Space Research XII — Akademie-Verlag, Berlin 1972

EFFECT OF ESCAPING PHOTOELECTRONS IN A POLAR EXOSPHERIC MODEL

J. LEMAIRE

Institute for Space Aeronomy, Brussels, Belgium

The effect of a photoelectron escape flux on a new polar wind model is discussed. It is shown that the additional electric drag force due to the escaping photoelectrons can accelerate the ions to higher velocities if the photoelectron flux is larger than the escape flux of the thermal electrons. Furthermore, it is shown that, even if the number density of the photoelectrons remains small compared with the number density of the thermal electrons, their kinetic pressure becomes predominant at very high altitudes. As a consequence a positive gradient in the electron "temperature" can be expected in the sunlit polar cap upper region.

1. Introduction

The polar wind concept has been introduced by Axford [1], who suggested that a flux of 2×10^8 cm^{-2} s^{-1} of escaping photoelectrons is required to drag out of the polar ionosphere all the He^+ ions produced in the atmosphere. The effects of such photoelectron fluxes on the density, bulk velocity and pressure distributions of a polar wind model are investigated in the following paragraphs.

2. The Model

The electron and ion temperatures $T_{e,i}$, are assumed to be equal to 3000 °K in the models. The neutral particles (O, H, He) are distributed according to Nicolet–Kockarts atmospheric model ($T_N = 750$ °K); (private communication).

The boundary conditions are taken from the OGO 2 ion-composition measurements [2]: $n_{O^+} = 7 \times 10^3$ cm^{-3}, $n_{H^+} = 320$ cm^{-3} are typical values observed in the sunlit polar cap region at an altitude of 950 km. Using these values and $n_{th, e^-} = 7.32 \times 10^3$ cm^{-3} as boundary conditions, we integrated the hydrodynamical equations (mass and momentum equations for each ionic species) described by Banks and others [3–6]. Each of the hydrodynamical solutions can be characterized by the value of the bulk velocity (or by the upward diffusion flux) at the reference level of 950 km. From the calculated bulk velocity and density distribution one can estimate the deflection mean free path (mfp) of the He^+ ions, and define the baropause as the altitude where the mfp becomes equal to the electron or O^+ density scale height [7]. Above this altitude a kinetic calculation is adopted to determine the structure of the ion exosphere [8, 9]. The requirement that the thermal escape flux of the ions must be equal to the diffusion flux in the collision-dominated region is a new criterion to select a unique hydrodynamical solution. This solution is not necessarily the "critical solution" adopted in completely hydrodynamical polar wind models. Both of these solutions however converge rapidly in the lower altitude range.

The photoelectrons are considered as a separate kind of collisionless particle with a truncated* (no trapped, nor incoming orbits being populated) Maxwellian velocity distribution at the baropause, and a mean energy of 10 eV ($T_{ph.e^-} = 1.16 \times 10^5$ °K).

In the models Nos. 1, 2 and 3, the number densities of the photoelectrons at the baropause ($h_0 = 1250$ km) are respectively 0, 0.2 and 0.4. The corresponding photoelectron escape fluxes $F_{ph.e}$ are 0, 9×10^6 and 1.8×10^7 cm^{-2} s^{-1} at an altitude of 3000 km. The flux of H^+ at the same altitude is calculated to be 1.9×10^7 cm^{-2} s^{-1}; this flux, which is the same for all three models considered here, is determined by the boundary conditions at the baropause.

3. Results and Discussion

The density distributions of O^+, H^+ and of the thermal and photoelectrons are shown in Fig. 1 for these three models. The dashed lines (model No. 4) correspond to a special case where there would be as many photoelectrons

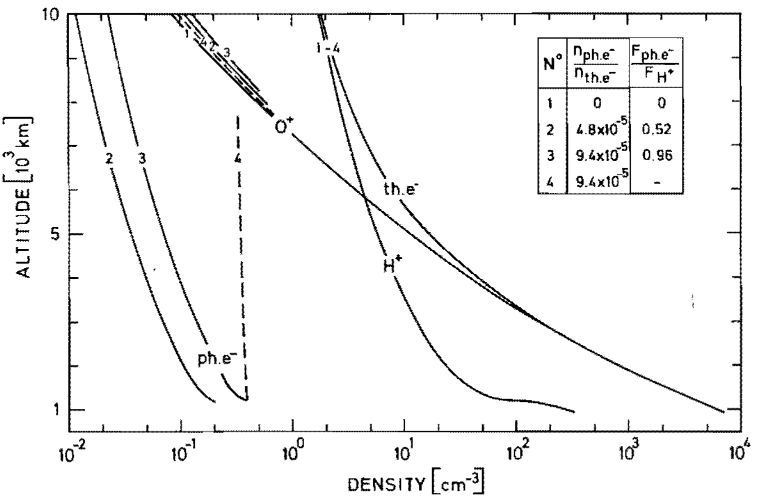

Fig. 1. Density distribution of the oxygen ions, protons, thermal and photoelectrons in four different polar wind models, with the effect of increasing photoelectron escape fluxes shown.

* It is assumed that the trapped photoelectrons with two magnetic mirror and/or gravitational reflection points above the baropause are missing in the velocity distribution. The particles coming from infinity and travelling towards the baropause are also absent in the models Nos. 1, 2 and 3.

flowing in as flowing out of the ionosphere. It can be seen that the O^+ distribution is influenced by an outward flux of photoelectrons. This effect becomes most important when F_{ph,e^-} is larger than the thermal electron escape flux, F_{th,e^-}. In this case (e.g. model No. 3) the polarization electric field is significantly enhanced compared with that of model No. 1 where no photoelectrons are present. This additional electric drag due to the escaping photoelectrons is most efficient at very high altitudes where the relative abundance of the photoelectrons reaches its maximum value. The larger O^+ density scale height of model No. 3 is a consequence of this effect. Furthermore, the larger electric field intensity in a model with escaping photoelectrons increases strongly the subsonic bulk velocity and escape flux of the O^+ ions. Although the supersonic proton velocity is nearly unchanged below 10000 km altitude, it reaches, at very high altitudes, a larger asymptotic value:

$$w_{H^+}(h \to \infty) = \frac{n_{ph.e^-}}{n_{th.e^-}} \cdot \frac{1 + F_{th.e^-}/F_{ph.e^-}}{1 + n_{ph.e^-}/n_{th.e^-}} w_{ph.e^-}$$

which depends drastically on the relative abundance of the photoelectrons at large distances ($h \to \infty$); e.g., in model No. 3, $F_{th.e^-}/F_{ph.e^-} = 2.6 \times 10^{-2}$, $n_{ph.e^-}/n_{th.e^-} \to 10^{-2}$, and $w_{H^+}/w_{ph.e^-} \to 10^{-2}$. As $\frac{1}{2} m_e w_{ph.e^-}^2 = 10$ eV, it can be concluded that $\frac{1}{2} m_H w_{H^+}^2 \to 1.8$ eV, and $w_{H^+} \to 21$ km s^{-1}.

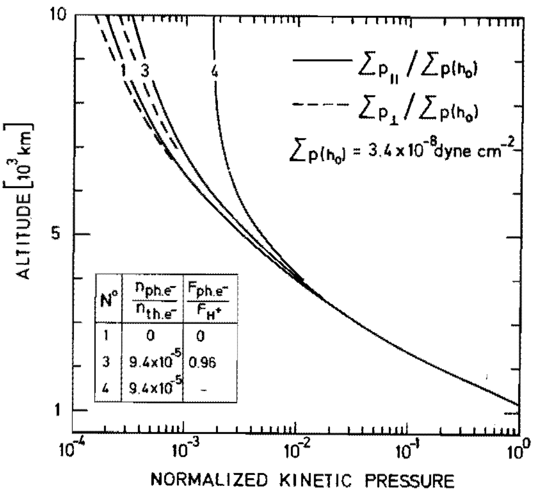

Fig. 2. Normalized total pressure components (parallel and perpendicular to the magnetic field) in four different polar wind models, with the effect of increasing photoelectron escape fluxes shown.

Fig. 2 shows the normalized total kinetic pressure components versus altitude in the models 1, 2, 3 and 4. At heights of 5000 km and above, the electron gas makes the largest contribution to the total pressure. The anisotropy of the kinetic pressure becomes significant above 7000 km. Although the photoelectrons remain a minor constituent in model No. 3, it can be seen from Fig.2 that these particles, however, contribute significantly to increase the kinetic pressure and its anisotropy. As a consequence, when "suprathermal" electrons are present in the polar wind, any "temperature" deduced from the total kinetic pressure (or energy density) of the electrons will increase with altitude. In the lower region of the polar ion-exosphere where the kinetic pressure is mainly due to the thermal ionospheric particles, the energy spectrum of the electrons has a large peak at 0.3 or 0.6 eV.

At very high altitudes it will have a peak near 10 eV, if photoelectrons are present. In the intermediate height range (4000–10000 km) the spectrum would have two peaks whose relative importance depends on the location along the magnetic field lines. As such a doubly peaked velocity distribution generally leads to plasma instability, one can expect that turbulent wave-particle interactions will play a significant role and give rise to energy redistribution and electrostatic or electromagnetic emissions at high altitudes above the sunlit polar cap region.

Model No. 4 illustrates a case in which all the escaping photoelectrons would be backscattered at a high altitude level. From Fig. 2 it can be seen that the total kinetic pressure would then remain isotropic, and that it would be greatly enhanced. The upward and downward photoelectron flux (that an *in situ* experimental device would measure) at 3000 km, would be equal to 1.8×10^7 ph e^- cm^{-2} s^{-1}.

Acknowledgments

We wish to thank Dr. M. J. Rycroft and COSPAR Secretariat for their help in preparing this manuscript.

References

[1] W. I. AXFORD, J. Geophys. Res. **73**, 6855 (1968).
[2] H. A. TAYLOR, JR., et al., J. Geophys. Res. **73**, 5521 (1968).
[3] P. M. BANKS and T. E. HOLZER, J. Geophys. Res. **73**, 6846 (1968).
[4] P. M. BANKS and T. E. HOLZER, J. Geophys. Res. **74**, 6317 (1969).
[5] J. E. HOLZER, J. O. FEDDER and P. M. BANKS, J. Geophys. Res. **76**, 2453 (1971).
[6] K. MARUBASHI, Rep. Ionosph. Space Res. Japan **24**, 322 (1970).
[7] J. LEMAIRE, Conf. on Theoretical Ionospheric Models, Pennsylvania State University, June 1971 (to be published in J. Atmos. Terr. Phys. 1972).
[8] J. LEMAIRE and M. SCHERER, Planet. Space Sci. **18**, 103 (1970).
[9] J. LEMAIRE and M. SCHERER, Phys. Fluids, **14**, 1683 (1971).