POPULAR SCIENCE PROJECT ABSTRACT

Water seems to be an uninteresting substance. It is transparent, tasteless, odorless, and above all ubiquitous (it is the second, behind hydrogen, the most common molecule in the Universe). Moreover, it was studied numerous times. Despite this, phenomena connected to water are not completely understood. Although a very simple structure (just two hydrogen atoms attached to a single oxygen atom), water behaves differently than most substances. It can be observed in everyday life, for example, ice floats on water. Already 300 years ago first unusual property of liquid water was recognized: whereas most liquids contract with decreasing temperature, water begins to expand when its temperature drops below 4 °C. It can be tested in a simple kitchen experiment in a glass of unstirred iced water. The bottom layer remains at 4 °C while colder layers “float” on top. The temperature at the bottom remains constant until all the ice has melted. This and several other unintuitive behaviors of water are called water anomalies. They become more pronounced if carefully cooled below 0 °C water avoids freezing (the supercooled state). Some properties extrapolated to lower temperatures appear to become infinite at the temperature -of 45 °C, which is unreachable for liquid water, in so-called “no man’s land”.

One of the ways to reach “no man’s land” is by confining the water in voids of the size of several billionths of a meter. Such nanovoids are present inside mesoporous materials, forming together a significant amount of empty space, where water can be introduced and cooled. Although confined water does not crystalize during cooling, it does not remain liquid either. Instead, it becomes glassy water (also called amorphous ice), which is solid, but its structure exhibits a disordered liquid-like arrangement. In nanovoids, water behavior is partially determined by its interaction with the walls of the confinement. Therefore, the transition temperatures between the liquid phase, intermediate plastic phase, and glassy phase are shifted according to non-confined water. To find what they would be for normal water various amounts of water filling different mesoporous materials can be used. It should allow us to understand the influence of confinement on water properties. Another difficulty is probing the properties of water confined in such small voids. Fortunately, this is possible with a method called positron annihilation lifetime spectroscopy.

Positrons are antimatter particles. Among others, they are emitted during the decay of certain radioactive isotopes, which exist in small amounts even in the human body. If a positron encounters an electron, they both annihilate, which consists in changing the mass of these particles into energy. This energy is emitted as electromagnetic radiation, which can be detected and thereby confirm an annihilation occurrence. Also, the moment of positron formation can be detected for some radioisotopes, which emit positron and electromagnetic radiation with characteristic energy almost simultaneously. This is used to measure the lifetime of the positron, the period that elapsed from its formation to annihilation. This time depends on how easily a positron can encounter an electron, and thus on the structure of the material in which a positron annihilates. Instead of immediate annihilation with an electron, a positron can “intercept” it and create a positronium atom. It is the equivalent of a hydrogen atom, in which the nucleus has been replaced by a particle of antimatter. In a vacuum, one of the two forms of positronium, ortho-positronium, can survive relatively long (millionths of a second) before annihilating. However, if the ortho-positronium is trapped in a material, it annihilates significantly faster meeting “foreign” electrons. As in the case of the positron, its lifetime depends on the environment, namely the size of the space where the positronium annihilates. On this basis, one can specify the number and size of free volume in the material. This allows for the distinction of various solid phases as well as liquid, where ortho-positronium “pushes” water molecules creating a bubble of size depending on liquid surface tension.