National Aeronautics and Space Administration
Goddard Space Flight Center
Contract No. NAS-5-12487

ST - AI - PF - 10 598

ON THE ROLE OF CORPUSCULAR RADIATION IN THE FORMATION OF LOWER IONOSPHERE

by

V. F. Tulinov

(USSR)

3 MAY 1967

ON THE ROLE OF CORPUSCULAR RADIATION IN THE FORMATION OF LOWER IONOSPHERE

(*)

Kosmicheskiye Issledovaniya
Tom 5, vyp.2, 240 - 4,
Izdatel'stvo "NAUKA", 1967.

by V. F. Tulinov

SUMMARY

This paper describes the results of direct measurements of electron fluxes with energy > 40 kev in the upper atmosphere to 100 km altitude. Calculations are conducted, which show that the contribution of electrons to the ionization in the 70 - 90 km altitude range may be predominating.

*
* *

Up to the present time the least studied region of the ionosphere is its lower part, the so-called D-region.

The most widespread viewpoint at present on the formation of lower ionosphere (see, for example, [1, 2]) is the following: the main agent responsible for the ionization above 85 km is the hard ultraviolet and X-radiation of the Sun; in the range 65 ÷ 85 km the ionization is conditioned by L_α-line absorption by NO molecules, and below 65 km the main contribution to ionization is provided by cosmic rays.

When explaining the ionization mechanism in the 65 ÷ 85 km altitude range the greatest indefiniteness takes place, for it is necessary to assume at these heights a substantial concentration of NO molecules. As to the presence of ionized NO^+ molecules, registered at these heights by direct measurements, it is possibly linked not with the absorption of L_α but is explained by various photochemical reactions [2].

Thus, it is interesting to consider, besides the Sun's electromagnetic radiation and cosmic rays, other possible sources of ionization of the lower ionosphere. In connection with the latest development of research with the aid of rockets and particularly satellites, a notable role in the formation of

---

(*) [O ROLI KORPUSKULYARNOGO IZLUCHENIYA V FORMIROVANII NIZHNEY IONOSFERY] the upper ionosphere was ascribed to corpuscular radiation, i. e.,the solar corpuscular streams and Earth's radiation belts. However, the significance of corpuscular radiation as the ionizing agent of the lower ionosphere (below 100 km) is so far to a significant degree undetermined.

There exist at present only some indirect data for, as well as against, a notable role of corpuscular radiation in the ionization of the lower ionosphere. To the number of the former we may refer the well known rise of ion concentration in the atmosphere with the increase of the latitude of observations [4]. At the same time this viewpoint is in contradiction with the great daily effect of electron concentration [2] (in daytime the concentration of electrons is by about one order greater than in nighttime), which is naturally explained by the electromagnetic nature of the ionizing agent of solar origin. However, direct measurements of concentration of positive ions at these heights, not showing any daily effect, are presently available [5].

In connection with the above there arises the necessity of conducting direct experiments on the registration of corpuscular radiation in the upper atmosphere.

The present work expounds certain preliminary results of measurements of charged particle fluxes on meteorological rockets to altitudes of $\sim$ 100 km.

A system of three Geiger counters of the type SBT-9, with 1 mg/cm^2 thickness of inlet window, was part of the measurement apparatus. These counters allowed us to register effectively electrons and protons with respective energies above 35 - 40 kev and 0.5 Mev, and also cosmic rays. One of the counters was used as "background" for the registration of cosmic rays, with inlet window shielded. The other two counters were so disposed that one of them was "looking" upward by the inlet window during ascent, and the other - downward, whereupon in order to decrease the influence of rocket's frame on the number of counts of the latter, its axis was at 35° relative to rocket axis. The utilization of two counters with opposite disposition of inlet windows allowed us to conduct the radiation registration at ascent as well at descent.

Upon passage of amplifying and shaping cascades, the pulses from counters proceeded to integrating devices, from whose outputs were fed dc voltages proportional to radiation intensity. This apparatus is described with more details in ref. [6].

The results of processing of telemetry data have shown that the intensity of the radiation registered by the background counter at altitudes > 55 - 60 km remains practically constant through maximum heights of rocket ascent. At the same time, the counters registering the soft radiation have noted (at ascent, as well as at descent) a significant rise of radiation above 70 - 75 km.

The experimental data on the complementary flux of charged particles at various heights (minus the cosmic ray background), taking into account the corrections for the effective area and the solid angle of the counters for the soft radiation, are plotted in Fig.1. The sum of thickness of residual atmosphere and counter's inlet window are in abscissa and the intensity is in ordinates.

In order to ascertain the role of the registered radiation in the ion formation of the lower ionosphere one must be aware of the dose of energy ($\Delta\varepsilon$), lost by the charged particles of the kind i during the passage of an air layer Δh. These energy losses may be expressed in the following form:

$$\frac{\Delta\varepsilon_i}{\Delta h} = \int\limits_{E_{\kappa p}} N_i(E) \frac{\Delta E}{\Delta h}(E)_i dE, \quad (1)$$

where $N_i(E)dE$ is the differential energy spectrum of particles, $(\Delta E/\Delta h)\ (E)_i$ is the loss of energy by a particle with energy E to ionization at passage of the air layer Δh, E_{kp} is the minimum energy of the particle, at which it is still able to ionize the matter.

In other words, in order to resolve the question of the contribution of corpuscular radiation to ionization one must know the nature of particles, and differential energy spectrum, and also the losses of energy by particles of various energies to ionization during passage through the atmosphere.

The data on ionization losses by particles of various nature are sufficiently extensively treated in literature dealing with the investigation of radiation passage through matter (see, for example [7 - 9]). The energy spectrum of particles may be determined on the basis of the results on particle absorption in the atmosphere obtained in the present experiment (see Fig.1).

In order to ascertain the nature of registered particles it is necessary to have recourse to certain additional data, for the results of measurements with the aid of the Geiger counter do not permit a unilateral response to this question. In the experiment counducted by counters electrons with energies from 40 to 150 - 200 kev, as well as protons with energies from 0.5 to 4 - 5 Mev can be registered. The lower energy threshold is determined by the threshold value required for the passage by the particle through the counter window, and the lower limit is determined by the penetration depth of radiation into the atmosphere.

The question of the nature of particles may be resolved by way of involving data on ionization measurements in the atmosphere, for the ionization, induced by protons and electrons, their fluxes being equal in the indicated energy intervals, differs by several orders.

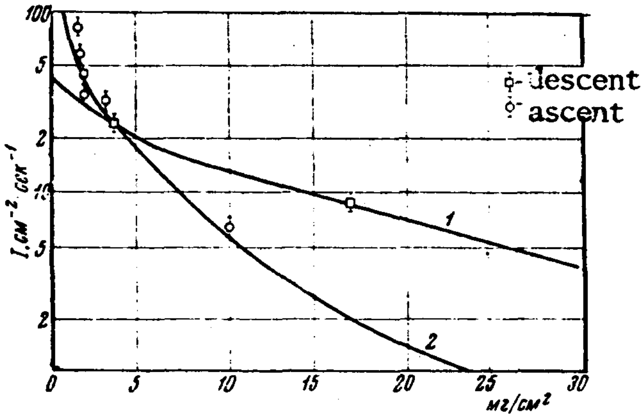

Fig.1

The estimates performed below show that had the registered radiation been due to protons, they would have induced too great an ionization, which is not observed experimentally. Taking this remark into account, we shall consider that the registered particles are electrons.

As already noted, we may use the absorption curve in the atmosphere (see Fig.1) in order to determine the differential energy spectrum of electrons. In the case under consideration the atmosphere is considered as a certain absorbing medium. To that effect, the inverse problem should be resolved, namely, to select such a spectrum of particles that would satisfy the obtained absorption curve. Indeed, if the energy spectrum (trial spectrum) at any level of the atmosphere is known, we may, by utilizing the well known relations for energy losses (dE/dh)(E) by particles of various energies, determine how the spectrum will transform during the passage of the layer of matter Δh. Thus we may determine the spectrum at any depth in the atmosphere. The integration of energy spectra over energy from E_{thr} = 40 kev (E_{thr} being the threshold energy of electrons corresponding to the thickness of counter's input window) for different altitudes will give the integral fluxes of particles at these altitudes. From the comparison of computed values of fluxes with the registered ones experimentally at various heights we may determine the differential energy spectrum of particles sought for.

Another way of determining the energy spectrum of particles, in fact equivalent to the preceding one, consists also in the solution by the method of assorting an integral equation of the form

$$\Pi_k = \int_{E_{\text{пор}}}^{\infty} N(E)\sigma_k(E)\,dE, \qquad (E_{\text{пор}} \text{ means } E_{\text{threshold}})$$

where N(E) is the spectrum sought for, Π_k is the flux of particles obtained experimentally at the k-th level, $\sigma_k(E)$ is the probability of passage of a particle with energy E to the assigned level, E_{thr} has the preceding value of 40 kev.

For the determination of $\sigma_k(E)$ we may utilize the well known absorption curves of electrons with various energies in the matter (see, for example, [10, 11]). The calculations, conducted by both the above methods, have shown that differential spectra of the form

$$N(E)dE \sim E^{-\gamma}dE,$$

where γ = 2 : 4, may satisfy the obtained altitude course within the precision of the experiment.

The curves 1 and 2 in Fig.1 represent the results of calculation of the altitude dependence of electrons in the atmosphere at

$$N(E)dE = 0.1E^{-2}\ dE\ \text{electron/cm}^2\cdot\text{sec}\cdot\text{kev}$$

$$N(E)dE = 0.33E^{-4}\ dE\ \text{electron/cm}^2\cdot\text{sec}\cdot\text{kev}$$

for $E \geqslant 40$ kev. Having determined the energy spectrum of particles, we may, by utilizing Eq.(1), compute the total energy losses on the ionization in any atmosphere layer Δh. At the same time, the following should be underscored. We obtained the spectrum of electrons in the energy region $\geqslant$ 40 kev. However, the absence of data on the spectrum in the region of lesser energies is not manifest in the calculation of total energy losses of electrons to the ionization below 95 km, since the electrons with energies < 40 kev are practically totally absorbed in the air layer above that level (the thickness of residual atmosphere above 95 km, $d \sim 1$ mg/cm^2).

On the other hand, starting from the well known relations on energy losses by particles of various energies as they traverse atmosphere matter, it is known how the initial spectrum is transformed at the different levels, i. e., it is known how particle "creep" takes place by the spectrum from the region of higher energies (≥ 40 kev) to the region of lower energies.

In other words, carrying out such calculations and taking into account that for the creation of a pair of ions in the air, an energy of about 35 ev as an average is prerequisite, we obtained the altitude dependences of the rate of ion formation in the atmosphere (number of pairs of ions per cm^3.sec), conditioned by the registered corpuscular radiation (curve 1, Fig.2). The boundaries of the hatched region correspond to extreme assumptions concerning the index of the energy spectrum of electrons, $\gamma = 2 \div 4$.

Plotted in Fig.2 are also the data borrowed from ref.[1], on the rate of ion formation for middle latitudes at the expense of X- and ultraviolet radiations of the Sun, on the L_α absorption line of NO, and also on cosmic rays (respectively curves 2, 3, 4).

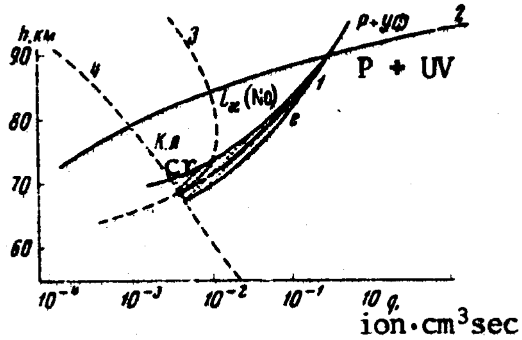

Fig.2

It may be seen from Fig.2 that above 95 km and below 65 km, the main sources of ionization are respectively the X-ray, the ultraviolet radiations and cosmic rays. In the intermediate region, the corpuscular radiation is prevailing.

The conducting of further investigation of the latitude and longitude dependences, and also of the daily effects of corpuscular stream intensity and their temporal variations may possibly lead to the requirement of revision of the existing representations on the basic formation mechanisms of the lower ionosphere.

The author extends his thanks to E. G. Shvidovskiy for the useful discussions and his interest in the work.

**** T H E E N D ****

Manuscript received on 26 April 1966

Contract No.NAS-5-12487
VOLT TECHNICAL CORPORATION
1145 19th St.NW
WASHINGTON D.C. 20036.
Tel: 223-6700; 223-4930

Translated by ANDRE L. BRICHANT

on 2 May 1967

REFERENCES

1. M. NICOLET. Aeronomiya. Izd-vo 'MIR", 1964.
2. R. BOURDEAU (R. BURDO). UFN, T.87, vyp.4, 659, 1965.
3. PR.S. NARCISI, A. D. BAILEY. J.Geophys. Res. 70, 15, 3687, 1965.
4. G. S. IVANOV-KHOLODNYY. Geom. i Aeronomiya, 9, 3, 417, 1964.
5. YU. A. BRAGIN. Kosm. Issledovaniya, 5, 3, 1967. (still in press)
6. V. F. TULINOV. Tr.Tsentr.Aerolog.Observ. No.77, 1967.
7. EXPERIMENTAL'NAYA YADENAYA FIZIKA (EXPERIMENTAL NUCLEAR PHYSICS). Pod red. E. Serge. Izd. I.L. p.143, 1955.
8. V. G. BOBKOV, V. P. DEMIN, I. B. KEURIM-MARKUS ET AL. Radiatsionnaya bez-opasnost' pri kosmicheskihh poletakh. Atomizd.1964.
9. A. A. MOISEYEV, V. I. IVANOV. Kratkiy spravochnik po radiatsionnoy zash-chite. Atomizdat, 1964.
10. T. GUBERNATOR. Zs. f. Phys. 152, 183, 1958.
11. S. FLAMENSFELD. Ib. 156, 179, 1959.