ON THE MODELING OF THE THREE-FLUID STRUCTURE
OF THE QUIET SOLAR WIND

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Abstract. The reciprocal influence of the electrons and protons, on one side, and the α-particles, on the other side in the quiet solar wind is investigated within the framework of a conductive three-fluid model (with frictional forces included). For this purpose two mathematical methods are used, namely: I. Simultaneous solution of the fluid equations for all three species; and II. Solution of two-fluid equations (for electrons and protons) followed by that of a ‘modified’ one-fluid equation for the α-particles (in which the two-fluid solutions are used for electrons and protons).

The results of our investigation indicate the following: (a) The macroscopic α-particle characteristics as obtained from the two methods of solution are almost identical. Thus, the differences between the ‘three-fluid’ and ‘two-fluid’ characteristics of the electrons and protons represent a second order (and negligible) effect on the α-particle characteristics. In both approaches, the frictional interaction between α-particles and protons raises the (lower) α-particle streaming velocity to that of the protons and decreases the relative α to proton density ratio to a value about 0.035, as observed at 1 AU, (b) The electron and proton characteristics obtained from ‘three-fluid’ and ‘two-fluid’ solutions are similar, except for the proton temperature. The ‘two-fluid’ solution provides T_p-values which, though within the observational error, are larger than those obtained from the simultaneous three-fluid solution (at 1 AU, the difference amounts to about 30%). Thus, the α-particles affect the temperature profile of the protons in the solar wind through heat exchange (mainly), dynamical friction, as well as through their contribution to the interplanetary electrostatic field.

1. Introduction

The observed gross features of the α-particles in the quiet solar wind at 1 AU raised a number of questions, among which were: (i) why is the ratio of the α-particle to proton streaming velocities peaked around unity?; (ii) why is the long-term average α/proton density about 0.037 (as compared to about 0.1 in the lower corona)?; (iii) why is the α/proton temperature ratio about four? (see, e.g., Ogilvie and Wilkerson, 1969; Robbins et al., 1970; Formisano and Moreno, 1971; Bollea et al., 1972; Asbridge et al., 1973; Hirshberg et al., 1974).

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To answer these questions, during the last decade, a number of workers investigated the three-component structure of the quiet solar wind (consisting of electrons, protons and α-particles) mainly within the framework of the fluid description (see, e.g., Yeh, 1970; Geiss et al., 1970; Fahr, 1973; Weber, 1973; Cuperman and Metzler, 1975, [hereafter referred to as CM]; Ryan and Axford, 1975; Metzler and Dryer, 1978, [hereafter referred to as MD]). These investigations provided significant insight for the understanding of various particular aspects of the α-particle behaviour in the quiet solar wind (i.e., the questions raised above). A detailed review of these investigations is given in Cuperman (1980).

This paper is concerned with the problem of the reciprocal effect of the electrons and protons on one side and α-particles on the other side, in the quiet solar wind. More specifically, here we investigate (i) the way in which the two-fluid (i.e., electrons and protons) influence the gross features of the α-particles and (ii) what is the effect of the α-particles on the two-fluid quiet solar wind?

For this purpose, we consider a three-fluid model consisting of continuity, momentum and energy equations for the quiet (undisturbed) expanding corona. Friction forces due to possible occurrence of different e, p and α streaming velocities are incorporated in the model equations. The transport coefficients are allowed to include (besides collisional interactions) phenomenological contributions from turbulent wave-particle interactions existing in the solar wind. The model assumes spherical symmetry and neglects effects such as viscosity, rotation and magnetic fields. However, the inhibition of heat flux across the interplanetary magnetic field is implicitly taken into account in the expression for the anomalous thermal conductivity.

In order to provide the desired answers to the problem of the reciprocal influence of the three species, as mentioned above, we solve the three-fluid equations in two different ways: I. Simultaneous solution of the fluid equations for all three species (Metzler and Dryer, 1978) and II. Solution of the two-fluid equations (for electrons and protons) followed by that of 'modified' one-fluid equations for the α-particles (in which the two-fluid solutions are used for electrons and protons (Cuperman and Metzler, 1975; see also McKenzie et al., 1979), in which this method is applied for further investigations). The important point here is that for both method I and II we use the same physical (boundary) conditions as well as the same numerical code. Thus, the two-fluid solutions to be used with method II are obtained by solving simultaneously the equations for all three species in which we replace the charge and mass of the α-particles with those corresponding to protons.

2. Model Equations

The three-fluid model equations for a steady spherically expanding flow, ignoring effects such as magnetic fields, solar rotation, pressure anisotropy, and fluctuations, may be written (e.g., Braginskii, 1965) as

\[ n_e v_e r^2 = J_e \quad (J_i's \ are \ constant \ values), \]  

\[ n_p v_p r^2 = J_p \quad \]  

\[ n_\alpha v_\alpha r^2 = J_\alpha \quad (J_i's \ are \ constant \ values), \]  

(1)-(3)