Relative Change of Viscosity of Water under a Transverse Magnetic Field of 10 T is Smaller than 10^{-4}

Kikujiro Ishii,* Shunsuke Yamamoto, Masatsugu Yamamoto, and Hideyuki Nakayama
Department of Chemistry, Gakushuin University, 1-5-1 Mejiro, Toshima-ku, Tokyo 171-8588

(Received March 18, 2005; CL-050365)

Viscosities of pure water and aqueous NaCl solutions were measured under magnetic field with special cares for the temperature fluctuation and magnetic force acting on the sample. The relative change in viscosity of water at the magnetic field of 10 T was found to be smaller than 10^{-4}. The result is discussed in comparison with the values reported in earlier papers.

Influence of magnetic field on materials arouses broad concern in a wide range of science and technology. Since water is the most familiar material to us, changes in its properties under magnetic field are important even if the magnitudes were small. Recently,[1] water has been reported to show a relative increase of refractive index as small as 10^{-3} under the magnetic field (magnetic-flux density) of 10 T.

We are interested in the magnetic-field effect on the properties of molecular liquids from the viewpoint of cluster formation in liquids. We noticed that several papers have been published on the magnetic-field effect on the viscosity of water.[2–4] Lielmezs and co-workers[2,3] reported that neat water showed a relative change of viscosity of about 2×10^{-3} in the transverse magnetic field of 1 T. Viswat and co-workers,[4] however, checked this using a sophisticate apparatus, and reported that the relative change was as small as 3×10^{-5} in the magnetic field up to 2.3 T.

In the viscosity measurement under a strong magnetic field, the transport of the sample between the positions with non-equivalent magnetic-field strengths causes a potential-energy change sometimes comparable to that arising from the gravity. In addition, the sample temperature must be kept constant when a small change in viscosity is studied. We thus conducted a study of the magnetic-field effect on viscosity of water bearing these points in mind.

Figure 1 shows the essence of the apparatus. We employed a glass viscometer for the measurement, since the use of magnetic materials was undesirable in the present study. A superconductor magnet (JASTEC, 10T100) equipped with a helium refrigerator was used. In the room-temperature bore (100 mm in diameter) of the magnet, we set a long aluminum water bath through which temperature-controlled water was circulated using a thermostat (Haake, DC50-K35). The viscometer suspended in the water bath had a capillary part (0.2 mm in inside diameter and 20 mm in length) with its direction perpendicular to the magnetic field.

The viscometer 800 mm in length was designed so as to locate the menisci of the sample 500 and 600 mm, respectively, from the maximum magnetic-field point where the capillary was located. The magnetic fields at these points were 0.12 and 0.6 T, respectively. Thus for diamagnetic materials such as water, the difference in magnetic-potential energies at these points was about 10^{-5} times of that coming from the gravity, and negligible. Two optical-fiber systems were attached to the viscometer to monitor the fall of the upper meniscus. We recorded the electric outputs from these systems in a personal computer. The time τ required for the meniscus of water to fall the distance between two optical systems was about 2000 s. We obtained τ with an accuracy of 0.1 s.

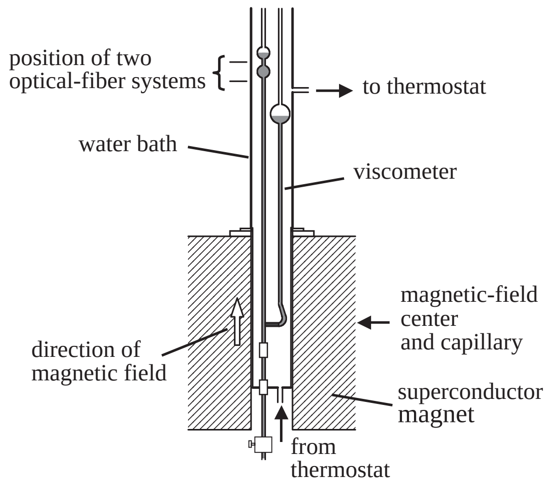

Figure 1. Schematic presentation of the structure of the apparatus. Sample liquid was handled with air pumps and a liquid reservoir attached to the three ports of the viscometer.

To monitor the temperature fluctuation, a platinum-resister temperature sensor (Lake Shore, PT-111) was fixed at the capillary. The temperature measured with a temperature monitor (Lake Shore, 218) showed short-term fluctuation of about 0.05 K, but the average temperature during a period of one trial of the meniscus falling was kept within 0.01 K.

We carefully prepared the liquid samples as follows. Distilled water was purified further with a system, Simpli Lab-UV (Millipore). NaCl solutions were made using the pure water prepared as above and reagent-grade NaCl (Sigma). All the samples were filtrated further with a membrane filter with 0.22 µm pore (Millipore) before use.

We checked the function of the viscometer by measuring the viscosity η of NaCl solutions without magnetic-field. The results are summarized in Figure 2. The ordinate indicates η relative to that of pure water. The values were actually calculated for the product of the observed τ and density of each sample.[5] The solid curve represents the literature data.[6] The results indicate that our viscometer gives reasonable values although its structure is simple.

Figure 3a summarizes the results of the magnetic-field effect for a pure-water sample. The abscissa indicates the sequence

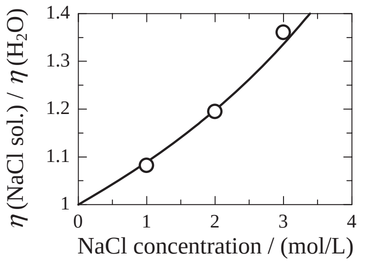

Figure 2. Concentration dependence of viscosity η of NaCl solution relative to that of water (293 K, without magnetic field); open circles: present study, solid curve: calculated from literature data (ref 6).

number of the meniscus-falling trial. We repeatedly measured τ at the magnetic fields of 0 and 10 T alternately. One cycle of the measurement took about one hour. Along the ordinate, τ is indicated as well as the average temperature T during one falling. Water samples did not show any remarkable change in τ when the magnetic field of 10 T was applied, while the temperature monitor showed the raise of about 0.08 K at 10 T. We consider that the latter was a mis-indication due to the change of platinum resistivity under a strong magnetic field, since no consistent viscosity change expected to such a temperature change was observed.

In Figure 3b, similar results for a 2 mol/L NaCl solution are shown. In this case, τ showed systematic increase when the magnetic field of 10 T was applied, although the sample temperature drifted slightly by about 0.05 K during the experiment for about 9 h.

We estimated the change in τ due to the application of magnetic field using the average $\bar{\tau}_{0\,T}$ of τ at 0 T before and after a particular trial at 10 T. Thus we estimated the relative change ξ in viscosity due to the application of the magnetic field of 10 T as follows.

$$\xi = \left\{ \frac{1}{N} \sum \frac{(\tau_{10\,T} - \bar{\tau}_{0\,T})}{\bar{\tau}_{0\,T}} \right\}, \quad (1)$$

where N is the number of the trial of meniscus falling at 10 T for the samples with the same concentration of NaCl. Similarly, ξ for pure water was estimated. The results are summarized in Figure 4 for pure water and NaCl solutions. Error bars indicate the standard deviation for all the measurements on three or four independent samples. Obviously, ξ for NaCl solutions increases as the concentration was increased. However, ξ for pure water is almost zero.

The reason of the positive ξ for NaCl solutions and its increase with NaCl concentration is not clear at the moment, but it might be caused by Lorentz force acting on the flowing ions in the capillary under the transverse magnetic field. Namely, if the ions shift between flows with different velocities, this may lead to the increase of apparent viscosity. In the meantime, the same shifts of ions with opposite signs induce an electric field owing to their opposite replacement. This may suppress further shifts of ions, and may compete with the Lorentz force giving rise a steady-state straight flow of the liquid in the capillary. Further studies are desired to clarify the above reason, but the actual positive ξ observed for NaCl solutions indicates at least the fact that a strong transverse magnetic field affects the flow of NaCl solutions.

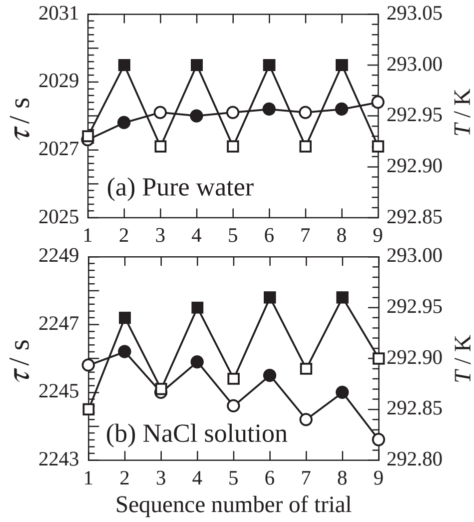

Figure 3. Meniscus falling time τ of (a) a pure-water sample and (b) a 2 mol/L NaCl solution; open circles: τ at 0 T, closed circles: τ at 10 T. Average temperature T during each meniscus falling is also indicated; open squares: T at 0 T, close squares: T at 10 T.

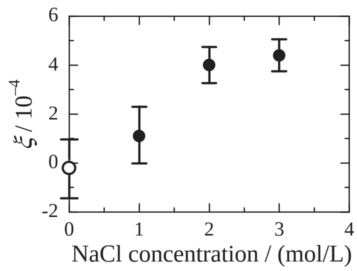

Figure 4. Summary of relative change ξ of pure water (open circle) and NaCl solutions (closed circles). Error bars indicate standard deviation for the repeated measurements.

In contrast to NaCl solutions, pure water does not show a detectable value of ξ that exceeds the standard deviation of the order of 10^{-4}. Thus we conclude that the relative change of viscosity of pure water under the transverse magnetic field of 10 T is smaller than 10^{-4}. This value is much smaller than that reported by Lielmezs et al.,[2,3] and supports the result by Viswat et al.[4] Measurements with improved temperature stability of the apparatus are planed as well as new experiments with a capillary directed along the magnetic field.

References

1 H. Hosoda, H. Mori, N. Sogoshi, A. Nagasawa, and S. Nakabayashi, *J. Phys. Chem. A*, **108**, 1461 (2004).

2 J. Lielmezs, H. Aleman, and L. Fish, *Z. Phys. Chem. (Frankfurt am Main) Neue Folge*, **99**, 117 (1976); J. Lielmezs and H. Aleman, *Thermochim. Acta*, **21**, 225 (1977).

3 J. Lielmezs and H. Aleman, *Thermochim. Acta*, **20**, 219 (1977); J. Lielmezs and H. Aleman, *Thermochim. Acta*, **21**, 233 (1977).

4 E. Viswat, L. J. F. Hermans, and J. J. M. Beenakker, *Phys. Fluids*, **25**, 1794 (1982).

5 See for instance: D. P. Shoemaker, C. W. Garland, and J. W. Nibler, "Experiments in Physical Chemistry," 5th ed., McGraw-Hill, New York (1989), Chap. 11.

6 K. Schäfer, *Landolt-Börnstein*, **II/5a**, 318 (1969).

Published on the web (Advance View) May 21, 2005; DOI 10.1246/cl.2005.874