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Orientation of planetary O^+ fluxes and magnetic field lines in the Venus wake

H. Pérez-de-Tejada*, D. S. Intriligator† & C. T. Russell‡

* Instituto de Geofisica, Universidad Nacional Autónoma de México, México 20 DF, México
† Carmel Research Center, PO Box 1732, Santa Monica, California 90406, USA
‡ Institute of Geophysics and Planetary Physics, University of California, Los Angeles, California 90024, USA

The presence of 'contaminant' heavy ions of planetary origin in the solar wind has long been the subject of intense theoretical and experimental research. Studies of their abundance, acceleration, and direction of motion are important because of their implications on the composition and dynamics of planetary and cometary plasma wakes. The plasma and magnetic field observations made with the Pioneer Venus Orbiter (PVO) at Venus have provided the opportunity to examine the conditions in which planetary ions are picked up by the solar wind. We show here that in the outer regions of the venusian far wake the displacement of planetary O^+ particles, characteristic of the Venus upper ionosphere, does not occur necessarily along the magnetic field lines but approximately in the direction of the shocked solar wind.

The mass loading of the solar wind plasma with atmospheric ions in non-magnetic planets was first examined in connection with the limited capacity of the flow to accommodate added mass[1]. Contaminant material is expected to arise from photoionization processes and charge exchange collisions of the solar wind particles with exospheric atoms[2]. In most studies[3,4] the motion of the planetary ions is believed to result from electric $\boldsymbol{E}\times\boldsymbol{B}$ drifts superimposed on the Larmor gyration around the magnetic field lines. Wave–particle interactions associated with turbulent processes in the plasma[5,6] may modify this motion, however, and produce a viscous-like acceleration of the planetary ions[7].

The observation of heavy ions of planetary origin in the Venus wake was first reported[8] from the low latitude orbital passes of the Venera 9 and 10 spacecraft. These ions were identified as a cool low-energy component directed into the umbra behind the terminator. The results of the spectral analyses of other Venera plasma data[9] were also consistent with the presence of a component of planetary ions within the umbra.

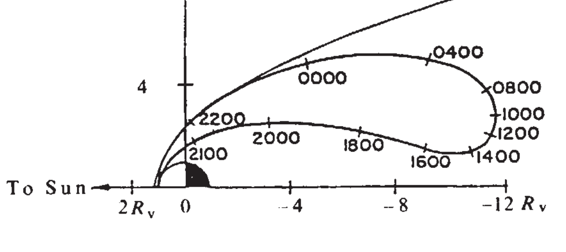

Fig. 1 Two-dimensional projection of the trajectory of the PVO in orbit 189, 11 June 1979.

The more recent measurements carried out with the PVO plasma probe[10,11] have now revealed the detection of significant fluxes of O^+ ions of planetary origin in the Venus far wake. The energies of these ions are consistent with their having been accelerated to solar wind speeds, and their angular distributions imply that their direction of motion differs, at most, by only a few degrees ($\lesssim 5°$) from that of the shocked solar wind. In addition, they seem to represent only a contaminant population because of the low (~1%) concentrations observed in the ambient shocked solar wind plasma. With such low densities their mass and momentum flux is significantly smaller than that of the shocked solar wind.

Simultaneous measurements of the magnetic field in the Venus wake carried out with the PVO magnetometer[12] have also indicated the existence of a peculiar magnetic geometry in that region. Most notable is a characteristic increase in the magnitude and fluctuation level of the magnetic field vector, which is predominately oriented along the Sun–Venus direction. Significant departures from this orientation may occur in the outer regions of the wake, however, and in particular at locations where the O^+ fluxes are detected.

From the comparison of the plasma and magnetic data in such regions, it is possible to examine the relative orientation of the magnetic field lines with respect to the direction of motion of the planetary heavy ions. Figure 1 shows the trajectory of the PVO during orbit 189 in a two-dimensional projection where the vertical coordinate is the distance perpendicular to the Sun–Venus axis. The spacecraft probed the magnetic wake between ~1230 and ~1730 UT and measured intense O^+ fluxes begining at ~1210 UT. The aberrated azimuthal angle of these fluxes[13] during the 1200–1400 UT time interval is illustrated in Fig. 2 together with the orientation of the local magnetic field (positive values result from directions with a component opposite to the orbital motion of the planet in a coordinate system where the x-axis is directed to the Sun).

The time interval shown is particularly useful because of the fairly persistent orientation of the magnetic field vector away from the solar direction between 1200 and 1300 UT. As shown in Fig. 2, this is predominately along directions which make appreciable negative angles with respect to that of the motion of the planetary ions. During this period the plasma probe measurements showed O^+ fluxes arriving from directions $\lesssim 5°$ away from the x-axis, and thus with no apparent agreement with the orientation of the magnetic field lines. Simultaneous measurements of the direction of the shocked solar wind plasma showed that this differs at most by a few degrees from that of the O^+ fluxes (both traces would be, in fact, practically indistinguishable at the scale shown). A similar situation is observed between 1300 and 1400 UT despite the fact that during this time interval the magnetic field vector is significantly more variable. Thus, with the exception of the orientation seen near 1300 and 1350 UT, the magnetic field vector again makes large angles with respect to the direction of motion of the planetary ions. Further analysis of the data obtained later in this orbit also indicates significant differences between the direction of the plasma fluxes and the magnetic field orientation. Deeper within the wake, however, the observation of the O^+ particles is more sporadic and the magnetic field vector is seen to suffer frequent and sudden changes in magnitude and direction. In these conditions it is more difficult to establish a clear identification with respect to the direction of motion of the O^+ particles.

The overall tendency of the planetary ions to move in the direction of the shocked solar wind flow is indicative of the type of mechanism that should be responsible for their acceleration. Most notable is the fact that the direction of motion of the O^+ ions appears to be uncorrelated with changes in the direction of the magnetic field vector. Thus, the differences in the orientation of the particle and magnetic fluxes are important not only because they reveal that the displacement of the planetary particles is not necessarily along the field lines, but also because the observations show that the same drift velocity

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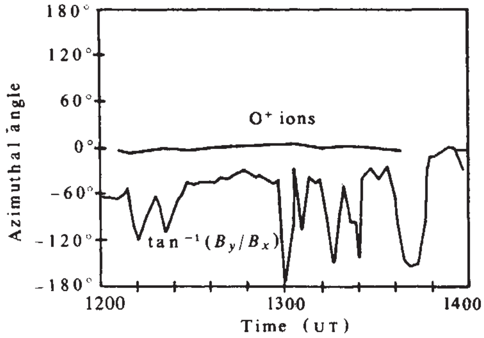

Fig. 2 Azimuthal angle of the magnetic field vector and of the direction of motion of the (peak intensity) O^+ fluxes in the Venus wake between 1200 and 1400 UT in orbit 189.

(nearly coincident with the shocked solar wind velocity) is measured consistently. This behaviour would not be expected if $\boldsymbol{E}\times\boldsymbol{B}$ drifts were solely responsible for the motion of the planetary O^+ ions. If this were the case, their direction of motion would reflect the changes of direction of the magnetic field encountered along the trajectory of the PVO. This circumstance seems to indicate that $\boldsymbol{E}\times\boldsymbol{B}$ pick up processes are not sufficient to account for the acceleration and direction of motion of the planetary ions.

As indicated above, the effects of wave–particle interactions associated with the turbulent character of the ionosheath flow, as revealed by the PVO plasma wave measurements[14], should give place instead to stochastic motions, and enhance the fluid-like behaviour of the local plasma. In these conditions the acceleration process should result from collective interactions between the solar wind and the ionospheric particles, and produce an effective viscous drag between both particle populations[7]. This should set the O^+ particles into motion with speeds and directions nearly coincident with that of the streaming solar wind flow, and independent of the direction of the magnetic field. The PVO observation of heavy ion fluxes in this latter direction, and of the different orientation of the magnetic field vector, is consistent with that interpretation and indicates that wave–particle interactions should have an important role in the acceleration of the ionospheric particles.

As the interaction between the solar wind and the Venus environment is primarily with the atmosphere–ionosphere and not with a planetary magnetic field, the above results are also probably relevant to cometary plasma wakes. If this is the case, then downstream of a comet we should expect to observe accelerated cometary ions flowing in a direction similar to that of the solar wind and independent of the local orientation of the magnetic field.

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Intergrown mica and montmorillonite in the Allende carbonaceous chondrite

Kazushige Tomeoka & Peter R. Buseck

Department of Geology and Chemistry, Arizona State University, Tempe, Arizona 85287, USA

Calcium-, aluminium-rich inclusions (CAIs) in carbonaceous chondrites such as Allende are of considerable interest because of their primitive character. There are, however, differences of opinions as to whether they formed directly by condensation from the early solar nebula[1] or by the evaporation of primitive dust[2]. The mineralogy of the CAIs potentially bears on this question and therefore much effort has been devoted to detailed petrographic studies. We present here high-resolution transmission electron microscopy (HRTEM) observations of a complex mixture of mica and montmorillonite that occurs within a fine-grained CAI in the Allende C3(V) meteorite. In spite of previous intensive petrographic investigations of this and related meteorites, the existence of such CAIs bearing mica and montmorillonite has not been reported previously, and there have been no previous positive identifications of these minerals in carbonaceous chondrites.

We extracted part of an ordinary petrographic thin section that includes a CAI, and ion-thinned it for electron microscope observations. The inclusion, round and ~0.4 mm in largest dimension, consists of fine-grained fragments ranging in diameter from <1 to 50 μm. Electron microprobe analyses show that the inclusion contains considerable Mg, Fe and Na in addition to major Si, Al and Ca, and that it exhibits extreme local compositional variations. The fine-grained fragments are mostly Fe-containing spinels that are characteristically enclosed by fine-grained rim material. These textural and chemical characteristics indicate that the inclusion corresponds to a fine-grained alkali-rich spinel aggregrate in Wark's[3] classification of CAIs and Type 3 in Kornacki's[4] classification of fine-grained CAIs in Allende. The fine-grained CAIs are rich in alkali and volatile elements in addition to the refractory Ca–Al-rich minerals, which makes it difficult to explain their origin by simple condensation models[5]. Studies of petrographic characteristics of the fine-grained inclusions in the Allende meteorite are reported elsewhere[3,6].

In low magnification TEM images, we have observed phyllosilicate that shows a complex, fluffy texture. It occurs along two cavities that appear to be interstitial to spinel grains and are located close to the margin of the inclusion. Investigation by HRTEM has shown that much of the phyllosilicate has a (001) basal fringe spacing of ~10 Å (Fig. 1). This feature clearly distinguishes it from serpentine-type phyllosilicates that are now widely accepted as major constituents of the C2 matrix phases. Possible candidates for the phyllosilicates having such (001) spacings include mica, dehydrated montmorillonite-type clay minerals, and talc[7].

The phyllosilicate grains display characteristic features in their morphologies and arrangements of lattice planes. Some crystals have a straight or sub-parallel arrangement of their lattice fringes. On the other hand, most crystals commonly show bending, terminating and overlapping fringes (Fig. 1). In some areas, fringes vary in spacing between 10 and 15 Å. These structural characteristics indicate a strong similarity to those observed in terrestrial mixed layered mica and montmorillonite[8–10].

Chemical analyses were performed with an energy dispersive X-ray spectrometer (EDS) on our TEM and scanning electron microscope (SEM). EDS spectra from the phyllosilicate reveal large Si and Al peaks and less intense K, Mg, Ca and Fe peaks. Sodium was detected in significant but variable amounts, and minor Cl and Ti were also encountered. These results preclude the possibility of talc. Based on data from imaging and chemical analyses, we conclude that the phyllosilicate is a complex

