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# Water's quantum weirdness makes life possible

By Lisa Grossman



WATER'S life-giving properties exist on a knife-edge. It turns out that life as we know it relies on a fortuitous, but incredibly delicate, balance of quantum forces.

Water is one of the planet's weirdest liquids, and many of its most bizarre features make it life-giving. For example, its higher density as a liquid than as a solid means ice floats on water, allowing fish to survive under partially frozen rivers and lakes. And unlike many liquids, it takes a lot of heat to warm water up even a little, a quality that allows mammals to regulate their body temperature.

But computer simulations show that quantum mechanics nearly robbed water of these life-giving features. Most of them arise due to weak hydrogen bonds that hold  $H_2O$  molecules together in a networked structure. For example, it is hydrogen bonds that hold ice molecules in a more open structure than in liquid water, leading to a lower density. By contrast, without hydrogen bonds, liquid molecules move freely and take up more space than in rigid solid structures.

Yet in simulations that include quantum effects, hydrogen bond lengths keep changing thanks to the Heisenberg uncertainty principle, which says no molecule can have a definite position with respect to the others. This destabilises the network, removing many of water's special properties. "It breaks down big time," says Philip Salmon of the University of Bath in the UK.

How water continues to exist as a network of hydrogen bonds, in the face of these destabilising quantum effects, was a mystery.

In 2009, theorist Thomas Markland, now at Stanford University in California, and colleagues suggested a reason why water's fragile structure does not break down completely. They calculated that the uncertainty principle should also affect the bond lengths within each water molecule, and proposed that it does so in such a way as to strengthen the attraction between molecules and maintain the hydrogen-bond network. "Water fortuitously has two quantum effects which cancel each other out," Markland says.

Until recently, though, there was no way to discover whether there is any variation in bond length within the water molecule.

Now, Salmon's team has done this. Their trick was to use so-called heavy water, in which the molecule's two hydrogen atoms are replaced with deuterium. This isotope of hydrogen contains a neutron as well as a proton. The extra bulk makes it less vulnerable to quantum uncertainties. "It's like turning the quantum mechanics half off," says Chris Benmore, of the Argonne National Laboratory in Illinois, who was not involved in the study.

Salmon and colleagues shot beams of neutrons at different versions of water, and studied the way they bounced off the atoms – a precise way to measure bond lengths. They also substituted heavier oxygen atoms into both heavy and normal water, which allowed them to determine which bonds they were measuring.

They found that the hydrogen-oxygen bonds were slightly longer than the deuterium-oxygen ones, which is what you would expect if quantum uncertainty was affecting water's structure (*Physical Review Letters*, DOI: 10.1103/physrevlett.107.145501). "No one has ever really measured that before," says Benmore.

## **"Water fortuitously has two quantum uncertainty effects which cancel each other out"**

We are used to the idea that the cosmos's physical constants are fine-tuned for life. Now it seems water's quantum forces can be added to this "just right" list.

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