EFFECT OF WEAK MAGNETIC FIELDS ON THE PROPERTIES OF WATER AND ICE

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We establish that a number of physical properties of water and ice are significantly changed by an alternating magnetic field of a certain frequency. The changes in the physical parameters of ice are several times stronger than the changes in the corresponding parameters of water. Heating water to 50°C destroys the magnetic effects. When the field is much weaker than the geomagnetic field, a change in water purity (bidistilled instead of distilled water) only broadens the extrema observed in the state dependences of water and ice on the frequency of the alternating magnetic field of constant amplitude. The magnitude and intensity of these extrema are unaffected by water purity. The effects of the geomagnetic field on the properties of ice and water are also discussed.

The overwhelming majority of investigations of the effect of magnetic field on water have been carried out in fields much stronger than the geomagnetic field, in conditions of turbulent flow through an inhomogeneous field. A detailed review of this research is available in the monograph by Klassen [1]. It is generally assumed that the changes in water properties induced by the field are largely due to impurities in the water. In this report we present new results on the effects of constant and alternating magnetic field, as well as of the rotation of the water cell, on a number of physical properties of water: ac electrical conductivity κ, speed of sound v_s, thermal conductivity χ, extent of supercooling ΔT, complex permittivity ε^* and loss tangent $\tan\delta$, refractive index n, surface tension σ, and adsorption.

First, let us discuss the effects of an alternating magnetic field. In our experiments the field amplitude H ranged from 0.02 to 700 A/m, the field treatment frequency f_{tr} ranged from 10^{-2} to 200 Hz. (Recall that the intensity of the geomagnetic field $H_g = 46$ A/m). We studied bidistilled H_2O ($\kappa = 1.2\cdot10^{-6}\ \Omega^{-1}\cdot\mathrm{cm}^{-1}$) and D_2O ($\kappa = 1\cdot10^{-6}\ \Omega^{-1}\cdot\mathrm{cm}^{-1}$). We observed that the parameters of H_2O undergo the greatest change from 4-5 h of treatment in such a field (D_2O after 6-7 h). In polycrystalline ice these times are much shorter: 1.5-2 h. At room temperature T_r the field-induced changes in water persist for 2-3 h and fall off to zero after 5-6 h. Thus we find that both ice and water can "remember" magnetic field effects, as was previously observed by Klassen [1].

When studying the properties of water and ice in different fields of constant intensities H as a function of frequency f_{tr} we observed several extrema.* To illustrate this in Figs. 1 and 2 we present the data on $\tan\delta$ and κ (Fig. 1), and supercooling (ΔT) and crystallization kinetics (Fig. 2). The quantity $\tan\delta$ was measured on the VM-409G Q-meter at measurement frequencies $f_m = 160$ MHz for water and $f_m = 20$ MHz for ice. The conductivity κ was measured in a standard cell with platinum electrodes in the 50 Hz to 20 kHz frequency range. The conductivity did not change appreciably with measurement frequency.

It turned out that at a given field intensity H all the studied parameters of water would be most affected at the same optimal treatment frequency (f_{tr}). For example, consider conductivity κ and $\tan\delta$ for liquid H_2O and H_2O ice shown in Fig. 1. By comparing the changes in the same parameters ($\tan\delta$ in Fig. 1) of water and ice we find that the water extrema are much broader. The extremum peaks were always higher in ice than in water. The same state of water or ice could be reached by changing the field amplitude H at constant frequency f_{tr}. The relation $f_{tr} = \gamma\cdot H$ [2] held at weak fields $H < 10$ A/m. Thus, doubling H would also double the treatment frequency f_{tr} at which the strongest supercooling maxima were observed (Fig. 2).

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*The amplitude H and f_{tr} were stabilized to better than 0.2%.

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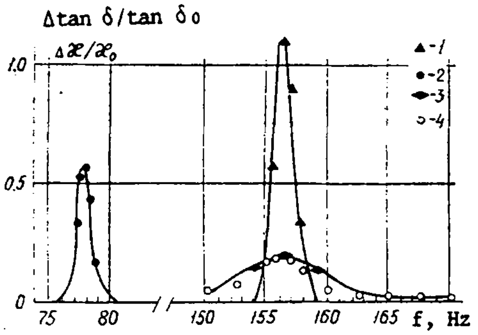

Fig. 1. Relative changes in tan δ for H_2O ice (1), D_2O ice (2) at T = −5°C, liquid H_2O at T = 21°C, relative change in conductivity of liquid H_2O (4) at T = 21°C in an alternating field of 12.3 A/m amplitude as a function of field frequency.

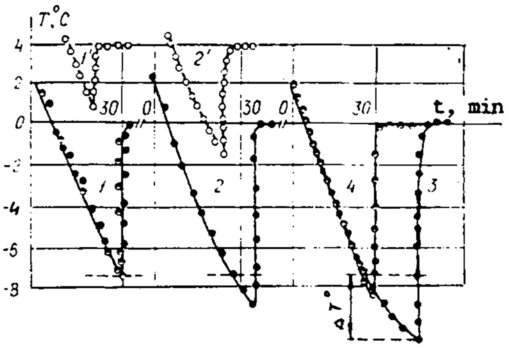

Fig. 2. Kinetics of supercooling and crystallization in liquid H_2O (solid lines) and D_2O (dashed lines) before magnetic treatment (1 and 1') and after 5 h in an alternating field with H = 6.2 A/m at T ≅ 21°C and frequency f = 80 Hz (2), 86 Hz (3), 90 Hz (4) for H_2O; and f = 43 Hz (2) for D_2O.

At the optimal frequency f_{tr} = 86 Hz magnetized water could be supercooled by an extra 2.5 ± 0.5°C over untreated water.

In heavy water the optimal extremum frequencies were lower by a factor of two compared to ordinary water at the same field intensity: for instance tan δ in Fig. 1 and T(t) in Fig. 2. Other behavior was unchanged.

We also conducted experiments in which the water-containing cell was rotated at rates of 0.1-20 rps in a constant solenoid field ranging from 0.1 to 10^3 A/m [2]. At constant field H and some optimal rps rate we observed extrema in κ, σ, n, ΔT, and v_s in the same (bidistilled) water. Similar extremal behavior was observed in experiments with a stationary cell in an alternating magnetic field.

As we have seen already, very weak magnetic fields can still affect the properties of water. Thus we decided to determine the effect of the geomagnetic field (H_g) on the parameters of water and ice. To this end the cell containing water on ice was placed in a solenoid whose field would compensate H_g. As the overall magnetic field passed through zero we observed extrema in n, tan δ, and water vapor adsorption on ferrous oxide and quartz. The changes in these parameters at the point of H_g compensation would be of the opposite sign compared to the effects of an alternating field. This tendency is illustrated in Fig. 3 with tan δ as an example. The alternating field has the effect of reinforcing the geomagnetic field. In order to reliably measure the effects of H_g it must be compensated with 0.06% accuracy. If the compensating field strayed from H_g by as little as 1%, changes in the parameters of ice could no longer be observed. This probably explains why a number of researchers failed to observe the effect of the geomagnetic field on the properties of ice and

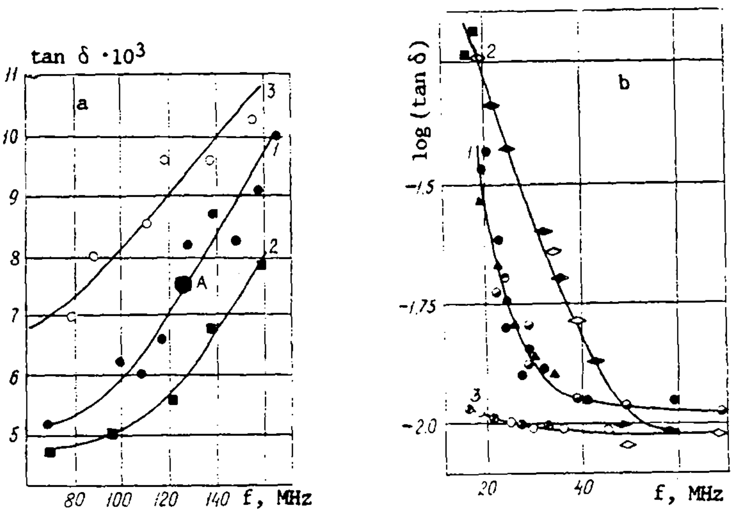

Fig. 3. Frequency dependence of tan δ in liquid H_2O at $T = 21°C$ (a) and ice at $T = -5°C$ (b): 1) prior to treatment, point A from handbook [3]; 2) after 5 h in an alternating magnetic field with $H = 12.3$ A/m and $f = 156.4$ Hz; 3) after 5 h in a field compensating the geomagnetic field. Different symbols indicate the reproducibility of results in different experimental runs.

water. The sensitivity of some parameters to H_g is so great that we could observe the influence of the latitude at which the experiment was conducted. The modulation of H_g due to solar activity was also measurable. This lends support to the results of Piccardi, Opalinskaya, Agulova, et al. (see monograph [1]). Interestingly, when the H_g-compensating field and a weak alternating magnetic field were applied simultaneously to water or ice, the times for which the alternating field "memory" persisted were reduced severalfold.

Klassen [1] is probably correct in assigning the leading role in field-induced changes to impurities when relatively strong (10-100 kA/m) magnetic fields are involved. When smaller fields are used (0.02-700 A/m in our experiments) the role of various impurities is significantly smaller. Changing from bidistilled water to distilled water (which alters κ by more than a factor of 3) only broadened the extrema in κ, tan δ, n, and ΔT, without shifting their position on the frequency scale. Introducing a 1% concentration of a chloride salt (K, Na, Li, Mg, Fe) did not affect the magnitude of changes in n and tan δ. The extrema positions were shifted in frequency however: positively hydrated cations shifted the extrema towards lower frequencies, whereas the negatively hydrated cation (K) shifted the extrema towards higher frequencies [2]. We noted that the introduction of impurities in alternating magnetic fields with $H > H_g$ leads to the appearance of additional extrema in n and tan δ. In strong fields ($H > 700$ A/m) the properties of water became polyextremal, in full agreement with earlier research [1]. In weak fields ($H < 1$ A/m) the number of extrema is not large (3-6) and their positions do not depend on impurities, but are determined by the water properties only.

Discovering the mechanisms responsible for the field-induced changes in the properties of water and ice obviously requires a detailed investigation employing a number of experimental methods. As a first step in this direction we studied the behavior of complex permittivity ε^* in the 20-160 MHz frequency range. This frequency range is particularly interesting because it includes the frequency origin of Debye dispersion for both water and ice. In the case of water we approach Debye dispersion from the lower frequencies; for ice the situation is reversed. The calculated behavior of tan δ is shown in Fig. 3.

It is apparent from Fig. 3 a that the treatment of water in an alternating magnetic field shifts the origin of Debye dispersion towards higher frequencies. In ice the Debye dispersion is shifted in the same direction. These shifts indicate a slightly increased mobility of H_2O molecules and a reduction of their relaxation times. Compensation of the geomagnetic field leads to the opposite result. The compensation effect is especially strong in ice.

Subjecting water to a weak alternating magnetic field changes other physical properties as well. Thus, at $H = 12.3$ A/m and $f_{tr} = 156.4$ Hz the speed of sound v_s increases by almost 3%; σ increases by 8%; the edge wetting angle at the water-quartz interface almost doubles; finally, the adsorption of water on powdered quartz (in the region of polymolecular adsorption) decreases.

All of these magnetic field-induced effects in water disappear when the temperature is raised to 40-50°C, at which point, according to Klassen [1], the structure of water changes.

Currently, the questions of the structure of water and the mechanisms by which its properties change as a result of physical interactions, including the effects of magnetic fields, are quite controversial. Different models — multistructural, continuous, dynamical, etc. — of liquid water have been proposed (see reviews [1, 4]). In addition to protons and hydroxyls, the existence of larger complexes like $H^+ + (H_2O)_i$ and $OH^- + (H_2O)_j$ has been hypothesized [4]. We note that the treatment frequencies f_{tr}, corresponding to extrema at constant H, are inversely proportional to the masses of complexes with $i = 0, 1, 2, 6$ and $j = 0, 1, 5$. Consequently the changes in water and ice induced by treatment in weak magnetic fields are somehow connected the different proton structural states. Our results agree with the soliton model of water developed by A. S. Davydov and his students [5]. According to this model the magnetic field affects the probabilities of proton transfer between water molecular clusters.

The most surprising result of our research has been the long-term (5-6 h) memory of the effects of extremely weak magnetic fields. This is probably due to the existence of metastable, nonequilibrium structural fragments in water and ice. Following the concepts developed in [6, 7] for solid phases, in a spatially disordered system like water nonthermal structural fluctuations can appear even in the absence of significant exothermal reactions. According to the fluctuation-dissipation theorem, an alternating magnetic field can influence these charged water fragments and alter the mean distance between clusters. This, in turn, would alter the proton transition probabilities within the framework of the soliton model [5]. There is the interesting possibility of analyzing these proton transitions in terms of percolation theory that has been successfully applied in the study of kinetic phenomena in disordered semiconductors [8].

Many studies of the properties of water and ice, including their dispersion [9], have employed the NMR technique, which requires a magnetic field. Our experiments imply that the results of these studies require corrections. In this regard we believe that research into the anisotropic optical properties of water and ice in electric and magnetic fields is more promising.

LITERATURE CITED

1. V. I. Klassen, Magnetization of Water Systems [in Russian], Nauka, Moscow (1982).
2. L. P. Semikhina, Kolloidn. Zh., 4, No. 2, 401 (1981).
3. Ya. Yu. Akhadov, Handbook of the Dielectric Properties of Pure Liquids [in Russian], Izd. Stardartov, Moscow (1972).
4. Yu. V. Ergin, Structure and Magnetic Properties of Electrolytic Solutions [in Russian], Nauka, Moscow (1983).
5. V. Ya. Antonchenko, Microscopic Theory of Water in Porous Membranes [in Russian], Naukova Dumka, Kiev (1983).
6. S. F. Timashev, Dokl. Akad. Nauk SSSR, 274, No. 6, 1407 (1984).
7. S. F. Timashev, Proc. All-Union Conf.: Synergetics, 1986 [in Russian], Shtiintsa, Kishinev (1986), pp. 80-83.
8. V. L. Bonch-Bruevich, I. P. Zvyagin, et al., Electronic Theory of Disordered Semiconductors [in Russian], Nauka, Moscow (1981).
9. V. I. Kvlividze, V. F. Kiselev, et al., Surf. Sci., 44, 60-68 (1974).