ChemMatters®

February 2024

Demystifying Everyday Chemistry

3D-PRINTED FOODS

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3-DIMENSIONAL HYDROGEL PRINTING. To test a 3D printing material she was working on, Lynn Stevens created an octopus with a bulbous head and tentacles thinner than 1 mm. Stevens, a Ph.D. student in Zachariah Page's lab at the University of Texas at Austin, researches methods for printing objects useful in biotech, medicine, and manufacturing. In this case, the octopus was made of a hydrogel resin containing mostly cell media, a material that one day could support living cells in therapeutic implants. Stevens hardened the hydrogel using a fluorescent, light-triggered catalyst, the little octopod glowed under ultraviolet light. —*Manny I. Fox, C&EN*

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OPEN FOR DISCUSSION

How to Read Science News and Spot Misinformation

The internet is buzzing with the latest news on coronavirus variants, climate change, and speculation about UFOs. Unfortunately, that also means misinformation is spreading fast.

With science-related news—including unfounded rumors—being released at a blistering pace on social media, we are constantly weighing the credibility of information. But how do we reliably do that?

HEALTHY SKEPTICISM

In your science classes, you ask questions about your experimental results. Did your experiment turn out as expected? Why or why not? The same approach to questioning applies outside of class, too. What is this [reporter, scientist, TikTok influencer] trying to tell me and why? What data are available? Do the data support the claims?

Even professional reporters aren't always asking the right questions. So you need to be sure that you are. In 2015, for example, gleeful headlines about the benefits of chocolate appeared around the world. "Why You Must Eat Chocolate Daily." "Pass the Easter Egg!" The stories originated from a real study with real data.

Reported in an online journal, called the International Archives of Medicine, the chocolate study might have appeared authentic to the untrained eye. But it was written by a journalist, John Bohannon, pretending to be a researcher, Johannes Bohannon. The paper was called "Chocolate with high cocoa content as a weight-loss accelerator."

Confessing his deeds in a Gizmodo article, Bohannon wrote that he wanted to know how easy it would be to turn bad science into big headlines. Many scientific journals, in which scientists publish results from their experiments, have excellent reputations and have high standards for the papers they publish.

But not all journals prioritize quality; and many are part of an industry of "predatory journals" that publish questionable science for a large fee and don't take time to review the merits of a study. Bohannon paid more than $600 to the journal that published his paper. Within two weeks of submission, the journal posted the paper without changing a word, Bohannon wrote in Gizmodo.

READING SIDE TO SIDE

To avoid falling for a hyped-up story, the Stanford History Education Group (SHEG) recommends using an online verification method called lateral reading.

In lateral reading, you open new tabs to quickly learn what you can about a story's source and content, rather than reading from top to bottom on a web page. If you had done this with a story about Bohannon's study, you would have quickly noticed that the Institute of Diet and Health he claimed to be associated with doesn't exist.

Mike Caufield, director of blended and network learning at Washington State University, builds on the idea of lateral reading with a process he calls SIFT: stop, investigate the source, find additional coverage, and trace claims back to the original source.

STOP. When you see a post or article, pause before reading and consider whether the source is reputable.

INVESTIGATE THE SOURCE. Check the "About Us" section of a website. Look for other stories the author or creator shares to see if you can discover an agenda for posting a particular story.

FIND ADDITIONAL COVERAGE. Removing bias from reporting is difficult, so seeing the news from multiple sources will help you understand it better. Suppose you have two headlines about a new study. One reads: "Treatment X doubles survival rate for severe COVID-19 cases." Another says: "Treatment X only effective in 8% of severe COVID-19 cases." Both report the same facts: Treatment X increases survival rates of severe cases from 4% to 8%. But the sources interpret those facts differently.

TRACE CLAIMS TO THE ORIGINAL SOURCE. You might find that a particular news story is years old, or that it has been reposted out of context. A story could also be based on a scientific claim that has been refuted. A claim that vaccines cause autism was made in a published article that was found to be fraudulent, but not until after it made the rounds in the media.

EVIDENCE VS. "EVIDENCE"

Just because you or someone you know falls sick after getting a flu vaccine doesn't mean that the vaccine causes the flu. Individual experience can't compare to a large, randomized study with a control group.

Remember Bohannon's chocolate study? The data were real. But the study only recruited 15 subjects. As Bohannon wrote in Gizmodo, a study measuring a large number of things about a small number of people is bound to give you false positives. And some reporters are happy to accept them without question.

This article was adapted from "How to Read Science News and Spot Misinformation," posted by inChemistry *on Nov. 13, 2020. For more tips, read the original article at bit.ly/readsciencenews.*

3D-PRINTED FOODS

By Alla Katsnelson

SHUTTERSTOCK

This article was adapted from "3D-Printed Foods Enter the Kitchen," which was originally published in Chemical & Engineering News *on February 2, 2022.*

What if, instead of trays of gooey pizza and wilted lettuce, the school cafeteria cranked out plates of food that were synced to your body's nutritional needs for optimum performance for the rest of the school day? Perhaps on Tuesday, your personalized lunch would contain an extra jolt of caffeine to make up for a late night of studying; maybe on Friday you'd need a dose of creatine to help your muscles recover from a strenuous morning game of pickleball.

To achieve that level of culinary nimbleness, researchers at the U.S. Department of Defense are turning to an unusual appliance: a 3D printer. In the Food Engineering and Analysis Lab, located at an Army facility in Natick, Massachusetts, Lauren Oleksyk and her colleagues are creating 3D-printed bars tailored to optimize performance in specific scenarios or to address the needs of individual soldiers. Printers that create such supplementary rations could one day be synced with wearable sensors that detect a person's physiological profile and nutritional needs in real time, Oleksyk says.

Three-dimensional printers deposit bits of materials—called filaments, which are usually made of plastic—through a nozzle onto a surface to build preprogrammed shapes layer by layer. The filaments need to flow through the nozzle and then fuse—melt and adhere together—to build the shape.

The plastics that are used, such as polylactic acid, become soft when heated and harden when cooled. They flow through the heated nozzle and solidify quickly when they hit the printing surface. To save on plastic, the inside of the shapes are often hollow, filled only enough to provide support.

Since the mid-1980s, manufacturers and home hobbyists alike have used 3D printers to make customized machine parts, medical implants, furniture, and even houses. Although 3D printing has touched many industries in the 40 years it has been around, the devices are in their infancy when it comes to printing food.

In the past decade, food scientists have been modifying the software and hardware normally used for sculpting plastic and putting it to work on printing concoctions of peanut butter and other ingredients. At the same time, they have been wrestling with how food that flows through the tubes of a 3D printer can be as tasty as the traditional stuff.

PLAYING WITH FOOD

The 3D technology can enable people to customize their food creations, and explore new culinary dimensions in their kitchens, making tastes and textures that have never been created before.

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Chocolate is an excellent material for 3D printing, its low melting point allows it to be heated gently for extrusion and then hardened on a cooled build plate.

For example, Hod Lipson, a robotics engineer at Columbia University in New York City, and his team printed a seven-ingredient slice of cheesecake with an elaborate internal structure. Because of the ways they constructed the layers, biting into the cheesecake released the taste of each ingredient in waves, says Jonathan Blutinger, a graduate student in Lipson's lab.

The novelty of 3D printing food would be even greater if researchers could figure out how to print and cook simultaneously, according to Lipson. Food 3D printers are mostly suited for producing intricate shapes and designs, not actually cooking the ingredients. "We spend such a lot of our lives making food," he says. "We broil; we panfry. Except for microwaves, [today's cooking] is all techniques that are thousands of years old."

Lipson was among the first to explore 3D printing with food—and it wasn't

JONATHAN BLUTINGER/COLUMBIA ENGINEERING

Seven trials were needed to create this 3D-printed cheesecake. Graham cracker paste was used on the sides to contain the softer ingredients such as jelly and banana puree. The top layer was laser-broiled.

even on purpose. In the early 2000s, most 3D printers could print with only a single material at a time, but his team was trying to figure out how to print machine components, such as batteries or actuators, out of multiple materials.

To calibrate the printer for each material, Lipson's students reached for food ingredients, such as cookie dough, cheese, and chocolate, which are easier to work with but have some of the same properties.

The food ingredients then "took on a life of their own," Lipson says.

Initially, colleagues poked fun at the lab's growing interest in food printing. But Lipson was drawn to the technological challenges. "I still have a hard time explaining this to my colleagues, but peanut butter is much more complicated [to work with] than aluminum," he says. Its properties are not linear, and small fluctuations in temperature—even just a degree or two—completely changes how it flows.

PRINTABLE EDIBLES

For 3D printers to become common kitchen appliances, though, the technology needs to mature. The hardware is pretty simple, Blutinger explains, the device "can pick up a syringe of food and then shoot it out based on some kind of directed path."

But there's no standard software or hardware optimized for the specific challenges of printing food. "We're using industry software designed for printing plastic and metal parts, and we have little hacks to make it work," Blutinger says.

The field also needs to amass standardized digital recipes that home cooks could download and use in their 3D printers, similar to the designs makers can download for making plastic toys or tools.

To create a printable food, researchers must mix and remix ingredients to adjust material properties, such as viscosity, adhesion between the printed layers, and the rate at which different layers get deposited, all through trial and error.

But it is still food, so researchers must also attend to its nutritional content and palatability. Generally, for foods made with an extrusion printer, viscosity is an important factor.

Viscosity is a substance's resistance to flow, or more specifically, how easily molecules move past each other. Small molecules, such as water, tend to move past each other easily and have low viscosity. Longer, larger molecules, such as oils, get tangled and don't move past each other easily and thus, have higher viscosity.

In 3D printing, viscosity determines how easily the material can be extruded from the printer nozzle. Materials with high viscosity require more force to extrude, while those with low viscosity may extrude with less force, but their low viscosity may mean they do not hold their shape.

WATCH NOW

How did Columbia Engineering print the cheesecake (left)? Watch the video to find out.

Scan to watch or visit tinyurl.com/software-controlled-cooking

"A big difference you have to watch out for with 3D printing of food versus 3D printing a plastic, for example, is gravity," says Linette Kucsma, cofounder and chief marketing officer at Natural Machines. When printing plastics, 3D-printer nozzles heat the material to its melting point as it comes out of the tip, and the plastic then hardens quickly as it cools. That process can work for some foods, such as chocolate, but not for others, such as peanut butter or cream cheese.

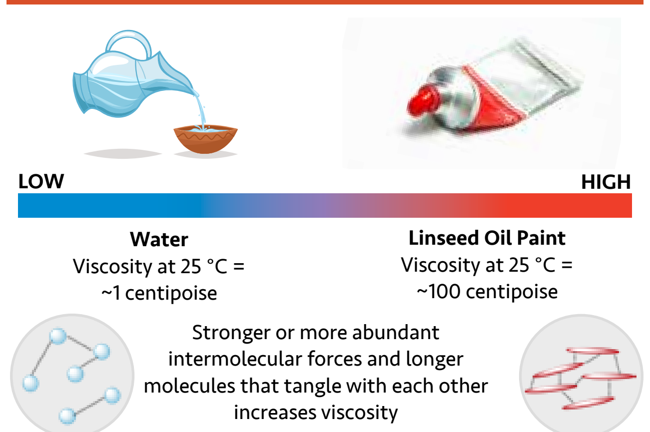
Ingredients that have the consistency of frosting are easiest to work with. Meats can be pulverized into that state, but vegetables, which have high water content, may need to be combined with a thickening agent, such as xanthan gum, Blutinger says.

He and his colleagues are also exploring ways to print non-paste materials such as powders, solids, liquids, and gels. Pastes can also serve as the structural components that hold together oozier or more solid materials, according to Michael Okamoto, a food material scientist in Oleksyk's lab.

MAKING MEAT

Satisfying all these requirements is far from trivial, even for a relatively straightforward creation like the tailored nutrient bars that Oleksyk's team is developing for soldiers. And, if the goal is to make something with a complex structure, creating a printable version is exceedingly more complicated.

VISCOSITY: RESISTANCE TO FLOW



KELLEY J. DONACHEY/SHUTTERSTOCK

For example, Redefine Meat is using 3D printing to create plant-based products that reproduce the structure, texture, and taste of beef steaks. "Meat"—which is muscle—"has a very sophisticated structure meant to provide the animal with the right function, mainly movement," says Daniel Dikovsky, Redefine Meat's head of innovation and technology.

The company analyzes meat's characteristics with a standard compression test and other custom tests to see how it changes and resists being chewed, which depends on the orientations of the muscle fibers. Redefine Meat also re-creates how the muscle fibers align with and adhere to each other, using 3D printers to deposit the company's proprietary plant-based fibers.

The idea, Dikovsky says, is to truly mimic the different components of a bite of steak, such as the muscle fibers, fat inclusions, and connective tissue, and to simulate the experience of eating it—all the way down to the aroma, flavor, and juices.

Whatever the ingredients, what's still unknown is how the 3D-printing process might alter a food's nutritional profile. So far, the effect seems minimal, according to Okamoto. Some nutrients, such as vitamin C, are inherently unstable, so forcing them through the printer's tubes and syringe might degrade them, especially when heat is involved, he adds.

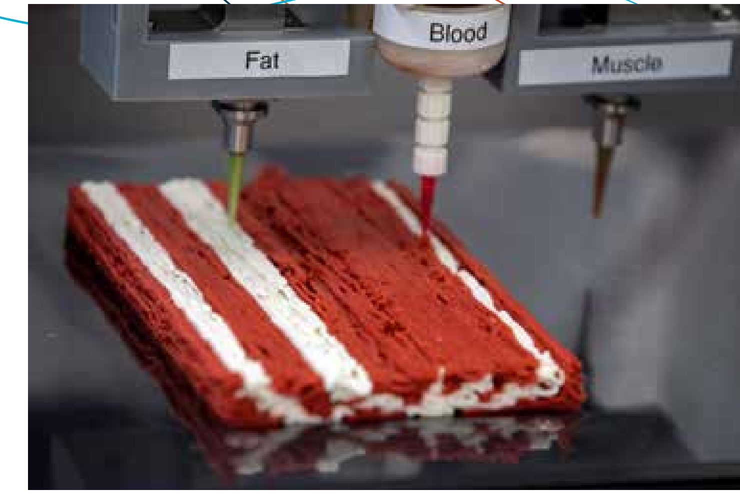
Researchers' efforts to combine 3D printing with cooking are adding a twist to nutritional calculations. Lipson's team added lasers to a food printer and used them to cook ground chicken breast as it emerged from the machine. The researchers are now working with Okamoto to test how laser cooking affects nutrient retention.

"Nobody has done laser cooking before, ever," Lipson says. He speculates that integrating cooking into the process, whether with lasers or some other form of heat, will be what puts 3D-printed food on the map and transforms this process into a full-fledged form of making a dish, from start to finish.

MEALS OF TOMORROW

In addition to providing a novel way for home chefs to move beyond their microwaves and food processors, 3D-food printing may have other uses. For example, 3D-food printing may help improve the appetites of people with dysphagia, who have difficulty swallowing, which can be caused by brain disorders, such as multiple sclerosis or Parkinson's disease.

> "We've only tasted a tiny amount of things that somebody figured out how to make. There's so much more that's possible that we've never tried."
>
> **HOD LIPSON**
> ROBOTICS ENGINEER, COLUMBIA UNIVERSITY



REUTERS

Printing a plant-based steak. To create the expected flavors and textures in meat, the plant-based proteins, fibers and emulsions used must mimic the texture, consistency, and flavor associated with muscle, blood, and fat.

Dysphagia often requires people to follow a diet of pureed foods, which have been run through a blender, draining an eater's pleasure in eating. But 3D printing allows foods to be rebuilt in their original shape, but with a texture that will allow it to be eaten by dysphagia sufferers, Oleksyk explains. Eating peas with a fork, even if they've been reconstituted, is far more enjoyable than slurping them through a straw, she says.

Researchers are also investigating how 3D printing can be used to stave off hunger and provide nutritional support to people in low-income settings. C. Anandharamakrishnan, director of India's National Institute of Food Technology Entrepreneurship and Management, is using the approach to develop snacks fortified with protein and fiber that can be provided as supplements in government-run programs focusing on women's and children's nutrition.

The snacks could be printed in a rotating array of cartoon shapes and colors and potentially produced cheaply on a local level, Anandharamakrishnan says. His team created 3D-printable chocolate-based bars containing different amounts of protein and fiber that children deemed tasty in tests of acceptability. The institute plans to conduct pilot trials of the snacks in schools to study whether they boost kids' nutritional profiles.

Beyond these uses, there's also the sheer gastronomical joy of exploring completely new food experiences. Lipson says, "So far, we've only tasted a tiny amount of things that somebody figured out how to make. There's so much more that's possible that we've never tried—because we didn't have the tools."

Alla Katsnelson is a freelance writer in Southampton, Massachusetts, who covers the life sciences and would happily devour a 3D-printed steak. Versions of this article first appeared in *ACS Central Science* 2021 [cenm.ag/3dfood] and *Chemical & Engineering News* on February 2, 2022.

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Caffeine

THE GOOD, THE BAD, AND THE WHY

By Wynne Parry

Maybe you've tried coffee as a quick pick-me-up first thing in the morning. Or, sought out the sweetened jolt from an energy drink before a long afternoon of studying. The effects of these drinks often comes down to caffeine, a compound that makes you feel more alert and energized.

Caffeine's effects, both the ones we want and those we don't, arise from its interactions with our normal brain chemistry. Through these interactions, caffeine changes how brain cells, called neurons, respond to two chemicals—adenosine and dopamine—which control how we feel.

WHAT IS CAFFEINE?

Caffeine is obtained from many plants. The kola nut once contributed to the flavor of Coca-Cola. Seeds from a variety of cultivated plants are high in caffeine: Arabica beans provide 60% of the coffee we drink, and guarana seeds contain almost four times the amount of caffeine as coffee beans.

Caffeine belongs to a class of chemicals, known as alkaloids, chemical compounds with at least one nitrogen atom. These substances often have strong effects on processes within the human body.

The drug cocaine and the poison strychnine are also examples of alkaloids.

In its purest form, caffeine is a white, odorless powder with a bitter taste. Like other, much more potent addictive substances, such as alcohol and cocaine, caffeine can alter how you think, feel, and behave.

Many people around the world, however, consume it daily, and although problems can occur, it is generally considered safe.

BLOCKING ADENOSINE TO WAKE YOU UP

Caffeine causes its signature effect—making you feel alert and energetic—by interfering with your brain's response to another chemical: adenosine. Adenosine is an organic molecule that occurs naturally within the body and consists of an adenine bonded to the sugar molecule, ribose.

The adenine half of adenosine belongs to the purine family. Purines are distinguished by their nitrogen-containing fused rings: one ring containing six atoms and the other containing five.

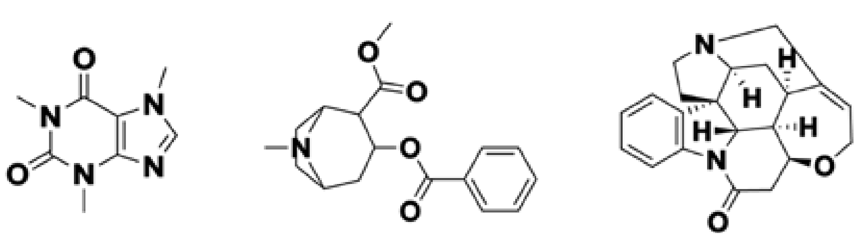
Adenosine is an important neurotransmitter, a chemical messenger within the brain, where it exerts a calming effect. Brain cells, called astrocytes, release adenosine, and over the course of a day, adenosine builds up in areas of the brain that control our daily cycle of wakefulness and sleepiness. As the amount of adenosine builds up throughout the day, you may feel more drained.

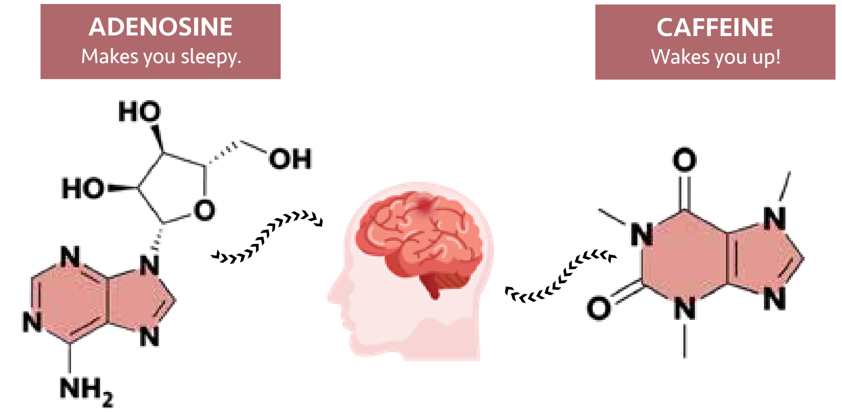
Caffeine is also a purine. Because of its similar shape, caffeine attaches to the same protein receptors as adenosine. Their competition for receptor proteins is at the heart of how caffeine perks you up when you consume it.

Normally, adenosine inhibits arousal and causes sleepiness when it binds to the surface of protein receptors. It acts as a central nervous system depressant. When caffeine binds these same receptors, however, the neurons' activity changes.

The blood vessels in the brain constrict, nervous system activity increases, and signals are sent to the adrenal glands to produce adrenaline. All of these contribute to making you feel more alert and energized.

ALKALOIDS





KELLEY J. DONAGHY/KELSEY CASSELBURY/SHUTTERSTOCK

WHEN CAFFEINE GOES WRONG

When too much caffeine reaches the amygdala—the part of the brain that processes emotions—you might experience a sense of nervousness or anxiety, according to Sergi Ferré, a scientist who studies brain receptors for the National Institute on Drug Abuse, part of the U.S. National Institutes of Health.

The amount of caffeine that causes anxiety varies depending on the person consuming it. The reason for this difference comes down to how quickly our bodies break down and eliminate caffeine from our systems.

If the levels of caffeine in our bodies stay high for long periods, the more unpleasant effects of caffeine will then be felt. As a result, people whose bodies break it down more slowly experience much more caffeine-induced jitters, according to Marilyn Cornelis, a nutrition researcher at Northeastern University in Boston, Massachusetts.

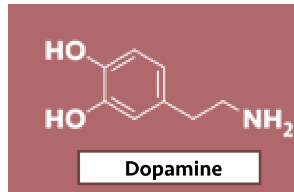
It takes the average person approximately six hours to metabolize, or break down, half the caffeine they consumed in a cup of coffee, energy drink, or soda. Some people can do the same in as little as 2 hours, while others need as much as 20 hours, according to Cornelis.

TAPPING INTO THE BRAIN'S REWARD SYSTEM

In addition to interfering with adenosine, caffeine also indirectly affects another brain chemical: dopamine. Dopamine is part of the brain's reward system. This chemical teaches the brain to seek out desirable experiences.

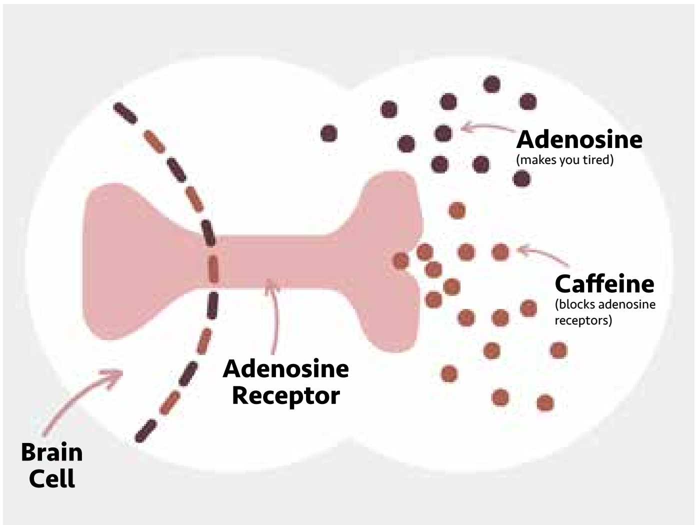
Ferré and his research colleagues have shown that a certain type of adenosine receptor connects to a certain type of dopamine receptor. When adenosine binds to its half of this duo, it interferes with the dopamine receptor's ability to function. Adenosine essentially puts the brakes on dopamine in the brain.

Caffeine lifts that brake, allowing neurons to respond to dopamine when they normally wouldn't, explains Ferré.



In this way, caffeine trains your brain to see it as a reward and makes you want to consume it more often.

If you develop a caffeine habit, you will, over time, need to consume more and more of it to achieve the same feeling of alertness. This effect is known as tolerance. Caffeine convinces



KELSEY CASSELBURY

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5 THINGS TO KNOW

If you're experimenting with caffeine, here are some tips to help you get the most out of it and reduce problems.

» **Pay attention to how you are getting the caffeine.** Drink coffee or tea, and you're also getting plant-made substances, such as polyphenols, known to have protective effects on health.

» **Don't drink caffeine late in the day.** Blocking the sleep chemical, adenosine, can cause difficulty getting to sleep.

» **Use it only when you need it most.** If you consume caffeine on a regular basis, you may become dependent on it.

» **Be aware you may get more (or less) than you think.** While some caffeine-containing products are clearly labeled, others are not, so it can be challenging to know how much you are consuming.

» **NEVER combine caffeine with more strongly addictive drugs.** Caffeine can interact with these substances in the brain, increasing the risk of dangerous consequences.

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your brain that all of its existing receptors are full, yet the brain continues to seek adenosine.

This causes your brain to produce more adenosine and more of a certain adenosine receptor protein to balance the constant caffeine consumption. Now that you have more adenosine and receptors to fill, the same amount of caffeine won't affect you as much as it did before.

If you miss your daily caffeine, without a blocker, the additional adenosine receptors will make you feel especially tired. This grogginess is part of a response known as withdrawal, which happens when someone stops taking a substance that their body has come to depend upon.

Used carefully—such as before a long afternoon of studying—caffeine can be helpful, Ferré says, "The good part is that it might help you, or motivate you, might wake you up," but drink it too often and "you need caffeine to get to normal," he cautions.

HOW MUCH IS OK?

The U.S. Food and Drug Administration (FDA) has said that 400 milligrams (mg) a day is a safe amount of caffeine for a healthy adult. Research has shown, however, that young people are more sensitive to caffeine's effects.

The American Academy of Pediatrics recommends that anyone between the ages of 12 and 18 limit themselves to 100 mg per day. Children under 12 are advised not to consume caffeine.

In extremely large amounts, caffeine can be dangerous. Toxic effects can occur if someone manages to consume 1,200 mg within a short period of time, according to the FDA. In rare cases, people have died from overdosing on highly concentrated sources of caffeine.

For some, no amount of caffeine is safe no matter the age. Caffeine has been shown to raise blood pressure and cause heart palpitations leading to strokes or heart attacks.

In sum, caffeine can be both your best friend when you are tired and run down or studying for finals, or It can be your worst enemy when trying to fall asleep. Use in moderation!

CAFFEINE CONTENT

	Number of Samples Tested	Lowest Amount	Highest Amount
16-oz. brewed Starbucks Breakfast Blend	6	259.2 mg	564.4 mg
16-oz. decaf coffee	16	None	13.9 mg
16-oz. fountain Coca-Cola	9	40.9 mg	48.4 mg
12-oz. carbonated soda	19	None	48.2 mg
6- to 8-oz. black, green, or white tea	15	14 mg	61 mg

KELSEY CASSELBURY/FREEPIK

WHAT IF CAFFEINE HAD BEEN DISCOVERED TODAY?

It's hard to imagine life without caffeine. For one thing, humanity has been consuming caffeine-laden tea and chocolate for thousands of years. Chemists have also figured out how to get caffeine into a much wider range of beverages and other products. Many products, from soda to energy drinks to caffeine pills, now contain the synthetic version.

But let's imagine this history didn't exist. What if, instead, caffeine was a new substance? "We'd have a very, very different relationship to it than we do now," suggests Murray Carpenter, the author of *Caffeinated*.

For example, if you tell someone you need a cup of coffee to wake you up, that person might say OK and even offer to join you, Carpenter says. "But if you brought out a little bit of caffeine powder and placed it on your tongue, they'd be like, 'Dude, you've got a problem.'"

In the latter scenario, the government would probably impose rules that don't currently exist for caffeine, according to Carpenter. For instance, the FDA might limit the amount of the new substance in beverages and foods that contain caffeine.

The government could also forbid people under a certain age from using these products, much like the minimum age mandate for purchasing alcohol.

On balance, Carpenter doesn't believe caffeine is good or bad. "If it's a product we're consuming daily, and it is for most Americans, we should understand it better," he says. "And, we should use it in a thoughtful, methodical manner that most benefits us."

Wynne Parry is a freelance writer based near Philadelphia, Pennsylvania. Her most recent *ChemMatters* article, "The Chemistry of Deception: How Invisible Ink Fueled Espionage and Other Trickery Throughout History," appeared in the December 2022 issue.

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COOKING CHEMISTRY: WHAT'S IN THE POT?

By Brian Rohrig

You've preheated your oven, mixed the batter, and poured it into a greased pan. When you look at the instructions on the back of a cake-mix box to set the timer, the times are based not only on the shape of the baking pan—round cake, cupcake, loaf, square, tube, or Bundt—but also the material the pan is made from—ceramic, glass, light-colored metal, or dark-colored metal. What's up with that?

Materials matter, so let's take a deeper dive into cookware and see how chemistry can help us choose tools to help us become the next MasterChef!

THERMAL CONDUCTIVITY

If you've ever stepped from a hardwood floor onto a tile floor, you know that the tile feels colder even though it's the same temperature as the wood floor. That's because the tile is a better thermal conductor and transfers heat away from your toes faster than the wood does.

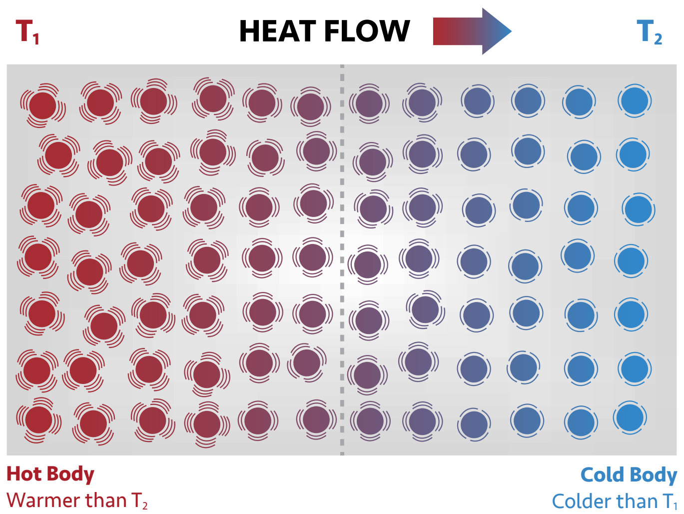
Thermal conductivity determines how fast heat moves through a material. Metals, such as aluminum, copper, gold, and silver, are good thermal conductors, meaning heat moves through them quickly. Heat is transferred when more energetic molecules or atoms transfer their energy to their neighbors.

Plastic, foam, glass, and other amorphous—disordered—materials are thermal insulators. The air pockets in these materials and the random nature of their molecular makeup means that heat moves through them less efficiently.

Composed of only carbon atoms, diamond is the best conductor of heat currently known. Its high heat transfer is how it got its street name "ice," and thermal conductivity is one way that gemologists can tell diamonds apart from cubic zirconia.

After diamond, silver is the second-best thermal conductor, so if you win the lottery, a solid silver skillet can be yours for just $12,000. Scrambled eggs can't help but taste divine in the world's most expensive frying pan.

SHUTTERSTOCK



SHUTTERSTOCK

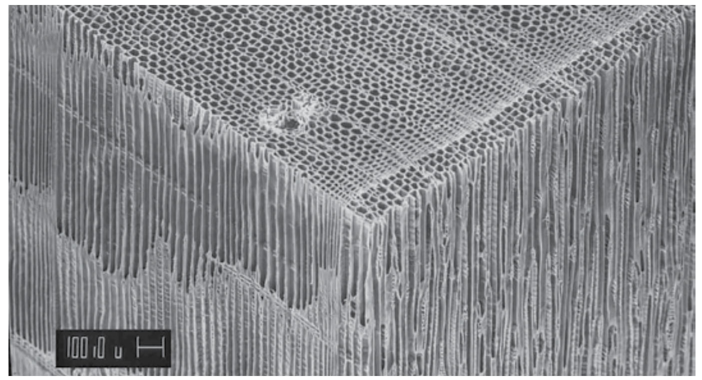
THERMAL CONDUCTIVITY

The heat from the burner on the stove causes molecules in the pan to vibrate faster, making it hotter. These vibrating molecules collide with their neighboring molecules, which also makes them vibrate faster. As these molecules collide, heat is transferred throughout the pan.

Metals are electrical conductors, meaning that they have electrons that can move easily through the material. These electrons can also carry heat efficiently by zipping around to transfer the kinetic energy from hot atoms to colder ones.

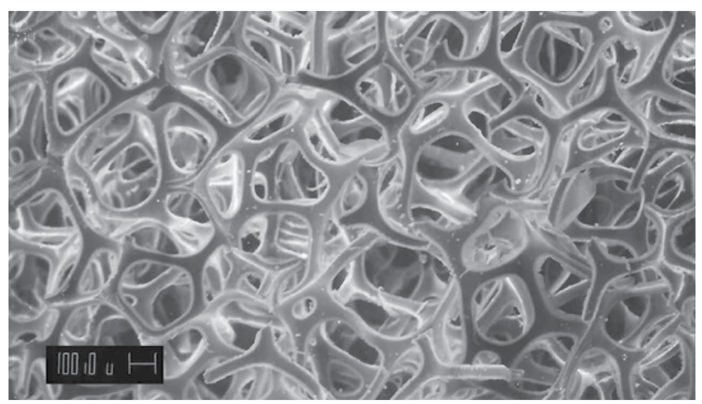
Insulators, such as glass, plastic, and Styrofoam have amorphous molecular structures. This creates holes in the structure and reduces collisions, and the heat energy is not transferred as quickly.

The holes trap air and gas molecules far apart, so there are fewer opportunities for them to transfer thermal energy.



Scanning electron micrographs of wood (above) and Styrofoam (below). The holes keep thermal energy from transferring easily, making them good insulators. Scale bars (in black) are 100 micrometers.

IMAGES COURTESY OF N. C. BROWN CENTER FOR ULTRASTRUCTURE STUDIES, SUNY-ESF, SYRACUSE, NEW YORK



There are, of course, less expensive alternatives to silver, and more easily machined materials than diamond. Copper is the third-best conductor, copper pans transfer heat almost as fast as silver. Copper is prized by chefs for its excellent thermal conductivity and durability.

A good conductor heats up quickly, so you are more likely to get even heat distribution throughout the pan. A pan made from a poorer conductor takes longer to heat up, leading to hot and cold spots within the pan, cooking food unevenly.

While not as expensive as silver, copper is still costly, so it is often used only for the bottom of the pan, which bears the brunt of the heat. The sides of the pan are often composed of less expensive metals, such as aluminum or steel—an alloy of carbon and iron—where high thermal conductivity is not as important.

Thickness is important, too! Thinner pans heat up quicker than thicker ones. If a pan is too thin it will heat up too quickly, making it easy to burn your food. Because a thicker pan takes slightly longer to heat up, the side in contact with the food will develop a more even heating surface.

The most important reason for using a pan that has good thermal heat conduction is to ensure heat from your cooktop or oven is evenly dispersed. If not, some parts of the dish would burn while other parts would still be cold.

HEAT CAPACITY

To get your pan hot takes energy. Ideally, pans that warm quickly and stay warm longer will take less energy overall to cook your food. Also, materials that heat up and transfer heat more slowly allow the inside of the food to cook before the outside burns.

When considering what kind of cookware to use, knowing the specific heat capacity of the material it is made from is useful. The specific heat capacity refers to how much energy in Joules per gram (J/g) that 1 gram of a substance must absorb to raise its temperature 1 °C.

Among metals, there is a wide range of heat capacities. Copper has a relatively low specific heat capacity—0.385 J/g °C. To raise the temperature of 1 gram of copper 1 °C, it must absorb 0.385 Joules of energy. Similarly, when 1 g of copper cools, it releases 0.385 Joules of energy for each 1 °C drop in temperature. Copper may be a good conductor, but it doesn't hold its energy very well.

Aluminum has a higher heat capacity (0.900 J/g °C) than copper, but is a poorer thermal conductor. Conductivity refers to how *quickly* energy enters and leaves a substance, but heat capacity refers to *how much* energy a substance absorbs.

If you want a skillet or wok that really holds in the heat, cast iron is the way to go. Cast iron has a specific heat capacity of 0.461 J/g °C, which, while greater than copper's heat capacity, it is significantly less than aluminum's.

But cast iron is nearly three times denser than aluminum, that is more mass per unit volume, so a cast iron skillet will hold more heat than the same-sized aluminum pan. Cast iron is relatively inexpensive and more economical.

A pan with a higher heat capacity takes longer to cool down—after it has been removed from the stove, it will continue to release heat into your food. If you want to fry chicken to crispy perfection, a cast iron skillet will keep the oil at a consistent temperature allowing the chicken to fry evenly.

NONSTICK COATINGS

There's nothing worse than making the perfect omelet only to have it stick to the pan. When food sticks to a pan it is literally bonding with the metal. These bonds might be strong covalent bonds or weaker intermolecular forces of attraction such as van der Waals forces.

Protein-rich foods, eggs and meats, are especially prone to sticking: As proteins become denatured—lose their natural complex shape—different groups of atoms are exposed and some of these groups can form especially strong bonds with metal.

Most chefs will tell you to use a nonstick or well-seasoned skillet coated with butter or oil. Either method involves using polymers—long-chain molecules made up of repeating units called monomers.

Cast-iron skillets have been called the original nonstick cookware. Cast iron that is well-seasoned and maintained will become more nonstick over time. This happens as the fats and oils used oxidize and reorganize during the cooking process.They polymerize and form a glossy black coating on the surface as it gets caught in the nooks and crannies of the pan's surface.

Owning a cast-iron skillet comes with responsibility. It must be properly maintained to retain that sought-after polymer coating.

In 1938, a DuPont chemist stumbled upon a new polymer, polytetrafluoroethylene (PTFE). DuPont patented the product and named it Teflon. It wasn't until the 1950s that someone coated a frying pan with Teflon. And, Teflon has been making cookware surfaces more nonstick ever since.

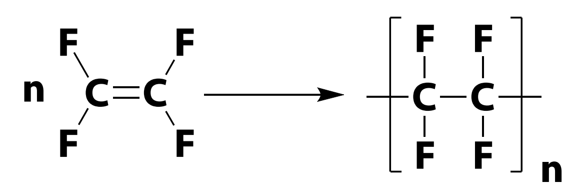
You may wonder if Teflon is so slick, then how do they get it to stick to the pan. One method is to sandblast the pan

CAST IRON VERSUS TEFLON: POLYMER COATING WARS

SHUTTERSTOCK

Cast iron (left) and Teflon (right) skillets have nonstick surfaces because of their polymer coatings. A well-seasoned cast iron skillet builds up a polymer coating from the oils used in cooking, while a coating of the synthetic polymer Teflon is applied to Teflon-coated cookware at the factory and therefore it is ready for use upon purchase. Cast iron becomes more non-stick over time, while Teflon coated pans become less non-stick when the surface starts to show wear and tear.

POLYTETRAFLUOROETHYLENE (PTFE) TEFLON



$n > 10^4$

PROPERTIES OF COMMON MATERIALS

TYPE OF COOKWARE	THERMAL CONDUCTIVITY (J/s•m•K)	SPECIFIC HEAT CAPACITY (J/g•°C)	DENSITY (g/mL)
Carbon (Diamond)	2200	0.540	3.53
Silver	428	0.235	10.49
Copper	401	0.385	8.96
Aluminum	237	0.900	2.70
Cast Iron	80	0.461	6.85-7.75
Stainless Steel	16	0.461-0.502	7.48-7.95
Corning Glass Ceramic	3.39	0.974	2.60
Glass	0.80	0.840	2.50

SHUTTERSTOCK

Copper pots and pans are prized by chefs for their excellent thermal conductivity and durability.

SHUTTERSTOCK

Cooking in a pot over an open fire provides thermal conduction via the flames to a pot as well as electromagnetic waves that radiate from the fire to slowly roast your marshmallows, making them a nice brown on the outside and gooey in the center.

with grit, creating a roughened, pock-marked surface. Liquid Teflon is then applied, which seeps into the nooks and crannies. It is then baked in at high temperatures, forming a durable, super-smooth finish.

Even Teflon-coated pans have an Achilles heel though. If a Teflon- coated pan is scratched, there are more surfaces for bonding to occur and you are likely to get more sticking. It is best to use plastic utensils with Teflon cookware to reduce damage to the surface.

COOKING METHOD COUNTS

How food will be cooked can determine the type of pan to use. Heat can be applied to foods in one of three ways, either through thermal conduction, heat convection, or electromagnetic radiation. Usually all three are involved, but one type typically dominates.

Thermal conduction involves direct contact: hot surface equals cooked food. When bacon sizzles in the skillet, it is primarily being heated by conduction. The vibrating molecules in the skillet collide with the bacon molecules making them vibrate faster during the cooking process. To ensure your bacon cooks evenly and without burning, you want a hefty metal pan that spreads the heat evenly and holds its heat.

Ovens on the other hand surround and bathe our food in heat: convection. Hot, less dense air rises from the bottom of the oven, cooling slightly at the top and then falling back down to be reheated. Remember, cold air is denser than hot air—as a gas is heated, its volume expands and spreads out the gas molecules, making the hot air less dense.

The high temperatures and long cooking times associated with convection cooking require a sturdy pan that can take the heat. Thin metal pans may transfer the heat too quickly, and the outside edges of your brownies may burn before the middle is cooked. Cast iron, ceramic, glass, or stoneware are good choices for oven cooking.

ELECTROMAGNETIC WAVES

Food can also be cooked using electromagnetic waves such as infrared waves and microwaves. Infrared are the heat waves that emanate from a campfire and slowly roast your marshmallows to a golden brown.

Although a very common kitchen appliance today, microwave ovens have only been around since the 1960s, and they were not initially designed for home use. It wasn't until 1967 that the first home model was made available and it was quite expensive.

Microwave ovens pass electromagnetic radiation through food with a frequency in the microwave region. These microwaves interact with polar molecules such as fats and water.

Like any wave, microwaves have a positive crest and a negative trough. As the microwaves move inside the oven, the polar molecules will align their positive and negative poles with those of the microwaves.

The energy of the microwaves is converted into thermal energy as the water molecules start to re-orient themselves to align with the motion of the waves.

Not all molecules align with microwave radiation—we say they don't absorb microwave radiation. That's why you can use a microwave-safe plastic bowl to heat soup in a microwave, but that same bowl would melt on a conventional stove.

Understanding when to use what material for your brownies, or your favorite tuna casserole, can be the difference between being crowned a *Masterchef* or appearing on *Worst Cooks in America*. Materials and cooking methods can make or break your culinary efforts.

Brian Rohrig is a chemistry teacher living in Columbus, Ohio. His most recent *ChemMatters* article, "Fighting Frost with Ice," appeared in the December 2023 issue.

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QUICK READ

CAN LIGHTNING BE STOLEN?

By Brenda S. Collins

Thunder and lightning have inspired myths and stories for millennia. They serve as symbols of power from Zeus, the Greek god of the sky, lightning, and thunder, to modern superheroes. Percy Jackson is even accused of stealing the master bolt, which the author of the *Percy Jackson and the Olympians* novels, Rick Riordan, calls "the original weapon of mass destruction."

But can lightning be stolen, or even harnessed for its power? These are good questions as we look for solutions to meet our energy needs.

"Lightning is a very long electrical spark, very long meaning greater than about 1 kilometer," says Dr. Martin Uman, professor emeritus of Electrical and Computer Engineering at the University of Florida in Gainesville.

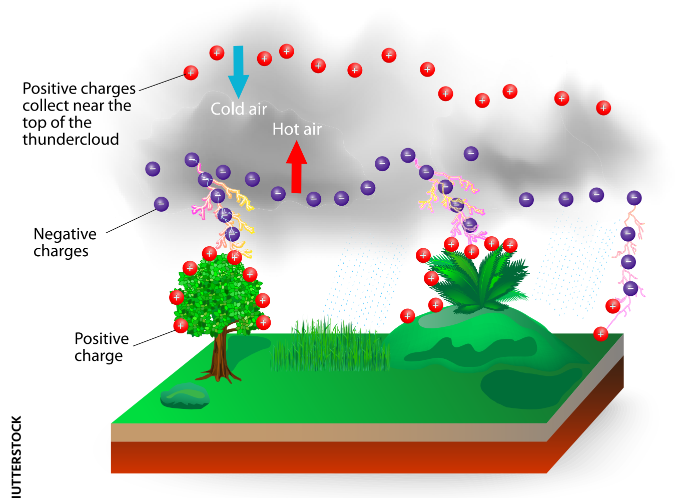
According to Dr. Joseph Martin, professor of physics and astronomy at the University of New Hampshire in Durham, "The exact mechanism that initiates lightning is not well understood, but it may involve localized electric field enhancements near hydrometeors—ice and water particles inside the cloud."

Within the thundercloud, small ice particles form as warm and moist air rises, while dense soft hail—graupel—falls. When the ice particles collide with the graupel, the ice particles become positively charged and the graupel becomes negatively charged.

As the graupel nears Earth, it repels the negative charges and positive charges form as a result. Opposite charges attract, so when the negative charges from the sky reach for Earth and the positive charges from Earth reach for the sky—the two meet in the form of lightning.

With an average of 1 billion joules (1 gigajoule (GJ)) of energy in a single strike, or enough energy to power 26 electric cars for 100 km, why aren't we tapping into nature's gift of energy?

HOW LIGHTNING IS FORMED



SHUTTERSTOCK

SHUTTERSTOCK

Benjamin Franklin of Philadelphia, Pennsylvania, may have been the first to try in 1752. While the story has been warped with time and retelling, Franklin was able to use wet hemp—a cord that conducts electricity—and a key attached to a kite to make a convincing discovery.

Franklin sent a kite into a thunderstorm and after a while, noticed the hemp fibers were standing on end; when he touched the key, he received a shock. It was the first time that anyone had proven lightning was electricity in a cloud!

"Lightning is extremely powerful. The problem is that it's only powerful for a few millionths of a second," says Uman. He and his team use rockets to trigger lightning on their own terms and even then, it can take weeks to have the right atmospheric conditions. He calls his research "half art and half science."

As a lightning bolt strike only lasts a few seconds, and most of the energy is used up in the bright light and loud thunder, we would only be able to harness a fraction of those gigajoules of energy.

Added to that is the randomness of where lightning strikes, and it just isn't a reliable enough source of energy for large-scale engineering efforts to harness and store the power in a battery. At least not yet.

With all this energy and mystery surrounding lightning, there's no wonder that Zeus was a little worried when someone stole his lightning bolt in the Riordan novel, *Percy Jackson and the Olympians: The Lightning Thief*.

Thunder and lightning are nature's power on display, and they will continue to inspire scientists, engineers, novelists, moviemakers, and artists alike.

Brenda S. Collins is a freelance writer based in Gaithersburg, Maryland. Her most recent *ChemMatters* article, "Hot and Cold Therapies for Injury and Disease," appeared in the December 2023 issue.

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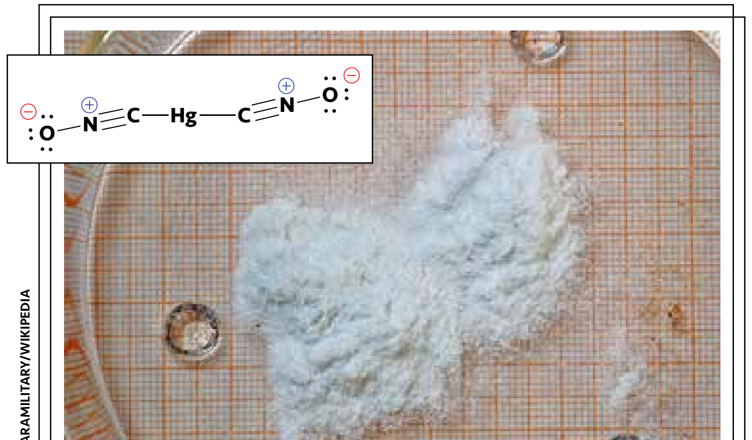
By Chris Eboch

MAD SCIENTISTS AND MISINFORMATION

You know you can't always believe the science you see on YouTube, TV, or TikTok, right? But is there good science out there, so does stretching the truth matter? Yes, and here's why.



Real mercury(II) fulminate is a gray powder. It would be exceedingly difficult to produce a large white crystal of such a reactive material, and it would explode with even the slightest vibration.

Since the first movie theater opened in 1895, the entertainment industry prioritized dramatic impact over realism. Today, the competition is fierce between more than 50 national television networks, more than 200 streaming services, and hundreds of movies released each year.

Facts get tweaked in favor of excitement, things such as visible and audible lasers in the vacuum of space—you can't see that laser cat toy until it hits something, right? And, how about those sequences zooming into a grainy photo from a video to get a clear shot of the suspect's face?

If only this were real, you'd be able to see the surface of Mars without sending a drone—we'd just dust off and zoom in on the old photos from the 1960s!

Maybe the misinformation in entertainment seems harmless, but the world benefits when people have a good understanding of science. Scientific literacy helps people make informed decisions on everything from personal nutrition to environmental issues affecting the planet.

"We must inspire the public to have confidence in scientists and in their science," says Donna Nelson, a professor of chemistry at the University of Oklahoma and former president of the American Chemical Society (ACS).

> "If scientists want the public to trust us, accept our innovations, and respect us for them, then we must convince them that we are trustworthy."
>
> **DONNA NELSON**
> FORMER PRESIDENT OF THE AMERICAN CHEMICAL SOCIETY

THE BAD CHEMISTRY OF *BREAKING BAD*

Part of public outreach is encouraging scientific accuracy in film, television, and other media. Errors show up everywhere. *Breaking Bad*, which ran on the American Movie Channel from 2008 to 2013, was steeped in chemistry.

The story follows chemistry teacher Walter White who turns an old RV into a drug lab to pay his medical bills. In one episode, White finds himself in a dangerous situation, so he throws a piece of fulminated mercury on the ground to make an explosion. But does this chemical do what the show claims?

To make fulminated mercury, red mercury(II) oxide (HgO) is dissolved in concentrated nitric acid (HNO_3) followed by the addition of ethanol (CH_3CH_2OH). Eventually the unstable and explosive mercury(II) fulminate ($Hg(CNO)_2$) forms (precipitates) as a grey solid.

As explosives go, mercury(II) fulminate is a good one, or a bad one depending on your perspective. Fulminated mercury is shock, friction, and heat sensitive, so any little misstep can result in a big explosion.

Not all unstable compounds are explosive, many simply degrade over time like fruit slowly going bad on the shelf. For a reaction to be explosive, it must be fast, exothermic, and produce gases. Mercury(II) fulminate fulfills all these requirements.

Once triggered, it rapidly decomposes to carbon dioxide and nitrogen gases, and metallic mercury. It also produces a lot of heat energy which causes the gases to expand rapidly—Charles' Law—creating a shock wave of rapidly expanding gases that impacts the immediate area.

REALITY CHECK

So, yes, a crystal of fulminated mercury is explosive. The explosion, however, wouldn't be as dramatic as depicted on TV. Nor could White have thrown around a bag of mercury(II) fulminate crystals as depicted. But would a large single crystal have gutted the room and left the occupants unharmed?

The producers of *MythBusters*, a science entertainment program that first aired on the Discovery Channel in 2003, tested the setup shown in *Breaking Bad*. They discovered that to get such an explosion, White would need a greater amount of the compound and a faster throwing velocity to get the crystal to hit the ground at a high enough kinetic energy to detonate.

Even explosive reactions need a minimum amount of energy—activation energy—to get started. Finally, the concussive blast would have killed him and everyone else in the scene. The *MythBusters* team called that episode—busted!

Another *Breaking Bad* episode included an attempt to dispose of a body by submerging it in an aqueous solution of hydrofluoric acid (HF) in a bathtub. On the show, within a few hours, the body was quickly reduced to soup and the bottom of the bathtub and floor beneath it were also destroyed.

Can hydrofluoric acid really do that?

Fluorine is at the top of the halogen group, Group 17, of the periodic table. It is highly reactive because of its small size and high electronegativity. Fluorine really wants to react with something! And, it will react with almost anything on the periodic table even the noble gas, xenon.

That said, unlike its group members, chlorine, bromine, and iodine, when combined with hydrogen, fluorine doesn't make a very good acid. Hydrogen and fluorine have a similar atomic size, which allows their valence orbitals to overlap easily. This overlap creates strong covalent bonds..

The strength of an acid is based on its ability to dissociate a hydrogen and make hydronium ions (H_3O^+) in water—more hydronium ions, stronger acid—but because the bond between hydrogen and fluorine is so strong, it is classified as a weak acid.

But even as a weak acid, HF is still very corrosive; it is used to etch glass, metal, and stone. Worse, its small size also makes it highly toxic. HF moves quickly through skin into tissues in the body, where it damages cells and eats away bones.

In *Breaking Bad*, the body in the tub was quickly reduced to soup—the *MythBusters* tested this one too, with pig flesh, and found that HF merely softened the tissue. Further, it didn't dissolve anything in the room, not the bathtub nor the floor. Busted again!

Even though the show was busted twice, *Breaking Bad* should get points for using real science as inspiration, even with exaggerated results. That's better than a lot of shows. But the TV and movie industry has shown a growing interest in getting the scientific details right, and practicing scientists are ready to assist.

$$HX(aq) + H_2O(l) \rightleftarrows X^-(aq) + H_3O^+(aq)$$

$$HF < HCl < HBr < HI$$

Increasing Acid Strength →

When acids formed from halogens (represented as X) dissociate, they form hydronium ions (H_3O^+) and the corresponding halogen anion. Stronger acids form more hydronium ions.

SCIENTISTS ON SCREEN

At a presentation during the 2012 San Diego Comic Convention, *Breaking Bad* show creator Vince Gilligan described the research they conducted for chemistry realism and for laboratory safety.

According to Gilligan, "Dr. Donna Nelson from the University of Oklahoma approached us several seasons back and said, 'I really like this show, and if you ever need help with the chemistry, I'd love to lend a hand.'"

"She's been a wonderful advisor. We get help wherever we need it, whether it's chemistry, electrical engineering, or physics. We try to get everything correct. There's no full-time [advisor] on set, but we run certain scenes by experts first," Gilligan says.

Nelson notes that ACS had been trying to establish connections with Hollywood. The goals were to influence them to: 1) include more science in their shows, and 2) represent science and scientists more positively and more realistically.

Throughout the twentieth century, scientists were typically portrayed as male villains or monsters and very rarely as heroes, or heroines. Even when they were neutral characters, they were shown with little to no details of their personal lives, very one dimensional.

Unfortunately, these characterizations are accepted by viewers and propagated as stereotypes. Chemists are almost always characterized as "mad scientists" leading people to mistrust science because they see it portrayed as dangerous.

"This is the reason I volunteered to help *Breaking Bad*," Nelson says. "If scientists want the public to trust us, accept our innovations, and respect us for them, then we must convince them that we are trustworthy."

As a science advisor, Nelson answered questions, checked scripts, provided dialogue for the actors, and drew chemical equations to be used as props. She even got to visit the *Breaking Bad* set and was filmed for a cameo.

On occasion, Dr. Nelson was invited to speak, even though the invitation might start out with something like, "We wanted Bryan Cranston, but we couldn't get in touch with him, so can we talk to you?" Nelson said she didn't care that she wasn't their first choice; she had a message to share.

Nelson is also advising on an upcoming TV series about the fentanyl crisis as another way to educate the public and inspire young scientists. Fentanyl, an opioid estimated to be 50 times more potent than morphine, is the number-one cause of death for U.S. adults between the ages of 18 to 45, according to the national nonprofit Families Against Fentanyl.

"Advances in chemistry hold hope of new ways to treat substance use disorder and prevent fentanyl poisoning," Dr. Nelson says. Chemists can be "soldiers in this war" by developing new treatments.

This demonstrates how science that starts in the lab or classroom can be life-changing in the real world. The entertainment industry can play a part by bringing the voices of scientists and scientific advancements to the public in an accessible and realistic way.

MAKING FICTION LOOK REAL

Special effects, both live and through computer animation, have become an enormous part of the movie business, so Hollywood needs experts with math or science backgrounds to help them keep it realistic.

Sometimes, science and art combine in surprising ways, as in the chemistry-inspired 2023 Disney-Pixar movie *Elemental*. Director Peter Sohn grew up as the son of Korean immigrants in New York City. When he saw the periodic table in a middle school science class, he pictured a community living in the boxes, like people in apartment buildings.

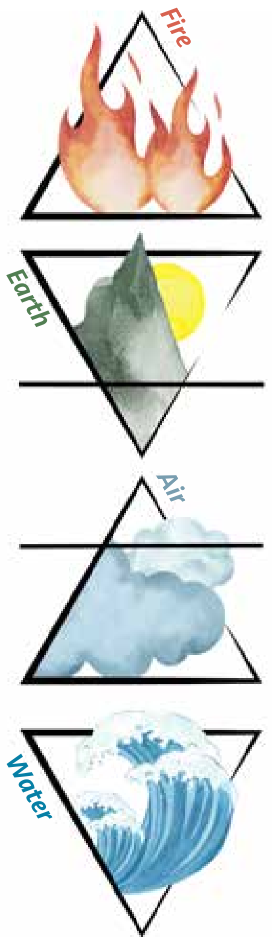
In *Elemental*, the city is a chemistry set with test tubes, and the characters are based on fire, earth, air, and water, the original four Greek elements. Our understanding of elements has grown dramatically, with 118 known chemical elements in the periodic table. Still, the four elements align with the four states of matter: solid (earth), liquid (water), gas (air), and plasma (fire).

Sohn and the other writers imagined how the elements—fire, earth, air, and water—would behave as people, which provided both inspiration and challenges. The lead characters are a fire elemental and a water elemental, who develop a friendship. And in what kind of building could a fire elemental live?

Perhaps these details are not strictly necessary, but basing the story and design on real science makes for a visually interesting and complex movie.

In recent decades, the ease of recruiting science consultants has led to better portrayals of science and scientists. Moviemakers may still tweak reality for better cinematography, but scientists can help them find a balance between realism and entertainment.

Meanwhile, more positive portrayals of scientists can inspire students to go into the science, technology, engineering, and math fields and encourage the public to support science ranging from pandemic preparedness to space exploration.



KELSEY CASSELBURY

Alchemists believed there were only four elements: fire, earth, air, and water. The symbols, which are represented with triangles and lines, can often be seen on the front of laboratory buildings.

Chris Eboch is a science writer who lives in Socorro, New Mexico. Her most recent *ChemMatters* article, "Shaking Out the Facts About Salt," appeared in the February 2016 issue.

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CHEMISTRY IN PERSON

Keeping People and the Environment Safe

Helping people work safely and protecting the environment is at the heart of what Trevor Cornish does all day. While pursuing a degree in environmental resources engineering, Trevor took advantage of several summer internships offered through his degree program.

It was during these internships that Trevor learned about environmental health and safety (EHS), a specialized field that ensures chemical and engineering companies are following federal, state, and local regulations. He says the critical thinking skills he developed in chemistry courses are vital to his day-to-day work. *—Raye Wiegel*


TREVOR CORNISH

TREVOR CORNISH

B.S.: Environmental Resources Engineering, SUNY-College of Environmental Science and Forestry (ESF)

M.S.: Environmental Health and Safety Management, Rochester Institute of Technology (RIT)

WHAT HE DOES NOW: Staff environmental engineer at Arcadis, a design, engineering, and consulting firm, and adjunct professor at RIT

This interview was edited for length and clarity.

Can you tell us a bit about what you do in general?

I'm an environmental engineer and associate project manager with Arcadis. I do EHS compliance, so it's all about helping our clients comply with the U.S. Environmental Protection Agency (EPA), the Occupational Health and Safety Administration, and state-level regulations to protect the environment and provide a safe and healthy working environment.

Additionally, I help clients with EHS auditing and management systems to manage these important issues.

How does chemistry play a role in what you do?

It's the most basic things about chemistry that play into what I do. At a high level, chemistry teaches you critical thinking skills: How to think, how to simplify things to the most basic concepts, and solve a problem based on a few principles that you really understand. While I don't draw Lewis Dot diagrams or balance chemical reactions daily, it's the basics that I still rely on every day: Unit conversions and dimensional analysis.

It's so important to be able to understand data—to interpret it and find its meaning—and apply what was learned from the data to a complex problem to promote good decision making. Regulations are complex, and critical thinking is a key tool to identify which parts of a regulation applies and how. Chemistry classes train you for this kind of thinking.

Do you have any words of wisdom, or anything that you would like to share with high school students who might be interested in taking the track you did.

One of the biggest things that high school students should do is focus on a few different principles or concepts or tools, and once you truly understand them, you'll be amazed at how much you can extrapolate from there. Take advantage of every special opportunity, such as internships, to learn more than what's offered in traditional classroom settings.

Can you tell us about a project that impacted you?

Usually, clients come to us with a problem that they can't solve. We work with them, we ask them questions, we do some research, and usually we go to their site and make observations. Then, we think like a scientist or engineer and present them with some solutions.

One specific case, in the Buffalo, New York, area, involved a client who approached us with some significant EHS compliance issues. They really hadn't had strong management in that area for quite a while. Their program was in poor order; they didn't know what they didn't know.

We started with an environmental audit to look at their compliance with regulations and we got all the findings on the table, and over the next year, we worked with them to disclose the compliance issues to the governing agencies. Then, we worked with the client and their attorneys to get corrective actions in place; we helped them build processes to manage their compliance obligations.

Did you always know that you wanted to do what you're doing today, or was it gradual?

It was a gradual thing. I'm in the minority of what ESF graduates do. I think most people do site remediation-type work, or more design-based work for water and wastewater treatment systems. For me though, EHS work was a perfect fit; I like managing processes and developing systems.

What are the impacts that this has on people?

Working people in America want to go home at the end of their workday in the same or better condition than when they arrived to work that day. Having no negative environmental impact is also important to them. These are reasonable expectations, so what we're doing is making sure that management knows how to make them happen.

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