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TEMPERATURE, PRESSURE AND DENSITY OF VENUS' ATMOSPHERE ACCORDING TO MEASUREMENT DATA OF THE AIS "VENERA-4"

by

V. S. Avduyevskiy
N. F. Borodin
V. V. Kuznetsov
M. Ya. Marov
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by V. S. Avduyevskiy, N. F. Borodin, V. V. Kuznetsov, M. Ya. Marov, ... ET AL(**)

SUMMARY

This paper is a preliminary communication relative to the results of measurements obtained on AIS VENERA-4, relative to temperature, pressure and density of Venus' atmosphere. As such, this paper seems to be superseded by the more extensive communication verbally presented at the Second Arizona Conference on Planetary Atmospheres in March 1968.(ST-LPS-PA-10704 of 19 April).

Since the mode of discussion, as well as some of the results differ from the above paper, cover-to-cover translation of this paper is presented.

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The Soviet automatic interplanetary station "VENERA-4" reached Planet Venus on 18 October 1967. The main problem of station's descending probe was the measurement of Venus' atmosphere parameters, i. e. pressure, temperature, density and composition.

Various hypotheses lay at the foundations of representations relative to Venus' atmosphere; they were based upon ground observations in optical and radiowave bands and certain theoretical estimates. They resulted in a great uncertainty when attempting to create the planet's model atmosphere. The assumed values of pressure at the surface lied in the interval from 1 to 100 atm, while the temperature range was from 300 to 650°K.The projection of scientific apparatus was done for a Venus' model atmosphere with the respective values of pressure and temperature at the surface of about 10 atm. and 700°K.

Two thermometers were installed to measure temperature. Hermetic resistance thermometers were used for sensors, capable to operate in dense gaseous and liquid media in the presence of chemically aggressive substances.

(*) TEMPERATURA, DAVLENIYE I PLOTNOST' ATMOSFERY VENERY PO DANNYM IZMERENIY AVTOMATICHESMOY MEZHPLANETNOY STANTSII "VENERA-4"

(**) There are altogether eight authors.

The sensitive part of the sensor was a platinum wire respectively with 36.8 and 16 ohm resistance at 20°C. The sensors were switched onto balanced bridge circuits. The unbalanced voltage was amplified by highly-stable semiconductor amplifiers. The range of measurements of the first sensor was 270 - 600°K, and that of the second 210 - 730°K. The root-mean-square error of temperature measurement σ_T by the first sensor did not exceed ±4°, and that by the second ±7°.

In order to determine the density a special densimeter was used, whose sensor was a ionization chamber. The principle of densimeter's operation was based upon the dependence of the magnitude of the registered current on gas density. The chamber constituted a hollow cylinder made of stainless steel of 14 mm in diameter and 25 mm in length with wall thickness of 0,3 mm. A thin layer of β-active strontium-90, with total activity of about 1 millicurie was spread over the internal surface of the cylinder. The measurement range of the densimeter was $5 \cdot 10^{-4} - 1.5 \cdot 10^{-2}$ g/cm³ for the air, CO_2, N_2, O_2 and the mixture of the indicated gases. The root-mean-square error of densimeter readings, constituted $\pm 0.18 \cdot 10^{-3}$ g/cm³ at the origin of measurements range and $\pm 3 \cdot 10^{-3}$ g/cm³ at the end of it.

Pressure was measured by an aneroid-type manometer. The range of measurements of the device was 100 - 5200 mm. Hg. The root-mean-square error of measurements $\sigma_P = \pm 150$ mm Hg.

The transmission of measurement data of Venus' atmosphere parameters began after the opening of the main parachute, when the transmitter of the descending probe was switched on. The velocity of apparatus' descent by parachute varied by about 10 to 3 m/sec and, consequently, could not exert any aerodynamic effect on the results of measurements.

The sensor interrogation by the telemetric commutator began at 07 h. 40 m. 52 sec Moscow time and was conducted with a frequency of once in 48 sec. The variation of temperature T, density P and density ρ as a function of time is shown in Fig.1. The measurement of temperature was conducted during the entire experiment up until radiocommunication with the descending probe has ceased at 09 h. 13 min.57 sec. The pressure and density were measured until the devices went off-scale, respectively at 08 h. 30 min. 31 sec and 08 h. 50 min. 00 sec. These moments of time are marked on graphs $P_{var}(\tau)$ and $\rho_{var}(\tau)$ in Fig.1. The limits of measured parameters' deviations, corresponding to the indictaed root-mean-square errors σ_T, σ_P and σ_ρ.

In the subsequent time intervals the values of P and ρ are obtained by way of extrapolation at a known temperature T variation and in the assumption that the atmosphere consists of CO_2. Shown on the entropy=pressure diagram of Fig.2 are the curves of gas state variation over the measurement segments computed according to T, P_{var} (curve 1) and T, ρ_{var} (curve 2). The curves are prolonged to the isotherm T = 544°K, corresponding to the last measured temperature and with inclination determined by terminal rectilinear portions of the curves. The condition $\Delta S \leqslant 0$ at temperature increase constitutes the atmosphere's stability condition. The dashed horizontal lines in Fig.2 correspond to the limit of extrapolation by the adiabat $\Delta S = 0$. The values of pressure obtained at the intersection of curves 1 and 2 with the isotherm T = 544°K are respectively equal to 19.5 and 20.75 atm. The extrapolated portions of curves P_{var} and ρ_{var} are plotted in the graphs of Fig.1 by dashes.

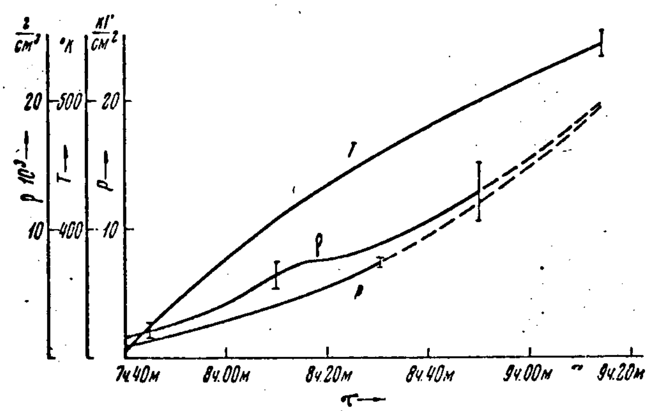

Fig.1. Results of measurements of T, ρ, P

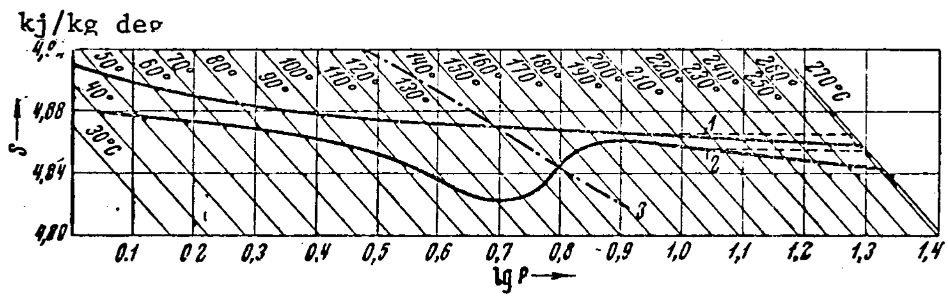

Fig.2. Diagram "entropy - pressure"

From the consideration of Figures 1 and 2 it follows that the course of the curves obtained with the aid of the manometer and densimeter is different up to the time τ = 08 h. 30 min. and T = 440°K. Compiled in Table 1 are the values of the molecular weight μ counted by measured P, ρ and T and the Clapeyron acceleration. Near 0830 hours the values of μ approach 44, which corresponds to CO atmosphere and agrees well with the direct measurement of the composition. The quantity μ = 44 is also preserved over the portions of extrapolation. In the preceding interval the overrating of μ is linked with the character of the measured course of the densi y curve and also with a greater relative error of devices at the beginning of measurements.

TABLE 1

Moscow time	kg/mole	Moscow time	kg/mole	Moscow time	kg/mole
7h. 40м.	56,6	8h. 15м.	57,5	8h. 45м.	45,0
45	52,0	20	50,7	50	44,7
50	50,3	25	46,7	55	45,5
55	50,6	30	44,9	9h. 00м.	44,7
8h. 00м.	49,5	35	45,2	05	45,2
05	51,7	40	44,7	10	44,7
10	56,7				

The density increase, registered approximately from 0803 to 0830 hours may be explained by the influence of Venus' atmosphere components on densimeter readings, which do not affect the readings of temperature and pressure sensors. Among one of the assumptions, it is possible to admit the hitting of densimeter's measurement chamber of moisture.

From the examination of Fig.2 it follows that the densimeter readings approach to of the manometer directly behind the curve of phase transition water - vapor (curve 3). The possible influence of water and also of some other components is presently investigated for the respective temperatures and pressures.

In order to obtain the distribution of atmosphere parameters in height, it is necessary to determine the alritude variation at probe descent by parac chute which was computed by two methods.

In the first case we utilized the equation of motion for a quasi-uniform descent:

$$H(\tau) = \sqrt{\frac{2mg}{C_x S}} \int_{\tau_1}^{\tau_2} \rho^{-1/2}(\tau)\, d\tau, \tag{1}$$

where C_x is the aerodynamic drag coefficient; S is the characteristic area; m is the mass of the descending probe.

In the second case we utilized the hydrostatic equilibrium relation

$$H(\tau) = \frac{1}{g} \int_{P_1}^{P_2} \frac{dP}{\rho} \tag{2}$$

(g = 880 cm/sec). The computations were conducted by gas parameters corresponding to the state curves 1 and 2 of the entropy diagram (Fig.2).

The curves of altitude variation in time, obtained by independent methods, (Fig.3), responding to the magnitude of the path covered by the descending probe in the atmosphere of Venus, as an average agree satisfactorily among themselves. The total height coincides with the readings of the radioaltimeter (26 $\pm$1.3 km) with a precision to 10 percent.

Eqs. (1) and (2) could have been used for independent extrapolation of initial values of pressures by the formula

$$P^{1/2} = P_1^{1/2} + g^{1/2}\sqrt{m/2C_x SR} \int_{\tau_1}^{\tau_2} T(\tau)^{-1/2}\, d\tau, \tag{3}$$

where R is a gas constant.

However, the character of atmosphere parameter variation is then unstable ($\Delta S > 0$). For constant values of coefficients condition (3) is not satisfied over the segment, where measurements were conducted either. This may be explained by the fact that local vertical flows exist in the atmosphere. Thus, for example, calculation by formula (3) agrees well with the curve 1 of Fig.2 for a value of descending flow velocity of gas near the surface ∿ 0.4 m/sec.

The maximum divergence in the determination of altitude by different methods including that by radioaltimeter, is evidently determined by errors of measurements of C_x, of atmosphere parameters and also by the presence of vertical flows and influence of the local relief during a possible probe drift by the wind.

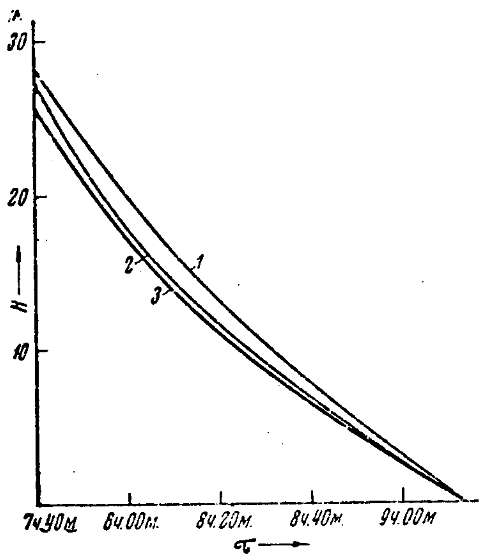

Fig.3. Altitude intervals.
1) according to P_{var}, barometric formula; 2) according to P_{var}, parachute; 3) according to ρ_{var}, parachute

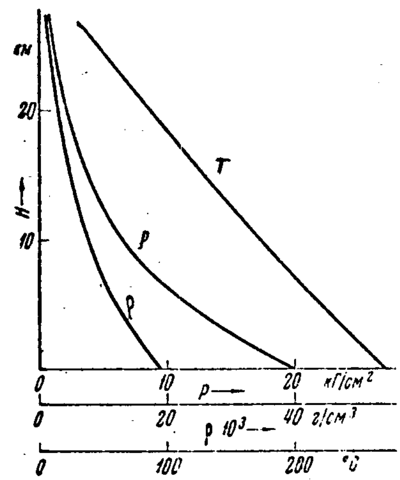

Fig.4
Model atmosphere

The cross-section of Venus' atmosphere in height is shown in Fig.4. In order to tie up the atmosphere parameters to altitude, we choose the curve of Fig.3 with nominal altitude H = 27.3 km.

The character of processes of gas state variation in the atmosphere of Venus to the altitudes of 10 - 15 km is close to adiabatic. The mean temperature gradient constituted about 8.5 to 8.7 degrees/km, which differs little from the adiabatic gradient for CO_2 at corresponding values of temperature and pressure. This is evidence of the fact that there exist in the lower layers of the atmosphere the conditions of convective equilibrium with intense mixing, and that the lower limit of the cloud layer lies above 27 km (or nted at the altitude of 29 - 33 km).

Thus, pressure on Venus' surface near the morning terminator on the night side constitutes 20 ± 3 atm, the density is $19 \cdot 10^{-3}$ g/cm³ ±15% and the temperature is 544 ±10°K.

The height of the uniform atmosphere at Venus' surface is found to be about 12 km, while the total mass of gas is about 10^{20} tons.

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VOLT TECHNICAL CORPORATION
1145 - 19th St. NW
WASHINGTON D.C. 20036.
Telephones: 223-6700 (Ext.36. 37)

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