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The Biophysical Basis of Benveniste experiments
Entropy, Structure and Information in Water

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J Benveniste had observed that highly dilute (and even in the absence of physical molecules) biological agents still triggered relevant biological systems. Some of these experiments were reproduced in three other laboratories who co-signed the article, *Nature* **333**, 816 (1988). Further works, *Medical Hypotheses* **54**, 33 (2000), *Rivista di Biologia / Biology Forum 97), 169-172(2004),* showed that molecular activity in more than 50 biochemical systems and even in bacteria could be induced by electromagnetic signals transferred through water solutes. The sources of the electromagnetic signals were recordings of specific biological activities. These results suggest that electromagnetic transmission of biochemical information can be stored in the electric dipole moments of water in close analogy to the manner in which magnetic moments store information on a computer disk. The electromagnetic transmission would enable in vivo transmissions of the specific molecular information between two functional bio-molecules. In the present work, the physical nature of such biological information storage and retrieval in ordered quantum electromagnetic domains of water will be discussed.

1. Introduction:

The pioneering experiments of Jacques Benveniste and his collaborators [1] left many biologists, chemists and physicists in an unnecessarily confused state. Our purpose is to examine the notion of memory in water within a standard physics theoretical context of electromagnetic interactions. Ordered thermodynamic phase regions in space can be employed for storing information. Ferromagnetic ordering

is routinely employed for storing memory information on computer disks. Wireless connections leave no doubt that information can be manipulated via electromagnetic waves with sources far from the information storage site. Recall the computer science definition of stored information memory [2]. If Ω denotes the number of states in a system, then the information memory capacity in "bits" is defined as

$$N = \lg \Omega \quad \Rightarrow \quad \Omega = 2^N . \tag{1.1}$$

On the other hand, the statistical thermodynamic entropy is defined [3] by

$$S = k_B \ln \Omega \qquad (k_B \approx 1.3806503 \times 10^{-16} \text{erg/K}) . \tag{1.2}$$

Thus the memory capacity of a physical system is related to the entropy via

$$\left[\frac{N}{\text{bit}}\right] \equiv \left[\frac{8I}{\text{byte}}\right] = \left[\frac{S}{k_B \ln 2}\right] \approx 1.44269504 \left[\frac{S}{k_B}\right], \tag{1.3}$$

wherein I is the memory capacity in bytes. The thermodynamics of computation, briefly discussed by Feynman [4], will now be reviewed.

2. The Thermodynamics of Computation:

The first and second law of thermodynamic quasi-static processes may be written

$$dE = TdS + \sum_{j=1}^{n} Y_j dX_j , \tag{2.1}$$

wherein the first term on the right hand side of Eq.(2.1) represents the heat flowing from the environment into the system and the remaining terms on the right hand side of Eq.(2.1) represent the work done on the system by the environment. In terms of the memory capacity in Eq.(1.3), one finds

$$dE = [k_B T \ln 2] dN + \sum_{j=1}^{n} Y_j dX_j . \tag{2.2}$$

The energy (heat flow into the system) required to add just one bit of memory capacity to the system is thereby

$$[k_B T \ln 2] = \left(\frac{\partial E}{\partial N}\right)_{X_1 \Lambda\, X_n} . \qquad (2.3)$$

Because the heat capacity is positive

$$C_X = \left(\frac{\partial E}{\partial T}\right)_{X_1 \Lambda\, X_n} = T\left(\frac{\partial S}{\partial T}\right)_{X_1 \Lambda\, X_n} \geq 0 , \qquad (2.4)$$

it follows that the energy is a convex downward function of entropy

$$\frac{T}{C_X} = \left(\frac{\partial^2 E}{\partial S^2}\right)_{X_1 \Lambda\, X_n} \geq 0 \;\Rightarrow\; \left(\frac{\partial^2 E}{\partial N^2}\right)_{X_1 \Lambda\, X_n} \geq 0 . \qquad (2.5)$$

Eqs.(2.3) and (2.5) imply that a program written on a system using up ΔN bits of system memory dissipates into the environment a heating energy of at least

$$\Delta E \geq [k_B T \ln 2]\Delta N . \qquad (2.6)$$

This constitutes an irreversible thermodynamic second law bound on the heat of a classical computation. In principle, a quantum computation can be made *reversible* but only at the expense of leaving quantum bits of information in a superposition of different states. On the other hand, a memory bit in a quantum superposition of states is unreadable. It is a very basic Bohr principle of quantum mechanics that all measureable data is *classical*. Thus, Eq.(2.6) is expected to hold true for all computations with output data.

3. Memory in DNA:

The biological polymer molecule which is best studied [5] with regard to memory properties is DNA. In human beings, it is believed that a four letter genetic program of size ~3 Gigabyte is stored on each DNA molecule. The code is written on the molecule in a highly fragmented fashion. If one includes so called "junk" segments, then it has been estimated that the total information capacity is ~100 Gigabyte. We argue below on thermodynamic grounds that the thermal DNA memory capacity is comparable to junk fragment estimates. Of course, memory capacities alone describe only very crudely the subtle nature of biological code. In this regard we note the recent work [6] in which a loop function (subroutine) was inserted into a DNA genetic program within a yeast cell. The modification of the DNA program was induced by exposure to galactose. After many cell divisions, the loop function (subroutine) remained intact *without galactose* nor without any

other sort of molecular trigger. The situation is closely analogous to the studies of Benveniste who observed that biological agents still triggered relevant biological systems in water even in the absence of the original physical molecules.

To illustrate thermodynamic reasoning about information and entropy we consider the DNA molecule. The normal coiled state of the DNA molecule can become uncoiled. It is experimentally possible to hold two points of a long molecule apart with optical tweezers and measure the molecular tension τ. If the length L denotes the distance between the two points, then the DNA molecular free energy F at temperature T obeys

$$dF = -SdT + \tau\, dL = -(k_B \ln 2) N dT + \tau\, dL\,. \tag{3.1}$$

Thus, the information per unit length can be related to the manner in which the tension varies with temperature; i.e.

$$\left(\frac{\partial N}{\partial L}\right)_T = -\left[\frac{1}{k_B \ln 2}\right]\left(\frac{\partial \tau}{\partial T}\right)_L . \tag{3.2}$$

From known variations of tension with temperature, we estimate for DNA molecules an information density of ~30 Gigabyte per meter comparable to the total information stored in DNA.

4. Thermodynamic Memory in Water:

Water contains electric dipole ordered domains of radius R~100 nanometers due to a condensation of photons [7-9] interacting with molecular dipole moments. The ordered domains [10-12] yield an anomalously high water heat of vaporization q* per molecule. Let Δs and Δv, respectively, be the entropy and volume gained by a molecule when evaporated from the liquid into the vapor. The information per molecule due to ordered domains of water may then be measured employing the vapor pressure coexistence curve

$$\frac{dP}{dT} = \frac{\Delta s}{\Delta v} = \frac{q^*}{T\Delta v} = \frac{(k_B \ln 2) N^*}{\Delta v}\,. \tag{4.1}$$

The anomalously high heat of vaporization q* per molecule implies the high degree of memory storage capacity $N^* \approx 23.5$ bits per molecule. Similarly, the partial entropy per molecule of an ionic species dissolved in an aqueous electrolyte [13, 14] imply many bits of information per ion which is sufficiently high as to expect such ions to be attached to an ordered water domain. Such an increase in the bulk coherent ordering volume of quantum hydration captured by an ion allows for semi-permeable membranes which can either pass an ion through a small

gap or forbid such passage depending in part on the state of order in the ion attachment. Such passage through or rejection from semi-permeable membranes based on information (or equivalently entropy) constitutes a *program* for biological cells closely analogous to polymer DNA based programs. The ionic flows through membranes in nerve cells allow for human memory storage in nerve cell networks residing in the human brain. These have about the same order of magnitude for biological information capacity density, far surpassing information density stored in commercial computer memory devices.

5. Diamagnetic Water Domains:

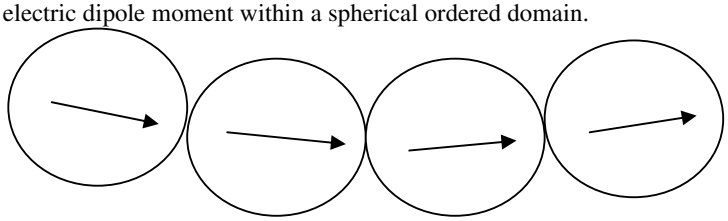
The magnetic properties of water are of equal interest to its electrical polarization properties. It is possible to float a small ferromagnetic needle over and above the surface of pure water. The magnetic needle floatation trick is most often demonstrated with perfect diamagnetic low temperature type one superconductors. The analogous floating of a magnetic needle above the water surface is due to the partial diamagnetic expulsion of Faraday magnetic field lines from pure water ordered domains. In the fringing magnetic field of a bitter magnet one may float a "bag of water" of the size of a frog and in fact one can float a frog. For a single water domain of radius R and volume $V = 4\pi R^3/3$ containing N coherent electrons, the diamagnetic polarizability β may be estimated in terms of the electronic mean square radius as

$$\frac{\beta}{V} = \frac{N}{6V}\left(\frac{e^2}{mc^2}\right)\overline{r^2} = \frac{N}{8\pi}\frac{r_e\overline{r^2}}{R^3} \sim \frac{Nr_e}{8\pi R} \sim 10^{-9}N \sim 1. \qquad (5.1)$$

A coherent ordered domain within water exhibits almost perfect diamagnetism. Yet the total diamagnetism in water is weak. The reason is that magnetic flux tubes can permeate normal water regions just as magnetic flux tubes (called vortices) can permeate type two superconductors via their normal regions. Trapped magnetic flux tubes can also carry information and in particular can give directionality to otherwise isotropic pure water. This will (perhaps negatively) affect the directional nuclear magnetic resonance imaging of biological objects such as the human heart. Magnetic flux tubes trapped in normal water regions may have some positive and some negative **medicinal** consequences.

5. Ferroelectric Water Domains:

The domains in water exhibit a rotating electric dipole moment. Under the application of an electric field, strings of electric dipole aligned water domains are formed as in electro-rheological fluids. A typical string of electric dipolar domains dipoles are shown schematically below. The arrows show the direction of the total electric dipole moment within a spherical ordered domain.



When an electric field is applied, many strings of dipolar ordered domains form a dipolar field bundle of strings. If the electric field is applied employing a voltage difference across electrodes, then the electric dipolar bundle starts on one electrode and continues to the second electrode. The strings of dipolar domains have an effect on the entropy and thereby the information capacity of water memory. Finally, and according the two fluid picture of water structure, an ion of charge *Ze* can flow with virtually no friction through the bundle of electrical dipolar strings skimming the along the domain surfaces and going from one electrode to another.

6. Del Giudice-Zhadin Diamagnetic Resonances:

If the bundles of electric field $\mathbf{E} = (E,0,0)$ induced dipolar string bundles are orthogonal to an applied magnetic field $\mathbf{B} = (0,0,B)$ which varies with time, then ionic transport resonance effects [15] can occur between the frequency of the time varying part magnetic field and the cyclotron frequency Ω associated with the uniform in time part of the magnetic field. To understand such effects consider the equation of motion for an ion to move through a dipolar string bundle parallel to an electric field uniform in time. With τ as the ionic frictional relaxation time,

$$m\left(\frac{d\mathbf{v}}{dt}+\frac{\mathbf{v}}{\tau}\right)=Ze\left(\mathbf{E}+\frac{1}{c}\mathbf{v}\times\mathbf{B}\right). \tag{6.1}$$

For the problem at hand in which the electric field is along the x-axis and the magnetic field is along the z-axis, one may employ a complex velocity wherein

$$\left(\frac{d}{dt}+\frac{1}{\tau}+\frac{iZeB(t)}{Mc}\right)(v_x+iv_y)=\frac{ZeE}{M}. \tag{6.2}$$

The phase change as a function of time associated with the cyclotron resonance is determined by the local angular velocity

$$\dot{\theta}(t)=\frac{ZeB(t)}{Mc}. \tag{6.3}$$

From Eqs.(6.2) and (6.3) one finds a (time averaged) mobility $\bar{v}_x=\mu E$ which is rigorously computed from

$$\mu[B]=\frac{Ze\tau}{m}\int_0^\infty e^{-s/\tau}\overline{\cos[\theta(t)-\theta(t-s)]}\frac{ds}{\tau}. \tag{6.4}$$

For the particular experimental magnetic field which contains a contribution uniform in time and a much smaller contribution varying periodically in time,

$$\frac{ZeB(t)}{Mc}=\Omega+\varpi\cos(\omega t), \tag{6.5}$$

the mobility has the form

$$\frac{M\mu(\Omega,\omega,\varpi)}{Ze\tau}=\int_0^\infty e^{-x}\cos(\Omega\tau x)J_0\left(\frac{2\varpi}{\omega}\sin\left(\frac{\omega\tau x}{2}\right)\right)dx, \tag{6.6}$$

wherein $J_0(x)$ is the Bessel function of order zero. Under the cyclotron frequency condition $\Omega\tau>>1$, Eq. (6.6) will have an observed resonance at the cyclotron and applied frequency values $\Omega=\omega,2\omega,3\omega,\Lambda\ ,n\omega,\Lambda$. The long lifetimes of the cyclotron frequency are due to the fact that the ion is moving through an electric dipolar bundle of strings in which the two fluid model of water dictates an ultra-high degree of mobility. Note that the cyclotron orbits in the above weak magnetic field regime are not large circles but merely small wiggles on the surfaces of the polar domains residing in the bundles of electrorheological strings induced by the application of the electric field between electrodes.

7. Conclusions:

The ordering of water via coherent domains yields sufficient structure for significant memory capacity. Statistical thermodynamics and thereby information theory supports this view. The information coding estimates of the genome, nerve cells in the brain and of water polarization domains are in full agreement with the thermodynamic information theory viewpoint. Ionic motions are affected by ordered water domain polarized string bundles which can serve as electronic switches in networks of nerve cells. These networks form for the basis of conscious human memory. Electrical polarization networks and the resulting filament magnetic flux and electric flux tubes in pure water should be measurable employing magnetic resonance imaging techniques.

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