Tapping the incredible weirdness of water

We need to harness water's strange behaviour to make sure there's enough to go around says physicist **Marcia Barbosa**

I AM fascinated by water. We can all agree that a liquid that occupies 70 per cent of Earth's surface and two-thirds of our body is very important. However, when I tell friends and family that I have dedicated 15 years of my life to studying water, they look at me with pity. Don't we already know everything about water? Then they suggest that, as a physicist, I should be studying something less common, such as carbon nanotubes.

It is a mistake to underestimate water. The more you look into it, the less common it seems.

Water is weird. It has 72 anomalies – physical and chemical properties that are very different from other materials. For scientists, anomalies can be the basis of technological breakthroughs. This was the case with silicon – its unusual properties have given us semiconductors, and hence the digital technology that has transformed our lives.

But while silicon exhibits about a dozen anomalies, water has six times more. This is what allowed water to become central to the development of life.

What makes water so strange? Its most well known anomaly is the way its density changes with temperature. Most materials contract on cooling, so they occupy less volume when solid than when they are liquid. This is not the case with ice, which floats in water and takes up more space than liquid water. The most amazing thing, however, is that water at 0 °C floats on water at 4 °C. This means that at sub-zero temperatures, lakes and rivers freeze from the top to the bottom, leaving a lowest layer of warmer 4 °C water where fish and plants survive.

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Another atypical property of water is its high heat capacity, which means that a large amount of heat input is needed to raise its temperature. This anomaly makes water an excellent heat reservoir in our bodies and in our planet. It is also a good buffer against temperature swings, providing a stability that helped life to develop. The best technological tool that the anomalies of water have given us is life itself.

These properties are possible because water molecules form hydrogen bonds with each other. The peculiarity of these hydrogen bonds is that each molecule can form up to four of them, making a tetrahedral structure that is quite stable. This bonded network also contributes to the strange way water moves.

In most liquids, particles become less able to move as the material becomes denser. For water this is not the case. At high density – or under high pressure – the molecules move around faster, not slower as we would imagine. This is a bit like being able to move around more freely as you get squashed in a tightly packed crowd. This counter-intuitive behaviour means that when water is confined within carbon nanotubes, the molecules form a single line in the centre. This allows them to flow a thousand times faster than expected – a surprising discovery made in 2001. This "superflow" of water in nanotubes is the focus of my research.

This mechanism has long been exploited by nature. Biological channels such as the aquaporins in cell membranes have narrow pores that allow the rapid flow of water, just like in carbon nanotubes. They also have charged residue at the centre of the pore that repels salts. In this way, kidneys make use of these biological nanotubes to desalinate our bodily fluids, and do so in a very energy-efficient way. What if we could harness this desalination process outside the body?

PROFILE
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Ice takes up more room than liquid water – just one of its many quirks

Today, 1 in 6 people on Earth have limited access to clean water. But this is an even bigger problem than it first seems, because we don't just need water for drinking – we need it for eating too. Around 70 per cent of water consumption is used for agriculture, compared to 10 per cent for household use. By 2025, the world's population is expected to rise by another billion and, if nothing is done to address the issue, it is estimated that two-thirds of the population will be living in areas with a severe lack of fresh water.

To avoid this drastic scenario, measures are being taken to improve the water distribution infrastructure. However, this depends on existing amounts of fresh water. The only way to increase water supply on a large scale is

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desalination. The most common desalination procedures are distillation and reverse osmosis, which entails forcing salty water through a membrane that is impermeable to salt. These methods currently provide fresh water for 300 million people. But even running at optimal efficiency, they are still too expensive for many developing countries.

This is where work on water's weird properties comes in. Research is under way on at least three desalination technologies that rely on recent discoveries about water's anomolous superflow when confined to the nanoscale. One approach, already in production, is to use a membrane with aquaporins in combination with reverse osmosis, which can produce fresh water using less energy than reverse osmosis alone.

Another approach is to create an array of densely packed nanotubes that only allow the passage of water molecules, not salt. This speeds up the water flow and, in combination with reverse osmosis, is already being commercialised but still requires tests for long term stability and scale. The third method combines distillation, reverse osmosis and carbon nanotube superflow – a speedier method because it uses water vapour, which flows even faster.

Although these techniques have yet to be rolled out, it is hoped they will cut the high energetic cost of separating water from salt, especially with the advent of large scale, low cost production of carbon nanotubes and aquaporins.

But what happens in landlocked regions with no sea water? Here, some promising research on harvesting water from fog is in the early stages. The idea is to mimic the way insects such as the Stenocara beetle capture small water droplets from the atmosphere. This beetle has a water-attracting region on its back that transforms vapour into liquid water, then it uses gravity and a water-repelling region to bring the liquid to its mouth. Coupling a similar process with nanotube superflow can improve the efficiency of water collection.

Nature is already adept at exploiting water's strange behaviour. I have high hopes we too can exploit these properties to help solve the world's water shortage problems. ■