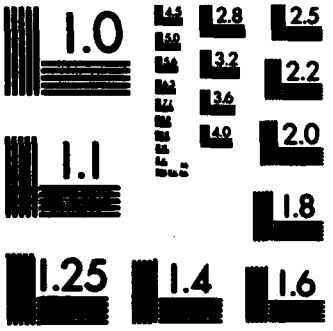
AD-A134 115 PLASMA THEORY AND SIMULATION(U) CALIFORNIA UNIV 1/1
BERKELEY ELECTRONICS RESEARCH LAB C K BIRDSALL
31 DEC 81 N00014-77-C-0578

UNCLASSIFIED F/G 20/9 NL

END

FILMED



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

DTIC FILE COPY

FOURTH QUARTER PROGRESS REPORT ON

PLASMA THEORY AND SIMULATION

OCTOBER 1, 1981 - December 31, 1981

DOE Contract DE-AT03-76ET53604
ONR Contract N00014-77-C-0578

APPROVED FOR PUBLIC RELEASE
DISTRIBUTION UNLIMITED

DTIC
ELECTE
OCT 20 1983
A

ELECTRONICS RESEARCH LABORATORY
College of Engineering
University of California, Berkeley, CA 94720

FOURTH QUARTER PROGRESS REPORT
on
PLASMA THEORY AND SIMULATION

October 1 to December 31, 1981

APPROVED FOR PUBLIC RELEASE
DISTRIBUTION UNLIMITED

Our research group uses both theory and simulation as tools in order to increase the understanding of instabilities, heating, transport, and other phenomena in plasmas. We also work on the improvement of simulation, both theoretically and practically.

Our staff is —

Professor C.K. Birdsall* *Principal Investigator*	191M	Cory Hall	(642-9672)
Dr. Thomas L. Crystal *Post-Doctorate; Lecturer, UCB*	119ME	Cory Hall	(642-3477)
Dr. Bruce Cohen	L630	LLNL	(422-9823)
Dr. A. Bruce Langdon	L477	LLNL	(422-5444)
Dr. William Nevins *Lecturers, UCB: Physicists LLNL*	L630	LLNL	(422-7032)
Dr. Mary Hudson *Guest, UCB; Senior Fellow, Space Science Lab.*		SSL	(642-1327)
Mr. Kwang-Youl Kim Mr. William Lawson Mr. Niels Otani Mr. Stéphane Rousset Mr. Vincent Thomas *Research Assistants*	119MD	Cory Hall	(642-1297)

* On sabbatical leave at Plasma Physics, Nagoya University, Nagoya 464, Japan Sept 1, 1981 - Feb 28, 1982.

December 31, 1981

DOE Contract DE-AT03-76ET53064-DE-AM03-76SF00034
ONR Contract N00014-77-C-0578

ELECTRONICS RESEARCH LABORATORY

University of California
Berkeley, California 94720

Accession For
NTIS GRA&I

TABLE OF CONTENTS

Section I: PLASMA THEORY AND SIMULATION 3

A.* Ion-Ion Two-Stream Mode in a Thermal Barrier Cell 3

B. Alfvén Ion Cyclotron Instability Particle Simulations 5

C. Plasma Sheaths: Electrostatic 1-d Particle Simulations 5

D. Plasma Diode: 1-d Vlasov Simulations 5

E.* Relativistic Quantum Conductivity Tensor for a Plasma 5

Section II: SUMMARY OF REPORTS, TALKS, PUBLICATIONS, VISITORS

Distribution List 7

* Indicates ONR supported areas

I. PLASMA THEORY AND SIMULATION

A. Ion-ion two-stream mode in a thermal-barrier cell ; local electrostatic stability analysis

V. A. Thomas (Dr. W. M. Nevins)

As discussed in the previous QPR(III ,1981), the ion distribution function in the thermal-barrier region of a tandem mirror machine can be unstable to electrostatic and/or electromagnetic two-stream modes. In this QPR we examine the analytic stability in an infinite medium of those electrostatic ion-ion two-stream modes which have their wave vector, k, parallel to the axial magnetic field (this is equivalent to examining 1-d "localized" stability). The point of our doing *in*homogeneous simulations is precisely to examine any non-infinite medium effects on the instability in a thermal barrier. Any unstable ion-ion two-stream modes are expected to have wavelengths of order λ_{D_i} ; since the thermal-barrier cell itself is much longer than this, our analytic ("local") approximation will provide at least a zeroth-order estimate of instability as well as as a reference from which to measure any inhomogenity effects recovered later by our particle simulation runs.

Recently, the stability of colliding Maxwellian ion beams was examined by *Foote* and *Kulsrud*[1]. Their work determined the stability of such Maxwellian ion beams to both electrostatic and electromagnetic modes, assuming an infinite homogeneous plasma. Because the actual thermal-barrier cell ion beams are *not* Maxwellian, we developed a code to calculate local growth rates using a more accurate model for the ion distribution function, taken from *Cohen*[2].

This instability requires, roughly, that $T_e/T_i > 3$ and that the relative drift between the two ion beams be on the order of several times the ion thermal velocity. The electron contribution to the analytic dispersion relation is modelled in our work as just the real quantity $(\omega_{pe}/kv_{th}^2)^{-2} = (k\lambda_{D_e})^{-2}$; the effect of this electron term is to eliminate the ion-acoustic instability. In these expressions, it is important to understand that temperature, T_e, and plasma frequency, ω_{pe}, refer just to the *thermal* electrons. That is, if a " hot " electron population and a " thermal " electron population are both present at the same location with $T_{hot} \gg T_{thermal}$, then the true shielding distance is determined by the Debye length of the cooler " thermal " population. This is an important consideration because if the thermal electron density is not high enough, then the ion density perturbations are not shielded sufficiently to prevent instability. On the other hand a high density of hot electrons (which are magnetically trapped) is necessary to the operation of the thermal-barrier cell: these maintain the large dip in electrostatic potential which is the essence of the thermal barrier. The trade-off between these two competitive factors is be explored in this note.

The notation of *Lontano et al.*[3] will be followed closely here. They considered essentially the same problem except that their distribution function did not include thermal-barrier *trapped* ions. The appropriate dispersion relation for our problem is

$$Z(\frac{\omega}{k}) = 1 + \frac{1}{k^2\lambda_{D_e}^2} - \frac{\omega_{pi}^2}{k^2}\int du\ \frac{dF(u)}{du}/(u - \frac{\omega}{k}) = 0$$

where $u = v_{\parallel}$ is the ion parallel velocity, and where

$$F(u) = \int f_i(\mathbf{v})\ \delta(u - \hat{\mathbf{k}}\cdot\mathbf{v})\ d\mathbf{v}$$

is the $v_{\parallel}$ "reduced" ion distribution (i.e., f_i integrated over $\mathbf{v}_{\perp}$). Here $\hat{\mathbf{k}}$ is a unit vector in the direction of the wave vector.

A standard Nyquist technique is used to determine the stability of this system. The dielectric function $Z(v_s)$ is examined as v_s (representing the phase velocity ω/k) is varied from $-\infty$ to $+\infty$ along a path which is slightly above the real axis; the Nyquist integration path is then

closed by a half-circle at infinity in the upper half ω plane. The *number* of unstable modes is given by the number of times the function $Z(v_s)$ encircles the origin. Figure 1, taken from Ref. 3, shows the hodograph for this integral. In our case, the quantity $\mathrm{Im}\,(Z(v_s))$ is seen to equal to zero at only five locations along the contour path.

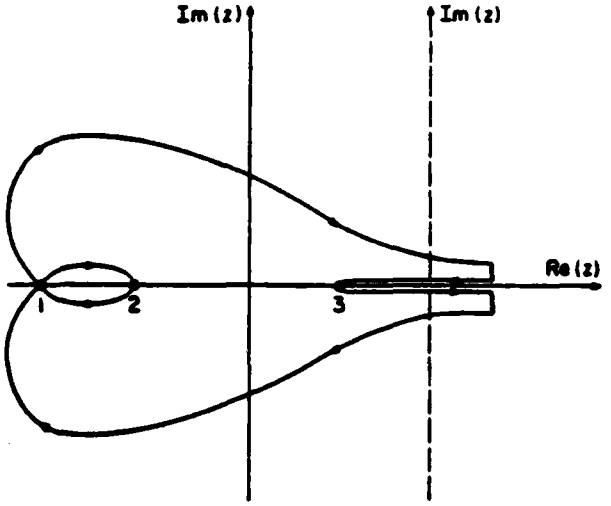


FIG. 1. Nyquist hodograph for the instability analysis: the point (1) corresponds to $v_s = \pm v_0$; the point (2) corresponds to $v_s = \pm\infty$ and (3) corresponds to $v_s = 0$. The solid $\mathrm{Im}\,(Z)$ axis is for a stable distribution and the dotted $\mathrm{Im}\,(Z)$ axis is for an unstable distribution. Although the figure is for the distribution function in Ref. 3, the contour topology remains the same for the model we study, taken from Ref.2 .

These five points are $v_s = 0$, $v_s = \pm\infty$ and $v_s = \pm v_0$ where these v_0 are the beam velocities, where the reduced ion distribution function has its maxima. From the figure it is seen that there is at most one unstable mode for our problem; and since $\omega = a + ib$ and $\omega = -a + ib$ are both solutions to our dispersion relation, we conclude that $a = 0$, and therefore that the unstable mode is purely growing. This fact facilitates the numerical analysis since it allows us to replace ω by $i\gamma$ in our numerical search for the unstable roots. A simple bisection method can then be used to determine the growth rate of an unstable mode for a given test problem.

For more detailed studies, where we are interested in more than just the unstable solutions to the dispersion relation, we decided to use a packaged complex root finder utilizing Muller's method (i.e., in performing these calculations we do not substitute $i\gamma$ for ω and then use bisection to locate roots). The time to find the first root is increased but all subsequent solutions have good initial guesses and converge rapidly. This also allows us the flexibility to examine all solutions to the dispersion relation in cases where that is desired.

We have checked the code results by adjusting the parameters of our model distribution function (taken from Ref. 2) so that the ion beams are *nearly* Maxwellian, and then comparing the stability boundaries recovered, against those given in Ref. 1. It should be pointed out, however, that the distribution function for the actual thermal-barrier is decidedly *non*-Maxwellian, especially near the cell midplane where $u_{drift}/v_{ti} \simeq 3$. Note also that the work of Ref. 1 neglects the quantity $(k\lambda_{De})^2$ compared to one: although this is valid for determining the stability *boundary* (since marginal stability occurs for $k\lambda_{De}$ equal to zero), this neglect may not always be valid for determining the growth *rate*. Stability boundaries using our ion model could well differ from those found assuming Maxwellian ion distribution functions. In fact, our initial results indicate that the thermal-barrier cell using our model ion distribution function is significantly *more* stable than it would be using a Maxwellian ion beam model. These results will be presented in detail in future publications.

References

1. Foote, E. A. and R. M. Kulsrud,"Stability of Colliding Ion Beams", *Phys. Fluids* 24, 1532 (1981).

2. Cohen, R. H., " Axial Potential Profiles for Thermal Barrier Cells" , *Nuclear Fusion* 21, 209 (1981).

3. Lontano, M., L. S. Pekker, and R. Pozzoli, "Inverse-loss Cone Instability in a Tandem Mirror", *Sov. Jour. Plasma Phys.* 6 (4) (1981).

B. Alfvén Ion Cyclotron Instability Particle Simulation

N. Otani (Dr. W. M. Nevins)

No special progress to report this quarter.

C. Plasma Sheaths: Electrostatic 1-d Particle Simulations

S. Rousset
No special progress to report this quarter.
The title will change to: "Time-Dependent Child-Langmuir Diode Simulation".

D. Plasma Diode: 1-d Vlasov Simulation

W. Lawson (Dr. T. L. Crystal)

No special progress to report this quarter.

E. Relativistic Quantum Conductivity Tensor for a Plasma

Kwang-Youl Kim (Dr. T. L. Crystal)

No special progress to report this quarter; further work will be given in a complete report.

II. SECTION II: SUMMARY OF REPORTS, TALKS, PUBLICATIONS AND VISITORS

A. ERL REPORTS:

(1) Quasineutral Hybrid Simulation of Macroscopic Plasma
by Douglas S. Harned, UCB/ERL Mem. M81/71 14 Sept 1981.

(2) Rotational Instabilities in the Field-Reversed Theta Pinch:
Results of Hybrid Simulations
by Douglas S. Harned, UCB/ERL Mem. M81/70 14 Sept 1981.

(3) Kink Instabilities in Long Ion Layers
by Douglas S. Harned, UCB/ERL Mem. M81/73 16 Sept 1981.

(4) Stabilization of the Lower Hybrid Drift Instability by Resonant Electrons
by Yu-Jiuan Chen, William M. Nevins and Charles K. Birdsall
UCB/ERL Mem. M81/72 16 Sept 1981.

B. JOURNAL ARTICLES:

Strong Ion Ring Equilibria Formed by Injection and Intrinsic Stochasticity of Orbits
by Alex Friedman, Jacques Denavit, and R. N. Sudan
Jour. Comp. Phys. 44 pp 104-133, Nov 1981.

University of California, Berkeley
Electrical Engineering & Computer Sciences

Fall 1981
Fridays 3:00-5:00 PM
Room 299 Cory Hall

T.L.Crystal
642-9672

EECS 298-9: PLASMA THEORY & SIMULATION SEMINAR

Oct 2 Yu-Jiuan Chen and Bill Nevins, LLNL
Use of the ZED postprocessor.

Oct 9 Tom Crystal
Kinetic simulations of Tokamak TEM

Oct 23 Niels Otani
The AIC instability: linearized e-s simulations.

Oct 30 Mary Hudson, Cyndi Cattell, Ilan Roth & Earl Witt, SSL
Space plasmas: special problems being studied with simulation

Nov 6 Vince Thomas
Ballooning instability and plasma density limitations in the Jovian magnetosphere.

Nov 13 AT 1:30 PM. Gary Smith, LLNL
Electron microinstability and negative reactors.

Nov 20 Kwang-Youl Kim
Quiet-start simulations of Rings & Spokes.

Dec 4 Stephane Rousset
1D diode simulations: progress since Langmuir's solutions.

DISTRIBUTION LIST

Department of Energy

Nelson, Sadowski, Winske

Department of Navy (ONR)

Florance, Roberson

Austin Research Associates

Drummond, Moore

Bell Telephone Laboratories

Hasegawa

Cal. Inst. of Technology

Liewer, Bridges, Gould

Calif. State Polytech. Univ.

Rathmann

Columbia University

Chu

Cornell University

Mankofsky

E.P.R.I.

Scott

General Atomic Company

Bernard, Helton, Lee

Hascomb Air Force Base

Rubin

JAYCOR

Hobbs, Klein, Tumolillo

Kirtland Airforce Base

Pettus

Los Alamos National Lab.

Lindemuth, Mason, Nielson,
Oliphant, Sgro, Barnes,
Kwan, Thode, Borovsky

Lawrence Berkeley Laboratory

Cooper, Kaufman, Kim, Lee
Kunkel, Pyle

Lawrence Livermore National Laboratory

Albritton, Anderson, Brengle,
Briggs, Bruijnes, Byers, Chambers
B. Cohen, R. Cohen, Denavit, Estabrook,
Fawley, Friedman, Freis, Fuss,
Harte, Killeen, Kruer, Langdon,
Lasinski, Maron, Matsuda, Max,
McNamara, Nevins, Nielson, Smith
Tull

Mass. Inst. of Technology

Berman, Bers, Gerver, Palevsky

Mission Research Corporation

Godfrey

Naval Research Laboratory

Boris, Drobot, Craig, Haber,
Orens, Vomvoridis, Winsor

New York University

Grad, Harned, Weitzner

Northeastern University

Silevitch

Oak Ridge National Laboratory

Dory, Meier, Mook

Princeton Plasma Physics Laboratory

Chen, Cheng, Lee, Okuda,
Tang, Graydon

Science Applications, Inc.

McBride, Siambis, Wagner, Smith

Sandia Labs, Albuquerque

Freeman, Humphries, Poukey, Quintenz

Sandia Labs, Livermore

Marx

DISTRIBUTION LIST (Continued)

Stanford University
Buneman

University of Arizona
Morse

University of California, Berkeley
Arons, Chen, Chorin, Grisham, Hudson, Lichtenberg, Lieberman , McKee, Morse

University of California, Davis
DeGroot, Woo

University of California, Irvine
Rynn

University of California, Los Angeles
Dawson, Decyk, Huff, Lin

University of Iowa
Knorr, Nicholson

University of Maryland
Guillory, Rowland, Winske

University of Pittsburgh
Zabusky

University of Texas
Horton, McMahon, Tajima

University of Wisconsin
Shohet

Culham Laboratory
Eastwood, Roberts

University of Reading
Hockney

Ecole Polytechnique
Adam

Bhabha Research Centre
Aiyer, Gioel

Israel
Gell

Tel Aviv University
Cuperman

Kyoto University
Abe, Matsumoto

Nagoya University
Kamimura

Max Planck Institute fur Plasmaphysik
Biskamp, Kraft

Universitat Kaiserslautern
Wick

Universitat Innsbruck
Kuhn

Riso National Laboratory
Lynov, Pecseli

Institute for Theoretical Physics
Schamel

Ecole Polytechnique Federale Lausanne
Hollenstein

Tohoku University
Sato, Saeki

Osaka University
Mima, Nishihara

University of Tromsø
Trulsen

University of Oxford
Allen

Plasma Theory & Simulation Group
DOE Contract No. DE-AT03-76ET3064-DE-AM03-76SF00034
ONR Contract NO. N00014-77-C-0078

ELECTRONICS RESEARCH LABORATO
University of California
Berkeley, CA 94720

5

SUMMARY OF PROGRESS FOR FIRST AND SECOND QUARTER, 1982

This is a summary of highlights of progress made by our group, for use by DOE and ONR contractors. The details appear in our Quarterly Progress Report.

Our group uses both theory and simulation as tools in order to increase the understanding of instabilities, heating, transport and other phenomena in plasmas. We also work on the improvement of simulation both theoretically and practically. We are the undersigned plus five graduate students, and are aided by professionals from the Lawrence Livermore National Lab and the Space Sciences Lab.

A. Ion-Ion Two stream Mode in a Thermal Barrier Cell

The model uses ion particles with isothermal Boltzmann ($T_e \approx T_i$) electrons plus hot ECRH localized electrons, with initial values obtained from a Fokker-Planck code. Ion test particles advanced in the equilibrium fields do maintain their initial distribution function, as desired. The next step is to be wholly self consistent.

B. Alfvén Ion Cyclotron Instability Particle Simulations No special progress.

C. Time-Dependent Child-Langmuir Diode Simulation The particle code and results are in an ERL report to be issued soon. The work is noteworthy, with especial attention to injections, applied potentials, and diagnostics, for one species. The results check Langmuir very well.

D. Plasma Diode:1d Vlasov Simulation (GASBAG Code) This electrostatic, non-neutral, 1d, bounded model is solved by integration of the Vlasov equation. Jump discontinuities in f(x,v) (e.g., due to accelerations of a half-Maxwellian) are avoided by a continuation procedure.

E. Weak Monotonic Double Layers Analytic solutions for two DL's (related to electron solitary hole and to ion acoustic solitary hole) are presented in an ERL report to be issued soon.

F. Plasma Sheath Formation, Ion Acceleration and Fluctuations in Steady State At a floating probe large ω_p oscillations in potential are observed (in simulation), with ion acceleration to αv_{sound} ($1 < \alpha < 2$) at the wall. (Abstract)

G. Sheath Formation and Fluctuations with Dynamic Electrons and Ions Similar to F, with results for $1 < m_i/m_e < 1600$ for $T_e \gg T_i$ and for $0.1 < T_I/T_e < 64$ for $m_i/m_e = 400$, showing the transient formation of a sheath.

H. Electron Diode Dynamics; Limiting Currents; Plasma Diodes A double layer is viewed as a virtual cathode next to a virtual anode, with expectations of both current (flux) limiting and oscillations.

Code Development: The postprocessor ZED is now available on the MFE-CRAY.

One ERL report was issued in this period (already distributed, Birdsall sheath survev): three talks were presented at meetings; visits were made to four foreign labs.

Charles K. Birdsall
Professor, Principal Investigator

Thomas L. Crystal
Post-Doctorate

Plasma Theory & Simulation Group
DOE Contract No. DE-AT03-76ET13064-DE-AM03-76SF00034
ONR Contract No. N00014-77-C-0578

ELECTRONICS RESEARCH LABORATORY
University of California
Berkeley, CA 94720

SUMMARY OF PROGRESS FOR FOURTH QUARTER 1981

This is a summary of highlights of progress made by our group, for use by DOE and ONR contractors. The details appear in our Quarterly Progress Report.

Our group uses both theory and simulation as tools in order to increase the understanding of instabilities, heating, transport and other phenomena in plasmas. We also work on the improvement of simulation both theoretically and practically.

Our group consists of Prof. Birdsall, Dr. Crystal and five graduate students. We are aided by professionals from the Lawrence Livermore National Lab and the Space Sciences Lab.

A. Ion-Ion Two-Stream Mode in a Thermal Barrier Cell; Local Electrostatic Stability Analysis. The system studied has opposing ion streams, with $f_i(v)$ obtained from Fokker-Planck thermal barrier studies of R. H. Cohen (1981), and warm electrons. The Nyquist technique was used to locate regions of instability and a root solver used for detailed roots. Initial results show that the thermal barrier cell is significantly more stable than it would be with a Maxwellian ion beam model.

Research on the following topics continue, with progress to be reported later:

B. Alfven Ion Cyclotron Instability Particle Simulation
C. Plasma Sheaths: Electrostatic 1d Particle Simulations
D. Plasma Diode: 1d Vlasov Simulation
E. Relativistic Quantum Conductivity Tensor for a Plasma

Four ERL reports were issued and distributed this quarter and one journal article published. Two reprints are distributed with this QPR; both by Douglas S. Harned:

"Quasineutral Hybrid Simulation of Macroscopic Plasma Phenomena", Jour. Comput Phys. Phys. 47, pp 452-462 Sept. 1982.

"Kink Instabilities in Long Ion Layers" Phys. Fl. 25 pp 1915-1921, Oct. 1982

Charles K. Birdsall
Professor, Principal Investigator

Thomas L. Crystal
Post-Doctorate

END

FILMED

11-83

DTIC