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Seventh Annual Symposium on the ANOMALOUS ABSORPTION OF INTENSE HIGH-FREQUENCY WAVES

ABSTRACTS

MAY 18-20, 1977

Ann Arbor, Michigan

THE SEVENTH ANNUAL SYMPOSIUM ON THE ANOMALOUS ABSORPTION OF INTENSE HIGH-FREQUENCY WAVES

MAY 18-20, 1977

The University of Michigan
Ann Arbor, Michigan

Partially Supported by United States Air Force Office of Scientific Research

Hosts: Nuclear Engineering Department
Aerospace Engineering Department
The University of Michigan

Committee:
D. R. Bach
J. J. Duderstadt
R. S. B. Ong
D. G. Steel

Seventh Annual Conference on

ANOMALOUS ABSORPTION OF INTENSE

HIGH-FREQUENCY WAVES

MAY 18-20, 1977

CONFERENCE TIME TABLE

TUESDAY, MAY 17

7:00-10:00 p.m.	Registration Rackham Lobby

WEDNESDAY, MAY 18

8:00-12:00 a.m.	Registration Rackham Lobby

All Conference sessions will be conducted in the Amphitheatre of the Rackham Building.

SESSION A. WEDNESDAY MORNING, CHAIRMAN, R.K. OSBORN

9:00- 9:35	A-1.	Invited Paper, T.W. Johnston, "One Theorist's View of our Current Understanding of the Laser-Plasma Interface in Current Investigations of Inertial Confinement Thermonuclear Fusion Using Lasers"
9:35- 10:10	A-2.	Invited Paper, S. Bodner, "Laser Fusion Research at the Navel Research Laboratory"
10:10- 10:20	Coffee Break	
10:20- 12:05	<u>Profile Modification and Related Phenomena</u>	
10:20- 10:35	A-3.	J.S. DeGroot, C. Randall, and W. Woo, "Laser Absorption at High Power"
10:35- 10:50	A-4.	K. Mizuno and J.S. DeGroot, "Anomalous Absorption of Microwave on Inhomogeneous Plasma"
10:50- 11:05	A-5.	R.J. Faehl and N.F. Roderick, "Intensity Dependence on Inverse Bremsstrahlung in an Inhomogeneous Standing Wave"
11:05- 11:20	A-6.	D.W. Forslund, J.M. [illegible], K. Lee, and E.L. Lindman, "Plasma Stability in the Presence of Extreme Profile Modification"
11:20- 11:35	A-7.	K.G. Eastbrook and W.L. Kruer, "Density Profile Model for Laser Pellet Interaction Codes"

11:35–11:50 A-8. J. Sheerin and R.S.B. Ong, "On the Schrodinger Equation with Exponential Nonlinearity"

11:50–12:05 A-9. V. Cottles and D. Giovanielli, "The Absorption of 1 nsec CO_2 Laser Pulses by Plane Targets"

12:05–2:00 Lunch

SESSION B. WEDNESDAY AFTERNOON, CHAIRMAN, R.S.B. ONG

2:00–5:00 Nonlinear Wave-Plasma Interactions

2:00–2:35 B-1. Invited Paper, N. Peacock, "Nonlinear Interactions Between CO_2 Laser Beams and Dense Plasmas"

2:35–2:55 B-2. C.S. Liu and H.H. Chen, "Nonlinear Theory of Two-Plasmon Decay in Laser-Irradiated Plasmas and Soliton Generation"

2:55–3:20 B-3. H.H. Chen and C.S. Liu, "Nonlinear Theory of Resonance Absorption by Soliton Generation"

3:20–3:30 Coffee Break

3:30–4:05 B-4. Invited Paper, A. Offenberger, "CO_2 Laser Induced Instabilities in Gas Target Plasmas"

4:05–4:20 B-5. J. Meyer and J.R. Myra, "Stimulated Scattering in a Plasma Filling an Optical Cavity"

4:20–4:35 B-6. D. Anderson, "Simple Approach to Some Problems of Resonant Wave Interactions in Inhomogeneous Plasmas"

4:35–4:50 B-7. D.L. Nguyen and K.J. Parbhakar, "Adiabatic Approximation Used in Nonlinear Theory of Backscattering"

4:50–5:05 B-8. D.R. Nicholson and M.V. Goldman, "Two-Dimensional Nonlinear Evolution of Parametric Instabilities"

5:05–5:20 B-9. N.H. Burnett, H.A. Baldis, M.C. Richardson and G. D. Enright, "Harmonic Generation in CO_2 Laser Target Interaction"

SESSION C. THURSDAY MORNING, CHAIRMAN, CLAIRE ELLEN MAX

9:00–12:10 Profile Modification and Resonance Absorption

9:00–9:35 C-1. Invited Paper, J.S. Pearlman, "Plasma Absorption Processes"

9:35- 10:10	C-2.	Invited Paper, J.M. Kindel, C.W. Cranfill, D.W. Forslund, D.B. Henderson, K. Lee, and E.L. Lindman, "Theoretical Calculations of a High Intensity CO_2 Laser Interacting with Fusion Plasmas"
10:10- 10:25	C-3.	I.B. Bernstein, C.E. Max and J.J. Thompson, "Pondermotive Effects"
10:25- 10:35	Coffee Break	
10:35 11:10	C-4.	Invited Paper, D.W. Phillion, W.L. Kruer, and R.A. Lerche, "Determination of the Density Scale Height Near Critical Density by Ellipsometry of the Scattered Light and Measurements of the Time Dependence of the Backscattered Light"
11:10- 11:25	C-5.	W. Woo and J.S. DeGroot, "The Effect of the Instability of the Critical Surface on Laser Absorption"
11:25- 11:40	C-6.	C. Grebogi, C.S. Liu and V.K. Tripathi, "Resonance Absorption in Magnetized Plasmas"
11:40 11:55	C-7.	M.A. Stroscio and E.L. Lindman, "Relativistic Corrections to the Ponderomotive Force and Their Effect on Profile Modification"
11:55- 12:10	C-8.	D. Babonneau and P. Guillaneux, "Conversion and Absorption of an Incident Radiation with Normal Incidence in an Inhomogeneous Plasma"
12:10- 1:30	Lunch	

SESSION D. THURSDAY AFTERNOON, CHAIRMAN, R.R. JOHNSON

1:30- 2:05	D-1.	Invited Paper, G.H. McCall, "Wavelength Effects in Laser Produced Plasmas"
2:05- 5:10	<u>Fast Particles and Related Phenomena</u>	
2:05- 2:40	D-2.	Invited Paper, J.R. Albritton, I.B. Bernstein, E.J. Valeo, and E.A. Williams, "Superthermal Electrons I"
2:40- 2:55	D-3.	E.A. Williams, E.J. Valeo, I.B. Bernstein, and J.R. Albritton, "Superthermal Electrons II"
2:55- 3:10	D-4.	D.C. Slater, "Pinhole Imaging of Fast Ions from Laser-Fusion Targets"

3:10- 3:20	Coffee Break	
3:20- 3:35	D-5.	E.L. Lindman, "Isothermal Rarefaction Waves in Laser-Produced Plasmas"
3:35- 4:10	D-6.	Invited Paper, W.L. Kruer and K. Estabrook, "Heated Electrons and Scattered Photons in Laser Fusion"
4:10- 4:30	D-7.	H. Dreicer, M.E. Banton, J.C. Ingraham, and B.L. Wright, "Observation of Negative Inverse Bremsstrahlung Absorption Due to Large Electron Drift Speed"
4:30- 4:50	D-8.	J.C. Ingraham, M.E. Banton, H. Dreicer, and B.L. Wright, "Transient Growth Phase of Parametric Instabilities for $\omega \gtrsim \omega_{pe}$ and Hot Electron Production"
4:50- 5:10	D-9.	B.L. Wright, M.E. Banton, H. Dreicer, and J.C. Ingraham, "Transient Measurements of Weak-Field AC Resistivity During the Growth of Plasma Turbulence"
6:00	Cocktail Party at Michigan League (across the street from conference building)	
7:00	BANQUET at Michigan League Speaker, Dr. Robert Hofstadter	

SESSION E. FRIDAY MORNING, CHAIRMAN, S. BODNER

9:00- 9:35	E-1.	Invited Paper, T. Sasaki, T. Yamanaka, K. Tanaka, H. Azechi, J. Mizui, and C. Yamanaka, "Compression Experiments on Laser Fusion in Osaka"
9:35- 10:35	<u>Profile Modification and Resonance Absorption</u>	
9:35- 9:50	E-2.	V.C. Rupert, P.H.Y. Lee, J.M. Auerbach, K.R. Manes, and J.E. Swain, "Experimental Determination of Angle Dependent Absorption of Laser Light"
9:50- 10:05	E-3.	J.J. Thomson, W.L. Kruer, W.C. Mead, and C.E. Max, "Theoretical Interpretation of Polarization-Dependent Light Absorption Experiment"
10:05- 10:20	E-4.	A.B. Langdon, "Absorption of Nonuniform Laser Beams"
10:20- 10:35	E-5.	J.G. Ackenhusen, D.R. Bach, P.D. Rockett, and D.G. Steel, "Penetration of an Overdense Z-Pinch Plasma by High-Intensity CO_2 Laser Light"
10:35- 10:45	Coffee Break	

10:45- 11:20	E-6.	Invited Paper, F.J. Mayer, "Recent Absorption and Transport Experiments at KMSF"
11:20- 12:10	<u>Anomalous Transport</u>	
11:20- 11:40	E-7.	R.K. Osborn and T.E. Blue, "Inverse Bremsstrahlung and Electron Thermal Conductivity"
11:40- 11:55	E-8.	W.C. Mead, C.E. Max, and C.F. McKee, "Effect of Transport Inhibition on the Ablation of a Spherical Laser Target"
11:55- 12:10	E-9.	C.E. Max and C.F. McKee, "Derivation of Density Profiles from Jump Conditions in the Flow of Laser Plasmas"
12:10- 1:30	Lunch	

SESSION F. FRIDAY AFTERNOON, CHAIRMAN, C.S. LIU

1:30- 2:50	<u>Magnetic Field Effects</u>	
1:30- 2:05	F-1.	Invited Paper, R.L. Berger, "Anomalous Resistivity of Lower Hybrid Heating of Tokamaks"
2:05- 2:20	F-2.	W. Halverson, N.G. Loter, W.W. Ma, R.W. Morrison, C.V. Karmendy, and J.H. Watts, "CO_2 Irradiation of Solid Targets in High Magnetic Fields"
2:20- 2:35	F-3.	P.B. Bandurian and R.E. Aamodt, "Magnetic Field Gernration in Inhomogeneous and Anisotropic Collisionless Plasmas"
2:35- 2:50	F-4.	M. Porkolab, "Some Aspects of Lower Hybrid Parametric Decay Instability in a Torus"
2:50- 3:00	Coffee Break	
3:00- 4:35	<u>Absorption and Other Experiments</u>	
3:00- 3:35	F-5.	Invited Paper, A. Hasegawa and K. Mima, "Envelope Solitons for Random Phase Waves"
3:35- 3:50	F-6.	B. Grek, T.W. Johnston, F. Martin, H. Pepin, and F. Rheault, "Ruby Laser Diagnostics Accurately Synchronized with the Plasma Created by a Short Pulse CO_2 Laser
3:50- 4:05	F-7.	H. Kuroda, title to be announced

4:05- 4:20	F-8.	W.M. Manheimer and D.G. Colombant, "Further Studies of Laser Absorption by Ion Acoustic Fluctuations"
4:20- 4:35	F-9.	B. Ahlborn and J. Kwan, "Gas Shell Targets for Laser Fusion"

Business Meeting

Additional Papers:

R.L. Morse, "Status of Soviet Laser-Fusion Research"
Time to be announced

V.V. Korobkin, Lebedev Institute "Harmonic Generation in Laser Plasmas"

9:00 a.m. - 12:05 p.m. Wednesday, May 18

SESSION A

Chairman:
R.K. Osborn, The University of Michigan

Abstract for an Invited Presentation at the
7th Annual Anomalous Absorption Conference
University of Michigan, Ann Arbor, Mich.,
May 18-20, 1977

One Theorist's View of Our Current Understanding of the Laser-Plasma Interface in Current Investigations of Inertial Confinement Thermonuclear Fusion using Lasers

Tudor Wyatt Johnston
INRS-Energie, C.P. 1020, Varennes, Québec, JOL 2PO, Canada

While much of the earlier parametric instability analysis on uniform or weakly non uniform systems with application to intense laser irradiation of plasmas retains its intrinsic value, it seems that profile modification effects due to present day lasers require direct inclusion of ponderomotive effects and violent density variation. The WKB era is nearly over and strong nonuniformity is a dominant feature now. Current trends along these lines will be reviewed with some thoughts for the near future. Some key words are surface waves, surface stability, surface solitons, nonlinear stimulated Brillouin scattering.

Laser Fusion Research

at the Naval Research Laboratory

S. Bodner-Invited
Naval Research Laboratory
Washington D.C.

Laser Absorption at High Power*

J. S. DeGroot**, Curt Randall**†, and Wee Woo
Department of Applied Science
University of California
Davis, CA 95616

ABSTRACT

At high laser power ($v_{os}/v_{th} \gtrsim 1$, i.e. $I \gtrsim 2 \times 10^{15}$ W/cm^2 and T_e = 1keV for a glass laser) the density profile is strongly modified by the electromagnetic and electrostatic ponderomotive force. In addition, the steepened density profile near the critical surface is unstable to parametric instabilities which ripple the critical surface. These effects can greatly increase laser absorption. The surface ripples increase absorption because laser fields parallel with the critical surface are resonantly absorbed. In a focused laser beam, there are other profile modification effects which increase absorption. The form of the critical surface and the density profile in the underdense region can be modified so that resonant absorption is increased. We have investigated the absorption of a focused beam using a 2-D hydrodynamics and 3-D electromagnetics code. We assume that the laser is circularly polarized so that the ponderomotive force is axially symmetric. The resonantly excited electrostatic waves are included. We find that for high power ($v_{os}/v_{th} \gtrsim 1$), the initially spherically symmetric density profile is drastically modified. A hole develops in the center of the beam. This concentrates the light and the critical surface is strongly modified. This process greatly increases absorption.

* Work supported by USERDA and LLL under Intramural Order 3233503.

** Also with the Lawrence Livermore Laboratory.

† Fannie and John Hertz Foundation Fellow.

Anomalous Absorption of Normally Incident Microwave on Inhomogeneous Plasma*

K. Mizuno and J. S. DeGroot
Department of Applied Science
University of California
Davis, CA 95616

ABSTRACT

Strong microwaves are incident normally on to a gentle inhomogeneous plasma (inhomogeneous scale length is $L/\lambda_{De} \approx 10^3$). Absorptive parametric instabilities[1] are excited near the critical surface where the microwave frequency ($\omega_0/2\pi$=1.2GHz) equals the plasma frequency. We have observed the spatially resolved time evolution of the waves and the plasma density. The ponderomotive force of the localized waves blows the plasma out of the region near the critical surface, and pushes the critical surface towards the plasma core, which is accompanied by the simultaneous expansion of the instability region. The plasma densities continue to steepen with time until a density plateau adjacent to a sharp step in which the density changes from sub- to super- critical ($0.6n_c$ to $1.4n_c$, n_c is the critical density) is produced. After this density profile is generated, the wave amplitude is greatly reduced ($\langle E^2 \rangle$ can be as small as 20% or less of the peak value) due to the steep density gradient. The strong plasma pressure then prevails over the ponderomotive force so that the plasma density begins to relax. The waves are then pushed back towards the initial region and the wave amplitude again increases. Thus the system shows a kind of relaxation oscillation. The size of the density jump is $\Delta n/n_2 \propto \eta$ in agreement with the theory ($\Delta n = n_2 - n_1$, n_1 and n_2 are the plasma densities of the sub- and the super- critical regions, and $\eta^2 = E^2/16\pi n_0 kT_e$). The anomalous power absorption coefficient, A, increases linearly with microwave power, P, i.e. $A \sim P_0$, for weak microwave powers. The absorption coefficient is roughly constant ($A_{max} \sim 0.2$) in the high power regime where the density is strongly modified. The suprathermal electron density also increases rapidly with P_0 in the weak power regime. The suprathermal heat flux along the direction of the microwave electric field increases as P_{abs}^{α}, where P_{abs} is the absorbed power and α is slightly less than one.

* Work supported by LLL under Intramural Order 3233503 and AFOSR under Contract F 49620-76-C-0014.

1 K. Mizuno and J. S. DeGroot, Phys. Rev. Lett. 35, 219 (1975).

Intensity Dependence of Inverse Bremsstrahlung Absorption in an Inhomogeneous Standing Wave*

by

R. J. Faehl and N. F. Roderick†
University of California
Los Alamos Scientific Laboratory
P. O. Box 1663
Los Alamos, New Mexico 87545

The intensity dependence of inverse bremsstrahlung due to the oscillating velocity of electrons in a laser field, can severely degrade collisional absorption efficiency. Previous work has concentrated on the classical and quantum expressions for the absorption rate. Total absorption requires evaluation of such expressions in the inhomogeneous field structure in the plasma, however. We have undertaken both analytic and numerical calculations to determine the magnitude of the fractional reduction in absorption for the realistic case of an inhomogeneous standing wave. A simple physical model is derived and extrapolated to Airy-like field distributions. Numerical calculations employing fluid simulations with a heuristic intensity dependence closely approximated Silin's[1] expression, were found to be in excellent agreement with the analytic model.

1. V. P. Silin, Sov. Phys. JETP 20, 1510 (1965).

† A.F.W.L., Kirtland AFB, N.M.

*Work performed under the auspices of the U.S. Energy Research and Development Administration.

Plasma Stability in the Presence of

Extreme Profile Modification*

by

D. W. Forslund, J. M. Kindel,
K. Lee and E. L. Lindman
University of California
Los Alamos Scientific Laboratory
P. O. Box 1663
Los Alamos, New Mexico 87545

We consider plasma stability in the regime of strong laser ponderomotive force, i.e., where $v_o/v_e > 1$. A purely growing instability localized at the laser-plasma interface and with a wavelength along the surface the order of the laser wavelength persists in this regime. We will present results on the linear and nonlinear properties of this instability. An extension of analytical work by Sagdeev yields growth rates comparable to those observed in simulation. For incident laser polarization out of the plane of incidence, the saturated state involves the formation of light bubbles. If a component of electric field exists along a density gradient so that resonant absorption hot electrons are produced, bubbles do not form; instead a finite density fluctuation amplitude $\Delta n/n \lesssim O(1)$ is reached such that light is both absorbed and scattered by the density fluctuations. For polarization completely in the plane of incidence, no instability has been observed in simulation.

*Work performed under the auspices of the U.S. Energy Research and Development Administration.

Abstract Submitted

For the Seventh Annual Symposium on the Anomalous Absorption of Intense High Frequency Waves

Ann Arbor, Michigan

May 18-20, 1977

DENSITY PROFILE MODEL FOR LASER PELLET INTERACTION CODES*

K. G. Estabrook and W. L. Kruer
University of California, Lawrence Livermore Laboratory
Livermore, California 94550

Magnetohydrodynamic simulation programs such as LASNEX do not directly model kinetic effects and consequently do not resolve well the density surface from .1 to 5 times the critical density. This talk presents analytic and empirical formulations from one and two dimensional kinetic simulations[1,2,3], combined to predict the time dependent density surface as a function of the initial density, Mi/Me, and dynamic electron temperature and laser power density which can be used by the MHD codes. The positions of the critical and quarter critical surface can be compared with experiments by observing the 3/2 and 2 wO light as a function of time as the Rochester group has done.[4]

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[1] W. L. Kruer, K. G. Estabrook, and K. H. Sinz, Nuc. Fusion 13, 952 (73).

[2] W. L. Kruer, E. J. Valeo, and K. G. Estabrook, Phys. Rev. Letters 35, 1076 (1975).

[3] K. G. Estabrook, E. J. Valeo, and W. L. Kruer, Phys. Fluids 18, 1151 (1975).

[4] S. Jackel, B. Perry, and M. Lubin, Phys. Rev. Lett. 37, 95 (1976).

* Research performed under the auspices of the U.S. ERDA, Contract No. W-7405-Eng-48.

On the Schrodinger Equation

with Exponential Nonlinearity*

J. Sheerin and R. S. B. Ong

The University of Michigan

Ann Arbor, Michigan 48109

Solutions to the one-dimensional Schrodinger equation with a potential exponentially dependent on the field amplitude are studied. In contrast to weakly nonlinear potentials the full exponential nonlinearity saturates where the wave is trapped in the density cavity.

The "steady-state" equation is integrated once in an inertial frame. An analogy with an energy equation is made, and the "potential energy" is plotted as a function of the normalized field amplitude. The value of the integration constant naturally divides the potential into several regimes. A characteristic solution exists in each of these regimes. The value of the minimum of the potential is found in terms of the nonlinear frequency shift. Also the maximum field amplitude is determined as a function of the frequency shift and the constant of integration, the two parameters of the system.

*Work supported by Grant AFOSR-76-2904.

THE ABSORPTION OF 1-NS CO_2 LASER PULSES BY PLANE TARGETS

by

Vernon M. Cottles and Damon V. Giovanielli

University of California
Los Alamos Scientific Laboratory
Los Alamos, NM 87545

Measurements have been made of the value of absorption of short (1-2 ns) CO_2 laser pulses by thick plane targets using a 2 π-10 μm scattered light collection system. The irradiance on the targets ranged from 10^{12} W/cm^2 to 3 x 10^{14} W/cm^2 with the axis of the f/2 pulse focusing system tilted 4 degrees from the target normal. The implied absorption (from the energy balance) for CH_2 is 45 ± 7% over the entire irradiance range explored. The results obtained using plane targets made of Au give the same value with no atomic number effects being discernable. Angular distribution studies of the light scattered at angles greater than 13° (i.e., outside of the focusing optics) indicate that the diffuse scatter is peaked and has its centroid along the laser beam - target normal axis for this geometry. The angular distribution for the azimuthal angle did not show any structure that correlates with the polarization of the incident laser pulse.

2:00 - 5:00 p.m. Wednesday, May 18

SESSION B

Chairman:
R.S.B. Ong, The University of Michigan

Invited Paper

Nonlinear Interactions Between CO_2 Laser Beams and Dense Plasmas

N. Peacock

Abstract Submitted

for the Anomalous Absorption Conference

at the University of Michigan, Ann Arbor

May 18-20, 1977

Nonlinear Theory of Two-Plasmon Decay in Laser-Irradiated Plasmas and Soliton Generation, C. S. LIU and H. H. CHEN, University of Maryland-- Experiments on 3/2 ω_L emission shows a threshold laser power density of about 10^{13} watt/cm^2, above which the emitted intensity increases five orders of magnitude. This threshold is consistent with the theoretical prediction for the two plasmon decay at quarter-critical density. We study here the soliton formation as a saturation mechanism for the two plasmon decay processes and also its effect on the 3/2 ω_L radiation. The level predicted is consistent with the experimental observations. The absorption coefficient due to two-plasmon decay is also obtained, typically a few per cent for the present experimental parameters, but increases with increasing temperature.

Abstract Submitted

for the Anomalous Absorption Conference

at the University of Michigan, Ann Arbor

May 18-20, 1977

Nonlinear Theory of Resonance Absorption by Soliton Generation, H. H. CHEN and C. S. LIU, Univ. of Maryland--Analytic theory of soliton generation at resonance of an obliquely incident radiation in an inhomogeneous plasma is formulated. When pump field exceeds a threshold value, solitons are generated at the resonance. The soliton initially grows linearly in time but the growth is saturated when phase detuning due to inhomogeneity and nonlinearity between the pump and soliton sets in. Subsequently, the saturated soliton convects away and a second soliton starts to grow. With this simple model, we find the absorption coefficient is independent of incident laser power "p" and other plasma parameters. The experimental observation of hot electron temperature dependent on $(P\lambda^2)$ is explained in terms of electron-soliton interaction.

Invited Paper

CO_2 Laser Induced Instabilities in Gas Target Plasmas

A. Offenberger-Invited
University of Alberta, Edmonton

Stimulated Scattering in a Plasma Filling an Optical Cavity

J. Meyer and J.R. Myra

Department of Physics,
University of British Columbia
Vancouver, B.C., Canada

Abstract

Stimulated scattering processes in a homogeneous plasma inside an optical cavity are studied theoretically. In particular, attention is focused on the Raman and Brillouin instabilities. The coupled equations for the wave amplitudes are solved subject to optical cavity boundary conditions, and it is shown that for a wide range of plasma lengths and cavity mirror reflectivities, the threshold values for instability are approximately those for the temporal problem (waves uniform in space, growth or decay in time). Sample results are calculated numerically for the Raman instability in a typical laboratory plasma. Finally, the physical significance of these results is discussed and compared with experimental observations.

Simple approach to some problems of resonant wave interactions in inhomogeneous plasmas.

by D. Anderson , Institute for Electromagnetic Field Theory, Controlled Thermonuclear Fusion and Plasma Physics (EUR-FS), Göteborg, Sweden.

Abstract:

By means of a simple physical approach the maximum amplification of steady state parametric processes in inhomogeneous plasmas is determined for various cases including arbitrary wave dampings. The analysis is based on the concept of a local growth rate which gives explicit expressions for interaction or amplification lengths and accompanying total or maximum amplifications, e.g. we find that for a linearly varying inhomogeneity profile the maximum amplification is given by exp Λ where

$$\Lambda/\Lambda_0 = \frac{2}{\pi}\left[\tan^{-1}\left(\frac{\gamma_0^2}{\Gamma_1\Gamma_2}-1\right)^{1/2} - \frac{\Gamma_1\Gamma_2}{\gamma_0^2}\left(\frac{\gamma_0^2}{\Gamma_1\Gamma_2}-1\right)^{1/2}\right]$$

Λ_0 denotes the total amplification factor in the lossless case, Γ_1 and Γ_2 the damping rates of the parametric waves and γ_0 the growth rate of the corresponding lossless and homogeneous process. For marginally exceeded damping thresholds the maximum amplification is significantly decreased as compared to the lossless result.

We also investigate the full three wave interaction including the equation of the pump wave, but under the simplifying assumption of heavy damping on one of the decay waves. The inhomogeneity in this case inhibits the mode conversion characteristic of a homogeneous situation.

Adiabatic Approximation Used in Nonlinear Theory of Backscattering. D.L. NGUYEN and K.J. PARBHAKAR, INRS-Energie, Université du Québec, 1650 Montée Ste-Julie, Varennes, P.Q. JOL 2PO.

In a homogeneous plasma stimulated scattering processes can in general be described by a three wave nonlinear resonant interaction governed by the equations

$$\frac{\partial w_1}{\partial t} + V_1 \frac{\partial w_1}{\partial x} + \nu_1 w_1 = - K\, w_2 w_3$$

$$\frac{\partial w_2}{\partial t} + V_2 \frac{\partial w_2}{\partial x} + \nu_2 w_2 = K\, w_3 w_1^*$$

$$\frac{\partial w_3}{\partial t} + V_3 \frac{\partial w_3}{\partial x} + \nu_3 w_3 = K\, w_2 w_1^*$$

We have solved the system of equations analytically for a stationary case ($\frac{\partial}{\partial t} = 0$) in a bounded dissipative plasma ($\nu_1 = \nu_2 = 0,\ \nu_3 \neq 0$). The boundary value problem is solved using inner-outer expansion technique. The exact solution is compared to the approximate adiabatic solution which corresponds to outer solution. The domain of validity of the adiabatic approximation is established.

Two-Dimensional Nonlinear Evolution of Parametric Instabilities

Dwight R. Nicholson* and Martin V. Goldman**

Department of Astro-Geophysics,
University of Colorado, Boulder 80309

The processes of laser-pellet fusion and particle beam-pellet fusion are thought to be accompanied by intense levels of Langmuir waves. Under certain circumstances, the temporal and spatial evolution of these waves is described by a nonlinear Schroedinger equation.[1] The physical processes inherent in this equation include three wave interactions, four wave interactions, and soliton collapse. We numerically solve this equation, in time and in two spatial dimensions,[2] for a variety of physical situations. In the case of beam-plasma interaction, our model includes a set of Langmuir waves with fixed wavenumber, growing exponentially due to linear beam-plasma instability. In the case of laser-plasma interaction, our model includes an external dipole pump wave of fixed frequency.

1 V. E. Zakharov, Sov. Phys.-JETP 35, 908 (1972).

2 N. R. Pereira, R. N. Sudan, and J. Denavit, Numerical Study of Two-Dimensional Generation and Collapse of Langmuir Solitons, Cornell LPS-195, August 1976.

* Work supported by National Science Foundation Grant ATM 76-14275.

** Work supported by NSF ATM76-14275 and AFOSR 49620-76-C-0005.

7th Anomalous Absorption Conference

Harmonic Generation in CO_2 Laser Target Interaction

N.H. Burnett, H.A. Baldis,

M.C. Richardson and G.D. Enright

National Research Council of Canada

Division of Physics

Ottawa, K1A 0R6, Canada

ABSTRACT

We report the observation of an extended series of integral harmonic lines in the spectrum of direct backscatter of 10.6 μm radiation incident at intensities $>10^{14}$ W/cm² onto planar solid targets. We have observed and spectrally resolved up to the 11th harmonic (0.95 μm) at intensities well above the Bremstrahlung background. Any emission at 3/2 ω_o (7.07 μm) in the present experiments was at a level at least 10 times less than the 3 ω_o emission or at most 10^{-5} of backscatter at fundamental. This remains an important distinction between 1.06 and 10.6 μm experiments. It seems likely that the higher harmonics are associated with plasma wave generation through optical resonance which has already been proposed as the source of 2 ω_o emission.

9:00 a.m. - 12:10 p.m. Thursday, May 19

SESSION C

Chairman:
Claire Ellen Max, Lawrence Livermore Laboratory

PLASMA ABSORPTION PROCESSES*

Jay S Pearlman
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ABSTRACT

Many absorption processes have been considered for the transfer of laser radiation into plasma energy including resonance absorption, parametric decay and inverse Bremsstrahlung. Resonance absorption is a particularly attractive process because of its potential for efficient deposition of laser light (> 50 percent). The existence of this mechanism has been inferred from indirect observations such as angular distribution of scattered light for strongly focused (f/2) target irradiation. Recently, the first direct measurements of resonance absorption have been completed in which nearly collimated (f/9 focused) laser beams were used to irradiate planar targets at well-defined angles of incidence.[1] By changing the laser polarization with a half wave plate, the polarization-dependent absorption was examined. In addition, the angular variation of the polarization dependence was evaluated by rotating the target.

The measurements of ion expansion characteristics, x-ray temperature and target condition after irradiation all show a statistically significant polarization dependent absorption with an approximately twofold enhancement for p-polarized (resonance absorption) irradiation at 17° incidence angle.

The angular dependence shows peak absorption occurring between 17 and 26° angles of incidence. Using the absorption theory of V. Ginzburg,[2] the plasma density scale length is estimated to be between 0.7 and 2.3 μm. This is to be compared with a scale length of 2.6 μm estimated by assuming an isothermal expansion at 300 eV temperature. An angular variation of s-polarized laser beam absorption was observed which was significantly smaller than that for p-polarized irradiation. The variation with s-polarization may be due, in part, to profile modification near the center of the focal spot. These experimental results are the first observations which directly suggest the existence of resonance absorption.

The presentation will review previous experiments concerning resonance absorption and compare these with the results of recent experiments.

REFERENCES

1. See also J. S Pearlman, "Effects of Incident Laser Beam Polarization on Plasma Absorption," Proceedings of the Sixth Annual Anomalous Absorption Conference, Vancouver, British Columbia, 1976.
2. V. L. Ginzburg, Propagation of Electromagnetic Waves in Plasmas, (Pergamon, New York, 1964).

*This work supported by the U. S. Energy Research and Development Administration.

Invited Paper

Theoretical Calculations of a High Intensity CO_2 Laser Interacting with Fusion Plasmas

J.M. Kindel, C.W. Cranfill, D.W. Forslund,
D.B. Henderson, K. Lee, and E.L. Lindman
Los Alamos Scientific Laboratory
Los Alamos, N.M.

PONDERMOTIVE EFFECTS

Ira B. Bernstein
Yale University
New Haven, Conn. 06520

Claire E. Max and J.J. Thompson
Lawrence Livermore Laboratory
Livermore, Cal.

A B S T R A C T

It is shown by separating the electron kinetic equation into a part changing in time on the scale of the high frequency illumination, and a slowly varying part, that there is an explicit pondermotive force which is just the running short time average of the force density on the electrons, and which can be transformed into the average of the Maxwell stress tensor which appears in the averaged center of mass momentum equation. In addition to the above, which is the familiar result, it is demonstrated that there is an implicit pondermotive effect in the electron contribution to the total averaged stress tensor, and moreover that pondermotive terms appear in the Ohm's law and the expression for the heat flow vector. For the case of mean free path less than wave length and energy gains per mean free path much less mean thermal energy the theory is worked out in detail, yielding a description in terms of transport coefficients.

DETERMINATION OF THE DENSITY SCALE HEIGHT NEAR CRITICAL DENSITY BY ELLIPSOMETRY OF THE SCATTERED LIGHT AND MEASUREMENTS OF THE TIME DEPENDENCE OF THE BACKSCATTERED LIGHT

D. W. Phillion, W. L. Kruer, and R. A. Lerche

Experimental evidence of a steepened electron density profile near critical density has been obtained from studying the light scattered by targets (10-μm thick disks and 100-μm diameter glass microballoons filled with deuterium and tritium gas) illuminated by linearly polarized, 1.06 μm light. Scale lengths on the order of 1 μm have been inferred both from the polarization of the reflected light and from the azimuthal asymmetry (asymmetry about the beam axis) of the time-integrated scattered light with respect to the laser electric field. The azimuthally asymmetric heating of the microballon targets indicated both by x-ray micrographs and by the spatial distribution of the plasma blowoff is consistent with the polarization dependence of resonance absorption.

Evidence for efficient stimulated Brillouin backscatter has been obtained in experiments where parylene and gold disks were irradiated at high intensities and with large scale lengths (4.10^{15} - $2.4 \cdot 10^{17}$ W/cm^2, 40-180 μm spot diameter, 200-400 ps FWHM pulsewidth). These targets reflected as much as 50% of the incident energy back through the f/1 lens and absorbed only 10-20% of the light. At high intensities, the momentum and energy of the ion-acoustic waves, excited by the Brillouin instability and strongly damped by ion trapping, will be quickly deposited in a localized region of the underdense plasma, creating a reflection front[1] where the density profile is nonlinearly steepened. The reflection front will move at supersonic speed into the plasma, eventually turning off the instability. Under experimental conditions where we expect this time to be long compared to the pulsewidth, no time dependence in the back reflected light is observed, while for conditions where the reflection front is expected to have time to move through the underdense region, initially the reflection is large, but drops to a lower value after a time which roughly agrees with estimate.

[1] W. L. Kruer, E. J. Valco. and K. G. Estabrook, Phys. Rev. Lett., Vol. 35, p. 1076 (1975).

Work performed under the auspices of the U.S. Energy Research & Development Administration under contract No. W-7405-Eng-48.

The Effect of the Instability of the Critical Surface on Laser Absorption*

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ABSTRACT

The plasma density profile is strongly modified by high power laser light. Both theory and 2-D fluid computation indicate that both decay and O.T.S. instabilities occur along the critical surface. For angles of incidence larger than a certain value, the decay type dominates and has a maximum growth rate near the backscatter angle. For smaller angles of incidence, shorter wavelength O.T.S. waves grow much faster. For p-polarization, the instability saturates when the inhomogeneity along the critical surface is large enough so that large amplitude electrostatic waves are resonantly excited along the surface which heat the particles. For s-polarization, no saturation mechanism was discovered. However, absorption is increased in 3-dimensions for either s- or p- polarized light. The instability of the critical surface results in density inhomogeneity parallel to the original critical surface. Thus laser fields parallel to the original critical surface resonantly drive electrostatic waves and result in resonant absorption.

* Work supported by Lawrence Livermore Laboratory under Intramural Order Number 3233503.

Abstract Submitted

for the Anomalous Absorption Conference

at the University of Michigan, Ann Arbor

May 18-20, 1977

Resonance Absorption in Magnetized Plasmas, C. Grebogi, C. S. Liu and V. K. Tripathi, University of Maryland, College Park, Maryland--Resonance absorption of an electromagnetic wave incident on an inhomogeneous plasma immersed in a weak magnetic field is calculated for both normal and oblique incidence. Absorption coefficient as a function of the magnetic field strength, scale length and angle of incidence is presented. Nonlinearly, the driven electrostatic waves form upper-hybrid solitons. Their growth, saturation and interaction with electrons are discussed.

Relativistic Corrections to the Ponderomotive Force and their Effect on Profile Modification*

by

M. A. Stroscio and E. L. Lindman
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For CO_2 lasers at 10^{16} w/cm^2 the electron "oscillating velocity" $P/m = e|E_0|/(m\omega) \simeq .6c$. Nonrelativistic treatments of the electron oscillating motion and its consequences are therefore not applicable and relativistic treatments are required. By considering single particle motion in an electromagnetic field with a gradient in intensity, the time-average force on an electron is easily evaluated. For circularly polarized light, the ponderomotive force in the direction of propagation can be evaluated trivially to obtain $F_p = -.5\ mc^2(1+\mu^2)^{-1/2}\ \nabla(\mu^2)$ where $\mu^2 = e^2|E_0|^2/(m\omega c)^2$. For elliptical and linear polarization formulae involving elliptic integrals are obtained. For CO_2 at 10^{16} w/cm^2 the relativistic correction factor $(1+\mu^2)^{-1/2} \simeq .8$. Thus, a 20% reduction is obtained in the circularly polarized case. Similar reductions are obtained in the linearly polarized case. Results for both cases will be presented and their effect on profile modification discussed.

*Work performed under the auspices of the U.S. Energy Research and Development Administration.

CONVERSION AND ABSORPTION OF AN INCIDENT RADIATION WITH NORMAL INCIDENCE IN AN INHOMOGENEOUS PLASMA

D. BABONNEAU and P. GUILLANEUX

Centre d'Etudes de Limeil - B.P. 27 - Villeneuve-St-Georges (France) 94190

We consider an electromagnetic wave normally incident on an inhomogeneous medium.

The $\frac{\vec{V}}{C} \wedge \vec{B}$ force (where B is the wave magnetic field) drives the electrons along the density gradient and produces, this way, a $2\omega_o$ frequency electrostatic component for the field.

At a high electronic temperature, the Landau damping for this component becomes important and leads, near the critical surface, to a signifiant absorption of the radiation (10 - 20 %), while collisional absorption is negligible and resonant absorption does not exist.

1:30 - 5:10 p.m. Thursday, May 19

SESSION D

Chairman:
R.R. Johnson, KMS Fusion

Invited Paper

Wavelength Effects in Laser Produced Plasmas

G.H. McCall
Los Alamos Scientific Laboratory
Los Almos, N.M.

SUPERTHERMAL ELECTRONS I

J.R. Albritton. I.B. Bernstein.* E.J. Valeo,** E.A. Williams
Laboratory for Laser Energetcs
College of Engineering and Applied Science
University of Rochester
Rochester, New York 14627

A B S T R A C T

The reduced quasi-static kinetic equation describing superthermal electrons has been solved analytically for the case of a spherical plasma where the electrostatic force is negligible and the incident distribution is arbitrary. Simple analytic expressions have been obtained for the rate of conversion of superthermal electrons to thermal electrons, the rate of energy transfer from superthermals to thermals, the superthermal pressure, and the superthermal heat flux vector. These can be readily adapted to hydrodynamic calculations of laser plasma dynamics.

The case of non-negligible electrostatic force has been solved numerically. The resulting velocity distribution functions are qualitatively similar to those found when the electrostatic field is negligible. Namely the distribution function at a given point in space tends to be substantially independent of speed for energies less than 0.8 of the energy of injection. A simple analytic criterion is provided as to when the electric field can be neglected.

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SUPERTHERMAL ELECTRONS II

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Rochester, New York 14627

A B S T R A C T

A reduced kinetic equation has been derived describing those electrons of energy so high that to lowest order they move freely in the radial electrostatic field in the outer region of a spherical laser plasma. It is assumed that they bounce many times off the Debye sheath at the edge of the plasma and the centrifugal barrier before they make a collision. The natural variables employed are J, the magnitude of the angular momentum and K, the adiabatic invariant associated with the radial motion. The distribution function f=f(K,J,t) satisfies a diffusion equation in K,J space involving the bounce averaged dominant collision team representing encounters between electrons and high Z ions. The effect of traversals of the critical surface is also included and manifests itself as an effective source.

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Abstract Submitted for
Seventh Annual Symposium on the Anomalous Absorption
of Intense High Frequency Waves

Pinhole Imaging of Fast Ions from Laser-Fusion Targets*

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Pinhole camera images formed by fast ions emitted from spherical glass shell targets uniformly irradiated by 1.06 μm wavelength laser light have been recorded on cellulose-nitrate films. Pinholes of 5 and 9 μm in thin nickel foils have been used with camera magnifications of 4x to 25x. The spatial resolution of the images has been shown to be consistent with the pinhole size. The images are generally circular with diameters varying from 0.3 to 2.2 times the magnified target diameters. For short pulse length laser shots, the size of the image relative to the target size provides the first measurement of the angular distribution of fast ion emission from spherical targets. The observed images indicate that the distribution is peaked in the radial direction, but can be much broader than the distributions measured in planar target experiments.[1] Most present models predict fast ion acceleration only in the radial direction.

Three conclusions can be drawn from the pinhole images. First, the image size relative to the target size increases as the laser intensity increases from 10^{14} to 10^{16} watts/cm^2, indicating that the width of the fast ion angular distribution is intensity dependent. Second, at intensities above 10^{15} watts/cm^2 fast ion tangential velocities are comparable to their radial velocity components. Finally, the difference between image and target sizes grows as the laser pulse length is increased, suggesting that the radius of the fast ion emitting region grows at an average rate of 1 to 2 x 10^7 cm/sec, comparable to the critical density surface expansion velocities predicted by hydrodynamic simulation codes.

1. A.W. Ehler, Journal of Applied Physics, 46 (1975) 2464.

*This research was supported by the United States Energy Research and Development Administration under contract ES-77-C-02-4149.

Isothermal Rarefaction Waves in Laser-produced Plasmas*

by

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When hot electrons are included in an isothermal rarefaction wave, a discontinuity in the density and velocity of the ions in the expanding plasma is obtained. If several ion species are included, peaks in ion probe current traces as a function of time are obtained at velocities corresponding to each species being accelerated through the same potential. Each species undergoes an acceleration at the discontinuity plus further acceleration similar to that obtained in a single-electron temperature isothermal rarefaction wave. The last ions to come through the discontinuity, before the laser stops generating hot electrons and they disappear collisionally, have the highest density and lowest velocity. Free-streaming over a large distance their high velocity compared to those which did not come through the discontinuity leads to a sharp drop in density just behind them at the ion probe. Peaks in the ion current trace are thus generated and the cold part of the ion rarefaction arrives much later. Analytic solutions of the 2-electron temperature isothermal rarefaction wave are multiple-valued requiring a discontinuous transition between slow and fast parts of the density and velocity curves. The use of fast ions to drive pellet implosions will be considered.

*Work performed under the auspices of the U.S. Energy Research and Development Administration.

Abstract Submitted - Invited Paper

For the Seventh Annual Symposium on the Anomalous Absorption

Of Intense High Frequency Waves

Ann Arbor, Michigan

May 18-20, 1977

HEATED ELECTRONS AND SCATTERED PHOTONS IN LASER FUSION*

W. L. Kruer and Kent Estabrook

University of California, Lawrence Livermore Laboratory

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The important role of collective effects in laser plasma experiments is now widely accepted. Although simple models of these effects have given at least semi-quantitative (factor of ≈ 2) agreement with many different experiments[1], many important aspects are still poorly understood quantitatively These include such basic questions as the actual mix of absorption processes, the energy and scaling of heated electrons, and the quantitative role of stimulated scattering. We present some recent results on each of these topics.

A warm wave breaking model is proposed for resonantly-driven plasma waves. We show that the plasma temperature plays an important role in limiting the plasma wave amplitude - an effect not accounted for in the usual wave breaking model even when a steepened scale length is used. Comparison of the model with large 2-D simulations is made, and applications to laser fusion are given. The role of relativistic effects on wave breaking is also briefly discussed.

The role of stimulated scattering is re-evaluated for laser plasma experiments with long pulse lengths and large focal spots. Past experiments with light intensities $\geq 10^{16}$ W/cm^2 (1.06 μ light) have used rather small focal spots and/or short pulses. Because the region of underdense plasma was so restricted, caution must be used in extrapolating these results to experiments with longer pulse lengths and larger focal spots. Such experiments are soon to be common with the advent of lasers delivering terawatts of power. Some estimates are given for cases in which the induced scattering can be sizeable when nonlinear effects are taken into account. Preliminary experimental confirmation is discussed. A simple model of Brillouin scatter which includes the long term effects of ion heating is presented. This ion heating can also have an important, indirect effect on the mix of absorption processes.

Finally an interesting mechanism for the absorption of very intense laser light is discussed. The absorption is termed $J_L \times B_L$ heating, where J_L is the oscillating electron current in the electric field of the light and B_L is its oscillating magnetic field. The heating takes place in the skin of a very overdense plasma and appears to be interesting for very intense light, such as 10^{16} W/cm^2 (CO_2 laser).

[1]R. A. Haas et. al, Phys. Fluids 20, 322 (1977).

*Research performed under the auspices of the USERDA, Contract No. W-7405-Eng-48.

OBSERVATION OF NEGATIVE INVERSE BREMSSTRAHLUNG ABSORPTION DUE TO LARGE ELECTRON DRIFT SPEED*

H. Dreicer, Martin E. Banton, J. C. Ingraham, and B. L. Wright
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A high Q microwave resonator is used to observe inverse bremsstrahlung absorption by a fully-ionized plasma in which the electrons drift with an average speed, v_D, relative to the ions. The experiment is carried out for $(\omega_{pe}/\omega)^2 < 1$ on a single-ended Q-machine plasma in which the electrons are suddenly accelerated by a fast-rising (< 0.1 μs), positive voltage pulse applied to the cold collector plate of the Q-machine. This pulse is short enough (0.4 μs) to avoid Buneman instability and minimize ohmic heating. The plasma absorption rate is deduced from the decay rate of energy stored in the TM_{010} mode of the resonator after excitation by a short (100 ns), low level microwave pulse tuned to the resonant frequency of the mode. The observed absorption for $v_D = 0$ agrees with the positive inverse bremsstrahlung absorption rate computed for non-drifting Maxwellian electrons. Application of the acceleration pulse reduces the observed plasma absorption. Our results indicate that as v_D is increased further the absorption actually becomes negative, that is, stimulated emission predominates over stimulated absorption. Electron current and density measurements show that the transition from positive to negative absorption occurs for $mv_D^2/(2kT_e) \gtrsim 1$ in agreement with computational results to be presented.

*Work performed under the auspices of the U.S. Energy Research and Development Administration.

TRANSIENT GROWTH PHASE OF PARAMETRIC INSTABILITIES FOR $\omega \gtrsim \omega_{pe}$ AND HOT ELECTRON PRODUCTION*

J. C. Ingraham, Martin E. Banton, H. Dreicer, and B. L. Wright
University of California, Los Alamos Scientific Laboratory
Los Alamos, New Mexico 87545

A study of the transient growth phase of the oscillating-two-stream (O-T-S) and parametric decay (P-D) instabilities and the resultant hot electron production is carried out for $\omega^2 \cong 1.1\ \omega_{pe}^2$ using a high Q resonator surrounding a Q-machine plasma column. The electric field of the TM_{010} resonator mode is used as a pump for the instabilities and is suddenly driven above the threshold for instability by a 0.2 μs pulse of microwave power. After termination of the excitation pulse, the pump energy first decays at a rate determined by classical electron-ion collisions in the plasma and skin-depth losses in the resonator walls. If the peak pump power is driven sufficiently far above the instability threshold, then we find that this early decay is suddenly followed by a more rapid decay due to anomalous absorption. The onset of anomalous absorption is observed to occur earlier as the peak pump power is raised. Strong non-thermal heating of the electrons is also observed to occur primarily after the period of strong anomalous absorption and results in a pronounced bump-in-tail velocity distribution. We analyze the period of anomalous absorption prior to the production of hot electrons using a model that assumes all anomalously-absorbed pump energy goes into plasma wave energy, that no wave energy leaks out of the resonator, and that these waves are damped only by collisional and Landau damping. We thus obtain the growth rate and absolute amplitude of the unstable waves as a function of time, or pump power. We find that these deduced growth rates agree well with the predicted O-T-S and P-D growth rates, but the unstable wave energy density can reach levels more than a factor of 10 greater than the pump energy density. This latter result is probably related to the fact that the pump energy density occupies a much larger volume in the resonator than does the wave energy density.

*Work performed under the auspices of the U.S. Energy Research and Development Administration.

TRANSIENT MEASUREMENTS OF WEAK-FIELD AC RESISTIVITY DURING THE GROWTH OF PLASMA TURBULENCE*

B. L. Wright, Martin E. Banton, H. Dreicer, and J. C. Ingraham
University of California, Los Alamos Scientific Laboratory
Los Alamos, New Mexico 87545

By using a high-Q, dual-mode resonator surrounding an alkali plasma column, we have made simultaneous measurements of the absorption in a plasma of strong (driver) and weak (test) electromagnetic fields. These two microwave fields differ from each other slightly in frequency ($\Delta f = \pm$ 15, $\pm$ 28 MHz) with an average frequency (f_{ave} = 2100 MHz) somewhat above the plasma frequency. As the driver field is pulsed to power levels exceeding the threshold for parametric instabilities, it exhibits enhanced absorption and a controllable level of plasma turbulence is produced. We measure the effects of this turbulence on the absorption rate of the subthreshold test field. The data reported emphasize transient phenomena observed during the onset of the ac parametric instabilities induced by the driver field. The onset is characterized by a sudden decrease in the driver field's energy (pump depletion) and by the rapid growth of plasma waves. During the onset, the ac resistivity measured with the weak test field is greatly enhanced relative to its classical, collisional value--even when the test field frequency is above that of the driver field (and hence outside the normal Stokes spectrum of parametrically unstable plasma waves). We also observe that the test field absorption rate is independent of test field amplitude. The data suggest that the spectrum of growing, unstable waves is substantially broadened and that this results in the brief appearance of plasma waves at frequencies above that of the driver field. We shall discuss the possibility that enhanced absorption of the weak test field is due to a decay process stimulated by the driver-produced plasma waves.

*Work performed under the auspices of the U.S. Energy Research and Development Administration.

Thursday, May 19

6:00 p.m.	Cocktail Party Michigan League
7:00 p.m.	Banquet Michigan League Speaker: R. Hofstadter, Stanford University

9:00 a.m. - 12:10 p.m. Friday, May 20

SESSION E

Chairman:
S. Bodner, U.S. Naval Research Laboratory

COMPRESSION EXPERIMENTS ON LASER FUSION IN OSAKA

T. Sasaki, T. Yamanaka, K. Tanaka, H. Azechi, J. Mizui*,

and C. Yamanaka

Institute of Laser Engineering, Osaka University, Osaka, 565, Japan

*Institute of Plasma Physics, Nagoya University, Nagoya, 464, Japan

We have performed two types of the experiments to investigate the energy transportation and the implosion process as well as to get the information of pellet design. The first is a physical simulation experiment of compression using multilayer thin film targets. The second is a spherical compression experiment of various microballoon pellets pressurized by deuterium gas. Two beam glass laser system whose energy is 30J in 30psec was used.

1. Anomalous transparency (Ausaka effect)

Metal coated thin film of polyethylene (4μm thick) was used as a target. The specular reflection, the transmitted laser light and the energy distribution of plasma particle were measured. When the laser beam came from the polyethylene side, the transmitted laser was almost constant about 1% of the incidence at the laser intensity of 10^{14} - 10^{15} W/cm^2. The polyethylene target without metal coating showed the same result. But when the laser beam came from the metal side, the transmittance had a maximum and the specular reflection showed a minimum at the laser intensity of 4×10^{14} W/cm^2. The transmittance increased from 16% to 50% proportional to the thickness of the nickel in the range of 1~ 4μm. This effect is partly related to the transportation of light through the filamentation in plasma. But at present we do not understand the detail mechanism of this enhanced transimission

2. Compression of microballoon

Using SHG laser light, we have measured the fundamental process of pellet compression by laser. At the early period of compression (150ps after main laser irradiation), we could clearly see the spherical shock front going to the center with the velocity of 5×10^7 cm/s. In a time of sub-nsec, a whole balloon was plasmarized whose density was beyond the cutoff, then it became opaque. The focusing condition was very critical to have uniform compression. The compression ratio of deuterium filled glass microballoon the diameter of which was 60μm reached about 100.

Multi layer pellet target is now under investigation to clearify the influence of ausaka effect.

(references)

1) C. Yamanaka et al : IAEA Conference on Plasma Physics and Controlled Thermonuclear Fusion, CN 35/F5 (1976)
2) C. Yamanaka et al : Annual Progress Repts., Inst. Laser Eng. Osaka Univ. ILE-APR-76 (1976)

EXPERIMENTAL DETERMINATION OF ANGLE DEPENDENT ABSORPTION OF LASER LIGHT*

V. C. Rupert, P. H. Y. Lee, J. M. Auerbach

K. R. Manes, and J. E. Swain

Lawrence Livermore Laboratory

University of California

Livermore, California 94550

ABSTRACT

Angle dependent absorption of laser radiation was determined experimentally using planar targets and a f/10 lens to illuminate the targets. The well characterized Janus 1.06 μm laser beam was focused on parylene disks which were tilted with respect to the incident beam up to 60°. Both p and s polarizations were investigated. Absorption was determined by light energy balance using calorimeters which covered more than 96% of 4π around the target. Each calorimeter used is capable of an accuracy of 1% or better. Experiments were conducted at irradiation levels of a few 10^{15} W/cm^2 where inverse Bremsstrahlung absorption is expected to be small compared to angle dependent absorption mechanisms such as parametric instabilities and resonance absorption. The use of both s and p polarized light enabled us to unambigously separate these two phenomena. Experimental results are described and compare favorably to the theoretical models proposed by Kruer et.al.

*Work performed under the auspices of the U.S. Energy Research and Development Administration under Contract No. W-7405-Eng-8.

Abstract Submitted

For the Seventh Annual Symposium on the Anomalous Absorption of Intense High Frequency Waves

Ann Arbor, Michigan

May 18-20, 1977

THEORETICAL INTERPRETATION OF POLARIZATION-DEPENDENT LIGHT ABSORPTION EXPERIMENT*

J. J. Thomson, W. L. Kruer, W. C. Mead, and C. E. Max

University of California, Lawrence Livermore Laboratory

Livermore, California 94550

Plasma theory indicates a significant polarization and angle dependence for the absorption of intense light obliquely incident on a planar plasma. Absorption due to inverse bremsstrahlung and parametric decay, while not polarization dependent, decrease with increasing angle. Resonance absorption occurs only in the p-polarization, and maximizes for a certain finite angle of incidence. While these effects have been seen in plasma simulations, the experimental situation is not so clear. An experiment has been performed at LLL to test the polarization and angular dependence of absorption. We include in our analysis of this experiment the following non-linear effects: 1) steepening of the plasma gradient; 2) deformation of the critical surface due to beam ponderomotive force; and 3) rippling of the critical surface. These effects tend to broaden the theoretical p-polarization absorption curve and lower peak absorption, as seen experimentally. We show comparisons between theory and experiment for both polarizations.

*Research performed under the auspices of the United States Energy Research and Development Administration, Contract No. W-7405-Eng-48.

Abstract Submitted

For the Seventh Annual Symposium on the Anomalous Absorption
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Ann Arbor, Michigan
May 18-20, 1977

ABSORPTION OF NONUNIFORM LASER BEAMS*

A. Bruce Langdon

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Light incident on laser fusion targets commonly contains intensity irregularities with localized "hot spots" a few wavelengths in size. This structure leads to nonuniformity in the expansion of the heated plasma. As a result one expects a decreased sensitivity of absorption to angle of incidence (for example an increase in absorption at normal incidence) and a cone of reflected light wider than for the incident light. Both of these features are seen in recent experiments. The polarization dependence of the structure of the critical surface we have discussed previously is considered in an extreme example of a narrow filament of light penetrating a few wavelengths past the critical surface. Computer simulations with the ZOHAR plasma code examine aspects of these topics.

*Research performed under the auspices of the United States Energy Research and Development Administration, Contract No. W-7405-Eng-48.

Abstract Submitted
for the
Seventh Annual Symposium on the
Anomalous Absorption of Intense High
Frequency Waves

May 18 - 20, 1977
Ann Arbor, Michigan

Penetration of an Overdense Z-Pinch Plasma by High-Intensity CO_2 Laser Light*

John G. Ackenhusen, David R. Bach,
Paul D. Rockett** and Duncan G. Steel‡

The University of Michigan, Ann Arbor, Michigan

ABSTRACT

We are investigating the transmission of radially incident, high intensity (2×10^{11} W/cm^2, 38 nsec) CO_2 laser light through an overdense, low temperature ($T_e < 25$ eV) helium Z-pinch plasma. The important diagnostics include temporal and spatial examination of the transmitted beam and time-resolved UV holographic interferometry. The plasma, produced independently of the laser, is characterized in part by a critical scale length $N_c/\nabla N_e$ as short as 100 μm. The electron quiver velocity in the oscillating laser field is thus comparable to the thermal velocity. This regime is similar to that found in laser pellet experiments. A sequence of interferograms and comparison of transmitted and incident laser pulse shapes indicate the evolution of the interaction. Enhanced plasma continuum emission provides evidence for laser absorption. Fresnel rings on the transmitted beam suggest that a hard aperture in the plasma is produced by the laser.

*Work supported in part by the National Science Foundation, AFOSR, and The University of Michigan, College of Engineering.

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Invited Paper

Absorption and Transport Experiments at KMSF

Frederick J. Mayer
KMSF
Ann Arbor, Michigan

Inverse Bremsstrahlung and Electron Thermal Conductivity

R.K. Osborn and T. E. Blue

It has been shown[1] that plasma collective behavior can significantly modify laser light absorption by inverse bremsstrahlung, This same phenomenon may well also substantially influence electron thermal conduction. The plasma kinetic equations - from which the hydrodynamic equations are usually derived - include electron-photon collisions as well as particle-particle collisions. Thus electron-photon collisions will contribute to the electron thermal conductivity - crudely according to $\lambda = \lambda_s/(1+\nu_B/\nu_{ei})$, where λ_s and ν_{ei} are the usual "Spitzer" conductivity and electron-ion collision frequency respectively and ν_B is a net inverse bremsstrahlung collision frequency. The ratio, ν_B/ν_{ei}, is intensity dependent and can become quite large in the vicinity of the critical density surface. Thus electron thermal conduction may be considerably reduced in the region of strong absorption.

1. Richard K. Osborn, IEEE Trans. on Plasma Science, PS-3, 116 (1975).

Abstract Submitted

For the Seventh Annual Symposium on the Anomalous Absorption

of Intense High Frequency Waves

Ann Arbor, Michigan

May 18-20, 1977

EFFECT OF TRANSPORT INHIBITION ON THE ABLATION OF A SPHERICAL LASER TARGET*

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We derive analytic solutions for plasma flows in a spherical laser target. Electron thermal conduction is found to be classical near the ablation front, but can be flux-limited near the critical surface under conditions typical of fusion irradiations. Characteristics of the plasma flow, such as the Mach number and ablation rate, are shown to depend sensitively on the degree of transport inhibition in the flux-limited regime. Our theory yields new scaling laws for the ablation properties of a spherical target. We compare our analytic solutions with computational results from 1-D hydrodynamics calculations, and give some guidelines on when the steady-state theory may be expected to agree with the full hydrodynamical results.

*Research performed under the auspices of the United States Energy Research and Development Administration, Contract No. W-7405-Eng-48.

†Permanent Address: University of California, Berkeley, CA.

Abstract Submitted

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DERIVATION OF DENSITY PROFILES FROM JUMP CONDITIONS IN THE FLOW OF LASER PLASMAS*

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Abstract

We show that steady state density profiles at the critical density may be divided into three categories, depending on the size of the outflow velocity relative to the critical surface. Flow velocities which are sufficiently subsonic produce ordinary profile-steepening. Flows which are sufficiently supersonic result in a shock-like compression just beyond the critical surface. There is a range of intermediate flow velocities for which no steady-state profile exists.

*Research performed under the auspices of the United States Energy Research and Development Administration, Contract No. W-7405-Eng-48.

†Permanent address: Physics Dept., University of California, Berkeley, CA.

1:30 - 4:35 p.m.

Friday, May 20

SESSION F

Chairman:
C.S. Liu, University of Maryland

Invited Paper

Anomalous Resistivity of Low Hybrid Heating of Tokomaks

R.L. Berger-Invited
Princeton University

CO_2 LASER IRRADIATION OF SOLID TARGETS IN HIGH MAGNETIC FIELDS*

W. Halverson, N.G. Loter, **W.W. Ma, **R.W. Morrison, † C.V. Karmendy, ** and J.H. Watts**

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Gain-switched CO_2 laser pulses are focused onto solid planar targets with strong magnetic fields parallel to the beam-focusing axis and perpendicular to the target surface. The mass loss induced by 225 J pulses on carbon targets is reduced more than 20-fold by the application of a 100 kG field. Above 20 kG, the mass loss and the cross-sectional area of the blow-off plasma approximately follow a power law of $B^{-1.2}$.

Plasma diagnostics include an image-converter camera, an optical spectrometer, a simple x-ray camera, and differential soft x-ray detectors to measure the electron temperature. The electron temperature of the plasma close to the carbon targets is 250 to 350 eV during the gain-switched spike of the laser-pulse and has a rapid temporal and spatial decay at all values of the magnetic field. At fields greater than 30 kG, a strongly radiating plasma is partially confined for periods up to 300 nsec in a region extending several cm from the target. The time of formation of this plasma, whose electron temperature is approximately 100 eV, is reduced with increasing magnetic field. The dependence of the plasma cross section and mass loss on magnetic field can be interpreted in terms of an adiabatic model of the plasma expansion against the magnetic field.

We will present results of experiments conducted with the magnetic field parallel to the target. These experiments will partially simulate the effects of self-generated magnetic fields on the dynamics of laser-pellet plasmas.

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** Also Physics Department, M.I.T.

† Permanent address: Physics Department, Carleton University, Ottawa, Ont., Canada.

‡ Supported by the National Science Foundation.

Magnetic Field Generation in Inhomogeneous and Anisotropic Collisionless Plasmas.*

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The interaction of intense radiation with a plasma creates temperature anisotropies and modifies particle density gradients. Both of these radiation induced processes produce free energy sources which have the potential for collisionlessly generating transverse wave instabilities. We have developed a self consistent, inhomogeneous, collisionless plasma model which determines the linear dispersion relation for unstable waves including the effects of energy flux gradients on instability modes of the Weibel type. Numerical solutions of the dispersion relation, within the usual local approximation, along with a physical description of the instability mechanism produced by spatial gradients will be presented. This physical picture dictates the relevance of this collisionless-instability phenomenon in explaining the intense magnetic fields observed in various laser-pellet experiments.

* Work supported in part by the U.S. ERDA, under Contracts Nos: EY-76-S-02-2081 and AT-(04-3)-1018.

SEVENTH ANNUAL ANOMALOUS ABSORPTION CONFERENCE

18-20 May 1977

The University of Michigan, Ann Arbor, Michigan

<u>Some Aspects of Lower Hybrid Parametric Decay Instability in a Torus.</u>* M. PORKOLAB, <u>M.I.T.</u>--We examine two effects associated with parametric decay instabilities near the lower hybrid frequency. (1) Influence of magnetic shear upon the threshold, and (2) saturation of short wavelength decay waves due to orbit diffusion. We find that the effect of magnetic shear is to introduce radial convective loss which yields a threshold $U^2/C_s{}^2 = Q(m_i/m_e)^{1/2}/kL_s$, where $U = CE_0/B$ is the $E \times B$ drift velocity, C_s is the acoustic speed, Q is a coefficient of order unity, and L_s is the shear length. The effect of orbit diffusion is to smear out the coherence of orbits and to introduce perpendicular ion Landau damping. This will provide a stabilizing effect which tends to saturate the decay instability at levels $\varepsilon/\varepsilon_{th} = R\ (\Omega_i/\omega_{pi})^2$, where $R = (\omega_2/k_\perp V_{ti})$ if $R >> 1$, and $R = (\Omega_i/k_\perp V_i)$ if $R << 1$.

*This work was supported by the U.S. Energy Research and Development Administration (Contract EY-76-C-02-3070*000)

Submitted by

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ENVELOPE SOLITONS FOR RANDOM PHASE WAVES

by

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ABSTRACT

A general property of envelope of random phase waves in nonlinear dispersive media will be presented using the wave kinetic equation. Bernstein-Greene-Kruskal solutions for the phase space density $f(\underset{\sim}{k},\underset{\sim}{r},t)$ of waves are obtained for 1, 2 and 3 dimensional cases. Solitary wave polutions are also obtained from the moment equations of the wave kinetic equation and are compared with those of coherent waves (nonlinear Schrondinger equation.

* Permanent Address: Osaka University, Osaka, Japan

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Ruby Laser Diagnostics Accurately Synchronized with the Plasma Created by a Short Pulse CO_2 Laser

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The synchronous mode locking and pulse selection of the output from a short pulse CO_2 laser (1.7 nsec, 10 J) used for target irradiation and that of a shorter pulse (30 ~ 50 psec) diagnostic ruby laser has been achieved. The active mode-locking components for each laser oscillator are driven from a common source. Time displacement can be obtained readily with an electrical delay line and relative jitter is certainly better than 200 psec. Sequences of Schlieren photographs and, hopefully, holographic interferograms of the CO_2 laser produced plasma will be presented demonstrating some of the capabilities of the system.

This work is supported by Negotiated Development Grant D-59 from the National Research Council of Canada and by individual grants to Grek, Johnston and Pépin.

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Title to be Announced

Further studies of Laser Absorption
by Ion Acoustic Fluctuations.

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This paper reports on our continuing studies of a new class of absorption mechanisms[1] in a laser produced plasma. In an unmagnetized plasma, the electron thermal energy flux into the dense plasma is balanced by a return current of low velocity electrons into the underdense plasma. This return current can be unstable to ion acoustic wave turbulence propagating toward the laser. These self-generated ion fluctuations can give rise to strong anomalous absorption of the laser light.
For a magnetized plasma, the return current flows perpendicular to both the magnetic field and temperature gradient. In this case, the wave vector of the unstable ion acoustic wave can be parallel to the electric field of the laser light. This can give rise to even stronger absorption. Calculations of fractional absorption and energy flux limitation will be presented for magnetized and unmagnetized plasma.

1. W.M.Manheimer,D.Colombant,B.Ripin,Phys.Rev. Letters, in press

Gas Shell Targets for Laser Fusion

by

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The properties of a gas shell target generated with a laser blast wave prepulse (energy E_o) in a background gas (density ρ_o) are discussed with an analytical model. The "target" gas inside the shell is the rest of the laser fireball established initially and the high density shell is the shock compressed background which surrounds the laser plasma at a later time. It is assumed that the main laser pulse establishes an ablation front at the outer edge of the gas shell, driving a shock radially inwards which compresses the target gas inside. We find that the maximum pressure generated at the center scales as $p_m \sim W^{2/3} \Delta t^{6/5} E_o^{-2/5} \rho_o^{-4/15}$, where W is the power of the main laser pulse and Δt the time interval between prepulse and main pulse.