CC/NUMBER
SEPTEMBER 10, 1984

This Week's Citation Classic™

Buneman O. Dissipation of currents in ionized media. *Phys. Rev.* **115**:503-17, 1959.
[STARLAB, Stanford University, CA]

The destruction of electron drifts by instabilities is analyzed. The fastest stable drift is calculated (drift energy 0.9kT) and the energy of a faster drift is found to be dissipated into instabilities within, typically, 30 plasma periods. The growth of a local disturbance in this process is shown to take place without effective propagation. The 'turbulent' flow pattern created, eventually, under nonlinear conditions, is calculated numerically, demonstrating a tendency toward randomization of the initial drift energy. The effect stops 'runaway' in about 100 plasma periods after which there is 'heating' by 'collective collisions' instead. [The *SCI*® indicates that this paper has been cited in over 385 publications since 1959.]

Oscar Buneman
Department of Electrical Engineering
Stanford University
Stanford, CA 94305

May 4, 1984

"The intent of this paper had been to demonstrate to the (then small and young) plasma-physics fraternity that even in complete absence of collisions, a plasma will find its way to its most probable state. The avenue is provided by instabilities which rear their ugly heads whenever one tries to drive a plasma too far from statistical equilibrium.

"I chose the electron-ion interstreaming instability (which had been given my name) as an example and used particle simulation for computing its evolution in the nonlinear regime. Output plots, displayed on two pages of the *Physical Review,* caused quite a stir: they showed how the directed motion of the electrons had been stopped and turned into seemingly random motions—how the current had been turned into heat. This sort of noncollisional resistivity is called 'anomalous' nowadays.

"The message is probably not the reason for the frequent citation of this paper. The reason is that it presented and displayed perhaps the first useful 'computer simulation' of a plasma. Computational physics had not been invented. Computers were primitive, and theoretical physicists tended to frown upon their use. Only John Dawson[1] at Princeton had dared to indulge in practices similar to mine. In my paper, I mention the programmer (D. Thoe) and the computer, but no program is displayed. I do not even know in what language it was written.

"Nowadays, of course, particle simulation by computers is very popular and highly respectable, so references to its initiation have proliferated. Hockney and Eastwood[2] kindly dedicated their book on the topic to 'Oscar.'

"I had an interesting experience with another effort of mine in the area of computational physics. It led to a 'most-cited' paper, but someone else's. I had written a note, 'A compact non-iterative Poisson solver,' which, along with some novel trick in numerical analysis (now referred to as the 'Buneman algorithm'), contained a carefully written Fortran program. I thought the latter was the best part of that work. The note was rejected by four different journals and never published. The reviewers had not understood it, were prejudiced, objected to programs, or objected to Fortran. Fortunately, Bill Buzbee of Los Alamos picked up the note and, together with Gene Golub and Clair Nielson, wrote a learned paper[3] around it—which became a most-cited reference recently![4] I feel vindicated."

1. **Dawson J M.** One-dimensional plasma model. *Phys. Fluids* **5**:445-59, 1962. (Cited 60 times.)
2. **Hockney R W & Eastwood J W.** *Computer simulation using particles.* New York: McGraw-Hill. 1981. 540 p.
3. **Buzbee B L, Golub G H & Nielson C W.** On direct methods for solving Poisson's equations. *SIAM J. Numer. Anal.* **7**:627-56, 1970. (Cited 130 times.)
4. **Garfield E**. Journal citation studies. 36. Pure and applied mathematics journals, what they cite and vice versa. *Essays of an information scientist.* Philadelphia, PA: ISI Press, 1983. Vol. 5. p. 484-92.