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ON THE TOTAL AMOUNT OF NEUTRAL HYDROGEN IN THE UPPER ATMOSPHERE OF THE EARTH

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SUMMARY

The albedo dependence (ratio of scattered radiation intensity in the zenith and nadir) on altitude for various values of aggregate optical thickness is plotted on the basis of the approximate transfer theory of L_α - emission in the Earth's atmosphere, taking into account the degree of shadiness.

It is found that the best agreement of theory with experiment is obtained with the aggregate optical thickness $\tau_0 = 7$ for the dipping angle of the Sun under horizon equal to 40°, and at $\tau_0 = 12$ for 75°.

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The most precise method for the study of hydrogen distribution in the Earth's upper atmosphere is by observation of resonance scattering of Sun's L_α -emission. This problem has been considered from the theoretical viewpoint in the works [1, 2]. The results of these computations are in good agreement with one another, both, qualitatively and quantitatively. The curves of surface brightness dependence at observation in zenith (for a fairly small optical thickness τ_0 at the center of the line) have a nearly identical character for any values of τ_0.

Beginning from a height ~ 140 km, the brightness is nearly independent from height, increasing only with the rise of τ_0. The determination of the value of τ_0, of interest to us, can be made only with quite low precision since the observation must be absolutely calibrated. Unfortunately, at present the uncertainty with which calibration can be made is of a factor of 2 — 3,

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which imparts an error of the same order to the determination of τ_0. For the Fastie and Donahue observations [3], carried out at the zenithal distance of the Sun of 60° on 7 May 1963 and 29 June 1962, this value corresponds to a variation of τ_0 within the limits from 0.35 to 0.8. An analogous pattern takes place also in the observations of [4]. Apparently, only a general tendency of τ_0 increase can be perceived at transition from day to night. This agrees with the theoretical representations on hydrogen dissipation mechanism from the exosphere level, lying at about 500 km [5, 6]. For example, according to [7], $\tau_0 = 1, 2, 4, 6$ for the zenithal distances of 60, 90, 107 and 120° respectively. It may be assumed that the dependence thus found provides a realistic reflection of the asymmetry in the distribution of hydrogen.

In the light of the above attention should be drawn to the possibility of determining τ_0 from observations, at which the requirement of absolute calibration of the apparatus is not strict. We shall review such a method on the basis of the approximate theory of diffusion developed in [2]. The following simplifications were then introduced.

1. - The contour of line-L_α diffusion was assumed rectangular with width equal to $2\Delta\lambda_p$; the width of the solar emission line at intensity $\pi F_S = 3$ erg/cm^2 sec was $\Delta\lambda_S$. The ratio $\Delta\lambda_S / 2\Delta\lambda_p$ was assumed equal to 25.

2. - It was estimated that the emission diffused only along the Earth's radius.

3. — When computing the fraction of direct radiation it was assumed that the density of neutral hydrogen is proportional to r^{-3}, where r is the distance from the center of the Earth, expressed in terrestrial radii.

It was naturally assumed that the share of scattered radiation at infinity was zero when observing in the direction "from the Earth". At the level $\tau = \tau_0$, that is, at 110 km from the surface, the share of radiation coming from below is zero. At these simplifying assumptions, the following transfer equations were resolved:

$$\begin{aligned} \frac{1}{\sqrt{3}} \frac{dI_1}{d\tau} &= -I_1 + \frac{1}{2}(I_1 + I_{-1}) + \frac{1}{4}F, \\ -\frac{1}{\sqrt{3}} \frac{dI_{-1}}{d\tau} &= -I_{-1} + \frac{1}{2}(I_1 + I_{-1}) + \frac{1}{4}F, \end{aligned} \qquad (1)$$

where I_1 is the mean intensity of scattered radiation propagating downward; I_{-1} is the mean radiation intensity, propagating upward; F is the share of direct radiation, equal to

$$F = F_s \exp - \left\{ \frac{2\tau}{1+\cos\theta} \right\}. \tag{2}$$

Here the angle ϑ is counted from the direction "Earth — Sun". In the shadow region $(\tau > \tau_0 \sin^2\theta)$, it is evident that $F = 0$. The complete solution of the system (1) was brought out in [2]. Here, for illustration, we shall present only the dependence I_1 and I_{-1} for a single case (Fig. 1)

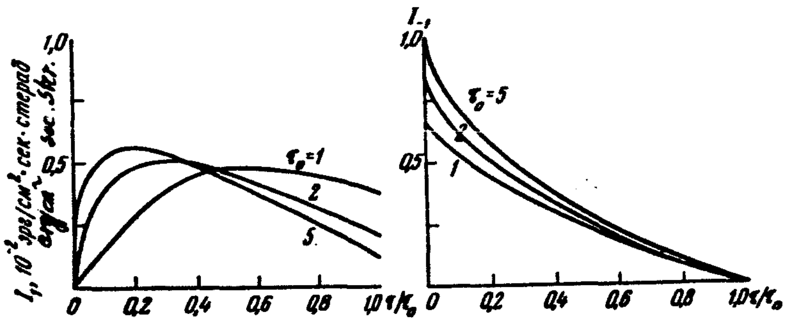

Fig. 1. - Intensity of scattered radiation in zenith, I_1 and in nadir I_{-1} for a 40° dipping angle of the Sun.

Evidently, it is not difficult to obtain the ratio $A_T = I_{-1}/I_1$ by resolving the equation (1); in the following we shall refer to this ratio as the theoretical value of the albedo. The values of A_T for various values of τ_0 as functions of the ratio τ/τ_0 at $\vartheta = 120°$, which corresponds to the dip_ing angle of the Sun under horizon of 30° and $\vartheta = 165°$. The dashed curve corresponds to very great τ_0. The character of the curve underlines the more or less obvious fact of isotropy of scattered radiation for all values of τ, excluding the region's boundaries: for the lower boundary at $\tau = \tau_0, A_\tau = 0$ and for infinity, where $\tau = 0, A_\tau = \infty$, since $I_1 = 0$. Thus, obtaining the value of A_T as a function of height, it is possible to construct a model of relative distribution of neutral hydrogen, and to define its normalization, that is the value of τ_0.

We shall now take into account two corrections that must be introduced in order to pass from the observed values of brightness at zenith and nadir, and also from their ratio A_{exp} to the corresponding theoretical values: I_1, I_{-1}, A_T.

The first correction is linked with the presence of extraterrestrial component's background, which may be explained by solar line L_α scattering over interplanetary and interstellar hydrogen [8, 9]. It was established in the first of these references, using the filtering method, that for a 25° dipping angle of the Sun under horizon 15 percent of radiation from the zenith region has an extraterrestrial origin. This refers to heights ~150 km.

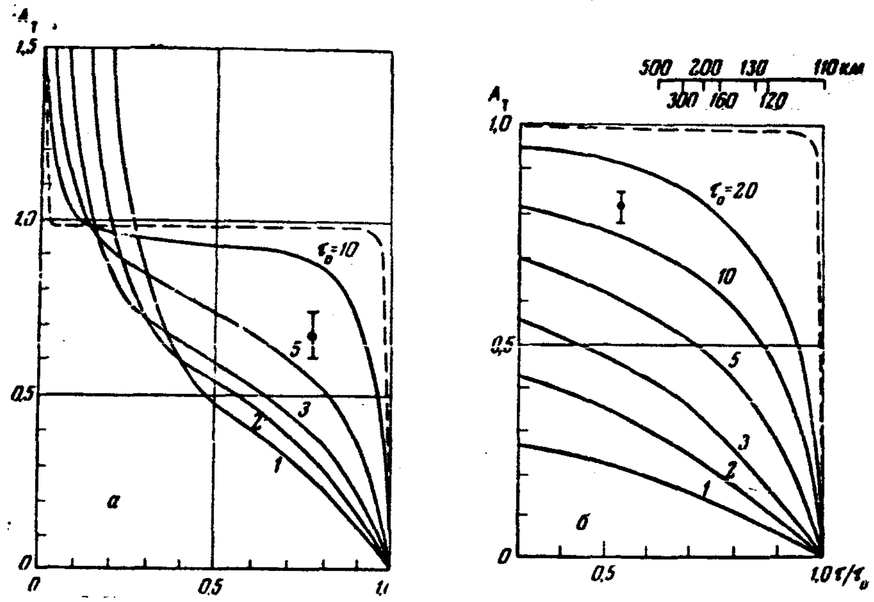

Fig. 2. - Dependence of the ratio I_{-1}/I_1 for $\vartheta = 130°$ (a) and for $\vartheta = 165°$ (б).

Direct measurement of sky brightness at the distance of $\sim 15 \cdot 10^6$ km from the Earth was made by the author of [9]. The obtained value of $1.5 \cdot 10^{-4}$ erg/cm^2$\cdot$sec$\cdot$sterad is in satisfactory agreement with the value determined by [8] Morton and Purcell, which is $4.1 \cdot 10^{-4}$ erg/cm^2$\cdot$sec$\cdot$sterad. If the latter value is referred to zenith brightness at 150 km height, this will give ~10%.

The second correction introduced into the value of A_{exp} account the Doppler widening of lines in a nonisothermic atmosphere. If we denote the observed values by B_1 and B_{-1}, the background brightness of the extra-atmospheric component by B_0, the following simple correlations are obvious:

$$B_{-1} \propto I_{-1}\sqrt{T_{-1}}, \tag{3}$$

$$B_1 = B_1' + B_0, \tag{4}$$

$$B_1' \propto I_1\sqrt{T_1}. \tag{5}$$

Assuming, in accord with the above-said, $B_o = 0.1 B_1$, we shall find the relationship between A_T and $A_{exp.}$ sought for :

$$A_\tau = \frac{I_{-1}}{I_1} = A_{exps} \cdot 1{,}1 \sqrt{\frac{T_{-1}}{T_1}}, \qquad (6)$$

where T_{-1} and T_1 are the weighted mean values of temperatures of atoms, lying below and above the point of observation, to which corresponds the current coordinate $0 \leqslant \tau \leqslant \tau_0$.

Let us now pass to numerical estimates of the value of τ_o. Unfortunately no continuous observations of the value of A_{exp} as a function of height are available, which excludes the possibility of constructing an experimental model of neutral hydrogen distribution. Only three observations are available [8, 10, 11]; they all correspond to different heights and were completed at various times.

The first experiment was completed on 28 March 1957 for a 40^o dipping angle of the Sun under the horizon. The measured albedo for the 130 – 146 km altitude interval was equal to 0.42. In the experiment of 17 April 1961 at 25^o dipping angle, the value of albedo found was of the same order (0.40 for heights ~ 170 km).The last experiment was completed on 14 January 1960 at substantially greater heights (1120 km). Unfortunately a series of instrumental malfunctions strongly reduced its scientific significance. For the height of 500 km, when the apparatus was functioning normally, the albedo, computed by measurements, constitutes ~65%. The last experiment was carried out for a dipping angle of the Sun ~ 75^o. For subsequent calculations it is necessary to achieve the transition from optical depth to altitude above the Earth's surface. To that effect we utilized a combined model: below 500 km according to Bates and Patterson thermosphere model [12], and above, according to the Õpik – Singer ballistic model [13]. It was admitted that the temperature at dissipation level is equal to 1000^o K. The concentration <u>n</u> of neutral hydrogen and the number <u>N</u> of atoms on the visual ray in arbitrary units are compiled in Table 1. It was then assumed that the concentration of atomic hydrogen at 500 km is 10^4 cm^{-3}. It is evident that for the given model of hydrogen distribution the ratio τ/τ_o will not be dependent on hydrogen density at 500 km for any height, for τ and τ_o are proportional to this value.

TABLE 1

h, км	n, см⁻³	N, см⁻²	τ	τ/τ₀	T, °K	h, км	n, см⁻³	N, см⁻²	τ	τ/τ₀	T, °K
110	$6,8\cdot10^{5}$	$2,4\cdot10^{13}$	0,48	1,00	200	250	1,4	1,5	0,30	0,62	990
120	2,0	2,0	0,40	0,83	380	300	1,3	1,5	0,29	0,60	1000
140	$5,7\cdot10^{4}$	1,8	0,36	0,75	670	350	1,2	1,4	0,28	0,58	1000
160	3,2	1,7	0,34	0,70	830	400	1,1	1,4	0,27	0,56	1000
180	2,3	1,6	0,32	0,66	910	450	1,0	1,3	0,26	0,54	1000
200	1,8	1,6	0,31	0,64	950	500	1,0	1,3	0,25	0,52	1000

It is now evident that the value of the albedo for 140 km, which is 0.42, should be referred to $\tau/\tau_0 = 0.75$, and 0.65 to $\tau/\tau_0 = 0.52$. Introducing the corresponding correction in accord with (6) and assuming that in the case $\tau/\tau_0 = 0.52$ the value of the background constituted only 15% of brightness at zenith, we find

$$A_\tau(\tau/\tau_0 = 0{,}75) = 0{,}65, \tag{7}$$

$$A_\tau(\tau/\tau_0 = 0{,}52) = 0{,}85. \tag{8}$$

For the determination of the values of T_{-1} and T_1 we computed the following integrals:

$$T_{-1}(h) = \frac{\int\limits_{110\text{ км}}^{h} n(h)T(h)\,dh}{\int\limits_{110\text{ км}} n(h)\,dh}, \tag{9}$$

$$T_1(h) = \frac{\int\limits_{h}^{\infty} n(h)T(h)\,dh}{\int\limits_{h}^{\infty} n(h)\,dh}. \tag{10}$$

For the first value (7) we took T_{-1} (1 (140 km) = 450 km, $T_1(140) = 900°$ and for (8) respectively $T_{-1}(500\text{km}) = 800°$, $T_1(500) = 1000°$. Note that the error in the determination of the aggregate optical thickness depends little on the admitted temperature dependence.

The values found are equal to 7 for $\vartheta = 130°$ and to 12 for $\vartheta = 165°$. It should be noted, however, that the approximate theory of [2] leads to overrated values of τ_0 for angles ϑ approaching 180°. To estimate this effect precisely is difficult. Assuming for the night $\tau_0 = 10$, we obtain for n (h) and N (h) values 20 times greater than those compiled in Table 1. The value of τ rises accordingly, while the ratio τ / τ_0 remains unchanged.

Taking into account that the daytime measurements provide a value $\tau_0 \sim 0.5$ event after accounting for possible eroors, we obtain that the total hydrogen content in the atmosphere varies by approximately a factor of 20.

******* THE END *******

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REFERENCES

[1].- G. E. THOMAS.- J.Geophys. R. No. 9, 2639, 1963.
T. M . DONAHUE, G. E. THOMAS.- Ibid. p.2661, 1963.

[2].- S. A. KAPLAN, V. G. KURT.- Kosm.Issl., 3, No. 1, 251, 1965.

[3].- W. G. FASTIE, T. M. DONAHUE.- IV Cospar M. Warsaw, 1963.

[4].- V. V. KATYUSHINA, V. G. KURT.- Kosm.Issl. 3, No. 1, 243, 1965.

[5].- T. M. DONAHUE.- On a Large Diurnal Variation in Hydrogen Abundance. Prep. Pittsburgh Univ., 1963.

[6].- W. B. HANSON, T. N . PATTERSON.- Plan.Space Sci. 11, 1035, 1963.

[7].- S. A. KAPLAN, V. G. KURT, V. V. KATYUSHINA.- IV Cospar, Warsaw, 1963.

[8].- D. C . MORTON, J. D. PURCELL.- Plan.Space Sci., 9, 455, 1962.

[9].- V. G. KURT.- Doklad na XY Kongresse MA F , Warshava, 1964.

[10].- E. T. BYRAM, T. A. CHUBB, H. FRIEDMAN, J. E. KUPPERIAN.- Pl.Sp.Sc. 1, 3, 1959.

[11].- T. A. CHUBB, H. FRIEDMAN, R. W. KREPLIN, P. MANGE.- Les spectres des Astres dans l'ultraviolet lointain (Spectra of Heavenly Bodies in the Far UV).- Liège, 1961.

[12].- D. R. BATES, T. N. PATTERSON.- Plan. Space Sci., 5, 257, 1961.

[13].- E. J. ÖPIK, D. F. SINGER.- Phys.Fluids, 4, 221, 1961.

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