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Minor Ions in the Solar Wind

Peter Bochsler

It has been recently recognized that the presence of ions heavier than hydrogen determines to a large extent the dynamics of the expanding solar corona. In the following I shall give a brief account of the most recent results related to minor ions (i.e. ^3He and ions heavier than helium).

ELEMENTAL ABUNDANCES

Table 1 gives elemental abundances as obtained by in situ measurements.

Table 1
Abundances relative to oxygen

	Solar Wind		Solar Energetic Particles		Solar System	
H	1900±400	[1]	---		1400	[11]
He	75±20	[2]	72±3	[8]	108	[11]
$^3He/^4He$	$(4.9\pm0.5)\cdot10^{-4}$	[3]	---			
C	0.43±0.02	[4]	0.435±0.040	[9]	0.60	[11]
N	0.15±0.06	[4]	0.124±0.010	[9]	0.12	[11]
O	≡1		≡1		≡1	
Ne	0.17±0.2	[2,5]	0.142±0.014	[9]	0.14	[12]
$^{20}Ne/^{22}Ne$	13.7±0.3	[5]	$9.2^{+1.9}_{-2.2}$	[10]		
Si	0.22±0.07	[6]	0.161±0.009	[9]	0.050	[10]
Ar	$(4.0\pm1.0)\cdot10^{-3}$	[5]	$(3.3\pm0.6)\cdot10^{-3}$	[9]	0.0048	[12]
Fe	0.19±0.07	[7]	0.154±0.015	[9]	0.045	[10]

[1] - Bame *et al.*, 1975
[2] - Bochsler *et al.*, 1986
[3] - Coplan *et al.*, 1984
[4] - Gloeckler *et al.*, 1986
[5] - Geiss *et al.*, 1972
[6] - Bochsler, 1987
[7] - Schmid *et al.*, 1987
[8] - Cook *et al.*, 1984
[9] - Brenemann, Stone, 1985
[10] - Mewaldt *et al.*, 1984
[11] - Anders, Ebihara, 1982
[12] - Meyer, 1985

These data remain incomplete since they do not include information on isotopic compositions except for helium and neon. Isotopic compositions of several additional elements, mostly noble gases, are available from the analysis of lunar soils. Recently, Wieler and co-workers (1986) have shown that lunar soil contains a surface implanted component with a $^{20}Ne/^{22}Ne$ ratio of 11.3±0.3 which they ascribe to Solar Energetic Particles (SEP). This result confirms the difference of the solar wind isotopic $^{20}Ne/^{22}Ne$ ratio (=13.7±0.3 – Geiss *et al.*, 1972) from SEP and it supports evidence for a secular decrease of the flux ratio of SEP to solar wind.

The ISEE 3/ICI (K.W. Ogilvie, P.I.) results have established strong correlations of the fluxes of the heavier elements with helium fluxes over time scales of several years. Undoubtedly there exist strong variations of these fluxes and their respective ratios as is well known for the case of

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helium abundances (Neugebauer, 1981). It is difficult to find significant changes of elemental ratios among minor species and to associate these changes with specific features of the solar corona or the solar surface. The clearest evidence of changes of elemental ratios emerges again from ratios involving helium which has an unfavorably low Coulomb drag factor and which requires a large ionization energy to feed it into the corona.

The composition of solar wind particles in the terrestrial magnetosheath has been measured with the CHEM instrument on AMPTE/CCE (G. Gloeckler, P.I.). It has been possible to unambiguously distinguish C^{6+} from the $^4He^{++}$ and N^{5+} from Si^{10+}, etc. and thus to add C and N to the list of measured elements. A remarkable general feature is the close agreement of the solar wind elemental composition with the composition of SEP. There appears to be a fundamental mechanism ordering abundances of elements with respect to their first ionization potentials. The process is not understood at present, but it seems that separation of ions from neutrals in the chromosphere or transition region occurs by diffusion (Geiss and Bochsler, 1985), by gravitational settling out of magnetic structures (Vauclair and Meyer, 1985), or by acceleration of magnetic loops filled with neutrals and ions (Bochsler, 1987).

CHARGE STATE DISTRIBUTIONS

The resolution of ions not only according to mass per charge but also according to mass opened a new dimension in solar wind studies. Although only measurements in the terrestrial magnetosheath which is occasionally compressed by the solar wind are available, the charge state distributions of several elements have been measured (Ipavich *et al.*, 1987). Surprisingly, in coronal hole associated flows, freezing-in temperatures as low as $1 \cdot 10^6$K have been found for carbon and oxygen, whereas iron shows significantly higher freezing-in temperatures as predicted by a theoretical study (Bürgi,1987).The solution of the mass and momentum conservation equation on the basis of electron densities observed in the inner corona has yielded a consistent picture of acceleration and the freezing-in process of charge states in the inner corona (Bürgi and Geiss, 1986).

VELOCITY DISTRIBUTIONS OF MINOR IONS

The rule $T_{kin}(i) \sim m(i)$ (equal velocity spread) has been confirmed in normal solar wind regimes for ions as heavy as iron (Bochsler *et al.*, 1985). This result, generally interpreted as consequence of wave heating action (Isenberg and Hollweg, 1983), should be revisited in regions of high collisionality in view of the work by Livi and Marsch (1987), who - without invoking wave action - find strongly skewed velocity distributions for electrons and protons in their simulation of an expanding coronal plasma. Another somewhat surprising result from ISEE 3/ICI is the fact that Fe (Schmid *et al.*, 1987) and Si (Bochsler, 1987) tend to lag behind $^4He^{++}$ in high speed streams, whereas for normal solar wind a good agreement among the speeds of all minor ions is found (Schmid *et al.*, 1987; Ogilvie *et al.*, 1982).

OTHER SOURCES OF PLASMA IN THE INNER HELIOSPHERE

By means of the SULEICA instrument on AMPTE/IRM it was possible to identify $^4He^+$ arising from interstellar pick-up ions (Möbius *et al.*, 1985). Comets as sources of weakly ionized atoms and molecules have been investigated and the contribution of extended planetary magnetotails to the interplanetary plasma has been studied (Macek and Grzędzielski, 1986).

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Solar Wind Interaction with Venus, Mars and Comets

M.K. Wallis

To model and quantify the comet-like *interactions with the atmosphere of* Venus the extent and time-variability of the suprathermal exospheric coronas need to be established. An extensive suprathermal O corona hypothesized to arise *via* dissociative recombination of the dominant O_2^+ ion was confirmed by the Orbiter's UV spectrometer. Uncertainties remain, firstly because the O-corona's extension beyond the observed limit of 1500 km altitude depends on the poorly-known partition between dissociation channels, secondly because the O_2^+ ionosphere varies substantially with solar UV inputs, and thirdly because the ionosphere and therefore O-corona decrease strongly from dayside to nightside (Kliore *et al.*, Adv. Space Res. 5(11), 1985).

Copious data available from Pioneer Venus Orbiter has allowed detailed study of atmospheric modification at Venus (Luhmann, Space Sci. Rev. 44 p 241, 1987). Confirming suggestions from the early Venus missions (Wallis 1972), the bow-shock is displaced sunwards from the position given by MHD modelling: this has been put on a firm statistical basis (Alexander *et al.*, GRL 13, p 917, 1986) and a solar cycle dependence demonstrated. Whether there is some weakening of the shock due to atmospheric ions created upstream of it - as strongly evident in Halley's comet - is unclear. The sunwards displacement and increased divergence (flaring) of the shock limbs has been demonstrated by gasdynamic modelling (Krymskii & Breus, Kosm. Issled. 24, p 778, 1986) with the atmosphere treated as sources of mass within the flow.

On one side of Venus, O^+ ions tend to be injected into atmosphere, but on the opposite side ejected further out. The precipitated flux from 30-80° zenith angle is calculated at 1-2% of the solar wind (Wallis, Geophys. Res. Lett. 9, p 427, 1982). Solar wind protons also probably penetrate into the ionosphere in similar fluxes, "diffusing" through to the ionopause under fluctuating fields (Gombosi *et al.*, JGR 85, p 7747, 1980). Other evidence for permeability of the 'magnetosheath' of enhanced $\mathbb{B}$-field (adjacent to the ionopause) are the small-scale "flux ropes" of twisted $\mathbb{B}$ found in the ionosphere. Consequent on the large O^+ gyroradii, asymmetry in the flow as registered by the bow shock distances on the flanks has now been demonstrated statistically (Alexander *et al.*, GRL 13, p 917, 1986). These authors also find

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