JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 102, NO. A2, PAGES 2125–2136, FEBRUARY 1, 1997

Helium abundance and dynamics in different types of solar wind streams: The Prognoz 7 observations

Yuri I. Yermolaev
Space Research Institute, Russian Academy of Sciences, Moscow, Russia

Vitaly V. Stupin
Irkutsk State Economic Academy, High Education Ministry, Irkutsk, Russia

Abstract. On the basis of the Prognoz 7 selective plasma measurements of α particles and protons the correlations of helium parameters (relative abundance n_α/n_p, velocity difference $\Delta V = |V_\alpha| - |V_p|$, and temperature ratio T_α/T_p) with bulk parameters in different types of solar wind streams are studied. Helium abundance increases with increasing wind velocity in quasi-stationary streams from 1.7 ± 2.6% in the heliospheric current sheet (HCS) up to 4.7 ± 6.6% in the coronal streamers (CS) and 6.6 ± 8.0% in the coronal holes (CH). The maximum value of n_α/n_p of 10.5 ± 10.1% is observed in coronal mass ejections (CME) and an intermediate value between HCS and CS 3.4 ± 4.2% in the shocked plasma. Helium abundance increases with increasing mass flux and density in streams from CHs and decreases in streams from CSs. Velocity difference ΔV increases with increasing velocity in HCS and streams from CSs and CHs, but it is usually small or negative in CMEs and in shocked plasma. The temperature ratio T_α/T_p increases with increasing velocity in the HCS and in streams from CSs, and it is approximately constant in streams from CHs, CMEs, and shocked plasma. No evidence has been obtained that the processes of α particle acceleration differ from each other in streams from CSs and CHs, but they differ from the one in the HCS. In contrast to processes of acceleration, the processes of α particle heating in streams from CHs and CSs are suggested to differ from each other, but they may be the same in streams from CSs and HCS. The value of α particle and proton heating in streams from CHs increases with increasing absolute value of velocity difference of α particles and protons.

1. Introduction

Study of the solar wind helium is important for two main reasons. On the one hand, the relative helium abundance under different conditions in the solar wind gives us valuable information about conditions and possible mechanisms of solar wind formation in the solar corona. Such information is important for investigation of the more common and unresolved problem of solar corona heating and solar wind formation. On the other hand, owing to their small but significant abundance and their mass per charge ratio of 2 instead of 1, as for hydrogen, the observed properties of helium ions provide important information on the physical processes in the interplanetary medium [*Hundhausen,* 1972; *Neugebauer,* 1981a, 1982; *Geiss,* 1985; *Bochsler,* 1992; *Yermolaev,* 1994a, b].

Paper number 96JA01635.
0148-0227/97/96JA-01635$09.00

Many space experiments have indicated different relationships between α particle and proton hydrodynamic parameters in different types of solar wind streams. The main conclusions of these studies are as follows: average values of velocity difference, $\Delta V = |V_\alpha| - |V_p|$, temperature ratio of α particles and protons, T_α/T_p, and helium abundance, n_α/n_p, are small in low-velocity streams, that is, in the heliospheric current sheet (HCS) and streams from coronal streamers (CS), and in streams disturbed by arrivals of interplanetary shocks; values increase in high-velocity streams from coronal holes (CH). In coronal mass ejections (CME) the ratio n_α/n_p is higher than in CHs, but ΔV and T_α/T_p are lower than in CHs (see reviews by *Neugebauer* [1981a], *Neugebauer et al.* [1994], *Yermolaev* [1994a], and references therein).

Correlations of helium parameters with various bulk parameters in different types of solar wind streams have been studied in a limited number of papers. The Prognoz 7 data were used to obtain two-dimensional dependences of helium parameters on density $n = \sum n_i \approx n_p$ and velocity V_p [*Yermolaev,* 1991, 1992a]. Onedimensional dependences of helium abundance n_α/n_p on density n_p and mass flux n_pV_p, ΔV versus V_p, ΔV versus τ_e/τ_s, T_α/T_p versus ΔV, T_α/T_p versus V_p, T_α/T_p versus τ_e/τ_c(where τ_e is time of solar wind expansion and τ_s and τ_c are times of momentum and energy exchange due to Coulomb collisions, respectively) were studied by *Yermolaev* [1992b, 1994b, 1995] and *Yermolaev and Zastenker* [1994]. Dependences of n_α/n_p on V_p were researched on the basis of ISEE 3 and IMP 6-8 data by *Neugebauer* [1992].

In this paper we present additional information about the dependences on several hydrodynamic parameters of the relative abundance, velocity difference, and temperature ratio of α particles and protons in different types of solar wind streams as observed on the Prognoz 7 satellite. Obtained results are used to study the physical processes of formation, acceleration, and heating of helium ions in different types of wind.

2. Methods of Measurement and Data Processing

The Prognoz 7 satellite was launched on a highly elliptical orbit with an apogee of $\sim$ 203,000 km, a perigee of $\sim$ 500 km, and a period of $\sim$ 98 hours. In this orbit the spacecraft spent 50-70% of the time in solar wind that was undisturbed by the bow shock or by the magnetosphere of the Earth.

The proton and α particle energy distributions and ion flux, nV_p (where $n = \sum n_i \approx n_p$), were measured with SCS plasma instrument on the Prognoz 7 satellite. The experiment is described in detail by *Vaisberg et al.* [1979] and *Yermolaev et al.* [1989]. An important advantage of these measurements was that the energy distributions of α particles and protons were selectively measured with an electrostatic analyzer with a Wien filter. The high sensivity of this selective analyzer allowed measurements of proton and α particle energy spectra over a wide range of solar wind parameters. The integral ion flux was measured with wide-angle Faraday cups. More than 11,000 energy spectra for each ion component (with a time resolution of 8 min) and about 54,000 values of ion flux (with a time resolution of 10 s) were obtained during the period from November 1978 to June 1979. The magnetic field was measured with the magnetometer SG-70 with a time resolution of 10 s (E.A.Gavrilova et al., preprint, 1986).

The hydrodynamic parameters of protons and α particles, that is, the bulk velocities, V_α and V_p, the temperatures, T_α and T_p, and the density ratio, n_α/n_p, were derived from the measured spectra based on the assumption of convected, isotropic Maxwellian velocity distributions. As the energy distributions of both ion components were measured along the Earth-Sun line, only the radial components of hydrodynamic parameters were derived. Because of restrictions on the velocity ranges (230-900 km/s for protons and 170-620 km/s for α particles), dependences on V_p were limited to $V_p \leq$ 550 km/s and dependences on other parameters to $V_p \leq$ 620 km/s. The SCS measurements of proton parameters show that time intervals with $V_p >$ 620 km/s contain less than 3% of total time of Prognoz 7 observations and distribution of these intervals over different types of solar wind streams is as follows: 7% in streams from CHs, 14% in CMEs and 79% in shocked plasma (i.e., shocked plasma intervals with $V_p \leq$ 620 km/s contain about 70% of total observations in shocked plasma). Obtained values of ion flux nV_p and proton velocity allow the determination of ion density n. The accuracy of the velocity determination is about 2-3%; that of the temperature, 20-30%. Actual values of helium abundance n_α/n_p may differ from the measured one by a factor of $\sim$ 2. To increase the reliability of results we exclude 1-hour intervals near interplanetary shock fronts from the analysis, and in several cases use hourly averaged data for the analysis.

On the basis of solar wind parameter distributions on the "density-velocity plane", we selected five different types of solar wind streams which may be related to well-known solar coronal structures and phenomena: (1) the heliospheric current sheet, (2) streams from coronal streamers, (3) streams from coronal holes, (4) solar wind streams observed after the passage of interplanetary shocks, and (5) plasma of coronal mass ejections [*Yermolaev*, 1990; 1991]. The method of data selection is described in the appendix.

The time intervals for the five types of solar wind streams were published by *Yermolaev and Stupin* [1992]. *Yermolaev* [1995] reanalyzed data related to the fourth and fifth types of streams and presented refined intervals. The large part of CME intervals coincided with the ISEE 3 observations of bidirectional superthermal electron streams, which have been identified as coronal mass ejections by *Gosling et al.* [1987].

Refined data on average values of several hydrodynamic parameters in five types of solar wind streams are presented in Table 1. The average values of helium abundance n_α/n_p, velocity difference ΔV (as well as the value of $\Delta V/V_A$, where V_A is the Alfven velocity), and temperature ratio T_α/T_p should be discussed in detail in several cases because the differences between average values in different types of solar wind streams are found to be less than derived dispersions, σ, and this raises the question of the significance of the derived differences. To reduce the probability of error in all cases of the averaging of α particle parameters (this is true for the results presented in Table 1 as well as those shown in the Figures 1-8), we performed additional checks of the results.

First, we identified error points that deviated far from average values. For this purpose, points that deviated more than 3σ from the average value (these points, as a rule, were not more than 1-3%) were dropped from the data set, and statistical characteristics were recalculated for the remaining data set. As a result of this procedure, the average values changed not more than

Table 1. Average Parameters of Plasma and Magnetic Field in Five Types of Solar Wind Streams

SW Parameters	Types of Solar Wind Streams				
	HCS	CS	CH	Shocked SW	CME
$V_p, km/s$	351 ± 45	359 ± 33	449 ± 52	539 ± 84	504 ± 67
$T_p, 10^4$ K	5.3 ± 4.4	5.4 ± 5.1	9.8 ± 8.5	19.8 ± 13.6	6.7 ± 6.2
n_p, cm^{-3}	29.6 ± 10.0	9.6 ± 4.2	6.1 ± 3.4	8.2 ± 6.1	6.3 ± 2.8
B, nT	6.3 ± 2.3	7.2 ± 3.0	6.9 ± 2.7	10.3 ± 6.6	10.2 ± 5.2
V_A, km/s	28 ± 9	53 ± 19	66 ± 24	67 ± 23	91 ± 35
β_p	2.0 ± 1.7	0.5 ± 0.6	0.6 ± 0.6	1.0 ± 0.8	0.3 ± 0.3
$n_pV_p, 10^8\ cm^{-2}s^{-1}$	10.5 ± 3.9	3.4 ± 1.4	2.7 ± 1.5	4.2 ± 3.1	3.1 ± 1.4
$m_pn_pV_p{}^2, 10^{-8}dyn/cm^2s$	6.3 ± 2.2	2.1 ± 1.0	2.1 ± 1.2	3.7 ± 3.0	2.6 ± 1.3
$m_pn_pV_p{}^3/2,\ erg/cm^2s$	1.13 ± 0.56	0.38 ± 0.20	0.47 ± 0.28	1.00 ± 0.92	0.68 ± 0.38
n_α/n_p, %	1.7 ± 2.6	4.7 ± 6.6	6.6 ± 8.0	3.4 ± 4.2	10.5 ± 10.1
$\lvert V_\alpha\rvert - \lvert V_p\rvert, km/s$	1 ± 18	-1 ± 19	9 ± 22	-2 ± 24	1 ± 21
$(\lvert V_\alpha\rvert - \lvert V_p\rvert)/V_A$	0.03 ± 0.70	0.03 ± 0.40	0.12 ± 0.38	-0.03 ± 0.27	0.03 ± 0.32
V_α/V_p	1.001 ± 0.05	0.996 ± 0.05	1.020 ± 0.05	0.995 ± 0.06	1.004 ± 0.05
T_α/T_p	2.7 ± 3.0	4.2 ± 3.6	4.4 ± 3.0	3.3 ± 2.6	3.9 ± 2.8
τ_e/τ_s	1.11 ± 1.27	0.31 ± 0.62	0.06 ± 0.20	0.02 ± 0.03	0.13 ± 0.35
τ_e/τ_c	2.43 ± 2.60	0.64 ± 1.26	0.10 ± 0.32	0.04 ± 0.06	0.21 ± 0.52

10-15%. The average values for n_α/n_p and T_α/T_p are found to be systematically larger than the main peaks of distributions. This allowed us to conclude the following: (1) arbitrary deviations are absent, and (2) the ΔV distribution has a sufficiently symmetric shape, but the n_α/n_p and T_α/T_p distributions have asymmetric shapes with long, low tails.

Second, we examined the stability of statistical characteristics as a function of the number of points in a bin. Since a goal of this paper is to study the relationship of average helium parameter values to variations in several other parameters, helium parameters were binned over specified ranges of the plasma parameters of interest (velocity, density, flux, etc.). The average values were checked by dividing the number of points in the bin into parts and comparing the two new (for shorter data set) averages to the previous (total data set) average. When the results differed by more than 30%, the bin sizes were increased to improve statistics. The number of measurements in the final averaging bins varied from 50 to 4600.

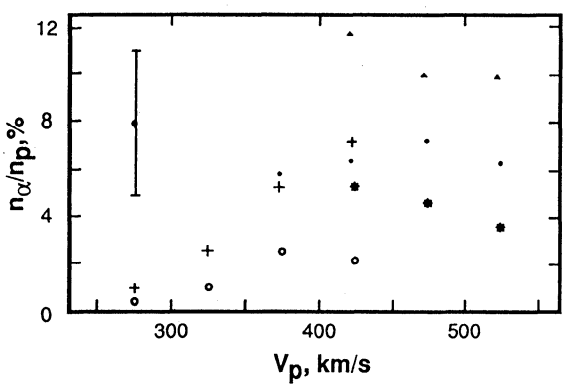

Figure 1. Dependence of the helium abundance n_α/n_p on the solar wind velocity V_p in the HCS (open circles), streams from CSs (crosses) and CHs (filled circles), streams of shocked plasma (asterisks) and plasma of CMEs (triangles).

3. Results

We first describe correlations of helium abundance with MHD parameters of solar wind. Velocity of solar wind allows selection of data over two large groups: low- and high-velocity streams of solar wind [*Hundhausen*, 1972; *Schwenn*, 1983]. The dependence of helium abundance n_α/n_p on the solar wind velocity V_p is presented in Figure 1 separately for low velocity ($V_p < 450$ km/s) streams in the HCS (open circles) and streams from CSs (crosses) and for high velocity ($V_p > 350$ km/s) streams from CHs (closed circles) and streams of shocked plasma (asterisks) and plasma of CMEs (triangles). An average error bar is also shown in the figure. To increase statistics in each velocity interval, the data have been averaged over a V_p range of 50 km/s. Table 2 presents coefficients of linear approximations for all types of solar wind streams in Figures 1-8. The symbols in Figures 2-8 are the same as those in Figure 1.

In the low-velocity range, with $275 < V_p < 425$ km/s, the helium abundance n_α/n_p increases from 0.4 to 2.1% in HCS and from 1.0 to 7.3% in streams from CSs . In the high-velocity range, with $375 < V_p < 525$ km/s, the behavior of n_α/n_p in different types of streams differs: in streams from CHs the value of n_α/n_p slightly increases in the range from ~6 to ~7%; in shocked plasma the value of n_α/n_p decreases from 5.3 to 3.7% and in CMEs it is high and decreases from 11.8 to 10.0%.

The values of density n and ion flux nV_p were used by *Gosling et al.* [1981] to select the dense plasma streams in the HCS and from CSs on the basis of the ISEE 3 data. So, it is interesting to analyze the dependences of helium abundance n_α/n_p on density n and ion flux nV_p

Table 2. Approximation Parameters in Five Types of Solar Wind Streams for Figures 1-8

Figure	Approximation [a]	Types of Solar Wind Streams				
		HCS	CS	CH	Shocked SW	CME
1	$n_\alpha/n_p = AV_p \times 10^{-2}$ $+B \times 10$	$A = 2.30 \pm 0.30$ $B = -0.57 \pm 0.11$	8.00 ± 0.45 -2.24 ± 0.16	0.54 ± 0.28 0.67 ± 0.13	-2.94 ± 0.32 2.00 ± 0.16	-3.99 ± 0.84 3.40 ± 0.42
2	$n_\alpha/n_p = AnV_p \times 10^{-9}$ $+B \times 10$	$A = -0.03 \pm 0.34$ $B = 0.23 \pm 0.04$	-9.28 ± 1.03 0.95 ± 0.04	2.72 ± 0.95 0.83 ± 0.03	2.26 ± 0.71 0.41 ± 0.04	-10.0 ± 3.59 1.73 ± 0.13
3	$n_\alpha/n_p = An \times 10^{-1}$ $+B \times 10$	$A = -0.28 \pm 0.14$ $B = 0.32 \pm 0.04$	-4.70 ± 0.36 1.09 ± 0.04	1.11 ± 0.41 0.84 ± 0.03	1.72 ± 0.36 0.36 ± 0.04	-2.47 ± 1.80 1.57 ± 0.13
4a	$\lvert V_\alpha\rvert - \lvert V_p\rvert = AV_p \times 10^{-1}$ $+B \times 10$	$A = 1.34 \pm 0.15$ $B = -4.56 \pm 0.55$	0.08 ± 0.11 0.15 ± 0.39	0.09 ± 0.12 0.16 ± 0.29	-0.46 ± 0.13 2.70 ± 0.65	-0.51 ± 0.14 2.68 ± 0.71
4b	$T_\alpha/T_p = AV_p \times 10^{-2} + B$	$A = 2.00 \pm 0.30$ $B = -3.73 \pm 1.08$	3.57 ± 0.29 -7.40 ± 1.06	-0.10 ± 0.13 5.94 ± 0.59	-0.22 ± 0.19 5.15 ± 1.00	1.54 ± 0.33 -2.43 ± 1.66
5a	$\lvert V_\alpha\rvert - \lvert V_p\rvert = AV_A \times 10^{-1}$ $+B \times 10$	$A = 5.86 \pm 0.97$ $B = -1.12 \pm 0.29$	3.28 ± 0.30 -1.40 ± 0.18	0.14 ± 0.22 0.15 ± 0.16	0.57 ± 0.41 0.02 ± 0.28	-1.78 ± 0.30 1.61 ± 0.30
5b	$T_\alpha/T_p = AV_A \times 10^{-1} + B$	$A = 1.42 \pm 0.19$ $B = -0.11 \pm 0.55$	1.22 ± 0.09 0.00 ± 0.53	0.03 ± 0.04 5.20 ± 0.32	-0.01 ± 0.06 3.98 ± 0.44	0.00 ± 0.07 5.29 ± 0.72
6	$T_\alpha/T_p = AX + B$	$A = 3.49 \pm 0.27$ $B = 3.52 \pm 0.17$	4.13 ± 0.18 5.91 ± 0.13	1.74 ± 0.16 5.29 ± 0.09	-0.25 ± 0.49 4.06 ± 0.18	1.70 ± 0.43 5.19 ± 0.27
7a	$\lvert V_\alpha\rvert - \lvert V_p\rvert = A\tau_e/\tau_s \times 10$ $+B$	$A = -0.56 \pm 0.05$ $B = 7.49 \pm 1.08$	-0.56 ± 0.06 0.34 ± 0.53	-1.20 ± 0.17 9.52 ± 0.49	-5.72 ± 2.35 5.27 ± 1.28	-0.25 ± 0.25 1.84 ± 1.26
7b	$(\lvert V_\alpha\rvert - \lvert V_p\rvert)/V_A = A\tau_e/\tau_s$ $+B \times 10$	$A = -0.24 \pm 0.03$ $B = 2.50 \pm 0.52$	-0.46 ± 0.04 1.08 ± 0.18	-0.17 ± 0.05 1.35 ± 0.13	-1.63 ± 0.38 0.95 ± 0.23	-0.46 ± 0.12 0.70 ± 0.24
8	$T_\alpha/T_p = A\tau_e/\tau_c \times 10 + B$	$A = -0.07 \pm 0.01$ $B = 5.14 \pm 0.20$	-0.15 ± 0.01 6.41 ± 0.14	-0.22 ± 0.02 5.73 ± 0.09	-1.07 ± 0.18 4.46 ± 0.18	-0.14 ± 0.04 5.46 ± 0.28

[a] Used parameters have the following dimensions: $[n_\alpha/n_p] = \%$; $[V_p] = [V_\alpha] = [V_A] = km/s$; $[n] = cm^{-3}$; $[nV_p] = cm^{-2}s^{-1}$.

in different types of streams obtained from the Prognoz 7 data and presented in Figures 2 and 3. The dependences on n and nV_p in corresponding types of streams are similar to each other. In streams from CSs and HCS the value of n_α/n_p decreases along a common curve from 5 to ~1.5 with increasing n and nV_p. The helium abundance slightly increases respectively from ~2 to ~4 in shocked plasma and from ~5 to ~6.5% in streams from CHs. In CMEs the value of n_α/n_p decreases from ~11 to ~6%.

Correlations of the velocity difference and temperature ratio of α particles and protons with the solar wind parameters make it possible to study processes of acceleration and of heating of α particles relative to the main ion (proton) component of the solar wind. The dependences of the alpha-proton velocity difference ΔV and temperature ratio T_α/T_p on the solar wind velocity V_p in different types of streams are presented respectively in Figures 4a and 4b.

As can be seen in Figure 4a, as proton velocity V_p increases from 275 to 375 km/s, the velocity difference ΔV increases from -9 to 7 km/s and from -8 to 5 km/s in HCS and streams from CSs, respectively. The velocity difference ΔV increases slightly from 7 to 10 km/s as proton velocity increases from 425 to 525 km/s in

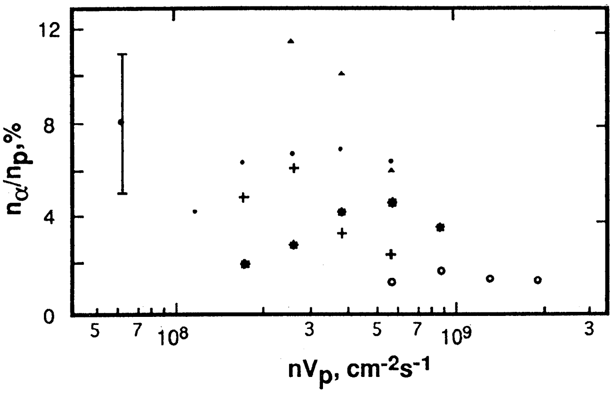

Figure 2. Dependence of helium abundance n_α/n_p on density n in different types of streams. Symbols are the same as those in Figure 1.

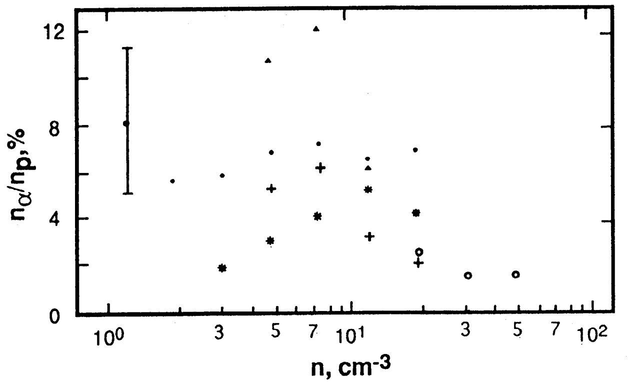

Figure 3. Dependence of helium abundance n_α/n_p on ion flux nV_p in different types of streams. Symbols are the same as those in Figure 1.

streams from CHs. ΔV decreases from ~5 km/s to ~0 in shocked streams. ΔV is not monotonic in CMEs.

Dependences of temperature ratio on wind velocity in different types of streams (see Figure 4b) are similar to those of velocity difference. Nevertheless, in contrast to Figure 4a, where the curves of velocity difference for streams from CSs and CHs have approximately similar slopes and are located near a general curve, the curves of temperature ratio in these types of streams differ: T_α/T_p increases from 1.5 to 5.0 as velocity increases from 275 to 375 km/s in streams from CSs, but is approximately constant in the range $425 < V_p < 575$ km/s in streams from CHs. Temperature ratio varies only slightly from 3 to 4 in shocked streams and increases from ~3 to ~5 in CMEs as velocity increases from 425 to 575 km/s.

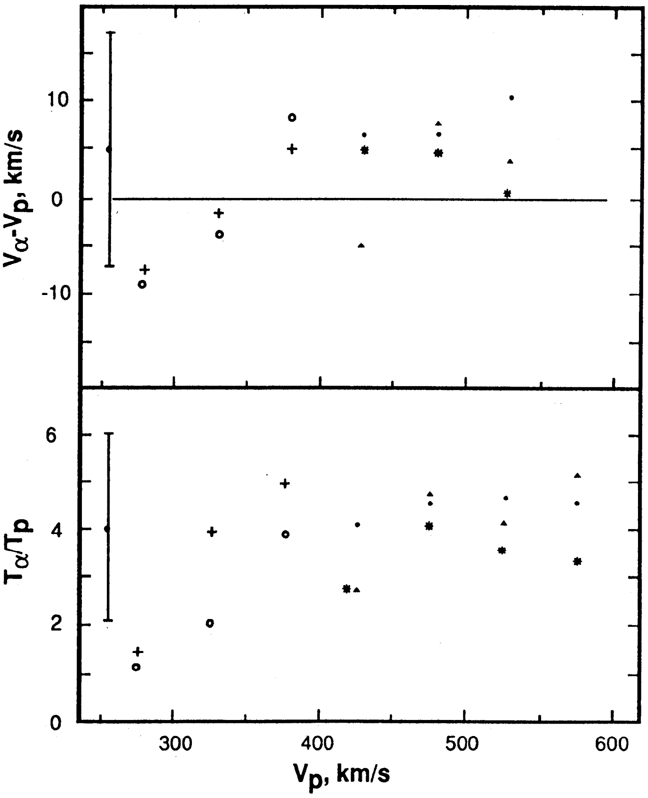

Figure 4. Dependence on the solar wind velocity V_p of (a) velocity difference $\Delta V = |V_\alpha| - |V_p|$ and (b) temperature ratio T_α/T_p for α particles and protons in different types of streams. Symbols are the same as those in Figure 1.

The acceleration and heating of α particles in the solar wind are suggested to be caused by interaction of Alfven waves with plasma. Many space experiments yield correlations between ΔV and the value of Alfven velocity V_A (see reviews by *Neugebauer* [1981a] and *Yermolaev* [1994a]). Dependence of T_α/T_p on V_A has been derived from the Prognoz 7 data by *Yermolaev* [1994a]. The dependences of the alpha-proton velocity difference ΔV and temperature ratio T_α/T_p on the Alfven velocity V_A in different types of streams are presented in Figures 5a and 5b, respectively.

The velocity difference ΔV increases from -8 to 16 km/s in HCS as V_A increases from 10 to 40 km/s. In the range 30 to 60 km/s the value ΔV increases from ~ -10 to ~ +10 km/s in streams from CSs and CHs, respectively; it continues to grow to ~ 14 km/s at $V_A =$ 80 km/s in streams from CSs, but decreases to ~ 8 km/s at $V_A =$ 100 km/s in streams from CHs. In shocked plasma the curve of ΔV changes similarly to ones in streams from CSs and CHs in the range of V_A = 40-80 km/s. No simple relationship exists between ΔV and V_A in CMEs: ΔV is 6-8 km/s when $50 < V_A < 70$ km/s and ΔV is -4 to -6 km/s when $80 < V_A < 110$ km/s (in this range the data were averaged in wider intervals).

The temperature ratio T_α/T_p in HCS and streams from CSs increases along a common straight line from ~1 to ~8 as V_A increases from 10 to 80 km/s. In streams from CHs, T_α/T_p grows slightly from ~ 4 to ~ 6 as V_A increases from 30 to 100 km/s. The temperature ratio changes slightly from 2.5 to 3.5 and from 4 to 5 for $50 < V_A < 100$ km/s in shocked streams and CMEs, respectively.

The Prognoz 7 measurements allow us to study the relationships between preferential heating and acceleration of α particles in the different types of solar wind streams. The dependences of the ratio of α particle to proton temperatures T_α/T_p on their velocity difference relative to their average thermal velocity, $X = \Delta V/[2k(T_\alpha/m_\alpha + T_p/m_p)]^{1/2}$, in different types of streams are presented in Figures 6. In the HCS the value T_α/T_p monotonically increases from 1.5 to 8 as X increases from -0.6 to + 0.8. In streams from CSs the dependence is similar, but the temperature ratio is higher than that in HCS and increases from 2 to 11 as X increases from -1.0 to +0.9. The dependence for streams from CHs is not monotonic, and the temperature ratio decreases from 8 to 4 as X increases from -1.0 to 0 and increases from 4 to 9 as X increases from 0 to +1.0. In shocked plasma T_α/T_p changes slightly from 3 to 4 in the range of X from -0.4 to +0.4. The temperature ratio in CMEs increases from 3 to 5.5 as X increases from -0.6 to 0.4.

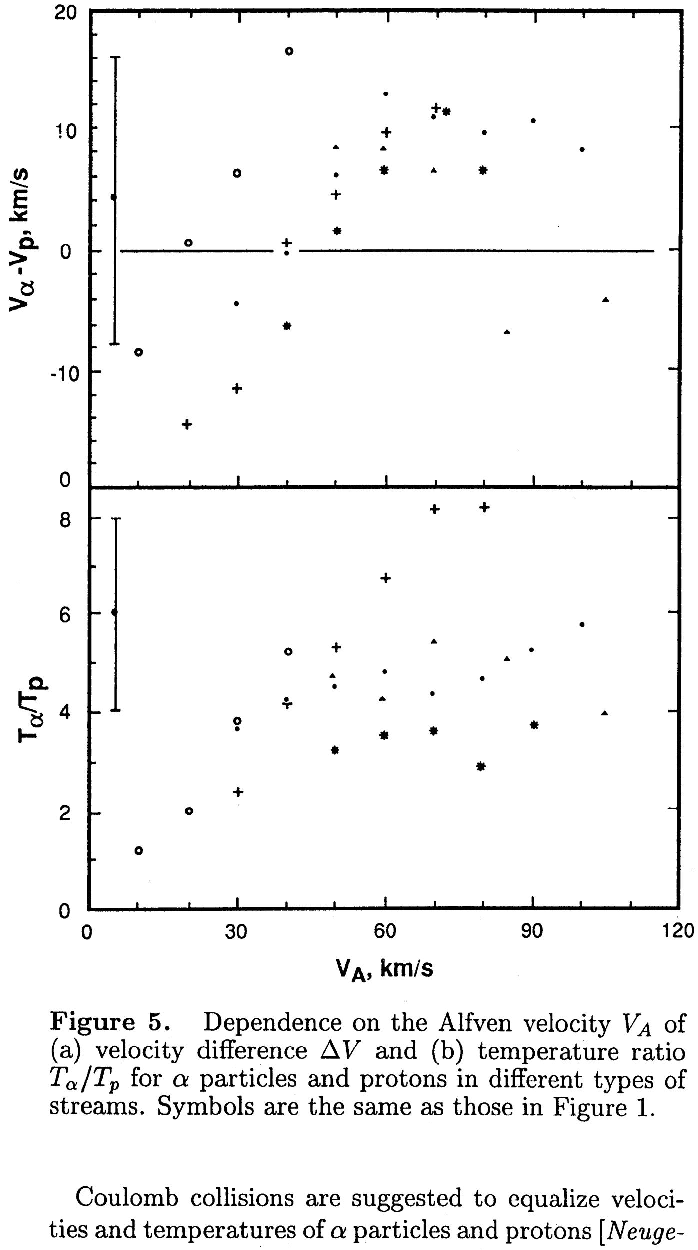

Figure 5. Dependence on the Alfven velocity V_A of (a) velocity difference ΔV and (b) temperature ratio T_α/T_p for α particles and protons in different types of streams. Symbols are the same as those in Figure 1.

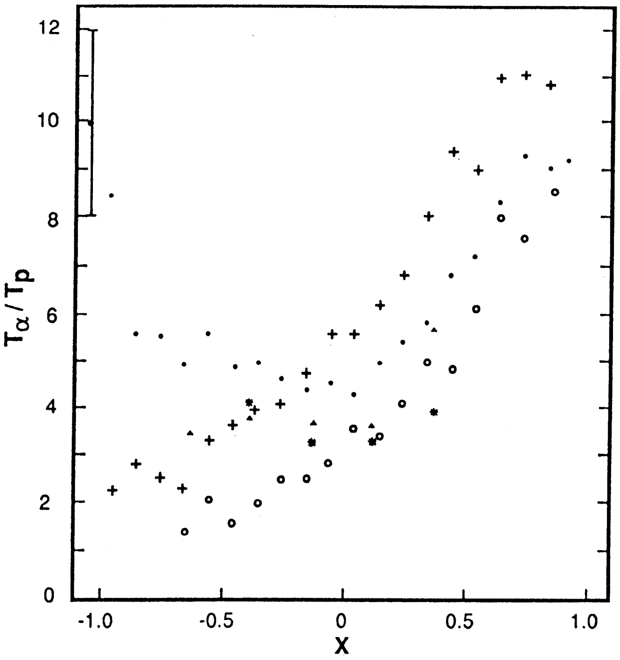

Figure 6. Dependence of α particle and proton temperature ratio T_α/T_p on relative velocity difference X (see text) in different types of solar wind streams. Symbols are the same as those in Figure 1.

Coulomb collisions are suggested to equalize velocities and temperatures of α particles and protons [*Neugebauer,* 1981a; *Yermolaev and Stupin,* 1990b]. Thus it is interesting to compare the velocity differences ΔV and $\Delta V/V_A$ with the ratio of time of solar wind expansion to the time of momentum exchange due to Coulomb collisions τ_e/τ_s (Figures 7) and to compare the temperature ratio T_α/T_p with the ratio of solar wind expansion time to the time of energy exchange due to Coulomb collisions τ_e/τ_c (Figures 8) in different types of solar wind streams. The parameters τ_e/τ_s and τ_e/τ_c were derived on the basis of the Prognoz 7 measurements using the formulae presented in papers by *Neugebauer* [1981a] and *Yermolaev and Stupin* [1990b].

In Figures 7a and 7b the dependences of the velocity differences ΔV and $\Delta V/V_A$ on τ_e/τ_s are presented for the HCS, streams from CSs and CHs, and shocked plasma and CMEs. These figures show that in a collisionless plasma ($\tau_e/\tau_s < 0.3$), the discrepancy between curves for streams from CHs and CSs is small, but in collisional plasma ($\tau_e/\tau_s > 0.3$) it reaches ~10 km/s and 0.3, respectively, and for both types of streams the velocity differences are negative. An unexpected result is the fact that the velocity differences in the HCS are higher than in streams from CHs and CSs. It should be noted that the number of observatins in collisionless plasma in the HCS is not large (~ 27% of the total number observations in HCS, or about 27 hours of observations). The behavior of ΔV in shocked plasma and CMEs is similar to that found in streams from CSs and CHs.

In contrast to the velocity differences, the temperature ratios of α particles and protons (see Figure 8) in streams from CHs and CSs differ, and the curve for streams from CSs is higher than the one for streams from CHs and is close to the one for HCS. The curve for shocked plasma is close to the one for streams from CHs, but the curve for CMEs is lowest of all. All curves reach ~ 1 in a collisional plasma ($\tau_e/\tau_c > 0.3$).

4. Discussion of results

Most of the dependences presented above have been published in other formats on the basis of measurements on different spacecraft. In this paper we present them in a single format after sorting the Prognoz 7 data over different types of solar wind streams. This approach makes it possible to find variations from one type of stream to another.

In general, data on n_α/n_p versus V_p dependences presented in Figure 1 agree with those obtained without selection on Vela 3 [*Hirshberg et al.,* 1972a, b], Explorer 34 and 43 [*Ogilvie,* 1972], Heos 1 [*Moreno and*

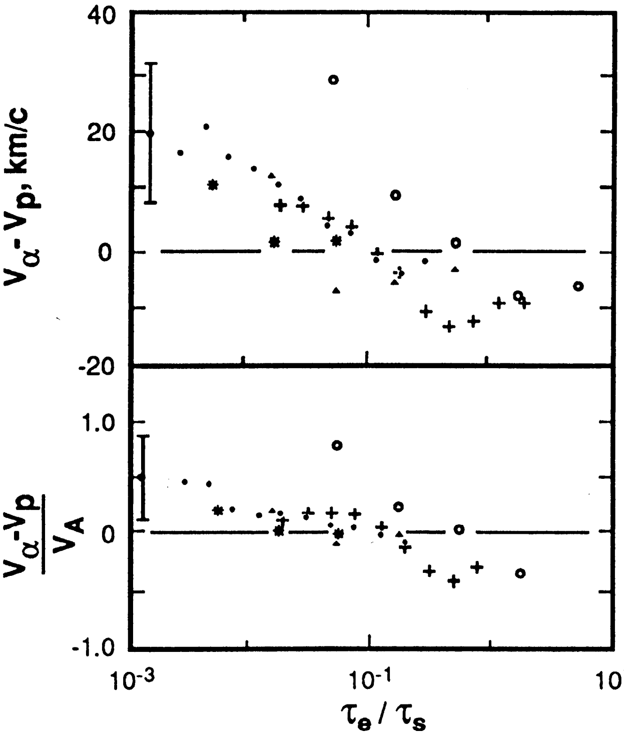

Figure 7. Dependences of α particle and proton (a) velocity difference ΔV and (b) velocity difference relative to Alfven velocity $\Delta V/V_A$ on the ratio of solar wind expansion time to time of momentum exchange due to Coulomb collisions τ_e/τ_s. Symbols are the same as those in Figure 1.

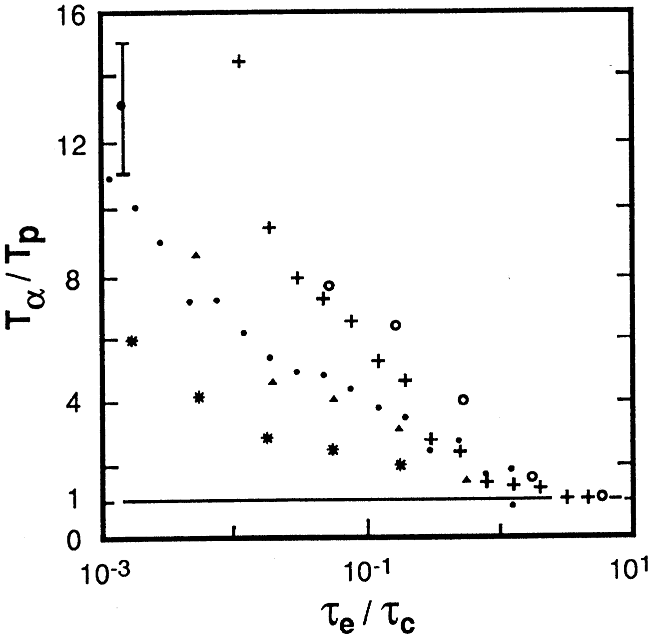

Figure 8. Dependence of α particle and proton temperature ratio T_α/T_p on the ratio of solar wind expansion time to time of energy exchange due to Coulomb collisions τ_e/τ_c. Symbols are the same as those in Figure 1.

Palmiotto, 1973], IMP 6-8 [*Bame et al.,* 1977], OGO 5 [*Neugebauer,* 1981a], ISEE 3 [*Ogilvie et al.,* 1989], and Prognoz 7 [*Yermolaev and Stupin,* 1990a; *Yermolaev et al.,* 1990].

Only in the paper by *Neugebauer* [1992] were the ISEE 3 and IMP 6-8 data sorted over five different types of streams: three quasi-stationary types (plasma sheet (PS), interstream (IS), coronal holes (CH)), and two transient types (bidirectional electron streaming (BES) and helium abundance enhancements (HAE)). The first three types of stream are likely to be similar to our first three types and may be compared to each other. It is our opinion that the BES and HAE types of plasma may be compared to CMEs, but there is no analogy in the paper mentioned above for the shocked plasma.

Both studies show that helium abundance correlates with solar wind velocity in all three quasi-stationary types of streams and anticorrelates in CMEs and HAEs. In addition, the Prognoz 7 data show that the shocked plasma has the same helium abundance as in the initial (before arrival of any interplanetary shock) quasi-stationary streams and are accelerated up to higher velocity. The anticorrelation of n_α/n_p and V_p in shocked plasma agrees with the conclusion that conditions near HCS are favorable for expansion of interplanetary shocks.

On the whole, the n_α/n_p versus nV_p dependences presented in Figure 2 are in good agreement with those obtained without selection on Vela 3 [*Hirshberg et al.,* 1972a], Explorer 34 and 43 [*Ogilvie,* 1972], Heos 1 [*Moreno and Palmiotto,* 1973], OGO 5 [*Neugebauer,* 1981a], and Prognoz 7 [*Yermolaev and Stupin,* 1990a; *Yermolaev et al.,* 1990].

On the basis of the Prognoz 7 data it has been shown that helium abundance correlates with ion flux in streams from CHs and anticorrelates in streams from CSs [*Yermolaev,* 1992b]. Figure 2 also shows that in HCS the helium abundance is almost independent of ion flux; it correlates with flux in shocked plasma and anticorrelates in CMEs.

The anticorrelation of helium abundance n_α/n_p and ion density n has been derived from the Explorer 34 data [*Ogilvie and Wilkerson,* 1969]. Later on the basis of the Heos 1 data no n_α/n_p versus n dependence has been found [*Formisano et al.,* 1970]. The Vela and IMP data showed that in slow and dense streams (from streamers) of solar wind, the helium abundance anticorrelates with density [*Gosling et al.,* 1981; *Feldman et al.,* 1981]. On the basis of the Prognoz 7 data it has been shown that helium abundance correlates with ion density in streams from CHs and anticorrelates in streams from CSs [*Yermolaev,* 1992b]. Figure 3 also shows that the helium abundance correlates with density in shocked plasma and anticorrelates in the HCS and CMEs.

Thus Figures 1-3 show that mechanisms of solar wind helium abundance for different types of streams differ. In particular, the obtained results support somewhat the hypothesis by *Geiss et al.* [1970] that only in CHs the minor ions may be dragged out from the solar corona into the interplanetary medium due to Coulomb friction with the proton component [*Yermolaev and Stupin,* 1990a; *Yermolaev,* 1991]. On the other hand, the qualitative model based on IMP and Vela observations during 1971-1978 [*Borrini et al.,* 1981; *Feldman et al.,* 1981; *Gosling et al.* 1981] is likely to operate in the HCS and streams from CSs. The helium abundance in shocked plasma may be the same as in the HCS, streams from CSs, and CHs and may depend on conditions of interplanetary shock expansion. The helium abundance in CMEs is connected with processes of plasma acceleration in the solar atmosphere, and it calls for further investigation.

The data on the ΔV versus V_p dependence presented in Figure 4a are in good agreement with those obtained without selection on Vela 3 [*Hirshberg et al.,* 1974], IMP 6-8 [*Asbridge et al.,* 1976; *Feldman et al.,* 1978], Heos 2 [*Grunwaldt and Rosenbauer,* 1978], OGO 5 and Explorer 43 [*Neugebauer,* 1981a], Helios [*Marsch et al.,* 1982], and ISEE 3 [*Ogilvie et al.,* 1982] over the total range of solar wind velocity, if for analysis in the range $V_p > 400$ km/s we use results obtained for streams from CHs and ignore CME and shocked plasma [*Yermolaev,* 1994a].

On the whole, the data on the T_α/T_p versus V_p dependences presented in Figure 4b are in good agreement with observations obtained without selection on Vela 3 [*Feynman,* 1975], Prognoz 1 [*Bosqued et al.,* 1977], OGO 5 and Explorer 43 [*Neugebauer,* 1981a], ISEE 3 [*Klein et al.,* 1985], and Prognoz 7 [*Yermolaev and Stupin,* 1990a; *Yermolaev,* 1994a] over the total range of velocity. (The ISEE 3 data were derived from the dependence of T_α/T_p on $t = R/V_p$ presented by *Klein et al.* [1985] where the plasma expansion time t is determined as the ratio of distance $R = 1$ AU and the local velocity of the solar wind).

On the basis of Prognoz 7 measurements it was noted that the maximum velocity difference and temperature ratio are observed in streams from CHs [*Yermolaev et al.,* 1991; *Yermolaev,* 1991]. On the other hand, based on the results of recent papers and especially on the data shown in Figures 4a and 4b it is evident that ΔV is small or negative in shocked solar wind streams and CMEs; T_α/T_p is usually less than 4 in shocked plasma and varies in the range 4-6 in CMEs. It should be noted that the most negative value of velocity difference and the least temperature ratio are observed during first 10-30 min downstream of the shock front. The fact that negative velocity differences and low temperature ratios were observed downstream of interplanetary shocks has been previously reported on the basis of the first α particle and proton selective measurements on the Prognoz 1 [*Zertsalov et al.,* 1976a, b] and more recent selective experiments on the ISEE 3 [*Ogilvie et al.,* 1982] and the Prognoz 7 and 8 satellites [*Zastenker and Borodkova,* 1984a, b; *Avanov et al.,* 1987].

Performed analysis shows that the Prognoz 7 data do not contradict the results of earlier papers and confirm the conclusion that at 1 AU there is a strong difference between α particle and proton velocities in fast streams from CHs, but it is absent in CMEs and it may be small or negative in streams behind interplanetary shocks and HCS and streams from CSs; the temperature ratio is low in HCS and streams from CSs and it is high in streams from CHs, CMEs, and behind interplanetary shocks (see Table 1).

Furthermore, the data of Figures 4a and 4b allow us to make some new conclusions. Figure 4a shows that ΔV correlates with V_p in HCS and streams from CSs and CHs and that these three curves are aligned with a common straight line. The velocity difference is likely to anticorrelate with V_p in shocked plasma and shows no unambiguous dependence on V_p in CMEs. In contrast to the velocity difference, the temperature ratio slope in streams from CHs differs from those in HCS and streams from CSs: the value of T_α/T_p correlates with V_p in HCS and streams from CSs and does not depend on V_p in streams from CHs. Temperature ratio is likely to correlate with V_p in CMEs and does not depend on V_p in shocked plasma.

The data on the ΔV versus V_A dependence presented in Figure 5a in general agree with those obtained without selection on Vela 6 and 7, OGO 5, Explorer 43 [*Neugebauer,* 1981b] and Prognoz 7 [*Yermolaev,* 1994a]. In accordance with the Prognoz 7 data the value of ΔV correlates with Alfven velocity in the range $10 < V_A < 60$ km/s in HCS and streams from CSs and CHs; the curves for CSs and CHs are very close to each other, and the curve for the HCS is confined to low values of V_A. The velocity difference for streams from CHs and after interplanetary shocks is almost constant at $V_A > 60$ km/s, and it anticorrelates with V_A in CMEs.

Dependence of the temperature ratio T_α/T_p on Alfven velocity V_A has been studied only with the Prognoz 7 data [*Yermolaev,* 1994a]. In contrast to the velocity difference, the curves for the HCS and streams from CSs in Figure 5b are close to each other and the value of T_α/T_p correlates with V_A; it slightly correlates in streams from CHs and is likely to be independent of V_A in shocked plasma and CMEs.

Figure 6 shows that T_α/T_p correlates with relative velocity difference $X = \Delta V/[2k(T_\alpha/m_\alpha + T_p/m_p)]^{1/2}$ in HCS, in streams from CSs and CMEs. In shocked plasma the value of T_α/T_p is likely independent of X. The behavior of the temperature ratio in streams from CHs is the most interesting: it anticorrelates with negative X and correlates with positive X. So, on the basis of Figure 6 data we can suggest that in streams from CHs the preferential heating of α particles does not depend on the sign of the velocity difference and that it increases with increasing absolute value of the velocity difference. Thus it may be concluded that mechanisms of α particle heating in streams from CHs must differ from those in other types of solar wind streams including streams from CSs [*Yermolaev and Stupin,* 1990b; *Yermolaev,* 1991; 1994a, b].

The data on ΔV versus τ_e/τ_s and $\Delta V/V_A$ versus τ_e/τ_s dependences presented respectively in Figures 7a and 7b agree with those obtained without selection on OGO 5 [*Neugebauer,* 1976], Heos 2 [*Grunwaldt and Rosenbauer,* 1978; *Neugebauer,* 1981b], Explorer 43 [*Neugebauer,* 1981a], ISEE 3 [*Klein et al.,* 1985], Ulysses [*Neugebauer et al.,* 1994,] and Prognoz 7 [*Yermolaev et al.,* 1990, 1991; *Yermolaev,* 1994a, b]. For all types of solar wind streams ΔV and $\Delta V/V_A$ anticorrelate with the time ratio τ_e/τ_s in accordance with the hypothesis that Coulomb collisions lead to equalization of velocities of ion components. The curves for streams from CSs and CHs, shocked plasma, and CMEs are close to each other but the curve for the HCS (in a collisionless plasma with $\tau_e/\tau_s \geq 0.3$) reaches higher values of ΔV.

The data on T_α/T_p versus τ_e/τ_c dependences presented in Figure 8 agree with those obtained without selection on IMP 6 [*Feldman et al.,* 1974], OGO 5 [*Neugebauer,* 1976], ISEE 3 [*Klein et al.,* 1985], and Prognoz 7 [*Yermolaev et al.,* 1990, 1991; *Yermolaev,* 1994a, b]. For all types of solar wind streams T_α/T_p anticorrelates with the time ratio τ_e/τ_c in accordance with the hypothesis that Coulomb collisions lead to equalization of temperatures of ion components. The curves for HCS and streams from CSs are close to each other and pass higher than those for other types of streams. The curves for streams from CHs and CMEs are close to each other and go between the common HCS-CS curve and the curve for shocked plasma.

The fact that ΔV versus V_A (Figure 5a), ΔV versus τ_e/τ_c and $\Delta V/V_A$ versus τ_e/τ_s (Figure 7) dependences are close to each other in streams from CHs and CSs and differ from those in HCS favors the hypothesis that processes resulting in a velocity difference of α particles and protons may be similar to each other in streams from CHs and CSs and differ from those in the HCS. However, Figures 4-8 allow us to suggest that processes which lead to preferential heating of α particles are likely to be the same in HCS and streams from CSs, but they differ from the ones in streams from CHs [*Yermolaev,* 1994a, b]. The arrival of interplanetary shocks and CMEs results in a decrease in velocity difference and temperature ratio of α particles and protons.

5. Conclusions

Mass-spectrometer measurements of α particles and protons separately in different types of solar wind streams on board the Prognoz 7 satellite (November 1978 through July 1979) allow us to reach the following conclusions.

1. The relative helium abundance n_α/n_p correlates with the solar wind velocity in the HCS and in streams from CSs and CHs, and it anticorrelates in shocked plasma and CMEs.
2. The helium abundance correlates with solar wind flux and density in streams from CHs and shocked plasma, and it anticorrelates in the HCS and in streams from CSs and CMEs.
3. The discrepancies in the helium abundance dependences on the solar wind flux and density in streams from CSs and CHs indicate that conditions and/or mechanisms of solar wind formation in these solar corona regions differ from each other.
4. The velocity difference of α particles and protons ΔV correlates with wind velocity and Alfven velocity in the HCS and in streams from CSs and CHs, but their temperature ratio T_α/T_p correlates only in the HCS and in streams from CSs, and it is approximately constant in streams from CHs.
5. The temperature ratio correlates with velocity difference in the HCS and in streams from CSs, and it correlates with the absolute value of the velocity difference in streams from CHs.
6. The processes of α particle acceleration are likely to be similar to each other in streams from CSs and CHs and differ from that in the HCS.
7. In contrast to acceleration, the processes of α particle heating in streams from CSs and CHs may differ from each other, but they may be the same in streams from CSs and the HCS.

Appendix

On the basis of selective measurements of proton and α particle bulk parameters and magnetic field on the Prognoz 7 satellite, the large-scale structure of solar wind has been studied and compared with the known structure of the solar corona [*Yermolaev,* 1990, 1991]. For that purpose the magnetic field value, B, proton temperature, T_p, ratio of proton thermal and magnetic pressures, β, and relative helium abundance, n_α/n_p, were represented as distributions on the $n - V_p$ (solar wind ion density-proton velocity) plane; that is, the two-dimensional dependences of these parameters on the density and velocity were studied. The average values and different behavior of these parameters on the $n-V_p$ plane allowed us to identify five regions (i.e., types of solar wind streams), which are shown in Figure 9b by numerals 1 through 5 and may be related to well known solar corona structure and events: (1) the heliospheric current sheet, (2) streams from coronal streamers, (3) streams from coronal holes, (4) streams behind interplanetary shocks, and (5) coronal mass ejections, which are shown in Figure 9a.

While selecting data from above-mentioned and subsequent papers, the limits of time intervals for the five types of streams were determined in the following manner. All data were averaged over 1 hour. If values V_p and n lay inside the regions (we suggested that regions for shocked plasma and CME are the same ones) of the $n - V_p$ plane presented in Figure 9b and any two parameters from B, T_p, β, and n_α/n_p fell within the predetermined and sufficiently wide ranges of given parameters (see Table 3), the considered measurement was assumed

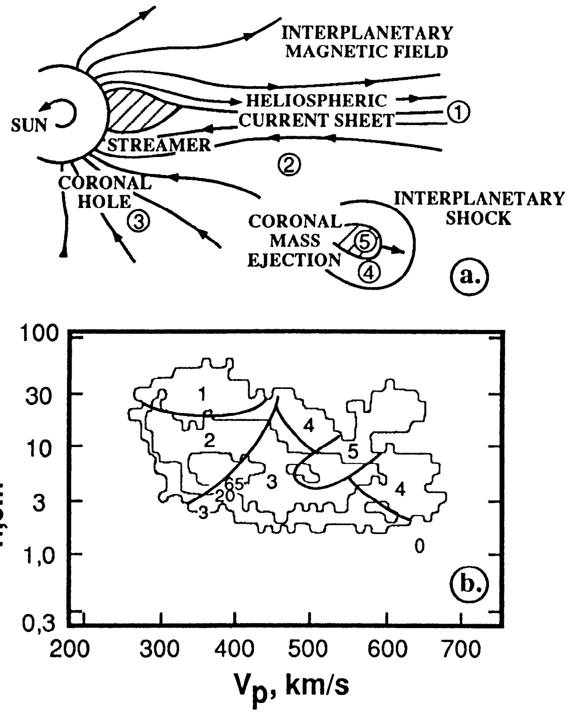

Figure 9. (a) A schematic view of different types of solar wind streams and their connection with solar corona structure and phenomena and (b) distribution of different types of streams on the density-velocity plane. From *Yermolaev* [1994b, Figure 1]. Reprinted with kind permission of Kluwer Academic Publisher.

to be identified. This procedure was found to be reliable for the three first (quasi-stationary) types of solar wind and insufficiently reliable for the two later (nonstationary) types of streams. Some points were identified simultaneously as fourth and fifth (or even third) types of wind, and these points were used for data processing of each type.

More recently we reanalyzed data related to the fourth and fifth types of streams [*Yermolaev,* 1995]. First, we changed the ranges of several parameters (see Table 3). Second, we analyzed not only a single parameter of single measurements but temporal variations in the total set of data. This new approach allowed more reliable selection of data in fast solar wind, and a smaller fraction of the points (not more than 10% of the total number of points for each type of solar wind streams) is simultaneously observed in two or three types of streams.

Table 3. Ranges of Parameters Used for Selection of Five Types of Solar Wind Streams

Value	Types of Solar Wind Streams				
	HCS	CS	CH	Shock	CME
		Previous Publications			
V_p, *km/s*	< 450	$250 - 450$	> 350	> 400	> 400
n_p, cm^{-3}	> 10	$3 - 10$	$2 - 20$	> 2	> 2
$T_p, 10^4 K$	< 10	$1 - 10$	$3 - 20$	> 10	> 5
B, nT	< 10	$3 - 15$	$3 - 15$	> 7	> 7
β_p	> 0.5	$0.1 - 1$	$0.1 - 1$	> 0.3	> 0.3
n_α/n_p, %	< 2	$2 - 6$	$3 - 8$	$3 - 8$	> 3
		New Publications			
$V_p, km/s$	< 450	$250 - 450$	> 350	> 400	> 400
n_p, cm^{-3}	> 10	$3 - 10$	$2 - 20$	> 2	> 2
$T_p, 10^4 K$	< 10	$1 - 10$	$3 - 20$	> 10	> 3
B, nT	< 10	$3 - 15$	$3 - 15$	> 7	> 7
β_p	> 0.5	$0.1 - 1$	$0.1 - 1$	> 0.3	< 1
n_α/n_p, %	< 2	$2 - 6$	$3 - 8$	$2 - 8$	> 6

Acknowledgments. We thank O. L. Vaisberg and A. Omelchenko, and other members of the Prognoz 7 plasma spectrometer team for participation in the experiment and help in plasma data processing and E. Eroshenko and V. Styazhkin for magnetic field data. We also thank G. Zastenker for his useful comments on the paper. We are very grateful to the two reviewers who provided very helpful comments on the manuscript. One of authors (Y. I. Y.) was supported in part by the Russian Foundation for Fundamental Research under grant 95-02- 03998.

The Editor thanks J.T. Steinberg and another referee for their assistance in evaluating this paper.

References

Asbridge, J. R., S. J. Bame, W. C. Feldman, and M. D. Montgomery, Helium and hydrogen velocity differences in the solar wind, *J. Geophys. Res., 81* (16), 2719, 1976.

Avanov, L., N. Borodkova, Z. Nemecek, A. Omeltchenko, J. Safrankova, A. Skalski, Y. Yermolaev, and G. Zastenker, Some features of solar wind protons, α particles and heavy ions behaviour: the Prognoz 7 and Prognoz 8 experimental results, *Czechoslovak J. Phys., 37* (6), 759, 1987.

Bame, S. J., J. R. Asbridge, W. C. Feldman, and J. T. Gosling, Evidence for a structure-free state at high solar wind speeds, *J. Geophys. Res., 82* (10), 1487, 1977.

Bochsler, P., Minor ions - tracers for physical processes in the heliosphere, in *Proceedings of Solar Wind Seven Conference, COSPAR Colloquia,* vol.3, edited by E. Marsch and R. Schwenn, p. 323, Pergamon, Tarrytown, N. Y., 1992.

Borini, G., J. T. Gosling, S. J. Bame, W. C. Feldman, and J. M. Wilcox, Solar wind helium and hydrogen structure near the heliosphere current sheet: a signal of coronal streamers at 1 AU, *J. Geophys. Res., 86,* 4565, 1981.

Bosqued, J. M., C. D'Uston, A. A. Zertsalov, and O. L. Vaisberg, Study of alpha component dynamics in the solar wind using Prognoz satellite, *Solar Phys., 51,* 231, 1977.

Feldman, W. C., J. R. Asbridge, and S. J. Bame, The solar wind He^{2+} to H^+ temperature ratio, *J. Geophys. Res., 79,* 2319, 1974.

Feldman, W. C., J. R. Asbridge, S. J. Bame, and J. T. Gosling, Long-term variations of selected solar wind properties: IMP 6, 7, and 8 results, *J. Geophys. Res., 83* (5), 2177, 1978.

Feldman, W. C., J. R. Asbridge, S. J. Bame, E. E. Fenimore, and J. T. Gosling, The solar origions of solar wind interstream flows: near-equatorial coronl streamers, *J. Geophys. Res., 86* (7), 5408, 1981.

Feynman, J., On solar wind helium and heavy ions temperatures, *Solar Phys., 43* (1), 249, 1975.

Formisano, V., F. Palmiotto, and G. Moreno, α particle observations in the solar wind, *Solar Phys., 15* (2), 479, 1970.

Geiss, J., Diagnostics of corona by in situ composition measurements at 1 AU, in *Proceedings of ESA Workshop on*

Future Mission in Solar, Heliospheric and Space Plasma Physics, Garmisch-Partenkirshen, Germany, *Eur. Space Agency Spec. Publ. ESA SP 235,* p. 37, 1985.

Geiss, J., P. Hirt, and H. Leutwyler, On acceleration and motion of ions in corona and solar wind, *Solar Phys., 12,* 458, 1970.

Gosling, J. T., G. Borrini, J. R. Asbridge, S. J. Bame, W. C. Feldmam, and R. T. Hansen, Coronal streamers in the solar wind at 1 AU, *J. Geophys. Res., 86* (7), 5438, 1981.

Gosling, J. T., D. N. Baker, S. J. Bame, W. C. Feldman, R. D. Zwickl, and E. J. Smith, Bidirectional solar wind electron heat flux events, *J. Geophys. Res., 92,* 8519, 1987.

Grunwaldt, H., and H. Rosenbauer, Study of helium and hydrogen velocity differences as derived from Heos 2 S-210 solar wind measurements, in *Proceedings of Pleins Feux sur la Physique Solaire, Editions CNRS,* p. 377, Toulouse, 1978.

Hirshberg, J., S. J. Bame, and D. E. Robbins, Solar flares and solar wind helium enrichments: July 1965-July 1967, *Solar Phys., 23* (2), 467, 1972a.

Hirshberg, J., J. R. Asbridge, and D. E. Robbins, Velocity and flux dependence of the solar wind abundance, *J. Geophys. Res., 77,* 3583, 1972b.

Hirshberg, J., J. R. Asbridge, and D. E. Robbins, The helium component of solar wind velocity streams, *J. Geophys. Res., 79* (7), 934, 1974.

Hundhausen, A. J., *Solar Wind and Coronal Expension,* Springer-Verlag, New York, 1972.

Klein, L. W., K. W. Ogilvie, and L. F. Burlaga, Coulomb collisions in the solar wind, *J. Geophys. Res., 90* (8), 7389, 1985.

Marsch, E., K.-H. Muhlhauser, H. Rosenbauer, R. Schwenn, and F. M. Neubauer, Solar wind helium ions: obsevations of the Helios solar probe between 0.3 and 1 AU, *J. Geophys. Res., 87* (A1), 35, 1982.

Moreno, G., and F. Palmiotto, Variations of α particle abundance in the solar wind, *Solar Phys., 30,* 207, 1973.

Neugebauer, M., The role of Coulomb collisions in limiting differential flow and temperature differences in the solar wind, *J. Geophys. Res., 81* (1), 78, 1976.

Neugebauer, M., Observation of solar wind helium, *Fundam. Cosmic Phys., 7,* 131, 1981a.

Neugebauer, M., Observations of solar wind helium, in *Proceedings of Solar Wind Four Conference, Rep. MPAE-W-100-81-31,* edited by H. Rosenbauer, p. 425, Max-Planck-Institut fur Aeronomie, Katlendurg-Lindau, 1981b

Neugebauer, M., Measurements of the properties of solar wind plasma relevant to study of its coronal sources, *Space Sci. Rev., 33,*, 127, 1982.

Neugebauer, M., Knowledge of coronal heating and solar-wind acceleration obtained from observations of the solar wind near 1 AU, in *Proceedings of Solar Wind Seven Conference, COSPAR Colloquia,* vol.3, edited by E. Marsch and R. Schwenn, p. 69, Pergamon, Tarrytown, N. Y., 1992

Neugebauer, M., B. E. Goldstein, S. J. Bame, and W. C. Feldman, ULYSSES near-ecliptic observations of differential flow between protons and alphas in the solar wind, *J. Geophys. Res., 99* (A2), 2505, 1994.

Ogilvie, K. W., Helium abundance variations, *J. Geophys. Res., 77,* 4227, 1972.

Ogilvie, K. W., and T. D. W. Wilkerson, Helium abundance in the solar wind, *Solar Phys., 8* (2), 435, 1969.

Ogilvie, K. W., M. A. Coplan, and R. D. Zwickl, Helium, hydrogen, and oxygen velocities observed on ISEE 3, *J. Geophys. Res., 87* (9), 7363, 1982.

Ogilvie, K. W., M. A. Coplan, P. Bochsler, and J. Geiss, Solar wind observations with Ion Composition Instrument aboard the ISEE-3/ICE spacecraft, *Solar Phys., 124,* 167, 1989.

Schwenn, R., The "average" solar wind in the inner heliosphere: structure and slow variations, in *Proceedings of Solar Wind Five Conference, NASA Conf. Publ. 2280,* edited by M. Neugebauer, p. 489, 1983.

Vaisberg, O. L., L. S. Gorn, Y. I. Yermolaev et al., Experiment on diagnostics of interplanetary and magnetospheric plasma on Venera-11, -12 spacecraft and Prognoz 7 satellite (in Russian), *Kosm. Issl., 17* (5), 780, 1979.

Yermolaev, Y. I., A new approach to study of large scale structure of solar corona on basis of measurements of solar wind parameters (in Russian), *Kosm. Issl., 28* (6), 890, 1990.

Yermolaev, Y. I., Large-scale structure of solar wind and its relationship with solar corona: Prognoz 7 observations, *Planet. Space Sci., 39* (10), 1351, 1991.

Yermolaev, Y. I., Helium abundance, acceleration, and heating and large-scale structure of the solar wind, in *Proceedings of Solar Wind Seven Conference, COSPAR Colloquia,* vol.3, edited by E. Marsch and R. Schwenn, p. 411, Pergamon, Tarrytown, N. Y., 1992a.

Yermolaev, Y. I., Solar wind heavy ions and proton/alpha particle relations observed on board the Prognoz 7 satellite, in *Proceedings of the First SOHO Workshop, Eur. Space Agency Spec. Publ. ESA SP-348,* p. 339, 1992b.

Yermolaev, Y. I., Observations of $^4He^{++}$ ions in the solar wind (in Russian), *Kosm. Issl., 32* (1), 93, 1994a.

Yermolaev, Y. I., Signature of coronal holes and streamers in the interplanetary space, *Space Sci. Rev., 70,* 379, 1994b.

Yermolaev, Y. I., Velocities and temperatures of protons and alpha-particles in different types of solar wind streams (in Russian), *Kosm. Issl., 33* (4), 381, 1995.

Yermolaev, Y. I., and V. V. Stupin, The heliun abundance dependence on the solar wind conditions: the Prognoz 7 measurements (in Russian), *Kosm. Issl., 28* (4), 571, 1990a.

Yermolaev, Y. I., and V. V. Stupin, Some alpha-particle heating and acceleration mechanisms in the solar wind: Prognoz 7 measurements, *Planet. Space Sci., 38* (10), 1305, 1990b.

Yermolaev, Y. I., and V. V. Stupin, Energy, momentum and mass fluxes from the Sun in different types of solar wind streams: Prognoz 7 observations (in Russian), *Kosm. Issl., 30* (6), 833, 1992.

Yermolaev, Y. I., and G. N. Zastenker, Differential flow between protons and alphas in the solar wind: Prognoz 7 observations, *J. Geophys. Res., 99,* 23503, 1994.

Yermolaev, Y. I., V. V. Stupin, G. N. Zastenker, G. P. Khamitov, and I. Kozak, Variations of solar wind proton and α particle hydrodynamic parameters: Prognoz 7 observations, *Adv. Space Res., 9* (4), 123, 1989.

Yermolaev, Y. I., V. V. Stupin, G. N. Zastenker, G. P. Khamitov, and I. Kozak, Variations in hydrodynamic parameters of protons and α particles in solar wind according to measurements on board the Prognoz 7 satellite (in Russian),, *Kosm. Issl., 28* (2), 218, 1990.

Yermolaev, Y. I., V. V. Stupin, and I. Kozak, Dynamics of proton and α particle velocities and temperatures in the solar wind: Prognoz 7 observations, *Adv. Space Res., 11* (1), 79, 1991.

Zastenker, G. N., and N. L. Borodkova, Some features of the interplanetary disturbances in the post-solar maximum year period, *Adv. Space. Res., 4* (7), 347, 1984a.

Zastenker, G. N., and N. L. Borodkova, Interplanetary shock waves during May-April, 1981 (in Russian), *Kosm. Issl., 22* (1), 87, 1984b.

Zertsalov, A. A., O. L. Vaisberg, and V. V. Tenmyi, Characteristics of the proton and alpha-particle components of the solar wind following the passage of interplanetary shock waves from observations on Prognoz satellite on May 15 and 30, 1972 (in Russian), *Kosm. Issl., 14* (2), 257, 1976a.

Zertsalov, A. A., J. M. Bosqued, C. D'Uston et al., Some results of measurements of solar wind α-component on the Prognoz satellite (in Russian), *Kosm. Issl., 14* (3), 463, 1976b.

Y. I. Yermolaev, Space Research Institute, Russian Academy of Sciences, Profsoyuznaya 84/32, 117810 Moscow, Russia (e-mail: yermol@afed.iki.rssi.ru)

V. V. Stupin, Irkutsk State Economic Academy, High Education Ministry, Lenin 11, 664003 Irkutsk, Russia

(Received June 5, 1995; revised April 2, 1996;
accepted May 23, 1996.)