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CONFERENCE REPORT FOR NUCLEAR FUSION PHENOMENA IN IONIZED GASES

BY

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Conference Report for Nuclear Fusion

PHENOMENA IN IONIZED GASES

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ABSTRACT

A summary of the Conference on Phenomena in Ionized Gases, held in Eindhoven, The Netherlands, is given. In particular, the format of the conference, and the content of the review papers is summarized.

This conference in Eindhoven represented the twentieth year anniversary of similar conferences held every two years on the topics of gas discharge and plasma physics. The first of these conferences was also held in The Netherlands. Since then, a considerable evolution of plasma physics occurred. Basically, the aim of the organizing committee was to combine both gas discharge physics and plasma physics approximately equally. However, of the total of 397 contributed papers, only 131 were on plasma physics. Of the thirteen invited papers, eight were concerned with plasma physics and controlled fusion research.

This year a completely new conference format was tried: approximately one-third of the contributed papers were presented orally, and the rest of the papers were displayed in poster form in the main hall. The contributed papers given verbally consisted of fifteen-minute talks, while each of the invited lectures was allowed a total of one hour.

The contributed papers were presented in two simultaneous sessions: one was mainly aimed at discharge physics and atomic (ionization) phenomena, while the other session contained mainly plasma physics papers. The invited talks included three general invited lectures and eleven topical invited lectures (none of them conflicted with each other in time). These lectures summarized some of the important recent developments in a given specific area of discharge and/or plasma physics research.

The format of this conference, in this reviewer's opinion, was an excellent one. By placing a good fraction of the papers on posters and by making available the texts of all the contributed papers before the conference allowed one to listen to all of the plasma physics papers presented verbally. In addition, there were several interesting discussion sessions in the late afternoons on specific topics of interest. One day of the conference was spent on field trips to various laboratories in The Netherlands. The local organizing committee did an excellent job of ensuring continuity in the case of absent speakers, and the facilities at the conference site were outstanding. Perhaps the only suggestion this reviewer could make is that, since both the Conference on Ionization Phenomena and the European Conference on Plasma Physics and Controlled Fusion are held every second year, it would be best if these conferences were held in alternate years (rather than two weeks apart, as in the present case).

In Table I below, we present the invited talks, including both the names of the speakers and the title of the papers. In Table II we present the specific topics in plasma physics which were discussed and the number of related papers presented. In the last row we also include the topics of the discussion sessions.

TABLE I.

INVITED TALKS

General Invited Lectures

R. S. Pease:	Experimental Guide-lines in Controlled Thermonuclear Research
W. P. Allis:	Review of the Glow to Arc Instability
R. Pellat:	Interaction of Articial Electron Beams with the Ionospheric Plasma

Topical Invited Lectures in Plasma Physics

D. E. Evans:	Laser Diagnostics in Plasma Research
H. Wilhelmson:	Wave-Wave Intereaction in Plasma
M. Porkolab:	High Frequency Parametric Wave Phenomena and Plasma Heating
D. C. Montgomery:	Plasma Kinetic Processes in a Strong D. C. Magnetic Field.
V. N. Tsytovich:	Strong Interaction of Relativistic Electron Beams with Plasma and Gas
R. Wienecke and G. Decker:	Plasma Focus Devices

Topical Invited Lectures in Discharges and Elementary Processes

D. C. Lorents:	The Physics of Electron Beam Excited Rare Gases at High Densities
J. Uhlenbusch:	Miscellaneous Arc Devices
J. Polman:	Recent Developments in Low Pressure Gas Discharge Research
C. Manus:	Collisions of Excited States in Ionized Media
V. N. Kolesnikov:	Spectroscopic Measurements of Pulsed Discharges

TABLE II

TOPICS IN PLASMA PHYSICS

	No. of Papers
Radiation	
(a) Optical measurements	15
(b) Scattering	6
(c) Diagnostic Methods	16
Wave Particle Interaction	14
Waves, Wave-Plasma Interaction	
(a) Wave Propagation, Excitation, Damping	24
(b) Wave-Wave Interaction	10
(c) Turbulence, Turbulent Transport	7
Theory	
(a) Statistical and Thermodynamic Theory	7
(b) Transport and Kinetic Theory	10
Laser Crested Plasmas, Dense Plasmas, Relativistic Electron Beams	22
Informal Discussion Sessions	
(a) Laser-Plasma Interaction	
(b) Strong Turbulence Phenomena	
(c) Laser Diagnostics	

We shall now give a summary of those aspects of the invited talks which may be of interest to the readers of Nuclear Fusion. The contributed papers have been published already (North Holland Publishing Co., 1975), and so we will not discuss them here. In particular, in this reviewer's opinion, the numerous review papers gave a good summary of the present status of plasma physics research.

SUMMARY OF REVIEW TALKS

1. Fusion Research

R. S. Pease (Culham, England) gave a detailed summary on the present status of controlled fusion research. A number of fusion devices presently pursued at various laboratories were discussed (mirrors, multiples, stellarators, pinches, toroidal pinches). He also briefly mentioned the laser-pellet type fusion concept (inertial confinement). A brief summary of the present status of MHD stability theory was given. (Well understood, except perhaps the cause of the disruptive instability in tokamaks.) Much of the talk was concentrated on tokamaks, which, according to the speaker, was our best bet at the present time to achieve controlled fusion. However, he emphasized that other confinement schemes should also be pursued until we achieve the Lawson criterion. The best results on tokamaks to date are those obtained on TFTR (France), with maximum temperatures of $T_e \simeq 3$keV, $T_i \simeq 1$keV. Although initially fluctuations are present in tokamak devices, they become stabilized as the discharge builds up. This "self healing" may be due to (a) formation of a mean magnetic well, allowing a high β_θ; and (b) for $q > 1$ the discharge connects itself to the outer layer without instability (speculative reason). However, experiments at

San Diego show that stable plasma can be achieved even when the walls are well away from the plasma. At the present time there is relatively good agreement between the observed ion temperature and neoclassic theory. However, the confinement time of particles is still not well understood (even the sign of the particle flux may be in disagreement with theory). There is also complete disagreement of neoclassic theory with the observed electron energy confinement time (by a factor of 100 too fast). This may be due to (a) initial creation of plasma, (b) trapped electron mode, (c) other mechanisms.

Important near-term goals include auxiliary heating schemes (neutral beam injection and rf heating). Another very important development in the near future in toroidal research will be the start-up of the PLT (Princeton) and T-10 (Moscow) tokamak devices (in a few months). Since the electron energy confinement is not understood, these new devices will give us crucial information concerning the scaling of confinement time with machine size. In particular, if diffusion is caused by microinstabilities, we get $\tau_{conf} \simeq L^2$, so that in the new devices confinement times of the order of $\tau \approx 0.1$ sec should be possible.

Then the next generation of devices (for example, the European JET) could achieve a confinement time of one second. He concluded his talk by emphasizing the present date optimism versus the discouraging results of the 1950's.

2. Diagnostics

D. E. Evans summarized the present status of both incoherent and collective laser shattering diagnostics for (a) measuring electron and ion temperatures, (b) measuring fluctuations. In particular, the following problems remain in conventional Thompson scattering techniques:

(i) Elimination of stray light; here important new development have been made at Los Alamos by using a series of gratings instead of limitors, etc. Using such techniques, rejection ratios of 10^{10} 10^{12} have been achieved. Thus, no stops or beam dumps are necessar

(ii) Continuous measurement of T_e. Here new techniques have been developed at Fontenay Aux Roses (Mettioli and Popoular) by using Ar ion lasers with 100 watts power (uses multireflection techniques with mirrors and 10-watt commercial laser). Thus, it appears that temperature readings can be taken at every 10^{-2} sec (over a JET-like tokamak lifetime of 1 sec). Another possible technique (although no better than the Ar^+ laser) is a 10 kW CO_2 laser (Evans, Culham);

(iii) Calculations were presented showing that above 1 keV temperature relativistic effects will be important in interpreting Thomson scattering data. For example, at 1 keV an error of 25% is introduced, whereas at 2 keV an error of 40% could be introduced

(b) In proposed collective scattering experiments one could measure T_i, impurities, and turbulence by using long wavelength infrared lasers (CO_2, CH_3F, D_2O, HCOOH). The ion temperature is obtained from the thermal (assumed) ion acoustic spectrum. For ion temperature measurements one needs to scatter from ion fluctuations with $K\lambda_d \simeq 1$, which for JET parameters corresponds to 0.5^o to 5^o scattering angles (using a CO_2 laser of $\lambda_\ell = 10.6\mu m$).

The spatial resolution may not be very good (10-40 cm along the laser light), but one could perhaps scan in two radial directions at right angle. One would use heterodyne detection techniques, and pulse powers of some MW's would be necessary, depending on the desired integration times. At present at least two groups (Gondalekhar et al at Stuttgart and Gehre et al at Garching) have obtained 30-50 kW single mode CO_2 pulses by combining a CW and a TEA (pulsed) laser in the same cavity. In the case of molecular lasers CH_3F ($\lambda_\ell \simeq 496\mu m$) appears to be the most promising (MIT, Culham). Moreover, the scattering angle for JET would be 30^o, giving good localization. However, detectors are not yet available with sufficient bandwidth (although they are being developed fast using Schottkey diodes or the Josephson effect type detectors (MIT)). At present the maximum power obtained with CH_3F is about 1 MW pulsed, but many lines are present. For collective scattering it is essential to use a single mode laser so that heterodyne detection may be utilized. Due to the fast development in this field it is hoped that a choice could be made between CO_2 or CH_3F lasers within the next few years. Such scattering techniques could be also utilized to (a) measure suprathermal fluctuations, and (b) obtain information about impurities which would modify the ion acoustic lines.

3. Wave-Wave Interaction in Plasmas

H. Wilhelmsson summarized the present status of theory of nonlinear wave-wave interaction in plasma. First, he reviewed the nonlinear interaction of coherent waves, including explosive instabilities, saturation due to nonlinear phase shifts and dissipation. He then considered stimulated Raman and Brillouin scattering, including pump depletion and incoherent pump. A numerical analysis of the problem of transition between a coherent wave state and a random phase state was also described.

Finally, the process of nonlinear wave-particle interactions was discussed as a possible candidate for plasma heating.

4. Parametric Instabilities and Plasma Heating

M. Porkolab summarized the present status of experimental research concerning parametric instabilities and related plasma heating. A comparison with theory was also given. The linear theory of parametric instabilities is in good agreement with experimental data in a uniform plasma. However, in a nonuniform plasma there is still no consistent experimental agreement with the presently available WKB theories.

It appears that theories with strong density gradients (i.e. ($\nabla n/n \sim \lambda_o^{-1}$, where λ_o is the wavelength of the incident electromagnetic wave) will be necessary to describe the laser pellet interaction. Recent microwave experiments indicate (Porkolab and coworkers at Princeton) that in the presence of an external magnetic field even with strong density gradients, parametric instabilities and plasma heating are observed. On the other hand, in the absence of a magnetic field the UCLA group (Wong and Stenzel) recently reported observation of large density cavities near the critical layer. The heating in the latter experiments is believed to be due to acceleration by the strong localized electric fields. Thus, further development of the theory of soliton formation is of great interest. Experimental verification of the nonlinear saturation theories (of which there are few) is still not satisfactory. Finally, it appears that the back-scatter instabilities (Raman or Brillouin) may not be present during laser-pellet interaction (or if present, the associated reflection of laser power is unimportant).

5. Diffusion in a D. C. Magnetic Field

D. C. Montgomery summarized the present status of diffusion theories based on the early work of Taylor and McNamara and Kraichnan, as well as the speaker's own work. These theories are based on two-dimensional dissipationless electrostatic guiding center motion. The limitations of such theories are still not well understood. There is still not much experimental evidence to support these theories, although two-dimensional computer simulations appear to be in satisfactory agreement. The author urged experimentalists to set up experiments to check the applicability of these theories. Interestingly, no mention of the recent work at Princeton (Okuda, Oberman, and their coworkers) was made by this speaker.

6. Strong Interaction of Beams and Plasmas

V. N. Tsytovich discussed the theory of excitation of strong turbulence in plasma by relativistic electron beams (REB). These theories are based on the formation of solitons, cavitons and spikons. Modulational instabilities due to REB were also discussed. The acceleration of ions to energies larger than the beam energy, and heating of plasma by beam-plasma interaction and return current was also analyzed. It was pointed out that three-dimensional theories are necessary to describe the occurrence of such phenomena in REB or laser-pellet experiments (rather than two-dimensional computer simulations). The author pointed out that the plasma state in which solitons, spikons and cavitons exist simultaneously may be considered as a new physical state, i.e. the state of strong Langmuir turbulence. To understand the collective interaction of such objects is essential to the understanding of energy deposition by REB's and lasers. The author believes that the development of such theories must be based on a statistical approach, and it must be based on three-dimensional motion.

7. Plasma Focus Devices

G. Decker gave an excellent summary of the present state of plasma focus devices. A new experiment at Frascati using a 1 MJoule capacitor bank is expected to be operational soon, and it is awaited with great interest. Perhaps as much as 10^{13} neutrons per shot may be produced in this experiment. The speaker believes that while these devices may be excellent sources for neutrons, their use for thermonuclear reactors is in a speculative stage. Although for a 200 MJoule bank one may get break-even, at the present time no official program exists yet in any country to pursue this approach for reactor purposes.

In conclusion, we note that the invited papers will be published next year in a special issue of Physica. Also, the next conference will be held in Berlin, GDR, 1977.