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HEATING AND IONISATION IN MHD SHOCK WAVES PROPAGATING INTO PARTIALLY IONIZED PLASMA

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ABSTRACT

A model of the structure of MHD switch-on shocks propagating in a partially ionized plasma, in which the primary dissipation mechanism is friction between ions and neutrals, is here compared favourably with experimental results. Four degrees of upstream ionization were studied, ranging from almost complete to very small ionization.

INTRODUCTION

Studies of shock structure previously obtained on SUPPER II indicate that the principal heating process in ionizing shocks is ion-neutral collisions (1). This series of experiments extends this work to examine the effect on shock structure of varying the neutral component in the upstream plasma. Four shocks were studied and their method of preparation differed only in the level of preionization. T_e, T_i and n (electron density) profiles were obtained for four shocks and these profiles compared with a model of shock structure based on ion-neutral friction.

EXPERIMENT

The SUPPER II plasma vessel is a stainless steel cylindrical shock tube. At each end of the vessel is a Pyrex endplate, in one of which is a short central electrode. The vessel was filled with 120 mtorr of helium and embedded in an axial magnetic field of 0.25 tesla.

The test plasma was prepared by driving a low power ionizing shock into the vessel. This shock was launched by discharging a 30 kA, 40 μsec half period, current pulse between the central electrode and the vessel wall. The plasma thus formed was allowed to settle to a quiescent state before launching the main shock. Since the initial plasma was rapidly cooling, varying the time between plasma preparation and shock preparation effectively controlled the level of preionization.

The shock waves were launched by discharging, at the appropriate time, a radial current pulse with half period 16 μsec and peak current 150 kA. The shock waves were all similar in behaviour with an axial velocity of 10^5 m/sec.

Electron density and temperature profiles were determined by 90° Thomson scattering of a 150 MW ruby laser beam. The ion temperature was estimated by measuring the Doppler broadening of the HeII line at 468.6 nm.

THEORY

The calculation of heating and ionization in the shock wave is similar to that in (1) for an ionizing shock in a 1 tesla field, i.e. the current and magnetic field profiles are assumed known and fed in to calculate the heating. However, this calculation is more complete in that all terms in the species energy equations are retained, including the adiabatic compression term.

The ions and atoms are assumed to have the same temperature, and ionization assumed to occur through electron-neutral ionizing collisions. Any second ionization of the helium is neglected. Dissipation terms in the energy equations (1) are calculated using Cowling's model of partially ionized plasma (2), the most important of these being the ion-neutral friction term.

Compression in the shock is calculated from the known switch-on field B_θ by means of the integrated overall momentum and energy conservation equations (3) (neglecting ionization energy). The resultant relation depends on the radial electric field, which is zero for the shock propagating into a non-zero upstream electron density and for the ionizing shock takes the value satisfying the Chapman-Jouguet condition (4).

DISCUSSION

(i) Highly ionized upstream plasma ($n = 2 \times 20^{21}$ m^{-3}, 50% ionization) (Figs. 1a, 1b). Computation with 50% ionization and the observed B_θ rise time of 1 μsec gives little heating and equal ion and electron temperatures. To gain good agreement with experiment it is necessary to assume that the upstream neutrals have been centrifuged to the walls, leaving 100% ionized upstream plasma. Also we assume a rise time of 0.2 μsec (i.e. the observed rise time of n and T_e) and a resistivity 5 times the classical value. This enhancement in resistivity could be due to the ion-acoustic instability discussed in (5).

(ii) Upstream ionization 25% ($n = 10^{21}$ m^{-3}) (Figs. 2a, 2b). Ions, neutrals and electrons are heated about equally, in agreement with observation. The rise time in B_θ used is 0.2 μsec.

(iii) Upstream ionization 6% ($n = 2.4 \times 10^{20}$ m^{-3}) (Figs. 3a, 3b). A B_θ rise of 0.5 μsec gives strong ionization and ion heating, as is observed.

(iv) Ionizing shock (Figs. 4a, 4b). The initial electron density is due to photoionization from the hot rear of the shock. Strong ion and neutral heating is observed in excellent agreement with experiment.

ACKNOWLEDGEMENTS

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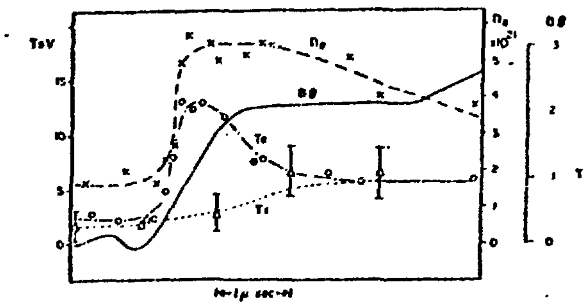

Fig. 1a

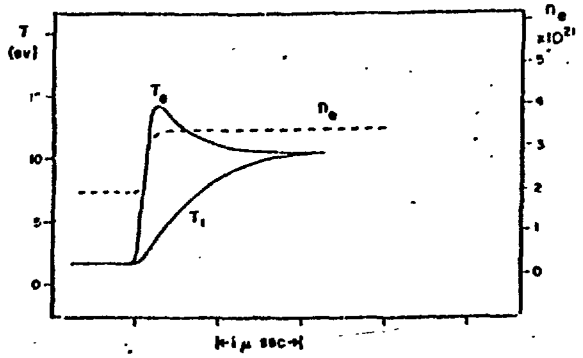

Fig. 1b

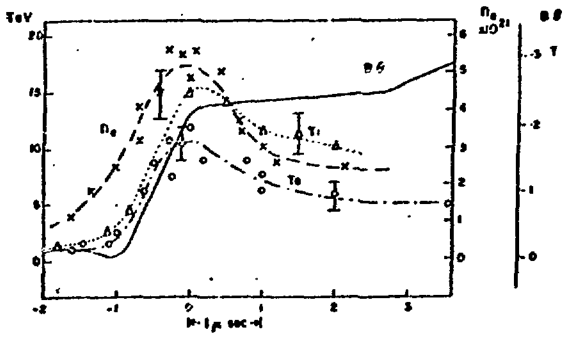

Fig. 2a

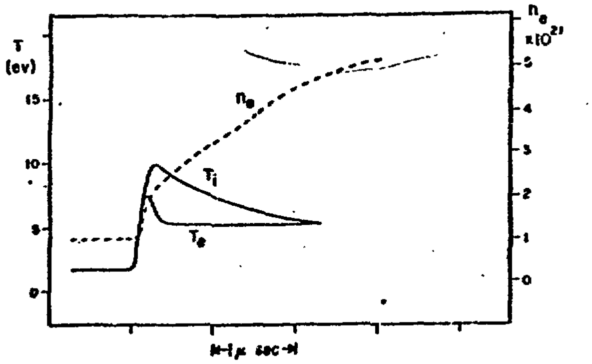

Fig. 2b

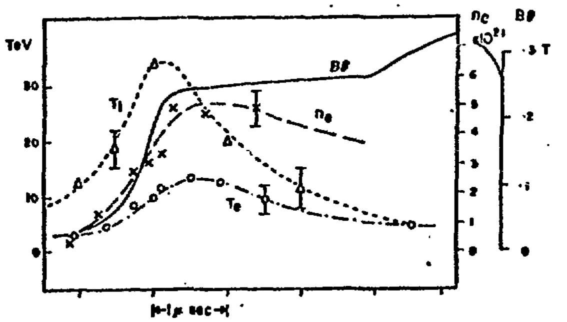

Fig. 3a

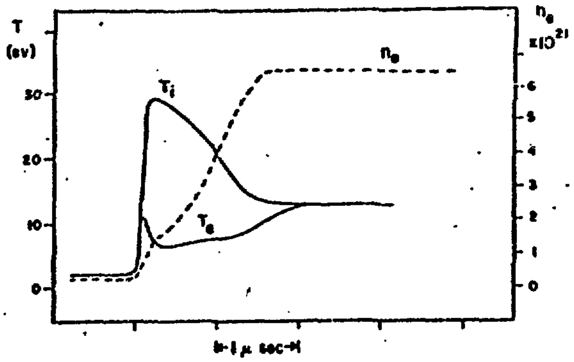

Fig. 3b

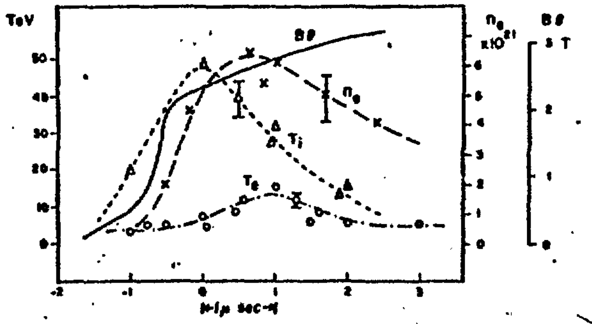

Fig. 4a

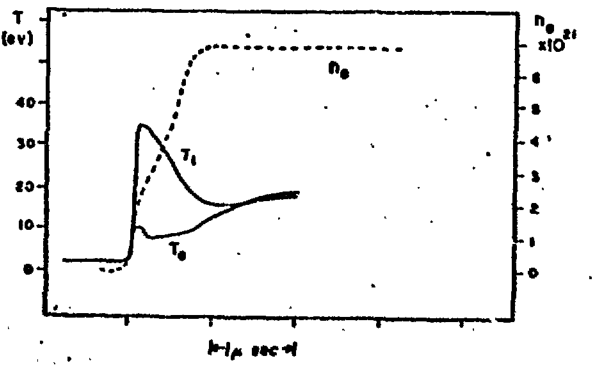

Fig. 4b