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This Week's Citation Classic

Lam S H. A general theory for the flow of weakly ionized gases. *AIAA J.* **2**:256-62, 1964.
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A general continuum theory for electrostatic probes of arbitrary geometry in a flowing plasma is developed, yielding analytical results for the plasma density and electrostatic field distributions and the probe current-voltage characteristics, showing clearly the parametric dependence of the results on Debye length, Reynolds number, probe geometry, and probe voltage. [The *SCI*® indicates that this paper has been cited in over 95 publications since 1964, making it the 3rd most-cited paper published in this journal.]

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"In 1961, a summer workshop was organized by the Princeton Plasma Physics Laboratory. As an assistant professor in the department of aeronautical engineering at Princeton University, I called to ask for permission to attend. I was told that I had to formally apply, that there was a registration fee, and that anyway I was already too late. Instead of making a fuss on formalities, I simply sneaked into the lectures.

"At that time, I did not know anything about plasmas, although the governing equations were familiar from my aerodynamics background. The lectures by Francis Chen (now at UCLA) on collisionless Langmuir probes fascinated me, and I carefully studied the definitive papers by Langmuir[1] and the more modern work by Allen, Boyd, and Reynolds[2] and Bernstein and Rabinowitz.[3] I knew Bernstein (who lectured on plasma kinetic theory and is now at Yale University) personally, and I went to him for help and discussed his paper with him. He told me that the smallness of Debye length had caused him and Rabinowitz considerable difficulties in the numerical computations, and that his numerical results were limited to moderate values of probe radius to Debye length ratios because of excessive computational costs.

"I remember the conversation well. The obvious idea came to my mind: why not analytically look at the limiting case when the Debye length is asymptotically small?

"The asymptotic theory of collisionless Langmuir probes in a quiescent plasma using the Bernstein and Rabinowitz formulation was developed very quickly covering both the small and the large Debye length limits. At that time, C.H. Su (now at Brown University) was my graduate student and he suggested that we do the corresponding continuum problem. Unknown to us at that time, Ira Cohen (now at the University of Pennsylvania) was also working on the same continuum problem under Martin Kruskal. When we finally compared notes when both works were near completion, we realized the similarities, so we agreed to publish our works simultaneously.[4,5] The mathematical technique used was singular perturbation, a technique used extensively in boundary layer studies in classical fluid mechanics. Once the 'boundary layer' nature of the electrostatic sheath was mathematically established, 'A general theory for the flow of weakly ionized gases' was developed easily (aided by the pioneering works of L. Talbot[6] and P.M. Chung[7]), clarifying the effects of convection on the probe response. Because of this interruption, the collisionless Langmuir probe work[8] which was studied first was published later.

"I believe this paper is frequently cited because of the generality of the formulation and the explicitness of the analytical results. Although the formal theoretical developments were quite mathematical, I made sure that the conclusions were physically meaningful and intuitively reasonable, and that easy-to-use analytical results were available.

"Although the Princeton Plasma Workshop was aimed at the plasma fusion community, there is no question that it has made a significant impact far beyond its intended audience.[9-11] In the 1960s, university research sponsors were much more flexible than they are now, and all of my plasma work at that time was supported by the Air Force under a general contract on hypersonics. Perhaps there is a lesson in this story."

1. **Suits C G**, ed. *The collected works of Irving Langmuir.* New York: Pergamon Press, 1961. Vol. 4.
2. **Allen J E, Boyd R L F & Reynolds P.** The collection of positive ions by a probe immersed in a plasma. *Proc. Phys. Soc. London B* **70**:297-304, 1957.
3. **Bernstein I B & Rabinowitz I N.** Theory of electrostatic probes in a low-density plasma. *Phys. Fluids* **2**:112-21, 1959.
4. **Su C H & Lam S H.** Continuum theory of spherical electrostatic probes. *Phys. Fluids* **6**:1479-91, 1963.
5. **Cohen I M.** Asymptotic theory of spherical electrostatic probes in a slightly ionized, collision-dominated gas. *Phys. Fluids* **6**:1492-9, 1963.
6. **Talbot L.** Theory of the stagnation-point Langmuir probe. *Phys. Fluids* **3**:289-98, 1960.
7. **Chung P M.** *Electrical characteristics of couette flow and stagnation boundary-layer flows of weakly ionized gases.* San Bernardino, CA: Aerospace Corporation, October 1962. TDR-169 (3230-12) TN-2.
8. **Lam S H.** Unified theory for the Langmuir probe in a collisionless plasma. *Phys. Fluids* **8**:73-87, 1965.
9. **Chung P M, Talbot L & Touryan K J.** *Electric probes in stationary and flowing plasmas: theory and application.* New York: Springer-Verlag, 1975. 150 p.
10. **Chen F F.** Electric probes. (Huddlestone R H & Leonard S L, eds.) *Plasma diagnostic techniques.* New York: Academic Press, 1965. p. 113-200.
11. **Swift J D & Schwar M J R.** *Electric probes for plasma diagnostics.* London: Iliffe Books, 1971. 334 p.

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