A METHOD FOR INFRARED DIAGNOSTICS OF A PLASMA AND ITS USE FOR THE INVESTIGATION OF IONIZATION AND RECOMBINATION OF XENON BEHIND THE FRONT OF A SHOCK WAVE

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Submitted January 21, 1970

Zh. Eksp. Teor. Fiz. 58, 1928–1937 (June, 1970)

A method is described for the determination of the electron temperature and electron concentration profiles behind the front of a shock wave. It is based on simultaneous measurement of emission and absorption by the ionized gas in the infrared region of the spectrum (λ = 10.6 microns). Results of an experimental investigation of ionization and recombination processes in xenon at T = 8200–9200°K are presented. Good agreement between the experimental data and recombination theory based on a modified Fokker-Planck theory is obtained.

1. INTRODUCTION

THE investigation of the structure of strong shock waves is of interest mostly because of the possibility of obtaining information concerning the elementary processes that lead to the excitation and ionization of gases. The results of numerous investigations[1-8] of ionization relaxation behind the front of shock waves in monatomic gases offer evidence that the mechanism of the ionization processes changes over the length of the relaxation region. Therefore, in the general case, it is possible to separate the following three zones in the development of the ionization process: 1) initial zone, where the formation of the priming electrons takes place; 2) the zone of evolution of the electron cascade in elastic electron-atom collisions; 3) the zone adjacent to the equilibrium region and characterized by the influence of recombination processes on the ionization kinetics.

There are different opinions in the literature concerning the mechanism of formation of electrons in the initial zone of the ionization process; the probable processes considered were atom-atom collisions (including the impurity atoms) and photoionization. Thus, for example, in[5] it was shown that a small admixture of air noticeably influences the time of ionization relaxation in monatomic gases. However, if we consider pure gases with an impurity level less than 10^{-4}, then the formation of priming electrons as a result of atom-impurity processes can be neglected. In this case the mechanism of electron formation in the initial zone will probably depend on the intensity of the shock wave. It is advantageous here to distinguish between (i) weakly ionizing shock waves with clearly pronounced atom-atom zones, (ii) strongly ionizing shock waves when there is practically no atom-atom zone and the formation of priming electrons is due to photo-ionization, while the zone of evolution of the electron cascade is adjacent to the front of the shock wave, and (iii) shock waves having a clearly pronounced pre-frontal structure.

In a number of investigations performed with weakly-ionizing shock waves[3,4] they measured the profiles of the growth of the electron density in the atom-atom zone and showed that in monatomic gases there is realized a two-stage ionization mechanism, in which the atom is first excited, followed by ionization from the excited levels. In this case, the process determining the rate of ionization is the excitation of the atom. As a result, it was possible to determine the cross section for excitation in atom-atom collisions for a number of gases (argon, xenon, krypton).

The laws governing ionization in the zone where the electron cascade developed in electron-atom collisions have been investigated to a lesser degree, this being due to the lack of a reliable method of plasma diagnostics with sufficient sensitivity and time resolution in the region of relatively high electron densities. The difficulty of investigating this region is compounded by the fact that to obtain information on the rate of the ionization process it is necessary to measure, simultaneously with the determination of the profile of the electron density, also the profile of the electron temperature behind the front of the shock wave.

The purpose of the present investigation was indeed to develop such a method and to investigate exhaustively the zones of the development of the electron cascade and of the near-equilibrium zone behind the front of the shock wave in xenon, so as to obtain the values of the ionization and recombination rate constants, and accordingly the cross sections of these processes. The proposed method consists of simultaneously recording the emission and absorption of the plasma behind the shock-wave front in the infrared region of the spectrum ($\lambda = 10.6\ \mu$), making it possible to determine the distribution of the electron density and of the temperature. It is known that in this region of the spectrum the main contribution to the processes of emission and absorption of light are made by free-free transitions of the electrons in the field of the ions. In fact, the ratio of the contributions of the bound-free and free-free transitions, for all atoms, at frequencies below threshold, is approximately $\exp(h\nu/kTe) - 1$, and therefore at a temperature on the order of 1 eV the contribution of the bound-free transitions at a wavelength $10.6\ \mu$ is small and can be neglected.