MARBLE: Multiple Ambipolar Recirculating Beam Line Experiment

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One of the major problems with beam-based electrostatic fusion efforts is due to the existence of un-neutralized space charge, which is however required when using electric fields to manipulate charged particles. Child-Langmuir limits are simply such that unimpressive currents, and thus low densities, will always prohibit useful fusion power for any reasonable device size. Another way of describing the issue is that in an IEC device the Debye length near the ion turning region must always be much longer than the dimensions of the apparatus near that region. Indeed, un-neutralized space charge forms the basis for the limitations of a great number of technologies, not only IEC fusion devices, but wherever intense charged particle beams are desired.

In Robert Hirsch's seminal publication "Inertial-Electrostatic Confinement of Ionized Fusion Gases" (J. Appl. Phys. 38, pg4522, 1967), it was recognized that a) space charge limitations represent the major limitation with the IEC approach, and b) to get beyond this problem, multiple populations of ions and electrons of various energies could theoretically be made to co-exist in an electrostatic storage device, setting up a series of virtual electrodes in the form of structures he termed "Poissors". However, such structures are generally believed to be hypothetical and speculative, and have been hitherto envisioned to form only to a limited extent, and under certain hard-to-attain conditions. Recently in our lab, a series of innovations have revealed a way to robustly design a plethora of virtual electrodes, both positive and negative, into an ion beam storage device. This represents a new means to contain vastly greater numbers of energetic charged particles whose orbits cross a shared core region, with the possibility for orders of magnitude larger density, and thus fusion reactivity, than has been achievable before in IEC devices.

Conventional ion beam storage devices provide stable containment for only a small volume in phase space (p, E). We have recently discovered that multiple, separate volumes in stable phase space can be effectively realized in a single linear trap with simple arrangements of electrodes. In addition, it is possible to confine both ions and electrons on stable orbits together and at the same time – purely electrostatically. Finally, the addition of an axial magnetic field produces an extraordinary effect: all electrons in the system are constrained to travel axially, regardless of energy. With a single externally located electron source, virtual cathodes are easily established along an ion trap device, such cathodes being located near the (negative) valleys of the free space vacuum potential. At the same time, the (positive) peaks of the vacuum potential are transformed into classical Penning traps, where cold electrons are extremely well confined and may be used to ionize a rarefied population of neutrals (acting as ion sources).

In early 2011, we designed and built an experiment which incorporates all the above mentioned features, dubbed "MARBLE-1". It is configured to trap five distinct recirculating ion beams. The system was constructed using only simple conically shaped electrodes, inexpensive parts, and went from design to pump-down in only six weeks. In this talk, I will describe the major physical principles involved with MARBLE, the pitfalls and unresolved issues, as well as the experimental apparatus. I will also present preliminary data and discuss possible non-IEC fusion applications.