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Creation of electric wind due to the electrohydrodynamic force [1]

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Collisional coupling (i.e. momentum and energy exchange) between charged particles and neutral particles (c–n) can significantly impact any natural phenomena involving weakly ionized gases. Solving the hydrodynamic problem of such phenomena has been of paramount importance for centuries and requires expertise in a wide range of disciplines. After the first observation of c–n coupling by F. Hauksbee in the 1700s, this phenomenon rapidly became a popular scientific subject and attracted the attention of notable scientists, including of M. Faraday and J. C. Maxwell [2].

In planetary or stellar atmospheres, including those of the Earth, the ion–neutral coupling profoundly affects ion and neutral particle kinetics and their properties. The neutral drag induces an electric field through the charge separation between ions and electrons under the geomagnetic field, while the ion drag resulting from the electric and geomagnetic fields exerts a force on neutrals. One of the well-known cases of this effect is the electric wind (also called ionic wind), which is created by an electrohydrodynamic (EHD) force in electrically charged fluids such as weakly ionized plasma and ionic solutions. the extraordinary gas flow is manifested also in plasma jets operating at atmospheric pressure.

In the plasma jets, where a horizontally ejected neutral helium gas flow is used, the gas flow trajectories, or free jet boundary, are typically bent upward due to the buoyant force. The flow trajectories are lowered toward the horizontal plane when the neutral gas flow is faster. Nevertheless, when the plasma is generated inside the same flow, the gas speed of the flow increases. Many efforts have been made toward discovering the c–n coupling associated with the electric wind for cases such as atmospheric- pressure plasma jets. However, the current experimental evidence and analyses of these electric winds are not sufficient to unravel its true origin.

Here, we show the origin of the electric wind through a simple model experiment, which is designed using a helium flow and a µs-pulsed plasma jet (Figure 1). Changes in the helium jet trajectory depending on pulse height and width allow to simply demonstrate the major contribution of EHD force on the electric wind in a plasma jet (Figure 2). This phenomenon is directly connected with the densities of charged species moving and interacting with neutrals that create a plasma head and electrons or ions coupling with neutrals behind generating the space charge. As such, we provide a direct observation of charged particle–neutrals couplings.

Our findings indicate that the contribution of the moving plasma streamer to EHD force generation is negligible. Second, the EHD force is mainly caused by the residual space charges after the plasma streamer propagates and collapses. The electric wind becomes more significant as the pulse width increases at a given pulse voltage and as the pulse height increases when the pulse width exceeds the bullet lifetime. This is directly connected with the densities of charged species moving and interacting with neutrals that create a plasma head and electrons or ions coupling with neutrals behind generating the space charge.

References

[1] S. Park, U. Cvelbar, W. Choe, S. Y. Moon, Nat. Comm. 9:371 (2018)

[2] M. Robinson, AIEE Trans. 80, 143 (1961)

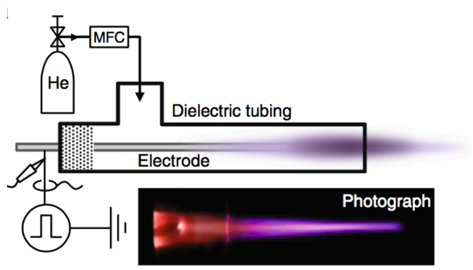

Figure 1. Atmospheric pressure plasma jet

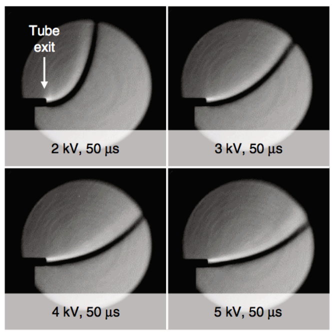

Figure 2. Variation in the gas flow trajectory depending on pulse height

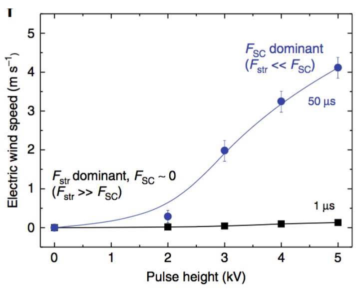

Figure 3. Electric wind speeds depending on pulse height