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PLASMA MEASUREMENTS CARRIED OUT IN THE VICINITY OF VENUS FROM THE VENUS-4 SPACE VEHICLE

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U S S R

To be presented to the 9-th COSPAR
Symposium (Tokyo, May 1968)

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The Venus 4 launched on June 12, 1967, carried four charged particle traps designed mainly for studying the charged particle density in the Venus ionosphere. The design of these traps were similar to that used earlier for investigating the Earth's ionosphere, in particular, on satellites of Electron type.[1],[2] During the motion of the space vehicle along the trajectory to Venus these traps were used for taking measurements of the solar wind flux values. However, this publication contains only the results of measurements which began at the distance of 35000 km from the Venus surface and were performed to the entrance of the space vehicle into the dense atmosphere.

Figure 1 shows the schemes of these traps, their connection and location aboard the vehicle, as well as their direction towards the Sun. Coupled connection of trap collectors provides the expansion of angular diagrams of traps. The collectors of the traps were connected to electrometric amplifiers with the electrometric tubes at the inputs. The grid currents of these tubes were about 10^{-14} amperes while the minimum recorded collector current was 1.10^{-10} amperes.

Such a ratio of above currents provided the high stability of zero indications of the amplifiers during the whole flight. Measurements ~~of~~ near the planet were carried out once per seven seconds. To differentiate the registration of ionospheric ions by the planar traps from the registration of high-energy particles of non-ionospheric origin, for instance, solar wind ions, once per 14 seconds positive voltage with respect to the vehicle body +50 volts was supplied to one of the grids of both planar traps. The variations of the collector current magnitudes with the variations in the voltage on the grid from 0 to 50 volts should provide the possibility of evaluating the contribution of ionospheric ions to measured current.

The planar traps allowed the measurements of ion densities in the ionosphere from 50 to 5,000 cm^{-3}.

Hemispherical charged particle traps were designed for measuring positive ion densities within the limits from $10^4 cm^{-3}$ to $10^7 cm^{-3}$.

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In the sensitive planar traps at distances from 36000 to 19000 km away from the planet records were made of nearly invariable magnitudes of the current corresponding to relatively small fluxes of solar plasma protons. The magnetometer installed aboard the Venus 4 (Ref.3) during this time recorded also the stable value of the magnetic field (about 16 gammas). Beginning with the distance of about 19400 km from the planetary surface, a considerable increase in the positive ion fluxes was recorded by the traps. Simultaneously an increase in the magnetic field strength was recorded.

Subsequently fluctuations in the values of positive particle fluxes, recorded by the traps, and of the field, measured by the magnetometer, were characterized by great degree of synchronousity (see Figure 2).

The picture of the rapid increase of charged particle fluxes and the magnetic field strongly resembled that observed during the approach of a spacecraft to the Earth when the space-craft crosses the front of the collisionless shock wave originating from the interaction of the solar wind and the geomagnetic field. However, near the Earth the closest approach of this shock wave occurs in the Earth-Sun direction and is approximately 14 R_E, i.e. about 80000 km from the Earth's surface (Refs.4 and 5).

It is highly probable that near Venus which has no magnetic field of its own, the shock wave is formed when solar plasma flux (in which the magnetic field is frozen-in) flows around the planet as a hard obstacle on the path of the flow. In this case the formation of the colisionless shock wave is possible since the Larmor radius of the solar wind protons is much less than the planet's linear dimensions.

An approximate estimate of the position of the shock wave front in this case may be made if, using the laws of gas dynamics instead of the velocity of sound during determining the Mach number in an undisturbed flow of solar plasma the Alfven velocity will be taken. Then the Mach number $M=v/(\gamma P/\rho)^{\frac{1}{2}} = v\Big/\sqrt{\gamma/H^2/8\pi\rho}$ where $\gamma=2$ for ionized gas, v is velocity of the undisturbed flow, H is the strength of the magnetic field and ρ is the density in the plasma flow. (All these parameters characterize the solar wind undisturbed by the planet).

Then the position of the shock wave front will determine ratio (see, for instance, Ref.5).

$$\frac{r}{r_s} = \frac{1+\sec\beta}{1+\sec\beta\cos\varphi}; \quad \sin\beta = \frac{1}{M}; \quad r_s = 1{,}24\, r_V \sec\beta .$$

All symbols are shown in Figure 3. The figure shows on an appropriate scale the results of such a calculation for $M=5 \pm 1$ which corresponds to the most typical velocity of the solar wind $V=350 + 100$ km per sec (Ref.6) and the magnetic field strength $H=7 \pm 3$ gammas (Ref.7). The smallest distance of the shock wave front from the planet (in the Sun--Venus direction) is 2000 km.

Having the trajectory data of the space vehicle it was possible to determine the angle between the radius-vectors directed from the planet's centre towards the Sun and the current point of the trajectory (see Figure 3). For these angles φ corresponding to the trajectory portion near the planet and the Mach number $M=5 \pm 1$, using formulas (1), distances to the shock wave front r were calculated and compared with the distances to the space vehicle ρ (see Figure 4). They turned out to be equal at about 21000 + 2000 km from the planet's surface. As pointed out above, the increase of positive ion flows and the magnetic field began with the distance of about 19400 km.

Thus the approximate estimates give grounds to believe that this increase is really associated with the shock wave formed near the planet.

In Johnson's paper (Ref.8) some ideas have been advanced concerning the possibility of the formation of the shock wave when the solar wind supersonic flux flows around the Moon.

These ideas may be applied to the solar wind flowing around Venus.

If the method similar to that used in Ref.8 will be employed for estimating the limit thickness of the non-conducting envelope which surrounds the Venus's conducting core and which is necessary for the formation of the shock wave with the solar wind parameters indicated at the beginning of the present section, it will be more equal to 0.05 Venus radius, i.e. the envelope thickness should not be than 300 km. The Earth's envelope surrounding the core is known to be about 3000 km thick (Ref.9). Various hypothes describing the properties and the structure of the Earth's core (Refs.10, 11 and 12) agree that it should possess metallic properties and, consequently, high electric conductivity and thermal conductivity, as well as the temperature higher than of the envelope layer adjacent to it.

If one supposes that the Venus core has similar properties and that the envelope, as it follows from the above estimate, is no less than 10 times thinner than the Earth's one, the above mechanism can explain the formation of the shock wave, and the hot core, situated close to the surface, may result in much greater temperatures near the Venus surface than these of the Earth's surface, as it follows from measurements performed aboard Venus 4 (Ref.13).

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As was mentioned above the experiment has allowed the estimates of the charged particle density in the Venus ionosphere over the dark portion of the planetary surface to be made.

There were assumptions rather frequently made in the literature, on the basis of which the conclusion has been drawn that the electron density in the Venus ionosphere considerably exceeds N_e in the Earth's ionosphere. There were estimates from which it followed that N_e in the Venus ionosphere reaches about $10^9 cm^{-3}$, i.e. N_e is 1000 times higher than ~~whole~~ in the Earth's ionosphere (Refs. 15, 16 and 17). However, throughout the flight the hemispherical traps with the sensitivity of $n_e = 5 \cdot 10^4 cm^{-3}$ have not record~~e~~ any currents. The analysis of the differences of the collector currents of the planar traps corresponding to the retarding potential on grid 2 (Figure 1) and to its absence, recorded near the planet, shows that the positive ion densities at height of the order of hundreds of kilometers over the Venus surface are no more then about $10^3 cm^{-3}$, i.e. are considerably (by several orders of magnitude) lower than the charged particle densities in the Earth's nighttime ionosphere at correspondent heights.

The whole flight trajectory of the space vehicle traversed over the dark portion of the Venus surface. The vehicle landed near the portion of the terminator which separates night from morning.

This to a great extent may account for the unexpectedly low charged particle densities.

It is natural to compare the data on the Venus upper atmosphere with the available data on the conditions in the Earth's upper atmosphere and ionosphere.

On the basis of the results of experiments conducted by A.P.Vinogradov and Yu.A.Surkov (Ref.18), as well as that of V.G.Kurt's experiment (Ref.19) performed from Venus 4, V.G.Kurt and V.I.Moroz have concluded that the scale height in the Venusian nighttime upper atmosphere is 13 km (Ref.20).

In the terrestrial upper atmosphere the scale height at identical altitudes is 3 to 4 times greater which means that the Venus upper atmosphere is less in its extent than the terrestrial one and hence on Venus there is less initial material for the formation of the ionosphere than on the Earth.

In the Earth's ionosphere ions are formed in the main at heights lower then 400 km and reach the higher altitudes moving along the magnetic tubes of force (Ref.21).

In the region where dominating are ions of one type and temperature balance occurs between neutral and charged particles the scale height of the ionized component should be equal to the double scale height of the corresponding neutral component (Ref.22).

Relating to the Venus conditions scale height for charged particles in the night ionosphere at altitudes of 100 to 400 km should be about 30 km, while on the Earth it is 80 to 100 km. This implies that the Venus night ionosphere should be of less extent and of less density than the terrestrial one, especially due to the fact that, owing to the lack of the magnetic field, Venus has no such effective mechanism of transportation and retention of charged particles at high altitudes as charged particle diffusion along the planet's magnetic lines of force. The latter factor should also affect the extent of the ionosphere on the daytime side of the planet.

If one takes into account that the Venus night lasts approximately 110 days (Ref.14) with the lack of an additional source which continuously maintains ionization at night, all ions in the planet's dense nighttime upper atmosphere should recombine. Turbulized (behind the front of the shock wave) solar wind fluxes which partically penetrate into the Venusian atmosphere, may be such a source. However, so far there are no data for quantitative estimates of the effect of this ionization source on the nighttime Venus atmosphere. The magnitudes of the fluxes and energies of ionizing particles are yet unknown. Nevertheless, at high altitudes the effect of this additional ionization source is negligible since the density of the Venus neutral atmosphere is low.

The small currents recorded by charged particle traps during the Venus 4 experiment therefore do not contradict the above considerations on low densities of charges particles in the nigthttime ionosphere of Venus.

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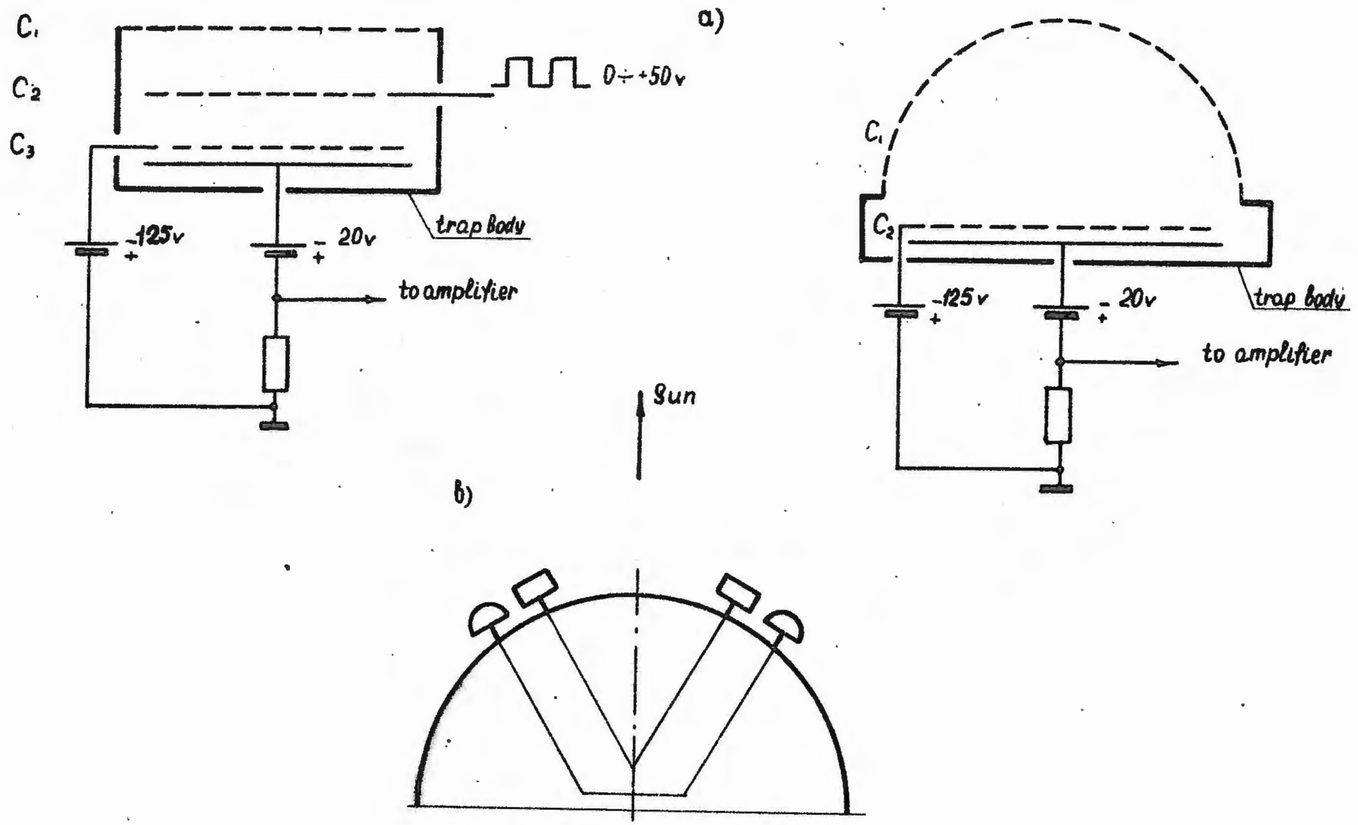
a)
C₁
C₂
C₃
0÷+50v
-125v
+
-
20v
+
trap body
to amplifier
C₁
C₂
-125v
+
-
20v
+
trap body
to amplifier
Sun
b)

Fig. 1.

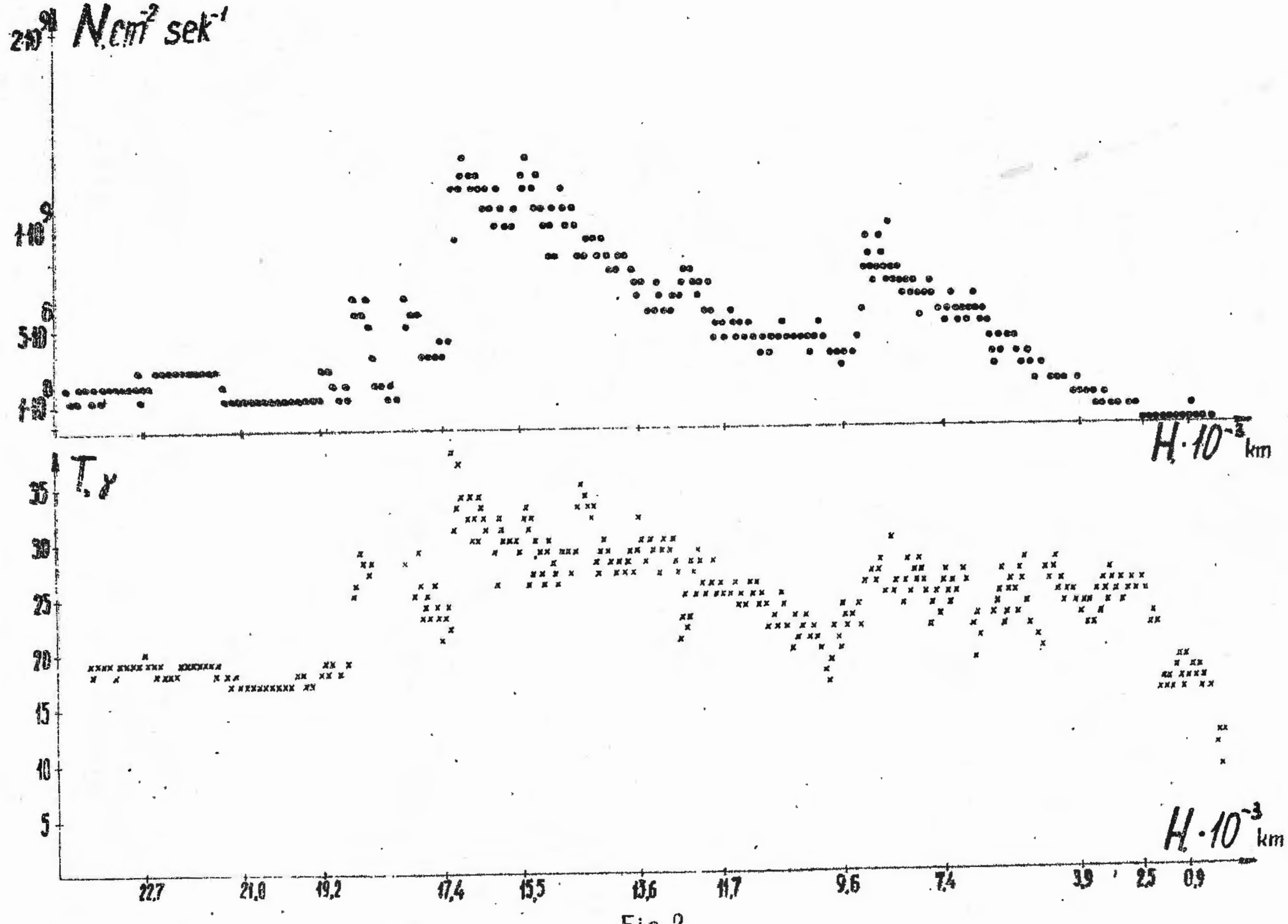
N,cm⁻² sek⁻¹
2·10⁹
1·10⁹
5·10⁸
1·10⁸
H·10⁻³ km
T, γ
35
30
25
20
15
10
5
H·10⁻³ km
22,7
21,0
19,2
17,4
15,5
13,6
11,7
9,6
7,4
3,9
2,5
0,9

Fig. 2.

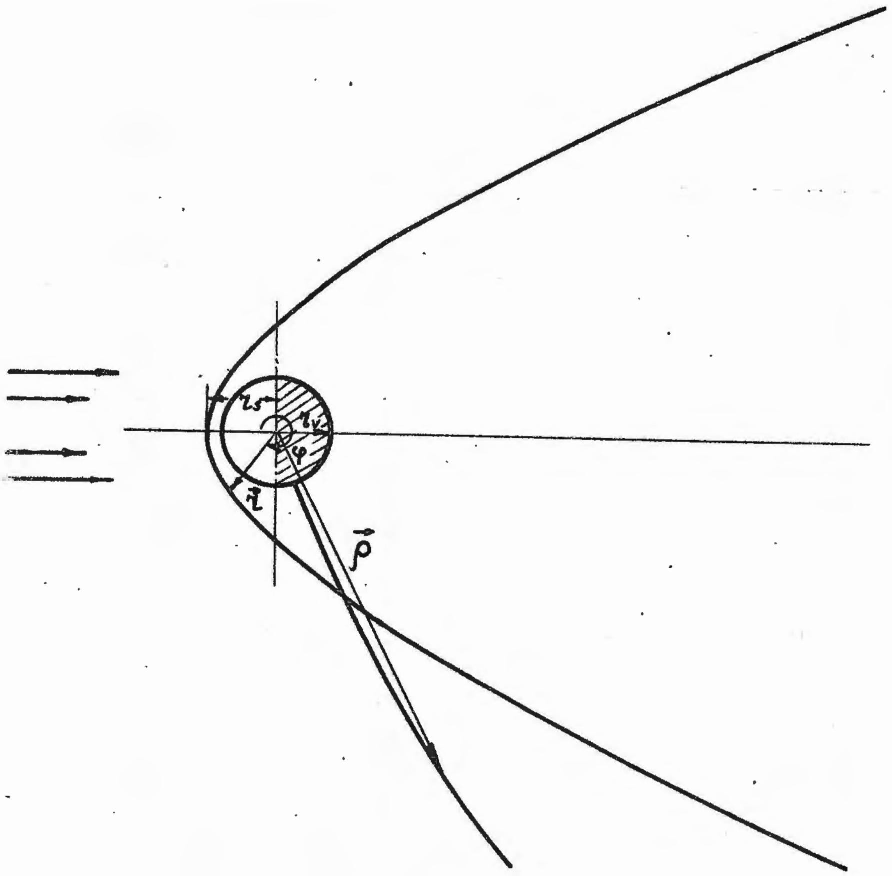

Fig. 3.

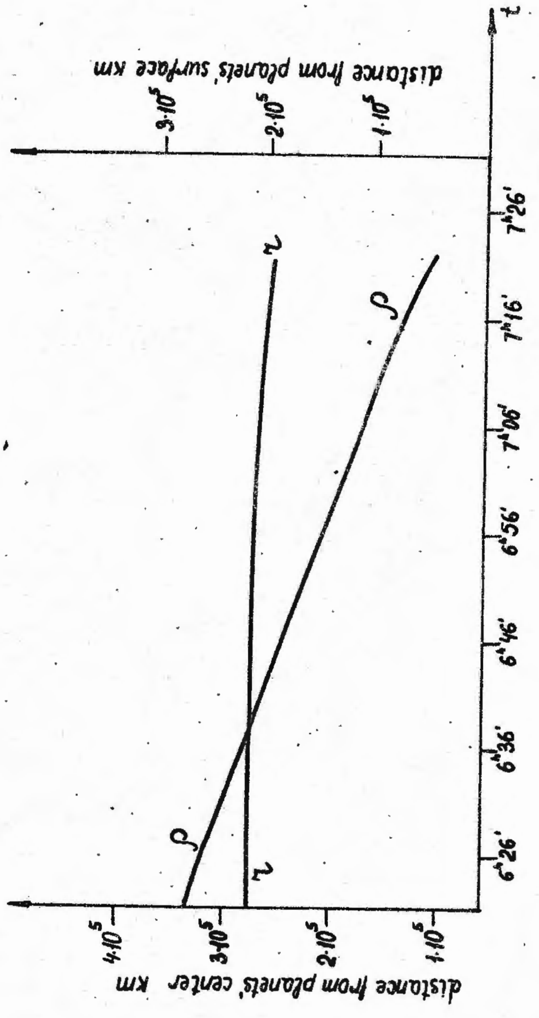

Fig. 4.

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