A blue-tinted photograph of water splashing over a grassy field under a cloudy sky. The water is captured in mid-air, creating a dynamic, flowing shape that spans across the middle of the frame. Below the water, a field of tall grass is visible, and above it, a bright blue sky with scattered white clouds. The overall composition is clean and minimalist, focusing on the natural elements of water and grass.

Water

Vincent Kotwicki

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Water is best

So, here we are. Traveling through space and time at inconceivable speeds on a veneer-thin crust of a gigantic ball of molten iron, basking in the scorching light of our mother star, and protected by a minute layer of air from the frigid and deadly realms of outer space. Welcome to *Spaceship Earth*.

This is our home. In time, we might roam galaxies, other universes, different spaces, dimensions, and times, but right now, Earth is the only home we have.

Everything that we see around us was created by water. Every tiny detail of the landscape, every living cell and elephant, every feeling that we experience is because of water. For nothing is more important for us than water, never was, nor ever will be. And, if we are alone in the Universe, then we, the *children of water on Earth*, may hold the key to its ultimate fate.

Water is our absolute and wonderful treasure. Naturally, of all things that exist, water is closest to us, as we are, physically, mostly water. Certainly, we are not water only, but we could fondly say that we are *18-karat water*. Water is the source, the matrix, and the medium of all life on Earth—and, since it is likely to have been instrumental in the birth of the Solar System, it is the seed of everything we know. This World of ours, with its ongoing informational, biotechnics and quantum revolutions, is the World where the fire of technology meets the watery flux of nature. We have achieved a great deal of understanding in our reductionist pursuit of H₂O. However, water is more than the sum of its molecules, and we need improve also our appreciation of the holistic angle of water, and its role in fostering everything that we see.

This book presents in one volume—after a fleeting glimpse of the nature of water, which in itself would require a whole library of far more substantial volumes—an overview of the occurrence of water on Earth as a world-shaping and life-giving fluid, and its significance for the wellbeing of the planet, including us.

Because, in our World, water is simply everything that is.



Above: The nature of water is most familiar to us from our own perspective, in logarithmic terms, half-way between the domains of general relativity and quantum mechanics. While we have some modicum of understanding of our watery neighbourhood, much has yet to be learned at the extremities of this scale, since the nature of water seems to exercise influence over the whole spectrum.



Water is best

Thales

If this book was reduced to one statement, this would be it.

Everything under the Sun was created by water



A drop of water

Water, water, everywhere, And all the boards did shrink; Water, water, everywhere, Nor any drop to drink.

The Rime of the Ancient Mariner
Samuel Coleridge, 1798

A few drops of water...

a glass of water	5000 drops
a human	1 million drops
Earth	100 trillion trillion (10^{26} drops)
1 drop of water	$1.5 \cdot 10^{21}$ molecules
1 g of water	$3.3 \cdot 10^{22}$ molecules
1 km ³ of water	$3.3 \cdot 10^{37}$ molecules
Earth	$4.5 \cdot 10^{46}$ molecules

Facts and Figures

- A drop of water is a trademark of water, and in a way, a symbol of life.
- Water is unique in so many of its properties that it stands alone as the most remarkable liquid on Earth.
- Liquid water is dotted with regions of 50 to 100 constantly reforming tetrahedrally arranged molecules, that stay put for less than a trillionth of a second.
- If everyone were a drop of water, they could fill an Olympic-sized pool.
- A large tip, held vertically, may yield 20 drops of water per mL. A tiny tip may yield 50 drops per mL.
- The size of droplets in the atmosphere ranges widely; drops in liquid aerosol solutions are 2 µm in diameter, cloud droplets have diameters in the range of 5-70 µm, while rain droplets range from 0.1 to over 3 mm in diameter.
- A single drop of water can contain as many as 50 million bacteria, the tiniest free-living cells.
- Water's density decreases as it approaches the liquid-vapour interface. This phenomenon, known as *surface relaxation*, increases the reactivity of molecules in this interfacial region.
- A drop of seawater may contain 50 billion viruses.
- A drop of watery solution can hold a trillion of biological nanocomputers that coexist and compute in parallel.
- 1 mole H₂O = 18 g H₂O = $6.02 \cdot 10^{23}$ molecules.
- An *attosecond* is to a *second* as a second is to 32 million years.
- Scientists have long pondered the orientation of water molecules at the surface of water, which is critical to the behaviour of the liquid.

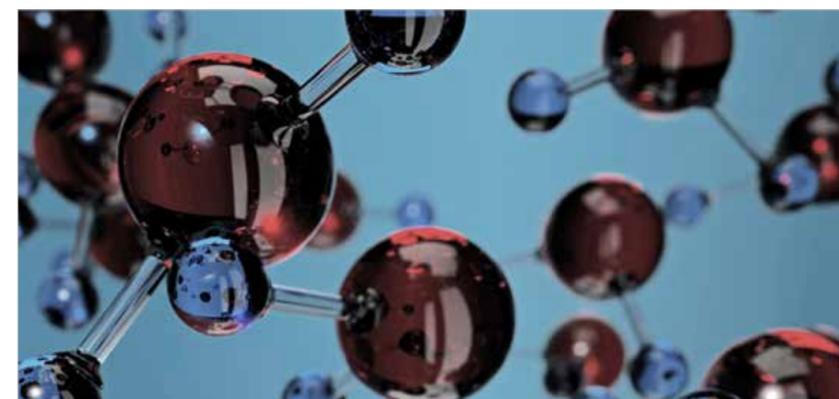
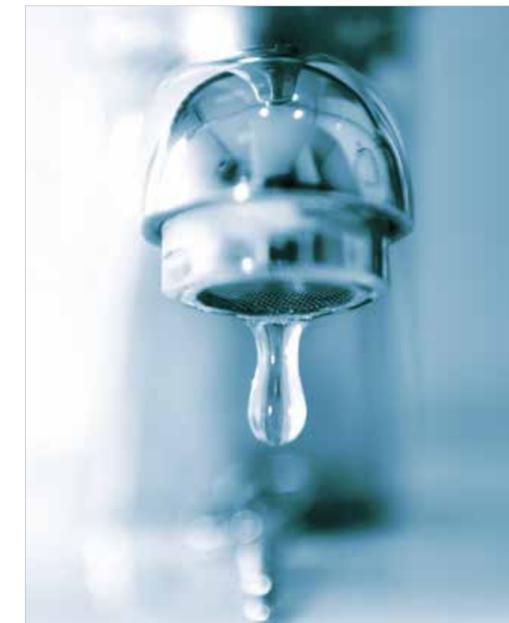
A drop of water

Every journey starts with a step and our journey of water wonders starts with a single drop of water. The humble, yet proverbial, every drop counts is a formidable entity. Just as much as a poet can see the Universe in a grain of sand, a scientist can observe it even more clearly in a drop of water.

Many books on the Pacific Ocean have been written but few on a drop of water. But then, it is easier to write a book on an ocean than one on a drop of water, since *the devil, as they say, lies in the details*. To contemplate a tiny drop of water requires supreme effort, since we are naturally primed to think big. We seem to understand what is happening in outer space on timescales of zillions of years and at distances of billions of light years, but we are pretty hazy around the edges on the happenings of a drop of water on a scale that is relevant to atoms. Things are happening there, but what are they? Much of the mystery is happening right in front of our eyes. While we are not accustomed to paying attention to nanoscales, life actually operates on these scales, and the matrix of the Universe on scales that are even smaller still. We look in awe at the mystery far off in outer space, but the mystery is right here, tantalizingly close, fiendishly hard to grasp, and unbeknownst in its vastness. The distance to the heart of the matter appears to be much greater than that to the edge of the observable Universe.

Coming back to the topic at hand, drops of water come in different shapes and sizes. It takes about fifty mid-size drops to make one gram of water, or several thousand to make a cup of tea, while many more drops need to be crafted together to make an ocean. We say *similar as two drops of water*, but are they actually the same? Everyone knows that snowflakes are lovely, white, and hexagonal, and each of them different to boot, but when it comes to water, we tend to see, by default, all drops as being more or less identical, well, mostly so. Nothing can be further from truth, though, since it can be successfully argued that no two drops of rain on Earth have been identical since the creation of our planet, when their masses, compositions and behaviour are taken into account on sufficiently short timescales. This is because a drop of water consists of ever-changing and reforming clusters of molecules: one could even venture to say that water *is perfectly balanced in constant motion*, and using a political parallel, a true democracy of molecules. Its structure is a matter of considerable research, with numerous working models; none of which, however, being able to fully describe the behaviour of the liquid in question.

So, looking at the World Ocean as a conglomerate of water drops appears to be easier than looking at a drop of water as a conglomerate of molecules. A physicist would say that it is even more difficult to look at a molecule as a conglomerate of its building blocks, whether they are quarks, leptons, and bosons, or elusive superstrings still to be discovered, but that is another story and should be told another time. Let us turn a leaf then, and give a thought to the *nature of water*, as a substance that harbours, and perhaps, creates life. For we do not know yet: perhaps life emerged somewhere in outer space and descended to our planet, perhaps it originated on Earth, or perhaps it is being created all day long everywhere. But one thing we know for sure; here or in the immensity of the heavens, in the eternity of the past or right now, there is only one substance that can kick-start life from lifeless matter and this substance is *water*. Whether it was an opportune one-off event here or there, or an all encompassing and ongoing process, life starts in a drop of water.



Top left: A drop in the ocean is a proverbially small quantity, and while it is indeed small, mathematics has a tidy number for it: it takes 20^{26} or 100 trillion trillion drops of water to form the World Ocean, a quantity comparable to the number of stars in the observable Universe.

Top right: When a drop of water comes out of a faucet, it has a tear shape, because the top of the water drop sticks to the water still in the faucet until it cannot hold on any longer.

Middle right: We need to drink a few litres of water per day, because one drop of water keeps us running for only about a second.

Bottom right: Drops of water come in many shapes and sizes, and it can be successfully argued that none of them are identical.

Bottom left: H₂O is a symbol of a molecule. Water is an environment of interacting H₂O molecules.



The nature of water

The nature of water is *beneficent*. An inquisitive thinker has said that the highest goodness is like water, for water is excellent in benefiting all things, and it does not exert effort. It occupies the lowest place, which men abhor, and, therefore, it is near akin to the Eternal.

The nature of water is *creative*. Through the intricate workings of water our consciousness was brought from non-existence into existence.

The nature of water is *merciful*. With our innate reverence for water rapidly vanishing in our insatiable pursuit of progress, we abuse, pollute and mismanage this essence of life, yet it gracefully purifies itself, and is always ready to serve, softer than a breeze and more everlasting than a rock.

The nature of water is *mysterious*. While a philosopher may ponder whether H₂O is *water* or merely *constitutes water*, water as H₂O actually does not exist: it is a mixture of 33 substances in relationships that change on unimaginably short time scales.

The nature of water is *dominant*. Water, the second most common molecule in the Universe and the most abundant solid material in space, is crucial to the formation of stars and planetary systems, and is the basis of the only form of life that we know.

The nature of water is *fundamental*. While Earth revolves graciously around the Sun, our human world rotates solely around water, whether we recognize it or not. The planet responds to the rhythm of water; it controls the environment, society, economy, settlement and is the most important factor in climate change. Water is the centrepiece, the cornerstone of human behaviour.

The nature of water is *hidden*. Water is usually perceived to be common as it is transparent, odourless, tasteless and omnipresent, while in fact, it is the most extraordinary substance, which has received more attention than any other area of human inquiry. And yet, who can confidently say that we know more than we do not know about water?

The nature of water is *irresistible*. This most common liquid is credited with a multitude of seemingly unusual properties, which some scientists call *anomalous*, while others point out that they can be duly expected. The small size of its molecules belies the complexity of its interactions and fascinating capabilities.

The nature of water is *all-encompassing*. A progression of cosmologies, from

shamanist through religious to scientific, have always maintained water as the focal point, the nucleus so to speak. Liquid water's extraordinary properties and chameleon-like nature seem to fit ideally into the requirements for life, but it creates a feeling of wonder: why water is the way it is?

The nature of water is *multi-faceted*. Since the stuff is really important, people make a variety of claims on its behalf—water has memory, metaphysical powers, and is even alive. While the scientific evidence for such claims is generally in short supply, enthusiasts point out that an *absence of evidence is not evidence of absence*. We come across *living water* and *water of life* every day phrases from childrens bedtime stories to adult life. Are they only metaphors, or is there something more to them?

The nature of water is *magnificent*, and paraphrasing Apostle John, we could say that *if one wanted to write down all that could have been written about water, the whole Earth would not be able to contain all of the books that would have to be written*.

The nature of water is the very nature of us.



Water and the Sage

Of all the elements, the Sage should take water as his preceptor. Water is yielding but all-conquering. Water extinguishes Fire or, finding itself likely to be defeated, escapes as steam and reforms. Water washes away soft Earth or, when confronted by rocks, seeks a way around. . . . It saturates the atmosphere so that Wind dies. Water gives way to obstacles with deceptive humility, for no power can prevent it following its destined course to the sea. Water conquers by yielding; it never attacks but always wins the last battle.

Taoist poet Tao Cheng, China, 11th century



The waters

First God made Heaven and Earth. The Earth was without form and void, and darkness was upon the face of the deep; and the Spirit of God was moving over the face of the waters.

Genesis, 1:1,y

A few technicalities

Systematic name	Water
Other names	Hydrogen oxide, Hydrate, Hydrogen hydroxide, Hydric acid, Hydroxic acid, Dihydrogen monoxide, Hydrohydroxic acid, Oxidane, μ-Oxido dihydrogen
Molecular formula	H ₂ O or H ₂ O
Molar mass	18.01524 g·mol ⁻¹
Appearance	Transparent, with a hint of blue
Density and phase	1000 kg·m ⁻³ , liquid (4°C) 917 kg·m ⁻³ , ice
Melting point	0°C, (273.15 K)
Boiling point	100°C, (373.15 K)
Triple point	273.16 K, 611.73 Pa
Critical point	647 K, 22.1 MPa
Specific heat capacity, gas	cp=1970 J·kg ⁻¹ ·K ⁻¹ @ 300 K
Specific heat capacity, liquid	4186 J·kg ⁻¹ ·K ⁻¹
Specific heat capacity, solid	2060 J·kg ⁻¹ ·K ⁻¹
Acidity (pka)	15.74
Basicity (pkb)	15.74
Viscosity	0.001 Pa·s at 20°C
Surface tension at 20°C	7.28 N·m ⁻¹

A detailed account of all the known properties of water would run into hundreds of volumes, far thicker than this book.

A touch of magic

Chemistry is a noble science but it cannot explain how water creates life. For this, we need to dig into quantum physics effects, the very fabric of the Universe.

Hydrogen bonds are the result of zero-point vibrations that stretch the bonds between oxygen and hydrogen atoms enabling them to link with neighbouring molecules more easily, and thus, creating a highly cohesive liquid. Heavy water, D₂O, is chemically identical to H₂O, but its hydrogen bonds are 4% longer, which affects its quantum effects and, therefore, biological properties.

Hydrogen bonds can be easily formed, and easily broken, which is an enormous advantage. Probably, its hydrogen bond length affects all of the properties of water.

DNA, genes, proteins and cells could not run around their business at all without direct help from water. Water helps amino acids to curl in the right way, thus determining the physical shape of proteins. Water molecules further facilitate the interactions of proteins and dna through electrostatic forces that are fundamental to all biological processes.

All in all, calls abound for a radical overhaul of the scientific view of water, and for a good reason. Without water it's all just chemistry, according to Felix Franks, add water and you get biology.

“Water is . . .

hydrogen two parts, oxygen one, but there is also a third thing, that makes it water and nobody knows what it is.”

D. H. Lawrencee

Facts and figures

- Water is the only pure substance found naturally on Earth that is in dynamic equilibrium between the liquid, gas and solid states at standard temperature and pressure.
- In 1781 Henry Cavendish discovered that water consists of two parts hydrogen and one part oxygen.
- Water has a V-shaped molecule with the formula H₂O. Its molecular diameter is 2.75 Å.
- The *Vienna Standard Mean Ocean Water* is pure salt-free water used as a standard material and containing 99.984426 atom % ¹H, 0.015574 atom % ²H (D), 18.5 · 10⁻¹⁶ atom % ³H (T), 99.76206 atom % ¹⁶O, 0.03790 atom % ¹⁷O and 0.20004 atom % ¹⁸O.
- Boiling water absorbs six times more energy in converting to steam than is needed to heat the water from freezing to boiling.
- In 1795, the *gram* was defined to be equal to the weight of a volume of pure water equal to a cube of one hundredth of a metre, and at the temperature of the melting ice.
- The average time for the atoms in an H₂O molecule to stay together is a millisecond.
- The structure of water is much more important than its chemical composition.
- The half-life of the hydrogen bond in liquid water is 10⁻¹¹-10⁻¹² s.
- Poetically speaking, water is an intermediary between man and the Creator.
- It is a paradox that water is highly hydrogen bonded and still a fluid and not a solid, which can be explained as follows: hydrogen bonds in liquid water are made and broken at a remarkably fast rate. The short range structure of liquid water is, therefore, statistical, since it is averaged over both space and time.
- Using supercomputers we can model the behaviour of 50 molecules of H₂O for 5 picoseconds, which is rather pale in comparison to the volume and age of the World Ocean.
- Textbook models suggest that at any given time some 10% of the hydrogen bonds in liquid water must be weakened and broken, while some recent research indicates that this number may be as high as 85%.
- In China, water is revered as the abode of the benevolent dragon, because all life comes from the waters.
- Water plays a key role in how information is exchanged on our planet.
- Those who perceive water as a mineral are missing a certain point. We can determine the chemical composition of a man down to many decimal places and write in on a blackboard. Will it have any semblance to a real man and is consciousness? Hardly any.