Memory of Living Beings and Its Three Characteristic Times

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In this study we first evaluate the time between collisions related to the transport properties in liquid water, provided by the protons motion tied to the hydrogen bonds. As water is an essential substance for the establishment of life in the living beings, we take this time as the basic unit to measure some kinds of retention time related to their memory. Besides this, integration is an important feature associated to the operation of the memory. Then we consider two possible ways of doing integration and an average between them. One of these characteristic times, the Darwin time, is given by adding over the N basic units which forms the memory. The other possibility, the recent time, is obtained by considering a kind of time-like random walk running over the N basic units. Finally we perform a geometric average between these two times and call it generations' time. As a means to estimate these characteristic times, we take the number of protons contained in a volume of water compatible with the dimensions of the portion of the brain responsible by its memory.

1 Introduction

It seems that water is fundamental to the flourishing of life [1], and the hydrogen-bond kinetics [2] plays an important role in the establishment of the transport properties of this liquid. Besides this, living beings which exhibit the property of to replicate, must have this feature encoded in its memory. In electronic computers, electrical currents are the agents responsible for writing or deleting the information stored in its memory. In this paper we propose that, in the living beings case, the protonic currents do this job. In order to accomplish this we will treat protonic currents in close analogy with the electrical currents in metals.

First we will evaluate the averaged time between collisions for protonic currents and after we will use this time in an integration sense, in order to find characteristic times of persistency of the information registered in the living beings memories. By integration sense we mean that we are looking for physical properties which depend on the whole system, a kind of cooperative effect, or an emergent property of the collective of particles.

2 Electrical conductivity through protons

Drude formula for the electrical conductivity of metals can be written as

$$\sigma = \frac{e^2 n\tau}{M}, \tag{1}$$

where e is the quantum of electric charge, n is the number of charge carriers per unit of volume, τ is the average time between collisions and M is the mass of the charge carriers.

Besides this in reference [3], starting from Landauer's paradigm: conduction is transmission [4], the relation for the electrical conductivity can be put in the form

$$\sigma = \frac{e^2}{\pi\hbar\ell_0}. \tag{2}$$

where ℓ_0 is the size of the channel of conduction. In the case of the charge carrier being the proton, the maximum conductivity is reached when the length, ℓ_0, becomes equal to the reduced Compton wavelength of it, namely

$$\ell_0 = \frac{\hbar}{Mc}. \tag{3}$$

Inserting equation (3) into equation (2) we get

$$\sigma_{max} = \frac{e^2 Mc}{\pi\hbar^2}. \tag{4}$$

Making the identification between the two relations for the electrical conductivity, namely equating equation (1) to equation (4), and solving for τ, we obtain for the maximum time between collisions the expression

$$\tau_{max} = \tau = \frac{M^2 c}{n\pi\hbar^2}. \tag{5}$$

It would be worth to evaluate numerically equation (5). In order to do this we consider that water molecules in the liquid state are relatively closed packed. Therefore by taking $n = 10^{29}\,\mathrm{m}^{-3}$, which seems to be an acceptable number for n, we get

$$\tau = 2.7 \times 10^{-7}\ \mathrm{s}. \tag{6}$$

This time interval is seven orders of magnitude greater than the time between collisions of electrons in metallic copper at room temperature [5].

3 Hydrogen bond and the transport properties of liquid water

As far we know, protonic currents have not been directly measured in water. Indeed, equation (5) for the maximum time between collisions, does not show explicit dependency on the quantum of electric charge e.

Meanwhile, from equation (27) of reference [5], we have

$$\lambda_{\rm F}^2 = \lambda_{\rm C}\,\ell\,. \qquad (7)$$

In equation (7), $\lambda_{\rm F}$, $\lambda_{\rm C}$ and ℓ, are respectively the Fermi and Compton wavelengths and the mean free path of the particle responsible by the transport property in water. Besides this, Luzar and Chandler [2] pointed out that: "In the hydrogen — bond definition employed by them, two water molecules separated by less than 3.5Å can be either bond or not bonded, depending upon their relative orientations. At large separations, a bond cannot be formed." This information comes from the first coordination shell of water, as measured by its oxygen-oxygen radial distribution function. We will idealize a lattice of water molecules, and by considering its Fermi length $\lambda_{\rm F} = 3.5$Å, and by taking $\lambda_{\rm C}$ equal to the reduced Compton length of the proton, we obtain from equation (7)

$$\ell = 6.2 \times 10^{-4}\ \text{m}. \qquad (8)$$

Equation (8) is an estimate of the proton mean free path in water. If we write

$$\ell = V_{\rm F}\tau \qquad (9)$$

where $V_{\rm F}$ is a kind of Fermi velocity of the system and solving for $V_{\rm F}$, we find after using equations (6) and (8)

$$V_{\rm F} \approx 2300\,\text{m/s}. \qquad (10)$$

We observe that this value of $V_{\rm F}$ is comparable with the speed of sound in water, approximately 1500 m/s. Therefore this time between collisions estimated for the proton motion performing the hydrogen bond in water seems to make some sense.

4 Three characteristic times tied to the living beings

Recently Max Tegmark [6] published a paper entitled *Consciousness as a State of Matter*. Tegmark was inspired in a work by Giulio Tononi [7]: *Consciousness as Integrated Information: A Provisional Manifesto*. According to Tegmark [6], Tononi [7] stated that for an information processing system to be conscious, it needs to have two distinct properties:

1. Have the ability to store a long amount of information;
2. This information must be integrated into unified whole.

Besides this, as was pointed out by Tegmark [6]: "Natural selection suggests that self-reproducing information processing systems will evolve integration if it is useful for them, regardless of whether they are conscious or not". In this work we are interested in look at the integrated effects with respect to time intervals, taking in account the great number N of basic units which compose the whole. By whole, we consider for instance, a substantial part of the brain of a living being responsible by its memory. We assume that the characteristic times are measured in terms of units of time-base. This unit will be taking as the time between collisions of the protons motion, related to the transport properties of water and associated to the hydrogen-bond dynamics.

4.1 Integrated time: first possibility

Let us to take a time-like string of N unit cells or basic units. We suppose that the time elapsed, $\tau_{\rm R}$, for the information sweep the whole string can be computed by considering a kind of Brownian motion on this time-like string. Then we can write

$$\tau_{\rm R} = N^{\frac{1}{2}}\tau. \qquad (11)$$

Eighteen grams of liquid water occupies a volume of approximately 18 cm^3 and contains $2N_A$ protons, where N_A stands for Avogrado number. We assume that this volume corresponds to a portion of the human brain compatible with the size of the region of memory storage. As a means to estimate $\tau_{\rm R}$, let us put numbers in (11) and we get

$$\tau_{\rm R} = (2N_A)^{\frac{1}{2}}\,\tau \approx 3 \times 10^5\ \text{s}. \qquad (12)$$

The time interval, given by equation (12), corresponds approximately to the duration of 3.5 days and perhaps can be associated to the recent memory of the human brain. If the volume of the memory's device is ten times smaller, namely 1.8 cm^3, the value of $\tau_{\rm R}$ is reduced to approximately one day.

As a means of comparison, we cite a statement quoted in a paper by S. Mapa and H. E. Borges [8] that a type of memory which they call working memory, may persist by one or more hours. Meanwhile, with chemical aids this time can be extended, as we can find in the words of Yassa and collaborators [9]: "We report for the first time a specific effect of caffeine on reducing forgetting over 24 hours".

4.2 Integrated time: second possibility

Another possibility to consider for the integrated time is assuming that the overall time is the sum over the basic time units. Thinking in this way it is possible to write

$$\tau_{\rm D} = N\tau\,. \qquad (13)$$

If we take $(2N_A)/10$ protons of 1.8 grams of water, we obtain for $\tau_{\rm D}$,

$$\tau_{\rm D} \approx 3.2 \times 10^{16} \approx 10^9\ \text{years}. \qquad (14)$$

We will call $\tau_{\rm D}$ the Darwin's time. This choice can be based in the following reasoning. According to Joyce [10]: "The oldest rocks that provide clues to life's distant past are 3.6×10^9 years old and by that time cellular life seems already to be established!" Another interesting paper about the origins of life can be found in reference [11].

4.3 Third characteristic time

The two characteristic times we have discussed before were associated by us to the recent memory time $\tau_{\rm R}$ (order of magnitude of one day) and the Darwin's time $\tau_{\rm D}$ (order of magnitude of one billion of years), this last one related to the establishment of life on earth. We judge interesting to consider another characteristic time corresponding to the geometric average of the two times we just described. We write

$$\tau_G = (\tau_D \tau_R)^{\frac{1}{2}} = N^{\frac{3}{4}} \tau . \quad (15)$$

Inserting $N = 1.2 \times 10^{23}$, the number of protons contained in $1.8\,\text{cm}^3$ of water and the unit of time interval $\tau = 2.7 \times 10^{-7}$ s in equation (15), we obtain for the generations' time τ_D the value

$$\tau_G = 1700\,\text{years}. \quad (16)$$

If we estimate a mean lifetime of the human beings as 70 years, the above number corresponds to approximately 24 generations.

5 Analogy with the polymer physics

Two characteristic times we have described in this paper can be thought in analogy with polymer physics [12]. In four dimensions, the scaling relation of polymers reproduces that of a single random walk.

If we think about a time-like string of time-length τ_D, composed by "monomers" having the duration of a unit-time τ, we have after N steps the relation

$$\tau_R = (\tau_D \tau)^{\frac{1}{2}} = N^{\frac{1}{2}} \tau . \quad (17)$$

We remember that τ_D is given by equation (13). Therefore the Darwin's time τ_D corresponds to the time-length of the string and the recent time τ_R looks similar to the end to end distance (equivalent to the gyration radius of polymers).

6 Concluding remarks

This work has been developed through two steps. In the first one, an averaged time τ between collisions was calculated, taking in account the proton current associated to the hydrogen bond in liquid water. As the human body, in particular its brain, is constituted in great extension by this liquid, it seems that any physical process occurring in it must consider the relevancy of water in supporting this task. Perhaps the above reasoning could be extended to all living beings. The falsifiability of the calculated τ was verified by obtaining a kind of Fermi velocity which is comparable to the sound velocity in liquid water.

In the second step we considered an important property of memory, namely its integrability. By taking a number N of hydrogen bonds contained in a volume of water representative of the memory device of the living beings, we was able to associate two characteristic times to them. The integrability given by simple addition of unit-base time gives the Darwin time which grows linearly with N. Another kind of integration, a time-like random walk, leads to the recent memory time which grows with the square root of N. An intermediate time interval given by the geometric average of the last two ones was also evaluated and we call it generation's time.

Although this work may sound very speculative, we think that it perhaps could inspire other more robust research on the present subject.

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