The Chemical Composition of the Venus Atmosphere Based on the Data of the Interplanetary Station Venera 4

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The general goal of the Venera 4 landing probe was the investigation of the physical and chemical characteristics of the Venus atmosphere. The chemical composition of the Venus atmosphere was investigated by gas analyzers which were constructed especially for this purpose. There were eleven gas analyzers which were divided into two groups. The first group consisted of five analyzers and operated at a pressure of approximately 550 mm; the second contained six gas analyzers and operated at a pressure of about 1500 mm.

There were many methods of investigation of the chemical constitution. The most simple and reliable physical-chemical methods were selected. The kinetic and thermodynamic reactions were investigated in the laboratory under conditions similar to those expected on Venus. Two types of analyzers, amplitude and threshold, were used. Some gas analyzers were cylindrical tubes divided into two parts by a thin membrane, one part containing the chemical absorber selected for the investigated component. Both parts were evacuated and sealed. In the operation process both parts were opened and the investigated gas penetrated simultaneously into them. Then they were closed, and the difference of the pressure in the two parts produced by absorption was measured.

For analyzing minor constituents more sensitive methods were used. These included measurements of the electrical resistance of the specially selected chemical absorber, the heat conductivity, etc. Investigations were made of the content of CO_2, N_2, O_2 and H_2O. Due to the previous uncertainty of the chemical composition of the Venus atmosphere, the sensors were designed with a large range.

The results of the investigation of the chemical composition of the Venus atmosphere are shown in Table 1. The presence of CO_2 is confirmed by four sensors. We conclude that the content of CO_2 in the Venus atmosphere is not less than 90%.

Both nitrogen sensors show the absence of a significant amount of this element in the Venus atmosphere. The first sensor gives an upper limit of 7% and the second sensor an upper limit of 2.5%. However, the second sensor is less accurate. Adopting a conservative point of view, we take 7% as the upper limit of nitrogen.

The oxygen content lies between the two limits obtained by two threshold sensors utilizing various methods. In the first sensor the tungsten filament was adjusted at the limit of about 3 mm partial pressure O_2, corresponding to 0.5% of oxygen at 550 mm pressure. This filament was burned out immediately. The second sensor was based on the selected absorption of O_2 by sublimated phosphorous vapor, in which, as a consequence of this reaction, P_2O_5 absorbs water vapor. This sensor was adjusted at 1.6% of (O_2+H_2O) and no overloading occurred.

The water content was estimated by three sensors. The first sensor, operating on the principle of the variation of the resistivity of P_2O_5, detected the presence of H_2O in an amount larger than 0.65 mg liter^{-1}. This corresponded to 0.1% H_2O for a condensation temperature higher than 22C. The second sensor, based on a similar reaction, also showed the presence of H_2O to be larger than 0.65 mg liter^{-1}. The third sensor, operating on the pressure difference principle (absorption by $CaCl_2$), showed that the partial pressure of water vapor is smaller than 11 mm ($<0.7\%$).

Summarizing, we have adopted the following composition (in volume per cent) of the Venus atmosphere:

CO_2	$90\pm10\%$ (probably $>90\%$)
O_2	$>0.4\%$, $<1.6\%$ (probably $\sim1\%$)
N_2	$<7\%$ (probably $<2.5\%$)
H_2O	from 1–8 mg liter^{-1}

In general, the Venus atmosphere is oxidizing and it corresponds to the greenhouse model.

It is very interesting to compare the present atmospheres of Venus and earth. The overall amounts of degassing products are approximately the same. But on earth, carbon is bound by carbonate sedimentary rocks, and its amount is equal to about $2\cdot10^{23}$ gm CO_2. Therefore, if one sublimates all the CO_2 from the carbonates and hydrosphere of earth to its atmosphere, the surface pressures would be increased by a factor of about 40. In other words, in order to obtain the Venus pressure of 20 atm, it is enough to set free about half of the CO_2

TABLE 1. Results of chemical analyses of the Venus atmosphere.

Analysis conditions	Component under determination	Type of cell	Method of measurement	Limits on measurements (% by volume)	Results of measurements (% by volume)
$H \sim 26 \pm 1$ km	CO_2	Threshold	Heat conductivity	Threshold 1	>1
$P_0 \sim 550$ mm	CO_2	Amplitude	KOH absorption	7–100	90 ± 10
$t \sim 25 \pm 10$C (first group	N_2	Amplitude	Preliminary absorption of O_2, CO_2 at 1000C	7–100	<7
of analyzers)	O_2	Threshold	W 800C outburning	Threshold 0.4	>0.4
	H_2O	Threshold	Electroconductivity of moistened P_2O_5	Threshold 0.1	>0.1
$H \sim 19 \pm 1$ km	CO_2	Amplitude	KOH absorption	2–30	>30
$P_0 \sim 1500$ mm	CO_2	Threshold	KOH absorption	Threshold 1	>1
$t \sim 90 \pm 10$C (second group	N_2	Amplitude	Preliminary absorption of O_2, CO_2 at 1000C	2.5–50	$\leqslant 2.5$
of analyzers)	O_2 (+H_2O)	Threshold	P vaporizing	Threshold 1.6	<1.6
	H_2O	Threshold	Electroconductivity of moistened P_2O_5	Threshold 0.05	>0.05
	H_2O	Amplitude	$CaCl_2$ absorption	Threshold 0.7	<0.7

bound in the terrestrial rocks. This process may be imagined by chemical reactions of the following types:

$$MgCO_3 + SiO_2 \rightarrow MgSiO_3 + CO_2,$$

$$CaCO_3 + SiO_2 \rightarrow CaSiO_3 + CO_2,$$

$$CaMg(CO_3)_2 + SiO_2 \rightarrow CaCO_3 + MgSiO_3 + CO_2.$$

These reactions develop from the left to the right side if the temperature is about 300C.

The only source of nitrogen in the Venus atmosphere may be NH_4. On earth NH_4 is degassing by volcanic action in the form of NH_4Cl, a stable salt sublimating only at 350C. On Venus there is much more CO_2 and $(NH_4)_2CO_3$ is therefore produced. This salt is less stable, decomposing at a temperature of 58C to form NH_3 which is then oxidized by oxygen to N_2, the oxygen being produced by photodissociation of water.

Let us discuss briefly the question of the origin of the Venus atmosphere. On planets of equal sizes endogenic processes, i.e., melting of the crust and degassing, are similar and develop by a zone melting mechanism. The subsequent evolution depends on the distance from the sun, the mass of the planet, and other exogenic conditions.

Let us draw some conclusions. Since Venus is closer to the sun than earth, its effective temperature as a naked planet would be higher by 50C, leading to the emission into the atmosphere of a large amount of CO^2 and H_2O, and to self-heating of the atmosphere. The oxygen is produced by photodissociation of water and is absorbed by surface rocks. The other product of photodissociation is CO, but this recombines to CO_2 with oxygen formed by H_2O photodissociation. The hydrogen was dissipated due to the high temperature and the absence of a magnetic field. This process led to the self-heating of the atmosphere and to an increase of the greenhouse effect. Some contribution to the thermal balance of the planet is due now to internal heating. When the temperature of the surface reaches approximately 250–300C, many carbonates react with silicates, releasing large amounts of CO_2. The conditions on Venus obtained by Venera 4 exclude the existence of a hydrosphere because water boils at a temperature higher than 100C.

Therefore, endogenic processes on both Venus and earth were probably similar. But the exogenic processes depending primarily on the distance from the sun were different. This led to the formation of different atmospheres on these planets, the Venus atmosphere becoming very heavy. Such conditions and an aggressive state of the atmosphere led to a deep denudation of the surface rocks. The intensive circulation probably produced the flattening of the planet's surface.