The physics of a car collision

By Andrew Zimmerman Jones, ThoughtCo.com on 09.10.19
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Level **MAX**

Image 1. A crash test dummy sits inside a Toyota Corolla during the 2017 North American International Auto Show in Detroit, Michigan. Crash test dummies are used to predict the injuries that a human might sustain in a car crash. Photo by: Jim Watson/AFP/Getty Images

During a car crash, energy is transferred from the vehicle to whatever it hits, be it another vehicle or a stationary object. This transfer of energy, depending on variables that alter states of motion, can cause injuries and damage cars and property. The object that was struck will either absorb the energy thrust upon it or possibly transfer that energy back to the vehicle that struck it. Focusing on the distinction between force and energy can help explain the physics involved.

Force: Colliding With A Wall

Car crashes are clear examples of how Newton's Laws of Motion work. His first law of motion, also referred to as the law of inertia, asserts that an object in motion will stay in motion unless an external force acts upon it. Conversely, if an object is at rest, it will remain at rest until an unbalanced force acts upon it.

Consider a situation in which car A collides with a static, unbreakable wall. The situation begins with car A traveling at a velocity (v) and, upon colliding with the wall, ending with a velocity of 0. The force of this situation is defined by Newton's second law of motion, which uses the equation of force equals mass times acceleration. In this case, the acceleration is $(v - 0)/t$, where t is whatever time it takes car A to come to a stop.

The car exerts this force in the direction of the wall, but the wall, which is static and unbreakable, exerts an equal force back on the car, per Newton's third law of motion. This equal force is what causes cars to accordion up during collisions.

It's important to note that this is an idealized model. In the case of car A, if it slams into the wall and comes to an immediate stop, that would be a perfectly inelastic collision. Since the wall doesn't break or move at all, the full force of the car into the wall has to go somewhere. Either the wall is so massive that it accelerates, or moves an imperceptible amount, or it doesn't move at all, in which case the force of the collision acts on the car and the entire planet, the latter of which is, obviously, so massive that the effects are negligible.

Force: Colliding With A Car

In a situation where car B collides with car C, we have different force considerations. Assuming that car B and car C are complete mirrors of each other (again, this is a highly idealized situation), they would collide with each other going at precisely the same speed but in opposite directions. From conservation of momentum, we know that they must both come to rest. The mass is the same, therefore the force experienced by car B and car C is identical, and also identical to that acting on the car in case A in the previous example.

This explains the force of the collision, but there is a second part of the question: the energy within the collision.

Energy

Force is a vector quantity while kinetic energy is a scalar quantity, calculated with the formula K = 0.5mv2. In the second situation above, each car has kinetic energy K directly before the collision. At the end of the collision, both cars are at rest, and the total kinetic energy of the system is 0.

Since these are inelastic collisions, the kinetic energy is not conserved, but total energy is always conserved, so the kinetic energy "lost" in the collision has to convert into some other form, such as heat, sound, etc.

In the first example where only one car is moving, the energy released during the collision is K. In the second example, however, two are cars moving, so the total energy released during the collision is 2K. So the crash in case B is clearly more energetic than the case A crash.

From Cars To Particles

Consider the major differences between the two situations. At the quantum level of particles, energy and matter can basically swap between states. The physics of a car collision will never, no matter how energetic, emit a completely new car.

The car would experience exactly the same force in both cases. The only force that acts on the car is the sudden deceleration from v to 0 velocity in a brief period of time, due to the collision with another object.

However, when viewing the total system, the collision in the situation with two cars releases twice as much energy as the collision with a wall. It's louder, hotter and likely messier. In all likelihood, the cars have fused into each other, with pieces flying off in random directions.

This is why physicists accelerate particles in a collider to study high-energy physics. The act of colliding two beams of particles is useful because in particle collisions you don't really care about the force of the particles (which you never really measure); you care instead about the energy of the particles.

A particle accelerator speeds up particles but does so with a very real speed limitation dictated by the speed of light barrier from Einstein's theory of relativity. To squeeze some extra energy out of the collisions, instead of colliding a beam of near-light-speed particles with a stationary object, it's better to collide it with another beam of near-light-speed particles going the opposite direction.

From the particle's standpoint, they don't so much "shatter more," but when the two particles collide, more energy is released. In collisions of particles, this energy can take the form of other particles, and the more energy you pull out of the collision, the more exotic the particles are.

Quiz

1 Read the following selection from the section "From Cars To Particles."

> *To squeeze some extra energy out of the collisions, instead of colliding a beam of near-light-speed particles with a stationary object, it's better to collide it with another beam of near-light-speed particles going the opposite direction.*

Which of the following conclusions can be drawn from the selection above?

(A) Scientists proved Newton's Laws of Motion using a particle accelerator.

(B) Scientists use particle accelerators to study collisions between large objects in motion.

(C) Scientists are attempting to maximize the force output during particle collisions in a particle accelerator.

(D) Scientists are attempting to maximize the energy output during particle collisions in a particle accelerator.

2 Which of the following claims does the author support the LEAST?

(A) Force and energy are distinct concepts.

(B) Energy can change forms, but is never destroyed in a collision.

(C) Inelastic collisions are uncommon in the real world.

(D) Collisions between moving objects tend to be more energetic.

3 What role does acceleration play in force?

(A) Force is determined by multiplying mass and velocity.

(B) Force is determined by multiplying mass and acceleration.

(C) Force is determined by multiplying acceleration and velocity.

(D) Force is determined by multiplying acceleration and time.

4 How does energy change over time?

(A) Energy cannot be transferred between objects or destroyed.

(B) Energy can be converted into other forms or destroyed.

(C) Energy is either transferred between objects or destroyed.

(D) Energy can be transferred between objects or converted into other forms.

Small university outranks many others in black physics grads

By Errin Haines Whack, Associated Press on 06.01.17

Word Count **854**

Level **MAX**

Graduates hold up their hands during a commencement ceremony at Dillard University in New Orleans, Louisiana, May 13, 2017. Dillard graduates more physics majors - and more female physics majors - than bigger schools with more resources. AP Photo

One of the smallest historically black colleges in the U.S. boasts a huge accomplishment: pound for pound, tiny Dillard University in New Orleans graduates more physics majors -- and, notably, more female physics majors -- than far bigger schools with more resources.

With an enrollment of 1,200, Dillard ranks second in the country in black physics undergrads.

The point was punctuated at Dillard's recent commencement exercises, which featured a keynote address from actress and singer Janelle Monae, one of the stars of "Hidden Figures." The award-winning film tells the story of the black women scientists who fought Jim Crow while doing essential mathematical calculations for America's space program.

"To see that we have this significant number of women representing (science and math) in the way that they are is a blessing to America and our future," Monae told The Associated Press in an interview before the May 13 graduation. "To have physicists coming out of New Orleans who are African-American women ... that's a huge deal."

Nine of the top 10 physics departments in the country — at black or white schools — producing the most African American undergraduates in physics are at HBCUs, according to the American Institute of Physics. Currently, the top producing school is Morehouse College, an all-male HBCU with nearly twice as many students as Dillard.

Dillard, the smallest on the list, ranked comparably with North Carolina A&T University, with more than 10,000 students. The private, liberal arts college has conferred 33 physics degrees since 2007, including nine to black women.

Degrees in physics are rare for women and minorities. That Dillard — with a campus that is 73 percent female — is outpacing its larger counterparts is significant, said University of Pennsylvania higher education professor Marybeth Gasman.

"They're taking a chance on these young women," said Gasman, director of Penn's Center for Minority-Serving Institutions and author of a forthcoming book on HBCUs and STEM -- science, technology, engineering and mathematics -- education. "They don't bring in people who they deem to be perfect. They bring people in who they deem to have potential and they work with them to discover this talent."

Dillard President Walter Kimbrough is one of the biggest champions of the school's physics program.

"I'd never met a black female getting an undergraduate degree in physics in my life until I got to Dillard," Kimbrough said. "It broadens the narrative of what black women do."

Dillard's powerhouse program is the work of physics professor Abdalla Darwish, who frames his efforts to steer black women into the major as "a movement."

"I believe in women, especially minority women," said Darwish, who arrived in 1998 and has built a multi-million dollar laser lab for research. "They are not less than anybody else. Just give them the chance and they will be the best. Give them what they need, and they will do."

Founded in 1869, Dillard is best known for its nursing program, the oldest in the state. Physics was established as a major at Dillard in 1940.

"You had those areas where we've traditionally expected women: teachers and nurses," Kimbrough said. "Now, we're going to be known as one of the best in physics. When I go out and talk about Dillard, it's a 'wow' factor for us."

Trivia Frazier loved math from a young age, but in high school, she gravitated to science out of a curiosity for why things happen.

"When I saw you could put an equation to something to describe it in a quantitative way, that's what really drew me to this field," Frazier said.

She was the only person in her graduating high school class to pursue physics in college. She chose Dillard because of its eager, approachable recruiters — including Darwish, who talked to her about post-graduate studies.

She went from being the only black girl in her school interested in physics, to having three "sisters in physics" at Dillard.

"We were able to support each other and understand the quirks about being a physicist and not having the most popular major," Frazier said. "That was one of the most important components of my foundation."

As an undergraduate, Frazier wondered what she would do with a physics degree, and considered adding mathematics to her major. Darwish was firm: A black woman in physics was special, he said.

"He told me, 'It's time for you to learn about the significance of where you are and who you can be,'" she recalled. "That conversation helped me to stay on track. It opened up my eyes in terms of understanding what was out there."

Darwish introduced her to other physicists. Frazier graduated with a degree in physics and pre-engineering in 2007 and went on to earn her doctorate in biomedical engineering in 2008 from Tulane University. She works at a bio innovation center in New Orleans as a tissue engineer, and returns to her alma mater frequently to inspire the next generation.

"Now, it's a part of my mission to let other young women know that this is possible," she said. "When you're aware of the opportunity, the future is just ... it's yours."

Quiz

1 Which of the following statements accurately represents the relationship between the article's CENTRAL ideas?

(A) There is not enough minority representation in the field of physics. Dillard University is working to empower African-American women in this field.

(B) Most people in the field of physics are white men. Dillard University believes that it should educate women to be teachers, nurses and physicists.

(C) Minority women do not account for a high percentage of people studying collegiate-level physics. Dillard was founded on the idea that minority women are strong physicists.

(D) The workforce is requiring more diversity in the field of physics. Dillard University believes it will recruit more people if it modifies its physics program to include more students of color.

2 Which of the following sentences in the article BEST develops a central idea?

(A) Currently, the top producing school is Morehouse College, an all-male HBCU with nearly twice as many students as Dillard.

(B) Dillard, the smallest on the list, ranked comparably with North Carolina A&T University, with more than 10,000 students.

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(C) Dillard's powerhouse program is the work of physics professor Abdalla Darwish, who frames his efforts to steer black women into the major as "a movement."

(D) That Dillard — with a campus that is 73 percent female — is outpacing its larger counterparts is significant, said University of Pennsylvania higher education professor Marybeth Gasman.

3 Read the selection from the article.

> *"I'd never met a black female getting an undergraduate degree in physics in my life until I got to Dillard," Kimbrough said. "It broadens the narrative of what black women do."*

Which of the following conclusions can be drawn from this selection?

(A) Kimbrough is probably from a small town that lacks diversity.

(B) Before Dillard's program, nobody believed that black women were capable of doing physics.

(C) In the future, Dillard hopes it will be normal for black women to be physicists.

(D) Most black women are not taught how to do physics until they get to Dillard.

4 Which of the following aspects of the article is NOT thoroughly discussed?

(A) Dillard's ranking among other American colleges with similar programs of study

(B) whether Dillard plans to motivate other schools to institute similar programs

(C) Kimbrough's opinions about the success of Dillard's physics program

(D) students' reactions to Dillard's physics program

These physicists finally figured out why microwaved grapes ignite

By Anne Ewbank, Atlas Obscura on 03.08.19

Word Count **704**

Level **MAX**

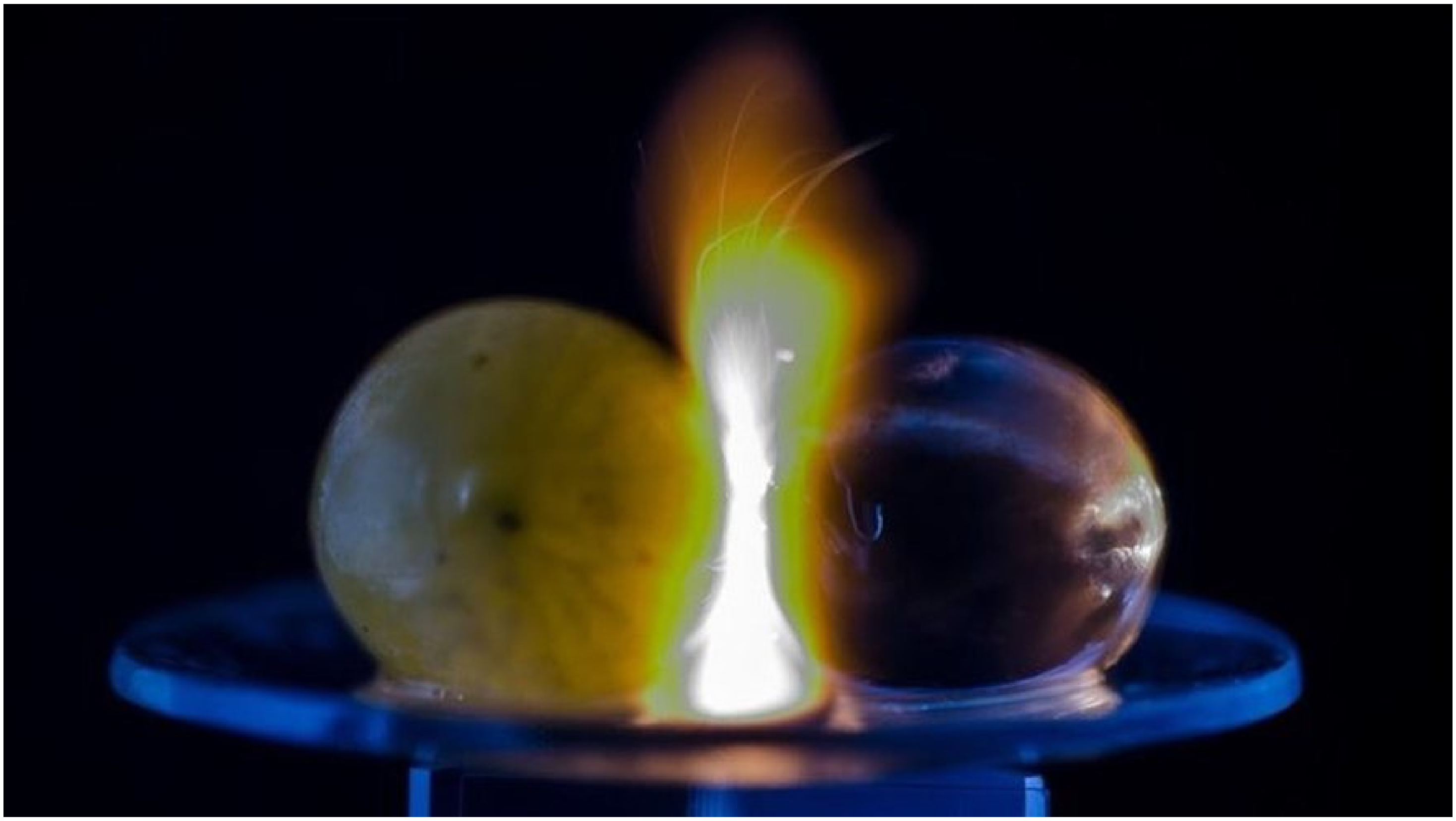
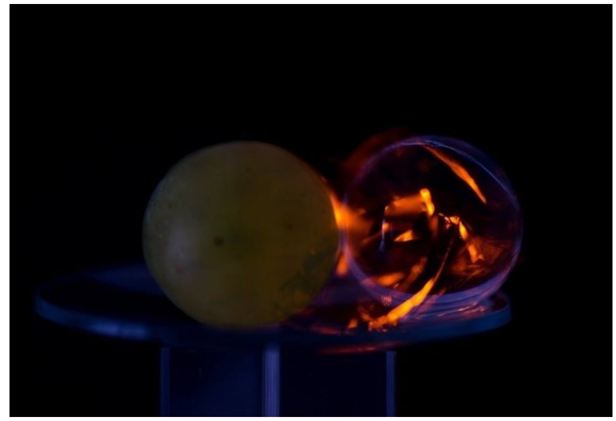


Image 1. A grape meets a hydrogel bead, and sparks fly. Photo by: Hamza Khattak/Slepkov Biophotonics Lab, Trent University

"It is a truth universally acknowledged that a pair of grape hemispheres exposed to intense microwave radiation will spark, igniting a plasma."

The literature-inclined will notice that the above quote is a riff on the famous first line of Jane Austen's "Pride and Prejudice." But while sparks may fly between Elizabeth Bennett and Mr. Darcy, that's nothing compared to the gouts of flame that ensue when two halves of a grape get close enough to touch while spinning inside a microwave. The above quote, in fact, is the first line of another great piece of literature, published yesterday by Proceedings of the National Academy of Sciences.

In the paper "Linking plasma formation in grapes to microwave resonances of aqueous dimers," physicists Hamza K. Khattak, Pablo Bianucci and Aaron D. Slepkova deployed many grapes and several microwaves in the name of science. Microwaving a nearly halved grape to watch the middle ignite is a popular, much-documented pastime, and for decades, this fiery parlor trick has been filmed and shared on the internet, where it mystified observers. The researchers set out to solve the mystery.



The leading theory was that when two halves of a grape are microwaved, the skin bridge connecting them acts as an antenna. The current that runs through the antenna heats up until a plasma forms. (Plasma, by the way, is an ionized gas that occurs when atoms are heated to the point that they release their electrons. Lightning is plasma, as is the sun.)

That turned out not to be the case, says study author Pablo Bianucci. A physicist at Concordia University, he's been fielding calls all day from journalists interested in their fiery findings. His fellow researcher, Slepkova, first learned about the grape phenomenon on the internet in 1995, and they began studying it together as a side project in 2015. But it was only when undergraduate Khattak joined the team in 2017, says Biannuci, that the research "pushed forward very quickly." Using rejiggered microwaves that allowed them to take photos, Slepkova and Khattak began microwaving grapes. According to the paper, the team used "thermal-imaging techniques and computer simulations" to examine what was happening.

It turned out that cutting the grapes wasn't necessary, and neither was the bridge of skin. Even two whole peeled grapes side-by-side could induce fireworks. In fact, any grape-like objects, including blueberries, cherry tomatoes, quail eggs and hydrogel water beads, do the same — a fact the researchers assiduously proved by microwaving each in turn.

This insight led the team to a new theory. In what Bianucci calls "a very lucky coincidence," grapes are mostly made of water, which, as it happens, reduces the wavelengths of microwaves significantly. From around 12 centimeters in the air, they go to around one or two centimeters in water: a bit smaller than your average grape. "Microwaves can get trapped inside the grape," says Bianucci. If a grape is microwaved by itself, a hotspot forms in its center from the trapped microwaves. But when two grapes are close enough, the waves can "hop" from one to the other. "This hopping results in a very strong electromagnetic field in between the grapes," he says. When the field is strong enough to ionize the sodium and potassium ions in the grapes, it results in a tiny fireball.

The team's discovery took several years and resulted in the deaths of 12 microwaves. (Even heavily modified microwaves "don't like to run empty" save for two grapes.) This might seem like lighthearted research, and the paper acknowledges that "observing a piece of fruit burst into flames in a microwave oven is exciting and memorable." But there are also real-world implications. As Bianucci explained to Physics World, these findings could come in handy in the field of nanophotonics (the study of light on a very small scale). Meanwhile, anyone interested in a free light show can microwave away (carefully), secure in the knowledge that we have a better idea of what's happening in there.

Quiz

1 The following evidence was gathered to support the idea that the study on microwaved grapes can have practical applications in the future.

1. *In fact, any grape-like objects, including blueberries, cherry tomatoes, quail eggs and hydrogel water beads, do the same — a fact the researchers assiduously proved by microwaving each in turn.*
2. *This might seem like lighthearted research, and the paper acknowledges that "observing a piece of fruit burst into flames in a microwave oven is exciting and memorable."*
3. *Meanwhile, anyone interested in a free light show can microwave away (carefully), secure in the knowledge that we have a better idea of what's happening in there.*

Is this evidence adequate support for the idea? Why or why not?

(A) Yes; it focuses on the grape-like objects that the researchers also learned about in the study.

(B) Yes; it explains that people microwaving grapes on their own will now know why it ignites.

(C) No; it fails to mention the possible ways the research can help the field of nanophotonics.

(D) No; it lacks information about the variety of other items that were tested in the microwave ovens.

2 Which of the following claims does the author support the LEAST?

(A) Khattak was motivated to rapidly propel the research study on microwaved grapes forward.

(B) Microwaving grapes and watching the middle catch on fire is a popular activity on the internet.

(C) The study found that skin did not affect whether a grape would ignite in the microwave oven.

(D) Other items that are similar to grapes are capable of igniting when placed in a microwave oven.

3 How did theories about why grapes ignite in the microwave change over time?

(A) At first, scientists theorized that the skin bridge between the two halves of the microwaved grape was like an antenna, which would form plasma as currents ran through it. Then, experimenting with grape-like objects helped researchers to see that cutting the grapes and having a skin bridge were not factors in making the grapes ignite. Finally, it led researchers to theorize that the water in grapes plays an important role and that strong electromagnetic fields between grapes could also spark a flame.

(B) At first, scientists theorized that the skin on the grapes was essential for the ionization process to occur properly. Then, experimenting with grape-like objects helped researchers to see that a skinless grape actually could increase the probability of plasma formation occurring. Finally, it led researchers to theorize that the wavelengths of microwaves tended to get longer once they entered the grapes, creating an electromagnetic field that would result in a tiny fireball.

(C) At first, scientists theorized that it was necessary for the grapes to be cut nearly in half, which would still allow them to be in contact through a skin bridge. Then, experimenting with grape-like objects helped researchers to see that the flames could ignite regardless of whether it was cut or left untouched. Finally, it led researchers to theorize that blueberries, cherry tomatoes, quail eggs and hydrogel water beads could ignite even more quickly and powerfully than the grapes could in the same microwave oven.

(D) At first, scientists theorized that their thermal-imaging techniques would lead to plasma formation, which would then start the ionization process. Then, experimenting with grape-like objects helped researchers to see that the thermal-imaging techniques were not as effective with other items placed in the microwave ovens. Finally, it led researchers to theorize that atoms release their electrons when plasma is formed, causing the grapes to catch on fire.

4 What role does the water in the grapes play in the creation of hotspots?

(A) The water in the grapes causes the wavelengths of the microwaves to reduce to a length of 12 centimeters and for the microwaves to "hop," thus forming a hotspot.

(B) The water in the grapes causes the wavelengths of the microwaves to increase to two centimeters and for the microwaves to build up in the grapes, thus forming a hotspot.

(C) The water in the grapes causes the wavelengths of the microwaves to grow dramatically and for the microwaves to move rapidly through the grapes, thus forming a hotspot.

(D) The water in the grapes causes the wavelengths of the microwaves to decrease in size and for the microwaves to get stuck in the grapes, thus forming a hotspot.

Confirmed: New phase of matter is solid and liquid at the same time

By Adam Mann, National Geographic on 04.19.19

Word Count **595**

Level **MAX**

A melting iceberg in Antarctica on December 12, 2018. Photo by: Costfoto /Barcroft Images/ Barcroft Media via Getty Images

Solid, liquid, gas ... and something else? While most of us learn about just three states of matter in elementary school, physicists have discovered several exotic varieties that can exist under extreme temperature and pressure conditions.

Now, a team has used a type of artificial intelligence to confirm the existence of a bizarre new state of matter, one in which potassium atoms exhibit properties of both a solid and a liquid at the same time. If you were somehow able to pull out a chunk of such material, it would probably look like a solid block leaking molten potassium that eventually all dissolved away.

"It would be like holding a sponge filled with water that starts dripping out, except the sponge is also made of water," says study co-author Andreas Hermann, a condensed matter physicist at the University of Edinburgh whose team describes the work in April in the Proceedings of the National Academy of Science.

The unusual state of potassium could exist under conditions found in Earth's mantle, but the element is generally not found in a pure form and is usually bound up with other material. Similar simulations could help study the behaviors of other minerals in such extreme environments.

Leaky Crystal

Metals like potassium are fairly straightforward on a microscopic level. When shaped into a solid bar, the element's atoms link up into orderly rows that conduct heat and electricity well. For a long time, researchers believed that they could easily predict what might occur to such crystalline structures under pressure.

But around 15 years ago, scientists discovered that sodium — a metal with similar properties to potassium — did something strange when compressed. At 20,000 times the pressure present at the Earth's surface, sodium transformed from a silvery block into a transparent material, one that did not conduct electricity but rather prevented its flow. By probing the sodium with X-rays, scientists could see that its atoms had adopted a complex crystal formation instead of a simple one.

Potassium, too, has been subjected to much experimental scrutiny. When compressed to similar extremes, its atoms arrange themselves into an elaborate formation — five cylindrical tubes organized into an X shape, with four long chains sitting in the crooks of this assembly, almost like two separate and non-intertwining materials.

"Somehow, these potassium atoms decide to divide up into two loosely linked sub-lattices," Hermann says. But as scientists turned up the heat, X-ray images showed the four chains disappearing, and researchers argued about what exactly was happening.

Hermann and his colleagues turned to simulations to find out, using what's known as a neural network — an artificial intelligence machine that learns how to predict behavior based on prior examples. After being trained on small groups of potassium atoms, the neural network learned quantum mechanics well enough to simulate collections containing tens of thousands of atoms.

The computer models confirmed that between about 20,000 and 40,000 times atmospheric pressure and 400 to 800 Kelvin (260 to 980 degrees Fahrenheit), the potassium entered what's called a chain-melted state, in which the chains dissolved into liquid while the remaining potassium crystals stayed solid.

This is the first time scientists have shown that such a state is thermodynamically stable for any element.

The machine learning technique that the team developed could be useful in modeling the behavior of other substances, says Marius Millot, who studies material under extreme conditions at the Lawrence Livermore National Laboratory in California.

"Most of the matter in the universe is at high pressure and temperature, for instance inside planets and stars," he adds.

Quiz

1 The following evidence was gathered to support the idea that certain elements do strange things in extreme conditions.

> 1. *While most of us learn about just three states of matter in elementary school, physicists have discovered several exotic varieties that can exist under extreme temperature and pressure conditions.*
> 2. *Now, a team has used a type of artificial intelligence to confirm the existence of a bizarre new state of matter, one in which potassium atoms exhibit properties of both a solid and a liquid at the same time.*
> 3. *When compressed to similar extremes, its atoms arrange themselves into an elaborate formation — five cylindrical tubes organized into an X shape, with four long chains sitting in the crooks of this assembly, almost like two separate and non-intertwining materials.*

What additional piece of evidence helps create the MOST COMPLETE idea that certain elements do strange things in extreme conditions?

(A) The unusual state of potassium could exist under conditions found in Earth's mantle, but the element is generally not found in a pure form and is usually bound up with other material.

(B) Metals like potassium are fairly straightforward on a microscopic level. When shaped into a solid bar, the element's atoms link up into orderly rows that conduct heat and electricity well.

(C) At 20,000 times the pressure present at the Earth's surface, sodium transformed from a silvery block into a transparent material, one that did not conduct electricity but rather prevented its flow.

(D) Hermann and his colleagues turned to simulations to find out, using what's known as a neural network — an artificial intelligence machine that learns how to predict behavior based on prior examples.

2 Read the following selection from the article.

> *The computer models confirmed that between about 20,000 and 40,000 times atmospheric pressure and 400 to 800 Kelvin (260 to 980 degrees Fahrenheit), the potassium entered what's called a chain-melted state, in which the chains dissolved into liquid while the remaining potassium crystals stayed solid.*

Which of the following conclusions can be drawn from the selection above?

(A) The chain-melted state of potassium only requires that either the atmospheric pressure is extreme or that the temperature is extreme.

(B) The chain-melted state of potassium could only exist in a computer model simulation and not in real life.

(C) The chain-melted state of potassium may not be a truly new state of matter because it has properties of two states that already exist.

(D) The chain-melted state of potassium occurs when both significantly high pressure and heat are applied.

3 What role does artificial intelligence play in scientists' conclusions that the chain-melted state exists?

(A) The artificial intelligence machine was a superfluous step in the process of confirming the existence of the chain-melted state of matter.

(B) The artificial intelligence machine discovered the chain-melted state even before scientists suspected something strange was happening.

(C) The artificial intelligence machine further clarified what scientists were already observing with potassium atoms in extreme conditions.

(D) The artificial intelligence machine caused scientists to disagree even more about whether or not potassium atoms entered a new state.

4 Which of the following ideas did the author develop the LEAST in this article about the discovery of a new state of matter?

(A) the effects that high pressure could have on sodium and potassium atoms

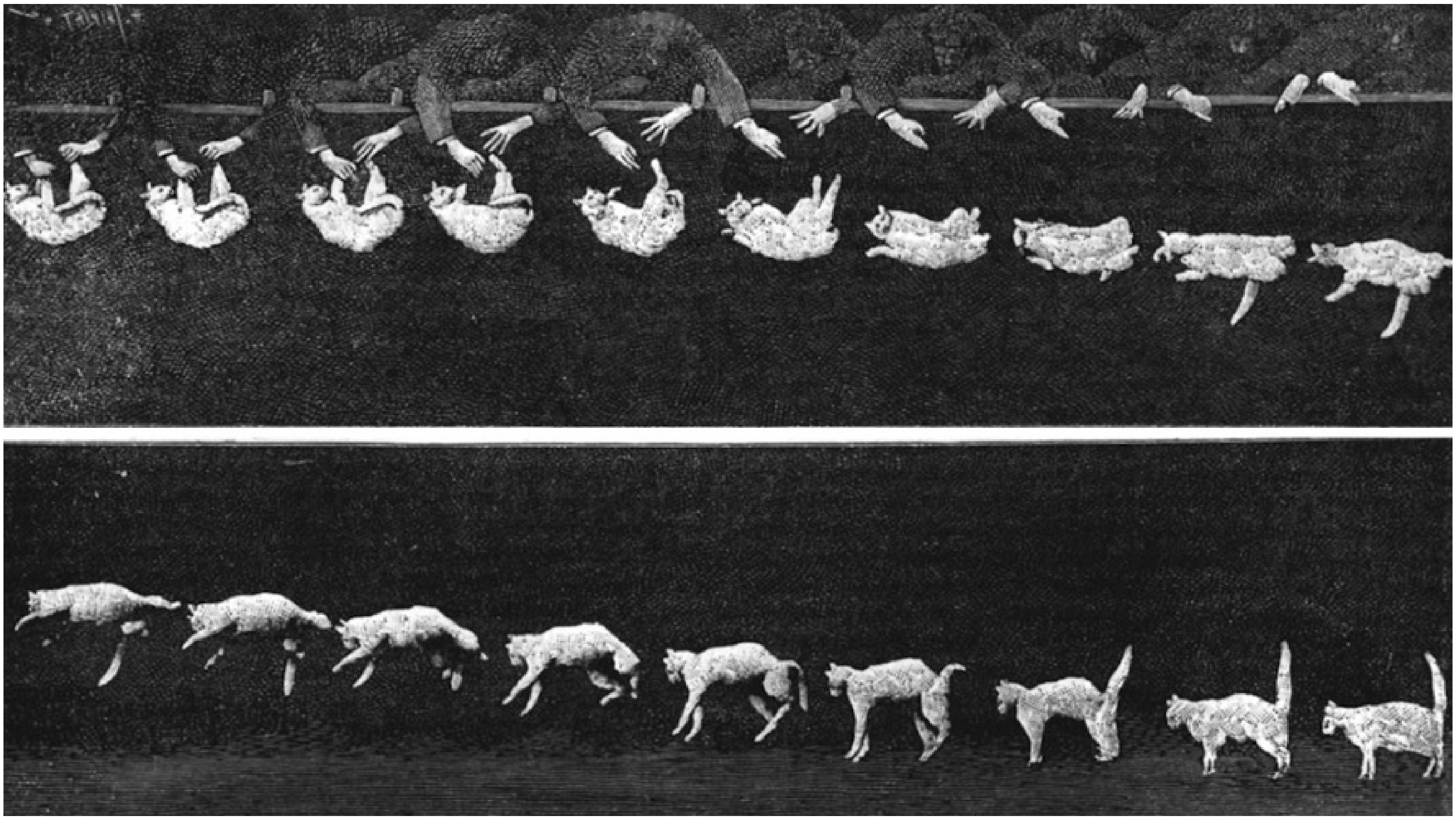
(B) the ways that the machine learning technique used in the study could be helpful in the future

(C) the use of a neural network in the study of the existence of a new solid and liquid state

(D) the description of potassium atoms when they are in the chain-melted state

Scientists just can't stop studying falling cats

By Karin Brulliard, Washington Post on 12.02.16
Word Count **1,254**
Level **MAX**



Images of a falling cat from the journal Nature, 1894. Etienne Jules Marey, via Wikimedia Commons

George Gabriel Stokes was a bushy-sideburned Irish physicist and mathematician who for half of the 19th century was the University of Cambridge's Lucasian Professor of Mathematics, a position held at other times by Isaac Newton and Stephen Hawking. A theorem Stokes formulated is taught to math and physics students today.

Stokes' contemporary, James Clerk Maxwell, was a bushy-bearded Scottish physicist who came up with the equations that formed the foundations of electromagnetism and underpin the design of everything electronic, including the device you're reading this on. He is known as the "father of modern physics."

Besides genius, Stokes and Maxwell shared something else in common: A fascination with holding cats upside-down and dropping them.

"He was much interested," Stokes' daughter later wrote of her father, "in cat-turning, a word invented to describe the way in which a cat manages to fall upon her feet if you hold her by the four feet and drop her, back downwards, close to the floor." In 1870, Maxwell wrote in a letter to his wife that upon visiting his alma mater, Trinity College, he'd learned there was a legend that he used to toss cats from school windows to watch them acrobatically land on their padded paws: "I had to explain that the proper method was to let the cat drop on a table or bed from about two inches, and that even then the cat lights on her feet."

Were they sadists? No, said Greg Gbur, a physics professor at the University of North Carolina at Charlotte, who has blogged about what is now known as the cat-righting reflex: "They were ahead of the curve."

That's because while this feat of kitty gymnastics is a useful instinct for animals that climb trees, it's also a physics conundrum — one that has occupied photographers, scientists and even NASA over the many decades since Stokes and Maxwell dropped felines. (Yes: Cats are even more mystifying than we knew.)

The issue is that the cat flip appears to violate the law of conservation of angular momentum, which says that when one thing rotates, something else rotates with equal and opposite angular momentum in another direction. Put more simply, Gbur said, when you push on the pedals of your bike and make its wheels rotate, the wheels push the surface of the Earth below with an equal force in the opposite direction (though the planet is way too heavy to actually move). But the cat is dropped with nothing to push off of — with no angular momentum to start with — and rotates all the same.

For a long time, Gbur said, the belief was that the cat must have been pushing off its dropper's hands. That changed with the advent of high-speed photography in the late 19th century, which early on was used to answer questions about animal motions — like whether all four feet of a galloping horse are ever off the ground at once (they are, which Gbur said means pre-19th-century "paintings of horses can often look very odd to the modern eye, because people were just guessing at the motion.")

Etienne Jules Marey, a French scientist and engineer, applied high-speed photography to cat dropping. He presented his sequence of 32 shots of a cat in midair at the Paris Academy of Sciences in 1894, and Nature published them the same year. The accompanying article, titled "Photographs of a Tumbling Cat," said that the images had "excited considerable interest," though it wryly noted that the cat's "expression of offended dignity ... indicates a want of interest in scientific investigation." Marey said his now-iconic photos showed the cat first tucked in its forelegs while stretching out its back legs, then switched them, which allows it to use the inertia of its own mass to flip.

Gbur said Marey called this "the tuck and turn" method, and it's illustrated by what figure skaters do: They pull their arms in to spin faster. When a plummeting kitty pulls in its forelegs, its upper body spins faster than the lower part counter-rotates. Then it switches them, slowing the front part of its body so it becomes the fulcrum for the flipping back part.

In 1935, the Dutch physiologists G.G.J. Rademaker and J.W.G. Ter Braak came up with a mathematical drawing of a falling cat, which introduced the idea that the cat's bent waist — as seen in the high-speed photos — was important. Their drawing basically made the case that the front and back parts of the cat are two soda can-like cylinders that rotate on two axes in opposite directions, resulting in a net angular momentum of zero, a move Gbur calls the "bend and twist strategy."

The math behind this cylinder idea was nailed down in the 1960s, when Stanford University engineer Thomas R. Kane tackled it, coming up with equations that could predict the amount of turning a cat could do with all this bending, tucking and twisting.

And that led to cats' improbable contribution to the heady space race of 1960s America.

NASA turned to Kane for help figuring out how astronauts could turn themselves around in zero-gravity, which a 1967 San Francisco Examiner article said they did at the time with "gas jets," whose gas ran out. They gave a $60,000 research grant to Kane, who used math to make computer drawings of the moves that gymnasts then acted out on a trampoline. "As for the cat, he does it without any mathematics at all," the Examiner article said. "He is therefore ineligible for a NASA grant."

Life magazine featured photos of Kane's falling cats and trampolining gymnasts in "spacemen" costumes in a 1968 issue. A year later, Kane and a colleague published what remains the definitive examination of the topic: A paper titled "A Dynamical Explanation of the Falling Cat Phenomenon" — which probably brought the first and only cat photos to the pages of the International Journal of Solids and Structures.

Falling felines have continued to mesmerize corners of academia and the Internet. A University of California-Santa Cruz mathematician built on Kane and Scher's work in the 1990s. In 1998, an Italian researcher dropped a cat named Esther 600 times — yes, 600 — to determine that she could fall on her feet when dropped from 2 to 6 feet, but not from 1 foot (Esther failed 100 attempts at that height. Ouch.) Last year, researchers published a study on how cat-righting might be applied to robotics.

"It turns out that it's an example of a very deep phenomenon in physics that's usually referred to as a geometric phase, and that connects to optics, quantum mechanics, geophysics," said Gbur, who occasionally lectures on the topic. "There's a lot of depth that you can learn about just from that cat behavior."

You read it here: Cats can teach us physics. Deep physics.

Gbur said the exact mechanics of the cat flip are still being debated, and he thinks that is because there's not one answer, which is frustrating to scientists.

"Probably the cat uses multiple different strategies to turn over," Gbur said. "Physics prefers and tends to look for the simplest possible explanation for a phenomenon, whereas evolution — if I anthropomorphize it — is always looking for the most efficient. Living creatures are doing whatever works best, which may not be the simplest option."

Gbur, for the record, said he is just a student of cat-dropping, not a dropper. "Not all cats are necessarily very good at it," Gbur said. "Stick to the videos."

Quiz

1 Which of the following sentences from the article shows the puzzling nature of how cats fall?

(A) The issue is that the cat flip appears to violate the law of conservation of angular momentum, which says that when one thing rotates, something else rotates with equal and opposite angular momentum in another direction.

(B) Put more simply, Gbur said, when you push on the pedals of your bike and make its wheels rotate, the wheels push the surface of the Earth below with an equal force in the opposite direction (though the planet is way too heavy to actually move).

(C) Marey said his now-iconic photos showed the cat first tucked in its forelegs while stretching out its back legs, then switched them, which allows it to use the inertia of its own mass to flip.

(D) In 1998, an Italian researcher dropped a cat named Esther 600 times — yes, 600 — to determine that she could fall on her feet when dropped from 2 to 6 feet, but not from 1 foot (Esther failed 100 attempts at that height. Ouch.)

2 Which of the following aspects of the article is NOT thoroughly discussed?

(A) the relationship between how cats fall and physics

(B) experiments examining the way cats fall

(C) the ideas of physicist Greg Gbur

(D) how cats evolved to fall on their feet

3 Read the sentence from the article.

> *That's because while this feat of kitty gymnastics is a useful instinct for animals that climb trees, it's also a physics conundrum — one that has occupied photographers, scientists and even NASA over the many decades since Stokes and Maxwell dropped felines.*

What does the phrase "kitty gymnastics" convey in the sentence?

(A) a sense of a strong connection between cats and gymnasts

(B) a sense of playfulness about the abilities of cats

(C) a sense of mystery about the abilities of cats

(D) a sense of drama about the abilities of cats

4 What is the BEST meaning of the word "heady" as used in the following sentence?

> *And that led to cats' improbable contribution to the heady space race of 1960s America.*

(A) exciting

(B) tedious

(C) intellectual

(D) conflict-ridden