The Time Evolution and Formation of Streamer Discharges in Single & Multiple Bubbles in Water

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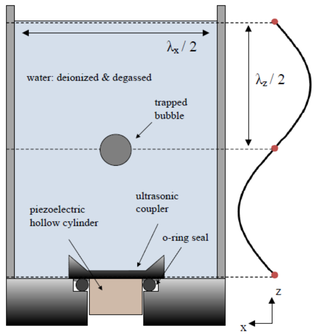
Project Overview

Understanding plasma interaction with liquid water represents a vital thrust towards unlocking a range of exciting new technologies and discoveries. Despite over two decades of research, the physics governing plasma ignition and propagation in liquid water has yet to be elucidated.

In this research, we explore the time-evolution and formation of streamers within submerged gas bubbles. By employing an ultrasonic levitation device, the gas bubble is suspended in liquid while high-speed imaging and IV diagnostics are used to experimentally investigate breakdown phenomena.



Key Applications

- **Purification of Drinking Water**

It is estimated that 35% of deaths in developing countries are due to bacterially contaminated water, [1] and globally, 2.6 billion people are unable to acquire clean drinking water. [2]

- **Cooling Water Management**

Cooling water is a necessity for removing heat from condensers in power plants, central AC units, and industrial facilities. Precipitation of $CaCO_3$ allows for overall reduced freshwater withdrawal in these systems.[3]

- **Algae Bloom Mitigation**

Algae blooms are often caused by excess phosphorous and result in microcystin, a dangerous toxin.[4] These blooms have caused water bans in the Midwest.

Acknowledgements

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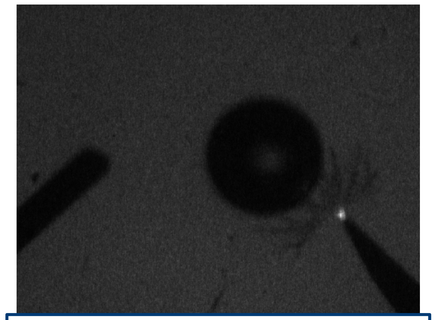
National Science Foundation
WHERE DISCOVERIES BEGIN

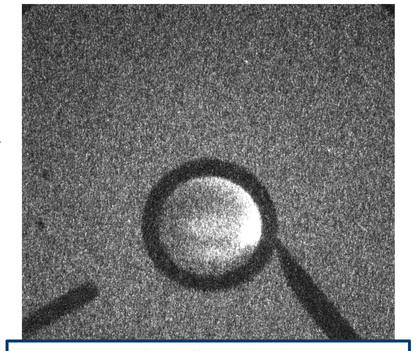
Analysis / Results

'Single Bubble' Breakdown Time Evolution

To analyze the time-evolution of a streamer impacting and breaking down a single gas bubble submerged in liquid water, a new bubble is carefully positioned after each with the same volume (same diameter) and distance from high-voltage electrode tip to the bubble center, so as to re-create the original bubble and adjust the camera delay by nanoseconds to reveal the initiation and progress of the plasma discharge.



Initial streamer propagation between high-voltage electrode and bubble surface.



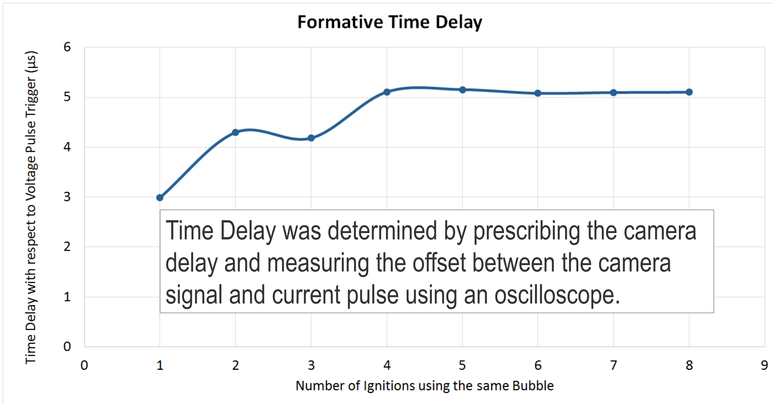
Early stage of a diffuse discharge

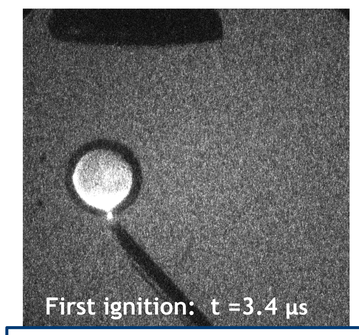
Propagation occurs along the air-water interface due to local electric field enhancement caused by $\nabla\epsilon$. [5]

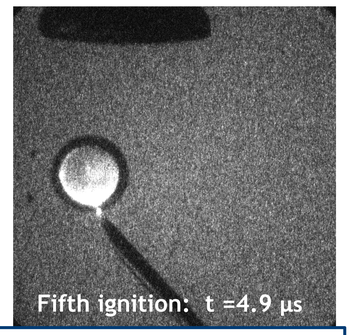
Late stage discharge; streamers have spread over most of the air-water interface.

'Successive Strike' Transient Gas Composition

By consecutively applying voltage pulses to the same bubble, the time until breakdown seems to increase until reaching a 'steady-state' that we hypothesize corresponds to a quasi-equilibrium gas composition.





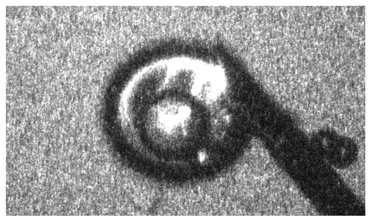


Plasma captured in both images, but the camera delay has increased by 1.5 µs.

Further Studies

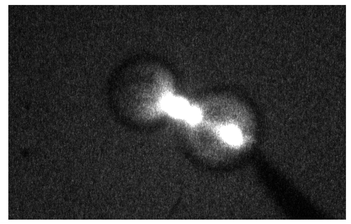
Transient Species Detection

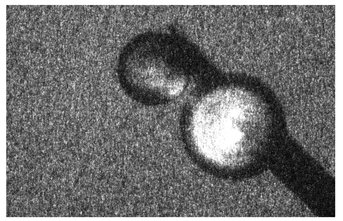
Using the high-speed cameras as spectrometers, transient gas species present during single and successive bubble breakdown will be measured.



'Bubble Hopping' Streamer Propagation

Since it has been theorized that microbubbles enable streamer propagation through liquid,[6] we propose (and have preliminarily observed) that plasma may 'hop' between bubbles to achieve greater plasma-surface exposure to liquid.





High Throughput Reactor

One of the ultimate goals of this project is to develop a high throughput plasma reactor capable of processing commercial volumes of water for drinking or other applications.

References

[1] World Health Organization. (2010) *Progress on sanitation and drinking water.*
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[4] United States Environmental Protection Agency. http://www2.epa.gov
[5] J. Phys D: Appl. Phys. **44** (2011) 082001
[6] Lewis, New Model for the Primary Process of Electrical Breakdown in Liquids, IEEE (1998).