The excitation of the turbulence is a consequence by the solar wind, a small anisotropy of this interaction with comet Halley is shown in Figure 1. The dependence of the wave energy density $W = \Sigma |B|^2$ on the distance $r$ from the cometary nucleus is described by the following equation

$$\frac{dW}{dx} = \frac{A}{r^2} \frac{m_i}{V_A} \frac{V}{g} \exp \left( \frac{-2}{5} \frac{1}{\cos \alpha} \frac{A}{m_p} \frac{u}{u_e} \right).$$

where $Q$ is the gas production rate, $\tau$ and $V$ are the characteristic time of photoionization and the velocity of cometary gas expansion, respectively, $A = 10$ is a numerical factor, $m_i$ is the mass of particles of species $j$, $V_A = B/\sqrt{4\pi \rho}$ is the Alfvén speed in the unperturbed solar wind with mass density $\rho$, $B$ is the magnetic field strength, $u$ is the angle $B$ between the solar wind flow and the magnetic field, and $u_e$ and $T_p$ are velocity and proton temperature of the unperturbed solar wind.

The first term on the r.h.s. of this equation describes the growth of Alfvén waves calculated in the quasilinear approximation. It is assumed that in spite of a fast isotropization of the velocity distribution of cometary ions picked up by the solar wind, a small anisotropy of this distribution is maintained due to continuous creation of new ions by photodetachment. The second term on the r.h.s. of Equation 1 describes the saturation of wave growth due to the induced scattering of waves by solar wind protons that is the main nonlinear effect in this problem. The induced scattering of waves results in a wave energy flux in $k$-space from the region of resonant wave-particle interaction towards larger scales (small $k$). The wave growth saturates at a high level with magnetic field fluctuations of the order of the unperturbed magnetic field strength. The solution of Equation 1 is shown in Figure 1 by a dotted line (for details see Galeev et al. (1986)). In our theoretical estimates we have used the solar wind and cometary gas parameters measured aboard the "Vega-1" spacecraft: $n = 12$ cm$^{-3}$, $u = 5 \times 10^7$ cm/s, $T_p = 1.7 \times 10^4$ K, $Q = 1.3 \times 10^{26}$ mol s$^{-1}$, $V_A = 2.1 \times 10^4$ cm (Gringauz et al., 1986) and $B_0 = 11$ nT (Riedler et al., 1986).

As has been stated by Sagdeev et al. (1986), the most important consequences of Alfvén wave generation is the fast isotropization of the velocity distribution of cometary ions. In this case, when describing kinetically the solar wind loading we should take into account that the
and 6 we find the degree of solar wind loading in front of a shock \( \frac{p_u}{n_u} u = 40/27 \), and finally with the help of Equation 3 we obtain the position of the \( M = 2 \) surface:

\[
\eta_s = \frac{27}{13} \int_{\infty}^{\xi} \frac{\exp(-\lambda \xi^2 + n_s^2)}{\xi^2 + n_s^2} \, d\xi
\]

where

\[
\lambda = \frac{\sigma}{V_g}, \quad \xi_s = \frac{x_s}{r_o}, \quad \eta_s = \frac{y_s}{r_o}, \quad r_o = \frac{\sqrt{p_m}}{\sqrt{\beta}}, \quad Q_m = \frac{\sqrt{\rho} v_o}{g}
\]

The subsonar stand-off distance of the cometary shock was calculated with the help of Equation 2 for the above listed solar wind and cometary gas parameters. Assuming also that \( m/m_w = 23 \) for a water dominated cometary gas we obtain \( x_s(y_s) = 2.7 \times 10^7 \) km. The \( M = 2 \) surface is plotted in Figure 2 by a dotted line.

The theoretical shape of the bow shock obtained by a two dimensional particle in cell simulation of the solar wind interaction with comets (Galeev and Lipatov, 1984) is also shown in Fig. 2 as well as the trajectory of the Vega spacecraft. We see that at the flanks the bow shock position deviates significantly from the \( M = 2 \) surface.

An identification of the bow shock crossings during the Vega encounters has been carried out by various detectors performing plasma (Gringauz et al., 1986), energetic particles (Somogy et al., 1986), and plasma wave (Klimov et al., 1986) measurements. The results are shown in Figures 3 and 4.

The most accurate determination of the shock position was given by the low frequency plasma wave analyzer APV-N (Klimov et al., 1986). It registered a sharp rise of wave intensity at frequencies below the lower-hybrid resonance at 3:46 UT, which corresponds to a distance of \( 10.1 \pm 0.1 \) \( \times 10^7 \) km from the nucleus for the inbound crossing of "Vega-1" (see Fig. 3). The magnetic field data at this moment \( B_1 = -6 \, n_T, B_2 = 5 \, n_T, B_3 = 8 \, n_T \) permit to calculate the angle

\[
\theta = \frac{3}{\sqrt{\eta_s^2 + \xi_s^2}}
\]

By computing the sound speed \( c = \sqrt{dp/d\rho} \) with help of these equations we obtain the local acoustic Mach number in the solar wind flow:

\[
M^2 = 12 \left( \frac{\sqrt{u} - u \, \sqrt{\bar{u}}}{u} \right)
\]

It follows from the obtained solution (6) for \( pu \) and Equation 3 that continuously decelerating flow is possible only for \( u/u_o > 1/4 \), i.e. for a local Mach number \( M > 1 \). This means that, as in ordinary gasdynamics, a smooth transition from supersonic to subsonic flow is impossible and a shock has to form. Following the results of the gasdynamic calculations we assume here that the shock is formed at the point where the local Mach number reaches the value \( M = 2 \). From Equations 8 and 6 we find the degree of solar wind loading in front of a shock \( \frac{pu}{n_u} u = 40/27 \), and finally with the help of Equation 3 we obtain the position of the \( M = 2 \) surface:

\[
\eta_s = \frac{27}{13} \int_{\infty}^{\xi} \frac{\exp(-\lambda \xi^2 + n_s^2)}{\xi^2 + n_s^2} \, d\xi
\]

where

\[
\lambda = \frac{\sigma}{V_g}, \quad \xi_s = \frac{x_s}{r_o}, \quad \eta_s = \frac{y_s}{r_o}, \quad r_o = \frac{\sqrt{p_m}}{\sqrt{\beta}}, \quad Q_m = \frac{\sqrt{\rho} v_o}{g}
\]
between shock normal and magnetic field ($\theta_{m} \approx 90^\circ$) and lead to the conclusion that "Vega-1" crossed a quasiperpendicular shock. Similar sharp rises of the lower-hybrid wave intensity were observed in front of the quasi-perpendicular Earth bow shock and have been explained as having been generated by solar wind protons reflected from the shock front (Vaisberg et al., 1983). By analogy it seems reasonable to assume that in our case the detected waves are excited by the picked-up cometary ions that are reflected by the shock and then accelerated along its front by the self-consistent electric field $E = - u \times B / c$. The accelerated ions form a beam moving almost perpendicular to the magnetic field and exciting high frequency magnetosonic waves with frequencies up to the lower-hybrid resonance. The wave spectra for electric and magnetic field oscillations in the vicinity of the lower hybrid resonance are shown in Figure 5. The ratio between electric and magnetic field amplitudes agrees well with the theoretical estimate for magnetosonic waves $E/B \approx (V_{i}(c) / m_{i} f_{m}) \approx 1/50$ (Fig. 5). All measurements mutually agree quite well and fit the theoretical calculations (Fig. 2). The burst of MHD turbulence serves as precursor of the shock. This is because the effect of convection of newly born cometary ions becomes very strong near the shock front where the gradients of plasma parameters are large. Thus the anisotropy of the velocity distribution of cometary ions is maintained at such a high level that the growth rate of plasma instability as well as the strength of MHD turbulence are also high. Due to the presence of this turbulence the cometary bow shock differs strongly from the well-studied planetary bow shocks and makes the identification of shock crossings somewhat difficult. In particular, the heating of solar wind protons due to stochastic Fermi acceleration by MHD turbulence (Anata and Formisano, 1985) is so large in the foreshock region that the peak of $\alpha$ particles becomes indistinguishable. This happened at the outbound crossing of the cometary bow shock by "Vega-1" Fig. 4). Here the level of MHD turbulence was larger than at the inbound shock crossing and considerable solar wind heating took place in the upstream region at distances of the order of $10^6$ km from comet (Fig. 4).
4). The position of the shock front on the outbound crossing can be identified by the decrease of solar wind velocity (Fig. 4) and by the enhancement of the level of MHD turbulence in the vicinity of the shock front (Fig. 1). It stands at the distance of \( (6 \pm 1) \times 10^7 \) km from the nucleus. This also agrees reasonably well with the theoretical estimates of the bow shock position shown in Fig. 2. The bow shock crossing by "Vega-2" was registered only for the inbound part of the trajectory approximately at the same distance from the comet as for "Vega-1", since neither solar wind nor cometary parameters were changed significantly. But the structure of this shock was much more diffuse. That is due to the fact that the bow shock in the second crossing was quasiparallel with an angle \( \theta_B \approx 45^\circ \).

The study of the structure of cometary bow shocks is of a great importance for the problem of collisionless shocks in a plasma, the first theory of which has been proposed more than 25 years ago (Sagdeev, 1959). As for the Earth's bow shocks, there are two different types of bow shocks: quasiparallel and quasiperpendicular. The computer simulation of the quasiperpendicular shock formed in an electron-proton plasma loaded by heavy ions (Galeev et al., 1985) shows that because of their large gyroradii heavy ions picked up by the solar wind leak easily out into the upstream region from behind the shock front. Thus they decelerate the incoming plasma flow and form a foot on the magnetic field profile in the shock with characteristic spatial scale of the order of the heavy ion's Larmor radius. That is approximately \( 10^7 \) km for solar wind conditions quoted above.

The quasiparallel bow shock registered by "Vega-2" is of quite different nature. There exists a close analogy between this type of cometary shock and cosmic ray diffusive shocks (Sagdeev et al., 1986). In both cases the high energy particles (cosmic ray protons or heavy ions picked up by the solar wind) moving along the magnetic field excite an intensive Alfvénic turbulence. The escape of particles from the shock front into the upstream region has the character of diffusion due to strong particle scattering by excited Alfvén waves. Thus the incoming plasma flow and form a foot on the magnetic field profile in the shock with characteristic spatial scale of the order of the heavy ion's Larmor radius. That is approximately \( 10^7 \) km for solar wind conditions quoted above.

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