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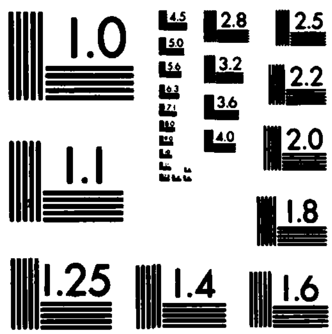

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18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The main effort ~~during the period of this grant has been~~ was to understand the physics of a very energetic ion beam propagating through a magnetized plasma roughly perpendicular to the magnetic field. It has been appreciated for several years that the central problem ~~concerning this problem~~ is the charge neutralization of this beam. For conditions where ion beam number density is comparable or larger than plasma number density, the motion of the electrons is quite complicated being controlled by the self fields produced by their motion. Thus, to solve this problem it was necessary to construct a rather complex computer code.

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20. During the first year of work the general nature of the electron motion was elucidated and a 2-D model of the problem was constructed that was sufficiently realistic to answer the charge neutralization question in general. Assuming sufficient charge neutralization was attained it was show that the beam could be held together against the radial expansional forces in the beam, the electrostatic repulsion force reduced by charge neutralization and beam divergence produced by the accelerator producing the beam. A rough indication of the necessary amount of charge neutralization, defined as the ratio of the difference of electron and ion number densities in the beam to the ion beam density, was obtained and shown to be v/c if the beam divergence is small enough. Also it was shown that the beam would move along a circular orbit with radius equal to the cyclotron radius of an individual beam ion. The end of the first year and the bulk of the second year was devoted to the construction of the computer code and its use to show that the required amount of charge neutralization could be attained. It was shown that the required axial variation to attain desired charge neutralization were easy to achieve in practice. Thus, it appears entirely possible to propagate an energetic ion beam a long distance through a plasma and to hold it together radially against expansional forces. Work planned for the renewal year of the grant will examine beam plasma instabilities the most important of which is expected to be the Helmholtz, or velocity shear, instability.

AFOSR-TR- 83-0816

FINAL TECHNICAL REPORT

ENERGETIC ION BEAM-PLASMA INTERACTIONS

by

Russell M. Kulsrud

Sponsored by: Air Force Office of Scientific Research

Grant # AFOSR-81-0106

Princeton University

Plasma Physics Laboratory

June 30, 1983

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SUMMARY

This final report covers the work carried out under the Air Force Office of Scientific Research Grant # AFOSR-81-0106 made to Princeton University during the period March 1, 1981 to February 28, 1983. This period was extended to March 31, 1983 by a 30 day no-cost extension. The research discussed in this final report is being continued under a new grant which commenced June 15, 1983.

In accordance with the grant work was authorized to

(a) settle the question of charge neutralization

(b) design an experiment to test charge neutralization

(c) investigate Helmholtz and velocity space instabilities

(d) determine diagnostics to aid in directing the beam

(e) consider beams of higher densities

In this report the results obtained in these areas is summarized in Section I. The papers presented and in preparation are listed in Section II and the research personnel engaged are listed in Section III.

I. ACTIVITIES AND ACCOMPLISHMENTS

The main effort of our group during the period of this grant has been to understand the physics of a very energetic ion beam propagating through a magnetized plasma roughly perpendicular to the magnetic field. It has been appreciated for several years that the central problem concerning this problem is the charge neutralization of this beam. This is because under certain assumptions about the current in the ion beam, the magnetic field of the plasma is largely undisturbed and prevents the flow of electrons across itself. Thus, no electrons can be carried with the beam and any charge neutralization must occur by the *in situ* electrons of the plasma flowing along the magnetic field. For conditions we considered, namely ion beam number density comparable or larger than plasma number density, the motion of the electrons is quite complicated being controlled by the self fields produced by their motion. Thus, to solve this problem it was necessary to construct a rather complex computer code.

During the first year of work the general nature of the electron motion was elucidated and a 2-D model of the problem was constructed that we felt was sufficiently realistic to answer the charge neutralization question in general. Assuming sufficient charge neutralization was attained it was shown that the beam could be held together against the radial expansional forces in the beam, the electrostatic repulsion force reduced by charge neutralization and beam divergence produced by the accelerator producing the beam. The inward force holding the beam together was the magnetic pinch force due to the electrical current of the beam. A rough indication of the necessary amount of charge neutralization, defined as the ratio of the difference of electron and ion number densities in the beam to the ion beam density, was obtained and shown to be v/c if the beam divergence is small enough. Also it was shown that the beam would move along a circular orbit with radius equal to the cyclotron radius of an individual beam ion. This work was reported in paper (1).

The end of the first year and the bulk of the second year was devoted to the construction of the computer code and its use to show that the required amount of charge neutralization could be attained. The trick necessary to attain this consisted of properly varying the ion beam density axially along its length in a sufficiently smooth fashion that the electrons are drawn into the beam adiabatically. The results of the code were presented as a determination of the mean amount of charge neutralization attained as a function of the rate of axial variation of the beam density. Results were presented in paper 2 and it was shown that the required axial variation to attain desired charge neutralization were easy to achieve in practice.

Thus, it appears entirely possible to propagate an energetic ion beam a long distance through a plasma and to hold it together radially against expansional forces.

The end of the second year was devoted to writing these results up (paper 3) and to considering various instabilities to which the beam plasma might be subject. The most obvious beam plasma instabilities do not appear to occur. The most important instability is probably the Helmholtz, or velocity shear, instability. However, because the motion of the electrons is highly nonlinear it is not possible to draw conclusions concerning it from the standard plasmas theories. Our code will again be necessary to draw conclusion about the true electron motion and thus to reach a decision concerning this instability. This is the work planned for the renewal year of our grant which commenced June 15, 1983.

II. PUBLICATIONS AND CONTRIBUTED PAPERS

1. "Propagation of Ion Beams Through a Magnetized Plasma", E. F. Chrien and R. M. Kulsrud (New York APS Meeting Nov. 1981) Bull. Am. Phys. Soc. 26, 871 (1981).

2. "Charge Neutralization of Ion Beams Propagating Through a Magnetized Plasma", E. F. Chrien, E. J. Valeo, R. M. Kulsrud, and C. R. Oberman (New Orleans APS Meeting Nov. 1982) Bull. Am. Phys. Soc. 27, 983 (1982).

3. "Propagation of Ion Beams Through a Tenuous Magnetized Plasma", E. F. Chrien, E. J. Valeo, R. M. Kulsrud, and C. R. Oberman to be submitted to Physics of Fluids.

IV. PERSONNEL SUPPORTED

Name	Period of Support
E. A. Chrien	3/81 - 9/81
L. Chen	9/82 - 4/83
P. K. Kaw	3/81 - 9/81, 3/82 - 8/82
J. A. Krommes	3/81 - 3/82
R. M. Kulsrud	3/81 - 4/83
C. R. Oberman	1/82 - 4/83
F. W. Perkins	3/81 - 3/82
W. M. Tang	3/82 - 4/83
E. J. Valeo	3/81 - 4/83

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