AMP 166

THE PRODUCTION OF BEV POTENTIAL WELLS

by

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AVCO CORPORATION
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June 1965

supported jointly by

HEADQUARTERS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
OFFICE OF ADVANCED RESEARCH AND TECHNOLOGY
Washington 25, D. C.

under Contract No. NASw-1101

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
Washington 25, D. C.

under Contract No. AF 49(638)-1553

It may be possible to produce large electrostatic potential wells by a method which avoids the usual breakdown limitations. The well would be produced by a cloud of electrons suspended in a magnetic field. Experimental and theoretical evidence bearing on the stability of such clouds are discussed by Janes.[1] Estimates to be presented below suggest that the Bev range may be accessible with large equipment. Ions introduced into the potential well would be both accelerated and contained. If the number of ions which can be contained in this way is limited by the accumulation of positive space charge, it would be possible to produce an overall reaction rate of the order of 10^{16} nuclear reactions per second. While the concept of achieving high energy nuclear reactions at such enormous rates is very appealing, it should be borne in mind that the entire concept is still in its infancy. Thus, although preliminary low voltage experiments[1] and stability analyses[2] are very promising, serious obstacles to achieving these conditions may yet be discovered.

The overall configuration is sketched in Fig. 1. An electron cloud is contained along the circular axis of a torus by a magnetic field parallel to this axis. This cloud produces a potential minimum along the circular axis and an electric field in the direction of the minor radius. Individual electrons rotate in the E x B direction around the circular axis at the E/B velocity. The electron cloud can be introduced into such a system by injecting the electrons onto magnetic field lines as the magnetic field is built up.[1] The magnetic field lines then carry the electrons into the system replacing the belt in a Van de Graaff.

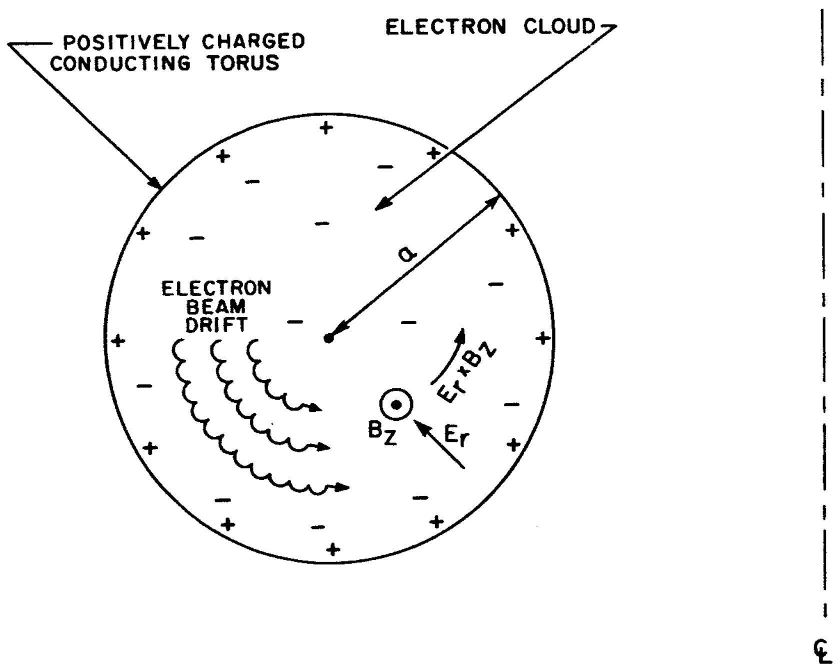

Fig. 1 Illustration of the toroidal geometry discussed in the text.

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The ordinary breakdown limitation of surface discharge is obviated since there is no insulator separating two electrodes. Furthermore, the limit associated with field emission of electrons from the negative terminal is also eliminated. If the breakdown limit is associated with ion extraction from the outer wall, electric fields in excess of 10^8 v/cm should be attainable.

The equilibrium for containment of the electron cloud is obtained by balancing the electric and magnetic stresses on the individual electrons ($E + v \times B = 0$). Coupled with Gauss's and Ampere's laws, this reduces to a balance of the sum of the magnetic and electrostatic stresses. For low electron densities, or more precisely if ω_p/ω_c (plasma frequency/cyclotron frequency) $\ll 1$, inertial stresses are neglible. If $E/B \ll c$, the magnetic field is unaffected by introducing the electron cloud. As E/B approaches the speed of light the magnetic field is decreased in the region of the electron cloud. In order to demonstrate quantitative relationships for this containment, lines of constant magnetic field intensity, electric field intensity, and electron density have been plotted in Fig. 2 on coordinates of E/B velocity (expressed in rest energy terms) and total depth of the potential well. The figure is drawn for a torus of one meter minor radius, and all quantities are measured at the outer edge of the plasma. Larger apparatus sizes would lead to larger voltages.

Ions injected into the system will be accelerated to an energy equal to the depth of the potential well or to an energy corresponding to the E/B velocity, whichever is lower, as indicated by the dotted lines in Fig. 2. The ion density which can be built up before the potential well is destroyed

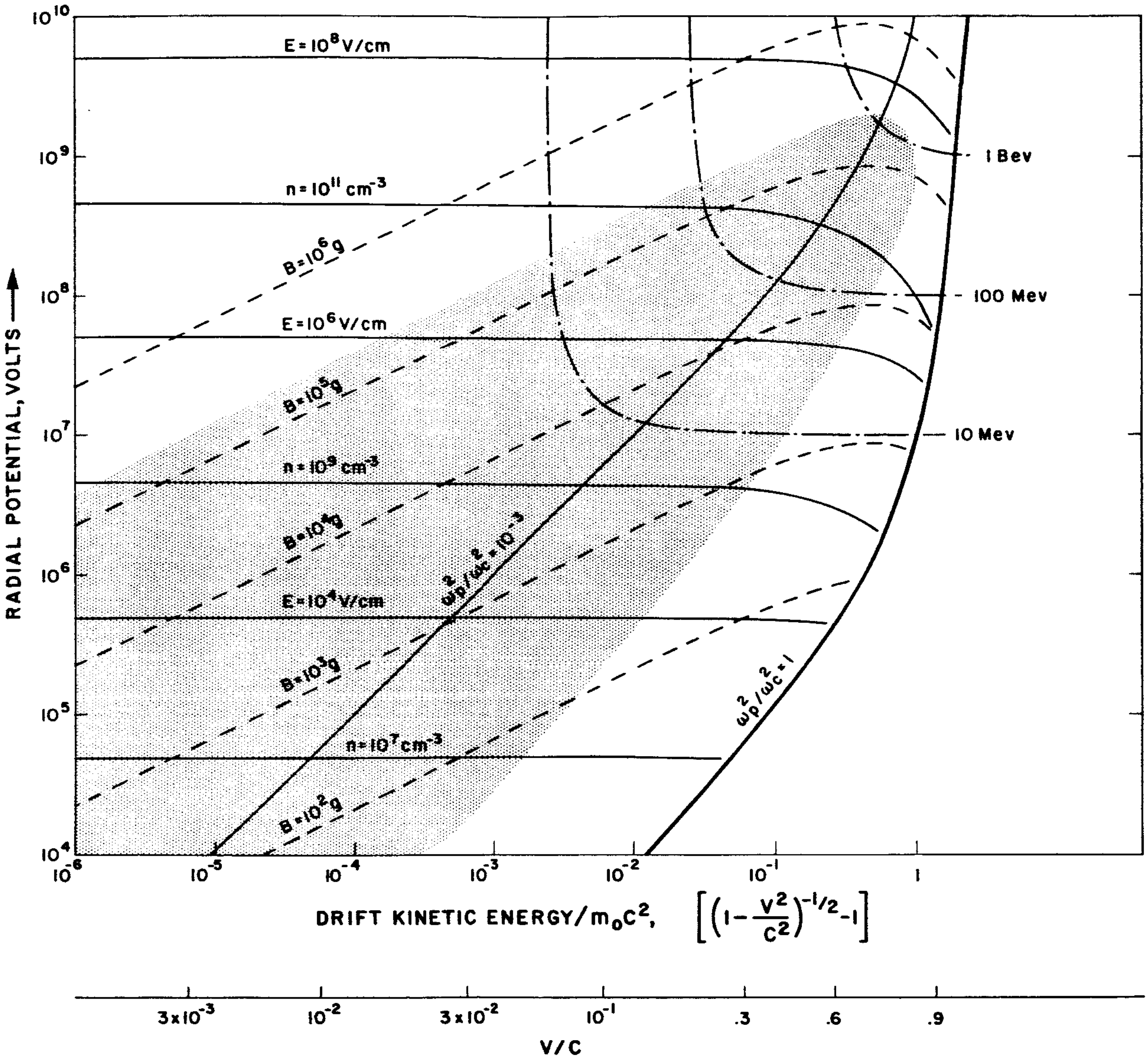

Fig. 2 Map of 1 meter electron plasma containment device. The shaded region is thought to be accessible.

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by positive space charge, or before neutral plasma forms of instability become important may be comparable to the initial electron density.

Figure 2 has been terminated along a line ($\omega_p^2/\omega_c^2 = 1$) for which the electron gyro radius based on the E/B velocity, r_e, is equal to the minor radius, a, since this is an absolute limit to containment of the electrons by the magnetic field. Low voltage experiments[1, 3] suggest that there may be an instability if ω_p^2/ω_c^2 becomes greater than about 0.05. The lower boundary of the shaded region represents a crude estimate of a limitation imposed by this instability. The upper boundary of the shaded region is determined by the upper stress limit to the strength of magnetic field which can be achieved ($\sim 2 \times 10^5$ gauss). The shaded area then represents an estimate of the accessible region.

The upper corner of this region corresponds to ion densities in excess of 10^{11} cm^{-3} and ion energies comparable with 1 Bev where the total meson production rate should exceed 10^{16} per second based on a cross section of 10^{-25} cm^2 and a system volume 10^8 cm^3. Since the ions move in random directions, the center of mass velocity may be small and in many of the above cases can lead to available C.M. energies in excess of the threshold for heavy anti-particle production. Since the cross sections for anti-particle production are of order 10^{-28} cm^2, one might expect a total yield of anti-particles in the range of 10^{13} per sec.

Since anti-protons will primarily be created near the center where E/B^2 is small, there is some possibility of containing them in the magnetic field despite their negative charge.

These considerations represent a considerable extrapolation from understood regions. Preliminary experiments[1] have been carried out at voltages less than 10 kV, with E/B velocities less than one-hundredth the velocity of light, and with somewhat different geometries. Similarly, theoretical stability analyses[2] have been restricted to neglecting the electron mass ($\omega_p/\omega_c \ll 1$), $E/B \ll c$, and assuming no spread in electron velocity at a point. Thus, although the experiments have verified the inductive charging principle and have demonstrated a stable range, no definitive statement can be made regarding extrapolation to the conditions discussed above. In very gross terms there is some reason to expect greater stability in this case than has been found for neutral plasmas. Since the plasma is charged, disturbances in the plasma make significant fields at the container walls. Either the natural image charges or fields obtained by adjusting the wall impedance can produce fields in the plasma which stabilize the disturbance. These image charges apparently stabilize in the region which has been studied.[2]

We may also note that an interesting facility can be obtained on a much smaller scale and with less extrapolation from known conditions. The upper limit of voltages obtainable with a Van de Graaff ~ 10 Mev can be reached with a torus of 10 cm minor radius, at magnetic fields of 5×10^4 Gauss including the restriction $\omega_p^2/\omega_c^2 < .05$. At this condition E/B is still small compared to the speed of light ($\sim 10^{-1}$).

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