The Venus Far Ultraviolet Observations with Venera 4

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1. Instrumentation

Far ultraviolet observations by means of the spacecraft Venera 4, continuing those obtained by Zond 1, Venera 2 and Venera 3 (Kurt, 1965, 1967), were carried out with photometers sensitive in two spectral ranges, 1050–1340Å and 1225–1340Å, as in previous observations (Babighencko et al., 1965).

The SFM-1 type of Geiger photon counter was used as the detector and had LiF windows with Ar+NO filling. An additional CaF$_2$ filter, 1 mm thick, was set in front of one of the counters. The detector was shielded with lead 3 mm thick. The counter spectral response and filter transparency were measured by means of a vacuum monochromator, using a hydrogen continuum light source, as described by Tilt et al. (1967). The counter efficiency was about 25% and the transparency of the CaF$_2$ filter was less than 10$^{-3}$ at the Lyman alpha line. The photometer fields of view were circles of 10$^\circ$ and 20$^\circ$ diameter for the first and second spectral ranges, respectively. The ultraviolet radiation was attenuated four times by an additional wire screen in the wavelength range 1050–1340Å. The output pulses were transmitted from the counters through preamplifiers to the logarithmic 20–2,000 counts sec$^{-1}$ rate meter.

Both counters were mounted on the shadow side of the spacecraft so that the angle between the photometer optical axis and the direction to the sun was about 105$^\circ$ when the spacecraft approached Venus. The positions of the spacecraft, and the planet, and the directions to the sun and to the earth from the spacecraft, are shown in Fig. 1. All the vectors defining the sun, earth and Venus directions lay in one plane, while the optical axis of the photometer was set at a right angle to this plane.

2. Lyman alpha scattered radiation

In the case of small optical depth, without taking into account the high order scattering, the scattered ultraviolet radiation intensity can be obtained from

$$I(R) = \frac{1}{4\pi} \int_{R}^{\infty} (\pi F_s) n_H(R) \sigma_0 \frac{\Delta \lambda_D}{\Delta \lambda_S} ds,$$

where $I(R)$ is the observed intensity of Lyman alpha radiation in erg cm$^{-2}$ sec$^{-1}$, $\pi F_s$ the solar Lyman alpha radiation flux near Venus, equal to 9 ergs cm$^{-2}$ sec$^{-1}$, $n_H(R)$ the unknown atomic hydrogen density in the Venus vicinity, as a function of distance from the planet's center, $\sigma_0$ the effective resonance cross section in the center of the Lyman alpha line, $\Delta \lambda_D/\Delta \lambda_S$ is the ratio of the scattered radiation line width to the solar Lyman alpha line width ($\sim 1\AA$), and $ds$ is the integration path element.

We note that the product $\sigma_0(2\Delta \lambda_D/\Delta \lambda_S)$ does not depend on the assumed temperature, because $\sigma_0 \propto T^{-4}$ and $\Delta \lambda_D \propto T$. It is obvious that if the intensity of Lyman alpha radiation $I(R)$ is proportional to $1/R^m$ where $R$ is expressed in $R_\oplus$, the atomic hydrogen density $n_H(R)$ will be proportional to $1/R^{(m+1)}$. The relation between the surface hydrogen density $n_H(R) \sim I(R)$ and the volume luminosity $F(R) \sim n_H(R)$ is given by

$$n_H(R) = \frac{\sqrt{\pi}}{2} \frac{\Gamma(m/2)}{\Gamma[(m-1)/2]} \frac{n_0}{R^m},$$

if one looks along the radius vector.

The far ultraviolet observations near Venus lasted 1.5 hr, beginning at a distance of 38,000 km from the center. However, a significant signal increase began when the spacecraft was 22,000 km from the planet's center. The observations continued until the moment

To the Sun

To the Earth

An optical axis

FIG. 1. The spacecraft orientation near Venus.
Fig. 2. Time variations of the observed data for 1050–1340Å (averaged over 35-sec periods) and for 1225–1340Å (averaged over 70-sec periods) for the first 80 min of data, a., and the corresponding data for the final 10-min period, b.

when the capsule separated for the descent to the surface, which probably occurred not higher than 100 km above the surface.

Fig. 2a shows telemetric data averaged per 35-sec periods for the spectral range including the Lyman alpha line and per 70-sec periods for the other band. All data for the last 30 min are shown in Fig. 2b. The stepped form of the signal is due to the digital telemetry.

During almost the whole period in which Venera 4 was approaching Venus, the spacecraft was illuminated by the sun. However, about 20 sec before separation of the capsule, the spacecraft entered the shadow zone, which is shown very well by the solar battery current data. This moment corresponds to a height of 300–350 km above the surface. In the last few telemetric cycles a small signal decrease was observed in the range 1050–1340Å, due to absorption by CO₂. An estimate gives the value, \( h_{\text{CO}_2} \sim 3 \times 10^{11} \text{ cm}^{-2} \) at \( h \sim 100 \text{ km} \). The results obtained by numerical analysis of the data are presented in Fig. 3. The calculation step increased gradually from 420 km at \( R = 22,000 \text{ km} \) to 640 km at \( R = 7720 \text{ km} \). At the very end it was about 300 km. Some of the results are presented in Table 1.

Using Eq. (2) with \( m = 3.5 \), i.e.,

\[
\frac{600}{R^{4.5}}
\]

(3)
gives good agreement with the observed results. This relation is shown as the solid line in Fig. 3.

3. The wavelength ranges 1225–1340Å observations

The second spectral range was intended for detection of airglow in the oxygen lines \( \lambda = 1302, 1304 \) and 1305Å. The analysis of the data in this spectral range is quite similar to the previous case. In the first spectral interval the background is due to the Lyman-alpha radiation scattered from atomic hydrogen in interplanetary space.
and in the second spectral interval in the background is due to the cosmic ray flux, which was about 20–25 counts sec$^{-1}$, in good agreement with the results of Vernov and Ljubimov.

The Vernov and Ljubimov measurements were prepared with the CTC-5 Geiger counter with a similar shielding ($E_e > 2$ MeV and $E_p > 30$ MeV). Since the overall accuracy of our measurements due to telemetry limitations and photon statistics is about 15%, the signal excess less than 3–5 counts sec$^{-1}$ above the background far from the planet can be established. Thus, we are able to estimate upper limits for both the charged particle flux in the vicinity of the planet, and on the atomic oxygen density on the lighted side of Venus. We obtain upper limits of 0.07 cm$^{-2}$ sec$^{-1}$ ster$^{-1}$ for electrons with the energy $E_e > 7$ MeV and protons with $E_p > 50$ MeV, and upper limits of 2 cm$^{-2}$ sec$^{-1}$ ster$^{-1}$ for particles penetrating through the counter window with energy $E_e > 300$ keV and $E_p > 3$ MeV.

The signal decrease observed near the surface of the planet is explained by screening of the celestial sphere by Venus.

An upper limit on oxygen density can be estimated from Eq. (1). The value of $\pi R_\odot$ near Venus is equal to 0.12 erg cm$^{-2}$ sec$^{-1}$ according to Detwiler et al. (1961), and $\sigma(2\Delta\lambda_D/\Delta\lambda_E) = 6.8 \times 10^{-18}$. In the direction at $90^\circ$ to the planet’s center, the quantity of atoms along the sight line is

$$n = n_0 \sqrt{\frac{\pi R_\odot H}{2}},$$

where $n_0$ is the atom concentration at the minimum height of observations and $H$ is the atomic oxygen scale height, assuming that the density is determined by the barometric formula, $n = n_0 \exp(-h/H)$, where $H = (kT/mg)$ is a constant and $T$ is a constant. Assuming $T = 300$ K, $H = 20$ km and $I(1300\AA) < 5 \times 10^{-7}$ erg cm$^{-2}$ sec$^{-1}$ ster$^{-1}$, we find that $N < 7 \times 10^7$ cm$^{-3}$, and for the height $h \sim 300$ km at which the spacecraft entered the shadow zone,

$$n < 2 \times 10^8 \text{ atoms cm}^{-2}.$$

### 4. Conclusions

The values obtained by these observations refer to the night side of Venus. We recall for comparison that the earth’s atmosphere contains about $3 \times 10^8$ oxygen atoms cm$^{-3}$ at 300 km. At a height of 300 km, atomic oxygen should be the main component of the atmosphere due to diffusive separation. It may be concluded that the night-side Venus atmosphere is cold, consists principally of molecular constituents, and undergoes a sharp transition to interplanetary space.

The temperature in the day-side thermosphere is probably high enough to support a fast rate of hydrogen escape. The night side temperature of the Venerian thermosphere is low compared with that of earth. We suggest that the principal part of the observed night-side atomic hydrogen content consists of an escaping flux of atoms arriving from the day side. These circumstances provide a quantitative explanation of the principal features of the observed data: 1) the distribution of atomic hydrogen, 2) the exceedingly low
atomic oxygen density, and 3) the absence of an ionosphere at high altitudes.

REFERENCES


