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Extremely far from equilibrium: the multiscale dynamics of streamers

UTE EBERT[1], CWI Amsterdam and Eindhoven Univ. Techn., The Netherlands

Streamers can emerge when high voltages are applied to gases. At their tips, the electric field is strongly enhanced, and electron energies locally reach distributions very far from equilibrium, with long tails at high energies. These exotic electron energies create radiation and chemical excitations at very low energy input, as the gas stays cold while the ionization front passes. Applications are multiple: highly efficient O^* radical production in air for disinfection, combustion gas cleaning, plasma assisted combustion, plasma bullets in medicine etc. In that sense, streamers can be considered as very efficient converters of pulsed electric into chemical energy, in particular, if the electric circuits are optimized for the application. Streamers are also ubiquitous in nature, e.g., in the streamer corona of lightning leaders, in sprite discharges high above the clouds; and streamers also seem to contribute to generating gamma-ray flashes and even to electron-positron beams in active thunderstorms. Unravelling the intrinsic mechanisms of streamers is challenging: they can move with up to one tenth of the speed of light, and they have an intricate nonlinear structure with a hierarchy of scales. I will review how theory and experiment deal with these structures, and I will discuss the basic differences between positive and negative streamers, electron acceleration at streamer tips and the consecutive radiation and chemical reactions, the propagation mechanism of positive streamers in different gases, streamer velocities and diameters varying over at least two orders of magnitude, streamer branching and interaction, and their three-dimensional tree structure. Both theory and experiment work with a patchwork of methods, and geophysics can provide movies that cannot be taken in the lab. I will sketch the state and outline open questions.

[1]http://www.cwi.nl/∼ebert