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GENERATION OF ENHANCED-SCALELENGTH PLASMAS AND ZEEMAN 1/1
STUDY OF MAGNETIC FIELDS(U) NAVAL RESEARCH LAB

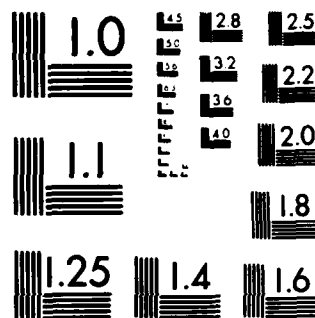
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20 ABSTRACT (Continue on reverse side if necessary and identify by block number) Using nonuniform laser illumination on flat targets, with moderate laser energies (200 J), we have produced enhanced density scalelengths; e. g., in excess of 0.5 mm at 0.1 of critical density. These enhanced scalelengths are of interest in simulating large, high-gain pellets, and investigating the potential impact of longer scalelengths on a variety of convective plasma instabilities. The non-uniform laser irradiation also affects the spontaneous magnetic fields. These fields were measured for the first time using the Zeeman effect. Space-and-time-resolved measurements, for both polarizations, were made of the 2271-2278 Å CV triplet ($2s^3S_1 - 2p^3P_{2,1,0}$) emission. A comparison with theory gave fields around 200 kG.		

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GENERATION OF ENHANCED-SCALELENGTH PLASMAS AND ZEEMAN STUDY OF MAGNETIC FIELDS

I. INTRODUCTION

For the past few years at NRL, we have been studying the physics of ablatively accelerated thin-foil targets in order to understand the physics of ablatively-imploded ICF pellets.

Recently, we have taken a new direction placing emphasis on the physics of long scalelength plasmas; ones that more closely simulate the physics of large, high-gain full-size ICF reactor pellets. Phenomena such as convective instabilities including stimulated backscatter are of particular interest.

A promising approach for producing these long-scalelength plasmas is to use nonuniform irradiation of the targets. A brief description of the production of these long-scalelength plasmas is given here and Mark Herbst in a separate paper describes some of our initial experiments in this area.

Nonuniform irradiation may also affect the spontaneous magnetic fields, and we have looked for these fields both with Faraday rotation and the Zeeman effect. We have, for the first time, been able to measure these fields with the Zeeman effect and most of the discussion is devoted to the Zeeman study.

II. GENERATION OF ENHANCED-SCALELENGTH PLASMAS

A 10-cm mask is placed in front of the focusing lens. Since the target is in the quasi-near field of the focused laser beam, the mask produces an intensity minimum at the center of the laser profile. This is depicted schematically in Fig. 1. The density profile then has a maximum near the center and has an enhanced density scalelength. Apparently, the central part of the plasma is hydrodynamically confined by a converging peripheral plasma flow. Such a flow is seen with tracer dots.

An actual radial laser profile is shown in Fig. 2, along with the corresponding radial density profile obtained from a shearing interferogram using a third harmonic laser probe. This was for a half-power shot ($\sim 5 \times 10^{12} \text{W/cm}^2$). Note the steep density maximum near the center with densities just above three-tenths of critical density.

The axial density variation of the on-axis density is shown in Fig. 3 for a full-power ($\sim 10^{13} \text{W/cm}^2$) shot. It is plotted in tenth-critical units of density (note 10^{-1} on ordinate). The axial density scalelengths at one-tenth critical is about 600 microns.

III. ZEEMAN STUDY OF MAGNETIC FIELDS

As noted earlier, we have used the Zeeman effect to look for spontaneous magnetic fields when we use this nonuniform irradiation. Generally speaking, we had expected that these fields would be much smaller for multnanosecond irradiation of large focal spots than for the tightly focused, subnanosecond pulses where Faraday rotation showed fields in the megagauss range.

The Zeeman study requires that we choose a suitable spectral line. We chose a helium-like carbon triplet because it was in the quartz UV range where optical components were available, because it had a small stark width, and because it was present at a relatively high-temperature—around 100 eV. This is the $CV 1s 2s^3S_1 - 1s2p^3P_{2,1,0}$ transition near 2270 Å. We have data for the complete triplet but have chosen the relatively isolated $J = 2$ components at 2271 Å for a quantitative analysis in order to evaluate the magnetic field.

In order to understand the observed structure in this line, let us look at the target along the main laser beam as shown in Fig. 4, and consider three regions. The observed helium-like carbon emission comes from ions in an expanding conical annulus shown in dark shade. There is a region inside affected by the masking and there is a region outside. The radial expansion of 1.4×10^7 cm/sec causes a 1.1 Å Doppler shift of the entire triplet. The red-shifted triplet from the location opposite to the side-on observer is not seen—indicating absorption by a relatively cool inside region. The blue-shifted triplet is partially absorbed—particularly at later times—by the outside region.

For purposes of illustration, the magnetic field is shown in a clockwise direction, but our experiment does not distinguish a clockwise from a counter clockwise field. Note, however, that the observer is looking at the laser axis so that observations are perpendicular to the magnetic field. Zeeman theory then shows that the emitted light has two linear polarizations: the pi components are polarized parallel to the magnetic field while the sigma components are polarized perpendicular to the field.

The experimental set-up used in the study is shown in Fig. 5. The laser beam, (35 to 40 J in 5 nsec) shown incident from the left, has its central region blocked by a 7-cm diameter mask. It is focused with an $f/10$ lens into a 50-micron thick carbon target. An $f/1.6$ parabolic mirror is used to collect light emitted parallel to the target surface. The light is directed with a series of mirrors into the spectrograph, allowing only small angles of incidence with respect to the mirror normals in order to minimize polarization effects. A 1-m McPherson spectrograph is used, with the grating blazed at 2000 Å. As shown in the side view, in the upper-left, the beam passes through a Wollaston prism before entering the spectrograph. The physical separation (8") of the Wollaston from the entrance slit causes a vertical separation of the two polarizations at the exit slit. Since the entrance slit is imaged, one-to-one on to the exit slit, the same separation occurs at the exit slit. Mirrors are used at the exit slit to deflect the two polarizations into two photomultipliers. We then record, simultaneously and separately, the time history of the pi and sigma emissions.

In order to measure the magnetic field, we must compare these measurements with a theoretical Zeeman profile. This calculation was done with a small computer code which allowed a magnetic field input in increments of 100 kG and was only done for the $J = 2$ component. The magnetic field input determines the relative amplitude and center wavelengths for each of the 9 component profiles: the three pi components (parallel to \underline{B}) and six sigma components (perpendicular to \underline{B}). Intermediate-field corrections calculated by Griem, were included. The optically-thin profiles $I_i(\lambda)$ are obtained by adding these components at each wavelength. As noted earlier, it is necessary to include opacity effects in order to calculate the actual emitted-line profiles $I_e(\lambda)$. This is done for the emitting and outside regions by modelling with input parameters, C_1 and C_2 .

$$I_e(\lambda) = (1/C_1) \underbrace{[1 - \exp - C_1 I_i(\lambda)]}_{\text{Emission Region}} \underbrace{\exp - (C_2 I_i(\lambda))}_{\text{Outside Region}} \quad (1)$$

Finally, in order to calculate the "observed" line profiles, one must convolve the emitted profiles with the instrument function. Our instrumental function half width of 1.5 Angstroms is greater than some of the Zeeman component separations. Thus, absorption will depend on locally different unresolvable structures for the two polarizations. However, because absorption changes the total intensity it can actually enhance the observability of these unresolved structure differences.

A comparison is shown in Fig. 6 of the experimental profiles observed 5 nanoseconds after the peak of the laser pulse with a theoretical profile for 200 kilogauss. Broadly speaking, one must account for the widths of the pi and sigma profiles, as well as the ratio of their intensities at profile center. The pi components are noted with crosses and the sigma components with circles. The right-hand point lies above the $J = 2$ theoretical profiles since it also includes a significant $J = 0$ contribution. Considering the normalizations, rather small opacity parameters C_1 and C_2 are required. The agreements at 100 kG and 300 kG were not nearly so close as 200 kG so that the data shows the field to be around 200 kilogauss. Nevertheless, a slightly smaller pi width would agree better with the data, indicating that a field slightly larger than 200 kG would agree somewhat better with the data.

A comparison is shown in Fig. 7 with observations made 8 nsec after the peak of the laser pulse. The striking feature here is that the sigma emission is nearly twice as intense as the pi emission at the center of the profiles. However, a field of 200 kG with a relatively absorbing outside region ($C_2 = 5$) gives a reasonably good fit to the data. In this case, a slightly smaller sigma width would give a better fit to the data, indicating that the field is just under 200 kG.

Thus, the Zeeman data shows fields decreasing from just above 200 kG at +5 nsec to just below 200 kG at +8 nsec.

IV. CONCLUSION

In conclusion, we recall the interest in long-scalelength plasmas and that a promising approach in their production is the use of nonuniform laser irradiation. We have produced density gradient scalelengths of 600 microns in this way.

The Zeeman effect has been used for the first time to observe spontaneous magnetic fields in laser-produced plasmas. The technique was surprisingly sensitive, allowing 200-kG fields to be observed and would allow 100-kG fields to be observed. The Zeeman result is consistent with the Faraday rotation study where the absence of a definite Faraday rotation light pattern indicated that the fields were no larger than around 200 kG. However, it remains to be seen whether these fields are small in the sense that they can be ignored in reactor applications.

V. ACKNOWLEDGMENTS

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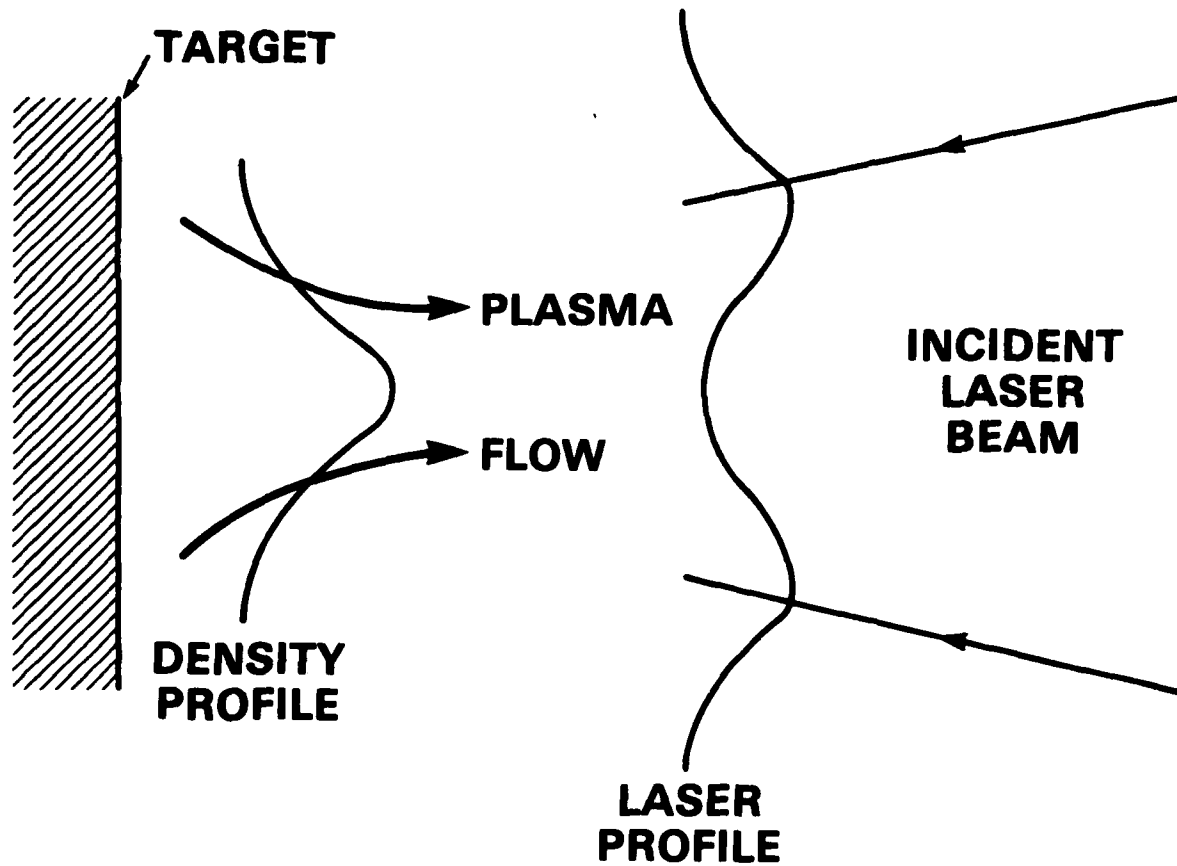


Fig. 1 - Enhanced axial density scalelengths from nonuniform irradiation of flat targets

PLASMA DENSITY
SHOT 10874
z = .21 mm

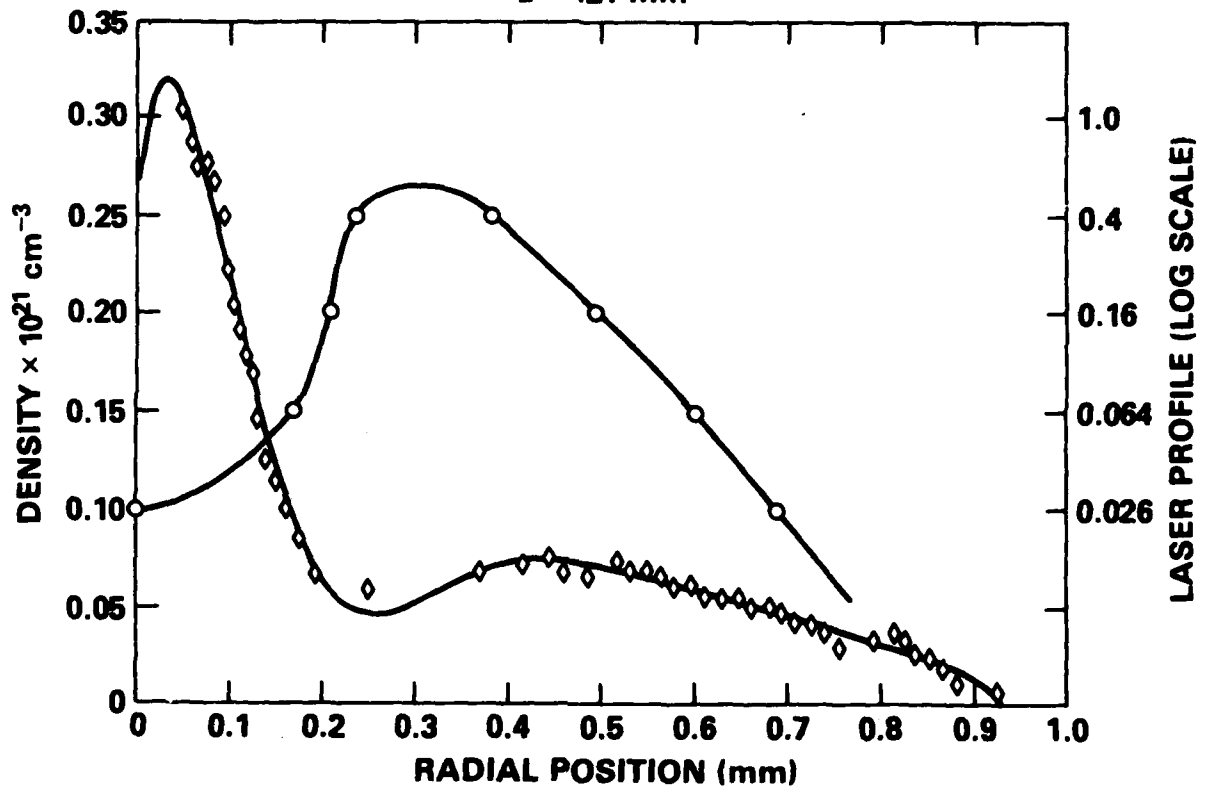


Fig. 2 - Radial laser profile and corresponding radial density profile

AXIAL DENSITY PROFILE WITH NONUNIFORM ILLUMINATION

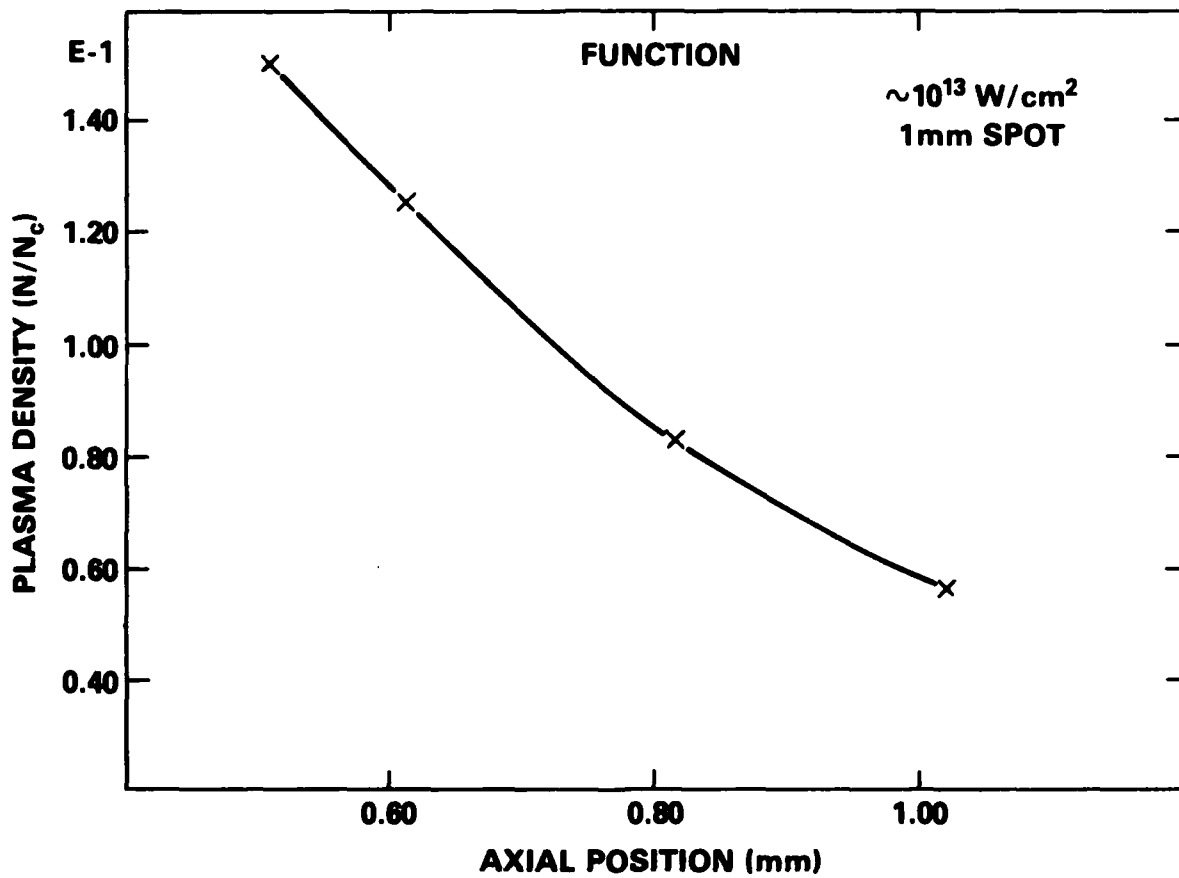


Fig. 3 — Axial density profile showing a scalelength of 0.6 mm at 0.1 critical density

CROSS-SECTIONAL VIEW OF PLASMA PLUME

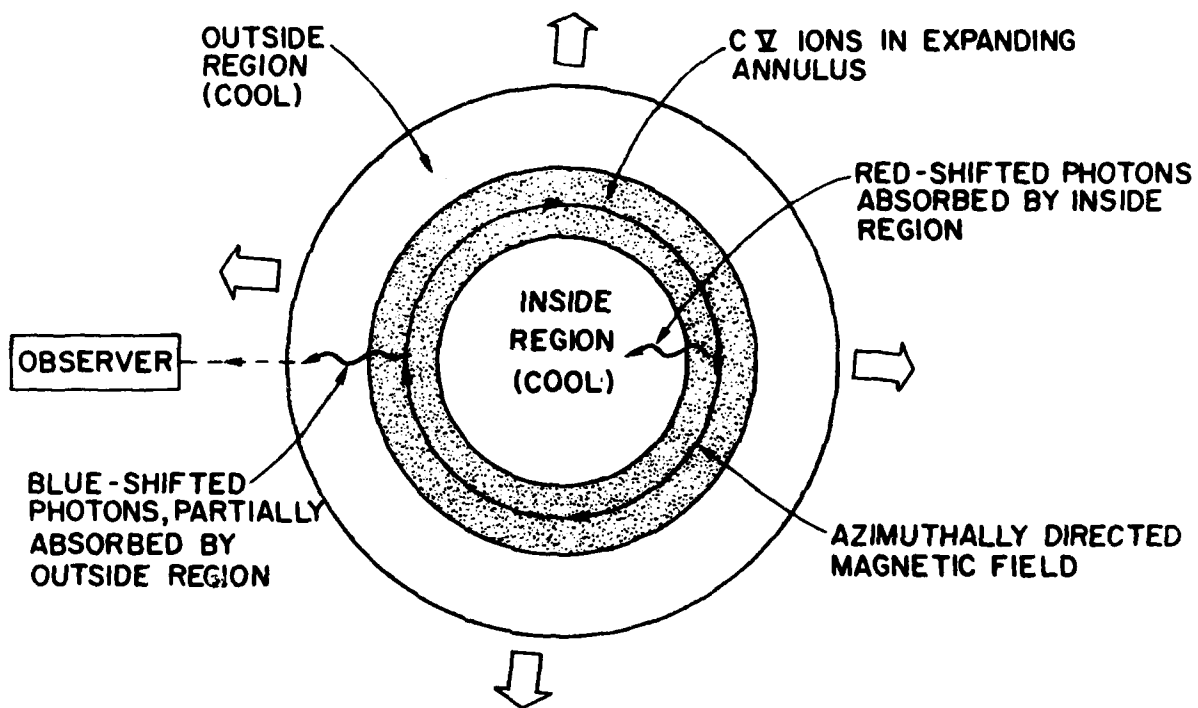


Fig. 4 - View along main laser beam, showing regions which affect the observed spectral profiles

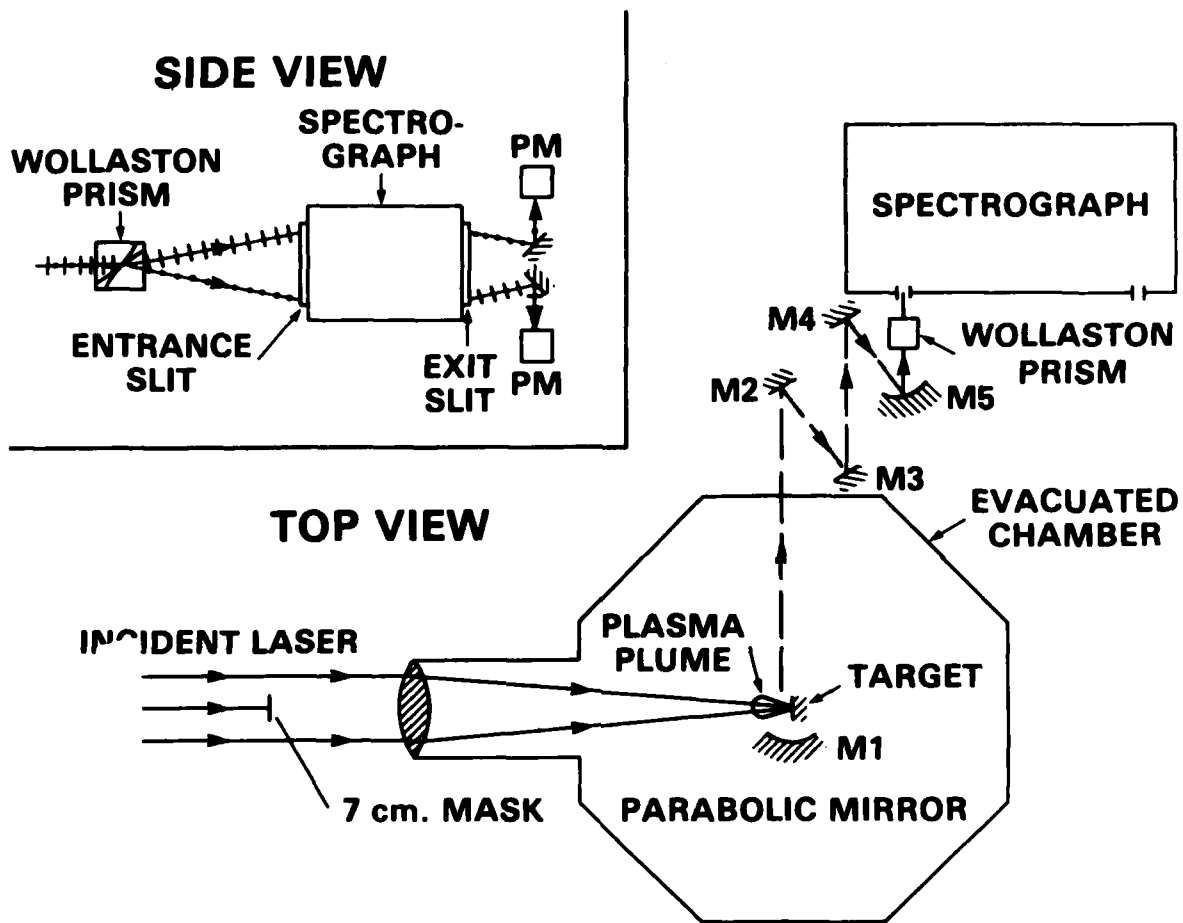


Fig. 5 - Experimental arrangement for Zeeman study of spontaneous magnetic fields

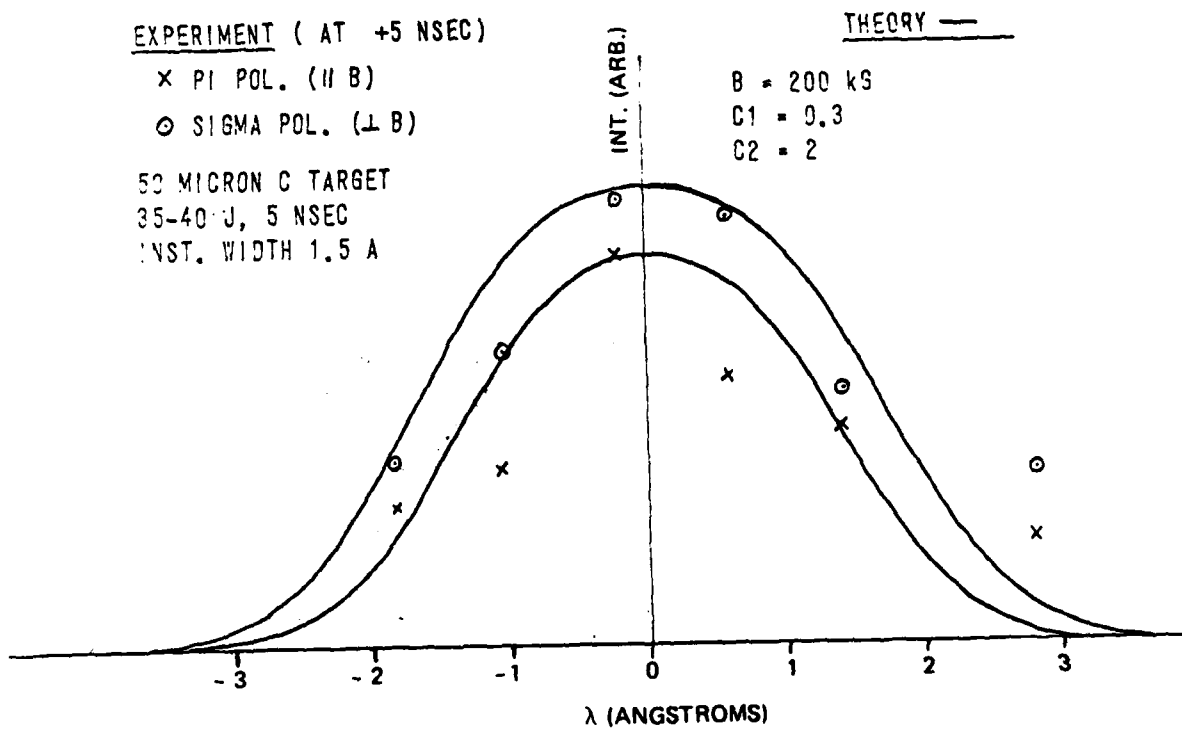


Fig. 6 - A comparison of theoretical profiles for 200 kG with experimental data taken 5 nsec after the peak of the main laser pulse

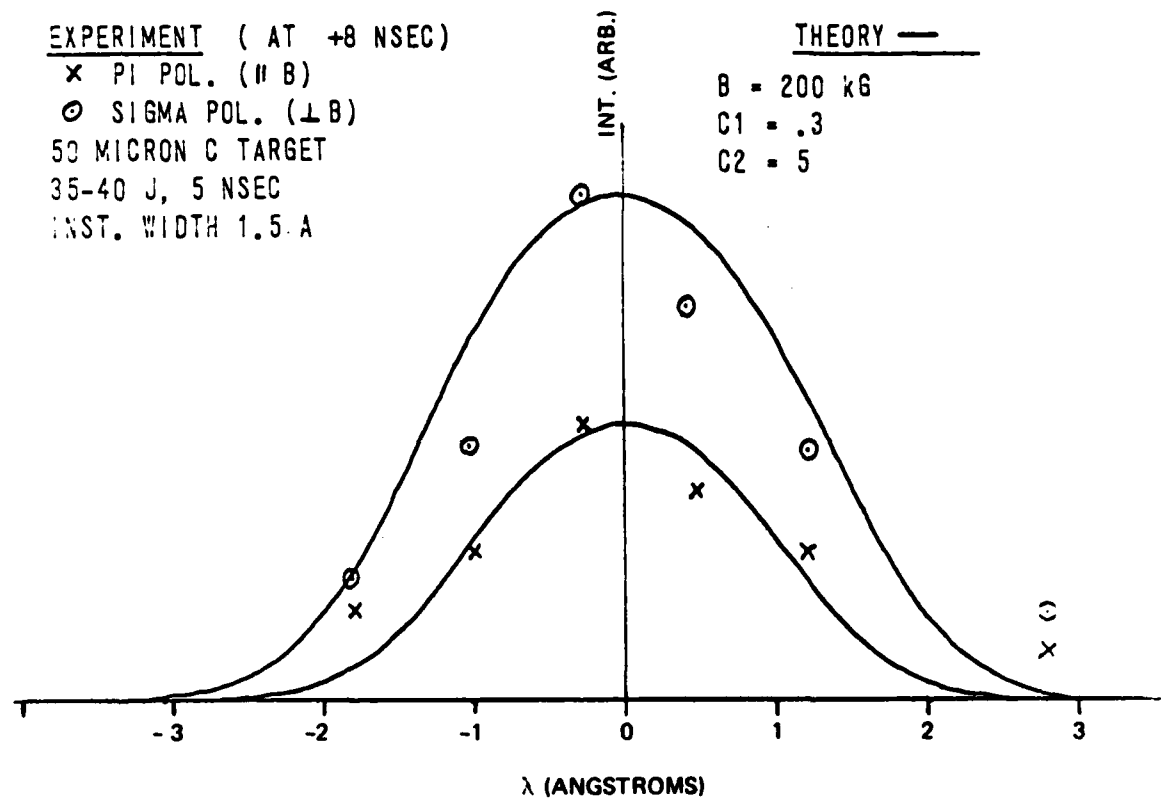


Fig. 7 - A comparison of theoretical profiles for 200 kG with experimental data taken 8 nsec after the peak of the main laser pulse

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