INSTITUTE OF PLASMA PHYSICS

NAGOYA UNIVERSITY

RESEARCH REPORT

NAGOYA, JAPAN

Electron-Flux Limitation Due to Ion Acoustic Instability

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IPPJ-254 June 1976

Further communication about this report is to be sent to the Research Information Center, Institute of Plasma Physics, Nagoya University, Nagoya, Japan.

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Abstract

The new flux-limited theory including the ion-wave effects is presented. Preliminary results of the two-dimensional particle simulations support this theory.

§1. Introduction

The major part of the laser energy absorbed in the irradiated D-T pellet is converted to high energy parts of the electron distribution[1-7]. It is of great interest to know how these electrons contribute to the transport phenomena. The first answer to this question is given by Morse and Nielson[8] who proposed "the flux limited theory". In this paper we present another theory which limits the electron thermal conduction due to the ion acoustic instability.

§2 Flux Limitation by Ion Wave

We assume that the electron velocity distribution function has the form

$$f=\frac{n_0}{\sqrt{2\pi}}\left\{\frac{(1-\alpha)}{\sqrt{T^c/m_e}}\exp\left[-\frac{m_e(u+u_d^c)^2}{2T^c}\right]+\frac{\alpha}{\sqrt{T^h/m_e}}\exp\left[-\frac{m_e(u-u_d^h)^2}{2T^h}\right]\right\} \tag{1}$$

where n_0 is the ion density, α the fraction of high energy electrons, u_d the drift velocity , T the temperature and m_e the electron mass. The superscripts c and h denote the main part (which we call cold electrons hereafter) and the high energy part of electrons, respectively. Initially there are cold electrons only. After a part of the pellet absorbs the laser energy and high energy electrons are produced there, these high energy electrons flow out into cold electrons, inducing an electric field. A returning current of cold electrons is induced to cancel this electric field. As a result, the electron velocity distribution function will have a form given by eq.(1).

This electron distribution may give rise to various instabilities such as a weak bump-in-tail instability, ion acoustic instability and buneman instability. Because the bump-in-tail instability saturates at relatively low level of amplitude, it is out of our interest. Among various instabilities regarding ion modes, we focus our attention into the ion acoustic instability. As the fraction of high energy part is assumed to be small, the ion acoustic instability is mainly caused by the cold electrons. Wave-particle interactions bring effective collisions on cold electrons. Thus cold electrons slow down, forming a current j. This current j makes an excess charge ρ_e in the pellet, and induces an electric field E again. If we introduce the scale lengh L of inhomogeneity, we can estimate ρ_e through

$$\frac{d\rho_e}{dt} \approx -\frac{j}{L} . \qquad (2)$$

Thus E can be connected with j by

$$\frac{dE}{dt} = -4\pi j . \qquad (3)$$

The electric field E will decelerates high energy electrons.

To illustrate these phenomena, we use the following model equations

$$\frac{d\,u_d^c}{d\,t} = \nu_{eff}\, u_d^c - \frac{e}{m_e} E, \tag{4}$$

$$\frac{d\,u_d^h}{d\,t} = -\frac{e}{m_e} E. \tag{5}$$

In the case of steady state we obtain the following equations from eqs.(3), (4) and (5)

$$j \equiv -n_0(1-\alpha)\, u_d^c + n_0 \alpha u_d^h = 0, \tag{6}$$

$$E=0, \tag{7}$$

$$\nu_{eff}=0 \qquad \text{or } u_d^c=0. \tag{8}$$

In eq.(8) we choose $\nu_{eff}=0$, because $\nu_{eff}=0$ will be reached earlier than $u_d^c=0$. The effective collision frequency of cold electrons due to the ion acoustic instability has the form[9)]

$$\nu_{eff} \propto u_d^c - c_s, \tag{9}$$

where c_s is the ion sound velocity defined as $c_s=\sqrt{T^c/m_i}$ (m_i is the ion mass). From eqs.(6)-(8) the steady state solution is obtained as

$$u_d^c= c_s \qquad \text{and} \qquad u_d^h = \frac{1-\alpha}{\alpha} c_s. \tag{10}$$

By use of eqs(1) and (10), the electron thermal flux q_t can be calculated as

$$q_t \equiv m_e/2 \int u^3 f du$$

$$= m_e n_0 (1-\alpha)/2 \sqrt{T^c/m_i}\,[-3T^c/m_e + 3T^h/m_e + \left(\frac{1-\alpha}{\alpha}\right)^2 \; T^c/m_i]$$

$$\approx 3 m_e n_0 (1-\alpha)/2 \;\; (T^h/m_e)^{3/2} \;\; [m_e T^c/(m_i T^h)]^{1/2}. \qquad (11)$$

§3. Simulations

To simulate this flux limitation due to the ion acoustic instability we use the two-dimensional PIC methods. In this paper we present only preliminary calculations. Figure 1 shows the initial electron distribution. Figure 2 shows the electron distribution at $t=25\omega_{pi}^{-1}$. In these calculations we put m_i/m_e =4. In Fig.3, the solid line shows the electron thermal flux q versus the time obtained by simulations and the dotted line denotes the electron thermal flux given by eq.(11). The figure shows that the thermal flux in simulations approaches the theoretical value when the phenomena approaches the steady state. Details of our simulation techniques and the advanced results will be published in the near future.

This work was carried out under the collaborating Research Program at Institute of Plasma Physics, Nagoya University, Nagoya.

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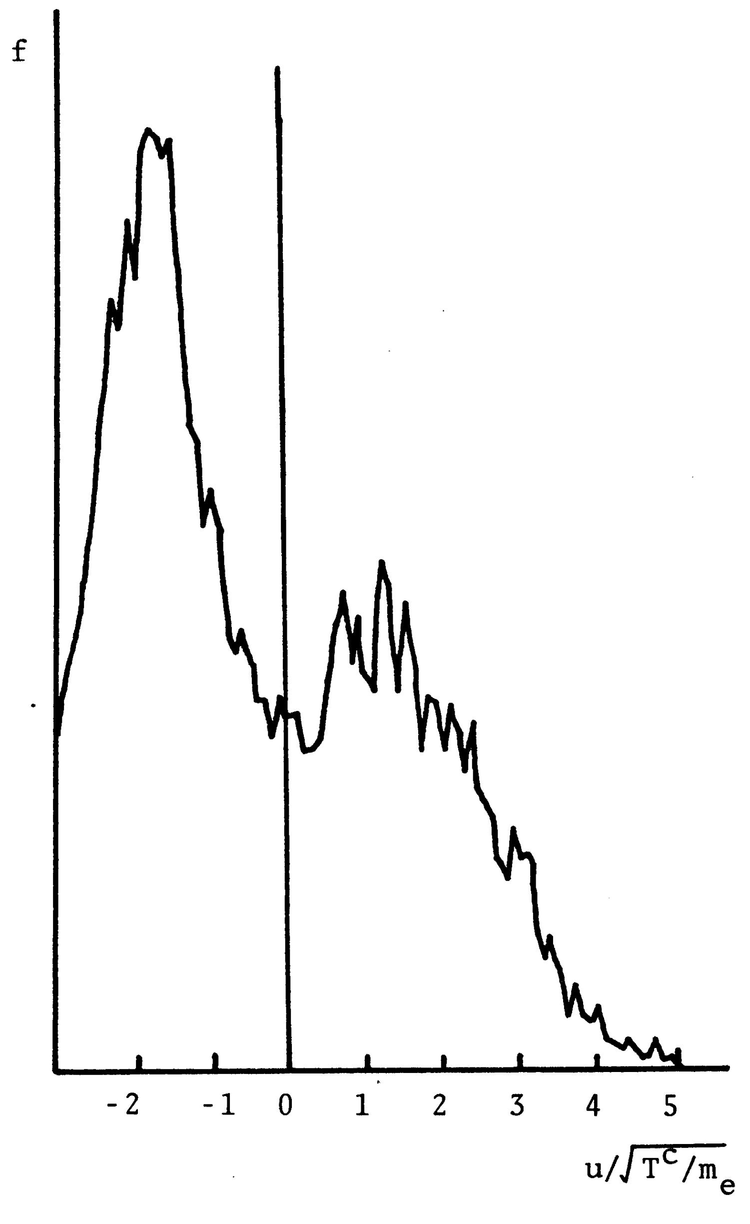

Fig.1 Electron distribution at t=0 in velocity space along the direction of the inhomogeneity.

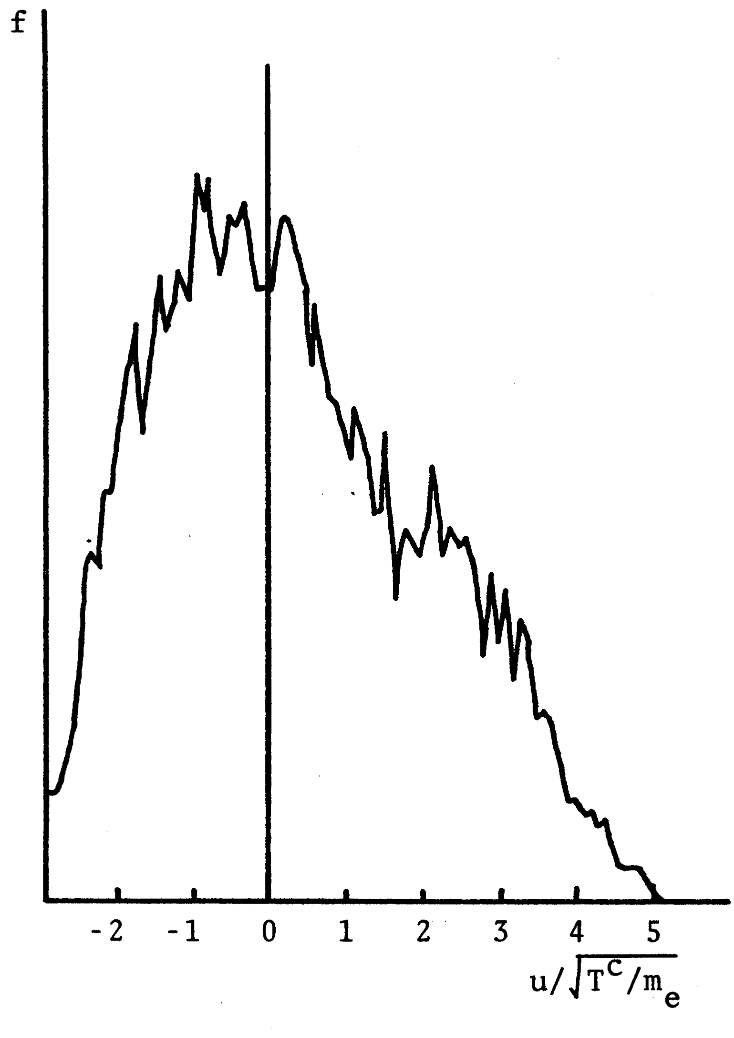

Fig.2 Electron distribution at $t=25\omega_{pi}^{-1}$ in velocity space along the direction of the inhomogeneity.

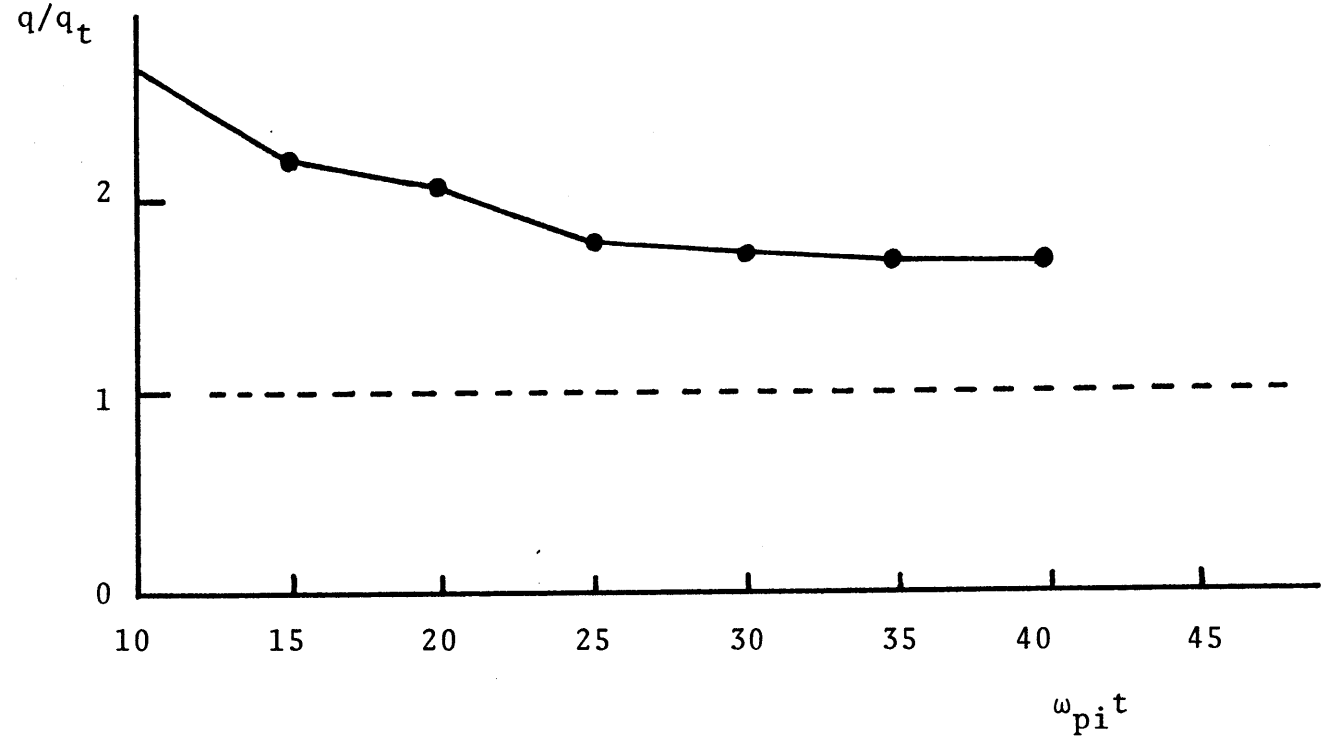

Fig.3 Electron thermal flux along the direction of the inhomogeneity. Dotted line denotes the theoretical value q_t which is given by eq.(11).