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"Plasma" and "Sheaths" — The Discharge Science of Irving Langmuir

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"We shall use the name *plasma* to describe this region containing balanced charges of ions and electrons" [1]. With these words, Irving Langmuir named our field. The following year he explicitly introduced the separation of a discharge into bulk plasma and sheath regions: "The word 'plasma' will be used to designate that portion of an arc-type discharge in which the densities of ions and electrons are high but substantially equal. It embraces the whole space not occupied by 'sheaths' " [2]. His remarkable contributions include [3]: Child-Langmuir sheaths, Langmuir probes, Langmuir waves, Langmuir's paradox, Langmuir's condition for double layers, Langmuir's isotherm for adsorption-desorption kinetics, and Langmuir-Hinshelwood surface reactions. Langmuir's famous talk, "Pathological Science," touched our field shortly after the "discovery" of cold fusion in 1989 [4].

Langmuir's plasma-sheath separation, along with particle, momentum and energy balance, has been very useful. The quasineutral plasma is described using simple diffusion models or more elaborate kinetic models, depending on the type of gas and pressure regime. The space-charge sheaths are modeled as low or high voltage, collisionless or collisional, dc or rf-driven, as appropriate. Exact conditions for joining plasma and sheath are well-known, but simple methods often suffice in practice. The analysis determines, in a transparent way, important discharge properties, such as ion and neutral radical fluxes to electrodes and ion acceleration energy across electrode sheaths. In a similar manner, for his adsorption-desorption isotherm, Langmuir made "assumptions which are as simple as possible ... to see whether the resulting equations can find a field of application" [5]. When extended to incorporate ion-induced desorption, one obtains a simple model for ion-assisted etching in terms of the fluxes and ion energies.

These types of simple assumptions did not please some people. "Langmuir is the most convincing lecturer that I have ever heard ... I have heard Langmuir lecture when I knew he was wrong, but I had to repeat to myself: 'He is wrong; I know he is wrong. He is wrong,' or I should have believed like the others" [6]. Hopefully, you will believe.

References: [1] I. Langmuir, *Proc. Nat. Acad. Sci.* **14** 627 (1928). [2] I. Langmuir and L. Tonks, *Phys. Rev.* **33** 195 (1929). [3] *The Collected Works of Irving Langmuir,* 12 volumes, C. Guy Suits, ed., Pergamon Press, New York, 1960–62. [4] Available from www.cs.princeton.edu/ ken/Langmuir/langmuir.htm; see also I. Langmuir and R.N. Hall, *Physics Today* **42** 36 (1989). [5] I. Langmuir, Nobel Lecture, December 14, 1932. [6] W.D. Bancroft, *J. Phys. Chem.* **35** 1904 (1931).