six months, but in the spring of 2018, Pica finally had software that could look at the ICR data and identify which PFAS lie within.

“Identifying which of these compounds filter through the soil into groundwater, and how treatment affects them, is the first step to dealing with them,” says Pica, now an environmental engineer with a Wisconsin construction firm. Now that scientists can tell which compounds are in a sample, Blotevogel and his team will be better able to test new techniques for treating water and remediating contaminated soil. Blotevogel, McKenna and Pica are also working on a new project, tracing the origin of PFAS found in the environment, whether from firefighting foam or something else.

Identifying which of these compounds is where the MagLab comes in. Pica was unsurprised to find many PFAS besides the notorious two — PFOA and PFOS — in her samples. “Industry is moving away from using these two,” she says, because of their well-studied danger. However, instead of replacing PFAS entirely, companies are switching to other fluorine-carbon molecules whose effects on health and the environment are still poorly understood.

“PFAS is a problem, but it’s not the problem. The problem is the human demand for a quick answer rather than a sustainable solution.”

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* A tesla is a unit of magnetic field strength.

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Environmental engineer Nasim Pica (left) and National MagLab chemist Huan Chen prepare samples.
Scientists Get Down to Earth on Climate Change

Researchers talk about what they’re doing outside the lab to protect our planet and how their training as scientists informs those efforts.

MUNIR HUMAYUN

Humayun is a professor in the Department of Earth, Ocean, and Atmospheric Science at Florida State University in Tallahassee, Florida, and a researcher at the National High Magnetic Field Laboratory. Although his expertise is meteorites, he’s passionate about doing what he can personally and professionally to tackle climate change.

When did you first become interested in climate change?
Probably in the 1970s, worrying about the fate of the world. And definitely in the 1980s — as a graduate student — I was exposed to a lot of discussion on climate change. Back then it was a problem for the future. Now, the future has arrived.

How have you adapted your lifestyle in response to climate change?
Improvements to home energy efficiency allow my home to operate at half the energy usage it had prior to the modifications, and about half the electricity other homes in my neighborhood use. Increased energy efficiency allows me to power my home entirely on a solar photovoltaic system. I drive an electric vehicle, and our other car is a hybrid (for longer trips than an EV allows currently). We recycle and compost, as well, to curb our carbon footprint.

Are there other ways you are active in fighting climate change?
On scientific and technical matters, I advise a coalition of environmental groups (Tally 100% Together) working to implement the resolution adopted by the Tallahassee City Commission in 2019 to go to 100% renewable energy by 2050. I would like to see the city lead the nation in the energy transition that must happen if we are to avert the worst effects of future climate change. This transition has to be made from the global level to the individual level by the adoption of electric vehicles, biofuels and renewable sources of electricity production. I do my part at each level possible.

I also teach a popular course at Florida State on energy and climate that examines the thorny issues that come along with extracting fossil fuels, including their ultimate disposal. I hope that my students carry that message farther than I can alone.

In what ways does being a scientist affect your personal response to climate change?
Being an Earth scientist provides a front-row view of climate change and a sense of responsibility that I cannot delegate this task to someone else to find a solution. It also provides the tools with which to assess how to make the transition away from our acute dependence on fossil fuels. As a species, we burned our way out of the ice ages by that great invention, fire. In the past century, we have perfected the age-old burning of carbon as a means of powering every facet of society. We’ve mastered the delivery of fossil fuels from the Earth at a rate limited only by society’s capacity for consumption. My task as a scientist is to help the human species kick the carbon-burning habit and to stop kicking the proverbial (climate) can down the road.
BENCE BERNAH

Bernath is a Ph.D. student in physics at the High Field Magnet Lab in Nijmegen, the Netherlands. A native of Hungary, he does research on free electron laser-based terahertz spectroscopy in high magnetic fields.

When did you first become interested in climate change?
Due to my education, I have been aware of the problem since childhood. But the conscious interest came during my time at university.

How have you adapted your lifestyle in response to climate change?
I try to avoid flying. If there is a work-related trip I can’t avoid, only then do I use airplanes. For commuting I use a bike; for longer trips I use public transportation. I try to have a lifestyle that does not require a car. I buy local vegetables and fruits and generally avoid buying anything with plastic packaging. I use my clothes until I cannot wear them anymore, and generally avoid wasting money on things I don’t really need. As an endurance athlete, I try to be as minimalist as possible: I run in “barefoot shoes” made from recycled materials and attend sponsor- and plastic-free competitions to avoid more rubbish, gadgets and other pointless items.

Are there other ways you are active in fighting climate change?
I financially support movements for which the aim is to decrease the human effect on climate. And of course I do not hide my opinion on this.

In what ways does being a scientist affect your personal response to climate change?
I believe that recent climate change has been induced by us. More scientists say that the changing climate is caused by us and only a few oppose this idea. My scientific mind says the following: We have to bet on climate change. If it is a hoax and we act, the worst that happens is we spend a lot of money for cleaner air and less plastic in the ocean. If it is not a hoax, and we do not act, we will be terminated. But if we do act, we save the air, the oceans and ourselves. So it is better to act because there is a measurable advantage for everyone.

ZELJKA POPOVIC

Popovic is a graduate research assistant at the National High Magnetic Field Laboratory and a student in the Department of Chemistry and Biochemistry at Florida State University. When not working on ion cyclotron resonance experiments and recycling stuff, she advances diversity in science, technology, engineering and math (STEM) as president of Graduate Women in STEM at Florida State.

When did you first become interested in climate change?
Funny enough, I really became interested in climate change when I found out that there are people who don’t believe in climate change.

How have you adapted your lifestyle in response to climate change?
Since my day-to-day schedule stays pretty busy, I don’t necessarily have the time to be on the forefront of climate change reform. So, to “do my part,” I have slowly made simple changes in my routine such as: understanding what to recycle and how; using reusable bags when possible; cutting down on meat intake; eating more locally sourced food; and making sure to buy products that are sourced in an environmentally friendly way.

People have this notion that they need to live a plastic-free life completely to make a difference, so they abandon the thought of such a lifestyle because, in today’s world, it’s nearly impossible to go completely plastic-free. But really, what we need to be doing is making a conscious effort to replace everyday plastics with more sustainable/eco-friendly containers. These small changes play a vital role in combating climate change.

Are there other ways you are active in fighting climate change?
I think a big part of fighting climate change is educating more and more people about the simple changes. I am always making sure to share the simple changes I have made with the people in my life.

In what ways does being a scientist affect your personal response to climate change?
I think being a scientist has taught me how to go about reading various climate change publications and studies in a more critical way than a non-scientist. This makes it easier to decipher facts from statements made with no scientific backing.

Visit fieldsmagazine.org/downtoearth to see how CERN scientist Chris Segal fights climate change.
Poison in the Pavement

By KRISTEN COYNE

A deeper understanding of petroleum molecules is shedding a harsh light on how some of them behave in our environment.

Like a lot of commuting parents, chemist Ryan Rodgers drops his kids off at school before heading to work, in his case to the National High Magnetic Field Laboratory. Toting lunches, backpacks and water bottles, his two girls climb into their Tundra and buckle up for the short ride to campus. Behind the family’s banter, the group Twenty One Pilots sings a nostalgic ode to a more innocent era.

“Wish we could turn back time, to the good ol’ days…”

At school, Rodgers gives his daughters a pair of high-fives before heading west across Tallahassee to work. It’s an easy, 8-mile trip – free of the gridlock many commuters endure. Still, Rodgers knows something most of those drivers don’t: Those smooth, asphalt roads that make his morning commute such a breeze may not be so safe after all.

Rodgers has built a career on studying petroleum, the most chemically complex substance on the planet. Using world-leading magnets and instrumentation, he helps oil companies better understand the molecular makeup of the stuff they pump out of the ground and researches the effects of oil spills.

So as Rodgers sips coffee at the wheel of his truck, he understands better than most that he’s driving on a petroleum product. Although the road is made mostly of stones, sand and gravel, something needs to glue it all together.

That something is a crude oil derivative called asphalt binder (or asphalt cement), a heavy, black, sticky goo made from the bottom-of-the-barrel stuff at the tail end of the distillation process.

By mass, binder makes up only about 5% of a road. But that adds up when you consider the vast surfaces it covers: hundreds of lane miles in Tallahassee alone, 274,000 across Florida, 8.5 million in the U.S. and many millions more crisscrossing the rest of the planet. And all that binder has Rodgers pretty worried.

A few years ago, he and his research group started studying a specific class of molecules found in petroleum called asphaltenes, which are particularly abundant in heavier crude oil distillates. At first, the scientists sought to shed light on the molecules’ structure, which they believed had been misunderstood. As their research progressed, they considered how those structures affected the molecules’ behavior. Through a series of experiments and publications and with a growing sense of urgency, they have slowly built a case that has not only important scientific significance but also far-reaching economic, environmental and health implications.

In addition to being chemically complex, petroleum is exceptionally useful; we have tapped it to run our cars, heat our homes and create countless consumer goods – from...
plastic dishwasher to candles. Given their complexity and ubiquity, it’s not surprising that petroleum-based products once thought harmless later turned out to be toxic. From benzene (used in many industrial processes) to naphthalene (found in mothballs) to, according to some studies, BPA-containing plastics and microplastics, some petroleum derivatives can indeed be hazardous to your health.

According to the National Asphalt Pavement Association, the U.S. alone produces about 400 million tons of asphalt pavement material a year, worth more than $30 billion. The work Rodgers and his team have been doing raises serious questions over every last square inch of it.

To understand something as seemingly simple as a paved street, though, requires a detour toward the anything-but-simple, and surprisingly controversial, molecular structure of its asphaltene-rich binder. And because this is science, after all, this road features a few twists, turns and delays as researchers follow their way through the twists and turns of the scientific method.

**Questioning accepted wisdom**

When scientists first began analyzing asphaltenes in the 1960s, the consensus was that they were made up of a central core of carbon atoms — petroleum coke — with the occasional hydrocarbon side chain (made up of hydrogen and carbon) poking out. When heated, those chains crack off, leaving behind an extremely stable, insoluble core that is not terribly useful. In fact, asphaltenes are often the bane of refineries, where they tend to build up in process areas, making it hard to get the heavy crude oil processed.

According to this so-called “island” molecular model, asphaltenes are a poor source of fuel, offering no energy-rich molecular bonds to break. Due to their high boiling point, they were also thought to have a high molecular weight. Indeed, measurements from that era suggested that crude oil contained some relatively light molecules (gasoline, for example) and some heavy ones (asphaltenes), but few species in between. That data supported the theory that asphaltenes were mostly heavy clumps of interconnected carbon rings.

By the 1980s, however, some scientists began to doubt this model. These skeptics included Canadian scientists studying heavy crude oil samples from northern Alberta known as Athabasca bitumen, or oil sands. Although these samples were known to contain a relatively high percentage of asphaltenes, they were yielding more fuel than the island model would predict for an asphaltene-rich crude.

The study of asphaltenes was becoming increasingly relevant because sources of easy-to-refine “light” crude oil, which flows easily and contains relatively few asphaltenes, were drying up. More and more, petroleum companies were left with the “heavier,” viscous crudes that contained higher percentages of asphaltenes.

Some industry scientists were also questioning the island model, said Murray Gray, a professor emeritus of chemical engineering at the University of Alberta who has worked with Canadian oil refiners. Their first-hand experience successfully refining heavier crudes suggested that the scientists focusing strictly on experimental measurements were missing something.

“When chemical engineers look at a refinery or processing plant, we are keenly aware that mass in has to equal mass out,” Gray said. “So, the chemical engineering experience was that you put the bitumen material containing lots of asphaltenes into processing plants and you got a range of material coming out. That just did not fit at all with this very simple picture of asphaltenes ... it was clear that the actual structures of the asphaltenes were much more complicated and diverse.”

Proponents of this model included chemist Mieczysław Boduszynski of Chevron Energy Technology Company, who challenged the idea that petroleum molecules could only be either “light” or “heavy.” Rather, he argued that their masses spanned the entire continuum in between, and molecules that boil off at higher temperatures in the distillation process aren’t all heavy. The higher boiling point constituents, he proposed, also tend to contain more oxygen, sulfur and nitrogen. These atoms promote stronger associations between molecules, resulting in the higher boiling point. At the time, the technology did not yet exist to confirm his ideas. But if they were true, they would explain how asphaltenes might include not just island structures, but lighter-weight archipelago species as well.

Still, some scientists held fast to the island-only view. After all, it aligned more closely with both the computational models of the time as well as with the data coming out of the instruments used to analyze complex mixtures.

Instrumentation, however, was advancing, and Rodgers was right in the thick of it. In the 1990s, under National MagLab chemist Alan Marshall, Rodgers began building an ion cyclotron resonance (ICR) mass spectrometer capable of analyzing compounds as complex as petroleum, eventually positioning Marshall’s group as leaders in the nascent field of petroleomics. Mass spectrometers are essentially fancy scales for molecules that use a strong magnetic field in a substance by its unique mass. Developing ICR magnets that could decode petroleum samples containing tens of thousands of different kinds of molecules was a formidable feat.

As Rodgers’ expertise in petroleum and instrumentation grew, so did his doubts about the island-only view of asphaltenes. In 2016, he hired Martha Chacón-Patiño, a postdoctoral fellow from Colombia who had studied asphaltenes in graduate school. With other members of the ICR team, they set about to rewrite the book on asphaltene through a series of experiments and articles designed to chip away at the island-only model and expose the true structure and behavior of these complex compounds.

On the surface, Rodgers and Chacón-Patiño are a study in opposites. A petite brunette, she is as polite as Rodgers is gruff, her speech as meticulous as his is freewheeling. When replying in the affirmative, Rodgers blurts a brusque “Yeah,” while Chacón-Patiño patiently nods along to her drawn-out “Yeeeessss.” Yet they share a certain inscrutability, perhaps due to having to defend their work against skeptics.

The MagLab’s effort to fully decode asphaltenes had three critical things going for it. First, an exceptionally powerful and accurate instrumentation for petroleomics research. Second, access to excellent asphaltene samples: one from Wyoming known to be rich in island structures, the other from Alberta believed to be rich in archipelago structures. Last but by no means least, Rodgers said, was the team’s expertise, in particular the talents of his postdoc. Roasted Rodgers, “We have Martha.”
Lesson #1: Don’t ionize all the molecules at once. Before you can weigh a molecule in a mass spectrometer, you need to give it a positive or negative charge (ionize it) so that the magnet can detect it. The MagLab team learned that when you ionize all the molecules from an asphaltene sample at once, the island structures ionize more efficiently than the archipelago; as a result, the archipelagos remain all but invisible to the magnet.

The solution? Divide and conquer. Chacón-Patiño separated the molecules into batches by solubility, then ionized and measured them separately. “That helped us to reduce the complexity,” she explained.

Lesson #2: To understand a picture, you sometimes need to break it. After properly ionizing the molecules and before weighing them with the magnet, Chacón-Patiño zapped them with lasers, mimicking the heat of the refining process and breaking off some of the side chains.

After fragmenting the Wyoming molecules and weighing the results, Chacón-Patiño saw just what she had expected to see: some heavy molecules representing large coke cores survived on one end of the mass spectrum.

By contrast, the Athabasca molecules, when broken down, weighed in along a much wider spectrum of masses, reflecting a variety of smaller coke cores that pointed to an archipelago structure. “It’s like a puzzle,” marveled Chacón-Patiño as she sketched the contrasting spectra.

Lesson #3: To see wee differences in weight, you need a darn good scale. Molecules are weighed in units called daltons. A water molecule, for example, weighs about 18 daltons. Petroleum is so complex that it contains hundreds of different kinds of molecules just within the span of a single dalton. The high-resolution ICR machines at the National MagLab allow scientists to detect each one of them; less sophisticated instrumentation, Chacón-Patiño said, reveals only a few dozen. So if you use the wrong machine, she said, “You will have the wrong answer.”

Up against decades of conventional wisdom, prevailing paradigms and entrenched interests, the MagLab group plotted a strategy: Conduct meticulous research, write up the findings, then lay it all out, one publication at a time. In 2017 they published the first in a series of articles called, “Advances in Asphaltene Petroeomics.” Since then three more have followed, and the final paper in the series is due out this year.

Gray was among the academics who quickly embraced the archipelago model, calling the MagLab work “transformative.”

“I regard that paper as a major breakthrough because, for the first time, it started to show the full range of chemical structure, demonstrating what we knew all along,” said Gray. “What Ryan and Martha are showing is really how you can be misled by artifacts and incomplete analysis.”

Other scientists also took notice, and more research on the topic began appearing in the literature. Scientific talks, including one at a symposium honoring Chevron’s Boduszynski at the 2017 American Chemical Society’s national meeting, generated more buzz. One of Rodgers’ prized professional mementoes, in fact, is a 1994 textbook on petroleum by Boduszynski, signed by the author. The inscription reads, “Thanks for proving me right.”

Cloudy water, clear message
Archipelago asphaltenes include more oxygen, sulfur and nitrogen atoms than are found in island asphaltenes. These heteroatoms, as chemists call them, make the molecules more likely to interact with other asphaltenes and with their environment, a tendency with potentially far-reaching consequences.

To learn more about how they react, the MagLab team conducted a fairly simple experiment designed to mimic an oil spill. Chacón-Patiño and graduate student Sydney Niles filled two beakers with artificial sea water. On one they placed a film of Wyoming asphaltene (with mostly archipelago asphaltenes). Then they exposed them to light.

On the second a film of Athabasca bitumen (with mostly island asphaltenes) were mostly island); on the second a film of Athabasca bitumen (with mostly archipelago asphaltenes). They then exposed them to light to simulate what happens to petroleum when
So photooxidation caused the island asphaltene to stick together and form the tar that sank to the bottom; the molecules didn’t dissolve. But photooxidation transformed the more reactive archipelago asphaltenes into new species that did dissolve in the water.

The results were exactly what Rodgers expected. Nonetheless, the sight of the dramatically different beakers took him aback. “Science is rarely, rarely that clear,” he said. “That’s because we have been so methodical,” chimed in Chacón-Patiño, “so we have the results that we have right now.”

It’s a potent illustration of how one strong image can cut straight to the point. Forget the fancy spectrometer: “You can use your own eyes as the detector,” Rodgers said. “I mean — come on!”

Avoiding a road to ruin

The logical next step was one that Rodgers had dreamed of for years: to run the same experiment using samples of asphalt binder. The results were similar to those obtained with the archipelago-heavy crude oil samples from the previous experiment: murky water into which some of the binder had clearly dissolved.

It adds up, said Rodgers. “You see the brand new asphalt roads go down and they’re smooth as silk on top. And then you look at one that’s 5 years, 10 years old, and you can see the [stone] aggregate. And you’re like, ‘Where the hell did all the cement go?’ And, we now know that it is most likely being photo-converted into water-soluble species. And when it rains, they go out,” into the surrounding environment.

The “they” could be quite a lot of things, some potentially toxic, as certain other petroleum-based products have proven to be. According to studies, soils near paved roads exhibit higher concentrations of polycyclic aromatic hydrocarbons (PAHs), which can be carcinogenic.

“You shine some light on asphalt binder and you get water-soluble species,” Rodgers continued. “And not five or six of them: There are tens of thousands of elemental compositions. Each one of those can have [hundreds of thousands of] different structures. So you’re just puking ungodly amounts of material that is aromatic. And it’s water soluble, and it has every structure that you can possibly think of. So the idea that one of them is bad for you is probably pretty good.”

The results are a vindication of sorts for the researchers, albeit a somber one.

“It’s a cool experiment, but it’s a sad result.”

Meanwhile, holding down the fort back in Utah, Deemyad wasn’t expecting good news. Because they had struggled with the pressure medium so long, she suspected it might be time to throw in that towel and try a different one — probably helium. That would take them back to square one in technique development.

Deemyad was following the experiment closely when she suddenly got a text from Grockowiak: It read, “QO at 28.5 kbar” (translation: quantum oscillations at 28.5 kilobars). She attached the photo of Bhowmick.

“I couldn’t believe it,” Deemyad says. “I was just super excited.”

“These results are not only exciting on their own, but they are also proof of principle that we can do way more,” Deemyad continues. “The door opened up to doing a whole new level of experiment.”

The success gave Deemyad confidence that her team will be able to get data from lithium up to 20 GPa. At those pressures, she says, they will be able to observe how electrons behave just before they transition into a superconducting state.

As those results gain acceptance, scientists, industry officials and policy makers will have to face how to deal with them. Could they break linkages between archipelago asphaltenes before using them in binder and other products, and would that even help? Should asphaltenes be banned from certain uses altogether, and is that even feasible?

Rodgers and his team will continue to probe these questions, but finding and implementing answers will almost certainly be passed on to scientists of his daughters’ generation. For now, at least, they have the hope that these new methods they’ve created will advance them much farther down the road toward better answers on asphaltenes.

CONTINUED FROM PAGE 10

“Phew!”

The Wyoming sample after the oil spill experiment.

Data from Deemyad’s lithium experiments. The purple peak shows the team’s most recent results: quantum oscillations at 28.5 GPa’s of pressure.

“Being able to get here changes the whole story,” Deemyad says.

And that’s where this particular story ends … at least until the next “Phew!” moment.

Other scientists contributing to this research include Stanimir Bonev from Lawrence Livermore National Laboratory and Sabri Elatresh from Cornell.
"We just kind of sit around and talk about science," said McKenna. Since its inception, the coffee hour has spread to the rest of Florida State University, where MagLab headquarters is based, and is now formally titled the FSU Women Faculty in STEM Network. Some meetings highlight resources or events, or focus on faculty development topics like proposal writing.

“It’s a space for women to have conversation without fear of judgment,” McKenna said. “We’ve found that women are more inclined to speak up and talk about their issues.”

Talking seems to be key. Though trained as a biologist, Shirley Malcom has spent most of her career at the policy level attempting to diversify science education and considers herself a “Jill of all trades related to diversity.” She currently serves as the senior advisor at the American Association for the Advancement of Science (AAAS) and the director of STEM Equity Achievement Change, or SEA Change, an AAAS initiative that supports institutional diversity, equity and inclusion in STEM.

“I’m not just a woman, I’m a woman of color,” she said. “So I get hit with multiple stuff. Being able to talk through things is just much better for my mental health. You need people who can help you gain perspective.”

Her science friends follow up the talk with action. The day her mother died, for example, Malcom called a friend and colleague for comfort; the woman agreed to give an important presentation in Malcom’s place.

Laura Greene, another highly accomplished member of the scientific community, also credits her friendships with getting her where she is today.

“Friendships are especially important for underrepresented groups because it makes you feel that you’re not alone,” Thirunavukkuarasu said. “It always helps to see that others have similar struggles, especially someone senior to you who is successful in spite of them.”

By connecting over shared experiences of marginalization, women in science can motivate each other to continue down their chosen career paths, despite the bumps.

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Thirunavukkuarasu isn’t the only woman scientist singing the praises of co-worker companionship.

While science’s gender gap is closing, women are still underrepresented in many science, technology, engineering and mathematics (STEM) fields, particularly physics. A 2019 report from the American Institute of Physics (AIP) found that, compared to men, women report slower career progression, fewer career resources and opportunities, and are more likely to make compromises, such as working less or quitting due to family reasons. Additionally, half of women working STEM jobs said they experienced gender-based workplace discrimination in a 2018 Pew Research Center report.

“Friends Indeed”

When physicist Komalavalli “Komu” Thirunavukkuarasu had a baby a few years back, a lengthy maternity leave wasn’t an option. As her family’s primary breadwinner, she had to return to work ASAP as a postdoctoral researcher studying the behavior of materials at the National High Magnetic Field Laboratory (National MagLab). She also felt like she couldn’t take time off due to the unforgiving nature of academia.

“It’s not yet very common that if you lose a few years due to personal reasons you can get back on track,” she said. “I was struggling to balance my job as a postdoc and as a mom.”

Her colleagues began to pitch in, babysitting while she finished meetings or bringing her food.

“The help I received from friends was life-changing,” said Thirunavukkuarasu, who is now a visiting research associate at the National MagLab and an assistant professor of physics at Florida A&M University in Tallahassee. “I owe most of my success to my friendships with colleagues.”

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“I owe most of my success to my friendships with colleagues.”

“All you need sometimes is someone else to say, ‘That happened to me too.’ It’s validation. It gives me goosebumps just thinking about it,” said Amy McKenna, a chemist at the National MagLab. After realizing how crucial friendship is to herself and other women scientists, she and a few colleagues created a group for women at the MagLab a year and a half ago. Since then, 15 to 20 faculty members have converged regularly over coffee.

“We just kind of sit around and talk about science,” said McKenna. Since its inception, the coffee hour has spread to the rest of Florida State University, where MagLab headquarters is based, and is now formally titled the FSU Women Faculty in STEM Network. Some meetings highlight resources or events, or focus on faculty development topics like proposal writing.

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“Friendships have been vital, it’s been crucial, it’s been life-saving,” said Greene, the MagLab’s chief scientist and the Krafft Professor of Physics at FSU, who studies quantum materials.
One young scientist benefiting from these structures is Nastaren Abad, a former research assistant at the MagLab who used magnetic resonance imaging to shed light on migraines. When she came to FSU in 2014 from Pakistan, she joined a living-learning community for female freshmen that seeks to increase retention of women in STEM by creating a supportive environment, which includes fostering relationships among students.

"Some of my main friendships have been from the women I met there," said Abad, who found the community especially supportive as an international student.

Abad, who recently completed a Ph.D. in biomedical engineering and started a new job at General Electric, is paying forward the help she’s received by informing others about gender discrimination and other biases. At the annual meeting of the International Society for Magnetic Resonance in Medicine last year, Abad and other young scientists in her lab group organized a session titled “Overcoming Bias.” After a panel discussion on unconscious and conscious bias in academia, attendees played games to identify their hidden biases.

“Overall I’m feeling really optimistic," Abad said, “because there’s more awareness and talking about everything.”

More awareness could lead to a more diverse body of scientists, which studies suggest can increase creativity and productivity of research teams.

“I think that across-the-board diversity in science is the key to making the next great breakthrough for issues that affect everyone, like antibiotic resistance and global climate change,” McKenna said.

Until then, Malcom suggests women stick together.

“Find each other. Support each other,” she said. “Together we can try to change the attitudes and the practices and the policies that disadvantage women and girls in science.”

Spectrum Analysis

In the first year of this new decade, we asked researchers about their most memorable first-time experiences as scientists. Here’s what they had to say.

Yawen Fang
Graduate student in the group of Brad Ramshaw, Cornell University

Last year I spent a week at the National MagLab to use the 41-tesla* resistive magnet to measure quantum oscillations on thin-film Sr2RuO4. I was both excited and very anxious — not only because I would be the first official user of this world-record magnet, but also because this would be my first time ever working alone at the MagLab. Before the week started, I prepared for potential difficulties and came up with a detailed plan, because both time and power for the magnet would be very limited. My experience went a lot more smoothly than I ever expected, thanks to the amazing user support team. This will be one of the most unforgettable experiences in my early career, because it gave me some ideas of how to prepare for an experiment at the magnet lab — which could happen a lot in my future career — as well as how to work with the user support team, communicate with other researchers and develop new ideas.

When I was 9 years old, during a family vacation, my father and I visited the National Bureau of Standards (now the National Institute of Standards and Technology, or NIST) in Boulder, Colorado. My father wanted to see the atomic clock that set the world time standard. We walked into the lobby and asked if someone could show us the clock. We were soon met by one of the scientists responsible for it, who happily gave us a tour and explained how it worked. I don’t remember much, but I do remember thinking how cool it would be to do something like that one day.

* A tesla is a unit of magnetic field strength.
I grew up in India, where the education system is completely different from the system in the United States. In our system, a lot of importance is placed on mathematics and sciences from early childhood. But the knowledge we gather is either from the textbooks we are assigned or from our teachers. We don’t have labs or field trips where you can apply what you learned.

Lucky for me, I had a great science teacher who was willing to go the extra mile. He often showed up to class with equipment that he bought with his own money or borrowed from friends in nearby universities. When I was in the ninth grade, he bought us a circuit board and components such as resistors, capacitors and inductors to look at. That was my first ever interaction with science in the real world. I realized that just seeing what the components looked like was not enough: I wanted to know how it all worked. I believe this was the moment when I decided I wanted to be an electronics engineer. And here I am doing what I always wanted to do and loving every minute of it.

Matthew Rowles
Facility leader, X-Ray Diffraction and Scattering, John de Laeter Centre, Curtin University

One of my more memorable firsts was the first paper I wrote as a postdoc. I came up with a nice geometrical solution to some issues I was having, and my supervisor suggested that I write up a short communication. When we next met after giving him my draft, the first thing he said was, “This is pretty good.” There wasn’t a single paragraph that didn’t have at least half a dozen corrections, alterations or suggestions. My first thought was, “I’d hate to see what he’d do if it was bad,” followed by, “Yeah, let’s finish this and get it out.”

Sujana Sri Venkat Uppalapati
Electronics engineer, National MagLab

When I was an undergraduate at Trinity College, the department chairman said, “Why don’t you work in my lab? I’m working on hemocyanin” — the blood of mollusks. So we learned how to kill mollusks and siphon off their blood, which is blue. I did oxygen titrations, looking at the oxygen binding curves and figuring out what the oxygen affinity was under certain circumstances. And that was my first real science experiment, which unfortunately never got published. It was really fun. I spent a vast number of hours on it when I should have been studying for my other courses.

My girlfriend at the time — now wife — worked on the same project and absolutely hated it. It was so frustrating. It took a lot of time. You had to be very patient. And she said, “This research business is not for me.” (She ended up a medical doctor, by the way, and loves it!) I, on the other hand, just loved it, knew that research was going to be great. It was just a fantastic experience. And I’ve told that story to many an undergraduate class here. Getting some experience really lets you know whether this is the path you want to go down, or this is not the path you want to go down. And both are tremendously useful pieces of information.

Tim Cross
Director of the Nuclear Magnetic Resonance Facility, National MagLab

This was a big first for me. Not only did I publish my first ‘first-author’ paper last year, but the paper included the first-ever example of a kagome lattice imaged from a bulk (or three-dimensional) material. A kagome is an arrangement of atoms in a pattern resembling a Japanese style of basket weaving called kagome. The image was taken at the MagLab with a special scanning transmission electron microscope (STEM). My paper described how these atoms move as temperature decreased. I grew this crystal, so it is like my baby. I calculated this structure based on X-ray data I had collected. The STEM image of the atoms in my crystal confirmed the structure I had predicted. The picture is both scientific and artistic: clear, beautiful and exactly what I expected. It’s like getting a gold star in kindergarten and having your artwork hung on the fridge.

Alyssa Henderson
Graduate research assistant, National MagLab

Read more Science Firsts at fieldsmagazine.org/firsts
High magnetic fields let you see things at the molecular and atomic level that you couldn’t otherwise see. As a bonus, those things sometimes generate not just great data, but great data — or cubism, pointillism or other style. We decided the year 2020 was the perfect time to celebrate this powerful and beautiful magnetic vision.

Here are some examples of charts, diagrams, scans and other visualizations of research conducted at national magnet labs. We stripped the notations and, with a few swipes of our Photoshop eraser, turned science into art. Gaze upon them as you might paintings in a gallery, and enjoy the feelings, questions and associations they conjure for you. Try to guess what exciting science story they tell. Then visit fieldsmagazine.org/dada-data to learn more about the cool science hidden in these images. — K.C.
Headquartered in Tallahassee, Florida, the National High Magnetic Field Laboratory is home to some of the world’s strongest and most unique magnets, and belongs to a network of high-field magnet labs around the world offering scientists cutting-edge instruments for their discoveries.

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