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## Abstract

## Full Text

Physics

V. N. KESSENIKH

# ON POSSIBLE WAYS OF MEASURING THE CONCENTRATION OF SLOW NEUTRONS IN THE $F_2$ LAYER OF THE IONOSPHERE

*(Presented by Academician V. D. Kuznetsov, 28 V 1958)*

One of the grounds for raising the question of the concentration of slow neutrons in the  $F_2$  layer of the ionosphere is the hypothesis of the partial origin of the residual nighttime ionization of this layer under the action of  $\beta$ -decay of neutrons (1-3).

Approximate calculations show that, at a neutron concentration of the order of  $1 \text{ cm}^{-3}$ , the  $\beta$ -electrons arising in neutron decay, having a mean energy of the order of 0.5 MeV, are captured by the Earth's magnetic field and, moving along helical trajectories with a radius up to 70 m, can produce up to  $1.5 \cdot 10^4$  secondary electrons for each primary  $\beta$ -electron. With a neutron half-life of 720 sec. (4) and with a neutron concentration of  $1 \text{ cm}^{-3}$ , the number of primary electrons with energy of the order of 0.5 MeV formed in 1 sec. will be  $10^{-3} \text{ cm}^{-3}$ .

Estimating the minimum number of secondary electrons formed as a result of ionization as 2 orders of magnitude smaller than the number indicated above, we obtain, as a lower limit for the intensity of ionization caused by neutron  $\beta$ -decay in the  $F_2$  layer, a value of the order of  $0.1 \text{ pairs cm}^{-3} \cdot \text{sec}^{-1}$  per 1 neutron in  $1 \text{ cm}^3$ \*. The presence of an ionization source of such intensity should make a clearly measurable contribution to the ionization of the  $F_2$  layer without the principal ionizing factor—solar photon radiation.

For values of the effective recombination coefficient presently accepted as the most reliable for the  $F_2$  layer at night (5) ( $\alpha = 2 \cdot 10^{-10} \text{ sec}^{-1}$ ), the equilibrium value of the electron concentration corresponding to an ionization intensity of  $0.1 \text{ cm}^{-3} \cdot \text{sec}^{-1}$  turns out to be  $2.2 \cdot 10^4$  electrons in  $1 \text{ cm}^3$ . This concentration corresponds to a critical frequency of 1.3 MHz.

If it is assumed that in the upper atmosphere there is constantly acting an ionizing factor due to  $\beta$ -decay of neutrons at a concentration of the order of 1 neutron in  $1 \text{ cm}^3$ , then it should be expected that, when all other ionizing factors are excluded, the minimum values of the critical frequencies of the ordinary ray for the  $F_2$  layer at night should not be below 1 MHz.

\* *Note added in proof.* The indicated calculation is based on an estimate of the

specific ionization at the molecular concentration in the  $F_2$  layer, taken to be  $2 \cdot 10^{10} \text{ cm}^{-3}$ , equal to  $4.5 \cdot 10^{-6}$  ion pairs per 1 m of path at an energy of 0.5 MeV. With this value of the specific ionization and with an energy loss of 35 eV per 1 electron, an energy loss of 0.1 MeV will correspond to a path of the primary  $\beta$ -electron of 635,000 km. Taking into account the helical nature of the  $\beta$ -electron trajectory and the angular distribution of velocities with respect to the direction of the intensity vector of the Earth's magnetic field, the actual number of secondary electrons formed in the  $F_2$  layer proves to be 2 orders of magnitude smaller than the value obtained from energy considerations.

Data from ionospheric observations at the Tomsk ionospheric station over 22 years, i.e., over two solar-activity cycles, including the minima of 1942–1943 and 1953–1954, show <sup>(6)</sup> that the smallest monthly mean values of the nighttime minimum of the critical frequencies of the  $F_2$  layer along the ordinary ray, observed in January 1943, did not fall below 2.0 MHz. Individual values of the nighttime minimum  $f_{F_2}^0$ , observed in Tomsk on particular nights in January 1943, decreased to 0.9 MHz. We know of no materials relating to ionospheric observations in which registered values of the critical frequencies of the  $F_2$  layer below this value were mentioned.

Such ionization sources as photon radiation of the stars <sup>(1)</sup> and cosmic radiation <sup>(3)</sup> are unable to produce in the  $F_2$  region the residual ionization necessary to maintain an electron concentration of the order of  $10^4 \text{ cm}^{-3}$ .

Thus, considering the ionosphere as an ionization chamber in which the electron concentration is measured by radiophysical methods, one may assert that the observed level of residual nighttime ionization indicates the presence of an ionization source of as yet unknown origin. If it is assumed that this ionization source is the  $\beta$ -decay of neutrons, then, in order to test this assumption, there arises the need for a direct measurement of the neutron concentration of the order of 1 neutron per  $1 \text{ cm}^3$ , using direct methods of detecting and counting slow neutrons.

The method for measuring the slow-neutron component of cosmic rays using unshielded counters with  $\text{BF}_3$ , enriched with the isotope  $_{5}\text{B}^{10}$ , used, for example, by Soberman <sup>(7)</sup>, makes it possible to measure neutron fluxes with confidence at a density of  $0.1 \text{ s}^{-1} \cdot \text{cm}^{-2}$ . On this basis one may assert that a neutron counter installed on an artificial Earth satellite should register a volume concentration of slow neutrons of the order of  $1 \text{ cm}^{-3}$  as a flux with density  $8 \cdot 10^5$  neutrons per 1 s per  $1 \text{ cm}^2$ , relative to the velocity of motion of the counter in the assumed neutron atmosphere.

If the sensitivity of such neutron counters is taken to be  $0.1 \text{ s}^{-1} \cdot \text{cm}^{-2}$ , then a neutron detector installed on an artificial Earth satellite should respond to neutron concentrations of the order of  $10^{-6}$ – $10^{-7}$  neutrons per  $1 \text{ cm}^3$ . Although a neutron concentration of the order of  $10^{-7}$  will no longer appreciably affect the residual ionization of the  $F_2$  layer of the ionosphere, even this concentration will be sufficient to obtain distinct counts from  $\text{BF}_3$  neutron counters installed

on an artificial Earth satellite.

The first attempts to estimate the neutron concentration at altitudes of 200–300 km were made by us <sup>(3)</sup> on the basis of the assumption that the main source of neutrons in the upper atmosphere is a layer at an altitude of 10–30 km from the Earth's surface, in which neutrons are generated from light atmospheric nuclei in nuclear reactions occurring under the action of primary cosmic particles and products of nuclear-cascade processes <sup>(8)</sup>.

The neutron counting rate measured by Soberman <sup>(7)</sup> and others corresponds to the number of neutrons generated through the entire thickness of the troposphere and stratosphere with a frequency of 2–3 per 1 s per 1 cm<sup>2</sup>. If it is assumed that even all the neutrons generated in this region have time before their decay to penetrate into the  $F_2$  region of the ionosphere, then for a column 100 km thick such a number of neutrons entering per 1 s per 1 cm<sup>2</sup> will maintain an average neutron concentration at the level of  $10^{-4}$  cm<sup>-3</sup>. However, as we have seen, a neutron counter installed on an orbital platform moving at a speed of  $8 \cdot 10^5$  cm · s<sup>-1</sup> should in this case register a flux of the order of 80 per 1 cm<sup>2</sup> in 1 s, which is almost 800 times greater than the flux density measured by Soberman at altitudes of 10–25 km.

The considerations presented indicate the possibility of measuring neutron concentrations down to  $10^{-7}$  cm<sup>-3</sup> by means of unshielded counters with BF<sub>3</sub>, mounted on orbital installations moving in the upper atmosphere.

Obtaining direct data on the neutron concentration in the upper atmosphere is of great importance for investigating the dynamics of the neutron component of the Earth's atmosphere and its possible role in the residual ionization of the ionosphere.

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

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