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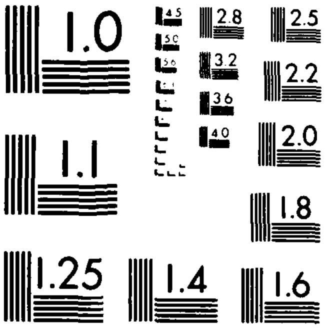

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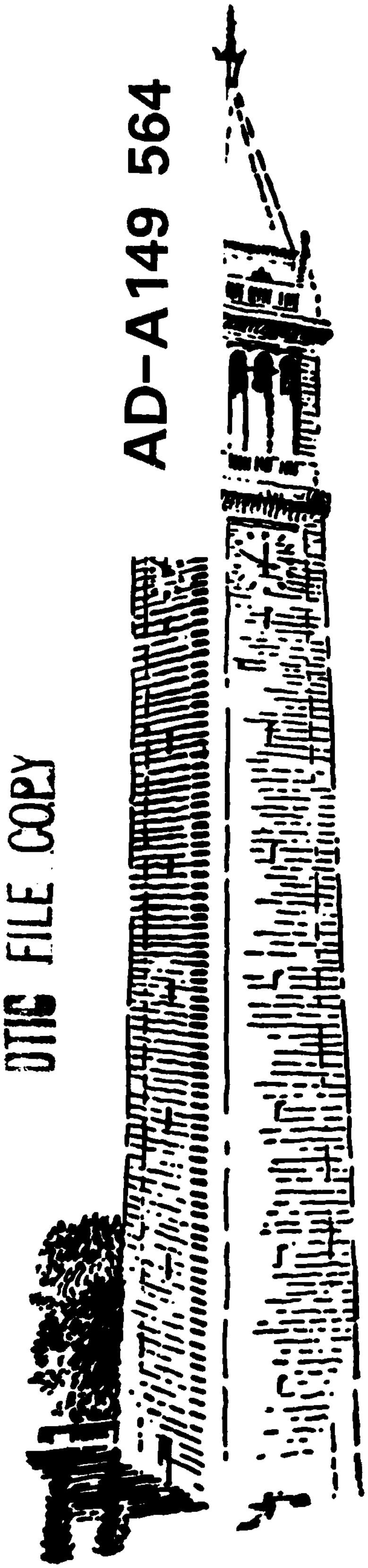

THIRD & FOURTH QUARTER PROGRESS REPORT ON PLASMA THEORY AND SIMULATION

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July 1 to December 31, 1983

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

ELECTRONICS RESEARCH LABORATORY

College of Engineering
University of California, Berkeley, CA 94720

Plasma Theory and Simulation Group
DOE Contract No. DE-AS03-76ER53064-
DE-AM03-76SF00034
ONR Contract No. N00014-77-C-0578

Electronics Research Laboratory
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SUMMARY OF PROGRESS FOR THE THIRD AND FOURTH QUARTERS, 1983

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.

This document contains reports about the [illegible]

~~Our grour uses~~ 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, Dr. S. Kuhn (visiting from Innsbruck) and six graduate students. We are aided by professionals from the Lawrence Livermore National Lab and the Space Sciences Lab.

I. Theory and Simulation

A. Simulation of the Ion-Beam-Driven Drift Instability in a Magnetic Trap

Complete report done and sent.

B. Application of Nonlinear Constants of Motion in a Single Electromagnetic Wave to the Study of the Alfven-Ion-Cyclotron Instability

Report now complete and sent.

C. Theory of Nonmonotonic Double Layers

Report now complete and sent.

D. Magnetized Sheath Simulations (joint with IPP, Nagoya)

For the magnetic field normal to a wall (same as the magnetic field in the 1d3ν model, the transient rarefaction wave is observed, moving into the plasma at c_s. For the B_0 field of angle $\psi \neq 0$ to the normal, the ion drift velocity at the wall drops off roughly as $\cos\psi$ for sufficiently large $(\omega_{ci}/\omega_{pi})$; the wall potential is rather insensitive to ψ, measured after the initial transient. $0 < \psi < 80°$ was used. (In previous QPR's, we showed for $\psi = 90°$, that the plasma becomes negative with respect to the wall).

E. Saturation Characteristics of Counterstreaming Warm Electrons

The distribution function at $\nu = 0$, $f(0)$, is found to overshoot the value for a Maxwellian for $\nu_{thermal}/\nu_{drift} < 0.3$ and drift toward the Penrose stable value for $\nu_t/\nu_d \geq 0.5$.

F. Electron Bernstein Wave Investigations Regarding Linear and Non-Linear Damping

For off perpendicular propagation, spatial (Landau) damping has been observed, as predicted.

G. Simulation of the Classical Pierce Diode

This well-known instability has been examined theoretically, through several eigenmodes, which has been verified by simulations.

H. Simulation of the Plasma-Sheath and Presheath Regions

Comparisons of simulations with time-independent theory for m_i/m_e = 40 and 100 for ϕ_{wall} are excellent. This work continues.

II. Code Development

A. Plasma Diode: 1d Vlasov simulation (GASBAG Code)
Report completed and sent.

B. PDW1, Plasma Device Code
Report completed and sent.

Publications

Two journal articles and five reports were published.

Distributed with this Progress Report are:

"Linear Longitudinal Oscillations in Collisionless Plasma Diodes with Thin Sheaths. Part I. Method," by S. Kuhn, Physics of Fluids, 27(7), July 1984, pp. 1821-1833.

"Linear Longitudinal Oscillations in Collisionless Plasma Diodes with Thin Sheaths. Part II. Application to an Extended Pierce-Type Problem," by S. Kuhn, Physics of Fluids, 27(7), July 1984, pp. 1834-1851.

"PDW1 User's Manual," by W. S. Lawson, ERL Technical Memorandum No. UCB/ERL M84/37, 27 April 1984.

"Simulation of the Ion-Beam-Driven Drift Instability in a Magnetic Trap I," by V. A. Thomas, W. M. Nevins, and Y-J. Chen, ERL Technical Memorandum No. UCB/ERL M84/45, 13 June 1984.

"Simulation of the Ion-Beam-Driven Drift Instability in a Magnetic Trap II," by V. A. Thomas and W. M. Nevins, ERL Technical Memorandum No. UCB/ERL M84/46, 13 June 1984.

"Vlasov-Poisson and Modified Korteweg-De Vries Theory and Simulation of Weak and Strong Double Layers," by K. Y. Kim, ERL Technical Memorandum No. UCB/ERL M84/47, June 1984.

"Application of Nonlinear Constants of Motion in a Single Electromagnetic Wave to the Study of the Alfvén-Ion-Cyclotron Instability," by N. F. Otani, ERL Technical Memorandum No. UCB/ERL M84/49, 16 July 1984.

Charles K. Birdsall
Professor, Principal Investigator

Thomas L. Crystal
Post-Doctorate

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THIRD & FOURTH QUARTER PROGRESS REPORT
ON
PLASMA THEORY AND SIMULATION

July 1 to December 31, 1983

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	(642-4015)
Dr. Thomas L. Crystal *Post-Doctorate; Lecturer, UCB*	187M	Cory Hall	(642-3477)
Dr. Siegbert Kuhn *Guest at UCB;* *Physicist, Univ. of Innsbruck, Austria*	119ME	Cory Hall	(642-3477)
Dr. Jens-Peter Lynov *Guest at UCB;* *Physicist, Riso National Lab, Denmark*	119ME	Cory Hall	(642-3477)
Dr. Bruce Cohen	L630	LLNL	(422-9823)
Dr. A. Bruce Langdon	L477	LLNL	(422-5444)
Dr. William Nevins	L630	LLNL	(422-7032)
Adjunct Lecturers, UCB; Physicists LLNL			
Dr. Mary Hudson *Guest, UCB; Senior Fellow, Space Science Lab.*		SSL	(642-1327)
Mr. Perry Gray *Senior Engineering Aide*	119ME	Cory Hall	(642-3528)
Mr. Kwang-Youl Kim Mr. William Lawson Mr. Niels Otani Ms. Lou Ann Schwager Mr. Vincent Thomas Mrs. Amy Wendt			
Research Assistants	119MD	Cory Hall	(642-1297)
	119ME	Cory Hall	(642-3528)

December 31, 1983

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ELECTRONICS RESEARCH LABORATORY

University of California
Berkeley, California 94720

SECTION I: PLASMA THEORY AND SIMULATION

A. Simulation of the Ion-Beam-Driven Drift Instability in a Magnetic Trap

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

The following is the abstract of a report in preparation.

Recent experiments on the TMX-U device at LLNL have indicated the possibility of a drift wave being driven unstable by the injection of neutral beams in the thermal barrier region. A review of linear theory is presented in the local approximation. In addition, particle simulations are used to understand the nonlinear characteristics of this instability. The particle simulations are performed using a 1d - 3v electrostatic particle simulation code and a 2d - 3v electrostatic particle simulation code. The instability is shown to saturate by beam trapping nonlinear electron effects, and nonlinear motion in parallel with the density gradient. Resonant **ExB** motion is a significant process for some of the beam particles. This process is closely associated with the trapping of beam ions. Harmonic generation is also observed, as in some of the experimental data. Qualitative nonlinear theory is presented in support of the particle simulations.

B. 1d Alfvén-Ion-Cyclotron Instability Particle Simulation

Niels F. Otani (Prof. C. K. Birdsall)

A final report is being readied, with title and abstract below.

Application of Nonlinear Constants of Motion in a Single Electromagnetic Wave to the Study of the Alfvén-Ion-Cyclotron Instability

ABSTRACT

Constants of motion are derived for particles moving in a single, circulary-polarized electromagnetic wave of arbitrary time-dependence propagating parallel to a uniform background magnetic field. The constant associated with helical symmetry is shown to restrict the particle motion to a very narrow region of velocity space. Features of the slow time-scale motion of fixed points associated with the existence of a fourth adiabatic invariant are described for the case of a slowly varying wave. Characteristics of the particle motion thus derived are applied to the analysis of 1d-3v simulations of the saturation of the Alfvén-ion-cyclotron (AIC) instability for a single wave. In particular, an explanation is offered for the appearance of a sharp edge in the velocity distribution function observed in the simulation.

C. Theory of Nonmonotonic Double Layers

K. Y. Kim (Dr. T. L. Crystal)

The following is an Abstract of a report in preparation.

We present a simple graphic method of solving a Vlasov-Poisson system associated with nonlinear eigenvalue conditions for arbitrary potential structures. We present a general analytic formulation for non-monotonic double layers and illustrate with some particular solutions. This class of double layer satisfies the time stationary Vlasov-Poisson system, while requiring a Sagdeev potential which is a double-valued function of the physical potential: it follows that any distribution function having a density representation as any integer or noninteger power series of potential can never satisfy the non-monotonic double layer boundary conditions. A K-dV like equation is found showing a relationship among the speed of the non-monotonic double layer, its scale length, and its degree of asymmetry.

D. Magnetized Sheath Simulations

Seiji Ishiguro, Tetsuo Kamimura (IPP, Nagoya, Japan)
(Prof. C. K. Birdsall)

Some rudimentary simulations were done with a magnetized sheath at IPP Nagoya. One object is to understand better the role of the angle of the magnetic field (with respect to a bounding wall) in determining the sheath potential drop and particle fluxes. These runs were done with our code ES1, modified to RAM (Reflect-Absorb-Mirror), done at IPP (Birdsall, Ohara; see our QPR 3,4 for 1982), with B_0 now added by Ishiguro. Hence, this is a joint project, with progress reported here.

The model is shown in Figure 1. Initially, the region 0 < x < L/2 is filled with thermal electrons and ions. There is no source so that the initial plasma eventually decays. The wall at x = L/2 absorbs all particles and is floating (not connected to an external circuit); the net surface charge σ(L/2) = $-E_x(L/2)$ gives one boundary condition for Poisson's equation. The wall at x = 0 reflects all particles (changes sign of v_x) and is set at zero potential, $\varphi(0) = 0$, for the second boundary condition.

RAM is obtained from ES1 as follows. Active charges exist only for 0 < x < L/2. The charge density ρ ($0 < x < L/2$) is mirrored across x = L/2 into L/2 < x < L but not inverted; the potential is obtained for 0 < x < L as usual. The active charges crossing x = L/2 are kept at x = L/2 (and doubled, to account for those coming from the right), providing σ(L/2), which is $-E_x(L/2)$. The potentials at 0 = x = L are zero; volume charge weighted to x = 0 is doubled to account for that weighted to x = L (there is no surface charge density at x = 0, L).

The parameters used are:

$L = 100\lambda_{De}$
$T_e / T_i = 100$
$m_i / m_e = 100$
$v_{te} = 1$
$\omega_{pe} = 1$
$\omega_{ci} / \omega_{pi} = 0, 0.1, 0.2, 0.3$
$(\omega_p / \omega_c)_i^2 = 100, 25, 11.1$
$\psi = 0, 10^\circ, \ldots, 80^\circ, 90^\circ$

Some results for an unmagnetized ($B_0 = 0$) plasma are shown in Figure 2, for $\varphi(x)$, $n_{i,e}$(x), $v_{drift.i,e}$(x) at intervals of $\omega_{pe}t = 100$, and in Figure 3 versus time. These results are essentially just the initial transient. The electrons charge the wall, dropping φ_{wall} to roughly $-1/2\, ln(m_i/m_e) = -2.3$ in a few plasma periods ($\omega_{pe}t \approx 20$). After about time $L/v_{te} = 100$, most of the fastest electrons are absorbed and φ_{wall} gradually rises, with oscillations at ω_p and (perhaps) near $\omega_{pi}/2$. The simulation would be improved with a source, either at x = 0 or distributed across part or all of L. Nevertheless, some results are of interest. Note that an edge in potential, density, and drift velocity propagate into the plasma at sound speed; this is a rarefaction wave, much as seen in a freely expanding plasma. However, the sheath edge (where n_i and n_e separate) is nearly stationary, about $5\lambda_{De}$ from the wall, as shown in Figure 4.

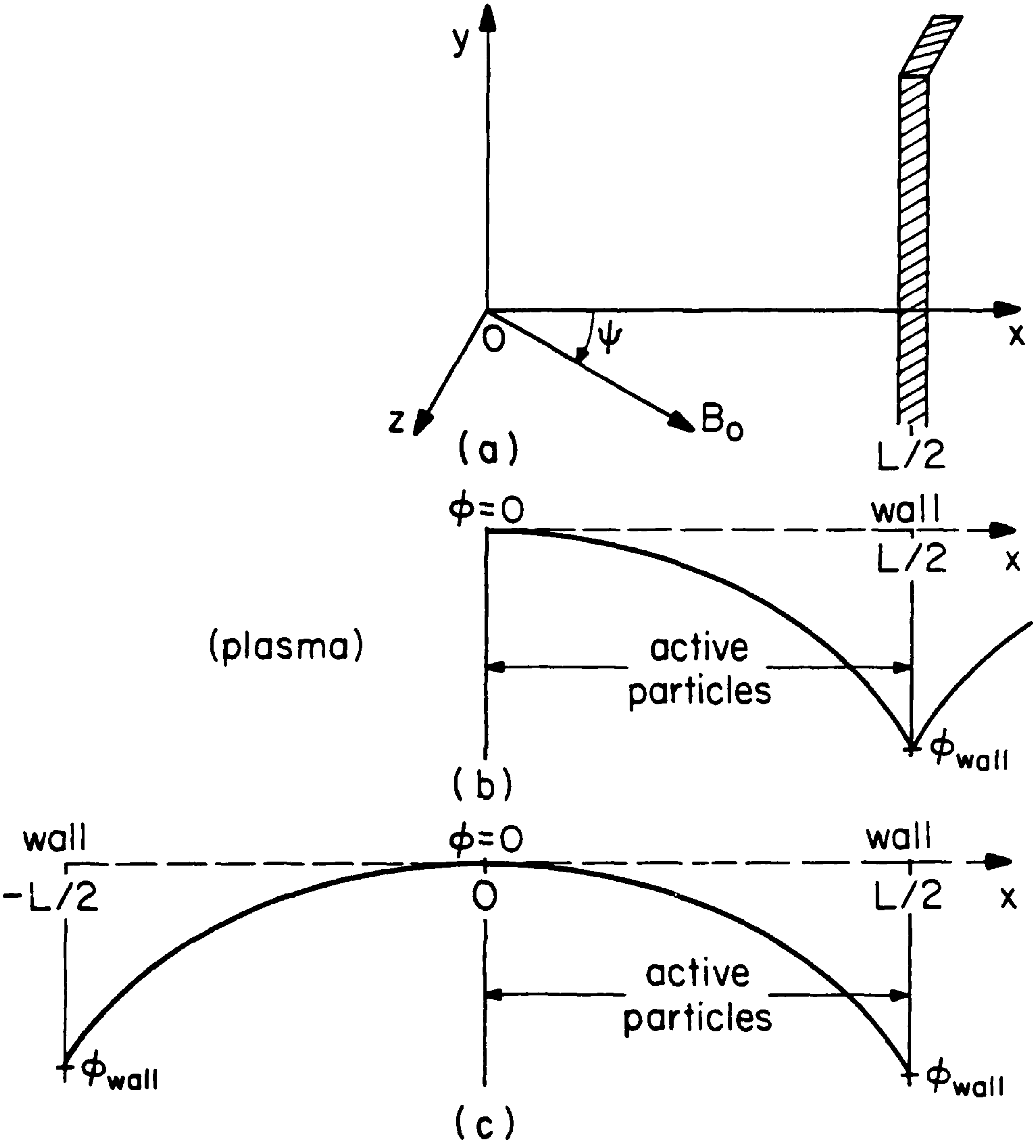


Figure 1. Reflect-Absorb-Mirror (RAM) model, magnetized. The electric field is $E_x(x,t)$ only. The magnetic field is B_0 independent of x, t. The wall at $x = \frac{1}{2}$ (and at $-\frac{L}{2}$) is absorbing and floating. This allows modeling the half space as shown in (b), rather than the full space in (c), or a full space $0 < x < L$, with a floating wall at L/2.

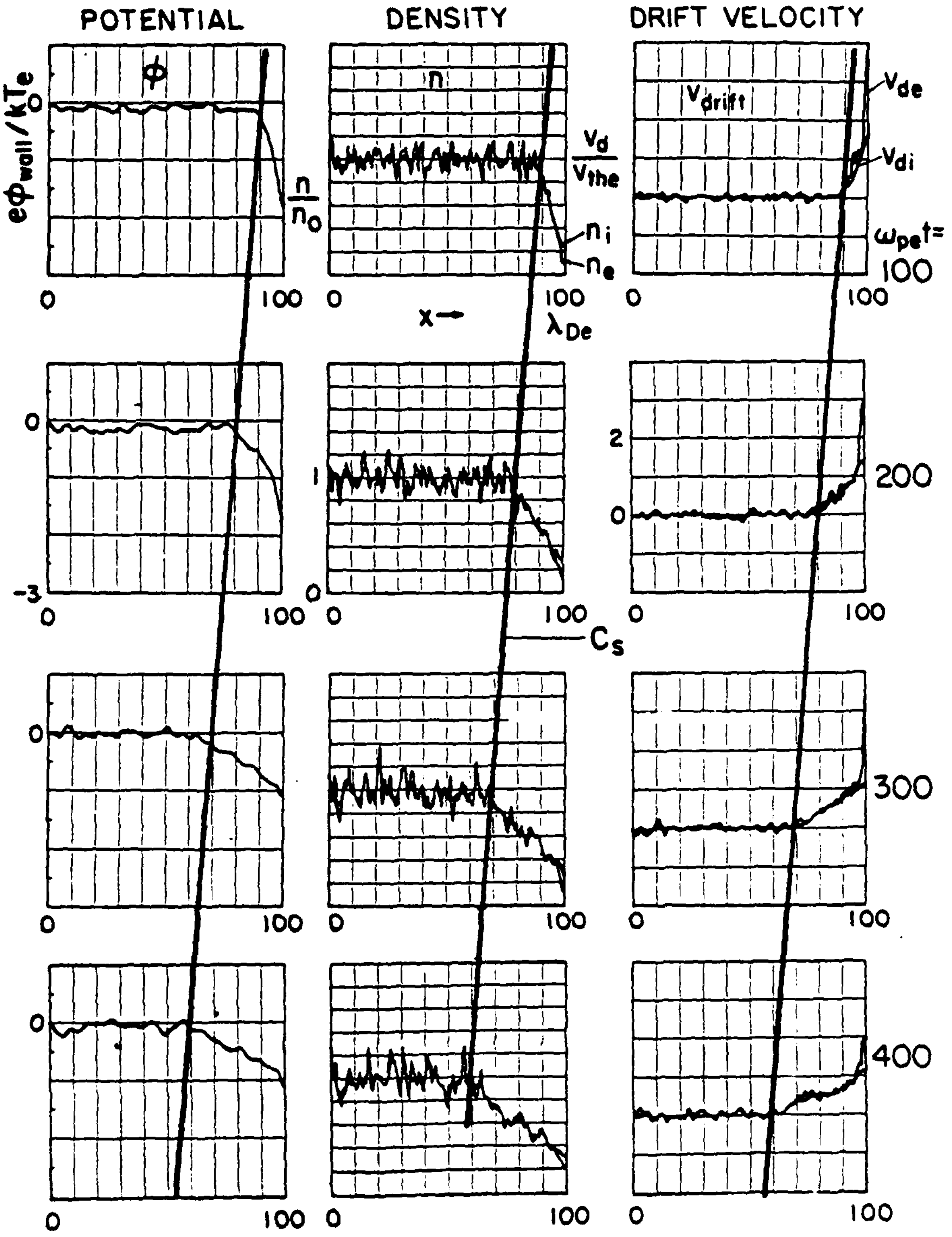


Figure 2. ϕ, n, v_{drift} shortly after t = 0. Both species drift to the wall, depleting the plasma, with the rarefaction traveling to the left at about sound velocity c_s, shown by the solid line.

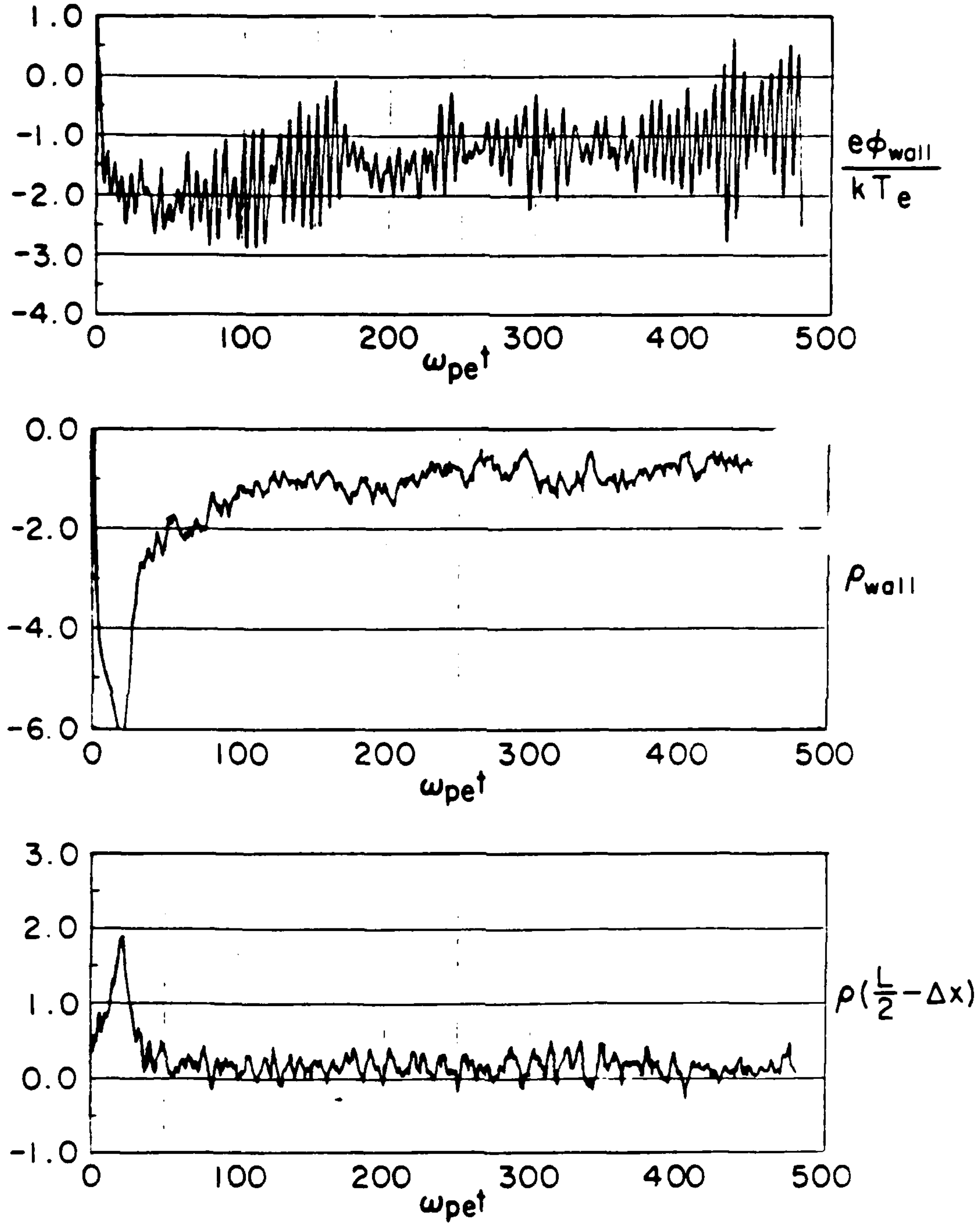


Figure 3. ϕ_{wall}, ρ_{wall}, $\rho_{nearwall}$ are shown versus time. The potential drops quickly to a value predicted by simple sheath theory, oscillating at about ω_{pe}, and modulated at (perhaps) $\omega_{pi}/2$; the slow rise reflects slow loss of the fastest electrons (there is no source). The wall charges negatively and the charge nearby shields the wall, as seen.

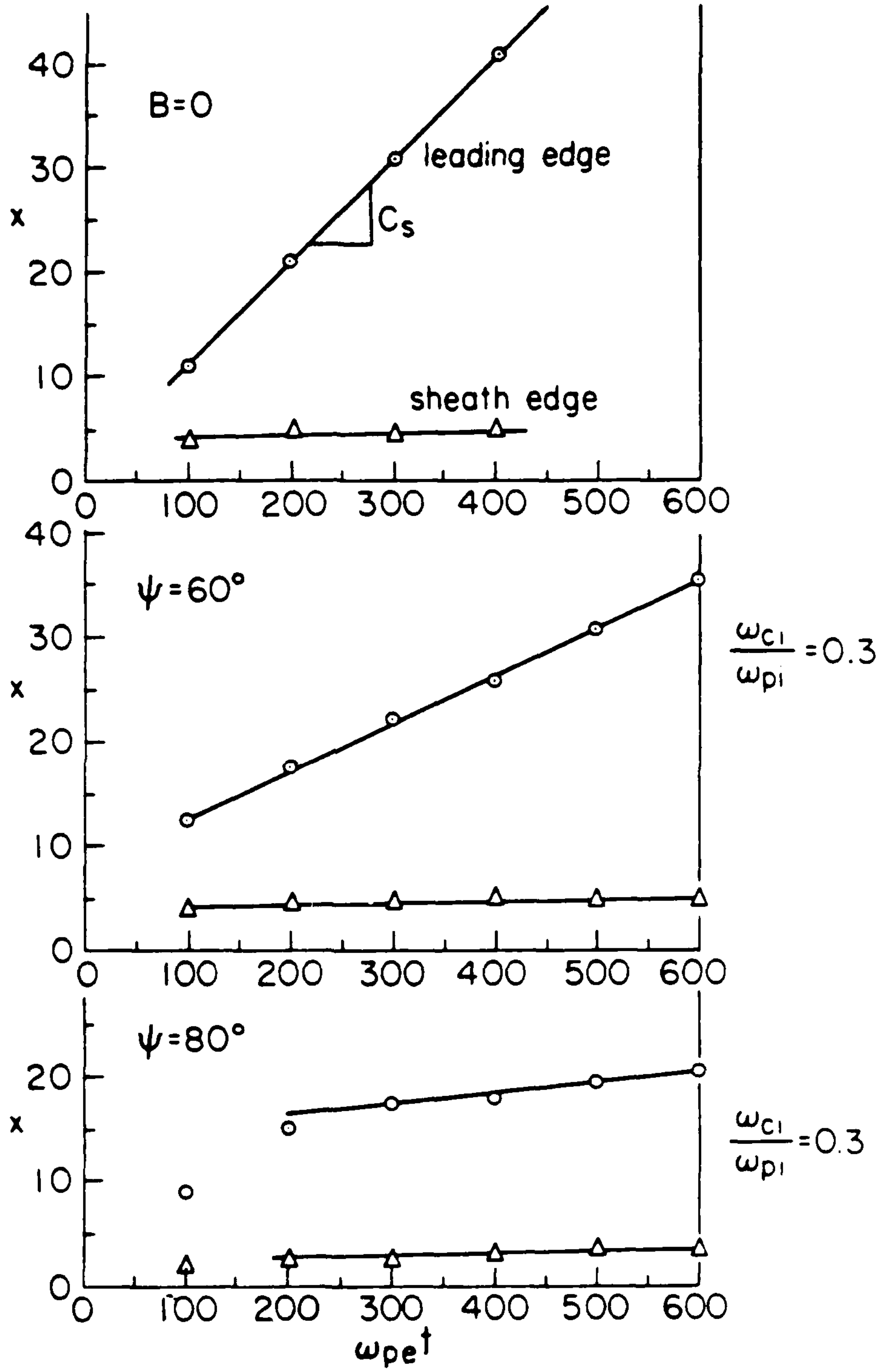


Figure 4. The magnetized sheath expands into the plasma as shown, becoming much slower as ψ → 90° (B_0 ∥ to wall). The sheath edge, however, is insensitive to the magnetization.

The magnetized plasma ($B_0 \neq 0$) behaves similarly, with some notable changes. First, as in Figure 5, the ion drift velocity (and ion flux) at the absorbing wall drops off, apparently as $\cos\psi$, as the magnetization is increased.

Second, as in Figure 6, φ_{wall} (measured at a time just past the minimum of φ_{wall}) appears rather insensitive to either ψ or strength of magnetization. However, additional simulations showed that φ_{wall} became positive with respect to the plasma for $\psi = 90^\circ$ (B_0 parallel to the wall), as also observed by L. A. Schwager (Berkeley PDW1 code, previous QPR). But, for $\psi = 88^\circ$, φ_{wall} is again negative; the electrons simply take some time to flow along B_0 to the wall. The time record of φ_{wall} now shows additional modulation apparently near $\omega_{ce} > \omega_{pe}$. Hence, $\psi = 90^\circ$ appears singular. These 90° effects (little or no ion drift and flux, positive wall potential or ion barrier) certainly need more thorough investigations, for fusion ion containment or for device application (making use of the high sensitivity to ψ for $\psi \approx 90^\circ$).

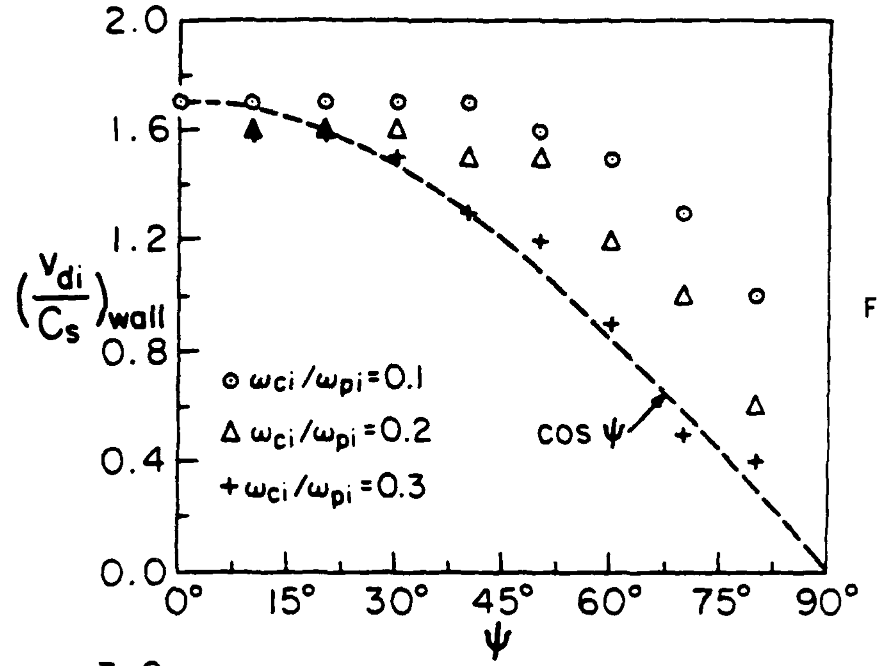


Fig. 5

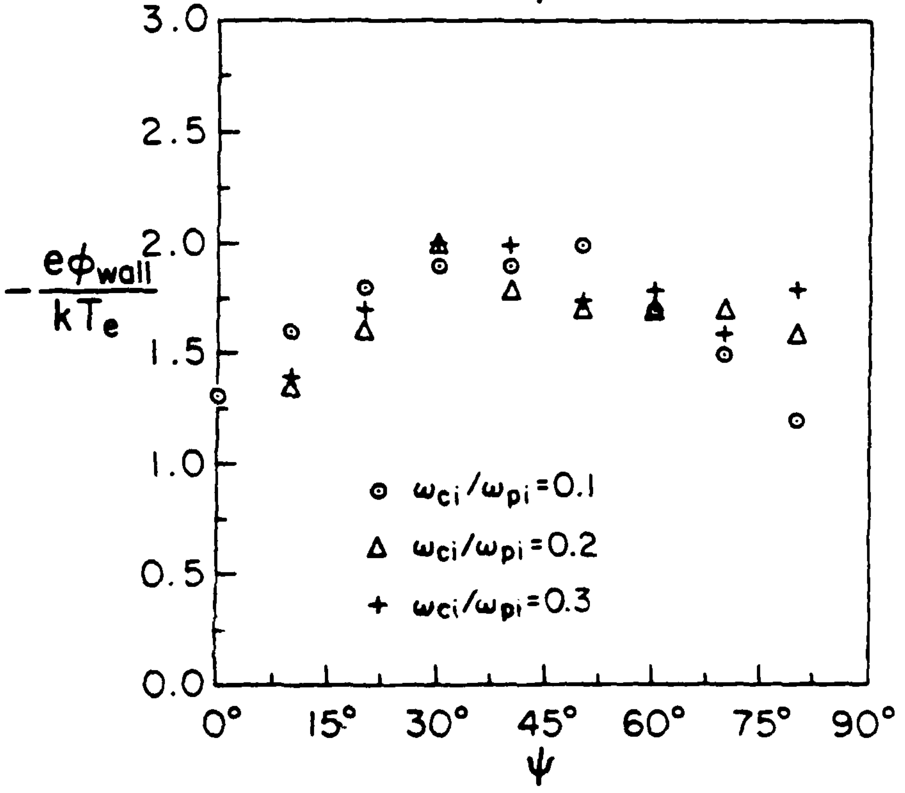


Fig. 6

Figure 5. Summary of magnetized sheath ion drift velocities at the wall, during the initial transient.

Figure 6. Summary of magnetized sheath wall potentials, measured well into the transient.

E. Saturation Characteristics of Counterstreaming Warm Electrons

Amy Wendt (Prof. C. K. Birdsall)

Counterstreaming warm electron beams are unstable for $\nu_0 \geq 1.4\nu_t$, as is well known. Our study is observation of growth as ν_t / ν_0 is increased from zero, with evolution of $f(\nu)$ from two peaks toward (perhaps) a Maxwellian. In particular, $f(\nu = 0)$ is followed in time and is seen to overshoot the value for a Maxwellian for $\nu_t / \nu_0 \leq 0.3$ and drift toward the value for Penrose stability for $\nu_t / \nu_0 \geq 0.5$.

A report is in preparation.

F. Electron Bernstein Wave Investigations Regarding Linear and Non-Linear Damping

J. P. Lynov (Risø) and Wm. S. Lawson

A modification of the code PDW1 is being used to investigate non-linear Bernstein waves in a plasma. The problem studied is that of a spatially localized exciter emitting waves into a plasma close to perpendicular to the magnetic field. At non-linear amplitudes, there will probably be a wavelength shift, and reduced Landau damping due to the trapping of particles. It is not presently known at what amplitudes these effects will become important, and it is the purpose of this research to find this amplitude as well as the character of these effects.

Also of interest, probably at some future time, is the mechanism of heating when these waves do damp. This is of possible importance to heating and current drive in Tokamak plasmas.

G. Simulation of the Classical Pierce Diode

T. L. Crystal and S. Kuhn

A report on this project is in preparation, and will be issued as an ERL Memorandum. This report covers recent particle simulations of the "classical" Pierce diode (1944), performed with the new bounded-plasma code PDW1. These simulations (i) successfully retrieve the linear behavior predicted from Pierce's characteristic equation, (ii) extend past the region where linear instability analysis is valid to recover the later nonlinear behavior, and (iii) display the final states of the diode system which might be either time-independent (steady-state) or oscillating, and which may depend on the initial conditions given to the simulation.

H. Simulation of the Plasma-Sheath and Presheath Regions

Lou Ann Schwager (Prof. C. K. Birdsall)

Our particle simulation studies of the plasma-sheath region compare favorably with analytical results of others. Our one-dimensional, bounded system has ions and electrons of equal temperature injected from one end and an absorbing plate at the other end, as shown in Figure 1. The code is PDW1.

Equal fluxes of ions and electrons are injected at x=L, simulating ions and electrons escaping from a plasma center cell. Some electrons repelled by the sheath at x=0 return to the injection plane, where they are thermalized and re-emitted, along with the injected flux. No ions are returned to the source. The sheath region of a symmetrical mirror reactor is modelled; returning electrons undergo collisions in passing through the center cell and flow to the other collector plate.

At the center cell plasma boundary (injection plane in our model), charge cannot accumulate so that the electric field is made zero there. Thermal ions and electrons are injected with equal densities and constant fluxes and temperatures. The system is initially empty. Mass ratios, m_i/m_e, of 40 and 100 are used to conserve computation time.

The model parameters are:

number of grids, NG = 128
length L = 2
time step $\Delta t = 7.8125 \times 10^{-3}$
injected flux = 500
injected current = 25
electron charge to mass ratio, $(q/m)_e = -1$
electron thermal velocity, $v_{te} = 1$

	Run 1	Run 2
m_i/m_e	40	100
$(q/m)_i$	0.025	0.010
v_{ti}	0.158	0.100
number of time steps, NT	6400	9000

The above parameters generate the following at equilibrium.

	Run 1	Run 2
m_i/m_e	40	100
final number of ions	4706	6997
average $\omega_p \Delta t$	0.085	0.103
average Debye length, $\lambda_D/\Delta x$	5.90	4.84
system length in λ_D	21.7	26.5

Final phase space and potential profiles are shown in Figures 2 and 3.

Near the emission plane the potential falls, accelerating the slowest ions to about sound speed, c_s, as seen in Figures 2b and 3b. The overall potential drop at equilibrium is 1.06 and 1.60 $e\varphi/kT$ for the light and heavy ion cases, respectively, as observed in Figures 2c and 3c.

The above results are compared with the sheath analysis of *Emmert, et al* [1] for a one-dimensional collisionless plasma with Boltzmann electrons, with a

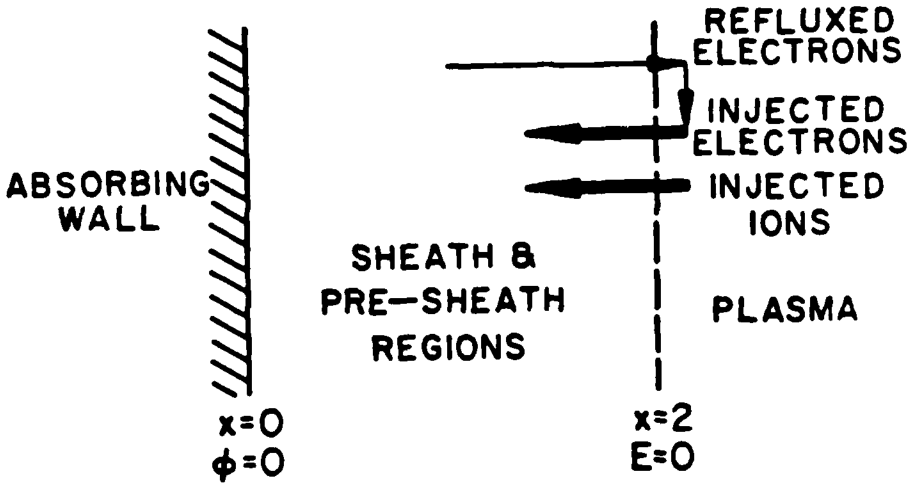
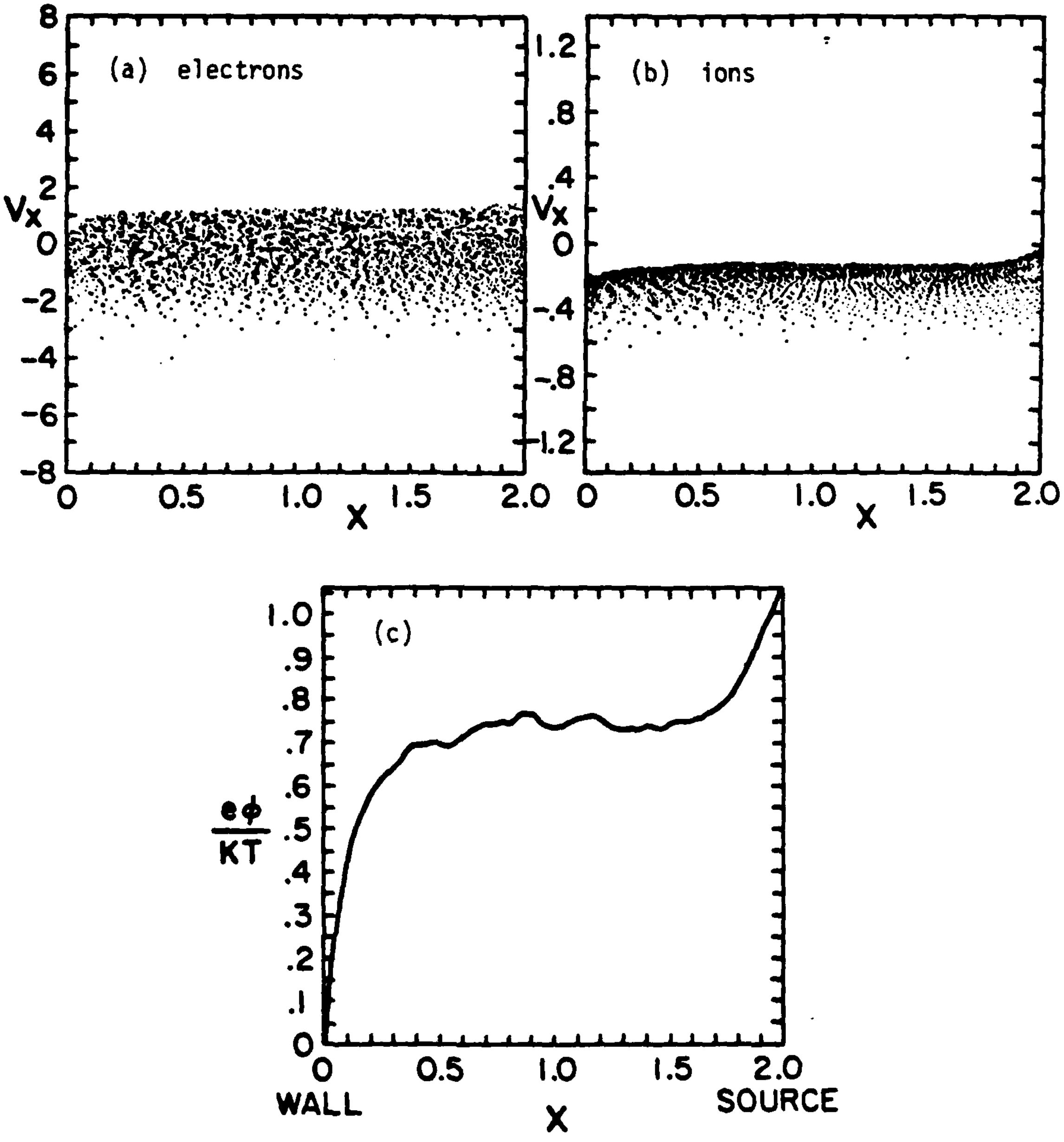


Figure 1. Bounded plasma model.



PHASE SPACE AND POTENTIAL PROFILES

AT EQUILIBRIUM FOR $m_i/m_e=40$

Figure 2.

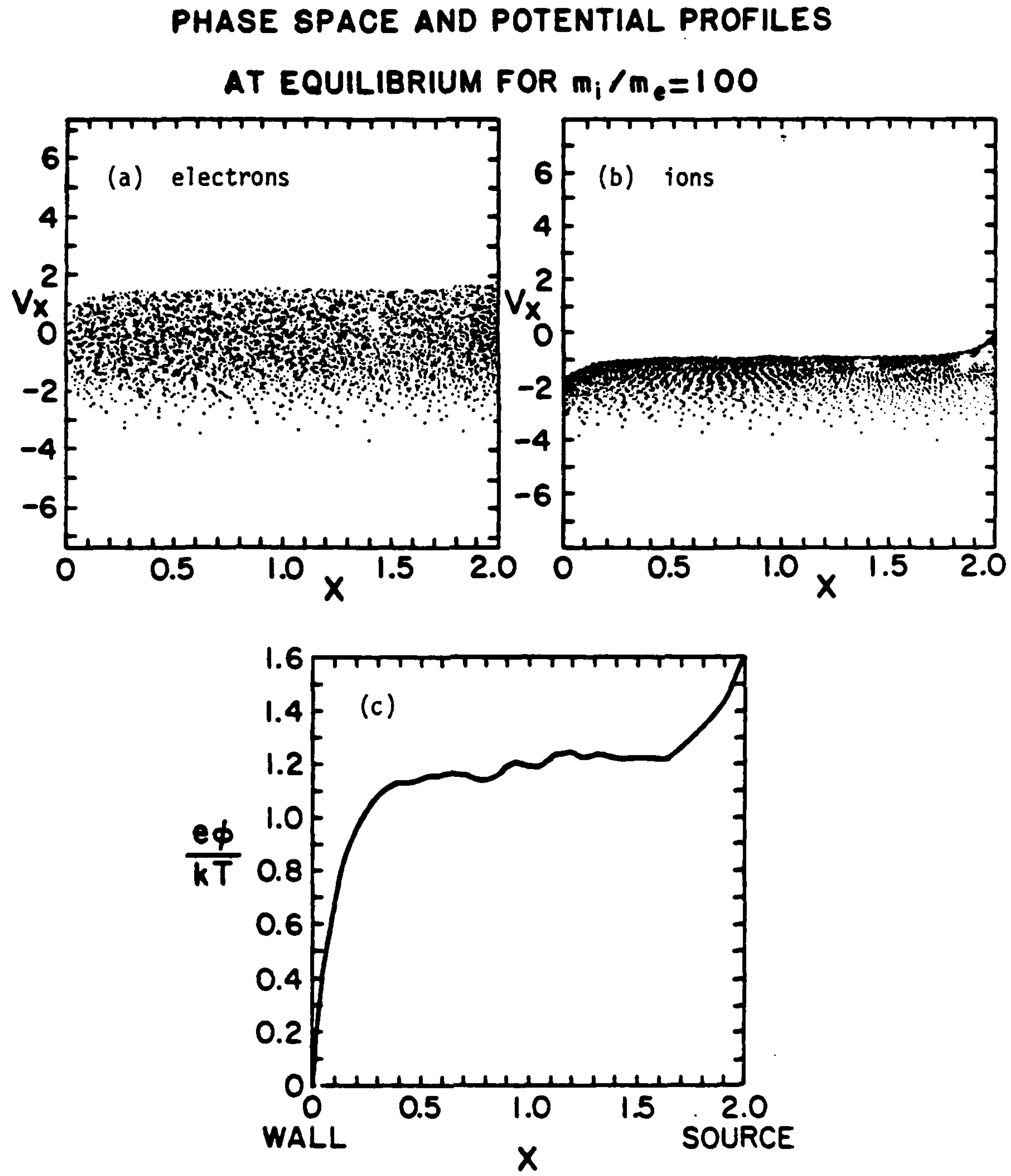

PHASE SPACE AND POTENTIAL PROFILES
AT EQUILIBRIUM FOR $m_i/m_e=100$
(a) electrons
(b) ions
V_x
6
4
2
0
-2
-4
-6
0
0.5
1.0
1.5
2.0
X
(c)
$\frac{e\phi}{kT}$
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
WALL
SOURCE

Figure 3.

uniform source. φ_{wall} dependence on m_i/m_e for Z=1 is obtained from their equations and appears in Figure 4 for T_i/T_e equal to 0.10 and 1.0 for a source width equal to L. The φ_{wall} of the two PDW1 runs are shown on the same plot, even though the source width is zero. Also graphed is the simple estimate commonly used, which assumes that ions have a half-Maxwellian distribution:

$$\frac{e\varphi_{wall}}{KT_e} = \frac{-1}{2}\ln\left(\frac{M}{m}\frac{T_e}{T_i}\right)$$

(Note: the paper appears to have a misplaced exponent.)

The paper also indicates that, in the part of the region where there is no plasma source, the potential profile is flat (except in the sheath). Hence, if one chooses a narrow source width, say, $10\lambda_D$ in a system length of $100\lambda_D$, the analytic potential profile in Figure 5 is obtained. This result is similar to the simulation profiles in Figures 2c and 3c, where the source width is zero (planar). For PDW1 with a Maxwellian ion distribution emitted at the plasma boundary, the "point" source appears to have a similar effective width. The agreement in Figure 4 may be fortuitous; however, Emmert et al. find the overall potential drop to be independent of the source width (shape) (see beneath their Eq. (35)), and nearly independent of the system length (see their Tables I, II).

Future work will add the effects of secondary emission at the collection plate, as well as binary collisions and charge exchange.

References

[1] G. A. Emmert, R. M. Wieland, A. T. Mense, J. N. Davidson, "Electric Sheath and Presheath in a Collisionless, Finite Ion Temperature Plasma," *Phys. Fluids 23*, pp. 803-812, April 1980.

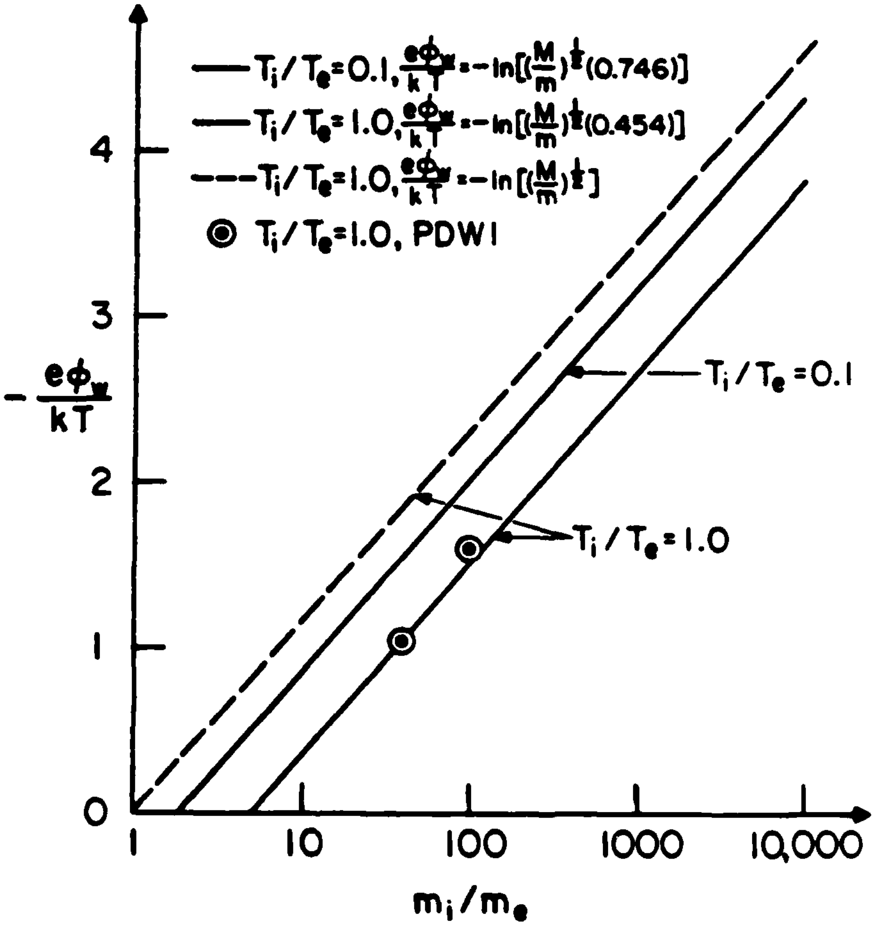


Figure 4. Wall potential versus mass ratio.

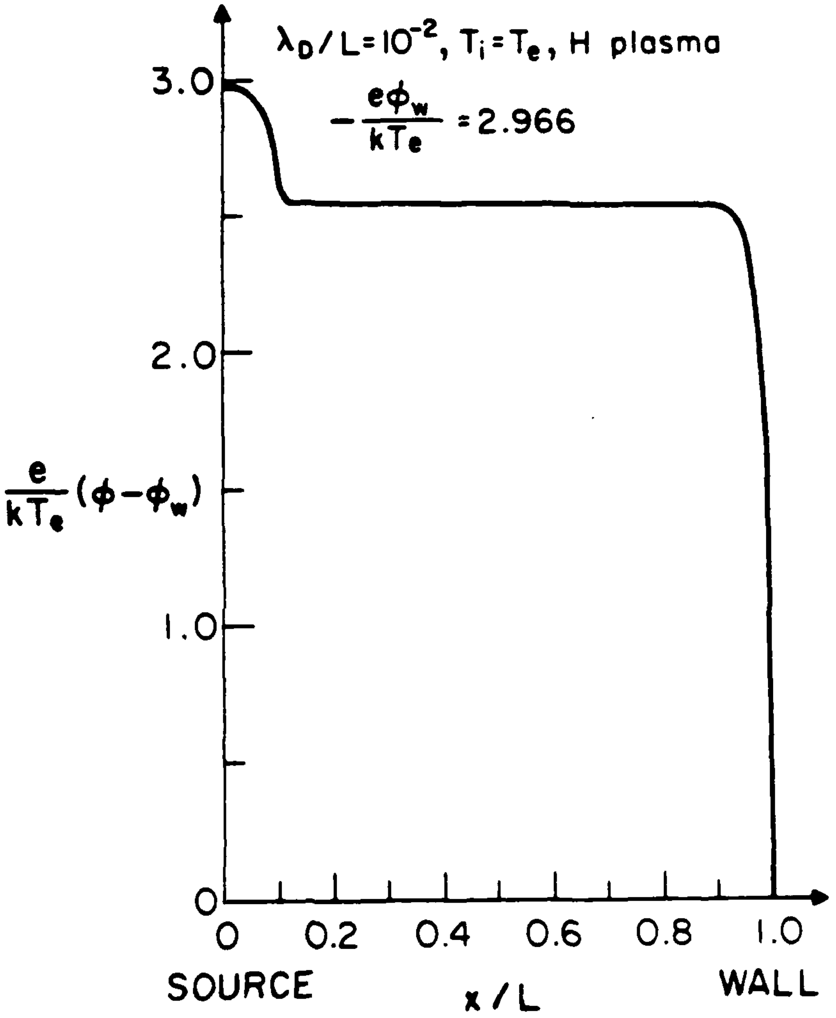


Figure 5. Potential variation with distance for source width of x/L = 0.1.

SECTION II: CODE DEVELOPMENT

A. Plasma Device Code: 1-d Vlasov Simulation (GASBAG Code)

William S. Lawson

A report is nearly completed, with titles and abstracts as follows.

A Method for Simulation of Vlasov Systems with Discontinuous Distribution Functions

ABSTRACT

A method is presented for simulating non-periodic (or periodic) Vlasov systems with discontinuous distribution functions. The method is a hybrid of a standard Vlasov method and the Waterbag method; the discontinuity is integrated separately from the distribution function. Sample runs and particle simulation comparison runs are included.

GASBAG User's Manual

Introduction

This guide is intended to be the sole external documentation for the GASBAG Vlasov plasma simulation code. Section 2 is a guide for the casual user who needs only enough information to run the code. Section 3 is for those who intend to use the code as a research tool, and will therefore want to make modifications such as new diagnostics, and new routines for loading or perturbations. The GASBAG code was written to be run on the National Magnetic Fusion Energy Computer Center CRAY computers. These are vector machines, and the code makes extensive use of this vector capability, as well as some software unique to the installation. Anyone wishing to modify the code for another installation will find the information in Section 4 useful.

It is assumed that the reader understands the method used by the code. Using the code without understanding the method is likely to produce bad results. For example, if the string of test particles finds its way too far up the tail of the Vlasov distribution, a small error in the position of the test particles will produce a large error in the charge density, current, and kinetic energy. A paper on the method has been submitted for publication in the Journal of Computational Physics, and is available from the author.

B. PDW1, Plasma Device Code

William S. Lawson

The following are the Abstract and part of the Introduction of the *PDW1 User's Manual* now in preparation.

ABSTRACT

PDW1 is a one dimensional, magnetized, electrostatic particle simulation with one, two or three velocity coordinates, and non-periodic boundary conditions, and includes a simple R, L, C, external circuit and ac/dc applied voltage. It is set up to inject Maxwellian distributions with arbitrary drift velocities and cut-off velocities, but is easily modifiable to suit other distributions. This document is both a user's manual, and a report on the principles of operation of the code. Inquiries should be directed to Prof. C. K. Birdsall.

Introduction

This report is intended as a guide to the use and modification of the simulation code PDW1. It includes detailed descriptions of the methods and algorithms used in the code. Some familiarity with numerical methods on the part of the reader is assumed. The report is broken up into six Sections and five Appendices. Section I is, of course, the Introduction, which describes the contents of this write-up, and some general programming concepts used in the design of the code. Section II is a guide to the mechanics of compiling and running the code. Section III describes the various parameters used to completely specify a given problem. Section IV will be helpful to anyone who wants to make minor modifications to the code (which will be almost everyone who uses the code). Section V is an exhaustive list of virtually all the variables in the program. Section VI gives in-depth descriptions of each of the major subroutines, including the algorithms, and descriptions of any subroutines called by the routines. The final five Sections are Appendices. The first Appendix contains flow charts for all the major routines, the second contains a description of the workings of the ZED interface (written by Niels Otani), the third contains some integrals which will make parameter selection easier, the fourth contains documentation on a minor but useful modification of PDW1 named PDWMAX, and the fifth contains some examples which should illustrate some of the problems PDW1 is capable of solving.

PDW1 is an acronym for Plasma Device Workshop. The code was written during, and for use in, a seminar workshop at the University of California at Berkeley on axially bounded plasma systems during the 1983 spring quarter. Since the code is in large measure a product of the information exchanged during this workshop, it was deemed appropriate to name it after the workshop.

SECTION III: SUMMARY OF JOURNAL ARTICLES, REPORTS, VISITORS, TALKS

Journal Articles

(1) K. Y. Kim, "Weak Monotonic Double Layers," *Phys. Letters* Vol. 97A, No. 1, 2, 8 August 1983.

(2) Yu-Jiuan Chen, William M. Nevins, and Charles K. Birdsall, "Stabilization of the Lower-Hybrid Drift Instability by Resonant Electrons," *Phys. Fluids 26*, September 1983.

Reports

(1) Stephane Rousset, "Time-Dependent Child-Langmuir Diode Simulation," Memo No. UCB/ERL M83/39, 11 July 1983.

(2) K. Y. Kim, "Theory of Asymmetric Double Layers," Memo No. UCB/ERL M83/45, 22 July 1983.

(3) S. Kuhn, "Linear Longitudinal Oscillations in Collisionless Plasma Diodes With Thin Sheaths, Part I. Method," Memo No. UCB/ERL M83/52, 31 August 1983.

(4) S. Kuhn, "General Path-Integral Successive-Collision Solution of the Bounded Dynamic Multi-Swarm Problem," Memo No. UCB/ERL M83/57, 23 September 1983.

(5) S. Kuhn, "Linear Longitudinal Oscillations in Collisionless Plasma Diodes with Thin Sheaths, Part II. Application to an Extended Pierce-Type Problem," Memo No. UCB/ERL M83/61.

Visitors

(1) Dr. Siegbert Kuhn - from Professor F. Cap's group at the Institute for Theoretical Physics, University of Innsbruck, arrived in December 1982. He is a guest researcher in our group for his sabbatical year (1983). He is working on formalisms for handling finite, bounded systems and aiding us in our efforts at simulating axially-bounded systems and sheath phenomena.

(2) Dr. Jens-Peter Lynov - from Risø National Laboratory, Roskilde, Denmark, to work on a variety of subjects, including heating and current drive using off-perpendicular electron Bernstein waves (six weeks).

(3) Dr. Michael J. Gerver was here for two weeks in July.

Poster Papers for the APS Div. of Plasma Physics Meeting, November 1983, Los Angeles

(1) (3Z14) Niels F. Otani, "Simulation of the Alfven Ion Cyclotron Instability in Tandem Mirror Plasmas."

(2) (5W11) S. Kuhn, "The General Perturbation Problem For the One Dimensional Collisionless Plasma Diode."

(3) (5W12) C. K. Birdsall, T. L. Crystal, S. Kuhn, A. B. Langdon, W. S. Lawson, and N. F. Otani, "Plasma Diode Simulation: the PDW1 Code."

(4) (5W13) W. S. Lawson, "Vlasov Simulation on a Finite Grid With a Discontinuous Distribution Function."

(5) (5W14) N. F. Otani, "Scaling of Magnetized Double Layers."

(6) (5W15) K. Y. Kim, "Weak Asymmetric Double Layers (ADL)."

(7) (5W16) T. L. Crystal, S. Kuhn, W. S. Lawson, "Pierce Diode Instabilities and Extensions: Simulations With PDW1."

(8) (7Q6) Vincent A. Thomas, U. C. Berkeley, William McCay Nevins and T. A. Casper, Lawrence Livermore National Laboratory, "Ion Beam Driven Drift Instability in Tandem Mirrors."

The abstracts are on the page following.

Simulation of the Alfvén Ion-Cyclotron Instability in Tandem Mirror Plasmas. NIELS F. OTANI, *Electronics Research Lab, U. of Calif., Berkeley, CA 94720.* Results are presented from one-dimensional particle simulations of the Alfvén ion-cyclotron instability in bimaxwellian plasmas, and in plasma distributions predicted to occur in the axicell region of MFTF-B. Instability and strong transport of resonant particles into the loss-cone are observed. Deviations from predictions of quasilinear theory appear to be caused by the existence of approximate constants of the motion due to the nature of the wave spectrum. Preliminary results from simulations of the instability in the presence of a transverse density gradient will also be presented.

* Work supported by DOE Contract. No. DE-AT03-76ET53064; computations facilities provided by NMFECC.

THE GENERAL PERTURBATION PROBLEM FOR THE ONE-DIMENSIONAL COLLISIONLESS PLASMA DIODE *

S. KUHN, *E.R.L., Univ. of Calif., Berkeley, CA 94720.* --

A method is proposed for treating linear oscillations in collisionless one-dimensional plasma diodes with non-uniform equilibria, allowing for very general initial, boundary, and external-circuit conditions. The method, which is an extension of previous work[1,2], is based on the basic (Vlasov - Poisson) and auxiliary equations in integral form. It is potentially applicable to a variety of neutral and non-neutral bounded plasma systems, such as Q machines or electron diodes. The general formalism is developed and applied to the special case of a positively biased single ended Q machine.

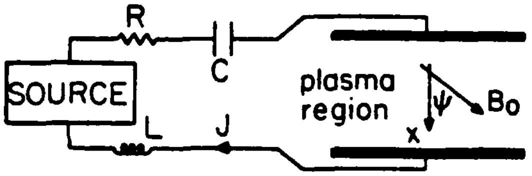
* Work supported under ONR contract N00014-77-C-0578, and Austrian Research Funds contract S-18/03.

1. S. Kuhn, Proc. 1982 ICPP, Göteborg, p. 11P-II-17.
2. S. Kuhn, submitted for publication.

PLASMA DIODE SIMULATION: THE PDW1 CODE

C.K. BIRDSALL, T.L. CRYSTAL, S. KUHN, A.B. LANGDON, W.S. LAWSON, N.F. OTANI, *E.R.L., Univ. of Calif., Berkeley, CA 94720.**

PDW1 solves for electron and ion motions in the self-consistent electrostatic field of a 1d(1,2,3v) plasma diode having external series RLC circuit as shown below. Among many options, one may model constant current drive, one electrode floating, or fixed potential drive. Standard code options include various particle injection schemes (e.g., drifting cutoff Maxwellians) from either or both electrodes, and a static magnetic field $\mathbf{B}_o$ at angle ϕ to the system axis. Recent applications, as documented in related posters in this session, include the Pierce, Langmuir (electron) and multispecies diodes; weak and strong double layers both with and without $\mathbf{B}_o$; and magnetic sheaths and first walls. PDW1 came from a Plasma Diode Workshop, chief programmer W.S. Lawson.



* Work supported by DOE contract DE-AT03-76ET53064 and ONR contract N00014-77-C-0578. Computations were done at NMFECC, Livermore.

VLASOV SIMULATION ON A FINITE GRID WITH A DISCONTINUOUS DISTRIBUTION FUNCTION.

Wm. S. Lawson *Electronics Research Laboratory, U.C. Berkeley, 94720.*

Ordinary Vlasov simulation methods are unable to deal with non-periodic boundary conditions because steep gradients in phase space and discontinuities are inherent in such problems. A method which shows promise of overcoming most of these difficulties is to extend the distribution function *past* any discontinuity, then keep track of the position of the discontinuity with a string of test particles. Only the part of the distribution function which is to one side of the string of test particles is then integrated in calculating the charge density. The unphysical extension of the distribution function does not influence the physics, yet it allows finite difference methods to be used to integrate the Vlasov equation. Well-behaved Vlasov integrators have been found, and results from a code based on this method (GASBAG) compare very well with particle simulation results. While the accuracy of the Vlasov simulation is not better than that of the particles, the noise level is far lower.

* Work performed under Dept of Energy contract DE-AT03-76ET53064 using the NMFECC computers

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SCALING OF MAGNETIZED DOUBLE LAYERS.

N. OTANI, *E.R.L., Univ. of California, Berkeley, CA 94720.**

Preliminary results from one-dimensional bounded electrostatic particle simulations employing constant current boundary conditions are discussed. We observe magnetized double layers persisting for several hundred electron plasma periods. A large current-driven positive potential structure eventually develops near the emitting wall, limiting the useful duration of our simulations. Obliquely magnetized double layers scale spatially as the Debye length during the first few ion-cyclotron periods.

* Work supported by DOE contract DE-AT03-76ET53064; computational facilities provided by NMFECC, Livermore

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WEAK ASYMMETRIC DOUBLE LAYERS (ADL)

K. Y. KIM, *E.R.L., Univ. of Calif., Berkeley CA 94720.**

A. Our analytic formulation for ADL involves a third constant of motion, $\mathrm{sgn}(x - x_m)$ where x_m locates the ADL minimum (or maximum) potential, in addition to the usual constants, total-energy and $\mathrm{sgn}(v)$. Only in this way can we guarantee that (1) the distribution function satisfies the Vlasov eqn and is continuous throughout phase space, and (2) the Sagdeev potential is double valued. Using amplitude dependent (nonlinear) boundary conditions with these distribution functions yields the determinantal equations producing the ADL.

B. Particle simulations of ADL have been successful in short systems ($L \leqslant 80\lambda_D$) and with low drift velocities ($V_d \leqslant 0.5\, V_{th}$ for the electrons). We have simulation results for systems driven by constant current and by constant applied voltage, both with and without applied magnetic field.

* Work performed under Dept of Energy contract DE-AT03-76ET53064 using NMFECC computers at Livermore.

PIERCE DIODE INSTABILITIES AND EXTENSIONS: SIMULATIONS WITH PDW1 *

T.L. CRYSTAL, S. KUHN†, Wm LAWSON, *ERL, U. C. Berkeley, CA 94720.*

Particle simulations of the classical (short-circuited) Pierce diode recover linear eigenmodes and eigenfrequencies as predicted by linear theory. Stability of this special plasma diode is governed by the free parameter $\alpha = \omega_p L / v_o$, reflecting effects of both the *plasma* properties and the *boundary* conditions. When the diode is unstable, the system evolves to a nonlinear final state which can depend fundamentally on the *initial* conditions. Simulations including external RLC circuit elements demonstrate that these seriously modify both the character and the stability of the diode system's response.

* Work supported under DOE contract DE-AT03-76ET53064, and ONR contract N00014-77-C-0578. One of the authors (SK) acknowledges partial support from the Austrian Research Funds under contract S-18/03.

† Permanent address: Inst for Theoretical Physics, Univ of Innsbruck, A-6020 Innsbruck, Austria. Computations done at NMFECC, Livermore.

Ion Beam Driven Drift Instability in Tandem Mirrors.*

VINCENT A. THOMAS, U.C. Berkeley, WILLIAM McCAY NEVINS and T.A. CASPER, Lawrence Livermore National Laboratory--Recent experiments with the TMX-U device at LLNL indicate the possibility of a drift wave instability occurring in the end plugs due to the injection of neutral beams. Solutions of the linear dispersion relation indicate the effects of the various system parameters on this instability. Possible stabilizing effects include Landau damping on both the thermal ion and electron populations as well as convective damping associated with the axial flow of wave energy to the low density region at the end of the machine. Two and one half dimensional particle simulations are used to examine the nolinear saturation of the instability. The final state of the ion beams is given particular attention.

*Work performed in part by the Office of Naval Research under Contract No. N00014-77-0678, and in part by the U.S.D.O.E., LLNL, Contract No. W-7405-ENG-48.

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