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Abstract

Full Text

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Astronomy

Academician A. P. Vinogradov, Yu. A. Surkov, B. M. Andreychikov

STUDY OF THE COMPOSITION OF THE ATMOSPHERE OF VENUS AT THE AUTOMATIC STATIONS “VENERA-5” AND “VENERA-6”

In our recent work ⁽¹⁾ we reported the results of studies of the composition of the atmosphere of Venus carried out at the automatic station “Venera-4” in 1967. As is known, before the flight of “Venera-4” ideas about the composition of the planet’s atmosphere were highly uncertain. In view of this uncertainty, as well as the uncertainty of the data on temperature and pressure in the planet’s atmosphere, the task of the first measurements appeared extremely complex and was of an evaluative nature.

In January 1969 two more stations, “Venera-5” and “Venera-6,” were sent to Venus; they reached the planet and made a smooth descent in its atmosphere. “Venera-5” and “Venera-6” carried out measurements along the descent path, where the pressure varied from 0.6 to 27 atm, and the temperature from 25 to 320° ⁽³⁾. The purpose of the experiments at the “Venera-5” and “Venera-6” stations was the further investigation of the physicochemical characteristics of the Venusian atmosphere and, in particular, the refinement of its chemical composition.

For this purpose, gas analyzers similar to those that had been on “Venera-4” were installed on these stations; certain design improvements were introduced into these instruments, and the ranges were narrowed (on the basis of the “Venera-4” data) and the accuracy of the analysis of the determined atmospheric components was increased. Each station carried two instruments. Both instruments determined the content in the atmosphere of Venus of carbon dioxide, nitrogen, water, and oxygen. The determinations were carried out during the parachute descent at pressures from ~ 0.6 to ~ 10 kg/cm². The gas analyzers had two types of sensors: some measured the quantitative content, while others measured only the upper or lower limit of the content of the given component.

The composition of the atmosphere of Venus was measured twice by each station. The first analysis by the “Venera-5” station was performed shortly after the opening of the main parachute, when the atmospheric pressure was ~ 0.6 kg/cm² and the temperature $\sim 25^\circ$. The second time the composition was investigated

by “Venera-5” in a lower part of the atmosphere at a pressure of about 5 kg/cm² and a temperature of ~ 150°. The “Venera-6” station also twice determined the composition of the Venusian atmosphere at different altitudes. The first measurement was made at a pressure of about 2 kg/cm² and a temperature of 85°, the second—when the pressure reached ~ 10 kg/cm², and the temperature was about 225°.

To determine the various components of the atmosphere in these gas analyzers, the simplest and most reliable physicochemical methods were used, based on well-studied chemical reactions possessing high selectivity. Each component was determined by its own method. For example, carbon dioxide and nitrogen (whose content was determined together with inert gases) were determined by the quantity of gas absorbed, oxygen by the oxidation of tungsten, and water by the wetting of phosphorus pentoxide. (The methods of analysis and the arrangement of the experiments may be examined in detail in our work ⁽⁴⁾.)

The measurement results obtained at all three stations are given in Table 1. As can be seen from the table, carbon dioxide has two quantita-

and three threshold determinations. The threshold determinations proved to be significantly below the true content. This is explained by the fact that the sensors had been designed to operate at lower pressures, and under these conditions the carbon dioxide values were beyond the sensor scale; therefore the table gives the upper limits of the scale. It should be noted that the carbon dioxide content obtained at the upper point of the atmosphere by *Venera-4* has a large determination error owing to the inaccuracy in the knowledge of the absolute pressure at the moment when the composition was measured. On the *Venera-5* and *Venera-6* stations the pressure was measured simultaneously with the sampling of the atmosphere,

Table 1

Results of determining CO₂, N₂, O₂, and H₂O in the atmosphere of Venus

Pressure of Venus' atmosphere, kg/cm ²	Temperature of Venus' atmosphere, °C	Measurement results, vol.%	Station	Pressure of Venus' atmosphere, kg/cm ²	Temperature of Venus' atmosphere, °C	Measurement results, vol.%	Station
CO ₂	CO ₂	CO ₂	CO ₂	O ₂	O ₂	O ₂	O ₂
0.6	~25	97 ± 4	Venera-5	0.7	~25	\$ \$0.4	Venera-4
0.7	~25	90 ± 10	Venera-4	2.0	85	\$ \$1.5	Venera-4
2.0	85	>56	Venera-6	2.0	85	\$ \$0.3	Venera-6

Pressure of Venus' atmosphere, kg/cm ²	Temperature of Venus' atmosphere, °C	Measurement results, vol.%	Station	Pressure of Venus' atmosphere, kg/cm ²	Temperature of Venus' atmosphere, °C	Measurement results, vol.%	Station
5.0	150	>60	Venera-5	5.0	150	\$ \$0.1	Venera-5
10.0	220	>30	Venera-6	5.0	150	\$ 0.1 Venera-5 * *N{2}** * *N{2}** * *N{2}** * *N{2}\$**	Venera-5
0.6	~25	\$ \$3.5	Venera-5	10	220	\$ \$0.2	Venera-6
0.7	~25	\$ 7 Venera-4 * *H{2}O, mg/l* * * *H{2}O, mg/l* * * *H{2}O, mg/l* * * *H{2}\$O, mg/l**	Venera-4				
2	85	\$ \$9.5	Venera-6	0.6	~25	~11	Venera-5
5	150	\$ \$4	Venera-5	0.7	~25	>0.7	Venera-4
5	150	\$ \$4	Venera-5	2	85	\$ \$8	Venera-4
10	220	\$ \$2.5	Venera-6	2.0	85	~6	Venera-6
10	220	\$ \$2	Venera-6	5.0	150	>0.7	Venera-5
				10	220	>0.7	Venera-6

therefore the determination error is significantly reduced. Thus, the carbon dioxide content in the atmosphere of Venus can now be taken as equal to $97 \pm$

4%.

The oxygen content was measured at four altitude levels by seven sensors. From the *Venera-4* data we had taken the oxygen content to be 0.4-1.5%. At present it is clear that, with sufficient justification, we can reduce its content at least to 0.1%, as shown by three sensors on *Venera-5* and *Venera-6*.

The content of water vapor was determined at 4 levels. At the upper points (at pressures of 0.6 and 2.0 kg/cm²) a quantitative determination of moisture was made; in the deeper layers of the atmosphere it was a threshold determination. As is evident from these data, the moisture content decreases with depth in the atmosphere. Its amount at the pressure level of 0.6 atm is close to saturation, which indicates the proximity of the cloud layer. If the temperature and pressure values are extrapolated into the region of lower values, the lower boundary of the cloud layer can be estimated. It occurs at a pressure of ~0.5 atm.

The amount of nitrogen was determined at 4 levels by seven sensors; moreover, 5 sensors showed content limits no higher than 2-4%. Since the amount of nitrogen together with inert gases was determined by the residue after absorption of the other components (CO₂, H₂O, and O₂), the measurement error could arise only from incomplete absorption. Thus, as a result of all the measurements, the upper limit of the nitrogen content together with inert gases can be taken as equal to 2%.

If all the considerations mentioned above are taken into account, the main results of the experiment can be presented in the form of Table 2.

As can be seen from these data, the results of measurements of the atmosphere of Venus obtained at the automatic stations “Venera-5” and “Venera-6” significantly refined the composition for all components. These data also confirmed the absence, in appreciable amounts, of any other components in the atmosphere of Venus besides those that had been established by us at the “Venera-4” station. This does not exclude the possibility of the presence of traces of CO, NH₃, HCl, and others, detected in very small fractions relative to the CO₂ content in the ionosphere.

As is known, the “Venera-4” station carried out measurements in the Venesian atmosphere only down to pressures of ~ 18 kg/cm². “Venera-5” and “Venera-6”

Table 2

Composition of the atmosphere of Venus

Components	Data from “Venera-4”	Data from “Venera-5” and “Venera-6”
CO ₂ , %	90 ± 10	97 ± 4
N ₂ , %	≪ 7 (possibly ≪ 2.5)	≤ 2
O ₂ , %	0.4—1.5	≤ 0.1

Components	Data from "Venera-4"	Data from "Venera-5" and "Venera-6"
H ₂ O (at $P=0.6$ atm.), mg/l	1—8	~ 11

penetrated deeper (to ~ 27 kg/cm²) and, during the parachute-descent portions, also measured temperature, pressure, and distance to the surface.

It turned out that the course of the change in temperature with altitude over the entire interval of measurements is close to adiabatic. If one assumes that the temperature down to the very surface changes according to the adiabatic law, then on the basis of the data from "Venera-5" and "Venera-6" one may take the pressure and temperature at the planet's surface to be, respectively, about 100 atm. and 500°.

Analyzing the results of the investigations carried out by the "Venera-4" station, we drew attention to the fact that on Venus and Earth the total amount of carbon dioxide released in the process of differentiation of the substance of the planets is approximately the same. At the same time, on the basis of the data on measurement of the thickness of the atmosphere obtained by "Venera-4," it was assumed that on Venus the greater part of the carbon dioxide is in a bound state. The new data give grounds to suppose that at such high temperatures on the surface of Venus practically all the carbon dioxide must have been released, as a result of the reaction of silicic acid with carbonates of sedimentary rocks, into the atmosphere, whose thickness, apparently, amounts to no less than 50-60 atm.

The oxygen content in the Venusian atmosphere proved to be lower than had been assumed earlier, while the data on nitrogen and water were somewhat refined and practically confirmed the previous measurements.

Thus, the results of investigations of the atmosphere of Venus at the stations "Venera-5" and "Venera-6" refined the data on its composition and provided new grounds for understanding the mechanism of its formation. An explanation of this mechanism has been given by us in works (¹, ²).

Institute of Geochemistry and Analytical Chemistry
named after V. I. Vernadsky
Academy of Sciences of the USSR
Moscow

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