ON THE STUDY OF THE ATMOSPHERE OF VENUS BY OPTICAL METHODS

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Abstract

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ON THE STUDY OF THE ATMOSPHERE OF VENUS BY OPTICAL METHODS

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1. It has been indisputably established that the atmosphere of Venus is strongly turbid. The fact that it practically completely masks the relief of the surface indicates that its optical thickness τ is at least several units. Under these conditions the effects of multiple scattering acquire a decisive role. At the same time, the approximate theory developed in (1–3) becomes applicable, at any rate for oblique incidence of the solar rays on the surface of the planet. In particular, for the brightness coefficient of any portion of the surface of Venus the following relations must hold:

$$R(\mathbf{r}',\mathbf{r}) \cong \frac{\cos\vartheta}{\pi}\left\{h(\mathbf{r}',\mathbf{r})e^{-s(\mathbf{r}',\mathbf{r})y} - g(\mathbf{r}')g(-\mathbf{r})\frac{\operatorname{sh} y}{\operatorname{sh} by}\times\left[e^{-by} - \frac{R_p \operatorname{sh} y}{\operatorname{sh} by - R_p \operatorname{sh}(b-1)y}\right]\right\} e^{-\tau_H(\sec\vartheta+\sec\vartheta')}, \tag{1}$$

if $\beta \lesssim 0.2$;

$$R(\mathbf{r}',\mathbf{r}) \cong \frac{1}{4\pi}\frac{\cos\vartheta}{\cos\vartheta+\cos\vartheta'} f_{11}(\mathbf{r}',\mathbf{r})\,\beta^{-1} e^{-\tau_H(\sec\vartheta+\sec\vartheta')}, \tag{2}$$

if $\beta \gtrsim 2$. Here $\beta = a/\sigma$ is the specific absorption coefficient of the planet' s cloud layer (a and σ are the volume coefficients of absorption and scattering); $y = \eta\sqrt{\beta}$; $b = \tau/l + 1$; η and l are constants depending only on the form of the scattering matrix $f_{ik}(\mathbf{r}',\mathbf{r})$ in the cloud zone; R_p is the albedo of the underlying surface, and τ_H is the vertical optical thickness of the layer of atmosphere above the clouds, caused practically only by selective absorption by the gases forming it. The direction of the solar rays $\mathbf{r}$ makes an angle ϑ with the normal to the planet' s surface, and the viewing direction $\mathbf{r}'$ an angle ϑ'. The functions $h(\mathbf{r}',\mathbf{r})$, $s(\mathbf{r}',\mathbf{r})$, and $g(\mathbf{r})$ are unknown and are subject to experimental determination or calculation, since their form is determined by the form of the scattering matrix f_{ik} (also unknown). There are grounds for assuming that under real conditions the functions h, s, and g do not depend strongly on the arguments and on the form of the scattering matrix and are, in order of magnitude, close to 1 (their equality to 1 would correspond to orthotropy of the surface of the cloud layer).

2. It follows from (1) and (2) that the brightness coefficient is affected not only by absorption of light in the layer above the clouds, but also by its absorption inside the cloud layer, a factor that until now has not been properly taken into account in interpreting spectroscopic data. Since even slight absorption in the cloud layer is capable of imitating a large optical thickness τ_H of the layer above the clouds, it must be acknowledged that existing estimates of the gaseous composition of the atmosphere of Venus, based on measurements of the intensities of absorption bands (in particular, the CO_2 bands), cannot claim reliability and require serious revision. It is not impossible that precisely here one should seek the cause of the known discrepancies in estimates obtained from measurements of different bands.

Owing to the weak angular dependence of the brightness coefficient of the cloud layer itself, the separation of effects due to the optical properties of the clouds and of the atmosphere above the clouds can be carried out by measuring the intensity of absorption bands in different zones of the planet’ s disk as a function of its phase. As applied to Jupiter, such measurements give irrefutable evidence that the principal absorption of methane light occurs in the cloud layer. In the region of strong absorption, when formula (2) is valid, such measurements should also make it possible to determine the scattering indicatrix $f_{11}(\mathbf{r}', \mathbf{r})$ of the particles forming the cloud layer.

3. In the region of very weak absorption, if $\eta\sqrt{\beta} \ll 1$ and $\tau \ll l/\eta\sqrt{\beta}$, expression (1), in the absence of absorption in the layer above the clouds ($\tau_{\text{n}} = 0$), takes the form

$$R(\mathbf{r}', \mathbf{r}) \simeq \frac{\cos\vartheta}{\pi}\left[h(\mathbf{r}', \mathbf{r}) - \frac{g(\mathbf{r}')\,g(-\mathbf{r})}{b + \dfrac{R_{\text{p}}}{1 - R_{\text{p}}}}\right], \tag{3}$$

whence it follows that the underlying surface must shine through weakly even through a thick cloud layer, which can explain the existence of blurred light and dark spots on the planet’ s disk. If this is so, observations of these spots may provide material for judging the rotation of Venus. It should, however, be borne in mind that the variability of the cloud cover may veil the surface relief to different degrees. On the other hand, light reflected from the underlying surface penetrates through the cloud layer only as a result of multiple scattering. Therefore it cannot retain its polarization characteristics. Consequently, the polarization of the light reflected by the planet as a whole must be determined by the conditions of reflection of light by the clouds, and its spectral dependence must be consistent with the spectral course of the absorption (the Umov effect) ([2,3]). There are no grounds for attributing the polarization of the light reflected by the planet to the properties of the underlying surface. On the contrary, the Umov effect can be used to separate absorption in the cloud layer from absorption in the region above the clouds. Likewise, the increase of the brightness coefficient near angles corresponding to specular reflection cannot be connected with the properties of the underlying surface (all the more so one of water, which has a small albedo). Such a quasi-specularity of diffuse reflection is characteristic of thick layers of many dispersed substances and is connected with the form of the functions $h(\mathbf{r}', \mathbf{r})$ and $g(\mathbf{r})$, i.e., ultimately, with the form of the scattering indicatrix, and therefore provides material for judging the latter.

4. In the case $\eta\sqrt{\beta} \ll 1$, $\tau \gg l/\eta\sqrt{\beta}$, relation (1), for $\tau_{\mathrm{n}} = 0$, takes the form

$$R(\mathbf{r}', \mathbf{r}) \simeq \frac{\cos\vartheta}{\pi}\, h(\mathbf{r}', \mathbf{r})\, e^{-s(\mathbf{r}', \mathbf{r})\, \eta\sqrt{\beta}}. \tag{4}$$

These conditions are fulfilled for a sufficiently thick cloud layer with small but appreciable absorption, and the underlying surface no longer plays any role. The observed absorption spectrum of CO_2 contains a rich set of absorption bands of very different intensities. Proceeding from theoretical estimates of their relative intensities and from measurements of the dependences of R on α for various components, one can, relying on (3) and (4), or on the more general expression (1), estimate the value of τ, i.e., the optical thickness of the cloud layer. At the same time, it follows from (4) that the usual methods for determining temperature from the structure of absorption bands require correction. Therefore spectroscopic data on the temperature of the atmosphere of Venus require reconsideration.

It should be expected that, with decreasing wavelength, the scattering coefficient σ must increase and, if α is unchanged, the quantity $\beta\tau$ must remain-

constant (for $\alpha \ll \sigma$). Consequently, moving into the ultraviolet part of the spectrum should strengthen the inequality $\tau \gg l/\eta\sqrt{\beta}$, and also increase the quantity b entering into (3). Therefore, the appearance of dark bands on the disk of the planet when it is photographed in ultraviolet rays cannot be associated with the underlying surface showing through the cloud layer. The only cause of their occurrence may be the existence of an absorbing substance, nonuniformly distributed in the cloud layer.

The extreme weakness of the absorption bands of vaporous and condensed water in the reflected light of Venus clearly rules out the possibility of water clouds existing on it. It should be supposed that taking into account the absorption of CO_2 in the cloud layer will also remove the known discrepancies with the value of the refraction.

5. Turning to formulas (2) and (4), we find that for $\tau_{\mathrm{n}} = 0$ measurement of the intensity of the absorption bands makes it possible to determine only the value β, but not the full content of the absorbing substance. However, if the substance is distributed uniformly in the cloud layer, then

$$\beta = \frac{\alpha L}{\sigma L} = \frac{L\alpha}{\tau}, \tag{5}$$

where L is the thickness of the cloud layer. On the other hand, measurements outside the absorption bands make it possible, according to (4), to estimate the value of b, and consequently also τ, which makes it possible, using (6), to estimate the value αL as well, i.e., the total content of the absorbing substance in the cloud layer (but not throughout the entire thickness of the atmosphere).

6. It follows from what has been said that obtaining reliable data on the atmosphere of Venus by optical methods is possible only if the effects of multiple scattering of light are taken into account; for this it is necessary to carry out a series of interrelated optical measurements, the totality of which can provide an amount of information sufficient for the interpretability of the results.

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CITED LITERATURE

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Note: Figure translations are in progress. See original paper for figures.

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