White Paper for *Frontiers of Plasma Science Panel*

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Indicate the primary area this white paper addresses by placing “P” in right column.
Indicate secondary area or areas by placing “S” in right column

	“P”, “S”
• Plasma Atomic physics and the interface with chemistry and biology	P
• Turbulence and transport	
• Interactions of plasmas and waves	
• Plasma self-organization	
• Statistical mechanics of plasmas	S

Indicate type of presentation desired at Town Hall Meeting.

	“X”
Oral	
Poster	
Either Oral or Poster	
Will not attend	X

Title:	Why we don’t understand water? Plasma physics of polar liquids.
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- ***A mystery that covers two-thirds of our planet***

Liquid water has unique set of physical, chemical, and thermodynamic qualities and is essential for sustaining life. The behavior of liquid water is a consequence of its polar atomic nature and the associated structure of the disordered three-dimensional hydrogen bond network. For the last century water was a subject of intense research that created more questions than answers [1]. Today, of all known dielectrics, pure liquid water is probably the least understood while the most studied.

A well know, but not fully explained aspect of water photoionization is the formation of solvated electron at light intensities well below the ionization potential of the liquid [2]. Energies as low as 6.5 eV have been reported in the literature [3] as threshold for the production of hydrated electrons in water. Appearance of hydrated electrons in below the band-gap interactions makes it difficult to determine the threshold energy required for direct excitation to the conduction band (today’s accepted values are between 8.5 and 11 eV). The reason for that difficulty lies in the fact that the same products are created in both above- and below-band gap ionization reactions [4]:

$$(H_2O + n\nu h) + H_2O \rightarrow e_{aq} + OH + H_3O+ \quad (1)$$

and up today there were no experiments in which a transition across the ionization threshold was clearly demonstrated. In reaction (1) nνh denotes a multiphoton excitation of water molecule by n photons and e_{aq} is hydrated electron [5]. The uncertainty in the energy of vertical ionization of water and appearance of different ionization paths makes it difficult to study even basic properties of this amazing liquid [1].

- ***Technical approach, challenges and new research tools and capabilities required for water studying.***

In liquid water, the hydrated electron is essential to many physical, chemical, and biological processes. Despite multiple attempts the ionization energies to solvated and conduction band electron in bulk water has not been measured experimentally.

Majority of the laser-water interaction experiments has been done with ultrashort (a few picoseconds to femtoseconds) or long (nanoseconds) laser pulses. Propagation of ultrashort laser in water is known to generate micrometers-scale diameter filaments over long interaction distances [6]. In order to avoid filamentation and other non-linear processes, studies of ultra-fast dynamic of hydrated electron were done with chirped pulse amplification lasers in very thin (100 μm or less) water jets. These studies usually involve very precise temporal resolution [7], but visual picture of the interaction inside such jets remains inaccessible. Interaction of water with nanosecond or longer pulses is different since it does not create tight plasma-based filaments even for high laser intensities [8]. Additionally, it is very hard to track nanosecond interactions with femtosecond temporal resolution, because no synchronized femtosecond or even picosecond probe is available. These two regimes of interactions represent two completely different mechanisms of water ionization, but up to day no one was able to pinpoint parameters and conditions of the transition.

NRL high power laser facility has unique tools for detailed studies of water ionization. In contrast to a typical water photo-chemistry experimental setup, NRL Plasma Physics Division has enough expertise to conduct water ionization experiments in bulk water, including analysis of non-linear effects and scatterings. Advanced set of plasma diagnostics is available for measurement of water ionization parameters, including 1) multiple colors femtosecond probe lasers, 2) multiple wavelength and durations (from 50 fs to a few ps, and from 30 ps to 200 ps) precisely synchronized pumps laser, 3) imaging spectroscopy microscope with sub micrometer spatial resolution, 4) precisely synchronized sources of broad-band radiation, and 5) compact and synchronized to the lasers sources high energy electrons and x-rays beams for pump-probe experimental studies.

Technical approach of water ionization experiments will be based on measurements of the earliest detectable interaction of long (10 -100 ps) pump laser pulses with water at different laser energies. The pump lasers will be precisely analyzed using 1 ps resolution streak camera that is available at the Plasma Physics Division. Using femtosecond resolution of precisely synchronized probe lasers and microscopic spatial resolution it will be possible to pinpoint the transition of water ionization regime across the band-gap. These measurements can provide previously inaccessible water ionization parameters that are critical for understanding the nature of liquid water.

- ***Importance of understanding of water structure on plasma science and related disciplines and potential for societal benefit*.**

Water at room temperature under ordinary conditions is a non-equilibrium open system that exchanges heat and gases with the environment and absorbs electromagnetic radiation and acoustic signals. When liquid water is ionized, it involves the ejection of an electron, which is subsequently trapped and solvated by water molecules. The resulting hydrated electron is highly reactive and accordingly plays an important role in many processes initiated by ionizing radiation in aqueous environments. The toxic effect of ionizing radiation on genetic material in cells is connected to cancer formation and therapy and it is therefore a vigorous field of research.

The hydrated electron plays an important role in many different fields of research in physics, chemistry and biology. Dynamics of hydrated electron have implication in topics such as radiation-induced DNA damage, hazardous waste treatment or electron-transfer reactions in solution.

References

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