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G.S. IVANOV-KHOLODNY

THE ROLE AND THE SOURCE OF PARTICLES IN IONOSPHERE AND AURORAL FORMATION

(Survey)

Corpuscules of various kinds were found in the upper atmosphere by means of rockets and satellites. Recently many papers on this question have been written. They are investigated by different methods and in various aspects. The present survey deals only with corpuscular fluxes, which consist of electrons and penetrate into a considerable atmosphere depth. These, corpuscular fluxes are likely to be of great importance in causing ionosphere events and aurorae. While studying such corpuscular fluxes there arise principle questions, concerning their source and origin, electrons acceleration, and conditions of their penetration into the atmosphere what is connected with the ionization (phenomenon, [illegible] and [illegible] of the atmosphere. Many of these important problems has not been solved yet, therefore it is of great importance to drew attention to them.

The first problem of the upper atmosphere physics in the [illegible] was the explanation of aurorae. However the problem is still not solved though many questions connect with the upper atmosphere, which were raised not long ago and some of them quite recently, has been solved. Aurorae have their maximum [illegible] and intensity in the region of

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20-25° just round the geomagnetic poles, but they differ greatly in form, their slight glow is sometimes observed at a rather low latitudes /I,2/. It was observed long ago, that intensive aurorae occur approximately a day after solar flare and generally aurora activity correlates with solar activity Thus aurorae are the display of solar activity. On the other hand, aurorae occur simultaneously with geomagnetic storms and sometimes they cover vast regions of the Earth, what makes us consider them to be a global geophysical phenomenon. These features stipulated the search of a theory, which might have explained aurorae by means of charged corpuscules fluxes, coming to the Earth from the Sun. The first such theory was worked out by Birkeland and then developed by Störmer and Vegard. The theory seemed to give a good qualitative explanation to auroral zones location and their connection with geomagnetic disturbances. The trajectories of charged particles motements in the magnetic field were studied in detail. However, this theory in its original form at close examination could not give a satisfactory quantitative explanaliton to such facts as particles spread in the interplanetary medium from the Sun to the Earth, particles ability to overcome the magnetic field and the earth atmosphere, peculiarities of particle effects on the geomagnetic field and nature of the latter variations, and excitation of typical aurorae glows, etc. Chapman, Ferraro and Martyn, Bennett and Hulburt, Alfven, Vetukhov and other developed the theory. These theories will not be discussed here as their rather detailed criticism survey was recently

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given by Chamberlain /3/. Owing to great difficulties, arouse while explaining aurorae and geomagnetic disturbances by dire effect of comparatively slow solar corpuscules, other theories were suggested, which consider charged particles acceleratio in the upper earth atmosphere above aurora zone.

Nowadays, it became clear from other different data, that aurorae are excited by electron fluxes with the energy of IO kev and less /4,5/, therefore the theory should explain the origin of such electron fluxes. Apparently, at present the aim of theories of aurorae is to find the acceleration mech mechanism and the source of soft electron fluxes, which excite aurorae, their connection with solar events, geomagnetic storms, and other phenomena.

When earth artificial sattelites and rockets investigations resulted in finding the earth radiation belts, consistin of electron and proton fluxes, which are advanced in high geomagnetic latitudes, naturally, there was made an attempt to connect aurorae origin with these belts.

It is interesting, that a year before the earth radiati belts had been revealed by Singer /6/ while developing a theory explaining magnetic storms and aurorae by shock wave coming from the Sun, suggested a trap mechanism of charged particles in Störmer prohibited according to Störmer region of the earth magnetic field. He indicated herewith that particles

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with small pitch angles could reach deep atmosphere layers and cause aurorae, night air glow, and ionosphere ionization.

After the radiation belts were revealed another sources of their trapped particles were suggested. The most popular was the hypotheses of the belts formation due to albedo neutrons decay, suggested by Singer /7/, Vernov et al. /8/, Kellogg /9/ and Hess /10/. This hypothesis was developed in detail by a numb number of investigators in 1959-1960 /11,12, 13,14/ and later by others.

These investigations resulted in obtaining intensity distribution in space, energy spectrum, and distribution of trapped particles velocities, calculation of their life time and discussion of the most probable ways of particles leakage loss from the radiation belts. It was as well indicated that albedo neutrons decay could be a source of only the inner more stable radiation belt. While considering the connection of the earth radiation belts with aurorae, let us pay attention to hypotheses explaining the outer radiation belt. Note however, that lately Fichella /15/ detected appreciable radiation intensity variations in the inner radiation belt following intense chromospheric flares. These variations are so great, and characteristic time of normal restoration intensity level is so short, that there appear serious grounds doubt that only neutron source contributes to the inner radiation belt.

A good stimulus, but simultaneously a touchstone for theories of the radiation belts origin and particles loss from the belts was the investigation of their connection with aurorae and the earth ionosphere.

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Experimental data on the relation of the radiation belts to AURORAE

One of the re sons which made some of the scientists think of a certain connection between the radiation belts and aurorae (Van Allen /16,17/, Rode /18/) was the detection of the close approach of the aurora latitudes to the outlet of magnetic lines of force from the outer radiation belt. V.I. Krassovsky et al. /19, 20/ connected the occurance of the radiation belts in the high latitudes with the atmosphere heating and expansion above these regions. The electron fluxes measured in the outer radiation belt seemed to correspond to aurora electron fluxes. The first measurements radiation intensity fluctuations in the lower belts /21/ demonstrated that these correlate with solar, magnetic and ionospheric activity including aurorae. It seemed natural, that in course of geomagnetic disturbances, when the general pattern of the geomagnetic field is altered, the particles are able to leave the radiation belts. Penetrating into denser earth atmosphere layers they could cause aurorae (11) and sporadic ionization in the ionosphere. Therefore at first radiation belts due to various qualitative ideas, were considered to be a natural source of aurorae . Then there appeared theories , which connected the outer radiation belts formation with solar corpuscular fluxes, I.S. Shklovsky et al /11/, Dess and Maid /22/,

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S.B.Pikelner /23/, Gold /24/. Though these authors differently treated the problems of particles and plasma clouds consisting of solar corpuscular fluxes trapped by the geomagnetic field, they left unsolved another important problem - energy transfer from slow ions of corpuscular fluxes to fast electrons of the radiation belts.

Further investigations concerned not only theoretical research: specification of the particle trapping and acceleration mechanism on the one hand, and on the other - finding out the mechanism of particles loss from the belts and the particles life time, but also an accumulation of experimental data of the spectrum and intensity of a particles at various altitudes, angular distribution of their velocities, variation with time and correlation with different phenomena. Let us consider these works in detail.

Considerable variations of particle fluxes intensity in the belts during geomagnetic storms are one of the most striking display of close connection of the radiation belts and geomagnetic field. Rothwell's et al. /25/ investigations on Explorer IV and Arnoldy's et al /26/ investigations on Explorer VI convincingly showed, that in the course of a geomagnetic storm development radiation in the belts considerably decreased and after the storm it is not only restored but it became more intensive than before the storm. During the storm the outer radiation belt profile and dimensions are changed as well as the energy spectrum of the particles, which became more rigid, during the storm.

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All this points to the complication of the mechanisms of loss and replenishment of particles of the belts. Alongside the discussion of possibility to peplenish the outer belt due to solar corpuscular fluxes, in /26/ there was made a suggestion, that particle flux variations in the belt could b be connected with variation of atmosphere density at high altitudes during geomagnetic storms, when some processes, accelerating the particles in the atmosphere are intensified. The fact that the upper atmosphere density is controlled by the solar activity /27,28,29,30/, can also give an explanation to the observed in the outer zone radiation intensity variation with solar activity.

When the position of the radiation belts in the earth magnetic field was investigated precisely it was revealed, that magnetic lines of force, going out of the outer radiation belt, reached the latitudes, which did not coinside with auroral regions, the most striking difference was marked in the ~~Southern~~ Southern hemisphere. Thus, only the outmost parts of the radiation belts are able to provide particles to excite aurorae. Certain difficulties arise when one tries to explain aurorae excitation due to ~~[illegible]~~ the particle loss from ~~of~~ the outer belt, as it should be assumed that there is p particles transition from the central part of the zone to

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the outer one. Meanwhile Argus experiments showed, that trapped particle shells appeared to be very stable in time, and particles transmission from one magnetic shell into another one with another geomagnetic latitude is not observed.

The basic assumption, that the intensity and spectrum particles in the radiation belts correspond to the intensity spectrum particles of aurorae, was also tested experimentally Here, it was important to compare corpuscular fluxes measurements, carried out by rockets, at about 100 km altitude with those of the radiation belts, particularly of their lower part Let's consider this problem in detail, as it is of principle importance for the theory, which could give an explanation to the emitation of aurorae glow and ionosphere ionization.

Experimental data Concerning Corpuscules in the Ionosphere and in Aurorae

Though many experiments were carried out on rockets and satellites, instrumented for penetrating radiation measurement at present only few data of the intensity and energytic spectrum of the corpuscular radiation, penetrating the ionosphere are available. This fact is connected with the following: when the earth radiation belts were discovered all the attention was drawn to the investigation of the maxima of the belts and finding their outer boundaries, because these data were of great importance for estimating radiation hazard for space flights (compare /36/). In the present survey on the contrary we are interested in the lowest part of the radiation zones, penetrating into the ionosphere and

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interacting with it. The ionosphere and aurorae are situated considerably lower than the belt maximum, which is situated at about 3000-4000 km altitude above the equator, and in the high latitudes - lowers up to ~500 km.

Van Allen and his collaborators were the first who by means of rockets in 1953 found corpuscular radiation in the upper atmosphere at comparatively low altitudes (~100 km). Penetrating radiation was recorded by means of relatively thick-walled (0.1 - 0.4 g/cm^2). Geiger counters at the ~ 50 km altitude in the polar region by Meredith, McDonald, Ellis, Van Allen et al./37,38,39/. The authors believed that there were recorded only electrons with the energy of >1 Mev their flux being (according to the isotropic assumption) ~ 10 - 20 electrons/cm^{2}sec. These results were confirmed by the data, obtained with the use of a scintillation counter /42/. At low altitude of about 50 km corpuscules effect only slightly contributed to the cosmic ray background, but at the 100 km altitude a thin - walled counter recorded radiation 5 times as intensive, as cosmic rays. The investigations of 1953-1955 showed that the corpuscular radiation fluctuates with time very much, it has clearly pronounced latitudinal variations with their maximum at the geomagnetic latitude 65-70°, i.e. coincide with the maximum zone of aurorae. This proved that corpuscules had electric charge.

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Further investigations by Van Allen carried out by means of scintillation counters /43,44,45/ showed that the primary corpuscular radiation consisted of electrons with the energy, mainly, 10-100 kev (at least < 200 kev). In the corpuscular radiation zone maximum the electron flux was 10^6-10^8 electrons/cm^{2}sec (energy flux 1-0.01 erg/cm^{2}sec.), these electrons decelerate at the 90-110 km altitudes, and produce bremstrahlung X-ray radiation with the intensity of 10^3 - 10^5 cm^{-2}sec^{-1} reaching the altitudes of about 50 km, and sometimes up to 25 km /46/. L.A.Antonova's et al /47,48/ reported, that a flux of electrons of 1-5.10^{-2} erg/cm^{2}sec steradians, the energy spectrum maximum of which being equal to 10-40 kev, was recorded by means of fluorescent screens with phosphor ZnS(Ag) at the 70-100 km altitudes in the middle latitudes and in the polar region. These results were recently confirmed by T.W.Kasatschevskaya et. al (49), who made measurements at the same altitudes using some other method: thermoluminescent phosphor Ca SO_4 (Mn). In /44/ it was indicated, that corpuscular flux intensity at the period of the maximum solar activity in 1957 was 3 times of that of in 1953-55.

All these experiments, carried out on rockets probably point out that at the 70-100 km altitude there is a permanent electron flux with effective energy - 20-50 kev. The electron flux appreciably fluctuates in time, its variation

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being probably 1-2 order of magnitude. The energy of the flux comes to a considerable value - about 10^{-2} erg/cm^2 sec. steradians, and in the geomagnetic latitude 67° it reaches its maximum about 1 - 0.1 erg/cm^2 sec. stered.

Considerable variation with latitude of the measured corpuscular flux intensity with a sharp maximum at 67° of the geomagnetic latitude, lying in the auroral zones (similar results were obtained for the Southern polar region /45/), and high intensity of the radiation, comparable with the energy which aurorae emitted in the visual part of the spectrum made Van Allen believe, that it is the corpuscular radiation that causes aurorae and it is somehow connected with them.

Aurorae Electron Fluxes measurements by means of Rockets and Satellites

Intensive corpuscular fluxes /44/, penetrating extremely deep into the atmosphere 745/ were recorded by the rocket fired on 14.VIII-57 into the luminous features of the aurorae.

Then several rockets have been fired into luminous features of aurorae to measure the primary corpuscular flux and its spectrum. The results of ion and electron fluxes measurements in diffusive aurorae forms of intensity class I, carried out on the rocket launched on February 21, 1958 and in the active of the aurorae - on February 25, 1958, were reported in McIlwain's papers /50,51/. Corpuscules with the

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energy ~17 - 20 kev were recorded by means of a scintillation counter with scintillator CsI, in front of which electromagnetic spectral analyser were installed. Electrons were first recorded at the 80 km altitude(the flux was 0.1 erg/cm^2 sec stered) and at the maximum altitude of 120 km the flux was $1.6 \cdot 10^{10}$ electrons/cm^{2}sec . The main part of the energy falls on soft electrons with the energy < 10 kev. Electrons energy spectrum in the energy region of 3-30 kev was equal to $2.5 \cdot 10^9 e^{-E/5 \text{ kev}}$ electrons/cm^{2}sec, and the total energy flux is about 20 erg/cm^{2}sec in the diffusive glow. Besides there was recorded a flux of protons of 80-250 km kev with the following spectrum: $j(>E) =$ $= 2.5 \cdot 10^6 \exp\{-E/30 \text{ kev}\}$ protons/cm^{2}sec stered. and with the total flux ~ $1.5 \cdot 10^7$ protons/cm^{2}sec. Almost monoenergetic electrons flux with the energy about 6 kev and with the maximum flux about $5 \cdot 10^{10}$ electrons/cm^{2}sec steard (~ 2000 erg/cm^{2}sec) /51/ was recorded in the active arc of aurora. Efficiency of electrons energy conversion in light energy emission in the atmosphere is about 0.2 per.cent. This important coefficient makes it possible to estimate electron flux in various aurorae occurences according to visual estimate of their intensity.

Papers by Meredith et al /52, 53/ inform of three rocket launchings into the luminous aurorae arcs on January 25, March 15 and 22, 1958. Geiger counters, proportional, impulse and scintillation counters were installed on the

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rockets. That allowed to measure not only a flux of corpuscules but also their energy spectrum.

When the rocket passed through luminous formations of aurorae a flux (up to 5 erg/cm^{2}sec) of comparatively soft electrons with the energy above 3 kev was recorded. Some data about electrons energy spectrum were obtained in the work: an electron flux with the energy $\geqslant$ 8 kev was 10 times as intense as an electron flux with the energy above 35 kev. Besides, here as well as in /50,51/ there was recorded an ion flux of $\sim 10^5$ particles/cm^{2}sec stered. the energy flux of which was by 2 orders of magnitude less than that of the electron flux. At the altitudes below 130 - 140 km there was observed the decrease of ion and electron fluxes and disturbance of isotropic angular distribution of particle velocity. It was noticed, that the electron flux above 140 km was not constant and in one of the experiments, had 3 maxima corresponding to 3 moments when the rocket got into auroral rays. Contrary to electrons which were not observed outside the regions of auroral display, ions were found in the upper layers irrespective of aurorae. It is of importance to mark, that up to the 178 km altitude electrons with small energy of 30-1000 ev within the accuracy of 10^9cm^{-2}sec^{-1}stered^{-1} have not been found.

An interesting result has been obtained on Explorer VII /54/. At the 1000 km altitude, when the satellite was passing just above the auroral arc (if the satellite trajectory is projected along the magnetic line of force) there was recorded an extremely powerful corpuscular radiation flux ($\geqslant 10^4$erg/cm^{2}sec

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The recorded corpuscular radiation, as well as in auroral regions, was unusually soft (the ratio j (> 30 kev)/ /j (> 70 kev) was 27:I instead of usual I4:I). Angular distribution of particles velocity was such, that the majority of the particles should have been absorbed in the atmosphere after several hundreds of oscillations (for about a few tens of minutes). Intensive corpuscular flux was also observed, when the satellite was passing above a long and wide aureral arc glowing in the line 6300 Å, the corpuscular radiation intensity decreasing in time in course of the aurora glow dying away.

Recently on Explorer XII and Injune I O'Brain et al /55,56,57/ obtained new important data about trapped particles flux and spectrum in the lower and central parts of the radiation belts. Earlier electron flux values 10^{11} $cm^{-2}sec^{-1}$(E > 20 kev) for the outer radiation belts appeared to be highly overestimated. The most recent data about the electron flux j measurements on Explorer XII and spectrum according to the measurements on Injune I an electron flux with E ≥40 kev comprises $j = 10^6 cm^{-2}sec^{-1}$ and according to one scintillation counter measurements the total energy flux for E ≥I kev is equal to ~10 erg/cm^2sec. sterad., and according to another one - ~70 erg/cm^2sec. sterad. listed in the following Table.

Table I

E kev	≥ 40	45-80	80-110	110-160	160-5000	5000
j $cm^{-2}sec^{-1}$	$\sim 10^8$	9.10^7	8.10^7	$< 10^8$	2.10^5	$< 10^3$

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In these fluxes ~~such~~ was small pitch angles values ~~are true~~, that the majority of those electrons should pass from the 1000km altitude to $\lesssim$ 200 km , and being there absorbed, they cause an aurora. It is likely, that it was those fluxes with which one connected the observed during 1957 almost continuous deffusive aurora, glowing on the whole sky /5/. The value varies considerably with time and geomagnetic latitude, forming a wide peak at $\varphi_m \approx 50^0$ and in the auroral zone. At higher altitudes the spectrum of electrons is as a rule steeper, i.e. here in the electron flux there predominate softer corpuscules. In auroral zones j varies for a few seconds by an order of magnetude, what corresponds to the distance of several tens of km covered by the satellites. It is appropriate to remind that the first investigations of soft corpuscular radiation carried out by Krassovski et.al /58,19, 20/ on the 3d Soviet Satellite by means of a luminescent ~~xx detector~~, revealed just the same peculiarities of corpuscular radiation.

The most suitable instrument, which has been used up till now, and in tended for corpuscular radiation studies, is a luminiscent screen combined with photomultiplier, described by Krassovski, Kushner, and Bordevsky /59/. Measurements with the help of fluorescent screen, made out of ZnS(Ag), which was particularly sensitive to soft electrons were carried out on the 3d Soviet Satellite, where there were obtained valuable results, though satisfactory measurements

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were very few (only one revolution on May 15, 1958), because of the instruments almost all the time were scaled off (60, 58, 19 20/. The threshold of the instrument sensitivity to the electrons (~ 10 kev) was the lowest of all used before. The lowest I intensity has been recorded above the geomagnetic equator in the inner radiation belt at the 1300 km altitude (in the Eastern Hemisphere). If the energy of electrons was about 20 kev, their flux was 10^{-14} a/cm^2 sterad = 6.10^7 electrons/cm^2 sec sterad /19/. On May 15 at night the 3d Satellite passed above the Pacific Ocean at the 1720-1880 km altitude 42-54°S. There was detected both electron intensity and energy variation in the flux with the Satellite revolution and geophysical latitude and very quick (~ 1 sec /60/) ~~temporal~~ intensity variations in time by an order of magnitude. Near the equator the electron energy was ~ 40 kev and in the polar region - it fell up to 10 kev. These experiments revealed, that particles movement direction is normal to magnetic lines of force, what indicates that the particles move along spirials round lines of force. Later disc-like distributions of particles velocities was confirmed by Van Allen et. al /16/ and Holly et. al /61/. The minimum flux recorded in those experiments at low altitudes was equal to about 1 erg/cm^2 sec. But the value was much higher that the particles fluxes, recorded by another methods. These experiments obviously show, that soft electrons possesses the major part of the energy both in the inner and outer radiation belts. In /60,58,19,20/ there were put forward some considerations concerning great [illegible] importance

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of these electron fluxes, capable to induce appreciable heating of the upper earth atmosphere, providing a sharp temperature gradient with height and detected by satellites atmospheric expansion in the polar regions, where flux intensity was higher. Futher investigations confirmed, that the fundamental part of energy in the radiation belts is carried by electrons.

According to new data /56/, electron flux with $E \geq 1$ kev is about 10^{10} erg/cm^2 sec stered, the angles between electron velocities and a magnetic line of force being so small that the majority of electrons should reach the ~ 200 km altitudes and cause aurora. Detailed investigations of angular electrons distribution /57/ indicate, that in various latitudes electron flux with $E > 40$ kev, penetrating the atmosphere, is $\sim 10^4$ cm^{-2}sec^{-1} stered^{-1} and total flux of electrons dumped into the atmosphere in the day-time is about 10 erg/cm^2 sec /56/.

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The problem of Corpuscular Acceleration in the Atmosphere

The obtained results are of principle importance, as they consider the problem of corpuscular origin, auroral and radiation belts particles origin in a new way. Continuous powful particle fluxes at appriciably low altitudes directed into the atmosphere, cannot be the result of the trapped particles loss from the belts. Therefore papers /56, 57/ indicated that it is necessary to assume that there exists a mechanism of their acceleration, located in the ionosphere. Probably the radiation belts are formed under the influence of the same mechanism, when the accelerated electrons enter the magnetic trap trajectory. Earlier Krassovski et.al /58,62/ in connection with the data obtained on the 3d Soviet Artificial Satellite made some consideration concerning soft particles acceleration in the earth magnetic field. Recently by means of the 2d spaceship Vernov et.al /63/ found considerable corpuscular fluxes in the atmosphere and also at the low altitude of 320 km, and declared for the hypothesis of electron local acceleration within the limits of the geomagnetic field.

The hypothesis about particles acceleration in the earth atmosphere caused by one or another process was considered by a number of authors (Alfven, Hayl, Lebedinsky) who tried to give an explanation to aurorae earlier /3/. Fan /64/ and Reid /65/ It was considered mechanisms of electron acceleration by hypothetical local electric fields in the ionosphere, the existence of which is believed to be highly presumable, Kellogg /66/ assumed that while deffusion in the geomagnetic field,

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particles accelerate. Chayashi /67/ considered Fermi acceleration mechanism to be due to hydromagnetic waves. The hypothesis of particles acceleration in the static magnetic field like in an original geocyclotrone, was suggested by Helliwell and Bell /68/. Coleman /69/ considered the effect of inhomogeneous gradually changing geomagnetic field and betatron mechanism of acceleration. Dessler, Hanson /70/ suggested an acceleration mechanism by a shock wave which is produced by a solar plasma entering the earth magnetic field. Singer /71/, Chamberlain /72/, Chamberlain et.al /73/ stated that it is necessary to assume that in the earth atmosphere there exists particles acceleration. A transverse electron acceleration mechanism in the outer part of ionosphere and whistlers was suggested by Parker /74/. Akasofu and Chapman /76,75/ made an attempt to connect geomagnetic disturbances, the radiation belts and the current ring. And they obtained original angular distribution of trapped particles velocity.

L.A. Antonova and Ivanov-Kholodny in papers /77,47,78/ proceeding from the hypothesis that there are corpuscular fluxes in the ionosphere, calculated energy spectrum of electrons producing night ionization. Rather low electron energy ($\gtrsim$ 100 - -200 ev) and steep electron spectrum $d(N/E) \propto E^{-\gamma} dE$, where γ -4.5 were obtained. Various observational data of the spectrum and the calculated spectrum for a quiet ionosphere are compared in Fig.I. These calculations can be carried out if it is assumed that there is an isotropic electron

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velocity distribution in the space. The measurements indicated that there is no isotropy. Taking into account the true velocity distribution one can obtain a variation of the calculated electron energy spectrum as well as another lower boundary spectrum value though the total electrons flux energy value about 1 erg/cm²sec is preserved. One of the displays of the corpuscular electron fluxes is X-ray radiation recorded on balloons. Let us consider experimental data concerning this radiation.

X-Ray in the Upper Atmosphere

Secondary X-ray produced by electrons penetrate deep into the atmosphere up to low altitudes, and this fact makes it possible easily to carry out investigations over a long period of time with the help of balloons. Intensive X-rays event at the level, characterized by the atmosphere depth of 8 g/cm^2 (~28km) has been recorded by Winckler and Peterson /79/ during one of the most intensive aurorae. X-rays intensity with quantum energy 50-80 kev reached 5 mr/h, i.e. 4.10^4 photons/cm^{2}sec (compare /80/). Mechanism of electron ~~radiation~~ deceleration resulting from passing through comparatively dense atmosphere layers was considered by Kellogg /81/, who indicated that when the electron energy is about 50 kev one quantum of X-rays is produced on the average per 10^8 electrons, and as for more energetic electrons the efficiency is higher. According to /82/ the efficiency for electrons with 300 kev energy is equal to 400 electrons/quant. Thus and the base of the observed X-ray flux value one might expect that there are extremely intensive electrons fluxes

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about [illegible] particles/cm^{2}sec in aurorae, what is in agreement with results of direct rocket measurements of the fluxes.

Rather intensive X-ray from aurora, passing through the zenith was observed by Winckler 23.IX.57 /83/ by means of an ionization chamber, installed in the balloon. Winckler estimated an electron flux, producing the observed X-rays of 8.10^9 electrons/cm^{2}sec ($\sim$10^{3}erg/cm^{2}sec) assuming that electron energy was about 100 kev. In the same work it is reported that a flux 50 times as intensive was observed on 13.IX.57. These values are somewhat overestimated, what is connected with some simplifications in calculations, in particular with the lack of precise values of energy spectrum of electrons.

In more recent years Winckler, Anderson, Peterson, Arnoldy et.al carried out numerous experiments with the help of balloons /[illegible],84,85,46,86,87,/. Summarized results of these works are given by Anderson /88/ and Winckler /83/.

The most intensive X-ray fluxes are observed during aurorae /37,43,79,85,86/, and during severe geomagnetic storms /84/. Sporadic X-ray has been observed for several hours with characteristic sharp and rapid intensity fluctuations.

During the magnetic storm on 29.VIII.57 Anderson /82,84/ recorded a flux of X-ray photons 20 photon/cm^{2}sec sterad. with the energy of 100 kev at the altitude characterizing residual atmosphere 1[illegible] g/cm^2. Consequently, taking into account absorption beyond the atmosphere [illegible] the flux should be about 7[illegible] photons/cm^{2}sec sterad. Thus an electron flux beyond the dense atmosphere layers was estimated (at about 100 [illegible] altitudes, to be [illegible].10^5 [illegible] sec.sterad. ($\sim$0.2 erg/cm^2 and even [illegible], if the

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assumed electrons were softer than 300 kev). It is clear that even assuming the comparatively high electron rigidity (see above) rather intensive corpuscular radiation fluxes in the upper atmosphere are obtained, though they are less intensive, than during bright aurorae. It is pointed out in /82, 84/ that the fluxes like in case of an aurora are of highly limited local ~~spectral and temporal~~ pattern, in space and time.

It is of importance to note that often the radiation was not connected with either geomagnetic or solar phenomena. Anderson /98/ indicated that usually X-rays decrease after sunset though it is rather a rule than a law. It was reported, that close to the magnetic pole no X-ray has ever been observed, even during geomagnetic disturbances.

Let us consider in detail X-ray observation results when there are no aurorae and magnetic storms.

During "quiet" periods of time in the polar region X-rays were observed for 30 per cent of the total time of balloons flights /87,88/, though the radiation intensity was 10-100 times less, than during aurorae. The above mentioned radiation was recorded by means of Geiger counters, ionization chamber, and as a result

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of these experiments differentiational photons spectrum was drawn up, which apparently was a reflection of the primitic electrons spectrum causing the radiation somewhere at the ~100 km altitudes.

In order to calculate with sufficient reliability according to the observed X-rays the electron flux causing the latter, it is necessary to know this radiation spectrum. Numerous spectrum measurements made by means of scintillation counters in the polar region were reported by Anderson /37,38/. The measurements were carried out in three spectrum regions 45- 95, 95 - 170, and 170 - 340 kev. Taking into account the absorption effect in the atmosphere three typical spectra given in /37, 38/ are well approximated by the formulae $dn(E) = \alpha E^{-\gamma} dE$

where $\gamma = 2.3 \div 2.6$ (see Fig. 4).

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In 1954-1957 X-rays spectrum beyond the auroral zone in the energy region of 200-1000 kev was also measured by Kupperian and Friedman /39/ with the help of scintillation counters, installed in rockets at the 23-114 km altitude. It was found out that with increase of height progressive increase of soft quanta intensity and decrease of rigid quanta intensity occurred in such a way that the total number of quanta remained approximately constant. These detailed spectrum measurements data at the 42-57, 66-7[illegible], and 110-114 km altitudes which give coinciding results in the energy region of 50-300 kev, are given in Fig.1. For 100-300 kev energy these results coincide with Anderson's measurements data /87,88/ however in the region of $E < 50$ kev they are not in agreement. Probably the data /88/, obtained in the polar region in the period of X-ray increase, reflected a peculiarity of the phenomenon, during which there occurs an additional intensity increase of particularly soft radiation.

It should be taken into account, that in the region of 100 -300 kev the data /88/ are by an order of magnitude higher, than those of /89/.

Thus, the abovementioned experiments show, that there is considerable X-ray radiation, the intensity of which greatly increases towards the small energies about 10-20 kev, in the upper atmosphere. These fluxes become more intensive during auroral and geomagnetic storms. Comparing these data with rocket observations of electron fluxes at the 100 km altitude it is easy to come to the conclusion that in the atmosphere there exists permanently sufficiantly intensive electron flux which

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reveals itself particularly due to deceleration electron radiation when they penetrate into relatively dense atmosphere layers at the ~ 100 km altitude.

Corpuscular flux intensity

The first corpuscular radiation data in the low parts of the radiation belts, were obtained by means of Geiger counters, designed for investigation of cosmic rays and therefore they were not sensitive to comparatively soft radiation being, as it was later found out the fundamental part of corpuscular radiation. Therefore the first observations gave underestimated values of intensity and overestimated values of particles effective energy, and at high altitudes the instruments scaled off both in the first American and Soviet satellites.

It has been already mentioned, that earlier electron flux intensity determinations were overestimated. According to Table I (p.12) the electron flux with energy $E > 40$ kev is about 10 erg/cm^2 sec. And the loss of energy of the flux totals only a migligible part. It is obvious that the flux energy is not sufficient to cause not only intensive aurorae, where electron fluxes with power of hundreds and thousands of erg/cm^{2}sec could be observed, but even weak ones, as here electron flux less scale is 1-10 erg/cm^{2}sec. So, according to O'Brian's et.al observation /56,57/ at the 1000 km altitude in an auroral zone electron fluxes with $E > 1$ kev reach 10-100 erg/cm^{2}sec. and considerable per cent of electrons penetrate into the atmosphere, producing ionization and excitation of atmosphere species at the 100-200 km altitudes. However these general fluxes could not excite

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at aurora, as when the coefficient of conversion of electron flux energy into radiation is about 0.2 per cent (compare with p.19) they produce about 0.02-0.002 erg/cm^{2}sec, what practically be next to impossible to observe at the nightglow background.

On the other hand, investigations of elementary processes in the ionosphere /77,78,90,91/ make it necessary to assume, that in the upper atmosphere there exist electron fluxes of about 1 erg/cm^{2}sec.

Summarizing various experimental data concerning electron fluxes in the ionosphere and aurorae at the 100-1000 km altitudes, let us emphasize some peculiarities of the fluxes, which are applied to the problem: from what regions electron fluxes originate.

Are the radiation belts particles the source of auroral

Experiments showed, that magnetic lines of force from the outer radiation belts approach the latitudes, situated below auroral zones, while corpuscular fluxes intensity maximum coincides with auroral zone at the altitude of 100 km. As a result of investigations on rockets and satellites it was established, that in the ionosphere regions during quiet periods corpuscular fluxes, comparable from the intensity point of view with electron fluxes in the radiation belts are observed. Not to mention highly intensive electron fluxes, causing aurorae one may say that the radiation belts, if we take into account their energy store, are unable to supply even these general

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electron fluxes in the ionosphere, as electron fluxes in the radiation belts are comaprably stable, at least they gradually vary, long-lived and hardly spending their energy. At the same time in the ionosphere below the radiation belts there exist comparatively rapidly varying, local electron fluxes, with considerable loss of energy particularly in the auroral zone. Besides present data testify to the fact that electrons energies spectrum in the radiation belts is probably more rigid and more sloping, than in corpuscular fluxes in the ionosphere and aurorae, in connection with it the latter are absorbed at the 200-300 km altitude (ionosphere) and ~ 100 km (aurorae) while particles from the radiation belts are able to penetrate up to D-layer and should cause ionization and (as a result) radio-wave absorption. It should be noted, that particle fluxes , which cause aurorae, posses, such great energy that the notion of the geomagnetic dipole field is not true for them. In this connection , the fact of coincidence of geomagnetic longitudes and aurorae occurrence moments in both hemispheres, revealed during IGY, needs special explanation. However at present this fact is disputed.

There can be presented some other arguments against the mechanism of formation of electron fluxes, causing aurorae, out of the radiation belts particles but the abovementioned arguments are probably enough. It is worth adding that the discussed in literature mechanisms of particles loss from the

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radiation belts cannot provide a formation of necessary intensive electron fluxes.

Mechanism of Electron Loss from the Radiation Belts

Perhaps, one of the most important problems, to which the theory explaining aurorae by particles of the radiation belts should give an answer, is the problem concerning the way of particles leaving the radiation belts for the atmosphere. As it was mentioned above, favourable conditions for particles loss from the radiation belts arise perhaps in the period of geomagnetic disturbances. There were also suggested another mechanisms of particles loss. Rode /85/, Singer /7/, Inoue et.al /92/ estimated the velocity of the loss due to the impact of particles from the belts with atmosphere particles. A charged particle of the radiation belts has the greatest probability of impact close to the turningpoints where almost every impact leads to the increase of the pitch angle and consequently quickens the particle loss due to absorption in the atmosphere. However this mechanism is rather slow. V.B.Pletnev /93,94/ considered a particle loss due to short--period geomagnetic field variations.

At different distances from the Earth there originate regions of lower intensity of the trapped particles flux, these distances corresponding to the observed data.

Matsushita /95 , 93/ considered a mechanism of electron loss under the ifluence of electrostatic fields, formed in the upper atmosphere during geomagnetic storms. Events like ionisation increase in F-layer, appearence of E_s, increase of $f E_1$ and increase of absorption of cosmic radio noise emission is

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the ionosphere D-layer is connected with penetration of electrons from radiation zones into the atmosphere /90/.

Kern and Vestin /97/ considered particles loss from the belts resulting from instability in the electron belts due to certain lowering of turning-points ~~at the trapped points~~, though the reason for the lowering is still unexplained. As we saw, the discussed mechanisms are not able to give an explanation to the formation of intensive, local rapidly varying soft electron fluxes. The results of investigations of the radiation belts and auroral particles discussed in the given survey show that the radiation belts are unlike to be the source of aurorae. And again there arises a question concerning the source of aurorae. Probably soft electron fluxes quickly loosing their energy, exciting aurorae and the ionosphere are formed in the upperest atmosphere itself at relatively low altitudes. One may believe /77,78/, that electron acceleration results from geomagnetic variations due to the earth magnetic field. However, as it is clear, at present the concrete mechanism of these electrons acceleration has not yet found.

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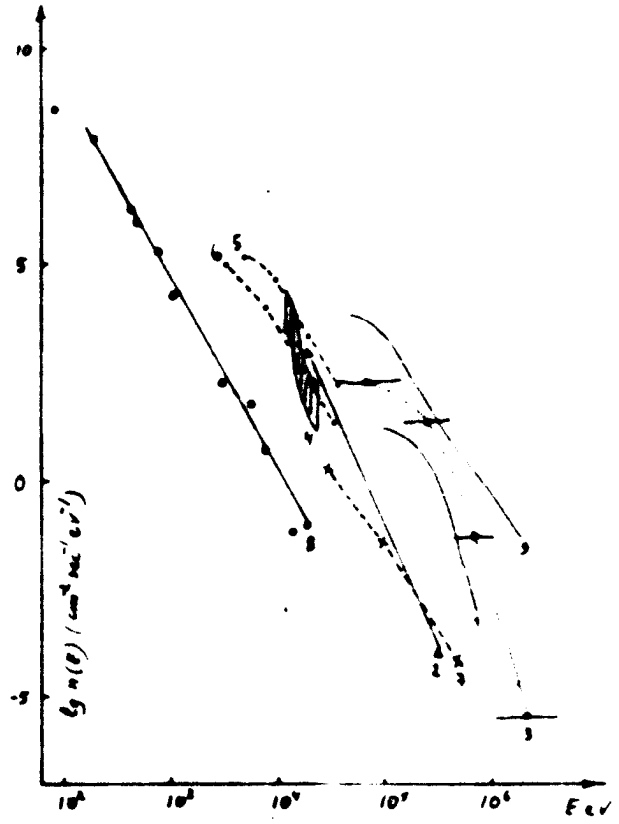

fig 1

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Legend to Fig.I

Fig.I. Energy spectra of electrons:

(I) from data by Cladis et. al. /98/

(2) mean spectrum, computed by Anderson from X "Bremsstr". /88/

(3) from data by Holly and Johnson /6I/ (in relative units)

(4) from data by V.Ihrassovski et al. /20/

(5) from data by McIlwain /5I/

(6) from data by Meredith et al. /52/

(7) computed from data by Kupperian and Friedman /89/

(8) computed /78/

(9) from data by O'Brien et al. /55/

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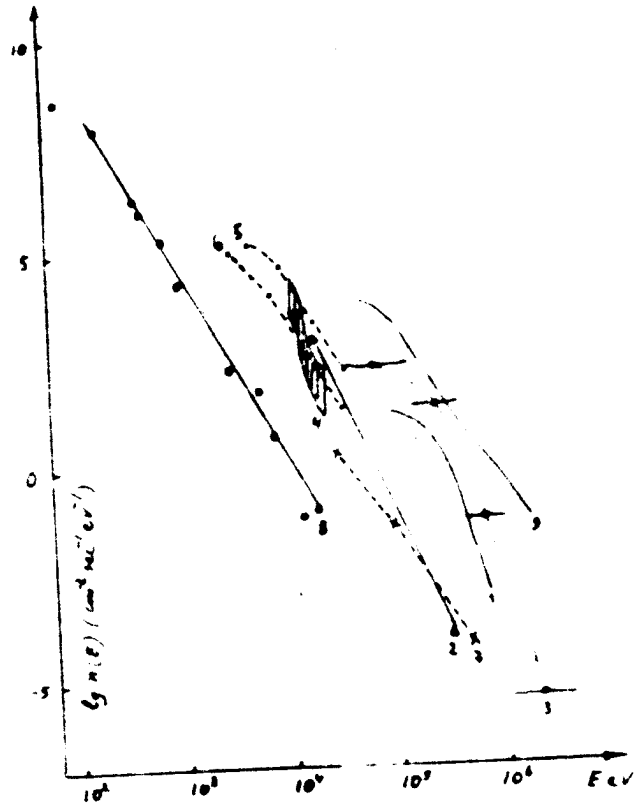

Fig 1

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