THE UNIVERSITY OF MICHIGAN
College of Engineering
Department of Nuclear Engineering

Progress Report

Microinstabilities in Inhomogeneous Plasma

January 31, 1972 - January 31, 1973

Terry Kammash

ORA Project 173430

Under Contract With
U.S. Atomic Energy Commission
Chicago Operations Office
Contract No. AT(11-1) - 1478
Argonne, Illinois

January 1973

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

peg

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

PROGRESS REPORT

Introduction

Since its inception the title of one project has been "Micro-instabilities in Inhomogeneous Plasma;" and although it continues to represent a major part of our effort it is by no means representative of all our research activity. Because of the wide spectrum of background and interest on the part of the students participating in this project we have diversified our effort to the degree that the title of our project might well be changed to "Theoretical Investigations Relevant to Controlled Fusion Research". The body of it is still in the area of Confinement Physics but some might be described as fusion technology studies. The following is a brief discussion of the problems investigated and results obtained in the period since the last progress report.

1. Two Dimensional Investigation of Absolute Instabilities of Mirror Plasmas

In this investigation a two dimensional criterion for distinguishing absolute instabilities with arbitrary propagation in an infinite magnetized plasma is developed and applied to mirror confined plasma. The results are then compared to available one dimensional calculations where propagation is restricted to the direction parallel to the magnetic field. It is shown that for all the "Loss Cone" modes the one dimensional calculation gives somewhat pessimistic results regarding the dimensions of a stable plasma. By allowing for spatial decay normal to the magnetic field the two dimensional results show that the plasma need not be as "stubby" to be stable against Loss Cone Modes. These results are described in a paper published in Nuclear Fusion 12, 5(1972).

2. Beam Plasma Interaction in Astron

The beam-plasma Interactions in this device are examined utilizing a model which consists of a homogeneous, cold, relativistic electron beam (E-layer) streaming through a Maxwellian plasma normal to a uniform magnetic field. The model shows that the strongest interactions occur at beam harmonics in the vicinity of the plasma normal modes which are near the upper hybrid frequency and above each subsequent multiple of the plasma electron cyclotron frequency. It is also shown that the combined effects of collisions and energy spread may lead to quenching of the unstable modes. The analytical results compared favorably with recent experimental observations; and they will appear in a near future issue of plasma physics - J. Nuclear Energy, C.

3. Energy Loss of Charged Particles in Maxwellian Plasma

Because of its relevance to plasma heating by neutron injection we have re-examined the problem of interaction of energetic heavy charged particles with plasma. Unlike other similar calculations we have incorporated in this analysis the "Quantum" region of binary collision theory which accounts for the small angle scattering that predominates in the slowing down of an ion in plasma. We have shown that in some cases up to 20% difference in the slowing down is obtained by using the appropriate quantum cutoff instead of the classical one commonly used. Moreover our results compare favorably with the more exact calculations of Sigmar and Joyce (Nuclear Fusion, 11, 447 (1971)) in which collective effects are included through the use of the Balescu-Lenard kinetic equations. In fact it is shown that collective effects comprise a minor portion of the energy exchange between heavy charged particles and plasma. The simple

(and easy to calculate) binary collision theory gives results that are within few percent of the more exact calculation. These results will appear in a paper to be published in volume 13, number 1 issue of Nuclear Fusion.

4. The Slowing Down of Relativistic Electrons in Plasma

In contrast to the interaction of heavy charged particles with plasma described above, the interaction of electrons with plasma is dominated by collective effects. The problem of plasma heating, by relativistic electrons must be examined with the tools of nonlinear theory of plasma instabilities. Nevertheless it is very desirable to have a mathematical formula with which one can estimate the slowing down and energy transfer from a relativistic electron to the plasma. This is the substance of this investigation in which a relativistically invariant slowing down formula was derived. In this case the quantum region only is valid and the results reduce to those given in (3) in the proper limits. These results have recently been submitted for publication in Nuclear Fusion.

5. Anomalous Confinement Tokamak Reactor

This calculation which might be classified under technology studies represents an effort in which we attempt to translate recent results in confinement physics to the engineering and design considerations of fusion reactors. The dynamic equations of a low beta Tokamak reactor are solved for a wide range of confinement laws. Time dependent solutions are obtained using 1) neoclassical confinement laws, 2) anomalous confinement based on recent results of Drift Wave turbulence, and 3) anomalous confinement based on trapped particle turbulence as charac-

terized by Bohm-like diffusion. Very interesting results emerged from these solutions! It is shown that neoclassical confinement does not lead to true steady state operation because the confinement time is much longer than the fusion reaction time. Because of lack of a good exhaust mechanism this confinement quickly leads to large beta which is not admissible by low beta confinement theory or for that matter for pressure limited systems. The anomalous confinement based on Drift Wave turbulence results in a stable steady state solutions at reactor parameters that are considered reasonable by today's standards.

6. Alpha Particle Heating of Mirror Plasmas

In our attempt to examine the thermal stability of a mirror fusion reactor the rate of plasma heating due to the alpha particles from the D-T reaction must be calculated in order to incorporate it in the dynamic equations of the system. Since all of the slowing down equations have been derived for Maxwellian plasma (as in 3 above) they cannot be directly applied to mirror confined plasma where the distribution is a "loss cone" distribution. As a result we have numerically simulated a loss cone ion distribution by the sum of five Maxwellian distributions with appropriate temperatures. It is shown that the alpha-ion energy exchange may be represented quite well by calculations using an "equivalent" Maxwellian which has the same average energy as the mirror distribution. These results will appear in the proceedings of the Texas Conference on the technological aspects of fusion reactors.

Conference Papers and Publications

1. D. L. Galbraith and T. Kammash, "Thermal Efficiency of Mirror Reactors with Direct Conversion", Nuclear Fusion 11, 575 (1971).
2. E. Linnebur and T. Kammash, "An Improved Hierarchy for Turbulent Magnetized Plasma" Part 1 Theory, J. Plasma Physics 1, 337 (1972).
3. E. Linnebur and T. Kammash, "Part 2, Application to resonant three-wave interactions", J. Plasma Physics 1, 363 (1972).
4. R. Jong and T. Kammash, "Two-dimensional Investigation of Absolute Instabilities in Mirror Plasmas" Nuclear Fusion 12, 5(1972).
5. C. Striffler and T. Kammash "Beam Driven Plasma Instabilities in Astron-Like Devices", 5th European Conference on Plasma Physics and Controlled Fusion, Grenoble, France, August 1972.
6. C. Striffler and T. Kammash "Collisional and Beam Energy Spread Effects on the Beam-Plasma Instability in Astron, Bull. Am. Phys. Soc. II, 17, 1050 (1972).
7. D. A. Spong, J. Clark and J. Rome, "Relativistic Electron Production in the Ormak Device", Bull. Am. Phys. Soc. II, 17, 1055(1972).
8. W. Horton and T. Kammash, "Model Tokamak Reactor Limited by Anomalous Diffusion and Synchrotron Radiation" Texas Conference on the Technological Aspects of Fusion Reactors, Austin, Texas, Nov. 1972.
9. D. L. Galbraith and T. Kammash, "Alpha Particle Heating of Mirror Plasma", Texas Conference on the Technological Aspects of Fusion Reactors, Austin, Nov. 1972.