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Further Investigations Using the NEUTRAL Code

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13. ABSTRACT (*Maximum 200 words*)

Some applications of the NEUTRAL code, as discussed in a previous NRL Memorandum report, are considered. NEUTRAL was run with an energy dependent cross section and the results were compared to the analytical expressions of Prono et al. Good agreement exists between these two approaches. A parameter study was done to see how the neutral energy varied with the background gas width. It was determined if one knew the cross sections exactly, then from measurements of the average neutral energy, one could infer an average gas width. NEUTRAL was also modified to model a linearly time rising electric]field, which is a closer representation to the actual operation of a reflex switch. It was found that the average neutral energy seems to increase linearly in time as well. A comparison is also made to a simple quasistatic model and only limited agreement is shown to occur. Discussion on the need to include a time rising current density is presented and it is mentioned that future work is being focused on this program.

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FURTHER INVESTIGATIONS USING THE NEUTRAL CODE

Introduction

NEUTRAL is a one dimensional code that was written to simulate ions, accelerated by an electric field, charge-exchanging in a background medium. This charge-exchange mechanism has been proposed by Prono et al.[1] to explain the premature shorting of the anode-cathode gap in ion diodes, and is also thought to occur in the reflex switch[2-4]. Further details can be found in reference (5), which we will denote here as memo1. This report will essentially be a continuation of memo1, but we will consider problems that are closer to the actual physical situation being modeled. We will also discuss and present a parameter study that was done with the NEUTRAL code. Parameter studies are very important in the charge-exchange problem, as it relates to the reflex switch, since no measurements of relevant physical quantities, such as density or electric fields, exist at the present time.

Comparison of Results

To complete the final testing phase of the NEUTRAL code, see memo1 for more details, we used the energy dependent cross section $\sigma(w)$ assumed by Prono et al.[1]. The form of this cross section was

$$\sigma(w) = \frac{\sigma_0}{\left[1 + \left(\frac{w}{w_0}\right)^2\right]} \tag{1}$$

with $\sigma_0 = 2.0 \times 10^{-15}$ cm^2 and w_0 = 10 Kev. Keeping the rest of the input variables the same as in the standard case, see again memo1 for specific values, and using the cross section given in equation (1), NEUTRAL produced figures 1 - 3. As in memo1, the dashed curves in figures 2 and 3 are the analytical results for direct comparison. However, unlike memo1, these theoretical solutions are those found by Prono et al.[1] and are given here for convenience

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$$g(W,X) = \alpha \frac{mF}{w_o C} H(X - \alpha W) e^{-B\alpha W} \left[1 - \frac{e^{-CB(X - \alpha W)}}{B} \right] \tag{2}$$

$$G_w(X) = \frac{w_o F}{\alpha B} \left[\frac{1}{CB} + e^{-BX} - \frac{e^{-CBX}}{C} \right] \tag{3}$$

$$G(X) = \frac{F}{CB} \left(1 - e^{-CBX} \right) \tag{4}$$

where

$$X = x/\lambda$$

$$W = w/w_o$$

$$\alpha = w_o/(qE\lambda)$$

$$C = e^{-\alpha\pi/2}$$

$$B = (1 - C)^{-1}$$

Note that these above equations are the corrected versions of the Prono et. al. solutions, given by Creedon[6]. As in memo1, g is the neutral distribution function and G_w is the neutral energy flux which we will not use here. And using the notation of Prono et al.[1], G is the net neutral flux. From figure 1 we determined that the ion flux $F = 4.3 \times 10^{15}$ cm^{-2} sec^{-1}. Figure 2 shows the neutral flux profile as a function of x. The dashed curve is just the plot of equation (4) with the ion flux F mentioned previously, and the solid curve represents the simulation results. In figure 3 we have the neutral distribution at the vacuum plasma interface (see memo1). Once again the dashed curve represents the analytical result, and this is given by equation (2) with $x = x_{max}$. We see from these figures that we have very good agreement between theory and simulation. This also shows that the assumptions made by Prono et. al.[1] in their derivations, were quite reasonable.

At this point one may be wondering about the magnitude of the ion flux F, and wether or not this has any physical basis. All we can say is that this flux was arbitrarily chosen since there has been no measurements, at least to our knowledge, of the neutral flux. For the test cases run so far it is not necessary that the values used as input reflect exactly the real charge-exchange problem, since we are just looking for consistency in our output. However, the use of reasonable estimates of physical quantities is certainly desirable. The same holds true for densities and electric fields, they should not be taken too seriously since we are just scoping the code
out.

A Parameter Study

Next we used another version of the NEUTRAL code that incorporates a spatially varing background neutral gas given by

$$n(x) = \frac{n_o}{\left[1 + \left(\frac{x}{x_o}\right)^2\right]} \tag{5}$$

For our purpose $n_o = 1.0 \times 10^{16}$ cm^{-3}, which is just the value used in the standard run case, see memo1 for more details. The quantity x_o is a measure of the width of the density profile and will be varied in our parameter study. This alternate version of the NEUTRAL code also contains a charge-exchange cross section that is derived from experimental data[7]. The form of this cross section is similar to that given by equation (1). A simple parameter study was done in which we varied x_o and observed the average neutral energy at the point $x = x_{max} = 0.1$ cm, which is just the width of the charge-exchange region in the reference standard case (see memo1). The result of this study is shown in figure 4. Computer runs were done for x_o = 0.005 cm, 0.05 cm, 0.01 cm, 0.1 cm, 0.5 cm, and 1.00 cm. As one can see the neutral energy increases quickly until x_o = 0.05 cm, after which the energy only rises slowly. We expect this type of behavior because when $x_0 >> w_0/qE$, where q is the ion charge, E is the magnitude of the electric field, and w_0 is the "cut off energy" of the charge-exchange cross section (see equation (1)), spatial effects are unimportant. It is only when $x_0 \sim w_0/qE$ or less that spatial effects become appreciable. For w_0 = 10 Kev, q = 4.8 x 10^{-10} esu and E = 1 MV/cm, we find that $x_0 \sim 0.01$ cm. Thus one can see from this example that if one knew the charge-exchange cross section with reasonable accuracy, and the electric field inside the charge-exchange region, then by measuring the average neutral energy one could estimate the thickness of the background neutral gas or anode plasma (see memo1).

Time Rising Electric Field

The NEUTRAL code has also been modified to simulate a linearly rising electric field in time, in the charge-exchange region. The time dependent electric field E(t) is assumed to have the form

$$E(t) = \left(\frac{dE}{dt}\right)t \qquad (6)$$

and t is the time in seconds. The quantity dE/dt is a constant and is just the slope of the time varying electric field. This modification to the NEUTRAL code is important since the electric field inside the anode plasma of the reflex switch is not static, as assumed in memo1. Thus we can estimate the average energy of a neutral as it enters the vacuum gap (see memo1 again for more details) as a function of time. At this point we would like to mention that a time rising electric field is only one part of the entire physical picture and this will be discussed later on in this report. The NEUTRAL code was run with the electric field, given by equation (6), with

$$\left(\frac{dE}{dt} \right) = 7.335681 \times 10^{11} \ \frac{\text{statvolt}}{\text{cm sec}} \tag{7}$$

and one half this value, namely

$$\left(\frac{dE}{dt} \right) = 3.667841 \times 10^{11} \ \frac{\text{statvolt}}{\text{cm sec}} \tag{8}$$

The first value of dE/dt was chosen such that at the end of the simulation the electric field had the final value of 3333.3333 statvolt/cm, which is just the electric field used in the reference run of memo1. Also the background neutral gas and the charge-exchange cross section were assumed to be constants in these simulations, with the same values as used in the formerly mentioned reference run. This makes comparison with a simple analytical model possible. We note that this time varying field version of NEUTRAL also uses an improved particle pusher algorithm. Figure 5 is the simulation using the value of dE/dt given by equation (7). The code results are given by the circles and the dashed straight line is an approximate best line fit, extrapolated to zero energy, at time t = 0., to this data. The solid line, with the dagger point markings, is the plot of the equation

$$\langle E_n \rangle (t) = (qE(t)\lambda) \left[\left(\frac{\lambda}{x_{max}} \right) \left(e^{-(x_{max}/\lambda)} - 1 \right) + 1 \right] \tag{9}$$

where $\langle E_n \rangle (t)$ is the average neutral energy as a function of time at the vacuum gas interface, or $x = x_{max}$. E(t) is of course the time dependent electric field given by equation (6). Note that equation (9) is just equation (15) of memo1, but with the static electric field replaced by E(t). This substitution, though somewhat questionable, should be valid if the electric field rises so slowly over time that the system goes through a succession of equilibrium states, i.e., the problem is quasistatic. As one can see from figures 5 and 6, this does not seem to be a too bad of an assumption. Figure 6 is the same situation except that dE/dt is now given by equation (8). This case was run to see if a smaller dE/dt would cause the simulation results to approach the expression given by equation (9). As one can see the code predicts nearly the same energy at t = 2.27 ns as equation (9), but for later times the accuracy is about the same as in figure 5, roughly ±3 Kev. To determine if the difference in slopes as seen in figures 5 and 6 is caused by code inaccuracies, we plotted the average neutral energy as a function of electric field, as given in figure 7. The code generated results are given by the circles, and as in figures 5 and 6, the dashed line is an eyeballed best line fit, extrapolated to zero. The solid curve is the analytical result, at $x = x_{max}$, given by equation (15) in memo1, see also equation (9). We also would like to point out, before we continue, that the neutral energies from the simulation were found by running the static electric field case for different field strengths, as was done in memo1. Referring again to figure 7 we see that, for a fixed time step, the energies differ by about 4 Kev at $E = 3.333 \times 10^3$ statvolt/cm, which is 1 MV/cm. These differences in energy may be due to the time step used, which is certainly the case when $E = 6.666 \times 10^3$ statvolt/cm, or the problem may be due to the particle pusher in the NEUTRAL code. Anyway we can be reasonably confident that the difference in slopes that are found in both figures 5 and 6 can be attributed to the code numerics and not some physical process.

Time Rising Current Density

As was mentioned earlier, the inclusion of a time varying electric field, though very informative, is only half of the full time dependent problem. Usually an electric field in a plasma is accompanied by a current, this can be seen from the simple Ohm's Law, given by (in c.g.s. units)

$$\vec{J} = \sigma\vec{E} \qquad (10)$$

where J is the current density, E is the applied electric field, σ is the (scaler) conductivity, and the arrows denote vector quantities. We see from this simple argument that a linearly rising electric field in time would result in a proportionally rising current. A similar reverse argument, again using (10) would imply a time varying current density is related to a time evolving electric field, given by $\vec{E} = \eta\vec{J}$, where η is called the resistivity and $\eta = 1/\sigma$. From the various measurements that have been done on the reflex switch one certainly observes a time rising current, see references 1 - 4. Now assuming for the moment a uniform current density J, the current I is related to J by J = I/A, where A is some cross sectional area. So we conclude that the full time dependent problem must include a time varying current density in order to be more realistic. From a computational viewpoint, if we input a known linearly rising current density and electric field, this automatically determines the resistivity or conductivity by equation (10). This could be very helpful in trying to theoretically determine the value of K in the empirical formula for anomalous gap closure in the reflex switch, as given by Creedon et al.[3,6] This formula has the form

$$\dot{J}^{\frac{1}{2}}\, t_s^{\frac{3}{2}} = K\, D_{AK} \tag{11}$$

with

$$\dot{J} = \frac{dJ}{dt} = \text{a constant}$$

where $\dot{J}$ is the time rate of change of the current density and t_s is the primary gap shorting time, with D_{AK} being the primary gap spacing. See memo1 for a diagram of the reflex switch. At this point in time preliminary work has been done to model the effect of a time rising current density and will be the subject of future reports.

Summary and Conclusions

We have used the NEUTRAL code to simulate the charge-exchange neutral problem as discussed in Prono et. al.[1]. There was good agreement between the two results. A parameter study was also run in which we varied the width of the background gas region and found the corresponding average neutral energy. We concluded that such parameter study would be beneficial in determining the width of the anode plasma region. We have also modified the NEUTRAL code to handle a linearly time rising electric field. We compared these results to an analytic expression which was derived by replacing the static electric field with the time varying one. A comparison of the code and the analytical expression showed limited agreement. It does seem however that, from the code results, a linearly rising electric field causes a similar increase in the average neutral energy. It was also noticed that by varying the electric field in the static case, NEUTRAL predicted lower than predicted average neutral energies. This may be caused by not choosing the correct time step or may even be the fault of the particle pusher, this should be investigated further.

Future Work

We are beginning to work on the problem of a time rising current density, since such a problem is a more accurate representation of the operation of a reflex switch. Such a simulation will provide useful input to future models describing the shorting of the vacuum gap.

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REFERENCES

1. D.S. Prono, H. Ishizuka, E.P. Lee, B.W. Stallard, and W.C. Turner, J. Appl. Phys. **52**, 3004 (1981).

2. J.M. Cree on, L.J. Demeter, B. Ecker, C. Eichenberger, S. Glidden, H. Helava, and G.A. Proulx, J. Appl. Phys. 57, 1582 (1985).

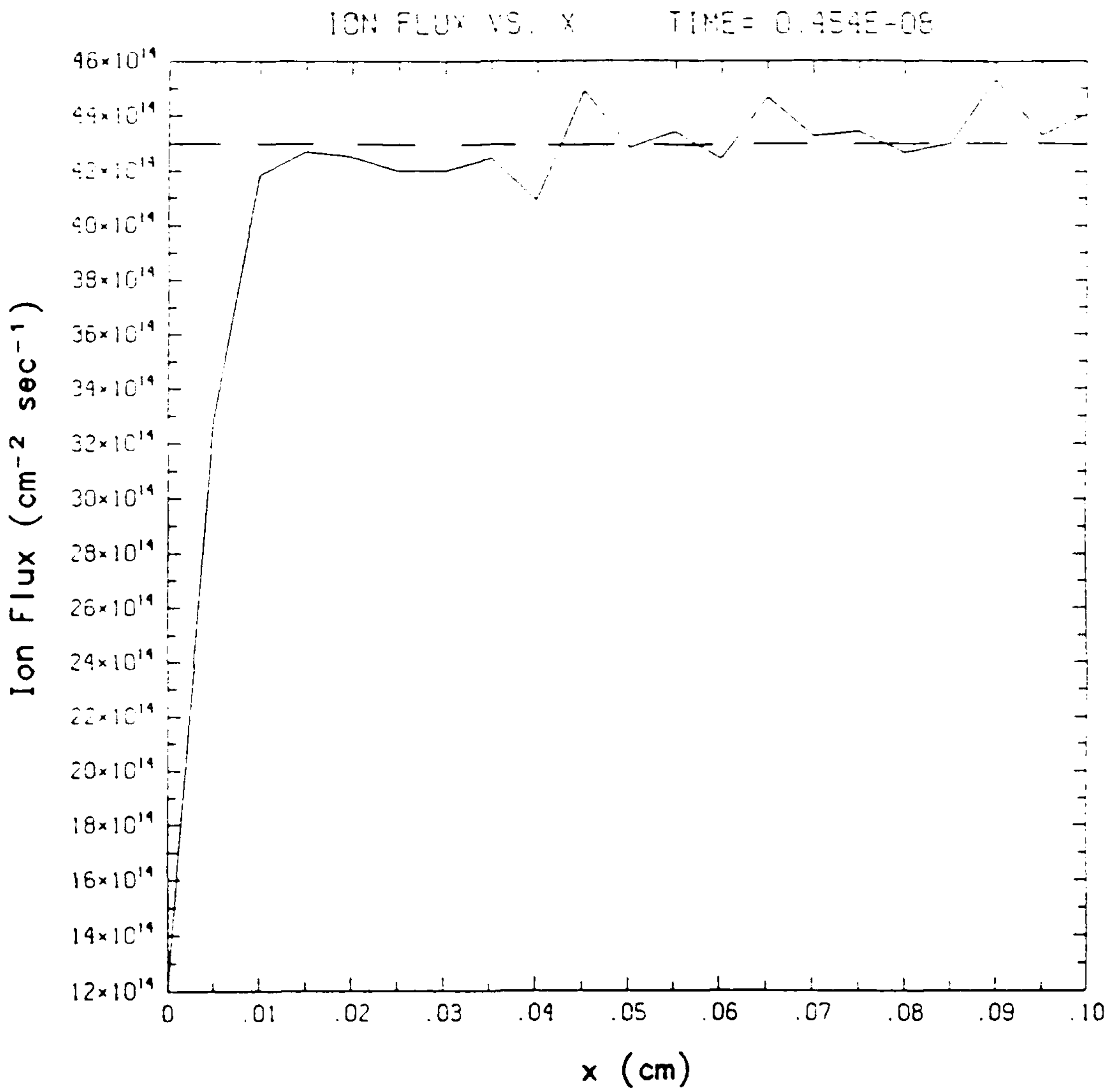
3. J.S. Levine, J.M. Creedon, M. Krishnan, K.D. Pearce, and P.S. Sincerny, 7th International Conference on High Power Particle Beams, Karlsruhe, July 4-8 (1988).

4. L.J. emeter, in **Opening Switches**, ed. by, A. Guenther, M. Kristiansen, and T. Martin, (Plenum Press, N.Y., 1987).

5. N.R.L. Memorandum Report (to be published).

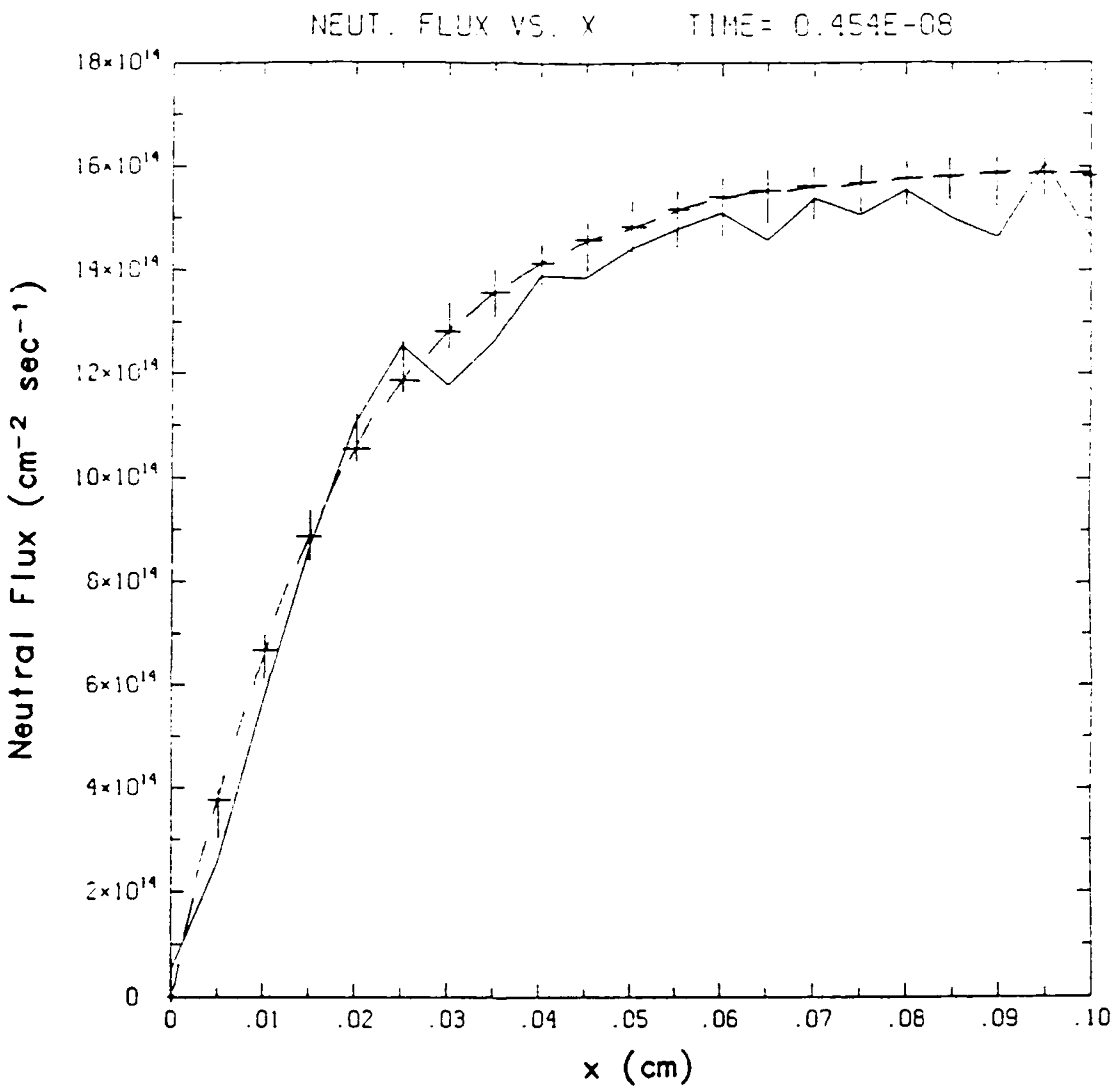
6. J.M. Creedon, Private Communication.

7. R.A. Mapleton, **Theory of Charge Exchange**, (Wiley, N.Y., 1972), pgs. 210, 214.



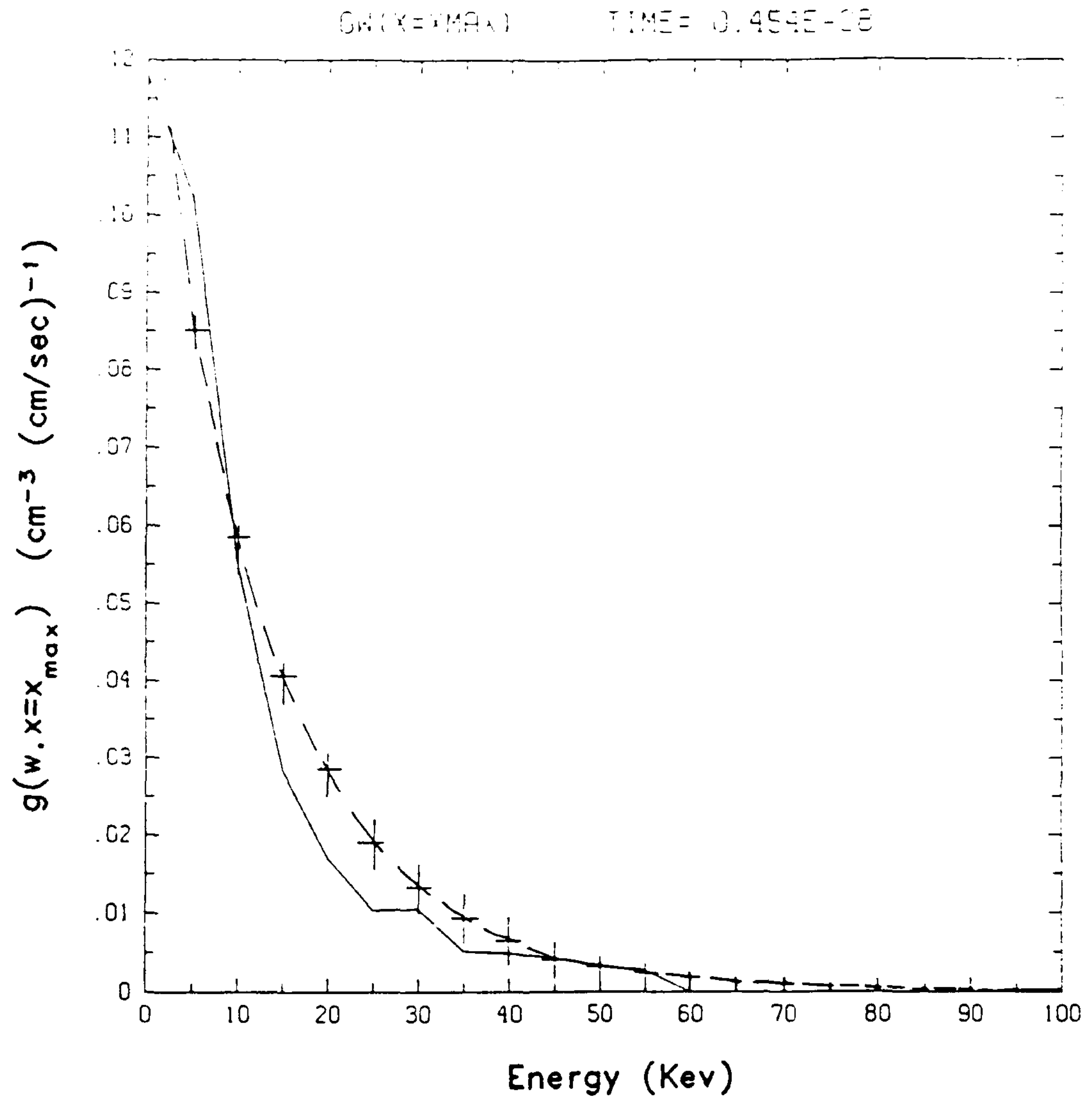
Ion Flux as a Function of x

Figure 1



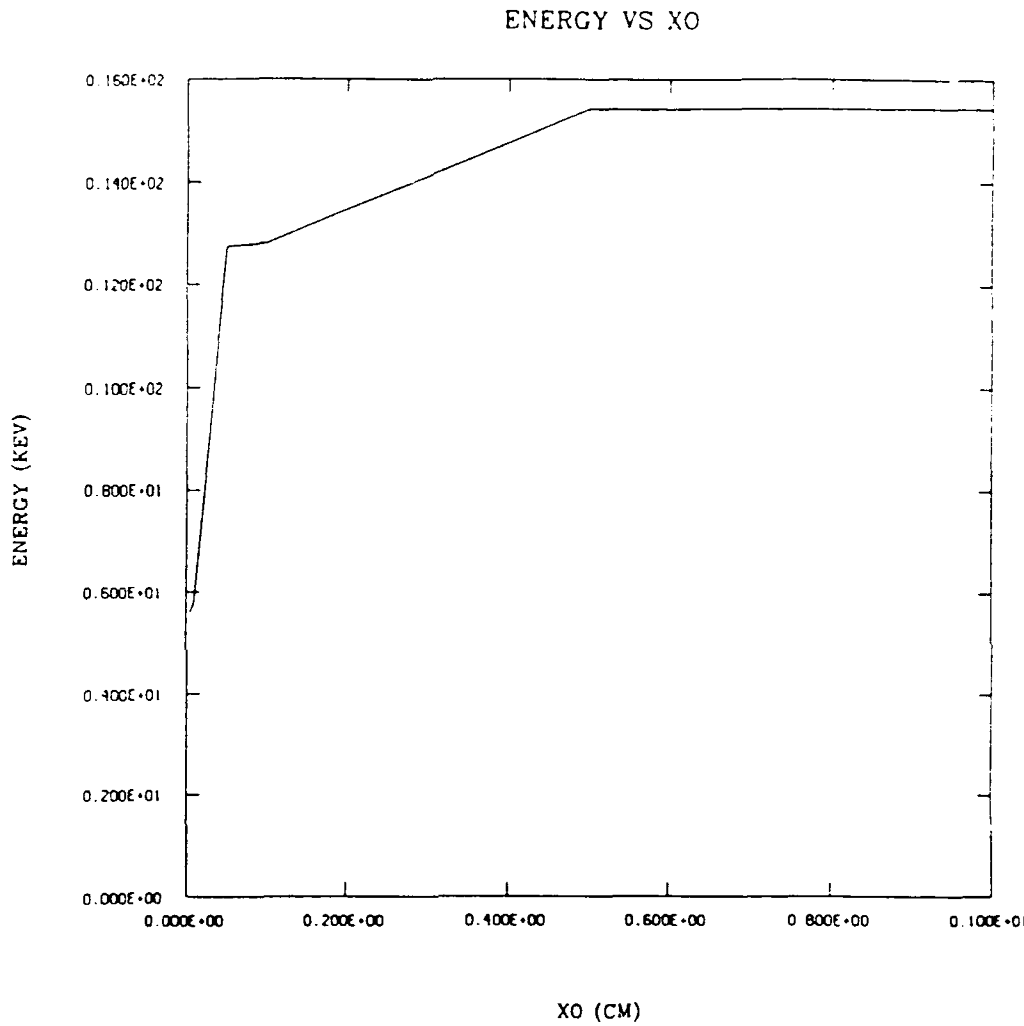
Neutral Flux as a Function of x

Figure 2



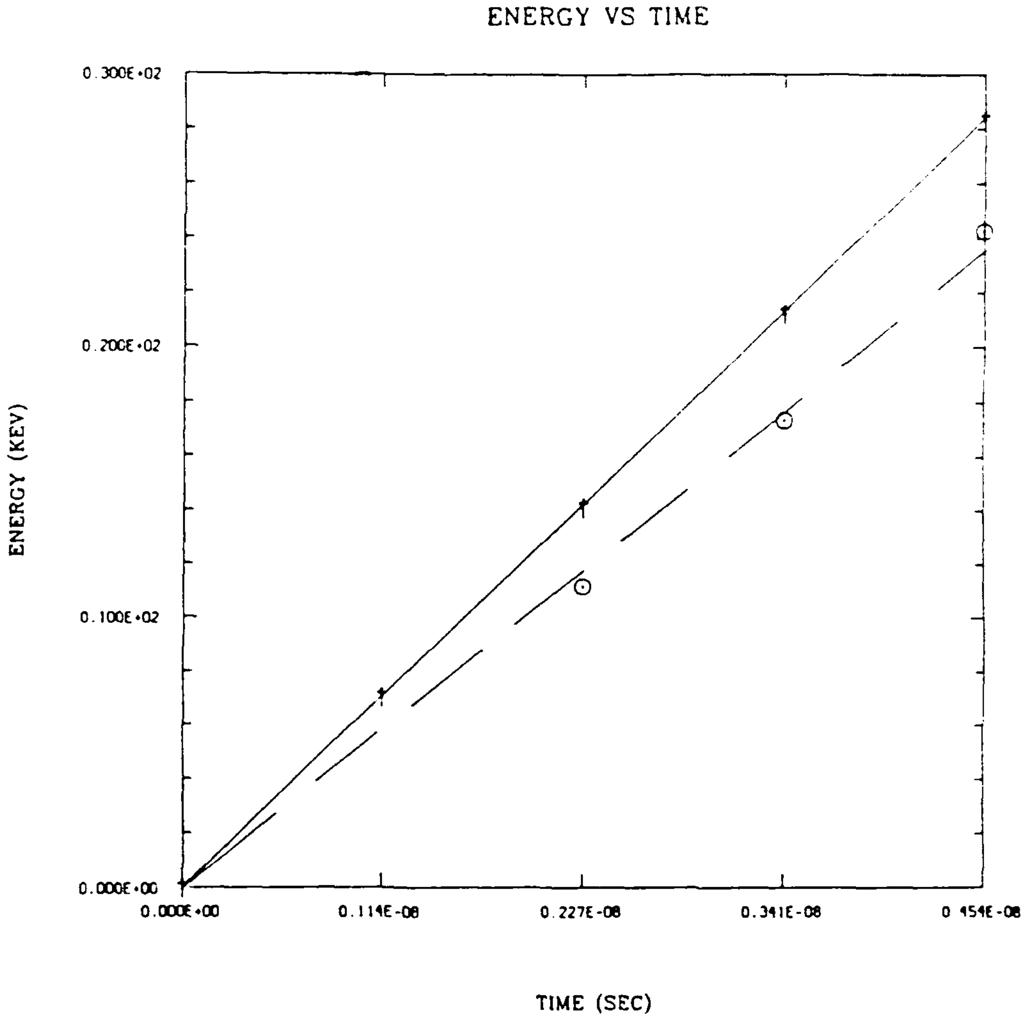
Neutral Distribution at the Vacuum Interface as a Function of Energy

Figure 3



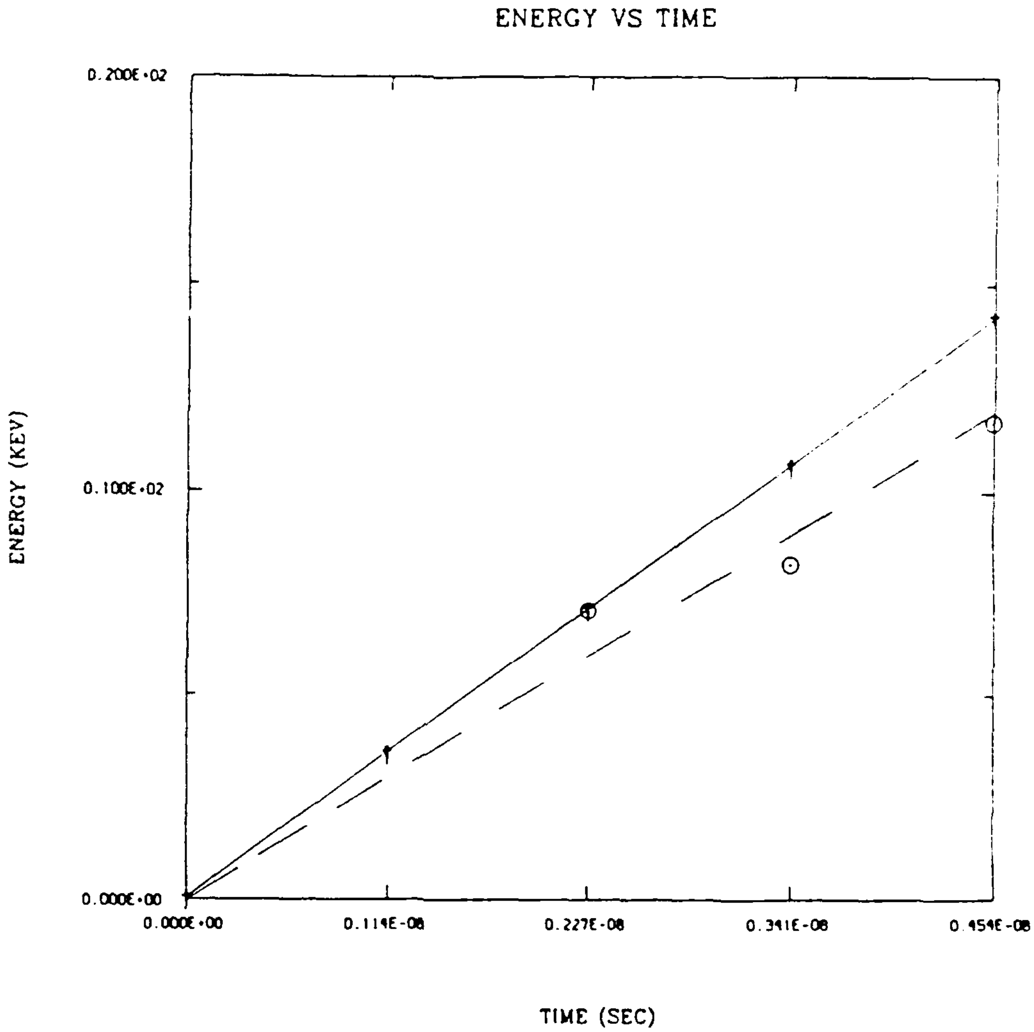
Energy as a Function of the Density Profile Width

Figure 4



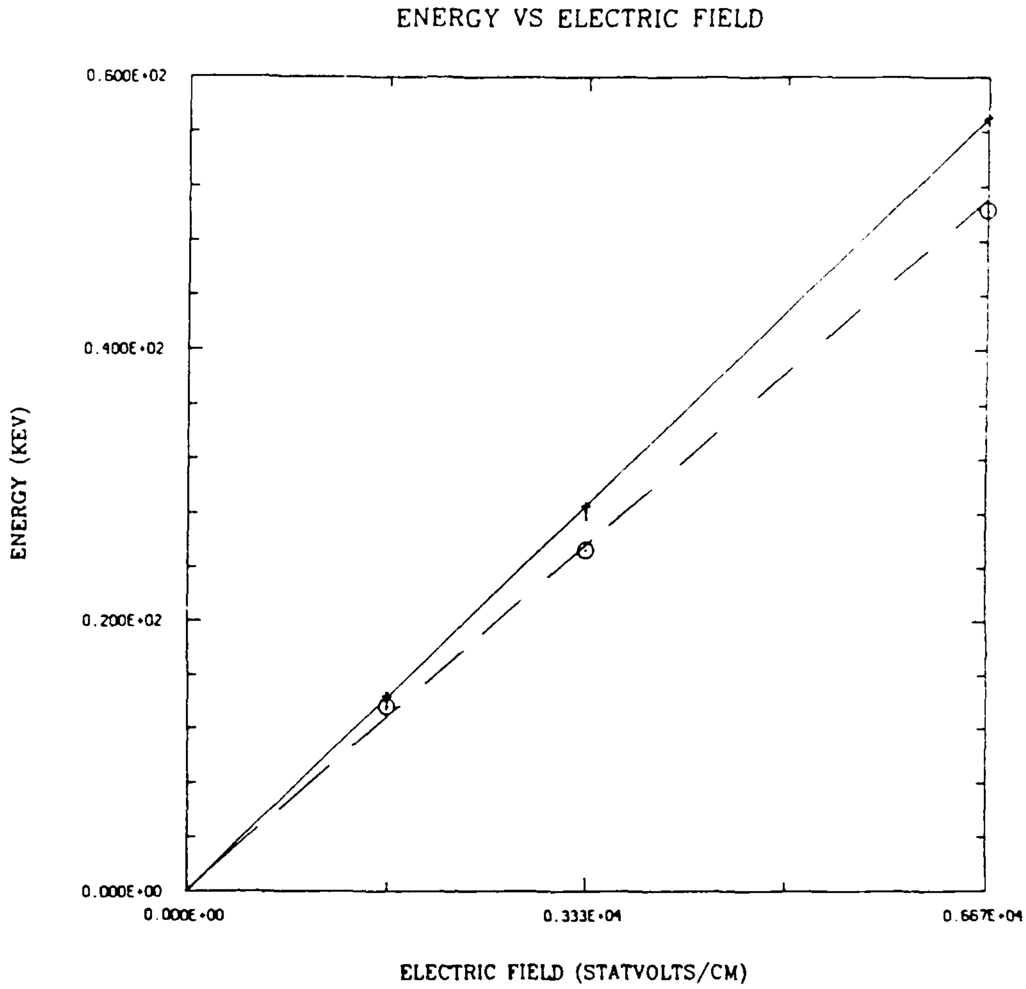
Neutral Energy at the Vacuum Interface as a Function of Time

Figure 5



Neutral Energy at the Vacuum Interface as a Function of Time

Figure 6



Neutral Energy at the Vaccuum Interface as a Function of the Static Electric Field

Figure 7

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