

RAMAN SCATTERING INVESTIGATION OF THE WATER-BRIDGE PHENOMENON: SOME PRELIMINARY RESULTS

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ABSTRACT. A floating water-bridge is formed if a high-voltage direct current is applied between two beakers filled of chemically pure water. Raman spectra of the OH-stretching region have been obtained at ambient condition of temperature and pressure. These preliminary results seem to indicate that the hydrogen-bond structure is only slightly modified by the presence of the electric field applied to form the floating water-bridge in agreement with recent neutron scattering investigation. In fact, the polarized Raman spectrum of the pure water and of the water-bridge is almost superimposable. We are planning to carry out further spectroscopic analysis, at different thermodynamic conditions, for better understanding the role played by the hydrogen-bond in driving the formation of the floating water-bridge.

Water is the most abundant compound on Earth and in living creatures, but at the same time is one of the most complex liquids. Although the individual H₂O molecule has a simple chemical structure, water is considered a complex fluid because of its anomalous behaviour [1]. Many of the water anomalies are due to the hydrogen bond. For example the liquid water is characterized by a tetrahedral hydrogen-bond network seemingly related to its kinetic and thermodynamic anomalies [2]. Although the study of the water has been performed under innumerable experimental conditions the understanding of some unusual effects remains an open question. One of these is related with the interaction of water with an electric field.

It is well-known that the chemically pure water behaves as an insulating. However, when a high-voltage direct current is applied to two beakers filled with de-ionized water a floating water bridge forms spontaneously. The effect was observed for the first time by Sir William Armstrong in 1893, who reported a remarkable direct-current high-voltage experiment to the Newcastle Literary and Philosophical Society [3].

From the theoretical point view recent studies have shown that the forces responsible for holding up the water bridge follow from the Maxwell electric field pressure tensor in dielectric polar fluids [4]. So the water bridge is represented as a flexible cable having an electric field induced tension sufficiently large so as to explain the water bridge support. In a quantum field theory context the effect can be framed with the introduction of the concept of coherence state. Some authors conjectured that at ambient condition the 40%

of the liquid water is in a state of coherence with its electric field [5]. Therefore an external electric field could align the coherent domains forming superdomains and creating a macroscopic coherence phase throughout the water bridge. Within a Ginzburg-Landau theory the huge increase of the coherence length indicates a phase transition between a fluid and a superfluid [6]. Recently, Fuchs and coworkers carried out a wide typology of experimental techniques in order to go deeply into the phenomenon [7, 8, 9]. The experiments were performed in a horizontal geometry (orthogonal with respect to gravity) under the application of a constant potential difference. The usual horizontal set-up consists of two beakers filled with deionized water. After a short electric discharge, which was build up between the two water surfaces, a water connection formed spontaneously between the two beakers; the water moved up the glass walls and built a water bridge. When exposed to a high dc (direct current) voltage by putting electrodes into the beakers, water forms a stable, cylindrical bridge between the two beakers. In this situation, the geometry of the insulator imposed the vertical alignment of the electric field, parallel with respect to the direction of gravity.

Through the Schlieren visualization technique a density change in the floating water was observed [9]. To rationalize this density change the presence of highly ordered microstructure was assumed [10]. Within this scenario, the high electric field could enforce smaller intermolecular distances leading to the density change observed in the floating water [7, 8, 9]. Subsequently, in order to investigate deeply the density change the same authors carried out a neutron scattering experiment on a floating D_2O bridge, thereby gathering information about the intermolecular distances and structural features inside the bridge. From the analysis of the structure factor the supposition that the density gradients were due to changes in the local structure of the liquid was discarded [11]. Many hypotheses have been put forward, but none seems to be conclusive.

Another spectroscopic technique able to probe the local structure of a molecular liquid is Raman scattering. Numerous studies have shown the usefulness of Raman spectroscopy to investigate the OH-stretching region of water consisting of a broad distribution carrying information about local symmetries of water molecules [12, 13]. Since the intra-molecular modes of water are deeply affected by the establishment of inter-molecular hydrogen bonding, we expect that any changes of the local structure, induced by polarization effects via the application of an external electric field, must reflect in a change of the OH stretching distribution.

In this brief note we report the first - to our knowledge - Raman measurements into the OH region of the floating water bridge. In order to perform a light scattering measurement on the water bridge under different electric fields, while controlling the temperature of the bridge itself, a cell for vertically oriented bridges was designed. This choice was suggested by the geometry of our Raman spectrometer, whose scattering plane is horizontal.

The cell (see Figure 1) is set up by a copper cylindrical container with the inner surface Teflon coated (0.5 mm thickness). The cell is fitted within a copper glove where a liquid from a thermostatic bath is circulated. The high voltage (HV) electrode is a platinum plate located inside the cell. The ground electrode is a platinum disk of about 7 mm diameter that is fixed to a polyvinyl chloride cylinder. The gap between the water surface and the HV electrodes is controlled by a vertical translator. The voltage and the current through the cell are monitored on line by a scope.

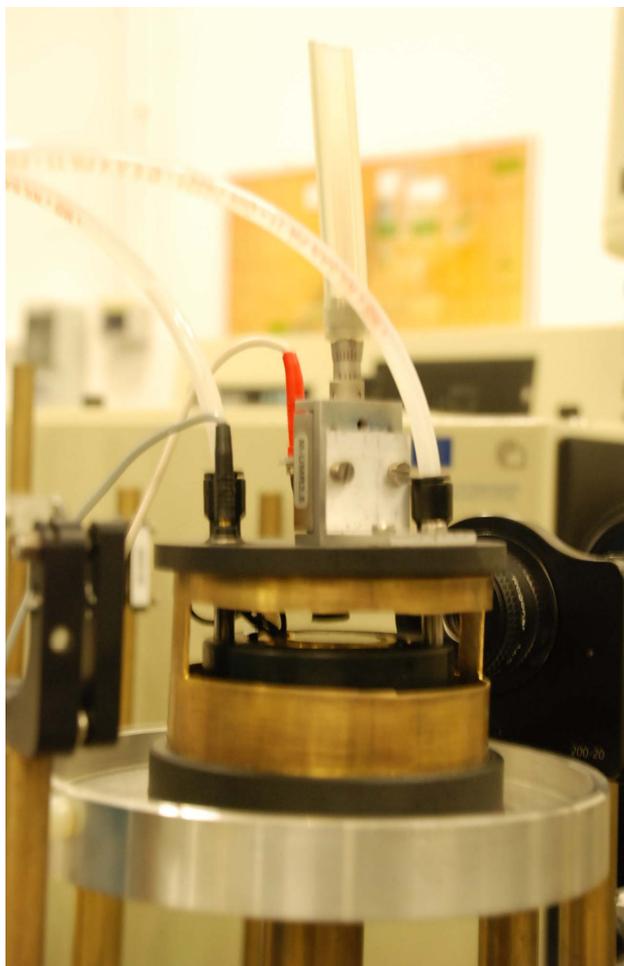


FIGURE 1. A picture of the cell: When a high voltage is applied and the cell is filled with de-ionized water a vertical floating water-bridge is formed.

Some clever device must be used to estimate the temperature of the floating water bridge. In fact, due to the high electric field the temperature cannot be monitored by a conventional PTC (Positive Temperature Coefficient or other similar device), nor there is room enough to put in position a conventional thermometer. So, the temperature is read by a thermo camera. In figure 2 we show the thermo image read by the Thermocamera (ThermaCAM PM575). As a consequence, it is not possible to place any glass window between the camera lens and the bridge (in fact, the glass stops IR radiation). So, at the moment, the outer glass cylinder has been substituted by a copper cylinder with large apertures to allow both the passage of the laser beam and the visual inspection of the bridge.

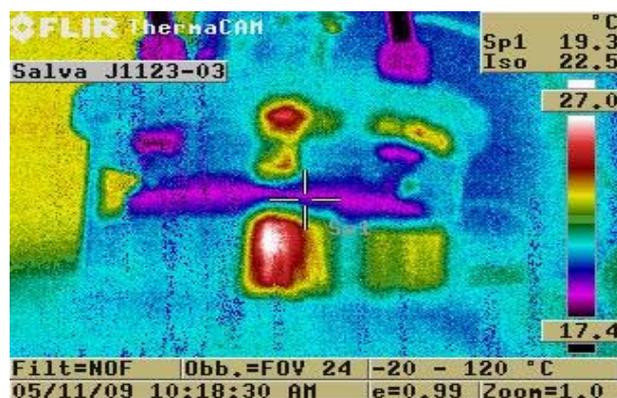


FIGURE 2. Thermographic visualization of the water bridge by using a thermo-camera (ThermaCAM PM575)

At variance with the experiments performed by Fuchs and coworkers, the bridge has been obtained under an alternate current field applied to a sample of deionized water. The need of chemically pure sample is due prohibiting conductivity effects from masking the insulating dielectric effects. This allows for having a lower value of the current and then the control of the temperature becomes easier. The frequency of the field was 100 Hz while the voltage was 4900 V (2500 V of amplitude with no d.c. offset). We measured a current of 2.1 mA (1.05 mA of amplitude) during all the measurement time and the gap between the upper electrode and the water surface (in absence of field) was about 1 cm. The section of the bridge was about 3 mm of diameter which represents a large enough volume for carrying out a scattering experiment. The temperature of the thermostatic bath was set at 17° while the temperature of the thermostated fluid (water) at the input and at the output of the cell (after about 1 m of path from the thermostatic bath) was read as 19°. We estimate the temperature of the floating water bridge to be about 35°. A 4880 line of an Ar+ laser was used as the probe, working at 400 mW.

The Raman spectra has been collected both in VV (parallel) and VH (orthogonal) polarization with a spectrometer pass-band of 5 cm⁻¹, collecting the spectra with a 5 cm⁻¹ step and with an integration time of two seconds.

The results are reported in figure 3. The spectra show seemingly nor local distortion of the original H-bond network induced by the high field applied neither any strengthening on the H-bond, driven by polarization effects, can be assumed. This would suggest us to refuse the hypothesis for some change of the local density of the water, previously reported in the literature [7, 8, 9]. Such a negative indication apparently confirms some results recently reported in literature from a neutron scattering experiment [11]. In this experiment the presence of a possible low-q peak at 0.5 angstrom (where q is the wave vector) in the factor structure has been interpreted considering a mesoscopic quasi-crystalline network composed by microbubbles whose formation is due to the electric field [11]. However,

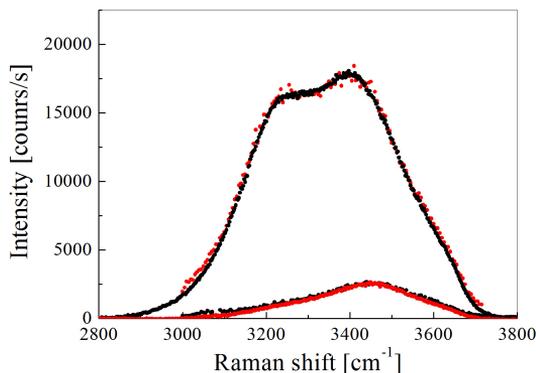


FIGURE 3. Intensity of Raman spectra of the OH stretching (parallel and orthogonal) as a function of the Raman shift of the floating water bridge (red circles) and of bulk water (black circles) at $T=35^{\circ}\text{C}$

we cannot exclude that some structural changes are taking place at the interface water-atmosphere at the bridge surface but further investigations are in plan to better verify this hypothesis. In particular, as the Raman scattering experiments is concerned a more careful analysis of the polarized and depolarized spectra as a function of the temperature is needed to reach to a conclusive answer [14].

In this note we have reported the first Raman investigation on a floating water bridge. This unusual phenomenon occurs when a high-voltage is applied to two beakers filled with deionized water. In this experiment we have, for the first time, observed that a similar phenomenon occurs also under application of an alternating electric field. We find that the polarized Raman spectrum of the floating water bridge is the same of the polarized Raman spectrum of the bulk at the same temperature. This result seems to suggest no local density change giving rise by the presence of the electric field. The measurement is coherent with the conclusion obtained by some neutron scattering investigations indicating that the microscopic density and near neighbour structures of the water bridge are the same as in the bulk [11]. However, further detailed Raman measurements, as a function of the temperature, are in progress, with special attention to the analysis of the depolarized ratio (I_{VH}/I_{VV}) [14]. Furthermore, in order to probe deeply the possibility of density gradients we are planning to carry our Brillouin scattering experiment which allows for obtaining direct information on the compressibility of the floating water bridge.

References

- [1] P. Ball, *Nature* **45**, 291 (2008)
- [2] C. A. Angell, R. D. Bressel, M. Hemmati, E. J. Sare and J. C. Tucker, *Phys. Chem. Chem. Phys.* **2**, 1559 (2000)
- [3] W. Armstrong, *The Newcastle Literary and Philosophical Society*, The Electrical Engineer, 154 (1893)

- [4] A. Widom, J. Swain, J. Silverberg, S. Sivasubramanian, Y. N. Srivastava, *Phys. Rev. E* **80**, 016301 (2009)
- [5] R. Arani, I. Bono, E. Del Giudice, and G. Preparata, *Int. J. Mod. Phys. B* **9**, 1813 (1995)
- [6] E. Del Giudice, G. Preparata, and G. Vitiello, *Phys. Rev. Lett.* **61**, 1085 (1988)
- [7] E. C. Fuchs, J. Woissetschlager, K. Gatterer, E. Maier, R. Pecnik, G. Holler, and H. Eisenkolbl, *J. Phys. D: Appl. Phys.* **40**, 6112 (2007)
- [8] E. C. Fuchs, K. Gatterer, G. Holler, and J. Woissetschlager, *J. Phys. D: Appl. Phys.* **41**, 185502 (2008)
- [9] J. Woissetschlager, K. Gatterer, and E. C. Fuchs, *Exp. Fluids* **48**, 121 (2009)
- [10] T. Head-Gordon and M. E. Johnson, *Proc. Natl. Acad. Sci.* **103**, 7973 (2005)
- [11] E. C. Fuchs, B. Bitschnau, J. Woissetschlager, E. Maier, B. Beuneu, and J. Teixeira, *J. Phys. D: Appl. Phys.* **42**, 065502 (2009)
- [12] G. D'Arrigo, G. Maisano, F. Mallamace, P. Migliardo, and F. Wanderlingh, *J. Chem. Phys.* **75**, 4264 (1981)
- [13] D. M. Carey and G. M. Korenowski, *J. Chem. Phys.* **108**, 2669 (1998)
- [14] R. C. Ponterio, M. Pochylski, F. Aliotta, M. E. Fontanella, C. Vasi, and F. Saija, *J. Phys. D: Appl. Phys.* **43**, 175405 (2010)

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