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EXPERIMENTAL RESULTS OF A BUMPY TORUS DISCHARGE*

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In an earlier article, a torus discharge called BAGEL was described, which consists of a pulsed, endless P.I.G. arc in a toroidal tube.[1] A plan view is shown in Fig. 1. In order to minimize the drift losses of the perfect torus, several theoretical studies involving "bumpy" geometries have been made.[2,3] Our guiding field suffered a somewhat involuntary bumpiness, and without such theoretical considerations, we obtained an optimal magnetic configuration by a trial and error process. The length of the coils along the torus is roughly equal to the length of their interspace; thus the magnetic lines are undulating and compensate the outward centrifugal forces. The optimum alignment is obtained by tilting the coils axially and azimuthally with respect to the toroidal tube in the following manner.

First we establish a constant cathode-anode voltage and gas pressure. Then we obtain a luminous discharge, when we begin to establish a magnetic field by energizing the coils. We locate visually the spots where the plasma is hit-

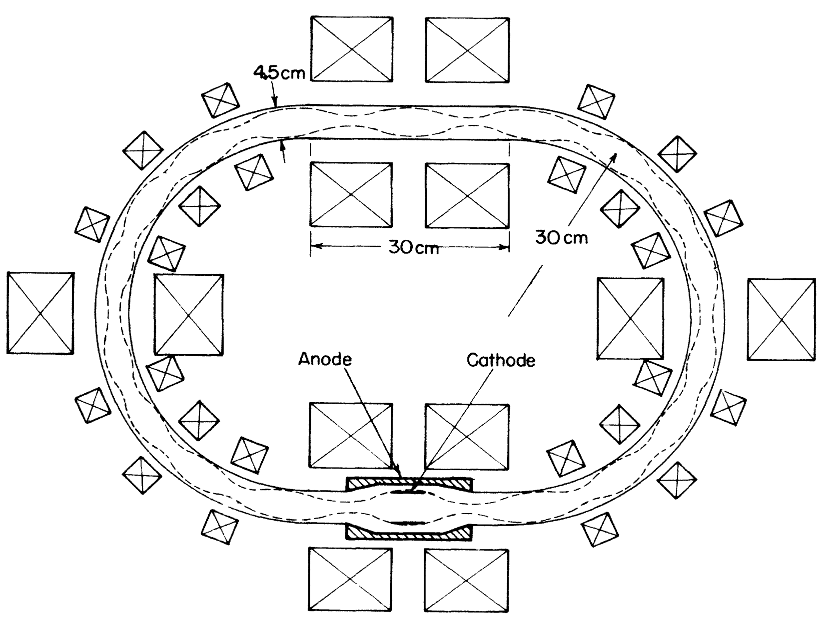

FIG. 1. Plan view of BAGEL.

ting or approaching the glass walls and move the surrounding coils to eliminate such obvious defects. Then we control the density of the plasma with the aid of an 8-mm interferometer and tilt the coils successively in order to obtain the maximum density. The optimum alignment was obtained after one day of cut and trial approach.

Experimental results: —The efficiency of the bumpy magnetic configuration is amazingly high. Ionization $[n/(n+N)]$ of 85% has been obtained in argon which indicates that the BAGEL machine is as efficient as the linear device, under the same conditions, during the pulse.[4] However, during the afterglow the magnetic confinement duration of the plasma is much longer because the end losses due to the tube terminals of the linear machine are almost eliminated. The plasma losses in BAGEL are mainly given by the drift losses across the magnetic field and by recombinations in the core of the afterglow plasma. Neglecting the recombinations, we have to consider three kinds of drift velocities: (1) the drift velocity due to the gradient and curvature of the magnetic field B in a torus, $\bar{v}_B = 2cKT/eBR$; (2) the diffusion velocity across B caused by long-range Coulomb collisions in the highly ionized plasma, $\vec{v}_p = c^2KT\nabla n/\sigma_{ei}B^2$ with $\sigma_{ei} \simeq ne^2\lambda_{ei}/mv^-$ and v^- the thermal electron velocity; (3) the ambipolar diffusion velocity across B caused by the collisions between electrons and neutrals,[4] $\vec{v}_D = D_a \nabla n/n$ with $D_a \simeq (v^-)^3\sigma_{eN}N/3(eB/mc)^2$. In the above formulas the velocities are in cm/sec, n and N are the plasma and neutral densities (cm^{-3}), σ_{ei} and σ_{eN} are the electron-ion and electron-neutral collision cross sections (cm^{+2}), R is the radius of curvature of the torus (cm), B is the magnetic field (gauss), T is the electron temperature (volts), $c = 3\times10^{10}$, $K = 1.6\times10^{-12}$, $e = 4.8\times10^{-10}$. Table I gives the order of magnitude of the above velocities in argon. We take $T = 4$ eV, $N = 10^{13}$, $n = 5\times10^{12}$, $R = 30$ cm, $\sigma_{eN} \simeq 2.10^{-15}$ cm^2, and $n \simeq \delta n/\delta r \simeq n(\delta r \sim 1$ cm), as representative values for our discharge.

Table I. Dependence of the loss velocities on B.

B (gauss)	$10^{-3}v_B$ ($\propto B^{-1}$)	$10^{-3}v_p$ ($\propto B^{-2}$)	$10^{-3}v_D$ ($\propto B^{-2}$)	$10^{-3}v_{\text{exp}}$
300	~100	~2.5	~6.4	~20
400	75	1.4	3.8	14
600	50	0.62	1.6	5.1
800	37	0.36	0.95	4

In the last column we give experimental values of the diffusion velocity v_{exp} deduced from the observed decay time τ of the plasma by the relation

$$\frac{1}{\tau} \sim \frac{1}{n}\frac{\delta n}{\delta t} = \frac{1}{n}\nabla n v_{\text{exp}} \sim \frac{v_{\text{exp}}}{\delta r}.$$

τ, the time necessary for a density decrease by a factor 2.71, was measured in the afterglow by 8-mm interferometer fringes. Specifically, we observed the decay from $n = 5.4\times10^{12}$ to $n = 2\times10^{12}$ which corresponds, respectively, to 3/4 and 1/4 of a fringe in a 4-cm diameter plasma. We choose this density range, because we observe it in the later afterglow which is supposed to be stable. Figure 2 shows the interferograms for 400 and 800 gauss.

We see that the experimental values of v are only a factor 2-3 higher than $\vec{v}_p + \vec{v}_D$, and vary like B^{-2}. They are an order of magnitude lower than the curvature and gradient drifts v_B which vary like B^{-1} and which would seem to have been eliminated by the bumpy geometry. However, an

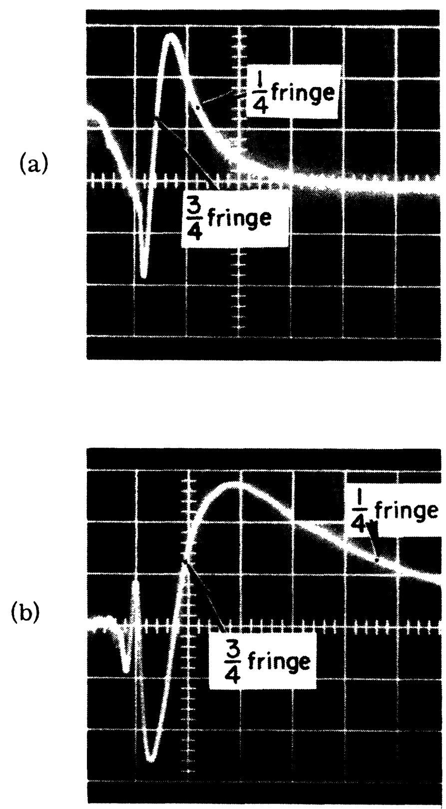

FIG. 2. (a) Interferogram for the afterglow plasma with $B = 400$ gauss. (b) Interferogram for the afterglow plasma with $B = 800$ gauss.

inhibition of the losses due to a radial conducting limiter, such as the anode, could also be considered.[5] In view of the necessary approximations made in the evaluation of T, n, σ_{ee}, σ_{eN}, and ∇n, it is encouraging to find agreement between v_{exp} and $(v_b + v_D)$ to within such a small factor. The strength of our deductions lies in the variation with B ($v_{\text{exp}} \propto B^{-2}$, not B^{-1}) rather than the absolute magnitude of v_{exp}. At a first glance, our results support a classical diffusion behavior in the afterglow, which is in agreement with other experiments.[6-8] However, the variation range of B is too small for a decisive conclusion on the absence of anomalous diffusion, and an extension up to 2000 gauss, with another set of coils, is planned.

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†Now on leave of absence from Saclay, France.

[1]R. Geller (to be published).

[2]B. B. Kadomstev and S. I. Braginsky, Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958 (United Nations, Geneva, 1958), Vol. 32, p. 233.

[3]G. Gibson, W. C. Jordan, and E. J. Lauer, Phys. Rev. Letters 4, 217 (1960).

[4]R. Geller and D. Pigache, J. Nucl. Energy 4, 229 (1962), Part C.

[5]T. H. Stix, U. S. Atomic Energy Commission Report TID7536, 1957 (unpublished), Part 2, p. 339.

[6]R. A. Demirkhanov, et al., Proceedings of the Fifth International Conference on Ionization Phenomena in Gases, Munich, 1961 (North-Holland Publishing Company, Amsterdam, 1962).

[7]V. E. Golant and A. P. Zhilinsky, Zh. Tekh. Fiz. 30, 745 (1960) [translation: Soviet Phys.—Tech. Phys. 5, 699 (1961)].

[8]R. W. Motley, Suppl. Nucl. Fusion, Part 1, 199 (1962).

MEASUREMENT OF THE THERMOELECTRIC POWER OF A FULLY IONIZED, LOW-TEMPERATURE PLASMA*

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During the progress of an experiment on an alkali-metal plasma (the Q-1 device[1]), it was found possible to measure the Seebeck coefficient, or the thermoelectric power,[2] of the plasma. The purpose of this note is to describe the measurement and to compare the result with a calculation based upon an approximate theory. Figure 1 shows a schematic of the apparatus. The plasma is generated by allowing a collimated beam of alkali-metal neutrals, in this case potassium, to impinge upon a hot tungsten plate. The neutral atoms are singly ionized on contact and, together

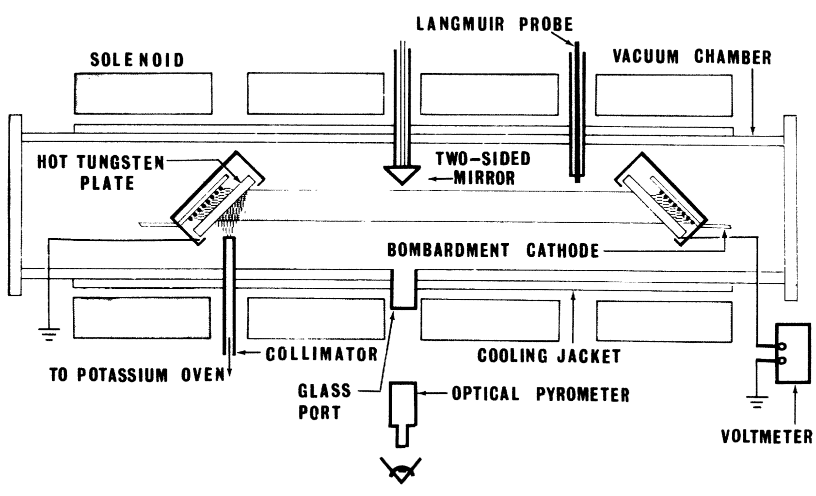

FIG. 1. Schematic of the Q-1 device as used in the measurement of the Seebeck coefficient. The tungsten plates were heated by electron bombardment.

(a)

(b)

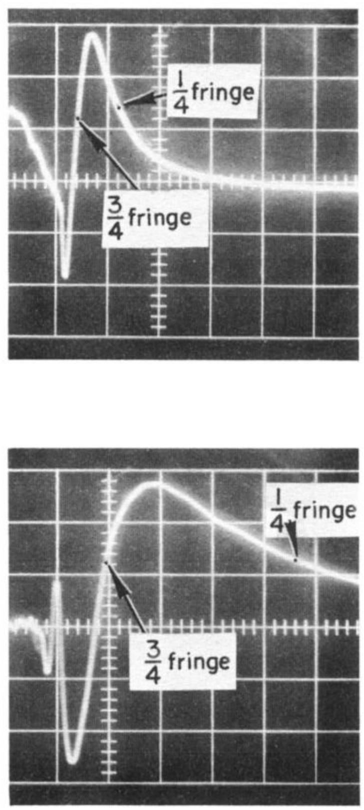

FIG. 2. (a) Interferogram for the afterglow plasma with $B = 400$ gauss. (b) Interferogram for the afterglow plasma with $B = 800$ gauss.