XXIV. INTERACTION OF LASER RADIATION WITH PLASMAS AND NONADIABATIC MOTION OF PARTICLES IN MAGNETIC FIELDS*

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RESEARCH OBJECTIVES

1. Mechanisms of the Hollow Cathode Arc

The present experiment to determine the gaseous electronic mechanisms that are important in sustaining the hollow cathode arc will, in all probability, be completed. The relative importance of thermionic emission, secondary electron emission by ions, photons, metastable atoms, and so forth will be evaluated quantitatively and compared with theoretical calculations.

M. D. Lubin, D. J. Rose

2. Interaction of Coherent Radiation and Plasmas

With the 70-80 watt cw nitrogen-carbon dioxide laser completed and the (approximately) 10^{-13} watt-Hz bandwidth detector completed, we shall complete experiments on coherent scattering of 10.6-μ radiation from a steady-state plasma with electron density $\approx 10^{14}$ cm^{-3}, electron temperature ≈3-10 eV, 50-95% ionized.

A doctoral program will be started to measure electron temperatures parallel to and perpendicular to the magnetic field, by using laser scattering to give more direct information on thermalization rates in the plasma.

A. A. Offenberger, L. M. Lidsky, D. J. Rose

3. Laser-Plasma Science and Technology

This heading includes gaseous electronics, plasma physics and technological aspects of devices that are likely to be of interest as gas lasers. This work continues, with changes of detailed topics. A small program to maximize the power-handling capability of an insulating tube-type argon laser will be completed, with a study of the utility of high-alumina tubes (G. E. Co. Lucalox) in such applications. A simple optical device is being constructed which will detect incipient thermal failure of such laser column tubes. A hollow cathode arc with side gas feed and plasma coming from both ends will be built to see whether the hollow cathode arc type of argon plasma can be made to "lase."

Finally, a pulsed variation of the nitrogen-carbon dioxide laser will be completed. Preliminary estimates show that it should be possible to pulse the plasma and increase the 10.6-μ output very substantially in the afterglow.

D. E. Crane, L. M. Lidsky, D. J. Rose

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4. Nonadiabatic Scattering

The first stage in our study of nonadiabatic scattering has been completed. We have measured the lifetime of electrons resonantly trapped in a magnetic-mirror field and developed a theoretical explanation of our experimental results. The theory, which predicts the point at which first-order perturbation theoretical estimates of velocity-space diffusion will become inadequate and furnishes a higher order estimate of the diffusion coefficient, has applicability to a wide range of problems. We are now investigating the following problems.

(i) Scattering in long coherence length, nonresonant perturbations.

(ii) Small-angle (in velocity space) scattering in very weak resonant perturbations. The toroidal device developed for this study provides over 100 transits of the perturbation region and very high sensitivity to changes in the direction of the velocity vector.

(iii) The possibility of using the techniques developed in our study of the corkscrew system to study wave-particle scattering with a view toward furnishing an experimental test of some predictions of plasma kinetic theory.

L. M. Lidsky, D. J. Rose, R. W. Moir, M. Murakami

A. NONADIABATIC TRAPPING IN TOROIDAL GEOMETRY

One goal of the toroidal injection experiment has been achieved: The nonadiabatic injection of a cw electron beam into a toroidal magnetic field to produce a circulating electron stream.

The experiment (described more fully in previous reports[1]) is a 6-meter circumference torus, with 11-cm minor diameter and 70 Gauss main field. An electron beam of a few microamperes at 1500 eV was injected through an injector snout with 80% of the energy perpendicular to $\vec{B}$. A magnetic field periodically perturbed in space (corkscrew) acted on the beam, converting perpendicular energy to parallel energy. The beam's

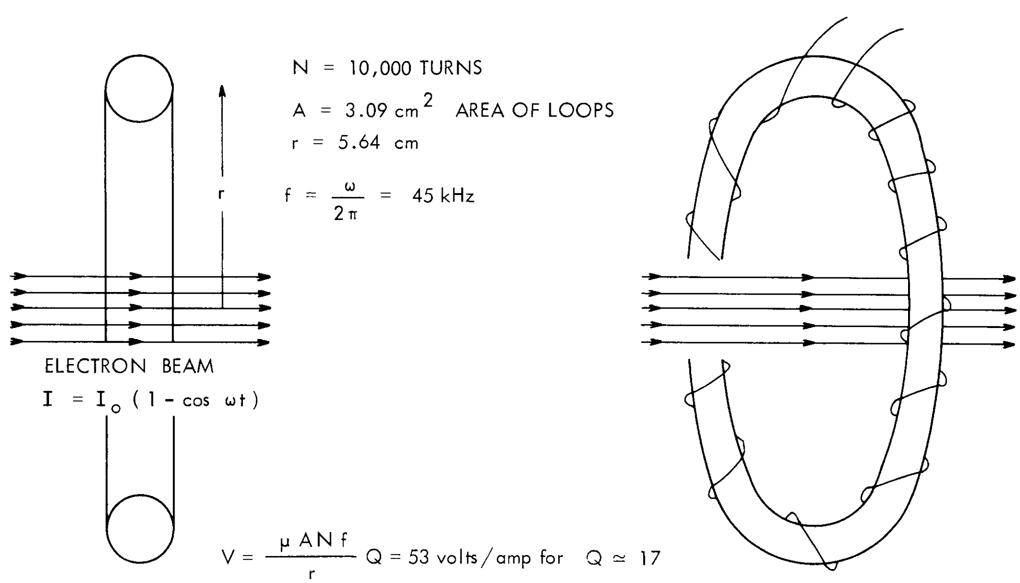


Fig. XXIV-1. Rogowsky coil.

guiding center remained on the axis, and 95% of the energy was parallel to B. This beam then circulated around the torus until it hit the injector snout or the walls. The beam lifetime was measured with an ion collector[1] and a new diagnostic, and Rogowsky coil, which is shown in Fig. XXIV-1. The electron beam was modulated at 45 kHz, the self-resonant frequency of the coil; this procedure enabled detection of less than 60 namps of current. The Rogowsky coil was chosen because of its insensitivity to the low-energy secondary electrons that plague charge collector techniques.

The Rogowsky coil measurements agreed within 5% with the ion collector measurements, both of which indicated 4-5 transits of the beam around the torus.[2] This number is in fair agreement with the 6.4 transits obtained by means of a computer calculation.[3]

We found that the resonant perturbation, even at the field strength ($B\perp/B = 4.3\%$) used for injection, preferentially scattered the beam energy into perpendicular motion, thereby resulting in very rapid loss. This preferential scattering was also seen by Clarke in his experiments on nonadiabatic scattering in mirror systems.[4]

In order to increase the number of transits, we decided to inject the beam into the torus by means of a pulsed E field. After the E field is switched off, the remaining fields are fairly uniform, yielding adiabatic motion and many transits. Figure XXIV-2

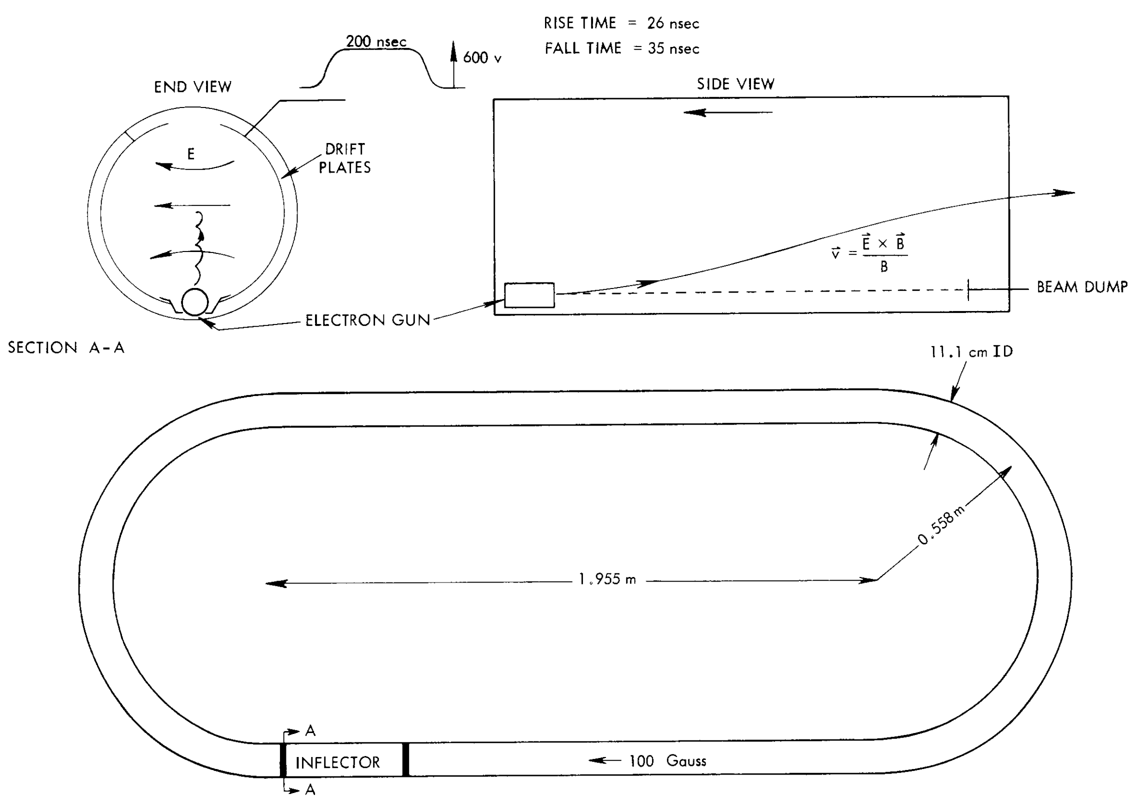


Fig. XXIV-2. Electron injection system.

shows the injection system.

The curved "drift" plates produce a horizontal $\vec{E}$ field which causes the beam to drift vertically at the E/B speed. In order to minimize the transverse energy contained in the cycloidal motion of the drifting electrons, the plates were made quite long (20 inches), which gave 4 or more complete cycloids for drifting to the torus axis.

With the injection field off, the electron beam from the continuously operating gun follows the magnetic field lines near the bottom of the torus to the collector electrode. Beam inflection is produced by a flat-topped 600-V pulse with ~30 nsec rise and fall times and variable width. The nominal injection time is ~200 nsec (slightly less than one transit time of the beam in its motion around the torus), but is variable over a wide range around this value. Injection for larger than a single transit time results in spillage of the beam that is already trapped. The injection pulse is repeated every 16 msec, and the beam decay (~30 μsec for complete loss) is observed during the interpulse periods.

The beam, which is actually a long column of electrons, then circulates around the axis until it diffuses to the walls.

The diagnostic was a cylindrical tube, 3 1/4" in diameter, through which the beam

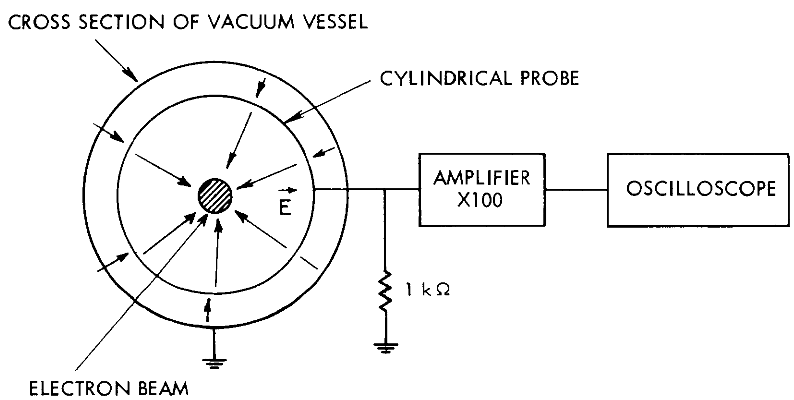
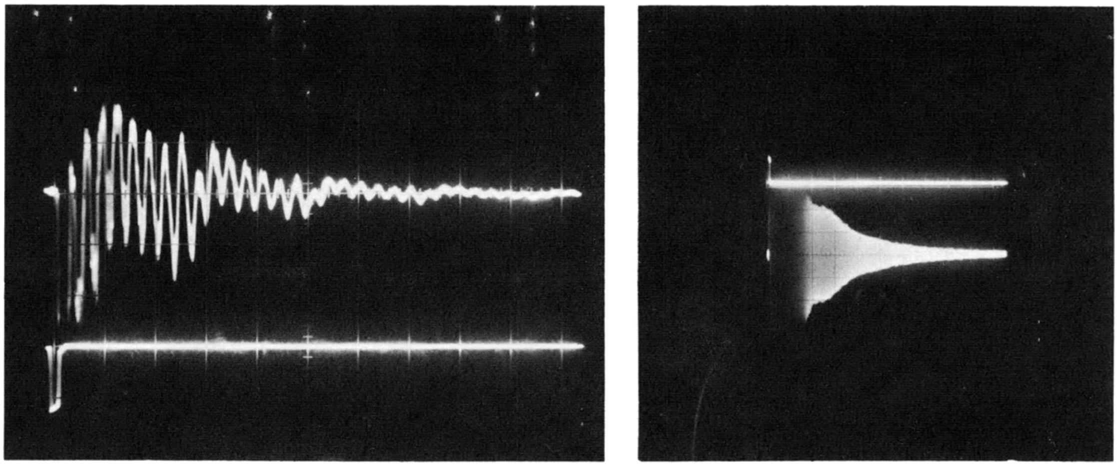


Fig. XXIV-3. Pickup probe.

passed. The E-field from the beam electrons induces a voltage on the cylinder (Fig. XXIV-3).

Figure XXIV-4a (lower trace) shows the voltage on the drift plates, and the upper trace shows the probe signal. Each oscillation indicates one transit. The oscillation period scales as $1/\sqrt{E_{\parallel}}$ (period = $\ell/v_{\parallel}$) where E is the parallel energy of the beam. The amplitude dies away as the beam is lost to the walls. The lower frequency oscillation period is caused by rotational transform of the magnetic field (ℓ = 2 Stellarator coils), and is thought to be due to the transform rotating the beam around an axis displaced from the axis of the torus, which thus brings the beam closer and then farther



(a) (b)

Fig. XXIV-4. Pickup probe data.
(a) Horizontal: 1 μsec/cm; 0.3 μsec/transit
Upper: 0.2 volt/cm
Lower: 500 volts/cm
(b) Horizontal: 5 μsec/cm; 0.3 μsec/transit
Lower: 5 mV/cm.

from the pickup probe. The transform angle a is found to be proportional to the square of the current in the Stellarator coil. $a \approx 360°/N = 50°$ for $N = 7$, where N is the number of oscillations during one period of the low-frequency oscillation (see Fig. XXIV-4a). Figure XXIV-4b shows a beam contained in a longer time; 37 transits for an e-folding, and 128 transits still observable.

While our results are preliminary, the rather long lifetime of the circulating beam meets our requirements for perturbation studies, and also provides a tool for investigating the closure of drift surfaces in closed B-field systems.

R. W. Moir, L. M. Lidsky

References

1. Quarterly Progress Report No. 77, pp. 164-167; Quarterly Progress Report No. 78, pp. 126-127; Quarterly Progress Report No. 79, pp. 131-132; Quarterly Progress Report No. 81, pp. 141-147.

2. We previously reported (Quarterly Progress Report No. 81, p. 145) 15 transits, but this enhanced value was due to secondary electrons.

3. Ibid; loc. cit.

4. Ibid; p. 147.