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Tutorial #1

Optical diagnostics of discharges in and in contact with liquids

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Discharges in liquids present a rich field of study due to the complex and highly coupled physical phenomena they exhibit, characterized by broad temporal and spatial scales [1]. Accurately diagnosing these discharges is challenging, as traditional diagnostic tools are often limited or produce data that are difficult to interpret. Optical emission spectroscopy (OES), while widely accessible and non-intrusive, encounters several obstacles in this context. These include the presence of optically thick media, dynamic plasma-liquid interfaces, significant spatial and temporal variability, and steep gradients in species densities. Consequently, extracting localized, time-resolved information is essential for understanding the evolution of discharge phenomena and for validating theoretical models.

Effective interpretation of emission spectra requires an understanding of the underlying mechanisms governing the system—ironically, the very insights researchers aim to derive from these observations. This circular dependency necessitates the careful establishment of interpretive boundaries and the cautious application of equilibrium assumptions in inherently non-equilibrium systems. Moreover, when observations are limited to macroscopic behavior, inferring the presence of multiple interacting phenomena becomes speculative.

In response to these challenges, there has been a growing integration of laser-based diagnostics alongside OES. Laser techniques offer spatial and temporal resolution with reduced reliance on a priori assumptions, providing more accurate measurements of reactive species densities. However, they often demand the averaging of signals across multiple discharge events, given their limited ability to capture single-shot data. This requirement is particularly problematic in liquid discharges, where stochastic behavior, filament formation, and initiation time lags introduce significant variability.

This lecture highlights the key challenges associated with optical diagnostics of plasma-liquid systems, explores recent advancements in diagnostic techniques, and addresses ongoing debates within the field. It also outlines opportunities for future research aimed at resolving persistent ambiguities in plasma behavior near and within liquids.

[1] T Belmonte, P Bruggeman, “Optical Diagnostics of Discharges in and in Contact With Liquids”, Plasma Processes and Polymers, 2025, 22 (1), 2400213