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Increased dielectric constant in the water treated by extremely low frequency electromagnetic field and its possible biological implication

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Abstract. Water is the most abundant compound on the surface of the Earth, and can be considered to be the most important molecule in living systems. Water plays a variety of cellular functions, being the solvent of most biological molecules, a substrate and product of enzymatic catalysis, an important component of macromolecules, and more. Because of importance of water in life, many physical and chemical treatments were invented to improve the quality of drinking water. Among them, the treatment with electromagnetic field is a well-known, but much debatable physical method. Although electromagnetic field has been utilized for treating water for 80 years, many reports on beneficial biological effect of electromagnetic field-treated water were either anecdotal or less convincing. To explore if there is any physical base for understanding possible biological effects of electromagnetic field-treated water, dielectric relaxation spectra of deionized water treated with an extremely low frequency electromagnetic (ELFEM) field were measured and compared with that of untreated water.
It was surprisingly found that the dielectric constant of the ELFEM field-treated water was 3.7% higher than the control over the frequency range of 1-10 GHz, which indicates a higher molecular polarization occurs in the ELFEM field-treated water. Electrostatic and thermodynamic analysis shows that proteins or other biomacromolecules would have more reduced free energy when they are hydrated in high dielectric constant water. Since free energy is of crucial importance for stability of proteins, protein folding and its conformational change, as well as catalytic activity of enzymes, the free energy reduction of the biomacromolecules hydrated with higher dielectric constant water may be responsible for many possible biological effects of electromagnetic field treated water.

1. Introduction

Water is the most abundant compound on the surface of the Earth and it is the principal constituent of all living organisms. The human body is about 65 per cent water by weight, some tissue such as brain and lung being composed of nearly 80 per cent water. For all practical purposes, water can be considered as the only solvent in the body. Water exists in the mammalian body as two compartments, each with several subdivisions. They are intracellular water compartment, which makes up approximately 60-65% of body water, and extracellular water, which makes up the other 35-40% of body water. Intracellular water compartment is found inside the bilayered plasma membrane, and is the matrix in which cellular organelles are suspended, and chemical reactions take place[1]. The extracellular water compartment is found in the space that surrounds the cells of a given tissue and provides the immediate microenvironment that allows for movement of ions, proteins and nutrients across the cell barrier. Besides these, water molecules even become part of protein structure, and are called as buried water molecules, which have no contact with bulk solvent. The buried water plays a role in structural stabilization of proteins. A cryogenic X-ray crystallographic study demonstrated that large-scale networks of hydrogen bonds covering the entire surface of proteins were quite flexible to accommodate to the large-scale conformational changes of proteins and seemed to have great influences on the dynamics and function of proteins [2].

Water property is of crucial importance because, very often, it determines the details of biological activity. For example, it was shown that a minimum amount of water (of the order of 3%) is necessary for the activity of proteins and that this amount of water corresponds to the percolation of hydrogen bonds in a first hydration layer [3]. More generally, it is a common statement that liquid water is a necessary condition for life. Because of importance of water in life, many physical and chemical treatment were invented to improve the quality of drinking water. Among them, the treatment with electromagnetic field is a well-known, but much debatable physical method since 1930s. The earlier devices mostly employed permanent magnets, but many now use alternating magnetic or electrostatic fields. In this paper, we are not going to deal with many confused reports, such as that Magnetic Treatment can reduce the effects of hard water, as an alternative to water softening [4], but mainly focus on whether the electromagnetic field-treated water is biological effectiveness. Ismail and Shoukry reported recently that the snails after 12 weeks exposure to magnetic water were slightly greater, had a much significantly increased number of eggs and egg-masses than the control group. They also observed that the hatchability rate of treated eggs in magnetic water for 5 days was higher than that in control group. However, a significantly reduced survival rate of newly hatched snails was observed in magnetic water for another 7 days after hatching [5]. D. Zhao and his coworkers reported that increased activity of antioxidant enzymes (including catalase, superoxide dismutase (SOD) and glutathione peroxidase) and reduced lipid peroxidation in the mice fed with magnetic field-treated water for one month, and reduced blood lipid level in rats fed with magnetic field-treated water for 5 weeks were observed in comparison with control groups [6]. It is a pity that the authors did not specify their used magnetic field and how was the water treated. Y.Liu and his coworkers investigated effects of the water, which was treated with an extremely low frequency electromagnetic field (abbreviated as ELFEM field) same as that used in this investigation, on leukocyte adhesion and microcirculation of mesentery, blood viscosity and erythrocyte deformation, potential and peristalsis of intestines and stomach, fatigue endurance capacity and activity of natural killer cell in rats. They found that drinking of the ELFEM field-treated water resulted in obviously reduced adhesion and migration of leukocytes, less aggregation of platelets, increased secretion of IL-1 and IL-6, reduced blood viscosity, improved gastrointestinal peristalsis and contractility, and higher activity of natural killer cell (splenocyte) in rats, as well as longer swimming time was found in mice fed with the ELFEM field-treated water [7-10]. Above mentioned biological effect of electromagnetic field-treated water on animals seems unbelievable. In order to understand such biological effectiveness of electromagnetic field-treated water, on one hand, some better-controlled animal experiments or clinical trials should be done to see if the biological, especially the health-beneficial, effectiveness of electromagnetic field-treated water could be confirmed, on the other hand, some solid physical or chemical bases should be established to explain possible biological effectiveness of the electromagnetic field-treated water. For this purpose, we examined if dielectric property of water, which may influence structure and function of hydrated proteins, has any significant change after treatment with electromagnetic field.

2. Experimantal Procedure

2.1. Electromagnetic field and treatment of deionized water

The extremely low frequency electromagnetic field (ELFEM field) used for treating water was generated in an appratus provided by Guangdong Junfeng BFS Industry Co.Ltd. The principal setup in the water treatment is shown as Fig.1. Deionized water 6 times flowed through the alterate ELFEM field perpendicularly in a non-ferrous pipe. Each time, the water remain in ELFEM field for about 1 second. The magnetic flux density of the ELFEM field $B = 2^{1/2}B_0\mathrm{Sin}(2\pi ft)$, in which B_0=0.15 Tesla, and f = 50 Hz.

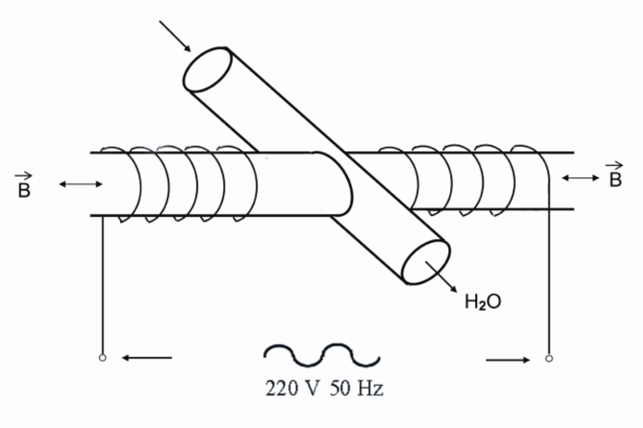

Fig.1. Diagram of the extremely low frequency electromagnetic field used for water treatment.

2.2. **Measurement of Dielectric Relaxation spectra**

All measurements were carried out in State Key Laboratory of New Ceramics and Fine Processing, Tsinghua University (Beijing) using a parameter network analyzer (Agilent/HP 8720ES-S, Agilent, Santa Clara, CA) with an open-end coaxial Agilent/HP 85070E Dielectric Probe (19 mm diameter) immersed in a glass beaker (total volume of 25 mL) containing a sample water. The beaker was held at 23 ± 1°C by a temperature-controlled circulator. The whole measuring system was placed in an air-conditioned room maintained at 23 ± 1 °C. The probe calibration was performed by three separate runs: open-circuited to the air, shortcircuited with mercury and in contact with pure water. Dielectric relaxation (DR) spectra were recorded for the frequency range of 50 MHz–20 GHz (200 frequency points in log-scale). The DR spectra of the ELFEM field-treated deionized water, $\varepsilon_{em}*$ (ν), and untreated deionized water, $\varepsilon_c^*(\nu)$, were each measured 6 times for obtaining average values and statistical analysis. Here ν is the relaxation frequency.

2.3. **Statistics**

Every 6 data on each frequency point in the DR spectra of ELFEM field-treated water and the every 6 data on each frequency point in the DR spectra of untreated water were subjected to Student's t-test. $p<0.01$ was used as a criteria to adjudge if the dielectric constant averaged over 6 data at each frequency point of the DR spectra from ELFEM field-treated water is significantly different from the corresponding dielectric constant from untreated water.

3. Results

The dielectric relaxation spectrum of ELFEM field-treated deionized water and the control that pass through the apparatus without switching on power are measured, and shown in Fig.2. It clearly shows that the dielectric constants of the ELFEM field-treated water at almost every frequency point are significantly higher than those obtained for untreated water. In average, the dielectric constant of the ELFEM field-treated water is 3.7% higher than the control over the frequency range of 1-10 GHz.

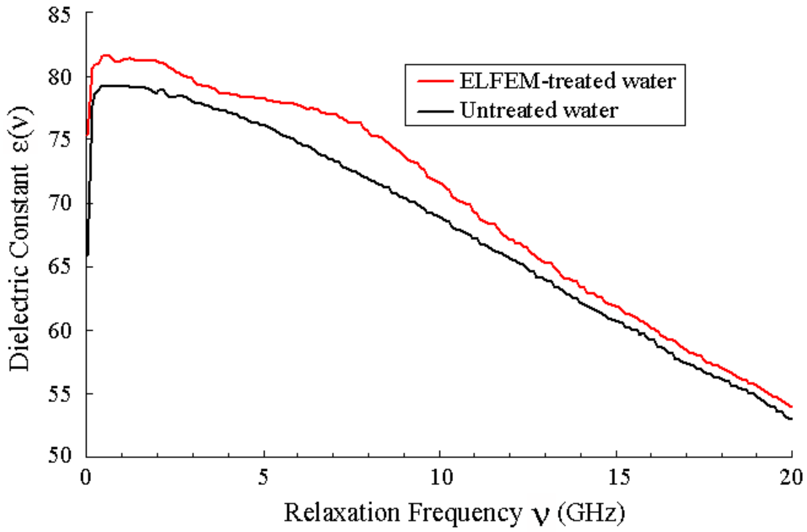

Fig.2. Dielectric relaxation spectra of deionized water with or without treatment of an extremely low frequency electromagnetic field.

The conductivity spectra of the ELFEM field-treated water and untreated water, $\sigma_{EM}(\nu)$ and $\sigma_c(\nu)$ can also be calculated from the imaginary part of the Dielectric relaxation spectra, $\varepsilon''(\nu)$, by following equation [11] :

$$\sigma(\nu) = 2\pi\nu\varepsilon_o\varepsilon''(\nu) \quad (1)$$

where ε_o is the free space permittivity , and has the value of 8.84 x 10^{-12} *F/m*. The calculated conductivity spectra of ELFEM field-treated water and untreated water are shown in Fig.3. It can be seen that ELFEM field-treatment did not cause any alteration in the conductivity of deionized water.

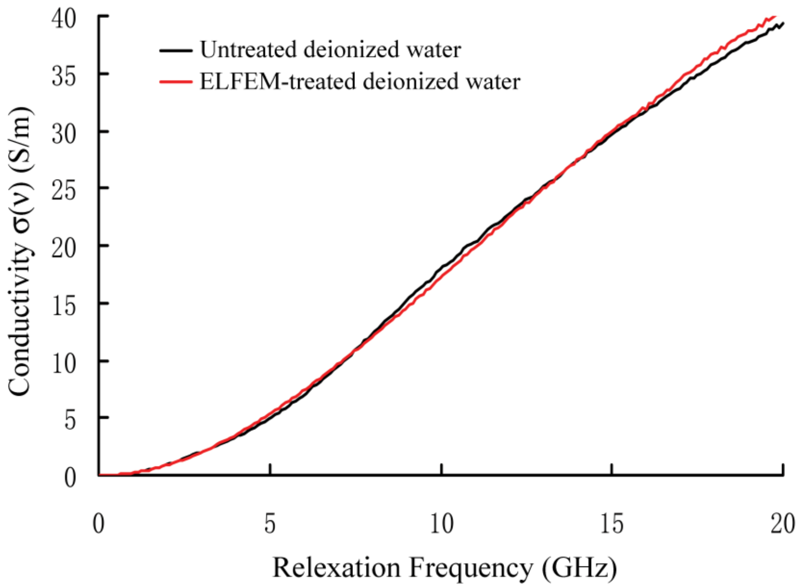

Fig.3. Conductivity spectra of deionized water with or without treatment of an extremely low frequency electromagnetic field.

4. Discussion

In the present investigation, the dielectric relaxation spectrum of deionized water was found significantly increased after the treatment by an extremely low frequency electromagnetic field. However, as expected, the ELFEM field-treatment does not cause any alteration in the conductivity of deionized water, since ELFEM field-treatment can not change either composition or concentration of remaining ions in deionized water. The latter result may even serve as an eviednce that the observed change of dielectric relaxation spectrum in deionized water is hardly due to any systematic error in experimental measurements.

Water is the substance with individual molecular dipole moments, μ_i. Dielectric relaxation spectroscopy probes the response of the total dipole moment, $M(t) = \Sigma\mu_i(t)$, to a time-dependent external electromagnetic field. This inherent ability to monitor the cooperative motion of a molecular ensemble distinguishes dielectric relaxation from methods like NMR or Raman spectroscopy which essentially yield information on the motions of individual molecules. Kirkwood firstly proposed the following famous equation to calculate dielectric constant of water [12]:

$$\frac{(2\varepsilon+1)(\varepsilon-1)}{9\varepsilon} = \frac{4\pi N_0 d}{3M}(\alpha + \frac{\mu^2 g}{3kT}) \quad (2)$$

where ε is dielectric constant of water, N_0 is Avogadro's number; d is the density of water; M is molecular weight of water; k is the Boltzmann constant; α is the molecular polarizability; μ is the molecular dipole moment; g is the Kirkwood correlation factor that accounts for nonrandom orientation of neighboring molecules, and T is the temperature of water. Based on this equation, it can be known that the increased dielectric constant of the ELFEM field-treated water means that ELFEM field-treated water has higher molecular polarization α. Since molecular polarization determines the higher order structural of water, orientation of H_2O dipoles and the angle of H-bonds in bulk water might be altered.

Among the unsolved problems of physics, that of the properties of liquid water is one of the more important, not only because of its fundamental aspects but also because of its impact on life. The importance of electrostatic effects as the primary correlation between structure and function of biological molecules has been pointed out [13, 14] and demonstrated [15] repeatedly. It is now quite clear that electrostatic effects play a major role in enzyme catalysis [16,17], electron transfer [18,19], proton transport [20], ion channels [21,22], ligand binding [23], macromolecular assembly [24], and signal transduction [25]. It has been well established that all bio-macromolecules including polypeptides, polynucleotides, and polysaccharides, are stiff molecular chains with restricted folding capacities due to inclusion of rigid ring structures or double amide bonds in the backbone sequence. This creates ''irreducible spatial charge separation'' between positive and negative partial charges, causing elevated electrostatic energy. As a conceptual diagram, Fig.4a shows that binding of water molecule to protein results in increased distance between amino group and carboxyl group. As Fig.4b shows, in vacuum, the work required to separate a charge pair (NH^+ and CO^-) on a biomacromolecule is [26]

$$W_V = \frac{q_1 q_2 (\frac{1}{s_0} - \frac{1}{r_{12}})}{4\pi\varepsilon_v}, \qquad r_{12} = s_0 + d \quad (3)$$

In water, the work required is

$$W_w = \frac{q_1 q_2 (\frac{1}{s_0} - \frac{1}{r_{12}})}{4\pi\varepsilon_w} = W_v \frac{\varepsilon_v}{\varepsilon_w} \quad (4)$$

Where q_1 and q_2 are charge on NH^+ and CO^- group respectively, s_0 and r_{12} are distance between NH^+ and CO^- group in vacuum and in water respectively. ε_v and ε_w are dielectric constant of water in vacuum and in water respectively. The work requried to separate a charge pair (NH^+ and CO^-) in dielectric water is reduced as $\varepsilon_v/\varepsilon_w$ of the work required in vacuum. Thus, the work required in ELFEM field-treated water would be further reduced by a factor of $\varepsilon_{em}^*(\nu)/\varepsilon_c^*(\nu)$ in comparison with the untreated water, which is about 1.037. (See section "Results"). The reduction of the work require to separate charge on NH^+ and CO^- groups means that the free energy of the hydrated protein is reduced in ELFEM field-treated water if the treated water could enters the cells, replaces the previously bound water, and keeps its dielectric property in full or certain degree.

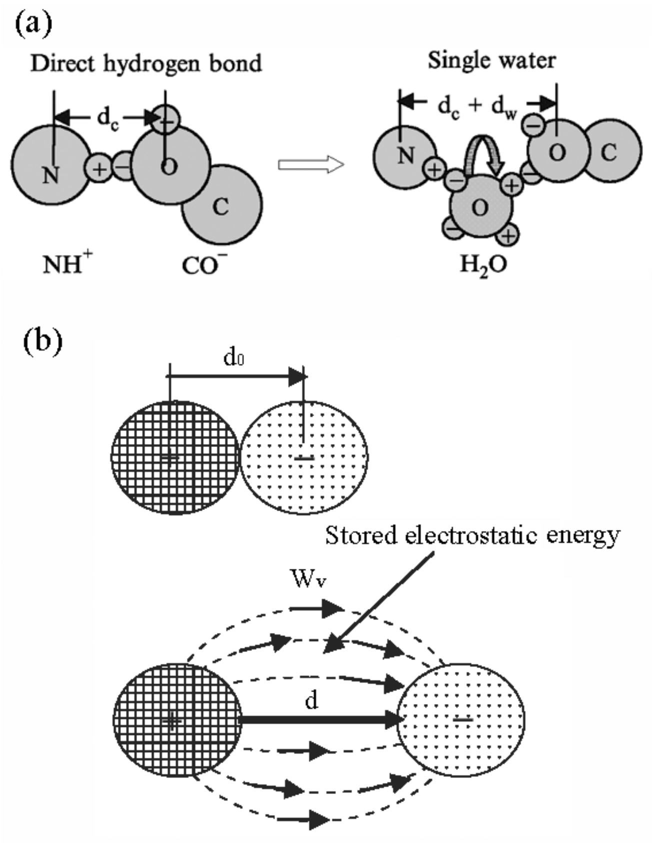

Fig.4. (a) The conceptual diagram showing formation of single water bridges between NH^+ and CO^- groups in hydrated proteins and (b) the Work is required to separate a charge pair. The irreducible separation of partial charges on the backbone of macromolecular polymers such as proteins creates an electrostatic field that stores this energy.

In fact, the conclusion "free energy of macromolecules in the water of high dielectric constant would be reduced" can be easily deduced from thermodynamics. The free energy $\Delta G = \Delta H - T\Delta S$ of water binding is the sum of negative electrostatic enthalpy ΔH partially compensated by the positive contributions from negative entropic change ΔS caused by the increased order of dielectrically aligned water molecules. It has been also well established that free energy is of crucial importance for stability of proteins, protein folding, conformational change of proteins, and catalytic activity of enzymes. The free energy function of protein has been a critical parameter for computational prediction of protein structure and function [27, 28].

Finally, it must be pointed out that all above discussion is based on an assumption that the electromagnetic field-treated water could still keep its high dielectric property in full or certain degree when it enters human body and living cells. The assumption seems to be reasonable, but solid evidence is still lack. Further study in this line would be necessary.

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