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SUMMARY

The contribution of corpuscular fluxes to the ionization of the D-region is investigated here on the basis of utilization of direct measurement data on their intensity at altitudes up to 90-95 km. It is shown that a high level ionization of D-region could be sustained at the expense of corpuscular radiation.

* * *

The question of the role of corpuscular radiation in the ionization of ionosphere's D-layer, especially in the region of middle and low latitudes, is still to a considerable extent open.

An overwhelming majority of rocket launchings with detectors of ionizing particles i performed in auroral zone, whereupon the obtained results are mainly related to altitudes above 100 km.

At middle and low latitudes the data on corpuscular fluxes below 100 km were obtained only during two rocket launchings [1,2]. During the flights at 70-100 km altitudes, mainly soft radiation was registered, which apparently consisted mostly of electrons [1]. It is shown in the work [2] that it must make a substantial contribution to the ionization of the D-layer. However, the results of work [2], obtained on the basis of only one rocket launching, may possibly have a particular character since it is unknown to what extent such an ionization source is stable in time.

In connection with the absence of any somewhat systematic data on direct measurements of corpuscular radiation below 100 km, when considering the processes taking place in the lower atmosphere, most of the investigators start from ideas formulated as early as 1960 [4] (for the review of the latest experimental works on the D-region see, for example, [3]).

Indeed, the basic agents of ionization in the D-region are the X-ray radiation and the L_α-emission in the Sun (ionization of molecule NO), as well as cosmic rays.

On the other hand, it is known that the accounting of only these ionization sources does not permit to explain the multitude of experimental results related to the D-region, for example, the existence of lower ionosphere at nighttime, the latitude and daily dependence of electron and ion concentration, the ion composition, etc.,

In connection with this, the investigation of other possible ionization sources and, in particular of corpuscular radiation, is of great interest.

With this in view, a series of direct measurements of corpuscular fluxes' intensity were conducted on the rockets in 1967 up to 90-95 km, in a great latitude interval in the Indian Ocean (up to 60° S. lat. from the equator). For the registration of radiation end SBT-9 type Geiger counters with equivalent thickness of inlet window of ~ 1 mg/cm^2 were used. The obtained experimental data were published in [5]. Shown here in Fig.1 are only data on the intensity of fluxes (circles) at the altitude of 87 km (after subtraction of cosmic ray background) as a function of McIlwain's L-parameter [6] characterizing the geomagnetic latitude.

Attention is drawn by the fact that they are agreeing well with the latest measurements. Considerable divergence could, to the contrary, be expected between these data, as they were obtained at a 2-3 year interval and in different longitudinal belts.

However, from our point of view, the most essential result of the performed investigations, is the fact that the corpuscular radiation was registered during all rocket flights, even at lowest latitudes, in the region of the geographic equator. This is evidence that, apparently, it is constantly present at the investigated altitudes. Therefore, when analyzing processes in the lower ionosphere, it is necessary to take into account that corpuscular fluxes are a permanently-acting ionization source at all latitudes. Moreover, with the rise of latitude, the role of this source increases.

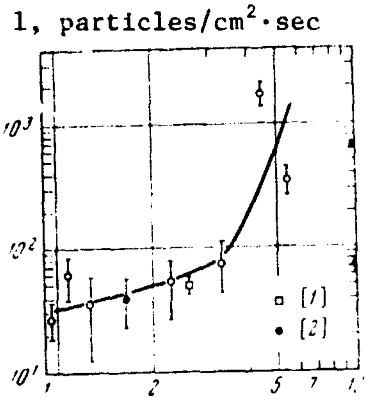


Fig.1.

A quantitative evaluation of the contribution of corpuscular radiation to the ionization of ionosphere's D-layer will be brought forth below.

A general approach to the solution of this problem, based on the data of direct measurements of radiation intensity at the investigated altitudes, is presented in [2]. However, with the presently available amount of information, such a consideration could be performed more correctly.

The rate of ion formation in the atmosphere is determined by the radiation's ionization losses. For the computation of ionization losses, it is necessary to know the composition of ionizing corpuscular radiation, the intensity and the differential energy spectrum of particles at the investigated altitudes, as well as the dependence of the ionization losses on particle energy.

From the theoretical and experimental works, only the function of ionization losses for particles of various nature, depending upon their energy, is well known at present. Concerning the information on the composition of ionizing corpuscular radiation, they are less speceific, while the measurement data of particles' energy spectrum at these altitudes are totally absent. In the experiments on the measurement of corpuscular radiation intensity by Geiger counters electrons with energy $\geqslant$ 40 kev, as well as protons with energy $\geqslant$ 0.5 Mev could be registered. There are at present few data on fluxes of protons with energies 0.5-5 Mev. The available isolated measurements on rockets [1,7] and satellites [8], show, however, that their intensity is by several orders lower than that of electrons with energy $\geqslant$ 40 kev. That is why in further computations we shall assume that electrons only were registered by the counters. Evidently, such an assumption may lead only to underrating the estimates of energy liberation to the ionization in the atmosphere.

For the determination of particles' energy spectrum, one may use the results of measurements of particles' integral flux at various altitudes.

In fact the total flux I of the registered particles at altitudes h, is linked with their differential energy spectrum N(E)dE by the following relation

$$I(x+a)=\int_0^\infty N(E)\sigma(E,x+a)dE. \qquad (1)$$

Here x + a is the total thickness of the absorbing layer in mg/cm^2, including the thickness a of counter's inlet window and x of the residual atmosphere above the level h ($x=\int_h^\infty \rho(h)dh$, where $\rho(h)$ is the atmosphere density), $\sigma(E, x+a)$ is the probability that a particle with energy E will pass through the layer of matter x + a and consequently will be registered by the counter.

Thus, for the determination of the energy spectrum from the integral equation, it is necessary to have additional data on the function $\sigma(E, x+a)$.

For the determination of σ, we used the results of experiments on electron absorption in thin aluminum foils [9,10], as the capacity of absorption of aluminum and air is about the same [11].

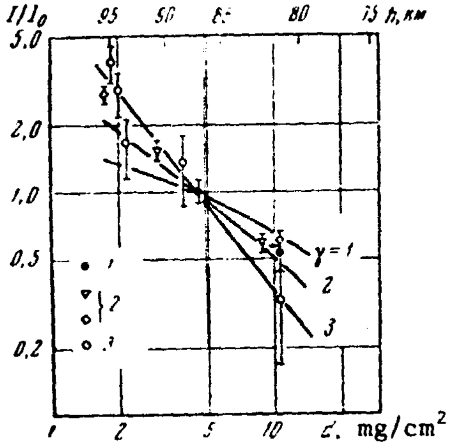


Fig.2.

It is well known [10], that in the energy range from a few tens to about 1500 kev, all electron absorption curves coincide with sufficient precision if they are presented in the form of a function $\sigma(x/R_e)$, where R_e is the so called extrapolated path. Thus, using the dependence $\sigma(x/R_e)$, one may plot the electron absorption curves of any energies, for which direct experimental data are absent.

The results of computation of the function $I(x + a)$ are presented in Fig.2, in the assumption that the differential spectrum has the form $N(E)dE = AE^{-\gamma}dE$ for three values of γ. The curves are normalized at the point corresponding to the altitude of 87 km. Plotted here also in relative units are the values of intensity at the altitudes of 87 and 81 km (1) averaged according to four rocket launchings at middle latitudes, to the results of two launchings at high latitudes (2), as well as to those obtained previously [2] at middle latitudes (3).

From the comparison of experimental data with the computations, it follows that the curve of particle absorption in the atmosphere, in the altitude region below 87 km, agrees better with the computation if $\gamma = 2$, and at the greater heights if $\gamma = 3$. A steeper altitude course of intensity with the increase of altitude is evidence that the energy spectrum of particles becomes softer with the decrease of their energy.

In order to obtain from relation (1) the values of intensity ~ 50 particles/cm^2·sec observed at the altitude of 87 km (see Fig.1) in the region of middle latitudes, it is necessary to take in the energy spectrum the normalized coefficients A equal respectively to $3{,}4\cdot10^3$ and $4{,}2\cdot10^5$ for $\gamma = 2$ and 3.

The obtained energy spectra were used for the computation of energy liberation $\frac{d\varepsilon}{dx}(h)$ at various altitudes according to formula

$$\frac{d\varepsilon}{dx}(h) = \int_0^\infty N(E)\frac{dE}{dx}(E)\,dE, \tag{2}$$

where $\frac{dE}{dx}(E)$ is the function of ionization losses of electrons in the air.

Two variants of the computation of function $\frac{d\varepsilon}{dx}(h)$ were carried out in accordance with the two chosen values of integrand $\frac{dE}{dx}(E)$. In the first case we used the well known function [11] for average electron losses on ionization without accounting for their Coulomb scattering. Qualitatively, it is clear, however, that because of scattering, their actual path in the layer dx will be greater and, consequently the losses of energy in the dx layer will be greater also.

In the second variant of the estimate, aggregate account was taken of the Coulomb dispersion as well as of fluctuation in ionized energy losses by means of the use of real electron absorption curves of different energy $\sigma[x/R_e(E)]$ in the matter. In this case the function of energy losses was taken in the form

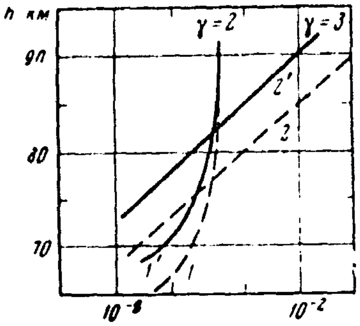
$$\frac{dE^*}{dx}(E)=\frac{dE}{dx}(E)\sigma\left[\frac{x}{R_{\text{э}}(E)}\right].$$

Knowing the function $\frac{d\varepsilon}{dx}(h)$, of energy liberation and taking into account also that for the formation of an ion pair in the air an average energy of 35 ev is required, it is easy to determine the altitude distribution q(h) of the rate of ion formation (number of ion pairs/cm^3·sec) from the relation

$$q(h)=\frac{1}{35\rho(h)}\frac{d\varepsilon}{dx}(h). \qquad (3)$$

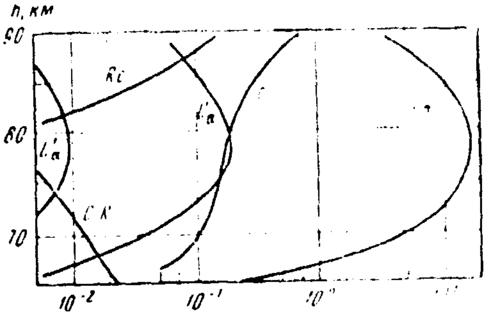
The dependence q(h) is presented in Fig.3, for the two values of the energy spectrum γ, equal to 2 and 3, and for the case when the particle flux at 87 km altitude is 1 particles/cm^2·sec.

In order to obtain the distribution q(h) for either latitude, it is necessary to multiply the value of q(h) shown in Fig.3, by the value of particle flux at 87 km altitude in accord with Fig.1. The curves 1,2 and 1', 2' shown in Fig.3, are respectively relative to the first and the second



q.ion pairs cm^{-3}·sec

Fig.3



q.ion pairs cm^{-3}·sec

Fig.4

calculation variant (i.e. when only the average energy losses and in addition the supplementary Coulomb dispersion and the fluctuations in energy losses were taken into account). It may be seen from Fig.3 that the calculation of dispersion and fluctuations in energy losses result in that the entire curve q(h) is somewhat shifted upward (by 4-5 km) along the scale height. It is obvious that the profile of the dependence q(h) in the region of altitudes above 85 km is determined by the curve corresponding to $\gamma = 3$, and at lower altitudes to $\gamma = 2$. It is of interest to compare the contribution of various ionizing agents to the formation of the D-layer.

The curves in Fig.4, represent the altitude dependences of the rate of ion formation under the influence of galactic cosmic rays (C.R.), Roentgen (R_e), corpuscular (e) radiations and Lα-emission (limiting values Lα' and Lα''') for middle altitudes.

The data on ion formation by X-ray-and-Lα-emissions are borrowed from the work [12]. A wide range of q variations under the influence of Lα-emission are linked with a greater uncertainty of molecule NO concentration at the investigated altitudes. For the calculation of q(h) at the expense of corpuscular radiation and with the view of improving the precision, the averaged results of the four launchings at middle latitudes were used, since here the latitude effect is not great (see Fig.1).

The calculation of cosmic rays' contribution to the ionization was conducted on the basis of data on cosmic ray fluxes obtained during the same rocket launchings as those for the corpuscular radiation. The curve (C.R.) in Fig.4, is related to the 45° latitude S. lat. The estimate of cosmic rays' contribution to the ionization is not investigated here in a more detailed fashion in view of its simplicity by comparison with the estimate of the role of corpuscular radiation. This is explained by the fact that cosmic rays are relativistic particles, their losses to ionization not depending on particle energy and, consequently, the ionization effect is determined, in principle, only by the general particle flux. Thus the curve (C.R.) will have the same latitude dependence as the intensity of primary cosmic rays.

Comparison of the curves shown in Fig.4, allows us to arrive at a series of interesting qualitative conclusions.

Firstly, we shall compare the contribution of corpuscular radiation to the ionization of the D-region at middle latitudes with the contribution of L_α-emission, even if we consider that the real curve of ion formation rate under the influence of L_α-emission lies somewhere between L_α'' and L_α'''. Hence, a rather high ionization level could be sustained in nighttime at the expense of corpuscular radiation [13].

Secondly, with altitude increase, the source of corpuscular ionization becomes more powerful; therefore, the general ionization of lower atmosphere, other conditions being equal (in particular, the invariability of recombination coefficients), must rise with latitude increase. Such a conclusion follows precisely from the analysis of numerous data on measurement of electron and ion concentration [14].

Thirdly, as the altitude decreases below about 85-80 km, a variation is observed in the ratio of the corpuscular radiation to L_α-emission in favor of the latter. It is possible that the well known altitude decrease of D-layer's disposition in daytime is explained precisely by this fact.

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