The Fourth Phase of Water: Beyond Solid, Liquid, and Vapor

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How can a Jesus Christ lizard walk on water? Why do pollen grains jitterbug in a puddle? Why do fair weather clouds form such lovely puffy white shapes? Why do your joints work without squeaking? Why do sprained ankles swell within seconds?

Answering these questions requires an understanding of water. Given water's simplicity and pervasiveness through nature, we presume that water must be completely understood, but in fact precious little is known about how water molecules line up — until recently.

Students learn that water has three phases: solid, liquid and vapor. But there is something more: in our laboratory at the University of Washington we have uncovered a *fourth* phase. This phase occurs next to water loving (hydrophilic) surfaces. It is surprisingly extensive, projecting out from surfaces by up to millions of molecular layers. And it exists almost everywhere throughout nature, including your body.

This newly identified phase of water has been described in a recent book: *The Fourth Phase of Water: Beyond Solid, Liquid and Vapor*. The book documents the basic finding and presents many applications including the ones mentioned above. It also deals with water's many anomalies, turning those anomalies into easily explained features.

The existence of a fourth phase may seem unexpected. However, it should not be entirely so: a century ago, the physical chemist Sir William Hardy argued for the existence of a fourth phase; and many authors over the years have found evidence for some kind of "ordered" or "structured" phase of water. Fresh experimental evidence not only confirms the existence of such an ordered, liquid-crystalline phase, but also details its properties. Those properties explain everyday observations and answer questions ranging from why gelatin desserts hold their water, to why teapots whistle.

The presence of the fourth phase carries many implications. Here, I outline some basic features of this phase, and then deal with several of those implications. I will touch on atmospheric science, and then focus on some biological and health applications.

Does Water Transduce Energy?

The energy for building water structure comes from the sun. Radiant energy converts ordinary bulk water into ordered water, building this ordered zone. We found that all wavelengths ranging from UV through visible to infrared can build this ordered water. Near-infrared energy is the most capable. Water absorbs infrared energy freely from the environment; it uses that energy to convert bulk water into liquid crystalline water (fourth phase water) — which we also call “exclusion zone” or “EZ” water because it profoundaly excludes solutes. Hence, buildup of EZ water occurs naturally and spontaneously from environmental energy. Additional energy input creates additional EZ buildup.

Of particular significance is the fourth phase’s charge: commonly negative (Figure 1). Absorbed radiant energy splits water molecules; the negative moiety constitutes the building block of the EZ, while the positive moiety binds with water molecules to form free hydronium ions, which diffuse throughout the water. Adding additional light stimulates more charge separation.

This process resembles the first step of photosynthesis. In that step, energy from the sun splits water molecules. Hydrophilic chromophores catalyze the splitting. The process considered here is similar but more generic: any hydrophilic surface may catalyze the splitting. Some surfaces work more effectively than others.

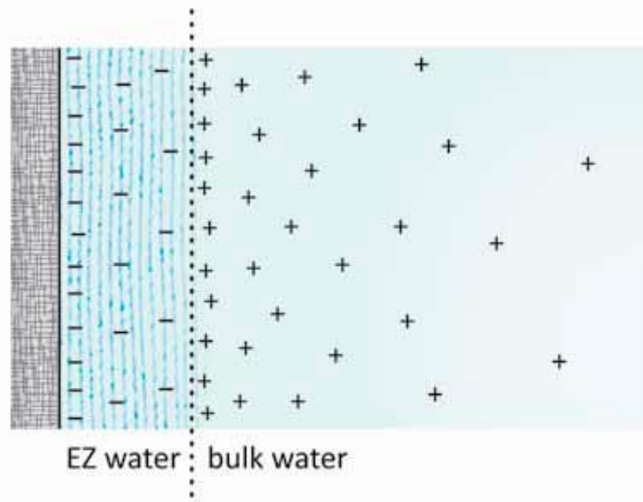

Figure 1. Diagrammatic representation of EZ water, negatively charged, and the positively charged bulk water beyond. Hydrophilic surface at left.

The separated charges resemble a battery. That battery can deliver energy in a manner similar to the way the separated charges in plants deliver energy. Plants, of course, comprise mostly water, and it is therefore no surprise that similar energy conversion takes place in water itself.

The stored electrical energy in water can drive various kinds of work, including flow. An example is the axial flow through tubes. We found that immersing tubes made of hydrophilic materials into water produces flow through those tubes, similar to blood flow through blood vessels (Figure 2). The driving energy comes from the radiant energy absorbed and stored in the water. Nothing more. Flow may persist undiminished for many hours, even days. Additional incident light brings faster flow. This is not a perpetual motion machine: incident radiant energy drives the flow — in much the same way that it drives vascular flow in plants. And, we have fresh evidence (see below) that it also assists the heart in driving blood in the cardiovascular system.

Applications in Biological Flow and Atmospheric Science

The water-based energy conversion framework is rich with implication for many systems involving water. These systems may range from biology and chemistry all the way to atmospheric science and engineering. The fourth phase appears nearly everywhere: all that's needed is water, radiant energy, and a hydrophilic surface. The latter can be as large as a slab of polymer and as small as a dissolved molecule. The liquid crystalline phase inevitably builds — and its presence plays some integral role in the system's behavior.

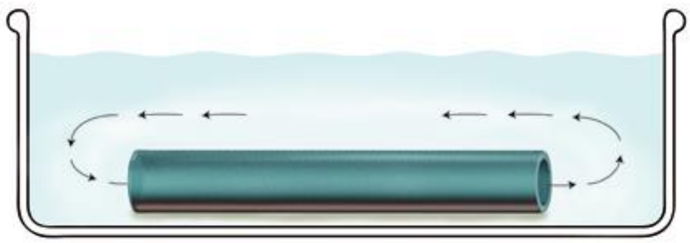

Figure 2. Practically incessant flow occurs through hydrophilic tubes immersed in water.

Let me provide a few representative examples.

One example is…you. Two thirds of your cells are water — by volume. In terms of the molecular fraction, that fraction translates to more than 99% because so many of those diminutive molecules are required to build that two-thirds volume fraction. Modern cell biology considers that 99% fraction of your molecules as mere background carriers of the "important" molecules of life such as proteins and nucleic acids. Conventional wisdom asserts that 99% of your molecules don't do very much.

However, EZ water envelops every macromolecule in the cell. Those macromolecules are so tightly packed that the enveloping liquid crystalline water largely fills your cells. In other words most of your cell water is liquid crystalline, or EZ water. This water plays a central role in everything the cell does — as elaborated in my earlier book, *Cells, Gels and the Engines of Life*.

What's new is the role of radiant energy: incident radiant energy powers many of those cellular functions. An example is the blood flowing through your capillaries. That blood eventually encounters high resistance: capillaries are often narrower than the red blood cells that must pass through them; in order to make their way through, those red cells need to bend and contort. Resistance is high. You'd anticipate the need for lots of driving pressure; yet, the pressure gradient across the capillary bed is negligible. The paradox resolves if radiant energy helps propel flow through capillaries in the same way that it propels flow through hydrophilic tubes. Radiant energy may constitute an unsuspected source of vascular drive, supplementing cardiac pressure.

Why you feel good after a sauna now seems understandable. If radiant energy drives capillary flow and ample capillary flow is important for optimal functioning, then sitting in the sauna will inevitably be a feel-good experience. The infrared energy associated with heat should help drive that flow. The same if you walk out into sunlight: we presume that the feel-good experience derives purely from the psychological realm; but the evidence above implies that sunlight may build your body's EZs. Fully built EZs around each protein seem necessary for optimal cellular functioning.

A second example of the EZ's central role is weather. Common understanding of weather derives from two principal variables: temperature and pressure. Those two variables are said to explain virtually everything we experience in terms of weather. However, the atmosphere also contains water: it is full of micrometer-scale droplets commonly known as aerosol droplets or aerosol particles. Those droplets make up atmospheric humidity. When the atmosphere is humid, the many droplets scatter considerable light, conferring haze; you can't see clearly through that haze. When the atmosphere contains only few droplets, you may see clearly, over long distances.

The Fourth Phase book presents evidence for the structure of those droplets. It shows that EZ water envelops each droplet, while hydronium ions occupy the droplets' interior. Repelling one another, those internal hydronium ions create pressure, which pushes against the robust shell of EZ water. That explains why droplets tend toward roundness.

How do those aerosol droplets condense to form clouds? The droplets' EZ shells bear negative charge. Negatively charged droplets should repel one another, precluding any condensation into clouds. Those like-charged aerosol droplets should remain widely dispersed throughout the atmosphere. However, droplets *do* often condense into clouds, and the question is how that can happen.

The reason they condense is because of the unlike charges that lie in between the droplets. Richard Feynman, the legendary Nobel Prize physicist of the late 20th century understood the principle, opining that: "like-likes-like because of an intermediate of unlikes." The like-charged droplets "like" one another, so they come together; the unlike charges lying in between those droplets constitute the attractors (Figure 3).

The like-likes-like principle has been widely appreciated, but also widely ignored: after all, how could like charges conceivably *attract*? A reason why this powerfully simple concept has been ignored is that the source of the unlike charges has been difficult to identify. We now know that the unlike charges can come from the splitting of water — the negative components building EZ shells, while the corresponding positive components provide the unlike attractors. With enough of those attractors, the negatively charged aerosol droplets may condense into clouds.

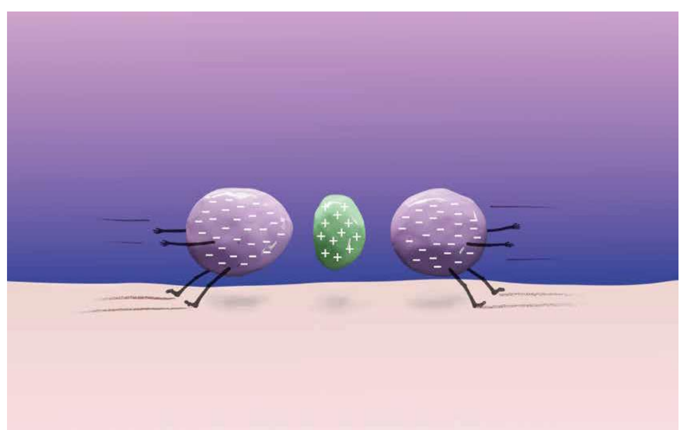

Figure 3. Like-charged entities attract because of an intermediate of opposite charge.

These two phenomena, radiant energy-induced biological function and like-likes-like cloud formation, provide examples of how water's energy can account for phenomena not otherwise explained. The fourth phase is the key building block that allows for construction of an edifice of understanding.

Practical Applications

Beyond scientific, the discovery of the fourth phase has practical applications. They include flow production (already mentioned), electrical energy harvesting, and even filtration. I briefly mention the latter two applications.

Filtration occurs naturally because the liquid crystalline phase massively excludes solutes and particles in much the same way as does ice. Accordingly, fourth phase water is essentially solute free. Collecting it provides solute-free and bacteria-free water. A working prototype has confirmed this expectation. Purification by this method requires no physical filter: the fourth phase itself does the separation, and the energy comes from the sun.

Energy harvesting seems straightforward: light drives the separation of charge, and those separated charges constitute a battery. Harvesting electrical energy should be realizable with proper electrodes. This technology development is underway in our laboratory, and has the potential to replace standard photovoltaic systems with simpler ones based on water. More detail on these practical applications can be found in the Pollack laboratory homepage: <http://faculty.washington.edu/ghp/>.

Practical applications also exist within our bodies, and I present two of them: why your joints don't squeak: and why dislocated or sprained joints will swell *within seconds*.

Joints are sites at which bones press upon one another (Figure 4). The bones may also rotate, as during deep-knee bends and push-ups. You'd think that rotation under pressure might elicit squeaky frictional resistance, but joint friction remains remarkably modest. Why so?

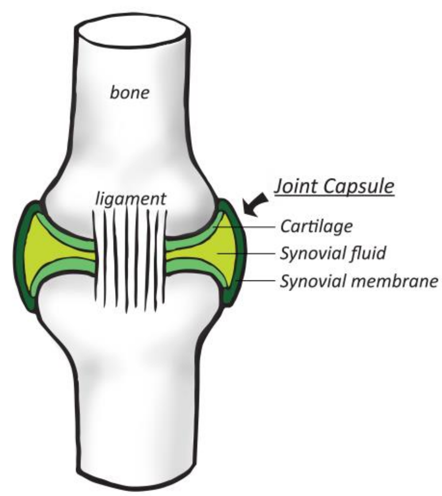

Figure 4. Enveloping the joint, the capsule ensures that the fluid's hydronium ions don't disperse. The concentrated hydronium ions repel, keeping surfaces apart and assuring low friction.

The ends of bones are lined with cartilage. Those cartilaginous materials do the actual pressing. Hence, the issue of joint friction reduces to the issue of the cartilaginous surfaces and the synovial fluid lying in between. How does this system behave under pressure?

Cartilage is made of classic gel materials: highly charged polymers and water; therefore, cartilage is a gel. Gel surfaces bear EZs, so cartilage surfaces should likewise bear EZs. The splitting of water associated with EZ buildup creates many hydronium ions in the synovial fluid between. Additional hydronium ions come from the molecules within that fluid, creating their own EZs and protons. Thus, many hydronium ions will lie in the area where two cartilaginous surfaces lie across from one another. The repulsive force coming from those hydronium ions should keep the cartilage surfaces apart — some investigators maintain that the cartilage surfaces never touch, despite heavy loads. That separation means that any rough spots, or asperities, will never come into contact as the respective surfaces shear past one another; and that in turn means low friction.

For such a mechanism to actually work some kind of built-in restraint should be present to keep the repelling hydronium ions in place. Otherwise, they may be forced out of the local region, thereby compromising lubrication. Nature provides that safety net: a structure known as the joint capsule envelops the joint. By constraining the dispersal of hydronium ions, that encapsulation ensures low friction. That's why your joints don't ordinarily squeak.

Regarding swelling, the second issue under consideration, osmosis evidently plays a role. Since the cell is packed with negatively charged proteins, the cytoplasm should generate an osmotic draw similar to the osmotic draw generated by diapers or gels. Physiologists know that it does.

A peculiar feature of cells, however, is their relatively modest water content. Compared to 20:1 or higher for many common gels, the cell's water-to-solids ratio is only about 2:1. The many negatively charged macromolecules of the cell should generate a strong osmotic draw; yet the water content in the cell remains surprisingly low. That limited water content may come as a consequence of the macromolecular network's stiffness: cellular networks typically comprise tubular or multi-stranded biopolymers tightly cross-linked to one another. The resultant stiffness prevents the network from expanding to its full osmotic potential.

If those cross-links were to disrupt, however, then the full power of osmotic draw would take effect; the tissue could then build many EZ layers and therefore hydrate massively, bringing huge expansion (Figure 5). That's what happens when body tissues are injured, especially with dislocations. The injury disrupts fibrous macromolecules and cross-links, eliminating the restraining forces that keep osmosis at bay; EZ buildup can then proceed virtually unimpeded.

Figure 5. Example of post-injury swelling.

The reason why swelling can be so impressive is that the cross-link disruption occurs progressively. Breaking one cross-link results in higher stress on neighboring cross-link; so disruption progresses in a zipper-like fashion. When that happens, the osmotic rush of water into the tissue can continue practically without restraint, resulting in the enormous immediate swelling that is often seen. The tissue will return to normal only when cross-links repair and the matrix returns to its normally restraining configuration.

Water and Healing

During childhood illness, grandmothers and doctors will often advise: "drink more water." In his now-classical book, sub-titled *Your Body's Many Cries for Water: You Are Not Sick, You Are Thirsty*, the Iranian physician Fereydoon Batmanghelidj confirms the wisdom of this quaint advice The author documents years of clinical practice showing reversal of diverse pathologies simply by drinking more water. Hydration is critical.

Batmanghelidj's experience meshes with evidence of healing from special waters such as those from the Ganges and Lourdes. Those waters most often come from deep underground springs or from glacial melt. Spring waters experience pressure from above; pressure converts liquid water into EZ water because of EZ water's higher density. So, spring water's healing quality may arise not only from its mineral content but also from its relatively high EZ content.

The same for mountain water: it too should have high EZ content. Our studies have shown that ice formation requires an EZ intermediate; i.e., bulk water does not convert directly to ice; it converts to EZ, which then converts to ice. Similarly for melting: melting ice forms EZ, which subsequently converts to bulk water. Fresh ice melt contains abundant EZ water.

For spring water and fresh ice melt, then, the high EZ content may explain the recognized health benefits. EZ water should rehydrate tissues better than ordinary water because of its higher dipole moment. To appreciate this argument, picture a bean with positive charge localized at one end, negative at the other. The positive end of that dipole orients toward the negatively charged cell, which then strongly draws in that dipole. The larger the dipole, the stronger will be the draw. Since EZs contain masses of separated charges, or large dipoles, EZ water should hydrate cells better than ordinary water. That's why EZ water may particularly promote good health.

Negative Charge and Anti-Oxidants

Humans are considered neutral, but I suggest that we bear net negative charge.

Physical chemists reasonably presume that all systems tend toward neutrality because positive charge attracts negative charge. The human body being one of those "systems," we assume that the body must be neutral.

Not all systems are neutral, however. The earth bears net negative charge, while the atmosphere bears net positive charge. Water itself can bear charge: Anyone watching MIT professor Walter Lewin's stunning demonstration of the Kelvin water dropper, where separated bodies of water eventually discharge onto one another, will immediately see that bodies of water *can* bear net charge. If any doubt remains, then the experience of getting an electric shock from touching certain kinds of drinking water (which my colleagues and I have personally experienced) should eliminate that doubt.

Charges can remain separated if input energy keeps them separated — something like recharging your cell phone battery and creating separated negative and positive terminals. Since we constantly absorb external energy from the environment, the theoretical possibility exists that we may bear net charge.

Consider the arithmetic. Cells make up some 60% of your body's mass, and they are negatively charged. Extracellular tissues such as collagen and elastin are next in line, and those proteins bear negative charge and adsorb negatively charged EZ water. Only some of the smaller compartments are positively charged with protons (low pH), and they commonly *expel*: urine, gastrointestinal system; sweat, and expired air (containing hydrated CO_2 or carbonic acid). They help *rid* the body of positive charge.

So, the arithmetic shows not only that our body bears net negative charge, but also that the body makes every effort to maintain that negativity by ridding itself of protons. It is as though maintaining negativity is a "goal" of life. Plants do it easily: they connect directly to the negatively charged earth; animals need to struggle a bit more to maintain their body's charge, in exchange for greater mobility.

How does our body's negative charge relate to the benefits of anti-oxidants?

Answering this question returns us to basic chemistry. Recall that "reduction" is the *gain* of electrons, while "oxidation" means electron *loss*. Oxidation strips molecules of their negative charge, working against the body's attempt to maintain high negativity. To guard against that loss we employ *anti*-oxidants. Anti-oxidants may keep us healthy simply by maintaining proper negativity.

The Future

Water's centrality for health is nothing new, but it has been progressively forgotten. With the various sciences laying emphasis molecular, atomic, and even sub-atomic approaches, we have lost sight of what happens when the pieces come together to form the larger entity. The whole may indeed exceed the sum of its parts. 99% of those parts are water molecules. To think that 99% of our molecules merely bathe the "more important" molecules of life ignores centuries of evidence to the contrary. Water plays a central role in all features of life.

Until recently, the understanding of water's properties has been constrained by the common misconception that water has three phases. We now know it has four. Taking into account this fourth phase allows many of water's "anomalies" to vanish: those anomalies turn into predictable features. Water becomes more understandable, and so do entities made largely of water, such as oceans, clouds, and human beings.

Various hour-long talks describe these fresh understandings. One of them is a University of Washington public award lecture. Another was delivered more recently, link. And here are two TEDx talks: TEDx GuelphU, TEDx NewYorkSalon.

A much fuller, well-referenced understanding of these phenomena and more appears in the above-mentioned new book, *The Fourth Phase of Water: Beyond Solid, Liquid, and Vapor*.

The insights described above arose out of a departure from mainstream science. They were gleaned mainly from simple observations and logical interpretations. I have purposefully ignored the "generally accepted," with some skepticism that all accepted principles are necessarily valid. I believe this skepticism has brought us a long way.