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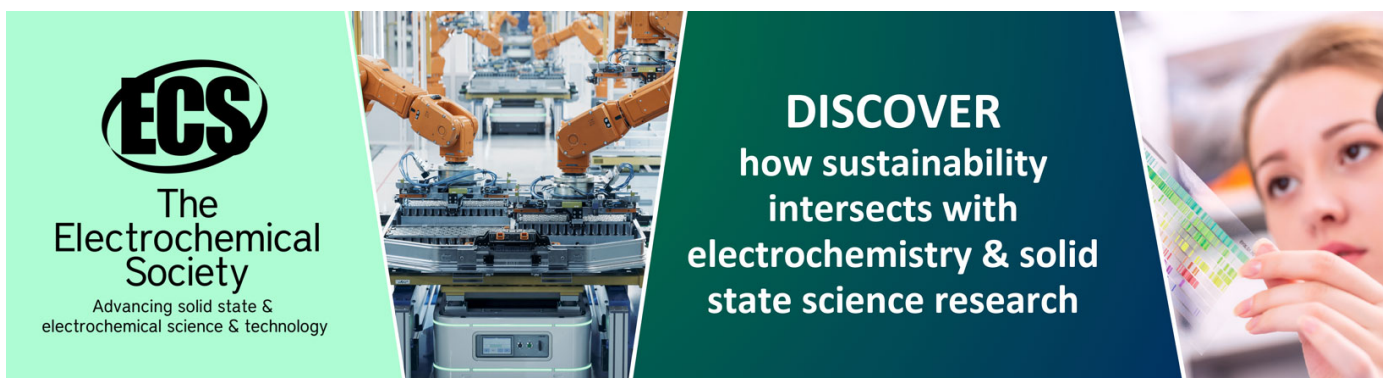
Magnetic field increases the surface tension of water

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Magnetic Field Increases the Surface Tension of Water

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Abstract. We studied what effects magnetic fields have on the surface tension of water-air interfaces. We measured the surface tension by means of the surface wave resonance method with very high precision. The surface tension increased by 1.83 ± 0.18 % at the magnetic field of 10 T. As for artificial effects and possible contributions to the surface tension increase, it seems most likely that the stabilization of hydrogen bonds increases the bulk Helmholtz's free energy, at least at the surface, which thereby increases the surface tension.

1. Introduction

Recently, effects of strong magnetic fields on the physical properties of water such as: infrared spectrum [1], refractive index [2], viscosity [3], and melting temperature [4] have been reported. These effects were attributed to the magnetic field stabilizing hydrogen bonds of water. However, the increase in Gibbs's free energy due to the stabilization of hydrogen bonds would generate a loss by the external work (pressure-volume term) due to an enlargement of the specific volume by hydrogen bonds. Therefore, the net increase in the Gibbs's free energy must be equal to that of the Gibbs's free energy observed as the surface level difference of ~ 4 cm at 10 T (so called "Moses effect"). This is comparable to the diamagnetic energy of ~ 6.5 mJ/mol (or 3×10^{-8}) at 10 T. Therefore, the magnetic field would not affect the bulk characteristics and the phase equilibrium. On the other hand, the surface tension of a flat interface is equal to the Helmholtz's free energy per unit area of the interface, which is given by the internal energy per unit area of the interface, minus the entropy per unit area of the interface, and multiplied by the temperature. That is to say, the increase in the energy of hydrogen bonds directly reflects the increase in the surface tension. Since the biological systems include water-air or water-macromolecule interfaces, a biological system would relate to the surface thermodynamic properties, including the surface tension of water. Langmuir-Blodgett (LB) membrane technology also strongly relates to the surface tension. Therefore, clarification of the magnetic field effect on the surface tension of water is desired in both science as well as in technology.

2. Method

Ultra-pure water (Lot. DPF2293, Wako, Osaka, Japan) was used for the sample without further purification. We have constructed a system for measuring the surface tension of water under the magnetic field by means of the surface wave resonance method [3]. We used a rectangular optical cell ($30 \times 10 \times 45$; made of fused quartz) as the surface wave resonator. Interleaved electrodes were fixed outside of the cell as a generator and a detector. A voltage controlled oscillator (FG-273A, Kenwood

TMI Co., Tokyo, Japan) generated an alternative voltage temporal wave. Surface waves were excited by applying the alternative voltage to the electrode of the generator. Then, standing waves were detected as capacitance changes of the electrodes of the detector. The capacitance changes were then converted to a frequency modulated high frequency signal by a capacitance to frequency converter (a clap oscillator, hand made). The high frequency signal was detected by a frequency modulation receiver (AR5000, AOR, Ltd., Tokyo, Japan), and led to a lock-in amp (LI-575, NF Co., Yokohama, Japan) with 2f mode. The quadrature output of the lock-in amp led to the control voltage of the voltage controlled oscillator through a control circuit (hand made). The resonator was set in the field center of the superconducting magnet (100 mm in bore, JMTD-10T100MK, JASTEC, Koube, Hyogo, Japan). The water-air interface was perpendicular to the magnetic field. The experimental system is shown in Fig. 1. The measurement system formed a feedback loop to lock onto a surface wave resonance. We chose the modes 4 and 5, which are shown in Fig. 2, with the in-phase and quadrature outputs from the lock-in amplifier. Zero crossing points of the quadrature output are locked by the phase locked loop system mentioned earlier. All measurements were carried out in a temperature-stabilized copper plate at 298.2 ± 0.1 K which was stabilized by a water bath (LTB-125, As One Co., Osaka, Japan). Figure 3 shows the stability of a locked resonance frequency in mode 5. The interfacial tension between water and air was obtained from the dispersion of surface waves given by [5-7]

$$\omega^2 = \frac{(\rho_l - \rho_g) g k + \sigma k^3}{\rho_l \coth(kd_l) + \rho_g \coth(kd_g)} , \quad (1)$$

where ω is the angular frequency of the surface waves, g is the acceleration due to gravity, σ is the interfacial tension, k is the wave number, ρ_l and ρ_g are the mass densities of the water and the air, respectively, and d_l and d_g are the thicknesses of water and air, respectively. To prevent the sample from heating up as well as any nonlinear effect on Eq. (1), the surface wave amplitude was kept under $1 \mu\text{m}$.

With solving simultaneously the dispersion equations of several resonance modes to cancel the inhomogeneity of the magnetic field, we were able to obtain measurements of the surface tension very precisely.

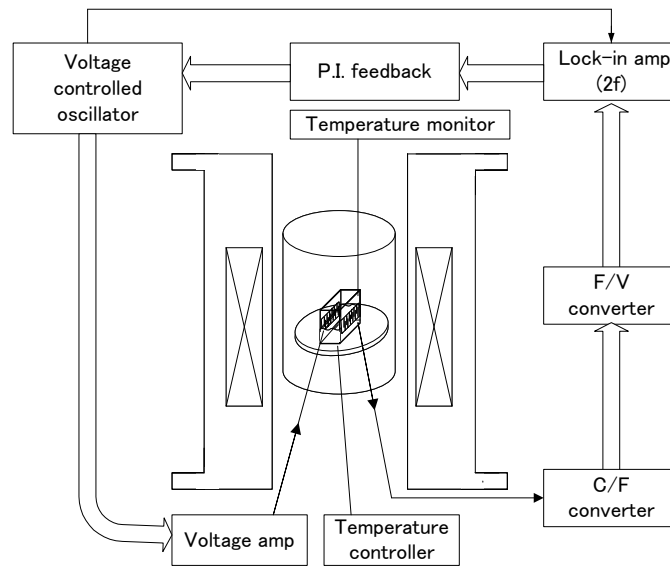


Figure 1. The experimental system.

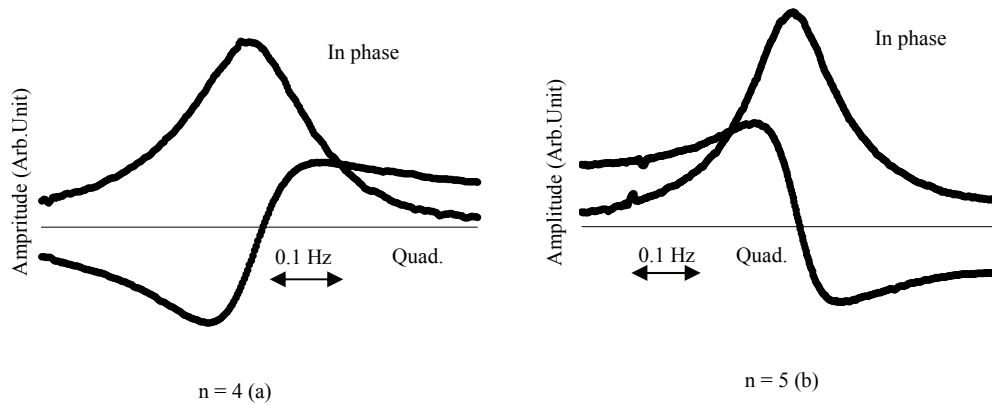


Figure 2. In-phase and quadrature outputs from the lock-in amplifier: mode 4 (a) and mode 5 (b).

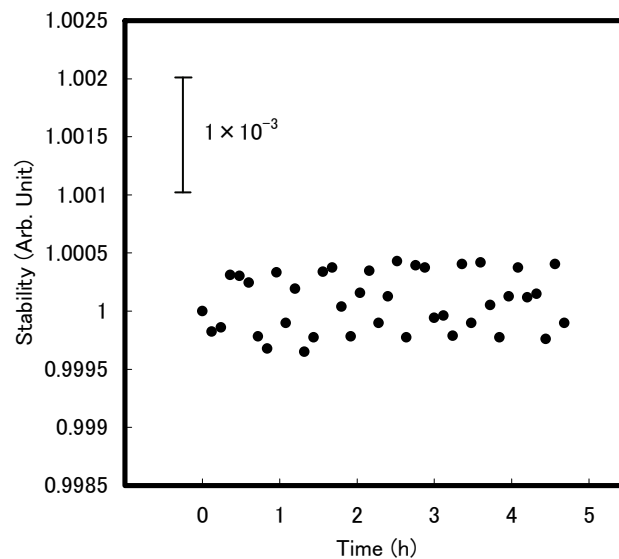


Figure 3. Stability of a resonance frequency.

3. Result and Discussion

We calculated the surface tension from the resonance frequencies. The values of the surface tension were 71.96 ± 0.14 mN/m at 0 T and 73.31 ± 0.16 mN/m at 10 T. The surface tension increased by 1.32 ± 0.13 mN/m or 1.83 ± 0.18 % at 10 T. Figure 4 shows the effect of the magnetic field on the measured surface tension over time. Initially, the value of the surface tension was 71.96 mN/m. The surface tension increased in response to the application of the magnetic field, and reached a value of 73.31 mN/m. With removing the magnetic field, the surface tension decreased and returned to the initial value.

At first we considered the artificial errors due to temperature fluctuations and the inhomogeneity of the magnetic field. Given that the temperature derivative of the surface tension of water was ~ 0.16

$\text{mNm}^{-1}\text{K}^{-1}$ at 298 K, a temperature fluctuation of ± 0.1 K yielded a surface tension error of ± 16 $\mu\text{N/m}$ or ± 0.02 % as shown in Fig. 5. The observed surface tension increases sufficiently exceeded the temperature fluctuations and the systematic errors of the thermometer.

The inhomogeneity of the magnetic field enlarged the length along the surface, which decreased the value of k and lowered the resonance frequency and apparent value of the surface tension. In our calculation of Eq. (1), the elongation of the interface was 17 ppm at 10 T, which yielded 0.2 % of the error in the value of the surface tension if a single mode was used to solve Eq. (1). The effect of the inhomogeneity of the magnetic field was canceled by the above-mentioned two mode simultaneous analysis to be roughly 0.05 % as shown in Fig. 5.

Next, we discuss the additional effects of oxygen, diamagnetic energy, and hydrogen bond stabilization on the surface tension increase. In general, molecules localized (delocalized) at the surface decrease (increase) the surface tension of a liquid because of the surface pressure of the molecules at the surface. The concentration of oxygen in the air is much greater than in water, indicating that the oxygen decreases the surface tension of water. If the magnetic field removes the decrease in the surface tension due to oxygen, the resulting increase in the surface tension is about 6 orders of magnitude less than the observed increase in the surface tension at 10 T as shown in Fig. 5.

The diamagnetic energy of water due to the magnetic field is only -6.5 mJ/mol at 10 T, which is comparable to the increase in the Gibbs's free energy, and only 0.3-1.2 ppm of the hydrogen bonding energy 5.4-18.8 kJ/mol [8] as shown in Fig. 5.

If the magnetic field stabilizes the hydrogen bonds of water, the increase in the diamagnetic energy affects not only the internal energy of water, but also the entropy of water, resulting in a large increase in the bulk Helmholtz's free energy. Iwasaka et al. and Hosoda et al. found that the hydrogen bond became more stable under the magnetic field. Their data implied that the hydrogen bonds are stabilized by roughly 1% at 10 T. This subsequently yields an increase in the Helmholtz's free energy of the order of 1 J/mol at 10 T, if we assume that the Helmholtz's free energy of water equals that which is due to the hydrogen bond formation. An increase of ~ 1 J/mol in the bulk Helmholtz's free energy would explain the magnetic increase in the surface tension as shown in Fig. 5.

The increase in the interfacial tension implies that the magnetic fields strengthen the hydrophobic bonds in biological systems and LB membrane, and steric conformation of biological molecules such as enzymes.

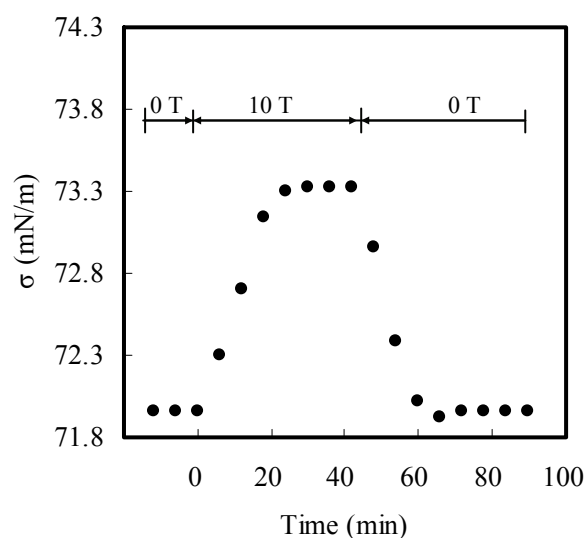


Figure 4. Effect of 10 T magnetic field on the measured surface tension over time.

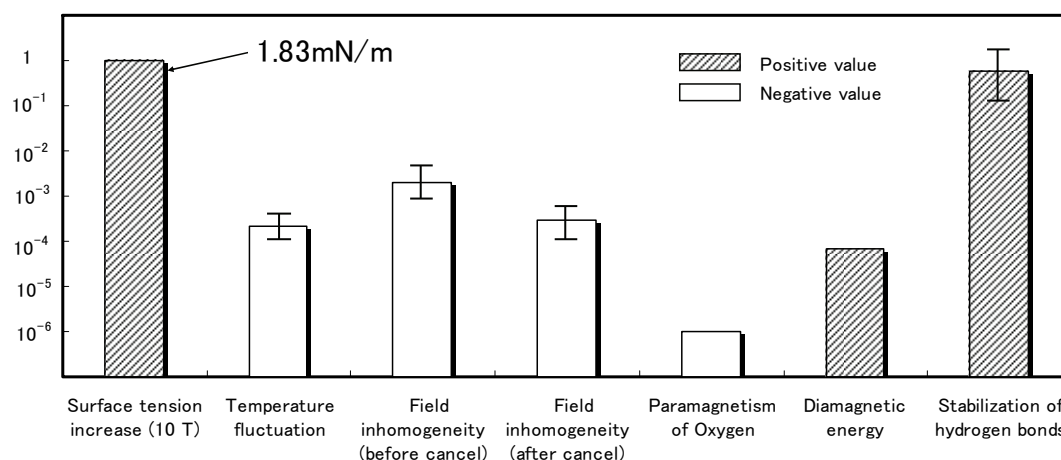


Figure 5. Factors suggesting an apparent increase of the surface tension.

Acknowledgments

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References

- [1] Iwasaka M and Ueno S 1998 *J. Appl. Phys.* **83** 6459
- [2] Hosoda H, Mori H, Sogoshi N, Nagasawa A and Nakabayashi S 2004 *J. Phys. Chem.* **108** 1641
- [3] Ghauri S A and Ansari M S 2006 *J. Appl. Phys.* **100** 066101
- [4] Inaba H, Saitou T, Tozaki K and Hayashi H 2004 *J. Appl. Phys.* **96** 6127
- [5] Iino M, Suzuki M, Ikushima A J and Okuda Y 1985 *J. Low Temp. Phys.* **59** 291
- [6] Iino M, Suzuki M and Ikushima A J 1986 *J. Low Temp. Phys.* **63** 495
- [7] Iino M, Suzuki M, Ikushima A J and Okuda Y 1983 *Jpn. J. Appl. Phys.* **23-1** 54
- [8] Eisenberg D and Kauzmann W 1969 *The Structure and the Properties of Water* (Oxford University Press, Oxford)