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Article *in* Nature · July 1980

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PRESSURE BALANCE AND PRESSURE DISTRIBUTION

ALONG THE

DAYSIDE IONOPAUSE OF VENUS

The existence of a bow shock near Venus was established during the Mariner 5 fly-by mission (1) and Venera 4 lander mission (2) in 1968. The close location of this shock to the planet demonstrated that Venus does not have a significant internal magnetic field and that the ionosphere of the planet is capable of deflecting a major part of the incoming solar wind plasma.

The Venera 9 and Venera 10 mission in 1975-1976 made detailed studies of the shock and the wake region of Venus (3-5). Recently the Pioneer Venus Orbiter performed important measurements of the structure of the Venusian ionosphere and its interaction with the solar wind (6-7). It was shown that above 200 km the dayside ionosphere is in a state of diffusive equilibrium with the O^+ ions as the main constituent. The elevated electron and ion temperatures in the ionosphere together with the number density below the ionopause provide, in most cases, enough pressure to sustain the solar wind dynamic pressure. The height of the ionopause is strongly influenced by the solar wind ram pressure (8-12).

The magnetic field measurements from the PVO have shown that the magnetic pressu within the ionophere is in most cases negligible, but above the ionopaus there is a region of increased magnetic field where the magnetic field pressure approximately equals the solar wind dynamic pressure. This region of increased magnetic field presumably transfers solar wind magnetic pressure to the ionosphere (10, 13-16).

Joint data on the solar wind, magnetic field and ionosphere are available only for the first period of Pioneer Venus Orbiter (PVO) observations in

December 1978 when the region of solar zenith angle (SZA) $\leq 61.5°$ was studied. It is frequently assumed that external pressure exterted on the Venusian ionopause changes as a simple Newtonian law of specular reflection, Cos$^2\psi$, where ψ is the SZA.But the deviations of the ionopause shape from that of a spherical surface external pressures should give rise to significant deviations from the Cos^2 law for large SZA. Further improvement may be obtained by taking into account a more realistic approximation of the external pressure. To obtain an estimate of the external pressure variation with SZA we assumed that the surface of the ionopause can be obtained from a simple ionospheric pressure balance (17). The parameter H/r_0, ratio of the ionospheric scale height to planetocentric subsolar dimension of obstacle, defining the approximate shape of the ionopause, was taken equals to 0.07 (10). It can be seen from Figure 1 that the mean magnetic field pressure in the region just outside the ionopause, or in the "magnetic barrier" closely follows the expected pressure variation along the boundary of the obstacle. The mean magnetic pressure within the magnetic barrier and its variations were taken from (16,~~18~~ 19). To fit the observation the pressure curves were normalized to 3.7×10^{-8} dynes/cm^2 at $\psi=0$ and this value is representative for mean subsolar magnetic barrier pressure for PVO period of observations. Data of Figure 1 confirm~~s~~ that pressure within the magnetic barrier is determined by pressure of external flow and shows that this condition holds up to SZA ~90°.

Distribution of measured values of ionospheric pressure just below the ionopause, magnetic pressure within magnetic barrier and solar wind pressure versus height of the ionopause for December 1978 is shown in Figure 2. Data are limited to SZA between 63° and 90°. Solar wind pressure was ~~measured~~ estimated from ρV^2 value corrected for pressure distribution along the boundary (Curve 3, Figure 1). Magnetic field pressure was multiplied by a factor of 1.5 to fit both the solar wind pressure and ionospheric pressure. Figure 2 shows good agreement between the measured ionospheric pressure below the ionopause and corrected for angle of incidence the solar wind pressure. It shows also that althoughthe magnetic barrier plays a major role in the transfer of solar wind pressure to the ionosphere, the plasma pressure within the magnetic barrier may provide about 1/3 of the total pressure.

Comparison of the behavior of the ionospheric pressure just below the ionopause with the mean ionospheric pressure distribution for the same SZA range appears to show significant differences between these distribution suggesting the modification of subionopause layer due to changing solar wind conditions.

The mangetic pressure distribution within the magnetic barrier as a function of the ionopause altitude and as a function of SZA was obtained with the use of data (16,18). This distribution, shown in Figure 3, allows one to find the "instant" profile of the ionopause for a given solar wind ram pressure. Provided that the hot plasma contribution to the magnetic barrier pressure is taken in to account. With the supposition that the plasma pressure within the magnetic barrier is 1/3 everywhere the shapes of the ionopaus for close to the mean solar wind condition, 1/2 and 2 of this value were obtained (Figure 4). It is seen from Figure 4 that the behavior of the model profiles is in reasonable agreement with the observed mean ionopause altitude dependency of SZA and with the observed distribution of ionopause crossings. Also, it can be seen that both the observational data and the ionopause model show that at SZA 70° the shape of the Venusian ionopause differs significantly from the simple hydrostatic equilibrium model of the ionopause (Curve 4 in Figure 4). This implies the important role of solar wind heating of the subsolar ionosphere (15,19,20) and the significant influence of transport processes within the ionosphere at large SZA (12).

CONCLUSIONS

It is shown that the pressure distribution within the magnetic barrier just outside the ionopause of Venus is similar to expected solar wind pressure variation provided the more realistic shape of the ionopause is taken into account. The ionospheric pressure just below pressure while mangetic field pressure within the magnetic barrier amounts to about 2/3 of both ionospheric and solar wind pressures. So we can expect that 1/3 of magnetic barrier pressure is accounted by the hot plasma contribution.

The model of the subionopause pressure distribution with the height and with the solar zenith angle suggests that reasonably represent the observed behavior of ionopause crossings at different SZA and allows one to obtain an "instant" profile of the ionopause for given solar wind ram pressure.

1. O.L. Vaisberg
2. D.S. Intriligator
1. V.N. Smirnov

1. Space Research Institute, USSF Academ~~ic~~y of Sciences, Moscow, USSR.
2. University of Southern California, Los Angeles, California, USA.

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FIGURE CAPTIONS

Figure 1. Dependence of magnetic field pressure in the magnetic barrier on solar zenith angle. Closed circles are from (18), open circles are from (16). Curves are: 1 - $Cos^2\psi^\circ$. 2 - $Cos^2\chi^\circ$, with χ equal to expected angle between normal to ionopause and solar wind flow direction and 3 - hydrodynamic pressure variation along the boundary (12). Curves are normalized to subsolar pressure value 3.7×10^{-8} dynes/cm^2.

Figure 2. Solar wind ram pressure, magnetic barrier pressure, increased by a factor of 1.5, and total (kinetic and magnetic) pressure of ionosphere below an ionopause plotted against observed ionopause altitudes on first orbits of PVO. Line 1 is drawn to show the change of pressure values at the ionopause with altitude for SZA range 65°- 75°. Mean ionospheric pressure model, 2, obtained from means of measured number densities and ion and electron temperatures for the same SZA range (6,7).

Figure 3. Magnetic barrier pressure distribution versus height for different solar zenith angles (indicated) obtained according to data of (16,18).

Figure 4. Observed ionopause altitudes vs. solar zenith angle. Expected "instant" ionopause profiles are shown for close to the mean solar wind ram pressure value - 1, one half of it - 2, and doubled mean pressure value - 3. Dashed line - model ionopause profile for $H/r_0 = 0.07$ and $r_0 = 6350$ km.

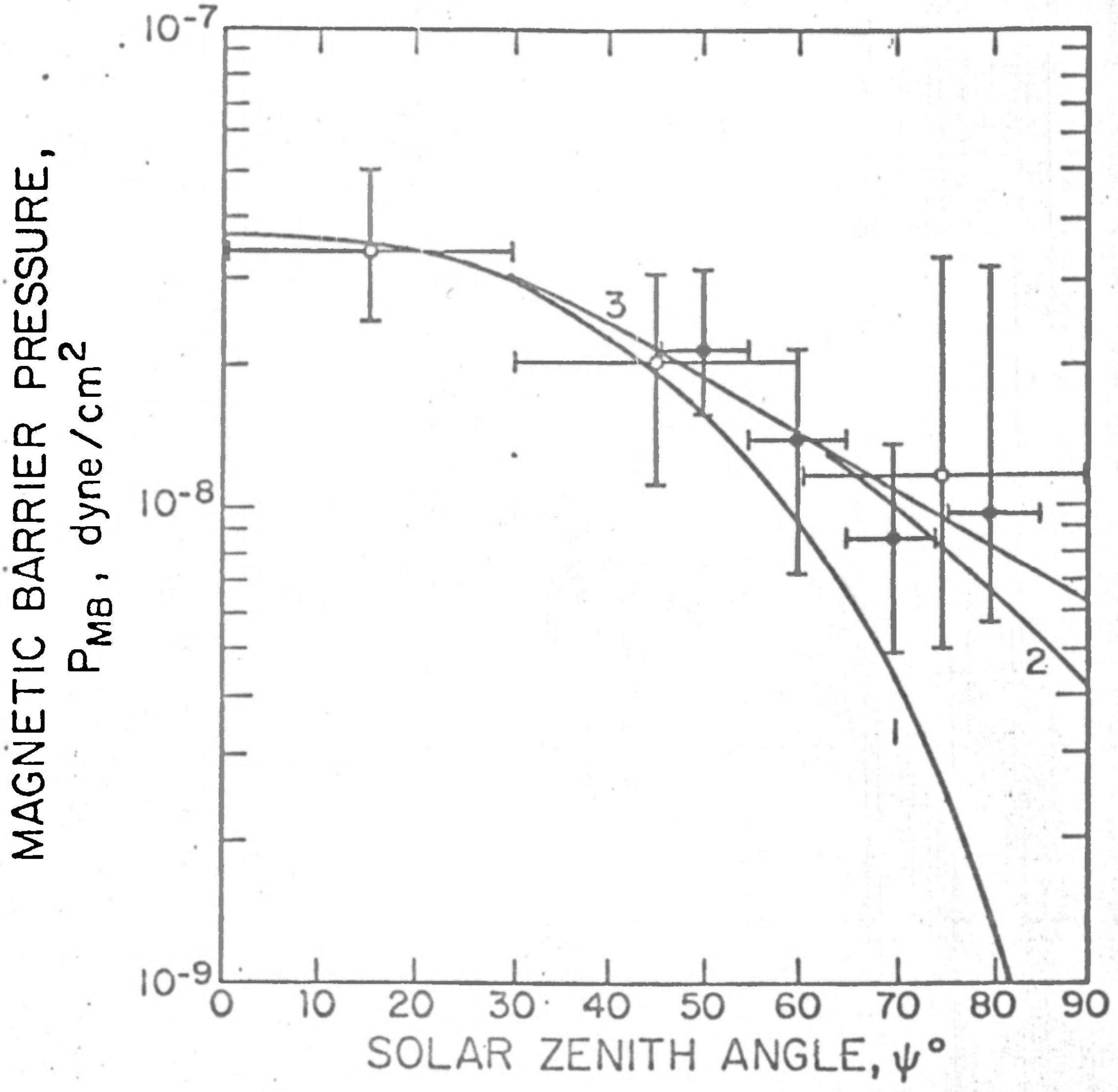
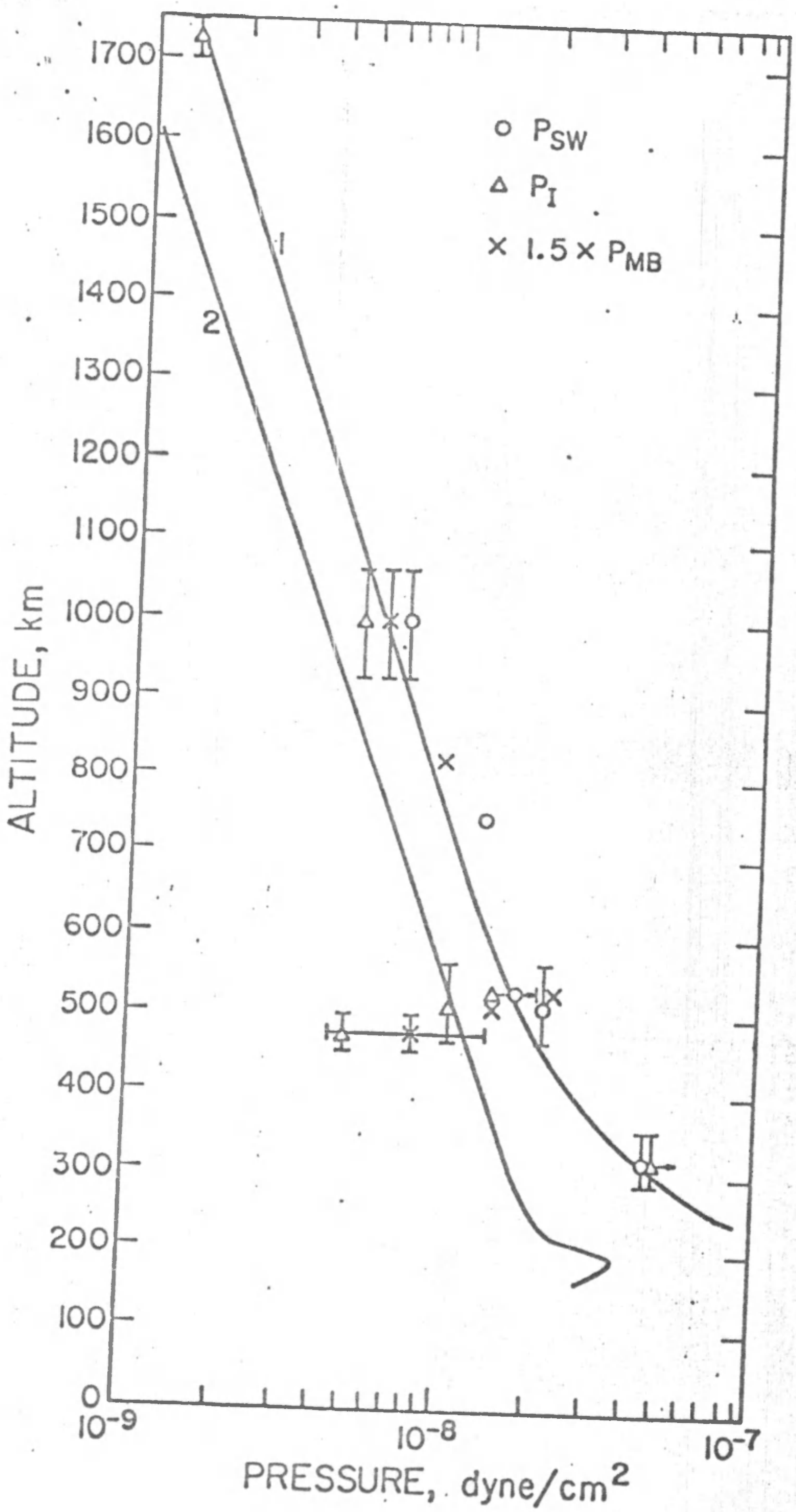

MAGNETIC BARRIER PRESSURE,
P_{MB}, dyne/cm^2
10^{-7}
10^{-8}
10^{-9}
0
10
20
30
40
50
60
70
80
90
SOLAR ZENITH ANGLE, $\psi°$
1
2
3

FIGURE 1

1



o P_{SW}
Δ P_I
× $1.5 \times P_{MB}$
1
2
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
ALTITUDE, km
10^{-9}
10^{-8}
10^{-7}
PRESSURE, dyne/cm^2

FIGURE 2

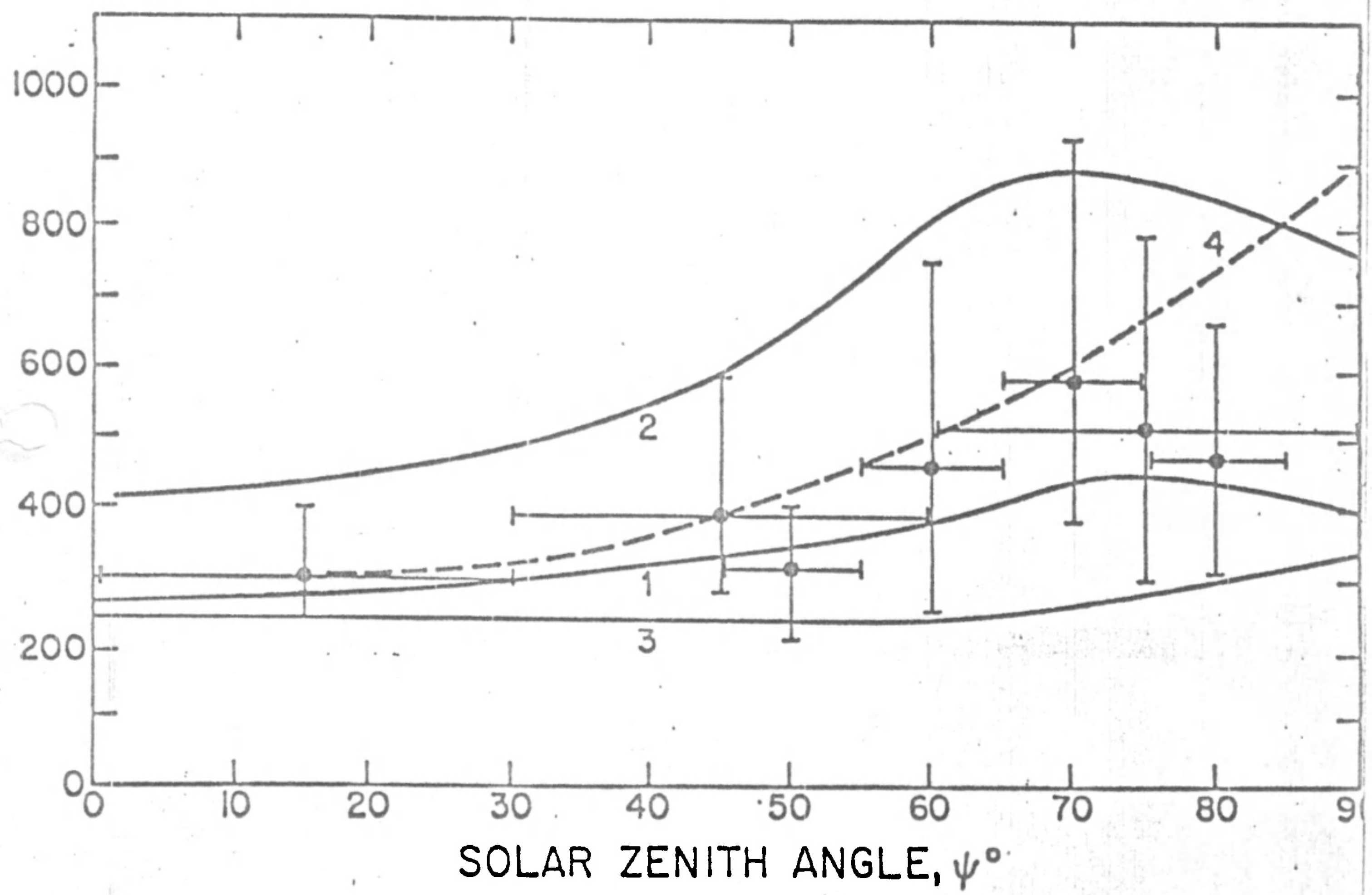


FIGURE 4

4

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