Life is Water Electric

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10 Life is Water Electric

Mae-Wan Ho

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New evidence suggests that the L-field is generated by, and embodied in, the quantum-coherent liquid crystalline water that makes up to 70–90% of organisms and cells, and is essential for life.

Water forms quantum coherent domains at ordinary temperatures and pressures. Within organisms, coherent domains become stabilized as liquid crystalline water on the vast amount of membrane and macromolecular surfaces, effectively aligning the entire body electrically to form a single uniaxial crystal. This liquid crystalline water makes life possible by enabling proteins and nucleic acids to act as quantum molecular machines that transform and transfer energy at close to 100% efficiency. It provides excitation energy to split water in photosynthesis, releasing oxygen for the teaming millions of air-breathing species that colonize the earth, at the same time generating electricity for intercommunication and the redox chemistry that powers the entire biosphere.

Living water is the means, medium, and message of life.

LIFE, THE UNIVERSE, AND EVERYTHING

In his book *Science and the Modern World*[1] first published in 1926, Alfred North Whitehead (1861–1947) showed how the mechanical laws that describe objects with 'simple location in space and time' utterly fail to represent natural processes, and argued it is only possible to know and understand nature as an organism. He wrote (p. 100): "The concrete enduring entities are organisms, so that the plan of the whole influences the very characters of the various subordinate organisms which enter into it. In the case of an animal, *the mental states enter into the plan of the total organism and thus modify the plans of the successive subordinate organisms until the ultimate smallest organisms, such as electrons, are reached*" [italics mine].

Whitehead's organisms include *everything* in nature, from the universe to galaxies, stars, planets, plants, animals, human beings, bacteria, right down to fundamental particles; they are bundles of electromagnetic activities—"vibratory organisms"—endowed with a kind of primal consciousness that experience their environment in acts of "prehensile unification," and most important of all, evolve as the result of the experience.

Whitehead was remarkably prescient, as evidence has been accumulating since the latter half of the twentieth century that our Universe is 99.999% electric plasma. Gigantic plasma currents and their magnetic fields are constantly engaged in creating super-galaxy clusters, galaxies, and stars, in direct contradiction to the conventional Big Bang theory based solely on gravity and Einstein's theory of general relativity.[2]

I have taken Whitehead's philosophy to heart. Not only is nature an all-encompassing electromagnetic super-organism, but the knower is also an electromagnetic organism maximally sensitive and responsive, fully engaged in mind and body, intellect and feeling to other organisms, ultimately to all nature.

THE ELECTRODYNAMIC ORGANISM ATTUNED TO THE COSMOS

There is substantial evidence that living things are fundamentally organized by electric fields and electromagnetic activities. Whitehead's concept of a "plan of the body" that modifies the motion of electrons within it anticipates

the discovery of physiologist Harold Saxton Burr at Yale University, who began his work in the 1930s.

Burr's book, *The Blueprint for Immortality,*[3] first published in 1972, offers a grand vision described on the book's back cover:

> This is a breakthrough book—the first *comprehensive* account ever published of one of the most important scientific discoveries of this century. It reveals that all living things—from men to mice, from trees to seeds—are moulded and controlled by 'electrodynamic fields', which can be measured and mapped with standard modern voltmeters.
>
> These 'fields of life', or L-fields, are the basic *blueprints of all life on this planet*. Their discovery, therefore, is of immense significance to all of us.
>
> To every man and woman in this troubled age it gives the comforting certainty that life is no accident and that all of us are integrated parts of the Universe, subjected to its laws and *sharing in its purpose and destiny. . .the Universe has meaning and so have we*.
>
> Since measurements of L-field voltages can reveal physical and mental conditions, doctors will be able to use them to diagnose illnesses *before the usual symptoms develop* and so will have a better chance of successful treatment.

Burr and his many collaborators over a period of 40 years documented L-fields in diverse organisms including eggs and seeds; and dramatic changes in L-field potentials closely correlated with growth, development, mental states, and key physiological events such as ovulation and cancer.

Burr attached electrodes to trees and simultaneously recorded electric potential differences in the atmosphere and in the earth continuously for 25 years. The records showed that the air and earth potentials fluctuated in phase with the trees' potentials. Statistical analysis revealed well-known diurnal rhythms in all four records, as well as the lunar cycle and the 11-year cycle of solar activity. These findings leave little doubt that trees in particular are sensitive to electric and electromagnetic fields from earth and outer space, acting as antennae to the universe. Trees connect us to the universe. This may be why a walk in the woods or being near to woods and forests is beneficial to health.[4]

Earth's magnetic field comes from the electric current generated in the conductive layer of molten iron in its outer core moving across the sun's magnetic field, which in turn generates a magnetic field. Birds, bees, amphibians and other animals are known to depend on earth's magnetic field for navigation. There are reports that animals and humans in environments shielded from earth's magnetic field aged faster, died more readily, suffered stress and pains, and pathological changes in the liver, kidneys, white blood cells, and urinary bladder.[5]

Earth also has an electromagnetic spectrum or Schumann resonance named after Winifred Otto Schumann (1888–1974) who predicted them in 1952. Schumann resonances are standing waves created in the space between the surface of the earth and the conductive ionosphere, and naturally excited by lightning discharges. Schumann resonances range between 3 and 60 Hz, appearing as distinct peaks at 7.83, 14.3, 27.3, and 33.8 Hz. These same frequencies are prominent in human brain waves and strongly correlated with different mental states. Evidence suggests that humans and other organisms actually synchronize their biological rhythms to the Schumann frequencies.[6,7]

Earth's electromagnetic activities are strongly affected by those of the sun. The beautiful northern lights are generated during periods of intense solar activity, or magnetic storms, when the solar wind carrying hot energetic plasmas of ionized particles from the sun increases in density and speed. The ionized particles are trapped by earth's magnetic field and accelerated towards its magnetic poles. Collisions between these ions and atmospheric atoms and molecules (mainly oxygen and nitrogen) cause light to be emitted as the excited atoms relax back to the ground state. Both higher and lower than average levels of solar and geomagnetic activities are associated with adverse health and psychological impacts on humans worldwide, possibly due to the suppression of the pineal gland secretion of melatonin as biological rhythms are desynchronized. This is also partly why artificial electromagnetic emissions from mobile phones, wireless, and high tension power lines are having dire effects on humans and wild life.[8–11]

THE LIFE-FIELD

Burr's L-field could be measured from the surface of the body or the egg or seed, and detected away from the body surface, as when measurements were done on salamanders in water. This was sign of a true field effect, as the field was not shorted out by water. When the salamander was rotated under the electrodes positioned some millimeters away, it acted like a dynamo as expected of a rotating electric field, giving a sine wave of rising and falling potentials.

L-fields of all organisms share some common features, such as a positive potential at the anterior, versus a negative potential at the posterior. However, the entire field is made up of subsidiary or local fields specific to the body plan (see Figure 10.1).

The L-fields are not static; Burr and his collaborators found L-fields changing slowly, increasing in strength during development to a plateau in adulthood, and declining gradually as the organism ages.

The precise nature and origin of L-fields are not yet known, and it would take rather more sophisticated equipment to map them out properly. However, they are almost certainly actively maintained by electric currents within the body, forming closed circuits, rather than static DC fields. These electric currents give rise to magnetic fields that can be detected outside the human body including the brain, and form the basis of magneto-encephalography (MEG), the mapping of brain activity with very sensitive superconducting quantum interference devices (SQUID) magnetometers.[13]

L-fields were confirmed by other laboratories working independently of Burr, and later by orthopedic surgeon/researcher Robert Otto Becker (1923–2008), who also documented DC potential changes during wound healing and regeneration in animals and humans. Notably, he showed that

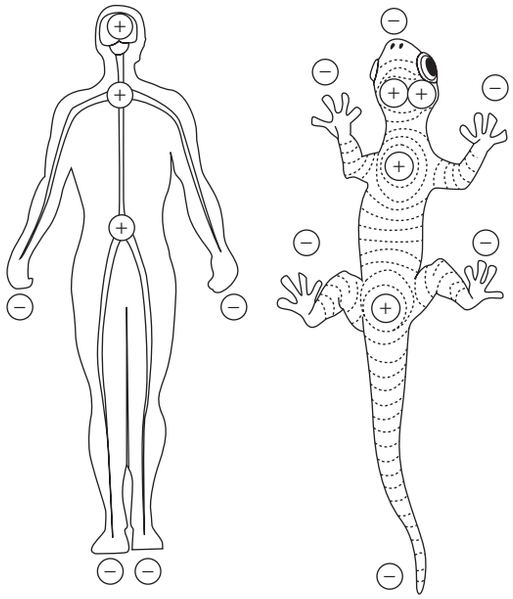

FIGURE 10.1 L-fields of humans and salamanders, measured by Robert O. Becker. (From Becker RO, Selden G. *Electromagnetism and the Foundation of Life*. New York: Harper; 1985. With permission.)

potential changes from regenerating and nonregenerating organisms differ markedly from each other (see Figure 10.2).

Becker's findings were described in numerous scientific papers, and in one of the most gripping, moving accounts of scientific discovery, *The Body Electric,*[12] published in 1985, 5 years after his research lab was shut down by scientists and politicians in a bid to silence his warnings on the health hazards of electromagnetic fields from overhead high tension power lines and other electrical installations. (This debate has continued to the present day over "nonthermal effects" including brain cancer resulting from mobile phone use and other electromagnetic smog in our environment; see Reference 14).

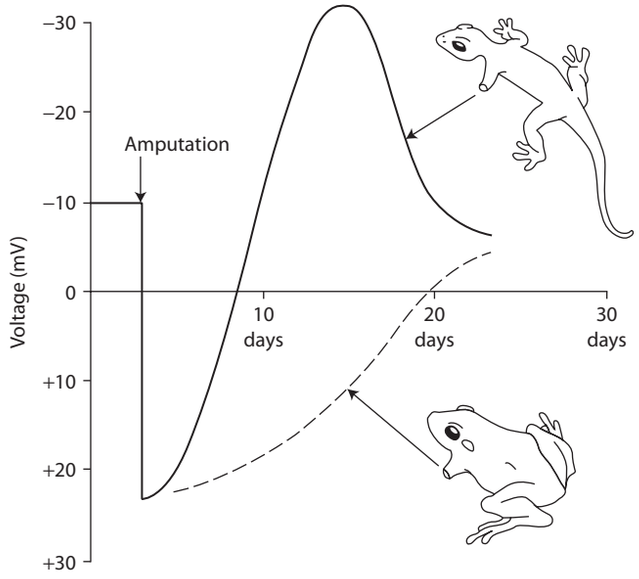

FIGURE 10.2 Electric potential changes at the cut end of the stump after amputation in salamander (top), which regenerates its amputated limb, and frog, which does not. (From Becker RO, Selden G. *Electromagnetism and the Foundation of Life*. New York: Harper; 1985. With permission.)

Becker knew that electromagnetic fields, when used accurately with the correct polarity, at the right time and place, and at the extremely weak levels characteristic of living organisms, could indeed help to heal persistent wounds and fractures, and even regenerate severed fingertips and nerves. However, exposures to inappropriate electromagnetic fields were likely to cause abnormal growth and cancer. Electromagnetic fields are a powerful, double-edged weapon, and must be used with utmost care and precision based on accurate knowledge from painstaking research; only then could it help restore the lives of people often reduced to utter despair.

Becker's discoveries anticipated by decades the recent findings on the transformation of differentiated cells into stem cells during healing and tissue regeneration, and by manipulations of gene expression in the laboratory.[15] Research is now also focused on enhancing stem cell repair *in vivo* without transplant by using drugs to encourage the process.[16] There has been no investigation on the effect of electric fields on the recruitment of stem cells thus far.

Today, it is possible to track electric potential changes in cells and embryos, and it is widely acknowledged to be involved in development, differentiation, regeneration, and cancer. But they are interpreted solely, and mistakenly, in terms of membrane potential of cells[17] with a major emphasis on identifying downstream gene activities, while important questions on the nature of the electrodynamical life-field and its relationship to health and disease are largely forgotten.

The most exciting serendipitous new discovery at Tufts University is the "face" of the frog roughed out in potential differences very early in development when the embryo is still a shapeless ball of cells with very few anatomical features.[18] A team led by Dany Adams used a combination of voltage and pH sensitive dyes to follow the development of *Xenopus* embryos under a microscope fitted with a time-lapse camera. It recorded "never-before-seen" dynamic patterns of electrical potentials on the outermost cell layer. These are clear signs of electrodynamic processes determining body structures that appear much later on (more on this later).

THE L-FIELD IS STORED ENERGY

Burr's insight was no less remarkable.[3] He surmised that the L-field reflects the energetic status of the organism; in particular, he assumed correctly that the energy flux of organisms is associated with the chemical flux of metabolism, but the L-field represents energy *stored* in potential differences across the body. Variations in the L-field, therefore, reflect variations in the flow of energy in the system. He wrote[3] (p.71):

> If this assumption is true, it follows, then that by studying potential differences during rest and during activity a record

> could be made of a general level of immediately available energy, as represented by algebraicly summated boundary potentials.
>
> In the face of the demand for activity this reservoir of potential energy could be tapped. When the biological system is at rest, the potentials could be recorded as DC potentials, but when protoplasm is thrown into any kind of activity, such as neural transmission, muscle contraction and similar events, the first sign of that activity would lie in the sudden withdrawal from the reservoir of electrical energy; in other words, a drop in potential difference. Then, mobilization of chemical properties might be expected to re-establish the original level of the potential difference.

The concept of *stored* energy is the key to living organization as emphasized in my book, *The Rainbow and the Worm, The Physics of Organisms.*[19] Stored energy is *coherent* energy, and the mobilization of coherent energy can be made with as little dissipation as possible, giving rise in the ideal to the zero-entropy quantum coherent organism (to be explained later).

As consistent with Burr's observation, a drop in "membrane potential"—depolarization precedes many important cellular events including growth and regeneration.[17]

ELECTRODYNAMIC ACTIVITIES AND PATTERN FORMATION

The L-field is separate from, and independent of, the action potentials of the brain or the electrical discharges from the heart measured respectively in electroencephalograms (EEGs) and electrocardiograms (ECGs). In fact, evidence already available to Burr[3] suggested that EEGs and ECGs are controlled by variations in the L-field, which would show up as baseline potential changes under the action potentials of the EEGs and ECGs, had they not been filtered away (!) in most readings as noise or a nuisance rather than important physiological and psychological information. For example, Burr and colleagues discovered that high potential differences measured between the left and right index figures might be predictive of mental instability.

Evidence that action potentials reflect global field potential changes also came from early embryonic development.

By far the most important unsolved problem in biology is how a relatively featureless egg can transform into a shapely highly differentiated organism in the process of development. I was among a very small number of scientists who believe electrodynamical processes are fundamentally involved in pattern formation.

We carried out several series of experiments described in a paper published more than 20 years ago,[20] which provided evidence of highly coherent electrodynamic processes responsible for *generating* body pattern during early development.

For our experiments, we collected synchronously developing batches of freshly laid fertilized eggs from *Drosophila*. The first series of experiments was carried out in the laboratory of electrophysiologist Charles Nicholson at New York University Medical School, who patiently taught me how to make microelectrodes to record the electrical activities from individual developing embryos without damaging them. The embryo, with its shell (chorion) removed, was attached by hydrophobic interaction between the vitelline membrane and the plastic surface of a petri dish. It was immersed in insect Ringer to keep it from drying out. The electrode was carefully inserted into the anterior or posterior polar pocket inside the vitellline membrane without puncturing the embryo.

The results were amazing. A series of action potentials from 1 to 30 Hz appeared at least as early as 40 min from the start of development and persisted for hours thereafter (see Figure 10.3). During most of the period in which pattern determination takes place, there is little or no cellular organization.

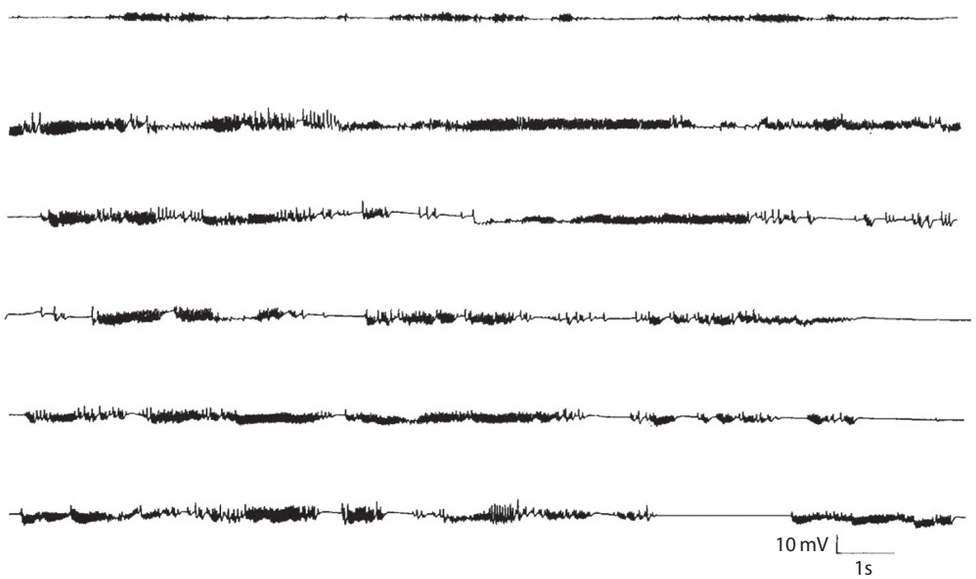

FIGURE 10.3 Action potentials at successive later time segments at nuclear migration stage (43–53 min from start of development). (From Ho MW et al. *J Sci Expl* 1992;6:59–77.)

The trace typically starts with clusters of 2, 3, or 4 volleys of discharges (about 30 Hz) each lasting 1 or 2 s, punctuated by 2–3 s of relative quietude. The volleys increase in amplitude and tend to coalesce into a continuous train. The peak amplitudes are about 10–12 mV. The highest frequency of the spikes are about 30 Hz, but can be as low as 15 or 3 Hz. Characteristically, the baseline potential shifts underneath the spiking activities, often coinciding with the start and end of the volleys, strongly suggesting that those shifts are global in extent, and both initiate and end the volleys.

In the second set of experiments carried out in my own laboratory, we exposed the synchronously developing batches of fertilized eggs for 30 min to weak static magnetic fields (0.5–9 mT) at different times during the first 3 h of development when pattern determination is known to occur. This resulted in high proportions of body pattern abnormalities 24 h later, when the first instar larvae would have normally hatched. The most frequent type of abnormalities is uniquely associated with exposure to static magnetic fields, and consists of variously twisted configurations of the segmental pattern. As static magnetic fields were used, the effects must have been due to moving electrical charges or more likely global field dynamics. As the energies in the weak magnetic fields were many orders of magnitude below the thermal threshold of random molecular motion, there could have been no effect unless the electrodynamical processes were highly coherent.[19–21]

In the third series of experiments done in the laboratory of Fritz Albert Popp, who taught me almost everything I know about quantum physics, the flies were induced to lay eggs in a quartz cuvette, then gently removed. The cuvette with freshly laid eggs was placed in a light-tight chamber connected to a sensitive photon counter, and the photons emitted were recorded with or without a single flash of white light (l min, 4 W/m^2). Photon emission changed with developmental time, which was not unexpected. Remarkably, when embryos less than 40 min old were stimulated with light, an entirely new phenomenon appeared that has never been observed before: intense light flashes were re-emitted, thousands of times stronger than the baseline. The flashes can be extremely brief (<1 s) or prolonged (minutes to hours), and can appear any time from 1 to 20 min, and up to 8 h after light stimulation.[19,20] The results are reminiscent of super-radiance in quantum optics, a collective resonant emission involving many, if not all individuals within the synchronously developing population.

These results together provide evidence of electrodynamical activities accompanying pattern formation that are coherent over the whole embryo and entire populations of embryos. It would be great to look at these embryos again with voltage sensitive dyes.

I was prompted to revisit these old forgotten findings on coming across a paper by Alexis Pietak from Kingston, Ontario in Canada[22] proposing a new mechanism for morphogenesis: the formation of resonant electromagnetic modes in a dielectric microwave resonator.

Resonant modes are standing wave patterns formed when a wave is confined within a resonator and subjected to reflection from internal boundaries where incident and reflected waves combine. This is something like the Schumann resonances generated in the cavity between the earth's surface and the ionosphere (see above), but on a much smaller scale of 0.1–1 mm, the dimensions of eggs and primordia. Consequently, the frequency of the electromagnetic waves involved is much higher, in the microwave to submillimeter range or GHz (10^9 cycles per second). Using the mathematical technique of finite element analysis Pietak produced resonant modes (in ellipses and a sphere) (Figure 10.4) whose patterns resemble different kinds of leaves.

As Pietak noted, this type of mechanism is not restricted to generating leaf patterns. The *Drosophila* egg is a long ellipse, and successive horizontal resonant modes are reminiscent of stages in the process of segment determination as revealed by the famous gene transcript patterns, which are most likely involved in downstream processes of pattern formation.

Pietak emphasized that "the model rests on the validity of biological coherence theories as described by Fröhlich. . .and/or quantum field theorists." Herbert Fröhlich (1905–1991)[23] proposed that organisms are condensed matter systems, and can be pumped by metabolic energy into states of coherent excitations (resonant modes) in analogy with the solid-state laser. Quantum field theorists Emilio Del Giudice and colleagues propose that interaction between ambient electromagnetic fields and soft condensed matter such as liquid water creates coherent domains oscillating in phase with the electromagnetic field.[24] I have described the work of Fröhlich in the *Rainbow Worm*[19] and quantum field electrodynamics is treated in some detail in my new book[25] *Living Rainbow H_2O*, both providing extensive evidence for the quantum coherence of organisms.

Field theories of morphogenesis go back at least to the 1920s associated especially with Alexander Gurwitsch (1874–1954) in Russia and Paul Weiss (1898–1989) in Austria; but they were rather vague [see the review in *Order and Life*[26] by Joseph Needham (1900–1995)]. A significant advance was made by John Totafurno and Lynn Trainor (1921–2008) in a paper published in 1987[27] using a vector-field model to predict baffling results of salamander limb regeneration. In these experiments, a limb was amputated, and the regenerating cell mass was transplanted and/or rotated, leading to abnormal limb regrowth that were determined by the way the cell mass was transplanted. A vector-field has both orientation and continuity, and any disturbance to the field lines need to be smoothed out and reconnected, with the result that extra limbs are generated in certain transplants.

I suggested that the morphogenetic field could be "written"—like memory—in liquid crystalline orientation patterns,[19,28] which in turn determine gene transcription patterns and growth, the latter reinforcing cellular memory, and committing the cell to differentiation along a developmental pathway.

Liquid crystals are well-known to respond to electric and magnetic fields in generating patterns, as well as in changing their alignments.[28] Thus, resonant electromagnetic

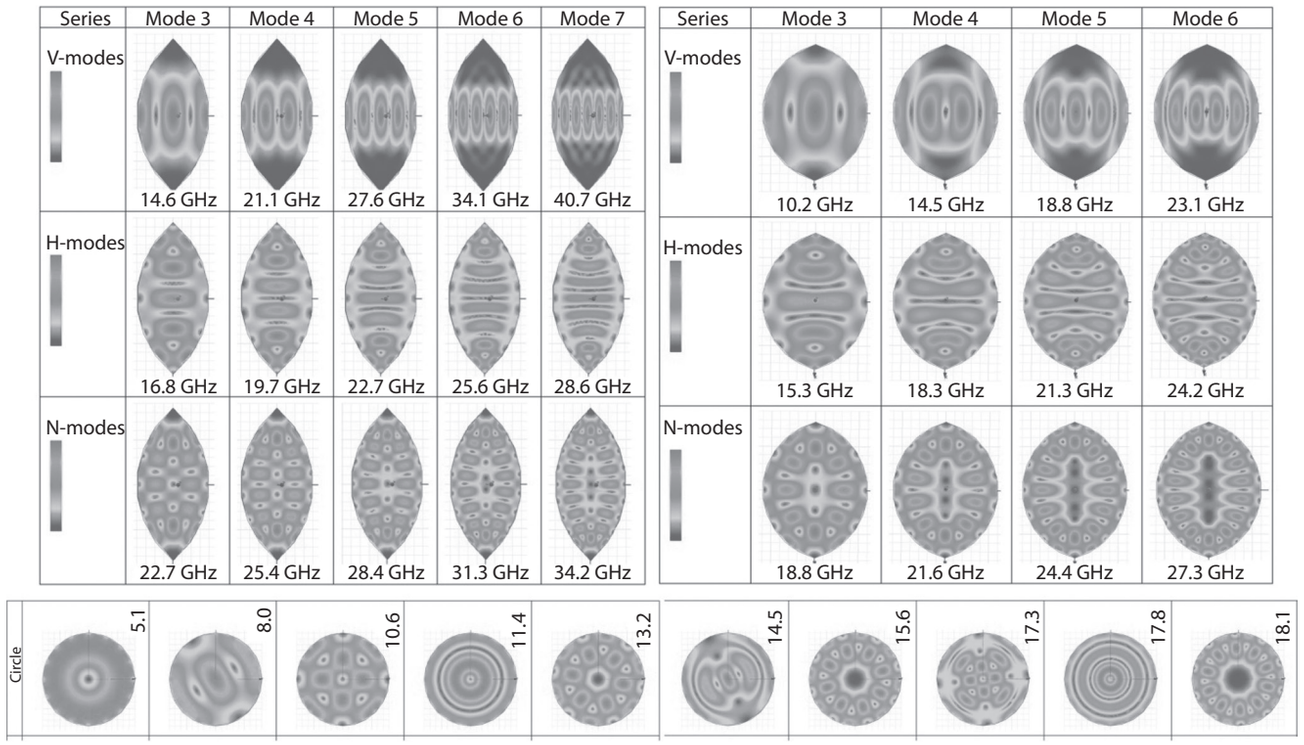

FIGURE 10.4 **(See also color plate section, page XX.)** Resonant modes in elliptical and spherical resonators generated by finite element analysis and the resonant frequencies in GHz; V, vertical, H, horizontal, N, nodal. (Rearranged from Pietak AM. *J Phys Conf Ser* 2011;329:012012. doi:10.1088/1742–6596/329/1/012012.)

modes generated in the *Drosophila* embryos could give rise to segmental patterns in the liquid crystalline cortex of the early embryos, which result in the well-known gene transcription patterns that lead in turn to the differentiation of the initially cryptic pattern. Static magnetic fields could indeed have a dramatic effect on the liquid crystalline patterning by resonant electromagnetic modes, and hence on the body pattern.

Despite substantial evidence on the existence of L-fields, and the fundamental importance of electrodynamic processes in living organization and function, there is still little clue as to how the L-field is generated and where it resides. I shall present evidence that liquid crystalline water in living organisms is both the body electric and the L field.

THE ORGANISM IS ONE UNIAXIAL LIQUID CRYSTAL

The tantalizing evidence of a coherent electrodynamic field involved in pattern formation from our experiments[20] suggested that we should be able to *see* some sign of coherence, specifically, a birefringence indicative of ordered alignment of liquid crystalline molecules in the early embryo.

Birefringence is an optical property of a crystal or liquid crystal with atoms or molecules aligned by electric polarity, so that plane-polarized white light (consisting of many wavelengths vibrating in a single direction) is split into two perpendicularly oriented rays, one travelling slower than the other. When the two rays are recombined with a second polarizer (the analyzer), the component wavelengths of light interfere constructively or destructively. That is how the rainbow colors are generated. In order to amplify the birefringence, it is usual to add a full wave-plate—the wavelength of green light—to the system, giving the characteristic pink background (Figure 10.5).

I had been working with *Drosophila* for over 15 years, yet I was completely unprepared for what greeted me as I peered down the polarizing microscope. A little larva was crawling

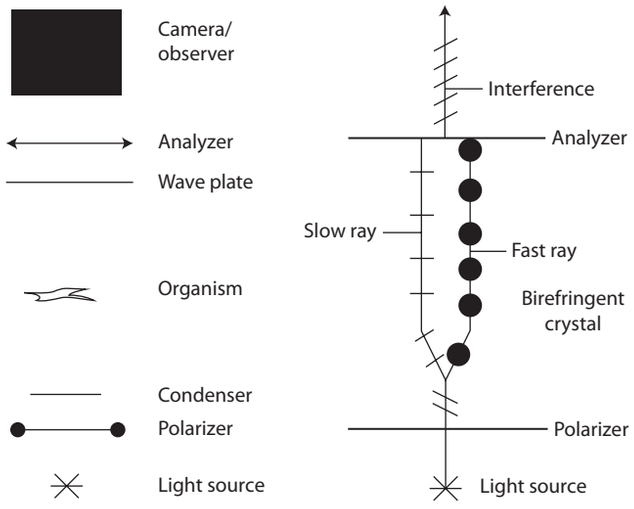

FIGURE 10.5 Polarizing light microscope (left) and birefringence (right).

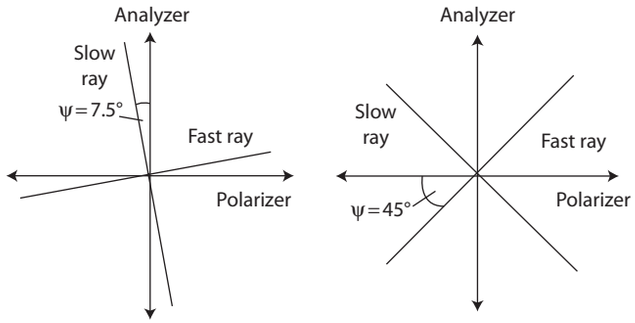

FIGURE 10.6 The new setting stumbled upon that is especially good for biological liquid crystals.

out of its egg, carrying a rainbow inside. Even the fully developed larva was coherent, and coherent beyond our wildest dreams. That is what the dancing rainbow inside its body was telling us, only it took a while to figure that out. That sublime vision was the immediate inspiration to writing.[19] *The Rainbow and the Worm, The Physics of Organisms*.

Because the expert in charge of the polarizing microscope was away, my colleague Michael Lawrence and I stumbled upon a new setting that was especially good for viewing biological liquid crystals. Instead of positioning the vibrating directions of the full wave plate at 45° to the polarizers, we placed it at a small angle of 7.5°[29–31] (Figure 10.6). The brilliant rainbow colors tell us that all the liquid crystalline molecules in the cells and tissues of the body are aligned, and more importantly, moving coherently together. As light vibrates much faster than the molecules can move, the orderly alignment of the molecules remains apparent to the light passing through. In fact, the most active parts are the brightest, indicating that the molecular motions are the *most* coherent.

Not only that, the entire organism is electrically polarized from head to tail, behaving optically as a single uniaxial crystal, like quartz. This is the life-field unveiled. Only, it is not just the macromolecules that are polarized; instead it is the water making up 70%–90% by weight of cells and tissues that is polarized together with all the macromolecules, as our detailed analysis showed.[31,32] In fact, it is the water that makes all macromolecules liquid crystalline, because living water, aligned along the abundant surfaces of membranes and macromolecules is itself liquid crystalline.[19]

LIQUID CRYSTALLINE WATER IS LIFE

Liquid crystalline water softens the macromolecules, making them flexible and enabling them to act as *quantum molecular machines* that transfer and transform energy at close to 100% efficiency. If organisms were working even with the efficiency of electronic machines say, our laptop computers, already much enhanced (in both sensitivity and efficiency) over ordinary machines, such as the motor-car, the amount of heat generated would burn them up before you could say "Christopher Robin!"[33] The energy transactions in living cells and tissues are much denser than those in a laptop (at least a billion times as dense), therefore, organisms *have* to be a lot more efficient; in other words, they have to approach the zero-entropy quantum coherent state.[19,34]

The archetypal quantum molecular machine is the enzyme. Enzymes speed up chemical reactions in organisms by a factor of 10^{10}–10^{23}. And they cannot do that without water. Water giving flexibility to proteins reduces the energy barrier between reactants and products and increases the probability of quantum tunneling by a transient compression of the energy barrier.

The *Rainbow Worm*[19] presents empirical evidence and theoretical arguments that the organism is quantum coherent, and that liquid crystalline water plays the lead in creating and maintaining the coherence of organisms.

However, the full extent to which life, and probably the universe and everything depends on water is still unfolding. Astronomers now think that water is the most abundant substance in the universe, and it may be present at the birth of the universe. In July 2011, two groups of astronomers in the United States discovered the largest, most distant reservoir of water—equivalent to 140 trillion times the water in earth's oceans—surrounding a massive black hole in a quasar more than 12 billion light-years away.[35] The conventional (big bang cosmology) view of quasars with hypothetical supermassive black holes and their supposedly enormous distance from us is seriously open to question,[2,36] but the presence of water is not in doubt. Could it be that the universe too, is powered by water electricity, as organisms are powered by water electricity? This makes Whitehead's[1] vision of the universe as an organism all the more remarkable.

I wrote a sequel to *Rainbow Worm* dedicated to water in living organisms in[25] *Living Rainbow H_2O*, which synthesizes recent findings in the quantum physics and chemistry of water that tell us why it is so fit for life. Water is "the means, medium and message of life, the beautiful rainbow within that mirrors the one in the sky." Already further new evidence has turned up since the book was published, and I shall bring the story up to date.

WATER IS WEIRD AND WONDERFULLY FIT FOR LIFE

The water molecule is a dipole with separated positive and negative charges associated with the oxygen and the two hydrogen atoms, respectively, therefore, it can engage in dipole interactions with other molecules of water or other dipoles (see Reference 25 and references therein). However, it seems to prefer to hydrogen bond most of the time, where the hydrogen atom of one molecule is shared between two oxygen atoms in neighboring molecules. The preferred configuration is a tetrahedron in which a molecule accepts two hydrogen atoms and donates two hydrogen atoms to neighboring molecules. It is estimated that at ordinary temperatures and pressures, over 90% of the water molecules are hydrogen-bonded, although the hydrogen bonds flicker on and off randomly in a matter of pico (10^{-12}) seconds.

BOX 10.1 MAJOR ANOMALIES OF WATER (SEE REFERENCE 37 AND REFERENCES THEREIN)

- Neighbors of oxygen form gases with hydrogen at ordinary temperatures and pressures, but water boils at 100°C and only freezes at 0°C under standard atmospheric pressure, which means organisms are composed of and bathed in liquid water on earth.
- Water has a high heat capacity and high thermal conductivity, thereby preventing temperature fluctuations, enabling organisms to better control their body temperature, and large bodies of water, such as oceans and seas, to serve as heat reservoirs, thereby moderating our climate.
- Other liquids increase in density on becoming solid, but ice is lighter than water and floats on it, most fortunately for fish and other aquatic inhabitants.
- Liquid water can be supercooled below 0°C without freezing, but on heating, the supercooled liquid does not expand like other liquids; instead, it contracts to a maximum density at about 4°C; this is very important for the hydrological cycle[38] as it plays a key role in rainwater percolating underground to refill the aquifers.
- Water's compressibility atypically decreases with increasing temperature reaching a minimum at about 46.5°C
- At ordinary temperatures below 35°C, increasing pressure results in decreased viscosity, facilitating flow, again at odds with other liquids.

Water is notorious for a host of anomalous properties (see Box 1), due to its propensity to form hydrogen-bonds; and the same anomalies are widely regarded as precisely the qualities that make water fit and essential for life.

QUANTUM DELOCALIZATION OF HYDROGEN BOND

The key to water's remarkable properties is the hydrogen-bond interconnecting water molecules, which is usually regarded as classical and electrostatic; but many observations are inconsistent with that picture.

Nobel laureate chemist Linus Pauling (1901–1994) in 1935 was the first to suggest that the hydrogen bond and covalent bond in ice may switch places in view of residual entropy (randomness) existing even at very low temperatures,[39] and thus, the hydrogen bond must be at least partly covalent.

In 1999, researchers at Bell Labs New Jersey in the United States, the European Synchrotron Radiation Facility of Grenoble in France, and the National Research Council of Canada in Ottawa teamed up to study the hydrogen bond in ordinary ice Ih with inelastic x-ray scattering at the Grenoble facility.[40] Beams of x-rays are bounced off electrons so both the energy of the electron and the x-ray are changed. The team investigated the intensity of scattering as a function of energy or momentum (Compton profile) at different orientations of a carefully prepared slab of ice. They found that the results were in good agreements with the predictions based on a fully quantum mechanical model, while predictions based on the classical electrostatic model did not agree with the data at all.

In the same year, Sander Woutersen and Huib Bakker at FOM-Institute for Atomic and Molecular Physics in Amsterdam used time-resolved pump-probe laser spectroscopy to investigate liquid water at room temperature and pressure. The experiments revealed resonant intermolecular transfer of OH-stretch excitations mediated by dipole-dipole interactions that are faster than the classical Förster mechanism would predict.[41]

A few years later, Huib Bakker and Han-Kwang Nienhuys at FOM showed that not only the electrons of the hydrogen bonds fail to conform to the classical electrostatic model; the protons too are quantum mechanical. Using ultrafast femtosecond (10^{-15} s) pulses of infrared light to excite and probe the O-H covalent bond vibration in *liquid* water,[42] they found that only quantum mechanical calculation of the vibrational wave functions could reproduce the experimental absorption spectrum.

The excited proton can be found simultaneously—delocalized—at the O−H bond distance from either of two neighboring oxygen atoms (belonging to two different water molecules). This delocalization increases the probability of proton transfer (I will come back to that later). The energy of excitation to the delocalized state is less than 20% of the O−H bond energy. These results show that liquid water has quantum properties, and may even be quantum coherent.

QUANTUM COHERENT WATER MAKES LIFE ON EARTH

Standard quantum theory does not predict quantum coherence for liquid water, largely because it ignores both quantum fluctuations and the interaction between matter and electromagnetic field; these are only taken into account in quantum electrodynamics field theory. However, conventional quantum electrodynamics field theory applies only to gases.

Theoretical physicists Giuliano Preparata (1942–2000), Emilio Del Giudice, and colleagues at University of Milan in Italy, extended conventional quantum electrodynamics theory to the condensed phase of liquids. They showed that interaction between the vacuum electromagnetic field and liquid water induces the formation of large, stable coherent domains (CDs) of about 100 nm in diameter at ordinary temperature and pressure, and these CDs may be responsible

for all the special properties of water including life itself[43–46] (see Reference 47 for a more accessible description). In particular, they showed that the propensity to form tetrahedral directed hydrogen bonds is a *consequence* of the excited state of water in the coherent domains that would not happen if not for interactions with the ambient electromagnetic field.

The CD in water is a resonating cavity produced by the electromagnetic field that ends up trapping the field because the photon acquires an imaginary mass, so the frequency of the CD electromagnetic field becomes much smaller than the frequency of the free field with the same wavelength.

Under ambient conditions, water is an approximately equal mixture of coherent domains surrounded by incoherent regions. (It is more accurate to say that the water molecules are dancing between the tetrahedral configuration corresponding to the CDs and nontetrahedral configuration, so both the CD and non-CD molecules are interchangeable.) This picture, according to Del Giudice and colleagues, is reflected in the many observations supporting a two-state model of liquid water.[48]

The special thing about water is that the coherent oscillation occurs between the ground state and an excited state at 12.06 eV, just below the ionizing threshold of water at 12.60 eV. In liquid water, the CD of about 100 nm diameter contains millions of water molecules, and nearly a million almost-free electrons—forming a plasma—that can be readily donated to electron acceptors. And this is why water is the means of life: it is this property that enables water to fuel the dynamo of life. Water is the basis of the energy metabolism that powers all living processes; it is both the chemistry and the electricity of life.

The abundant life on earth, including you and me, depends on photosynthesis in green plants, algae, and cyanobacteria that traps the energy of sunlight by means of chlorophyll (the green pigment in chloroplasts) to split water into hydrogen, electrons, and oxygen (Equation 10.1). This gives life access to an enormous, practically unlimited energy source, and perhaps more importantly, liberating oxygen for the evolution of air-breathing organisms including us that filled the earth with teaming millions of species. (If, as astronomers tell us, water is the most abundant substance in the universe, could there be abundant extra-terrestrial beings similar to us in the universe?)

$$H_2O \rightarrow 2\ H^+ + 2\ e^- + O \qquad (10.1)$$

Equation 10.1 says it all. The hydrogen ion (protons) and electrons go to reduce (or fix) carbon dioxide into carbohydrates, and biomass of photosynthetic organisms, which serve as food for herbivores, and down the food web to include the vast majority of air-breathers that break down carbohydrates with oxygen in mitochondria to obtain energy for growth and reproduction, regenerating carbon dioxide and water. This completes the living dynamo of photosynthesis and respiration, the magic roundabout that turns inanimate substances into living organisms.

However, it takes lots of energy to split water, 12.6 eV, to be precise, and requires an energetic photon in the soft x-ray region, which would destroy life, and is not what green plants and cyanobacteria use. They use mainly red and to some extent blue light in the visible spectrum.

More than 50 years ago, Nobel Laureate Albert Szent-Györgyi, the father of biochemistry suggested[49] that water at interfaces was the key to life. He proposed that water at interfaces, such as membranes in the excited state, requires considerably less energy to split than water in the ground state. A sign of the excited water is that a voltage should appear at the boundary between interfacial water and bulk water, which was indeed observed not long after Szent-Györgyi predicted it (see Reference 44). This property of water enables energy transfer to take place in living organisms. Most, if not all, water in living organisms is interfacial water, as it is almost never further away from surfaces, such as membranes or macromolecules, than a fraction of a micron.

A vivid demonstration of interfacial water was achieved by Gerald Pollack's research team at the University of Washington, USA.[50,51] Using a hydrophilic gel and a suspension of microspheres just visible to the eye, they showed that interfacial water apparently tens of microns or even hundreds of microns thick forms on the surface of the gel. This excludes the microspheres as well as other solutes, such as proteins and dyes, and hence, it is referred to as an "exclusion zone" (EZ).

EZ water is about tenfold more viscous than bulk water, it has a peak of light absorption at 270 nm, and emits fluorescence. Del Giudice and colleagues[45] suggest that EZ water is in fact a giant coherent domain stabilized on the surface of the attractive gel. Inside the cell, the EZ would form on surfaces of membranes and macromolecules, as envisaged by Szent-Györgyi.[49] Because coherent water is excited water with a plasma of almost free electrons, it can easily transfer electrons to molecules on its surface. The interface between fully coherent interfacial water and normal bulk water becomes a "redox pile." In line with this proposal, EZ water does indeed act as a battery, as Pollack's research team demonstrated.[52,53]

THE SUPERCONDUCTING ELECTRIC CURRENTS OF LIFE

The core chemistry of life is reduction-oxidation or redox reactions that transfer electrons between chemical species, and the movement of electrons is nothing if not an electric current. However, water electricity is special in that it also involves the movement of positive charges associated with protons.[54] Water conducts protons by a special kind of jump conduction down a chain of water molecules connected by hydrogen bonds. A proton leaps on one end of the chain, and a second leaps off at the other, while electrons are displaced in the other direction.

Some time ago, researchers at Drexel University, Philadelphia, the University of Illinois, Chicago, USA, and the Tokyo Institute of Technology, Japan, demonstrated for the first time the formation of structured water confined in carbon nanotubes less than 5 nm in diameter, that was completely different from the more ordinary looking water

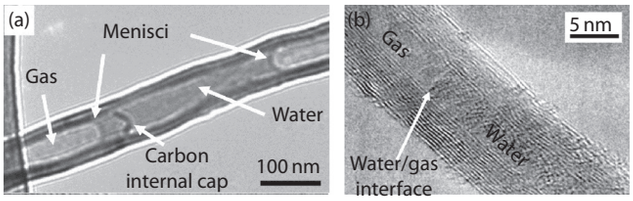

FIGURE 10.7 Structured water confined in narrow nanotube (right) compared with ordinary water in wide nanotube (left). (Rearranged from Ye H, Naguib N, Gogotsi Y. *JEOL News* 2004;39:2–7.)

confined in larger nanotubes[55,56] (Figure 10.7). I suggested that water confined in the small diameter nanotube, being more ordered, could be superconducting because proton jump-conduction could occur simultaneously down multiple chains of hydrogen-bonded water molecules.[57]

Later, Gary Fullerton and colleagues offered a convincing model of liquid crystalline nanotubes of water interwoven with the triple-helix molecules of collagen molecules in the collagen fibres[58,59] (Figure 10.8), which again suggested to me that such a water structure in the extracellular matrix could also be superconducting.

As mentioned earlier, the proton is actually in a delocalized quantum state even in bulk water under ambient conditions. Proton delocalization has been confirmed for water confined in nanotubes (see Reference 60 and References therein). Delocalized protons mean proton jump conduction[54] can be *very* fast indeed.

Greatly enhanced proton conduction has been observed for water confined in Nafion fibres. Nafion is a synthetic polymer used as a proton exchange membrane. The proton conductivity of fibers with diameters >2 μm was similar to the bulk Nafion film (~0.1 S/cm). However, when the fiber diameter was <1 μm, proton conductivity rose sharply with decreasing fiber diameter and reached 1.5 S/cm for the 400 nm diameter fiber, at least an order of magnitude higher than the bulk Nafion film, or silicon, a semi-conductor. Conductivity of the fiber also increased a hundredfold as relative humidity rose from 50% to 90%; in comparison, conductivity of the bulk film increased only tenfold.[61]

Nafion channels form inverse micelles with hydrophilic groups facing the cavity and hydrophobic groups facing out, which most resemble the condition inside the living cell. In the cell, the interstices between fibers of the cytoskeleton and cytoplasmic membranes form inverse micelle nanospaces and channels that drastically alter enzyme/substrate relationships and enzyme activity compared to bulk phase thermodynamic models that still dominate conventional cell biology (see Chapter 18 of *Living Rainbow H_2O*[25]). The inverse micelle model may be even more relevant to the extracellular *milieu* of multicellular animals, which is traversed by collagen fibers consisting of fibrils interwoven with nanotubes of water[59] (Figure 10.5). These water channels aligned with collagen fibers are most likely the anatomical correlates of the acupuncture meridians of traditional Chinese medicine, as I and David Knight first suggested in 1998[62] and the hypothesis is still very much alive and untested.[63]

Proton and electron currents coursing inside cells and over different extracellular distances deliver physical and chemical messages concerning the redox status. This sets in motion the requisite chemical reactions that restore local and global energy balance, as well as the peripheral chemistry and forms the basis of the highly nuanced passions and feelings that make life so exciting for organisms (as opposed to computers, which therefore cannot feel).

THE ELECTROMAGNETIC LANGUAGE OF CELLS AND MOLECULES

One important final question is how do cells and molecules actually find one another? Conventional wisdom says hormones and receptors, cell-cell recognition molecules, and lock-and-key principle for molecules that somehow bump into each other at random.

Actually, molecules find each other by electromagnetic fields, by resonating to common frequencies.[2] Molecules that react together were found to share a common frequency; which is how they can attract each other (see Reference 64 and References therein). This makes even more sense in the context of quantum coherent water.

Del Giudice and colleagues[44] argue that water CDs can be easily excited, and are able to capture surrounding electromagnetic fields to produce coherent excitation in the frequencies of the external fields. This, in turn, enables selective coherent energy transfer to take place. All molecules have their own spectrum of vibrational frequencies. If the molecule's spectrum contain a frequency matching that of the water CD, it would get attracted to the CD, and become a guest participant in the CD's coherent oscillation, and settle on the CD's surface. Furthermore, the CD's excitation energy would become available to the guest molecules as activation energy for the chemical reactions.

Is it possible that cells as a whole also intercommunicate by means of electromagnetic and electric signals? This is completely uncharted territory as far as conventional cell biology is concerned. It is the water in us that gives us life, and makes us sensitive to electromagnetic fields; there is a distinct possibility that we are sensitive to the fields of other organisms as we are sensitive to fields of the sun and the earth (see earlier), and possibly also from distant stars; all without our conscious knowledge. There is good evidence that clusters of galaxies and stars in our universe are interconnected in plasma current circuits spanning hundreds of millions of light years (see Reference 2 and References therein). It would not be surprising if galaxies and stars, too, intercommunicate by electromagnetic fields of intergalactic dimensions.

TO CONCLUDE

Life is quantum electrodynamical through and through, and water is at the heart of it all. A whole new vista has opened up thanks to all the dedicated water scientists who have contributed to this vision: Emilio Del Guidice, Gerald Pollack,

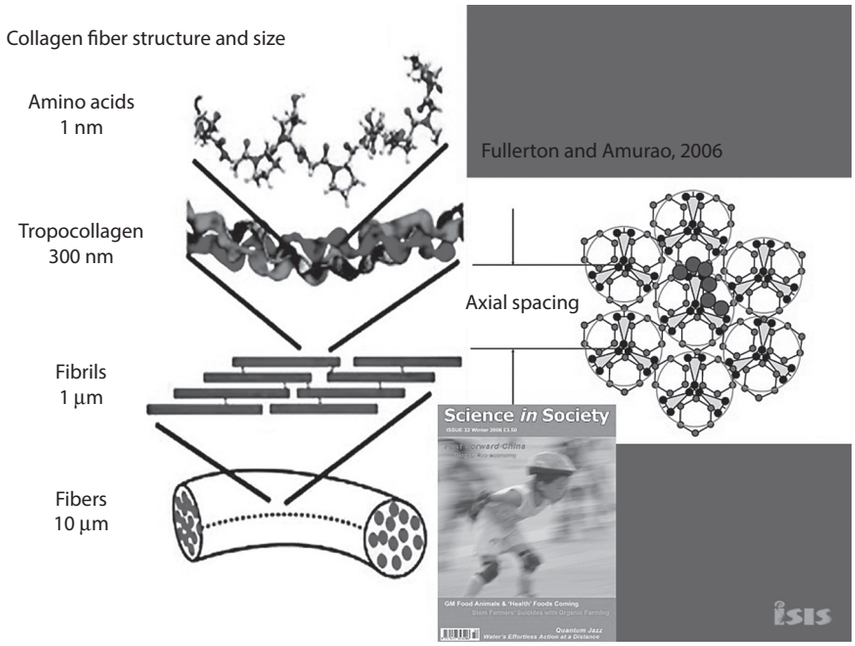

FIGURE 10.8 **(See also color plate section, page XX.)** Collagen water structure revealed.

James Clegg, Gilbert Ling, Philippa Wiggins, Walter Drost-Hansen, Norio Ise, Martin Chaplin, Ludwig Edelmann, Gary Fullerton, Ivan Cameron, Frank Mayer, and many others. Our adventures have only just begun.

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