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# Ice transmutes under pressure

## A rare form of water ice, so far imagined in theory, has been realised in the laboratory

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Water, abundant on Earth and basic to all life, displays great polyvalence in the forms it can take. It is present as vapour in the atmosphere, as a liquid in rivers and oceans and as a solid, in the form of ice. This last form, as a solid, is known to have 18 different compositions.

While ice remains essentially the same, at very high pressures, there is the possibility of the hydrogen and oxygen components of water separating. Such forms are imagined to be possible in the interior of giant planets and there have been theoretical studies of what the properties of such ice should be. Marius Millot, Sebastien Hamel, J Ryan Rygg, Peter M Celliers, Gilbert W Collins, Federica Coppari, Dayne E Fratanduono, Raymond Jeanloz, Damian C Swift and Jon H Eggert, at the Lawrence Livermore laboratory, California, the University of California at Berkley and the University of Rochester report in the journal, *Nature Physics*, that they have used laser-driven shock compression to create instances of ice as conjectured at very high pressures.

The most striking and commonly known feature of water is the way its components arrange themselves as liquid water approaches the temperature of freezing. Water reduces in volume, like most other materials, with lowering temperature and energy, till it reaches 4°Centigrade. From that temperature onwards, however, and till it freezes, water begins to expand, or grow less dense. And after it freezes, at 0°Centigrade, it shows a series of crystalline forms as it cools to lower temperatures.

Normal ice, with which we are familiar, exists in hexagonal crystals, which can arrange themselves in kaleidoscopic ways as snowflakes. The next form of ice is in cubic crystals arranged in diamonds, which forms below -53°C and changes to normal ice when warmed to -33°C. The next form of ice has a regular rhombohedral structure and forms when normal ice is cooled below -83°C and compressed.

Then there are forms of ice that are created with compression at high pressure and these forms are denser than water. When moderately cooled and compressed to about 3,000 atmospheres, ice forms as tetragonal crystals, the lightest of the high pressure forms.

There is also a kind of ice that is non-crystalline, or amorphous. This exists in three forms — low density, high density and very high density. When high density amorphous ice is warmed at a pressure of over 8,000 atmospheres and there are particles, like dust, it takes a rhombohedral crystal form. At just -20 °C and 5,000 atmospheres, we get the structure of a rectangular prism. At just -3°C and 10 million atmospheres, we get a tetragonal structure.

And in this way, water ice takes on different crystal forms at different temperatures and pressures. In all these forms, however, the electrical forces between the positively charged hydrogen, $H^+$, and negatively charged oxygen, $O^-$, components of water molecules are able to keep the parts together and the behaviour is non-conducting, like normal water.

In extreme conditions, of millions of atmospheres, however, displacements of the components of the water molecule can be so energetic that the electrical forces are overcome and $H^+$ and $O^-$ ions float apart. This is a form known as "ionic water" and has been so far a theoretical conjecture of a form that should exist. It is conjectured that at even higher pressure, "superionic water" would form, where the oxygen crystallises and charged hydrogen float about in a lattice of oxygen atoms.

As this form of water would be electrically conducting, the reality in the interior of Neptune and Uranus, the giant ice planets, should be truly unusual. It is hence important to test the milestones of theoretical understanding, to devise ways to verify conjectures about the superionic state, or the dynamics of the interiors of the giant planets. It is conjectured that superionic water would be as hard as iron and glowing yellow in colour.

The paper in *Nature Physics* outlines the work done so far in compressing water to high pressures in diamond anvils, but says that unam-

Giant planets like Neptune could support superionic conduction

biguous verification of the high electrical conductivity expected in the superionic state has not been possible. Even dynamic shock compression has not been able to bring water to the stable superionic state as the rise in pressure has been too fast.

In the present study, the paper says, laser-driven shock compression was distributed over a series of steps, resulting in measuring much higher electrical conductivity. The unit used for measuring conductivity is the Siemens and the practical unit for water is the micro-S or the milli-S. The conductivity measured in the shock compression trials came to ~ 30 S/cm and in the reverberating shock trials it came to ~150 S/cm.

The emergence of high conductivity alone was not enough to show that the superionic state had been reached, as high conductivity was also possible with conduction by electrons in place of conduction by positively charged hydrogen atoms, or protons, the paper says. Further study was hence carried out, to observe the conditions in which electronic conduction set in and these were found not to be there in the reverberating shock experiments. The indication was hence, "Altogether, the new data provide experimental evidence for superionic conduction in water-ice at planetary interior conditions," the paper says.

"Considering the abundance of hydrogen and oxygen in the Solar System, and the stability of $H_2O$ molecules, water is expected to be an important planetary building block," the paper says, "As astronomical observations and extreme-condition laboratory experiments improve in the near future, we are confident that tying planetary modelling with the fundamental properties of planetary constituents should soon yield a better understanding of the diversity of icy planet formation, structure and evolution."

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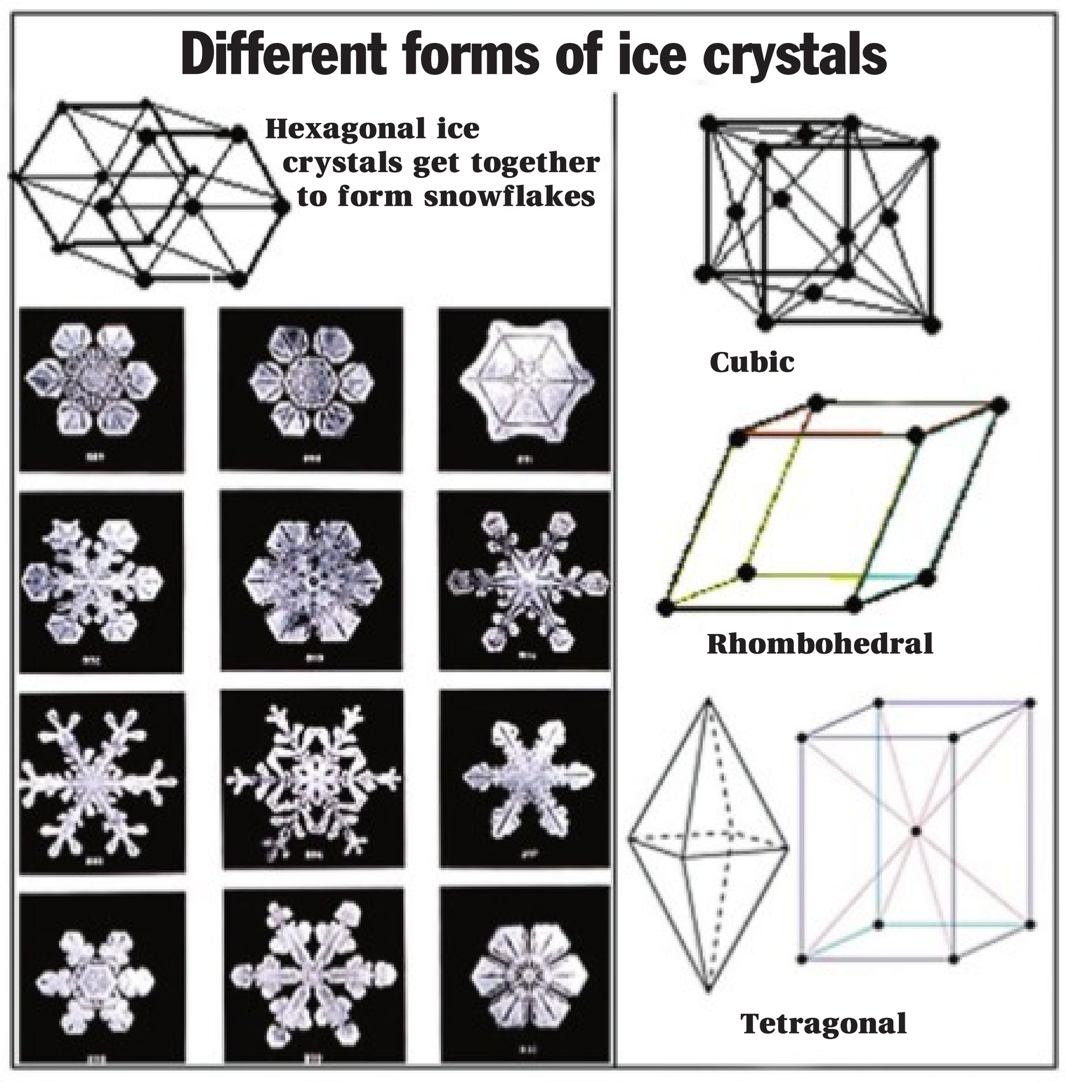
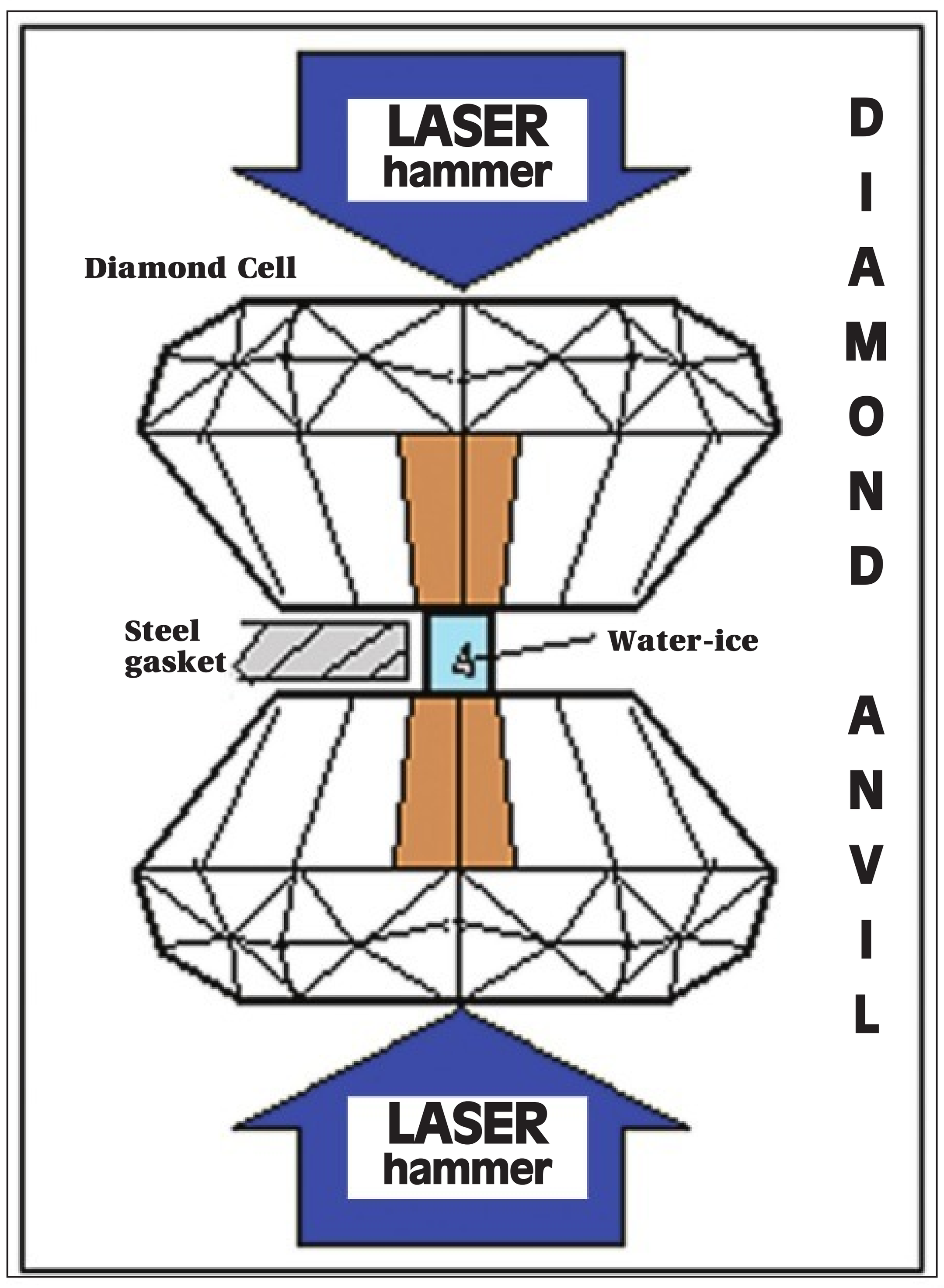



## PLUS POINTS

### Still light

Light normally travels at nearly 300,000 kilometres per second through space, but scientists have proposed a new way to bring it to a complete standstill.

In 2001, researchers worked out how to slow light down to a fraction of its original speed by trapping it in a cloud of ultra-cold sodium atoms. Another way to achieve the same result involves slowing light down using materials called photonic crystals.

Now in the journal, *Physical Review Letters*, scientists have outlined another theoretical method that makes use of a phenomenon termed "exceptional points". Exceptional points are when two different varieties or "modes" of light wave come together and combine into one mode, or "coalesce". When this happens, light stops in its tracks, but in most systems much of the light itself is also lost at these points.

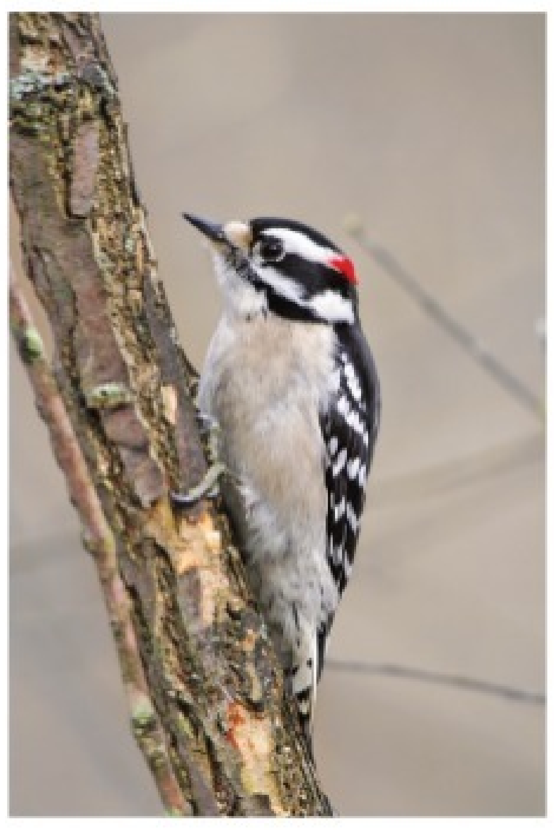
In their new paper, Dr Tamar Goldzak and Dr Nimrod Moiseyev at the Technion - Israel Institute of Technology, and Dr Alexei Mailybaev of Brazil's Institute for Pure and Applied Mathematics, proposed a way to stop light waves while preventing this loss using waveguides with something called "parity-time symmetry".

A waveguide is a physical structure that, as its name suggests, is used to guide the movement of waves. An optical fibre is an example of a waveguide that is used to transmit telephone signals. According to the scientists, waveguides could be used to adjust the two waves of light travelling through them, so that they balance each other out exactly. This would mean the light intensity remains constant as it approaches the exceptional point and stops.

"This result opens conceptually new possibilities for designing slow light devices, which exploit generic properties of the exceptional point and, therefore, may offer much larger freedom for technical implementation and operational capability," the researchers wrote.

The Independent

### Real head banger



For a person, slamming your head full force into a tree trunk could be enough to knock you silly. Woodpeckers do this, thousands of times during their lives, and these birds have thrived on Earth for some 25 million years.

But research published recently shows for the first time that all this pecking seems to carry consequences for the woodpecker's brain. Scientists said an examination found build-ups of a protein called tau in woodpeckers' brains that in people is associated with brain damage from neurodegenerative diseases and head trauma. The researchers examined brain tissue from Downy Woodpeckers and Red-winged Blackbirds, a non-pecking bird from collections at the Field Museum in Chicago and the Harvard Museum of Natural History. The woodpeckers had tau build-up while the blackbirds did not.

Boston University School of Medicine neuropathologist Peter Cummings, said, "One day in the lab I was talking to another professor about how we've designed different types of sports safety equipment, like football helmets, based on the biomechanics of the woodpecker, but no one had ever looked at a woodpecker brain."

Woodpeckers have several adaptations to mitigate the impact of pecking, involving their beak, skull, tongue and the space between their brain and skull. They face substantial g-force — the effect of acceleration on the body — from pecking for food like insects and tree sap or to attract mates. Pecking causes a force of up to 1,400 g's. A person can get a concussion from 60 to 100 g's.

The research was published in the journal, *PLOS ONE*.

The strait Times/ANN

# Aiming for the stars

## Some space advocates think the Falcon Heavy — being built by Elon Musk's SpaceX — could offer a quicker, cheaper path for Nasa to send astronauts back to the Moon

The cherry red Tesla Roadster inside the Falcon Heavy

KENNETH CHANG

On 16 July 1969, a towering Saturn 5 rocket sat on Pad 39A at Nasa's Kennedy Space Centre in Florida. At 9.32 am, the five enormous F-1 engines of its first stage ignited, expelling orange flame, dark smoke and 7.5 million pounds of thrust to lift the three astronauts of Apollo 11 into space. Buzz Aldrin and Neil Armstrong set foot on the Moon four days later.

Today, at that same launchpad, technicians working for SpaceX, Elon Musk's upstart rocket company, are preparing for the maiden flight of what is by most measures the world's most powerful rocket since the Saturn 5. The Falcon Heavy will be able to carry more than 140,000 pounds to low-Earth orbit, or more than twice as much as current competing rockets.

Aboard the demonstration flight, which may take off in the weeks ahead, will be a whimsical, cross-promotional payload for Musk — a cherry red Roadster built by his other business, the electric carmaker Tesla. The car is expected to travel around the sun in endless ellipses that extend as far out as the orbit of Mars.

Musk said on Twitter last month, "Payload will be my midnight cherry Tesla Roadster playing 'Space Oddity'. Destination is Mars orbit. Will be in deep space for a billion years or so if it doesn't blow up on ascent." When asked why, he replied in a tweet, "I love the thought of a car drifting apparently endlessly through space and perhaps being discovered by an alien race millions of years in the future."

Some space advocates think the Falcon Heavy could offer a quicker, cheaper path for Nasa to send astronauts back to the Moon. For SpaceX, the megarocket could help the company compete in new markets like the launching of large spy satellites for the US government. If successful, "it continues SpaceX's very impressive run of achieving launch milestones that have been viewed as very difficult", says Carissa Christensen, chief executive of Bryce Space and Technology, a consulting firm that follows the space industry.

But first, the Falcon Heavy has to get off the ground. That has been a long time coming, much longer than Musk originally promised.

SpaceX successfully launched 18 Falcon 9 rockets last year, a remarkable recovery from a launchpad mishap in September 2016 that destroyed a rocket and the $200m satellite on top. After years of falling short of optimistic predictions, SpaceX seemed to fall into a consistent, accident-free flow of sending payloads to orbit. For 14 of the launches, SpaceX landed the boosters, to be reused for future flights.

The Heavy — described by SpaceX as far back as 2005 — is essentially a Falcon 9 with two additional Falcon 9 boosters attached to the sides. That triples the horsepower of the rocket at liftoff. That approach allowed SpaceX to design a heavy-lift rocket largely by rearranging the same pieces.

"Because of the commonality between Falcon 9 and Falcon Heavy we're able to spread the overhead across both vehicles," Musk said at a news conference in 2011, "It's able to use the same tooling, be made in the same line, and I think therefore significantly improves the probability of being able to hold to our cost numbers."

SpaceX advertises a price tag of $90m for a Heavy launch. The modular design also cut the development costs of the rocket. "It is essentially the first time the nation has gotten a super heavy-lift vehicle at essentially zero cost to the taxpayer," says Phil Larson, an assistant dean at the University of Colorado's engineering school who previously worked at SpaceX.

In 2011, Musk said he expected that the Heavy would have its first flight in 2014. Now he admits that putting together the Falcon Heavy proved more daunting than he initially thought. "We were pretty naive about that," Musk said last July. "At first, it sounds really easy. Just stick two first stages on as strap-on boosters. How hard can that be? But then everything changes. All the loads change. Aerodynamics totally change. You've tripled the vibration and acoustics."

All of the parts of the Heavy finally arrived in Florida late last year. Since then, SpaceX has been modifying the launchpad to handle the larger rocket. In the coming days, the company is expected to conduct a critical test to light all 27 engines at once with the rocket anchored to the pad. If the test flight succeeds, SpaceX has four more Heavy launches scheduled, including one for the US air force.

Some wonder how much business exists for a rocket as big as the Heavy. "I've always scratched my head, why would you do this?" says Jim Cantrell, who was part of the founding team of SpaceX in 2002 but left soon afterward. He is now chief executive of Vector, which is building rockets much smaller than SpaceX.

Some suggest that Nasa could take advantage of the Falcon Heavy as a cheaper alternative to the Space Launch System it is developing to launch robotic probes and astronauts out into the solar system. Although the Nasa rocket would be larger and more powerful than the Heavy, it would fly only once every few years at a cost likely to exceed $1bn a launch.

The Trump administration has declared that sending astronauts back to the Moon is a priority and has advocated a greater role in the space programme for private companies. Its budget proposal for 2019 will be released this month.

Beyond the uncertain commercial prospects, Musk may be driven more by his long-term dreams of colonising the solar system. He has already described plans of an even larger rocket that could be used for sending people to Mars.

This year will be a busy one for SpaceX, which is aiming for more than 30 flights. It has also scheduled test flights of the Crew Dragon, the capsule it is building to carry Nasa astronauts to the International Space Station, although that date may slip again into 2019.

For the first flight of the Heavy, Musk has tamped down expectations. There is "a real good chance that that vehicle does not make it to orbit", Musk said in his July remarks. "I hope it makes it far enough away from the pad that it does not cause pad damage. I would consider even that a win."

Courtesy The New York Times/
The Independent