efforts throughout the calculations reported herein. We are also indebted to Dr. Lesley A. Morgan for programming assistance during the early development of the code and to Dr. M. J. Conneely for such assistance in recent months. All the calculations reported here were carried out on the CDC 6600 computer at Kirtland Air Force Base and we want to thank Colonel Truman Franklin and Major William Whitaker for permission to use that facility.

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[21]A stable calculation of the width of the $^4P^e$ state may require the additional coupling in of the $^3S^0$ term and the possibility of carrying out such a calculation on present computers is now under investigation.

ANOTHER APPROACH TO THE INJECTION OF RELATIVISTIC ELECTRONS INTO AN ASTRONLIKE DEVICE*

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Preliminary investigations of another approach to the injection phase of "Astron"-like devices are reported. A relativistic electron annular beam was passed through a cusped magnetic field with 25% efficiency and produced a rotating electron cloud. Gyrating electron behavior was examined in three magnetic field configurations by diamagnetic loops and x-ray detectors. Reduction of magnetic field intensity ranged from 15 to 32%, and confinement times of 0.4 to 3.0 μsec were obtained, depending upon the field configurations.

In 1958 Christofilos[1] suggested that a magnetic mirror with an internal current of relativistic electrons may serve as a "trap" for thermonuclear plasmas. The device known as "Astron" is the result of this suggestion.

The usual approach has been[2] to inject relativistic electrons across a magnetic field so that a "cloud" of gyrating electrons is produced. This cloud is "pushed" into the magnetic mirror where resistive rings dissipate some of the parallel energy of the electrons so that the electrons are trapped in the mirror and create the desired magnetic field configuration.

In this Letter a different approach to the injection problem is presented. It has already been shown[3-6] that electrons passing through a cusped magnetic field can behave nonadiabatically and, in the process, convert their parallel energy into perpendicular energy. Under some conditions the electrons tend to retain their radial positions.[7] It has been found that the electrons, in order to behave nonadiabatically, must satisfy the condition

$$r \leq \rho_{\mathrm{L}e}{}^* = \left(\frac{W_0^2 + 2mc^2 W_0}{e^2 B^2 c^2}\right)^{1/2}, \tag{1}$$

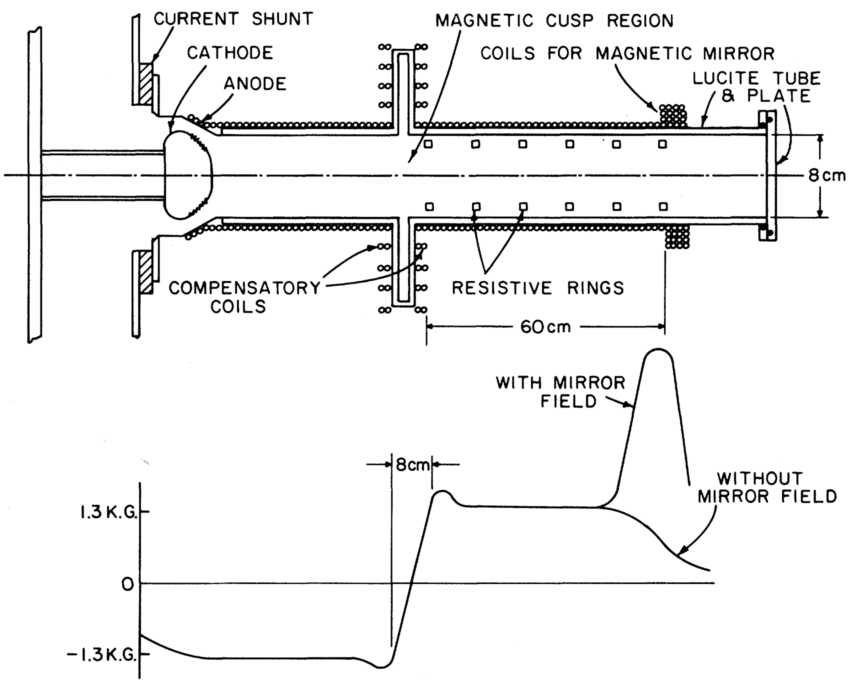

FIG. 1. Experimental layout (top) and magnetic field spatial variation (bottom).

where r is the electron radial position, W_0 is the energy of the electrons before entering the cusped magnetic field, and c, m, and e are the velocity of light, the mass, and the charge of an electron, respectively. Any method of injection of relativistic electrons in "Astron"-like devices should fulfill three conditions: (1) The electrons should have transverse energy $W_\perp$ greater than their longitudinal energy $W_\parallel$ (with respect to the magnetic field). (2) The Larmor radius ρ_{Le} has to be comparable with the radius of the magnetic mirror r^*,

$$r^* \gtrsim \rho_{Le} = \left(\frac{W_\perp^2 + 2mW_\perp C^2}{e^2B^2c^2}\right)^{1/2}. \qquad (2)$$

(3) The injector must be able to fill the mirror with relativistic electrons having a line density

$$N = (mc^2/e^2)\gamma, \qquad (3)$$

where $\gamma = (1-V^2/c^2)^{-1/2}$, and V is the electron velocity. Conditions 1 and 2 can be satisfied by passing an annular relativistic electron beam through a cusped magnetic field, as already mentioned, and condition 3 can be achieved by an accelerator that can produce 10^{15} to 10^{16} relativistic electrons per pulse. Using the Cornell electron beam accelerator,[8] an annular beam[9] of electrons has been injected into a magnetic field that resembles a cusp (see Fig. 1), and hence the three necessary conditions have been fulfilled.

Three types of magnetic field configuration were used to investigate the behavior of the electrons after they passed through the cusp: (a) homogeneous magnetic field, (b) homogeneous magnetic field with one magnetic mirror, and (c) the same as (b) but with six resistive rings.

The experimental layout and the magnetic field spatial variation are given in Fig. 1. The electron beam emerging from the diode has an annular shape of 3.0 cm o.d. and 1.8 cm i.d. Typical currents in the electron beam range from 10-20 kA for durations of ~50 nsec, and the electron energy is 400-500 keV. The experiment was performed using a magnetic field of about 1.3 kG, and base pressures of 10^{-4} Torr of air. Photographs of light emitted from a thin scintillator, located 60 cm beyond the cusped magnetic field, demonstrate that the initial annular shape of the beam is preserved after it passes the cusp. The behavior of the beam in the three previously outlined magnetic field configurations has been diagnosed by: (1) a calorimeter, (2) a diamagnetic loop, and (3) an x-ray detector.

The calorimeter has shown that $\leq 25\%$ of the electrons pass the cusp region. The total energy of the beam transmitted by the diode is ~120 J which agrees with earlier work that has been done with similar diodes.[6,9] From these experimental results it has been found that 5×10^{14}

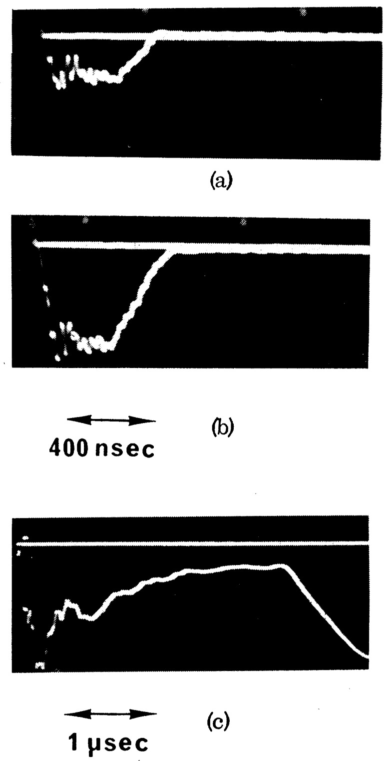

FIG. 2. Diamagnetic signals obtained in different magnetic field configurations, indicating amount of field reduction (ΔH). (a) Homogeneous magnetic field ($\Delta H \approx 200$ G). (b) One-sided magnetic mirror ($\Delta H \approx 400$ G). (c) One-sided magnetic mirror with six resistive loops ($\Delta H \approx 450$ G). For each case: Applied magnetic field ≈ 1.3 kG and base pressure $\approx 10^{-4}$ Torr of air.

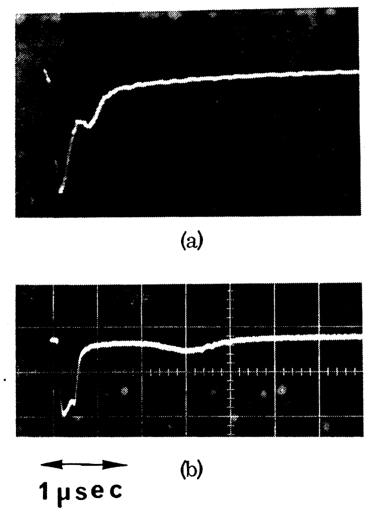

FIG. 3. X-ray signals obtained in different magnetic-field configurations, indicating confinement time of relativistic electrons. (a) One-sided magnetic mirror. (b) One-sided magnetic mirror with six resistive loops. Magnetic field and base-pressure conditions are the same as stated in Fig. 2.

electrons pass the cusp region successfully. The diamagnetic loop gives the reduction in the magnetic flux ΔH due to the presence of the gyrating electrons:

$$\Delta H = -(2N/r)\beta_\perp, \tag{4}$$

where $\beta_\perp = V_\perp/c$, N is the number of electrons per cm, and r is the radius of the gyrating electrons. From Eq. (4), the average value $\langle V_\parallel / V_\perp\rangle_{\rm av}$ can be calculated if the total number of electrons, Q, is known:

$$Q = \int \frac{I}{e} dt = \int N V_\parallel \, dt = \tfrac{1}{2}\int \frac{\Delta H r c}{e} \frac{V_\parallel}{V_\perp} dt, \tag{5}$$

where I is the longitudinal current of the electrons after the cusp region. From Eq. (5)

$$\langle V_\parallel / V_\perp\rangle_{\rm av} = 2Qe/\Delta H r c \Delta t, \tag{6}$$

where Δt is a characteristic time describing the duration of the diamagnetic signal. Figure 2 displays the diamagnetic signals for the three magnetic field configurations. For the first configuration [Fig. 2(a)], $\Delta H = 200$ G, $\Delta t \approx 400$ nsec, and $r = 1.5$ cm. Thus, Eq. (6) yields

$$\langle V_\parallel / V_\perp\rangle_{\rm av} \approx 0.15.$$

Figure 2(b) shows the influence of a one-sided magnetic mirror on the diamagnetic signal. Note that the amplitude of the signal increased by a factor of 2 indicating that most of the electrons are reflected back from the mirror. Figure 2(c) shows the influence of the resistive rings. The diamagnetic signal indicates containment of the electrons for a few μsec. The effect of the resistive rings is best shown on the x-ray signal (Fig. 3). The x rays are generated by electrons escaping from the mirror and striking a Pb target. The signal obtained in the presence of the resistive rings has a double-peak structure. Between these two peaks the electrons are stored and possibly create an "E layer".

This experiment was designed to explore a different injection method for "Astron"-like devices; so it is necessary to consider these results to be of preliminary nature. However, a more extensive investigation is possible. The number of electrons that pass the cusp is large enough to increase the dimensional scale of the experiment. Also, containment can be improved by better construction of the magnetic field configuration, by insertion of a background gas, and by the use of more and better-designed resistive loops. An improved experiment is now in progress that incorporates these modifications.

Helpful discussions with Professor N. Rostoker and Professor S. Linke are gratefully acknowledged.

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ANISOTROPIC ULTRASONIC PROPERTIES OF A NEMATIC LIQUID CRYSTAL

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Ultrasonic measurements (2 to 6 MHz) on a room-temperature nematic liquid crystal have shown the attenuation to vary strongly with the angle θ between the sound-wave propagation direction and the direction of an aligning magnetic field. The velocity change is quite small, amounting to some 0.1% between the $\theta = 90°$ and the $\theta = 0°$ case. The orientation-dependent attenuation is of the hysteresis type.

Many of the physical properties of nematic liquid crystals display a pronounced anisotropy associated with the orientational ordering of the long molecular axes in this phase.[1-3] We have measured a dependence of ultrasonic attenuation and velocity on the angle between the sound-wave propagation direction and the direction of an aligning magnetic field acting on *N*-(*p*-methoxybenzylidene)-*p*-*n*-butylaniline (MBBA) which, to the best of our knowledge, represents the first observations of anisotropy in the ultrasonic properties of a nematic liquid crystal.

MBBA (Distillation Products Industries, Inc.) is nematic in the range 20°-40°.[4] Measurements were carried out primarily at room temperature at frequencies of 2, 3, 5, and 6 MHz using the commercially available MATEC[5] unit as the electric pulse generator for the input quartz crystals. Voltage picked up by the output quartz crystal was amplified by a Tektronix-121 wide-band preamplifier and then fed into either the receiver portion of the MATEC unit or a Tektronix-545 oscilloscope. The cell is a cylindrical cavity hollowed from an aluminum block. The cylinder is $\frac{5}{16}$ in. long and $\frac{5}{8}$ in. diam and was sealed at its ends with the sending and receiving quartz crystals of $\frac{3}{4}$ in. diam each, which were fine ground and plated with chromium and gold.

The attenuation versus orientation, at 6 MHz, for a field of 10 000 Oe is shown in Fig. 1, and the general shape of the curve is similar at the other frequencies. These changes followed the field almost instantaneously. Background attenuation varied from 2.18 dB/μsec at 6 MHz to 0.37 dB/μsec at 2 MHz. This observed anisotropy is consistent with reordering a large portion of the

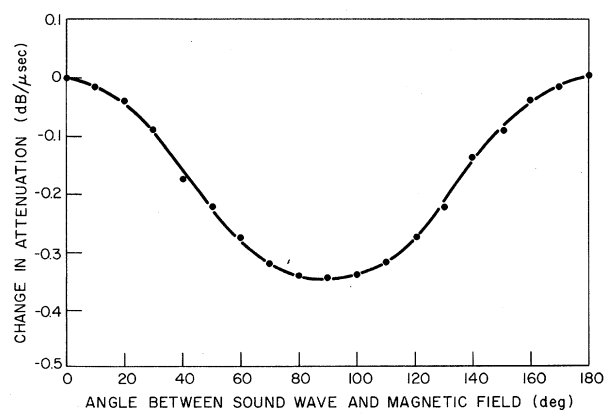

FIG. 1. Change in the ultrasonic attenuation as a function of the angle between the propagation direction of the sound wave and the direction of the aligning magnetic field.

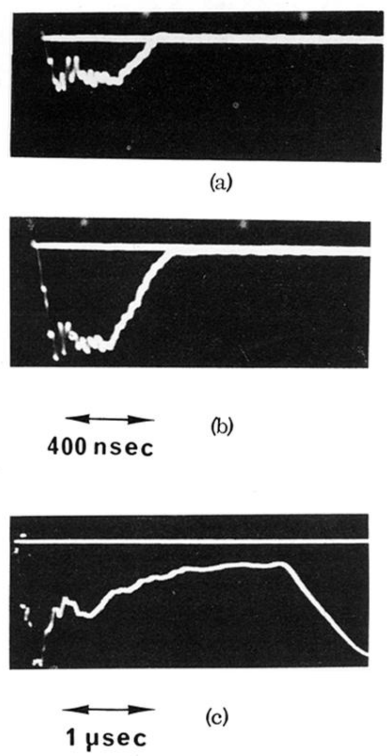

FIG. 2. Diamagnetic signals obtained in different magnetic field configurations, indicating amount of field reduction (ΔH). (a) Homogeneous magnetic field ($\Delta H \approx 200$ G). (b) One-sided magnetic mirror ($\Delta H \approx 400$ G). (c) One-sided magnetic mirror with six resistive loops ($\Delta H \approx 450$ G). For each case: Applied magnetic field ≈ 1.3 kG and base pressure $\approx 10^{-4}$ Torr of air.

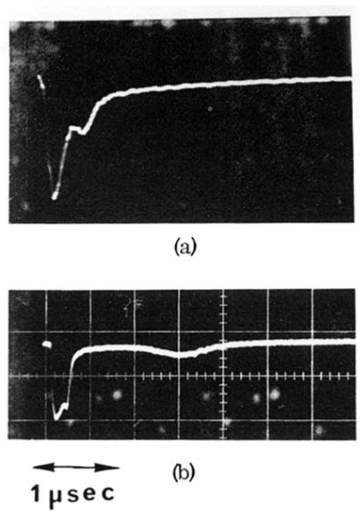

FIG. 3. X-ray signals obtained in different magnetic-field configurations, indicating confinement time of relativistic electrons. (a) One-sided magnetic mirror. (b) One-sided magnetic mirror with six resistive loops. Magnetic field and base-pressure conditions are the same as stated in Fig. 2.