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LASER-PLASMA CALCULATIONS WITH REFRACTION

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Laser-Plasma Calculations with Refraction*

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The details of the ray tracing LASNEX[1] has just been presented. Before using this code in actual laser-target simulations calculations, we made a number of checks to understand better the characteristics of the code. Some of these test problems have analytic solutions. Therefore, the performance of the code calculation can be rigorously checked. We discuss here several of these comparison problems, most of which demonstrate the ability of the code to predict correctly ray trajection.

The first of these test problems involves a light ray entering a medium with a linear density gradient. The analytic solution for this problem has been given by Shearer[2]. The first figure (Fig. 1) shows this result. Figure 2 shows the comparison between the analytic solution (dotted curve) and the code calculations.

The second problem involves light propagation in a medium with a quadratic density gradient transverse to the direction of propagation. The analytic solution for this problem is presented on the next figure (Fig. 3). Note the paraxial ray approximation. The value of A has been chosen as $\Pi^2/2500$ (1/micron^2) so that the maximum and minimum of

*Research performed under the auspices of the U. S. Atomic Energy Commission.
[1]G. B. Zimmerman, LLL Rpt. UCRL-74811, Oct. 1973.
[2]J. W. Shearer, Phys. of Fluids 14 183, 1971.

the sinusoidal oscillation will appear every 25 micron. Further, to make the comparison simpler, we check the solution one term at a time. That is, we set R_0, and R_0' to zero in sequence.

We will discuss our results for positive A first. Figure 4 shows the quadratic gradient used in these calculations. The next figure (Fig. 5) shows the paths of the rays calculated by the code. The rays enter the problem from the 150 micron side with R_0' equal to zero. The box on the figure shows the zone size used in the calculation, (1 x 2 micron). Next, we set R_0 equal to zero and let R_0' be 5, 10 and 15 degrees. The paths of the rays calculated by the code are shown on the next figure (Fig. 6). Notice that the ray which is entering at 5 degrees disagrees badly with the analytic solution. This is especially disturbing because this ray is closer to the axis than the other ray in the problem. The reason for this disagreement is due to the zoning. We recall that the slope of the density is flat at the center. Thus, the change in the slope is maximum at this point. In addition, we note that the 5-degree ray traverses only about 1-1/2 zones in the R direction. (Can also point out again the way the density is calculated in the code.) The next figure (Fig. 7) shows the code calculation for different zone sizes. The + curve is the same one shown in the preceeding figure.

For negative values of A, the ray should diverge. Figure 8 shows the result of this calculation. The effect of zone size is again obvious.

A third test problem is the propagation of light ray inside a spherical plasma with a density profile which increases with r. Ginzburg[3] presents an analytical description of the trajectory of such a ray--as seen on Fig. 9. LASNEX predicts the correct reflection point for a ray initially at 45° to a radius vector.

In addition to verifying that trajectories are properly computed, test problems also show that the spatial variation of intensity and inverse bremsstrahlung absorption rate are, as well, correctly predicted.

One important caveat must be imposed on the use of geometrical ray optics: the neglect of diffraction can, in certain cases, be a severe oversight, especially in cases of thermal self-focusing. As discussed by Perkins and Valeo[4] diffraction dominates in those cases where $D = k_{\perp}^2 L/2k_0$ is much greater than one. In such cases involving focusing to small diameter over long distances, geometrically optics predicts unphysical focusing.

With the proper attention to the regime of application and the appropriate zoning of the Lagrangian mesh, this ray tracing scheme is quite accurate.

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[3] V. L. Ginzburg, "The Propagation of Electromagnetic Waves in Plasmas", (Addison-Wesley, Reading, Mass., 1964), p. 378.

[4] F. W. Perkins and E. J. Valeo, Phys. Rev. Letters, 32, (1974), 1234.

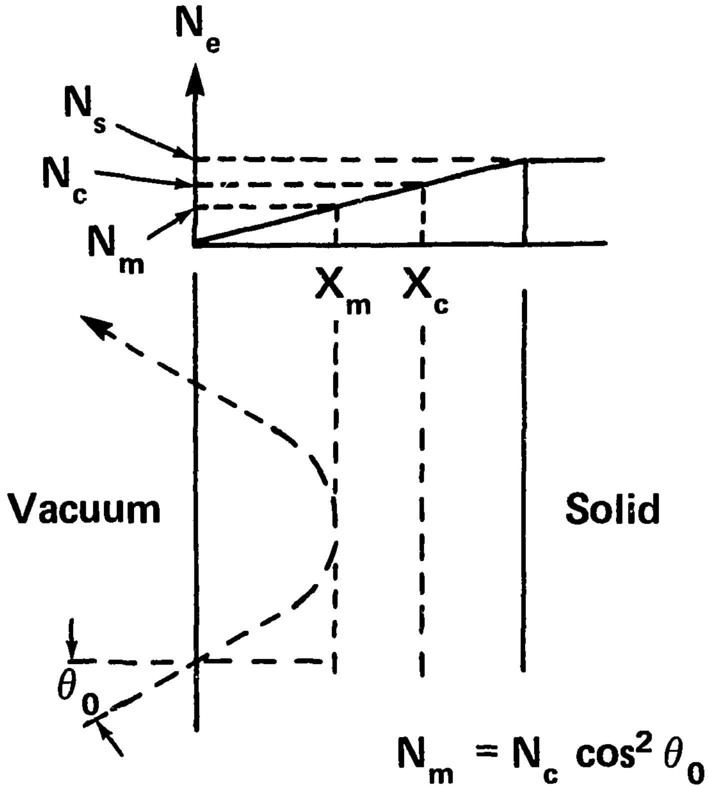

FIGURE 1

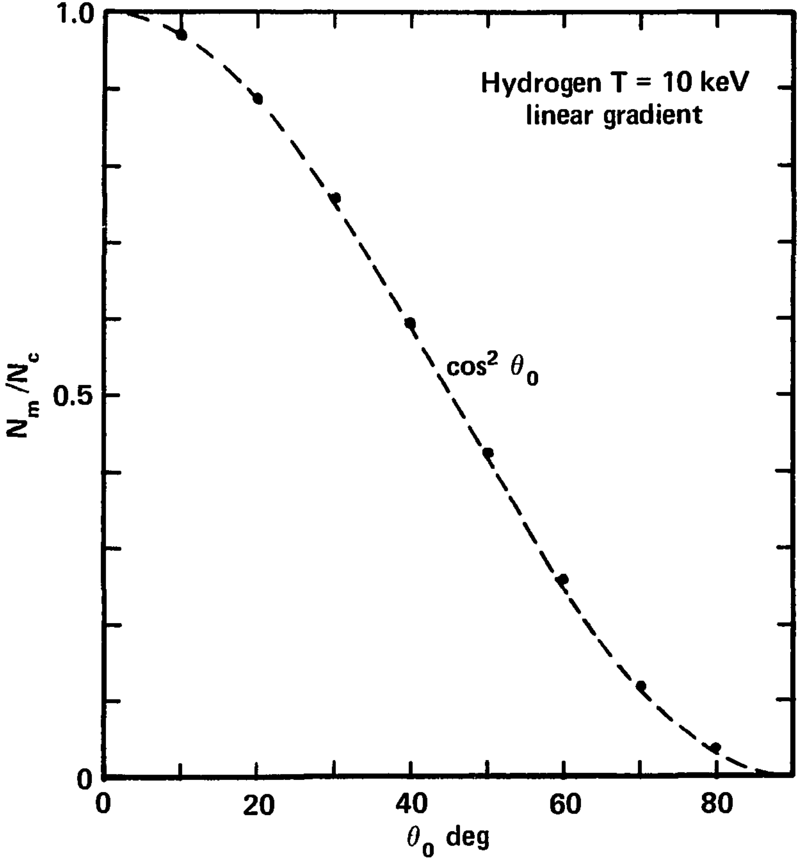
1.0
0.5
0
0
20
40
60
80
θ_0 deg
N_m/N_c
Hydrogen T = 10 keV
linear gradient
$\cos^2 \theta_0$

FIGURE 2

FIGURE 3

Physical cases:

(A) Propagation of Gaussian-like intensity profile laser beam in a slightly absorbing medium.

(B) Absorption of pump light in solid laser rods.

(C) Dielectric and optical waveguides; light pipes.

$$N(R) = N_0 \left(1 - \frac{1}{2} AR^2\right)$$

For paraxial rays:

$$\frac{D^2 R}{DZ^2} + AR = 0$$

For positive A:

$$R(Z) = R_0 \cos A^{1/2} Z + R_0' A^{-1/2} \sin A^{1/2} Z$$

For negative A:

$$R(Z) = R_0 \cosh A^{1/2} Z + R_0' A^{-1/2} \sinh A^{1/2} Z$$

FIGURE 4

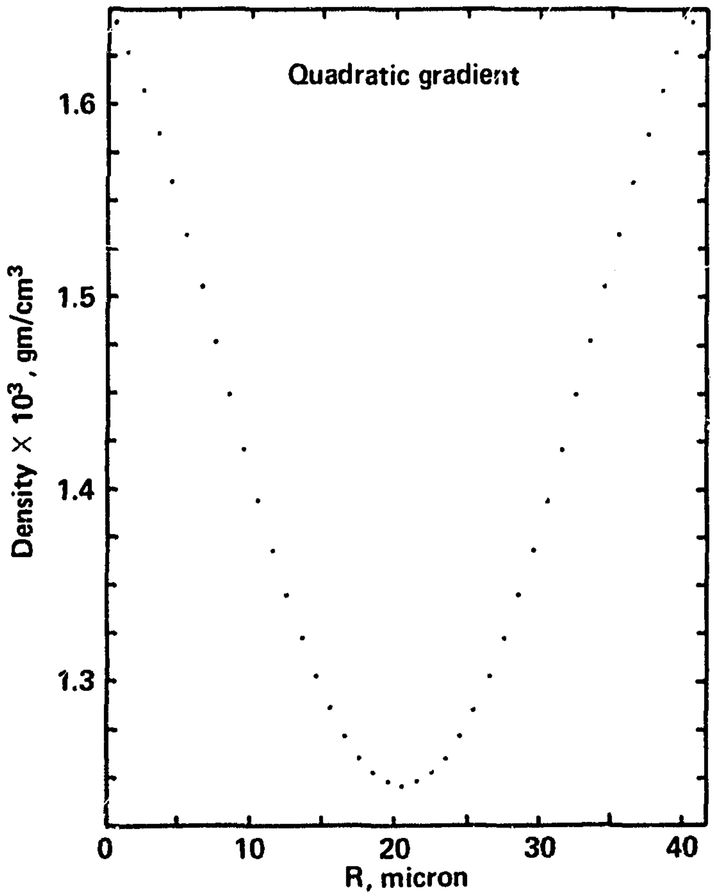
Quadratic gradient
Density × 10³, gm/cm³
1.6
1.5
1.4
1.3
0
10
20
30
40
R, micron

FIGURE 5

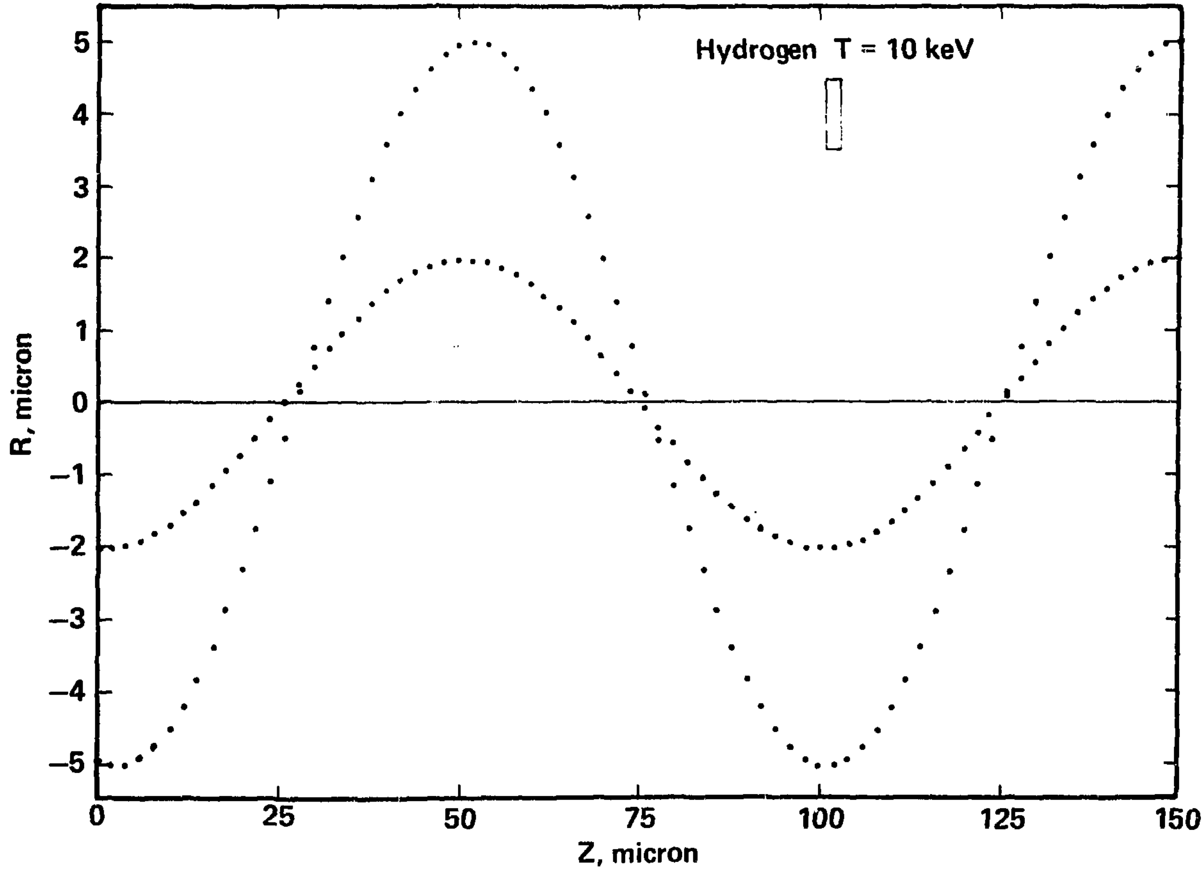
Hydrogen T = 10 keV
R, micron
Z, micron
5
4
3
2
1
0
−1
−2
−3
−4
−5
0
25
50
75
100
125
150

FIGURE 6

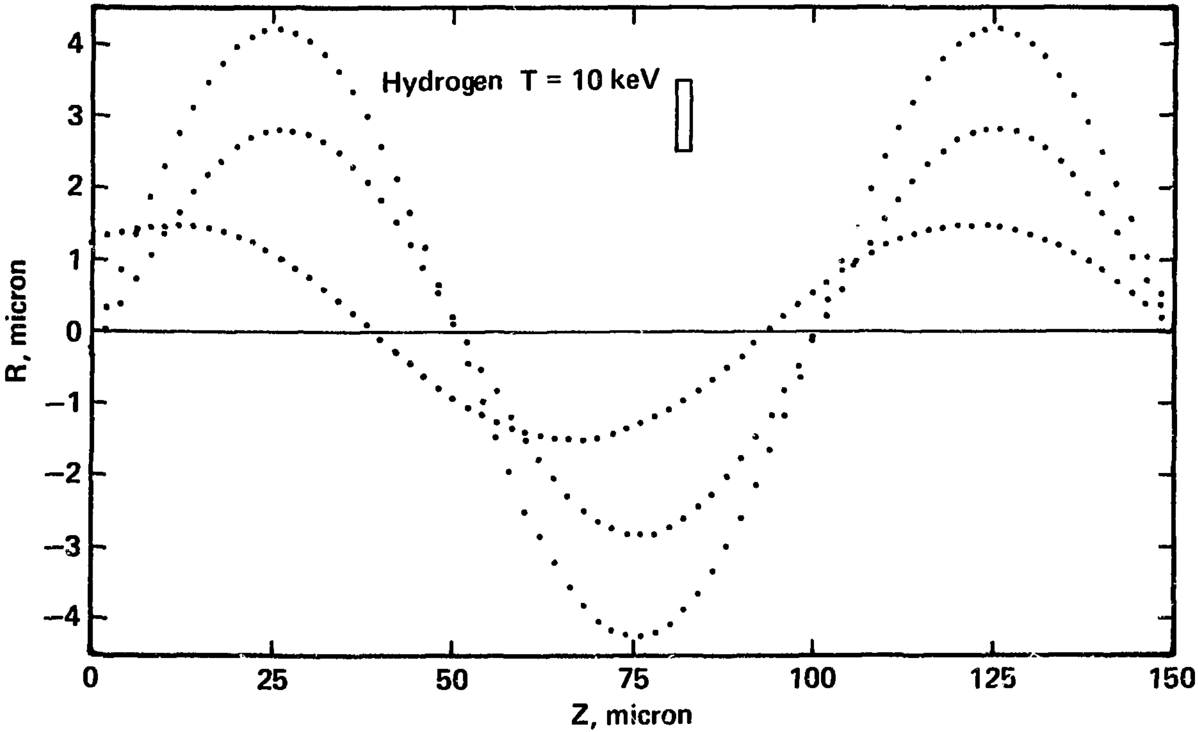
Hydrogen T = 10 keV
R, micron
Z, micron
4
3
2
1
0
−1
−2
−3
−4
0
25
50
75
100
125
150

FIGURE 7

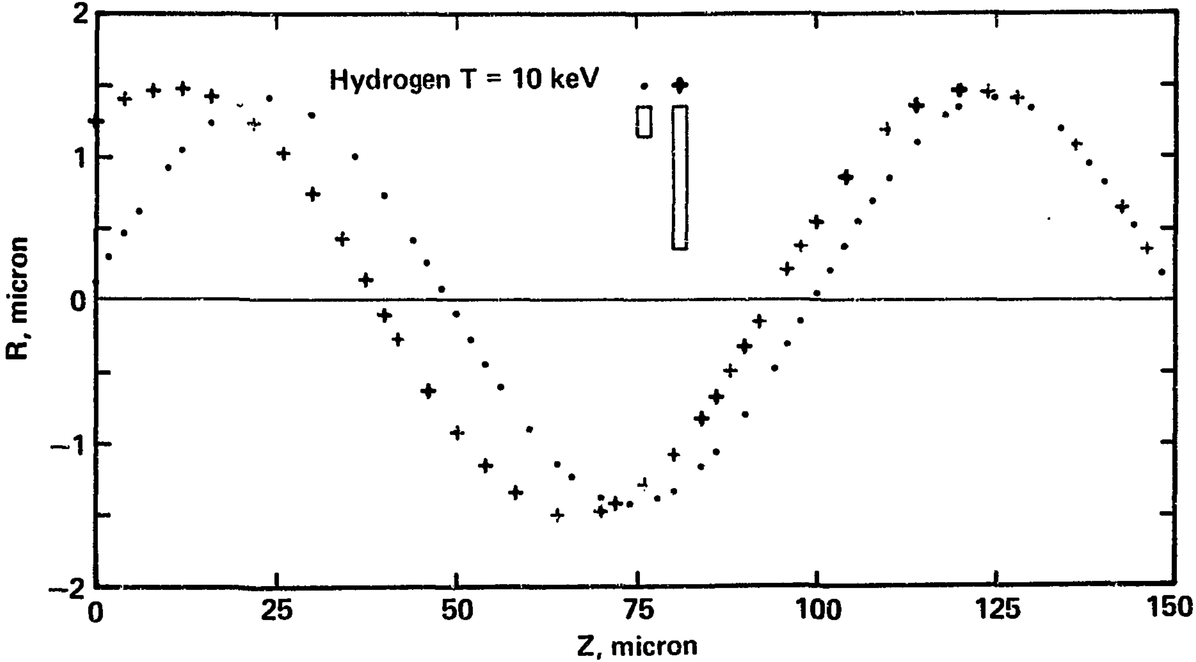

FIGURE 8

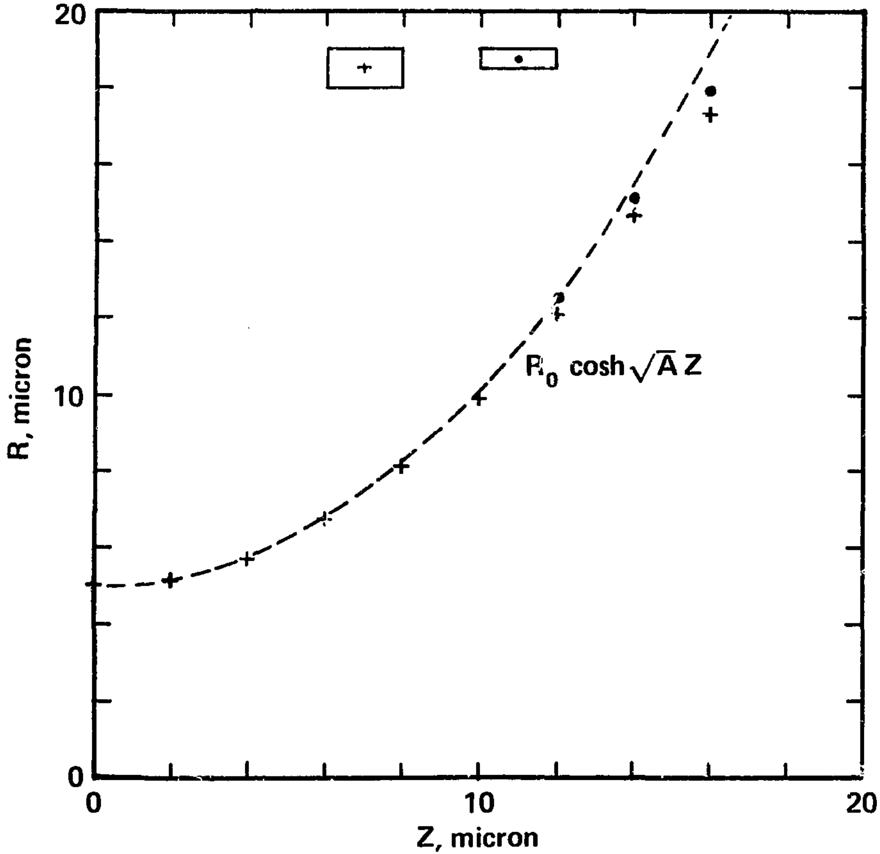

FIGURE 9

TEST OF RAY TRACE IN SPHERICAL PLASMA

$n(r)\, r \sin\theta(r) = \text{constant}$

Expect at turning point $n(r)r = n(r_0)\, r_0 \sin\theta(r_0)$

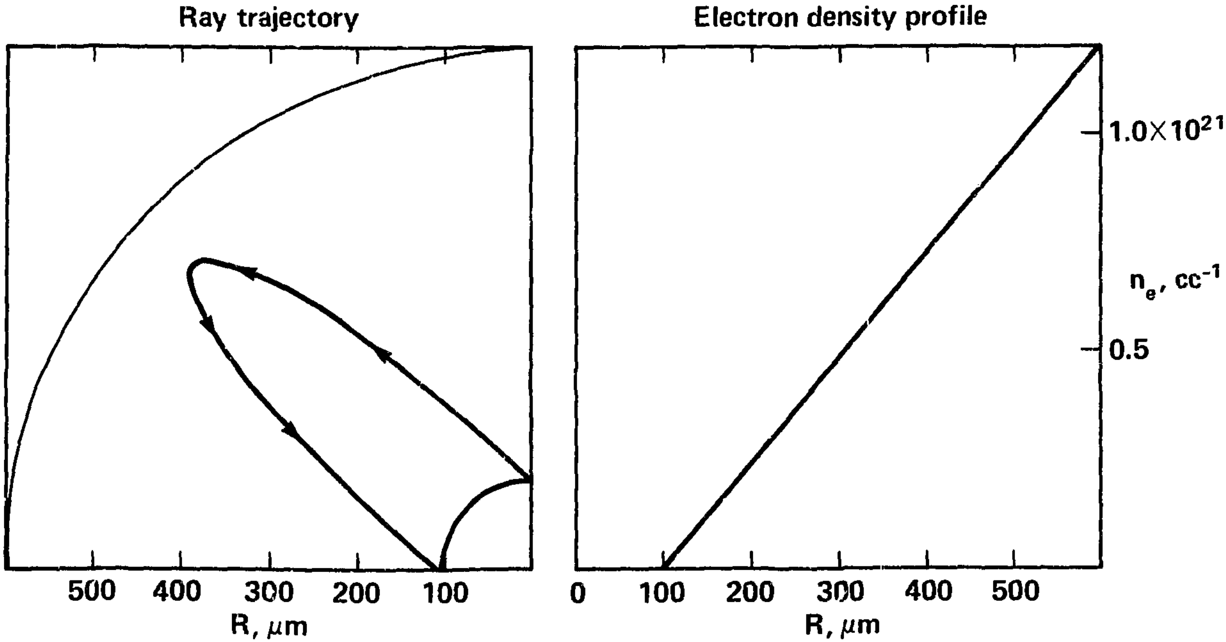

FIGURE 10