SOME DISCOVERIES IN TEACHING PLASMA SIMULATIONS

Charles K. (Ned) Birdsall, *Plasma Theory and Simulation Group (PTSG), EECS Dept., Cory Hall, University of California, Berkeley CA 94720-1770*

Introduction "Teaching is a great way to learn the subject" has been said many times. Having anomalies/discoveries arise in class which demand immediate explanations is part of the challenge, especially in running live simulations. Examples will be run live, with some solutions.

Landau damping Applying a small initial perturbation at one wavenumber, to a Maxwellian non-drifting plasma, real and imaginary parts of the frequency are readily observed, plus decay of electrostatic energy and gain in kinetic energy and changes of the distribution function, f(v). BUT, the damping rate is larger than predicted by linear theory. How to resolve? Go to v-x phase space, at the wave phase velocity, Re(ω)/k, and use the command TRACE to produce trajectories; particle trapping is readily seen, which is NOT part of linear Landau damping. Reducing the excitation [initial displacement ($x_1/\lambda_{D)}$ or initial velocity (v_1/v_t)], below about 0.001 makes the extent of trapping small and the damping rate asymptote toward the linear value.

Debye shielding With a periodic model, adding N ion sheets to a warm background of electrons (total is charge neutral) produces appreciable electron trapping for small N. But, textbook Debye shielding has no trapping. Trapping diminishes as N increases, as will be shown

Two-stream instability from initially cold to initially warm streams; different end states. The linear growth rate (in time) of two opposing electron streams (in an immobile ion sea) decreases as the stream initial thermal velocities approach about +/- 0.7 v_{drift}. Cold stream growth of $\omega_{imag} = \omega_p/2$, largest known, violently spreads out f(v), including making f(v = 0) larger than the Maxwellian value, then oscillating about that, but still trapping in phase space, not reaching a Maxwellian f(v) for a long time. Initially warm stream growth is smaller and has a much smaller f(v = 0), below Maxwellian, and approaches a stable Penrose double-humped f(v).

An initially uniform warm plasma between two grounded plates (or cylinders, or spheres), with E normal to the plates (1d, still 3v), exhibits a wealth of plasma phenomena. Sheaths are formed at the plates, with initial rapid loss of electrons, followed by slow loss of ions. The faster electrons incident at the walls have a spread of velocities; the ions emerge as beams, accelerated by the sheath electric fields. The bulk plasma is time-average neutral, but its potential oscillates at the bulk plasma frequency, $\omega_{p,}$ for many cycles, and are symmetric modes. The diode current oscillates at about $\omega_{series} = \omega_{p,bulk} (2s/L)^{1/2}$, where 2s is the time average total sheath width and L is the planar diode length (with a similar "length" for cyl, sph.). The "series" connection is the sheath capacitance (few electrons, vacuum) and the bulk plasma which is "inductive" for $\omega < \omega_{p,\, bulk}$. These resonances are asymmetric modes, and are cutoff frequencies for surface waves propagating along the walls. Lastly, sound waves propagate between the two sheaths at very low frequencies ($\omega < \omega_{pi}$), as observed by Keith Cartwright; the sheath region sound wave generation/reflection mechanism is not yet understood.

State change via an explosive instability: a capacitive discharge to a resistive discharge. To be in the 4-page Abstract.

Oral presentation requested, with computer projection of the above; live demonstrations.