https://doi.org/10.18524/1810-4215.2023.36.289978

FLAYERS IN THE PLANETS ATMOSPHERE

D. N. Doikov[1], M. D. Doikov[2]

[1] Dpt of Mathematics, Physics and Astronomy, Odessa National Maritime University, 34 Mechniov str, 65029, Odessa, Ukraine, *dmitro.doikov@gmail.com*

[2] Faculty of Physics and Technologies, Plovdiv University "Paisii Hilendarski", Plovdiv, Bulgaria, *marik.doikov@gmail.com*

ABSTRACT. Planets of the Solar System or exoplanets with atmospheres are complicated to investigate because of the absence of sufficiently intense energy fluxes reflected by their atmospheres. At a sufficiently high brightness of the neighboring star, the atmosphere of the exoplanet gives the absorption spectra of some molecules with a high dissociation potential. If the star's surface temperature is low enough and its activity is low, then the presence of thunderstorm activity in the planet's atmosphere can make it possible to identify it. We show the processes that lead to the formation of flare spectra in the γ- and optical ranges and ways to identify them. It is important to note that current discharges initiate intense nuclear transformations with the formation of proton-rich C11, N13, and O15 nuclei. The spectrum of such a medium is specific and different from the spectra formed by the neighboring star. The statistical irregularity of the frequency of thunderstorms and the variety of conditions in the atmospheres of planets makes it possible to study them due to their illumination in the optical part of the spectrum. It is shown that the integrated optical flow and the detailed γ-spectrum make it possible to trace the time evolution of the lightning head current cord and obtain quantitative values of the current strength. Such fluctuations of the current give changes in the magnetic field of the filament, comparable with the value and even greater than the intrinsic magnetic fields of the planets. To carry out the proposed research, M. Doikov developed a multichannel spectrograph consisting of a γ- and optical spectrometer, a highly sensitive magnetometer, and a radio wave recorder. Its design is discussed in his report. We also note here that the calculations make it possible to determine the statistical parameter of time signals, the operating modes of the equipment, and the selection of the necessary nodes for designing the final working layout of the multichannel spectrometer. The value of the choice of observation site is indicated. In mountainous areas, these are heights of the order of a kilometer. In this case, the devices are near lightning.

Keywords: γ- and optic ray spectra, lighting in planet and exoplanet, rapid nuclear processes, induce γ-ray spectroscopy, positron spectroscopy.

АНОТАЦІЯ. Планети Сонячної системи або екзопланети з атмосферами складні для дослідження через відсутність достатньо інтенсивних власних потоків енергії, відбитих і розсіяними атмосферами. При досить високій яскравості сусідньої зорі атмосфера екзопланети дають спектри поглинання деяких молекул з високим потенціалом дисоціації. Якщо температура поверхні зорі низька і активність мала, тоді наявність грозової активності в атмосфері планети може дозволити її ідентифікувати. Показано процеси, що призводять до формування спектрів спалахів в γ- та оптичному діапазонах та способи їх ідентифікації. Зроблено дослідження струмових розрядів, які ініціюють інтенсивні термоядерні перетворення з утворенням багатих протонами ядр C11, N13 і O15. Доведено, що спектри такого середовища специфічні і відрізняються від спектрів, утворених сусідньою зорею. Отримано, що статистична нерівномірність частоти гроз і різноманітність умов в атмосферах планет дозволяє вивчати їх завдяки їх освітленості в оптичній частині спектру. Показано, що інтегральний оптичний потік і детальний γ-спектр дозволяють простежити часову еволюцію струмового шнура блискавки та отримати кількісні значення сили струму. На малих дистанціях флуктуації струму дають зміни в магнітному полі нитки розрядження, порівнянні з величиною і навіть більші, ніж власні магнітні поля планет. Для виконання запропонованих досліджень, М. Дойковим розроблено багатоканальний спектрограф, що складається з γ- та оптичного спектрометрів, високочутливого магнітометра та реєстратора відстань до блискавок за допомогою радіохвиль. Про його дизайн йдеться в іншої доповіді. Тут також зауважимо, що розрахунки дають змогу визначити статистичні параметри сигналів часу, режими роботи обладнання, та вибрати необхідні вузли для проектування кінцевої робочої схеми багатоканального спектрометра. Вказано значення вибору місця спостереження. Запропоновано розміщувати обладнання у гірських районах де висоти встигають кілометра і вище. У цьому випадку пристрої знаходиться поблизу блискавки і вимірюванні фізичні параметри мало спотворюються атмосферою.

Ключові слова: γ- та оптичні спектри блискавки, блискавки на інших планетах сонячної системі або на екзопланетах, швидкі ядерні процеси, спектроскопія індуційних γ-променів, позитронна спектроскопія.

1. Introduction

In the history of the Earth, thunderstorms took place an important role in the chemical reaction of light gaseous. Until recently, it was believed that lightning had nothing to do with the fusion of nuclei of some common isotopes but was the product of their interaction with cosmic rays. On the other hand, lightning is a classic, widespread source of sharp disturbances in a wide range of radiation from local regions of the current plasma spectrum and different parts of the current cord. With the advent of sensitive spectrometers, fluxes of these radiations began to be recorded in soft γ- and hard X-rays. Of particular interest were the data from the γ-spectrograph placed after control measurements of radiation fluxes from destroyed atomic reactors recorded fluxes of hard quanta during lightning flashes. Moreover, the γ-spectrum indicated the reactions of synthesis of proton-rich nuclei of light elements and contained both positron annihilation products with electrons. It turned out that in atmospheric conditions there are physical conditions for the acceleration of electrons, protons, and helium nuclei – α-particles. The history of consideration of these currents shows that questions has been for electron current components. In our work we drew attention positive ions component in lighting.

The cross sections of nuclear reactions involving protons, He nuclei (α-particles), and Earth atmospheres CNO elements are well studied and presented in the works (Tanaka et al., 1994), (Doikov, 2020). The electrophysical structure of lightning is well-studied. Here we can talk about the characteristic parameters of the electric field of thunderclouds and its structure, and characteristic energies. Potential differences between clouds or clouds and Earth surface are in frame of $\Delta V \approx (10^8 - 10^9)$V, $E \approx 10^6$ V/m, $I \approx 10^5 A$. The given physical parameters of lighting show conditions for the proton, α-particle, and other positive ions acceleration. At sufficient collision energies, reactions occur with the formation of proton-rich nuclei ${}^{11}_{6}C, {}^{13}_{7}N, and\ {}^{15}_{8}O.$ The half-life of the listed isotopes does not exceed 20 minutes. Here we should observe the afterglow in the form of γ-lines from the annihilation of positrons and electrons injected into the environment with energy 0.511 MeV. Collisions between protons and α-particles lead to the formation of a background (continuous) γ-spectrum (Doikov D.N.& Doikov M.D. 2023 in press). For its registration, small times registration equipment is required. The presented processes are also accompanied by optical flayers, bursts of radio waves, and disturbance of the magnetic field near the lightning. The optical spectra are recorded by the binary detector developed in the previous work (Doikov M.D, 2022). In this article has been discussed the integration of a magnetometer, a lightning range finder, and a radio recorder into the already mentioned multichannel structure.

All of the above leads to the need to develop appropriate equipment and plan for monitoring lightning activity in the Earth's atmosphere. In this paper, we consider the possibility of observing lightning and its flare activity on other planets. Especially on exoplanets. For the identification of lightning on exoplanets, it turns out to be useful to have a statistical collection of characteristic parameters of their flashes and their features.

2. The physical structure of lighting

The light in the Earth's atmosphere is a combination of the electron, proton and α-particle currents in the conditioned cylindrical space of the corresponding atmosphere. Under the considered physical conditions, in the first microseconds of the discharge between clouds or between clouds and the Earth, the electron current forms a cylindrical structure of the plasma layer. Such a plasma is kept in a compressed state by the pinch effect and dissipates in a confined space. Unlike classical discharges, in our case the electrons, protons and positive ions acquire relativistic velocities and can initiate nuclear transformations. It is important to note that the electron flow is directed from the Earth towards or between the clouds, while the positive ion flow is in the opposite direction. In the first approach, we will calculate the kinematic properties of the plasma components mentioned, which are important for the following, taking into account the characteristics of the electric field mentioned above. We will spend the characteristic time between two successive collisions, taking into account the external Coulomb force, which is reduced due to the strong acceleration of the particles. The formulae presented in the textbooks have been used only for the estimation of the state in lighting.

2.1. The proton and α-particle flux

For protons $a_p = qE/m_p$, α particles $a_\alpha = \frac{qE}{m_\alpha} = \frac{a_p}{4}$ then the binary collision time is $t_b = \sqrt{\frac{2l}{a}}$. Under the conditions of the Earth's atmosphere, we have $t_b \approx 0.45 \cdot 10^{-10} s$ for protons and $t_b \approx 10^{-10} s$ for α particles. In the main part of the illumination observation the full lifetime is close to 0.1 s. Then, theoretically, each proton and α particle undergoes 10^{10} collisions. The change in speed between the collisions is $10^4\ m/s$. In other words, even taking into account the energy loss due to the ionization of the heavy particles, the protons and alpha particles reach relativistic velocities. In terms of kinetic energies, energies of 20 MeV correspond to a proton velocity of $V_p \approx 6 \cdot 10^7 m/s$. To account for this, we use the Bethe-Bloch formula:

$$-\left(\frac{dW}{dx}\right)_{ion} = NS\ . \tag{1}$$

In illumination $NS \approx 60 - 100\ erg/cm.$ The ionization rates during energy loss are

$$-\left(\frac{dW}{dt}\right)_{ion} = \frac{3}{4}\sqrt{2} c \sigma_{ph} \left(\frac{Mc^2}{W}\right)^{\frac{1}{2}} mc^2 ln\left(\frac{4W}{I}\right) n_e\ , \tag{2}$$

where N – projective ions is the number density in the illumination plasma, z is the charge number of the particle (in our case p or α particles), v_i is the particle velocity, β is the relativistic term $\beta = v_i/c$, $-\left(\frac{dW}{dx}\right)_{ion}$ is the specific ionisation loss over the unit length, I is the mean ionization potential (in eV), I= (13.5 eV) Z≈94eV, and the thermalization times t_I of the fast electrons are:

$$t_I = \int_I^W \frac{1}{-\left(\frac{dW}{dt}\right)_{ion}} dW \approx \frac{3{,}2 \cdot 10^{13}}{n_e} \left(\frac{W}{Mc^2}\right)^{\frac{1}{2}} \frac{W}{mc^2 ln\left(\frac{4W}{I}\right)} \ s \approx 8.57 \cdot \frac{10^{13}}{n_e} s \ . \quad (3)$$

In air, under normal conditions, the free path length is $l \approx 2{,}65 \cdot 10^{-3} cm$. The maximum free path length times of the motion $t_m \approx l/v \approx 10^{-3} cm/4.4 \cdot 10^6 cm/c \approx 0{,}17 \cdot 10^{-9} s$. The time t_m and t_I show that the transition from the non-relativistic to the relativistic regime gives electrons, protons and α-particles time to undergo several thousand collisions to reach relativistic velocities. This allows us to conclude that ionization losses are included with some delay. In this case, we can observe a pure combination of coincidence between inverse Compton, Bremsstrahlung, and synchrotron effects (CBSE).

Elastic collision. Let's start by estimating the energy loss due to elastic collisions that satisfy the Massey criterion. The collision should be described by a formula of elastic processes of particles α and β with masses m_α, m_β The kinetic energies K_α, K_β are suitable to satisfy the third condition. After each collision, energy $\Delta K_{\ \alpha}$ is transferred from particle α to particle β.

$$\Delta K_\alpha = -\frac{m_a m_b}{(m_a+m_b)^2}(1-cosv)\left(K_\alpha - K_\beta\right) \ , \quad (4)$$

where v is the scattering angle for the projectile particle colliding with the target particle β, $b \gg a$. Let $\chi_{\alpha\beta}$be:

$$\chi_{\alpha\beta} = \frac{2m_\alpha m_\beta}{\left(m_\alpha+m_\beta\right)^2} . \quad (5)$$

The$\chi_{\alpha\beta}$ coefficient is called the energy transfer coefficient (or energy exchange efficiency). If the kinetic energy of electrons $K_e \ < 10 \ eV$ and ions $K_i \ < 10^4 \frac{m_i}{m_H} eV$ for protons, then the Massey criterion for proton, α particle-atom collisions is fairly well met. Since Earth's atmosphere consists mainly of CNO element, some single atoms of inert gaseous, we considered targets mainly like ${}^{12}_{6}C, {}^{14}_{7}N, and \ {}^{16}_{8}O$. The source of proton is atmospheric water, of α-particle is single atoms of ${}^{4}_{2}He$ At the beginning the atmospheric gas is ideal gas. Then free path length l in normal condition is $= \frac{1}{\sqrt{2}\sigma n_\alpha} = 7.1 \cdot 10^{-3} cm$, $n_\alpha = 2.65 \cdot 10^{21} cm^{-3}$ is numerical density of atmospheric gas, $\sigma = 3.77 \cdot 10^{-16} cm^2$is average geometrical cross section of typical molecules N_2. At each distance l the homogeneous electric field accelerated ions and added to proton velocities $\Delta V = \sqrt{2qEl/m_p}$ where N is number of intervals after collision with resting atoms or molecules. Then V(N)= NΔV The next step is to calculate the third multiplier in (4):

$$K_p - K_N = \frac{m_p}{2}(N\Delta V)^2 - \frac{m_p}{2}\left((N-1)\Delta V\right)^2 = \\ = \frac{m_p}{2}(\Delta V)^2(2N-1). \quad (6)$$

After replacing in (4) we get:

$$\Delta K_p = -\frac{m_p m_N}{\left(m_p+m_N\right)^2}(1-cosv)\frac{m_p}{2}(\Delta V)^2(2N-1) \quad (7)$$

or for α-particle

$$\Delta K_\alpha = -\frac{m_\alpha m_N}{(m_\alpha+m_N)^2}(1-cosv)\frac{m_p}{2}(\Delta V)^2(2N-1) \, . \quad (8)$$

The next step is averaging over the scattering angles. It should be noted that in the case of intense electric fields, the proton reaches $\Delta V \approx 2.45 \cdot 10^6 cm/s$ or in atomic energy unit $K_p \approx 6.26 \ eV$. already on the first free path. Then the mean value of the multiplier $\overline{1-cosv} \approx 0.25$ The energy transfer coefficient is $\chi_{pN} \approx 0.104$, then $\Delta K_p = 0.109 \cdot 0.25 \cdot 6.26 = 0.17 eV$ when N=1. In the following intervals after collisions with nitrogen atoms, the proton velocity increases, which shortens the characteristic time between collisions. Very quickly, even taking into account the inertia of the collision processes, in a fraction of a microsecond, the processes of acceleration and energy transfer become like an avalanche. Let's see what it looks like in reality. First, we estimate how many collisions must occur to satisfy the Messi approximation. To do this, we substitute the value of the limiting kinetic energy for ions into the left side of the equation, taking into account that we are moving protons and α-particles.

$$10^4 \frac{m_i}{m_H} eV = 0.015 eV(2N-1) \, . \quad (9)$$

From (9) we can see that in order to reach the limits of energies at which the Messier approximation is still performed, collisions must occur. This is the case for $N = 6.67 \cdot 10^5$. This is followed by the ionization loss modes described by the Bethe-Bloch formula (1). However, in this paper we will use a form that is more convenient for solving the problem. At each further step up to proton energies of 10 MeV. The number of collisions in the light guide N=7·10^8 acts without ionization losses. The distance crossed by protons and α-particles along the flash head is 50-60 meters. Crossing time. The definition of the electron crossing time is given in the formula:

$$t = \frac{1}{N}(l/\Delta V) \approx \frac{1.31 \cdot 10^{-10}}{N} \ s \, . \quad (10)$$

Without resorting to plotting the characteristic times of the considered relativistic phase of proton and α-particle motion, we can conclude that all phases of their motion occur almost instantly, compared to the time of a lightning discharge. This means that the rest of the time, which is tens and hundreds of milliseconds, the reactions of nuclear transformations are continuously taking place with the formation of characteristic γ-spectra.

Heavy ions lose a lot of energy in the early stages of their motion, interacting mainly with nitrogen atoms. After passing through 10^5-10^6 collisions, they begin to participate in nuclear interactions, leading to the formation of proton-excess nuclei. Even protons and alpha particles can excite the radiative states of the nuclei of carbon, nitrogen and oxygen (Sigmund, 2014). The result is stimulated gamma radiation. The maximum radiation from the cross-section selection in our previous works is given by the nuclear reaction channel: $\alpha + {}^{14}_{7}N \rightarrow \gamma + \cdots$. presented in Table 1.

Table 1. γ-ray and neutron production cross section

E(MeV)	σγ(P+N14→ →γ+..) mbn	σn(α+N14→ →n+) mbn
7	9298	25,07
8	9635	48,18
9	10060	84,97
10	10540	126,1

2.2. The electron current in lighting

The electric current in lightning is formed in a large spatial slice, is responsible for bursts of electromagnetic energy in different regions of the spectrum, and forms a magnetic field perturbation. The perturbation of the magnetic field is $\Delta B \approx \frac{\mu_o I}{r} \approx 10^{-4}T \approx B_E$Typical currents in lighting are $I \approx 10^4 - 10^6 A$. The maximum time of the magnetic field change is 10 − 100 ms, and $\Delta B_l \approx B_E \approx 10^{-5}T$. The advantage of the detector designed by us is the possibility of synchronized measurements of the magnetic field with accuracy up to one pika Tesla. The induction of electric and magnetic vortex fields generates a wide spectrum of radio emissions. Taking into account the observational data on lightning, in addition to the "classical" radio emission, attention should also be paid to the formation of radio waves of a synchrotron and bremsstrahlung nature. In any case, we are dealing with a continuous spectral distribution. From lightning observations, it is possible to make a realistic estimate of the average velocity by dividing its characteristic scale h by the process time t.

Then we have the average velocity of the electrons $V_e = h/t \approx 10^5 m/s$. In further calculations we take into account that the average angle between the lightning and the direction of the Earth's magnetic field is π/4 rad. Taking into account the non-thermal, directed flow of electrons under the action of an external electromagnetic force, the calculations of the energy losses of electrons for radiation should be divided into two stages. Non-relativistic and relativistic. Observations of lightning storms also show the beginning of a burst of hard radiation before the onset of an electric discharge. That is, before the onset of ionization and the subsequent discharge. The same question arises as in the physics of cosmic rays about the prevalence of the corresponding energy loss mechanism for radiation. First, we consider the strict relations for the energy losses of electrons obtained by Bethe and Heitler (Haykava, 1974) for each mechanism separately. Then we will answer the question about the structure of the radiation produced by each of the given mechanisms. In the same section we will comment on the operation of such mechanisms

If electron energies are more than 10 eV the collisions are ruled by quantum mechanics. However, the electron energy will now be determined by the ratio between their energy losses from interaction with air atoms and the increase in kinetic energy as a result of the work of the electric field. In this paper, we single out only those mechanisms that lead to losses due to their radiation during their movement in the Earth's atmosphere. In the "prequantum mechanic regime" have been no more than 10^3 collisions in the air with normal conditions. At this time no observed optical radiation. But after this beginning concurrence between CBSE these effects produced part of the full energetic loss of already fast electrons including pare production, photo effect, and ionization losses. In this and the next sections, we considered only radiation loss and pair production haw the source of the hard radiation from lighting.

"Runaway electrons". The work of the known mechanisms of energy loss of electrons accelerated by an electric field forms the spectrum of secondary electrons. The distribution function of secondary electrons is such that the main part is represented by low-energy electrons. According to (Gurevich, 2001), high-energy secondary electrons form a stream of relativistic electrons called "runaways". The stream of relativistic electrons, unlike the stream of ions, undergoes an avalanche-like increase in its number. Gurevich proposed the dominance of the Bremsstrahlung emission in the γ-quanta background continuum. Another point of view of the statement in the work (Petrov, 2021). It shows that γ-quanta are formed due to the action of the synchrotron mechanism. However, the proof of the operation of such a mechanism can be only a high degree of polarization and a narrow directivity of the radiation pattern.

Bremsstrahlung emission. Bremsstrahlung emission is usually divided into three types of processes. Under the conditions of a lightning discharge, the deceleration (or acceleration) of charges can be caused either by their attraction or repulsion when electrons and ions approach each other, or by their centrifugal acceleration when moving in external magnetic fields (of Earth and sounder storms with lighting). The presence of multiply charged ions in a lightning discharge leads to a certain probability of the formation of quanta with energies comparable to the binding energies of the last filled level. On the other hand, for relativistic electrons, the time of the dipole interaction of an electron with an ion is exactly proportional to the velocity of the electrons. Bremsstrahlung emission of energy from units of plasma volume within a solid angle in a unit frequency interval in units of time (called emissivity) for electrons with Maxwell-distributed velocities.

$$J_v(T) = \frac{16}{3}\left(\frac{\pi}{6}\right)^{\frac{1}{2}} \frac{n_v Z^2 e^6}{m_e^2 c^3}\left(\frac{m_e}{kT}\right)^{\frac{1}{2}} g e^{-hv/kT} n_e n_i = 5.44 \cdot$$
$$\cdot\, 10^{-39}\frac{n_v Z^2 g}{\sqrt{T}} n_e n_i e^{-hv/kT} erg/(cm^3 s\ sr\ Hz)\ , \quad (11)$$

$J_v(T)$ in units of erg/(cm^3 s sr Hz). Where n_v is the refractive index, Z is the ion charge, n_e and n_ia are the electron and ion concentrations, g is the so-called Gaunt multiplier (in the optical range $g \approx 1$,, and in the radio range g≈5-6). The rate of plasma energy loss due to bremsstrahlung is:

$$W = 1{,}43 \cdot 10^{-27} T^{1/2} n_e n_i Z^2 (erg/(cm^3 s)\ . \quad (12)$$

After substitution of the data plasma $n_e \approx 10^{19} cm^{-3}, n_i \approx 10^{19} cm^{-3}, T \approx 10^5 K, Z \approx 6$ we have ≈ $1{,}69 \cdot 10^{16} erg/(cm^3 s)$. The rate change in specific heat energy $\Delta U/\Delta t \approx 3{,}66 \cdot 10^{14} erg/(cm^3 s)$. Thus, brems-strahlung losses are the main source of radiation energy and are comparable to changes in heat losses. Together with this, the formula (11) is limited $J_v(T)$ by hard radiation part.

$$J_\nu(T) \approx 0{,}089 \cdot e^{-\frac{h\nu}{kT}} \approx 0{,}089 \cdot e^{-\frac{h\nu}{8.8\,eV}}\ erg/(cm^3 s\ sr\ Hz). \quad (13)$$

The formula (13) consists of a sharp decrease of the bremsstrahlung intensity in the X-ray region. It has been shown that the bremsstrahlung of the electron component of the plasma under lightning discharges does not form γ-spectra. In lightning we have a different situation. First, fast electrons form a directed flow of fast electrons that is self-sustaining in the combined external electric and magnetic fields. In the lightning head, the electric field gradient is so large that the electron flow reaches relativistic velocities in 0.1 ns, but the avalanche-like ionization has not yet begun. The direction of the electron flow is maintained by two independent factors. The constancy of the direction of the electric field strength and the pinch effect. In this case, the angle between the electric field and the mean magnetic field will be 45 degrees. The energy loss of electrons due to bremsstrahlung without magnetic field and with magnetic field (magnetic bremsstrahlung) is considered separately. In this case, the energy loss is represented by the classical textbook relation (Sigmund, 2014):

$$\begin{cases} -\left(\frac{dE}{dx}\right)_{br}^{rad} = \int_0^{E-mc^2} \frac{N}{A}\sigma_r(E,k)kdk \\ = 4\frac{N}{A}z^2\alpha r_e^2 E\cdot\left(ln\frac{2E}{mc^2} - 1/3\right) \\ mc^2 \ll E \ll 137\cdot\frac{mc^2}{Z^{\frac{1}{3}}} \\ or\ 0{,}511\,MeV \ll E \ll 35\,MeV \end{cases} \quad (14)$$

and for the relativistic limit of electron energies bremsstrahlung energy loss is:

$$\begin{cases} -\left(\frac{dE}{dx}\right)_{br}^{rad} = 4\frac{N}{A}z^2\alpha r_e^2 E\left[ln\left(191\frac{1}{Z^{1/3}}\right) + \frac{1}{18}\right] \\ 137\cdot\frac{mc^2}{Z^{\frac{1}{3}}} \ll E\ or\ 35\,MeV \ll E \end{cases}. \quad (15)$$

For further calculations, we also need to know the comparative rate of electron energy loss due to bremsstrahlung, synchrotron radiation, and electron energy loss due to the inverse Compton effect.

$$\begin{cases} -\left(\frac{dE}{dt}\right)_{br}^{rad} = 4Z(Z+1)n\alpha v r_e^2\left[ln\left(\frac{2E}{mc^2}\right) - \frac{1}{3}\right]E \\ 0{,}511\,MeV \ll E \ll 35\,MeV \end{cases}, \quad (16)$$

$$\begin{cases} -\left(\frac{dE}{dt}\right)_{br}^{rad} = \begin{matrix} 4Z(Z+1)n\alpha v r_e^2\left[ln\left(\frac{191}{Z^{1/3}}\right) + \frac{1}{18}\right] \\ 35MeV \ll E \end{matrix} \end{cases}. \quad (17)$$

Where Z is the charge number, α = 1/137, $r_e = \frac{e^2}{mc^2} = 2.82\cdot 10^{-13}cm$, is the classical electron radius, $\alpha = 2\pi\, e^2/hc = 1/137$ the thin structure constant.

When studying the interaction of fast electrons with the atmosphere, it usually turns out that the energy of the detected bremsstrahlung quantum is limited by the time of interaction with the atomic field and the energy of the Coulomb field of the nucleus at distances comparable to the de Broglie wavelength. The potential energy of the Coulomb field near the nucleus on such scales is 1.99-2 MeV. Under lightning conditions, the electron undergoes collisions to reach similar energies without losses due to 10^8 collisions. Taking into account the latter, we have an order of magnitude greater number of collisions is 10^10. In this case, the passage length is 1 km and we conclude that the bremsstrahlung quantum of the electron current forms in the lower part of the illumination. However, the proton current generates γ-quanta in the flash head, but their origin is different and is described in the first part of this article. The ratio of the rate of energy losses caused by bremsstrahlung to the rate of ionization losses using the expressions given in this article leads to the relation

$$\eta = \frac{-\left(\frac{dE}{dt}\right)_{br}^{rad}}{-\left(\frac{dE}{dt}\right)_{I}^{rad}} = \frac{\left(\frac{e^2}{hc}\right)}{\frac{W}{mc^2}}\ . \quad (18)$$

The absence of optical radiation has been observed in classical plasma in the pre-optical period at the beginning of the γ-flash of illumination. In this case, according to the formula, we should assume the absence of ions in the presence of electrons that have already reached relativistic velocities. In the atmosphere under consideration, the times of the main radiative transitions are comparable to the times between two successive collisions, and the excited electronic state is removed by the impact interaction. As shown in this section, in classical collisions the electron loses only 0.1% of its kinetic energy for each collision. In order to reach relativistic speeds, it has to undergo about 1000 collisions under the conditions of the Earth's atmosphere. After that, we have optical flyers of light.

Synchrotron emission.

$$-\left(\frac{dE}{dt}\right)_{s}^{rad} = 6{,}5\cdot 10^{-4}H^2\left(\frac{E}{mc^2}\right)^2 eV/s\ . \quad (19)$$

Maximum power of synchrotron emission of an electron in a single frequency interval and in a unit solid angle:

$$P_\nu = \frac{1{,}6\cdot e^3 H}{4\pi mc^2} = 1.7\cdot 10^{-23}H\ \left(\frac{erg}{s\cdot sr\cdot Hz}\right), \quad (20)$$

where H is expressed in Ersted. The monochromatic radiation decreases at lower frequencies and decreases exponentially at higher frequencies (the hard radiation spectra).

$$P_\nu \sim \nu^{\frac{1}{2}}\exp(-0{,}29\nu/\nu_m)\ . \quad (21)$$

The registration of hard radiation under existing conditions in flash synchrotron radiation according to relation (15) is problematic.

The inverse Compton effect. The relation for this type of energy loss rate:

$$-\left(\frac{dE}{dt}\right)_{c}^{rad} = 2{,}67\cdot 10^{-14}W_{ph}\left(\frac{E}{mc^2}\right)^2 eV\cdot s^{-1}\ . \quad (22)$$

In the high energy range, the main contribution to radiation losses comes from the last two mechanisms. Bremsstrahlung dominates only in the intermediate energy range.

The main result of the performed calculations is the synthetic cumulative spectrum. In the process of energy acquisition, the electron covers a wide range of radiation and radio waves up to X-rays. In this sense, the question of the nature of gamma radiation remains open. Observations of lightning made it possible to register γ quants are formed in a few milliseconds before the ignition. One of the mechanisms responsible for the formation of γ quanta is the formation of electron-positron pairs. As in the case of bremsstrahlung, it is necessary to introduce the parameter ξ, where is the ratio of the energy of the emitted photon k to the kinetic energy E of the incident electron u = k/E (Haykava, 1974). Then:

$$\xi = 100\frac{mc^2}{E}\frac{u}{1-u}Z^{-1/3} \quad . \tag{23}$$

The ξ approximation predicts the desired ionization calculations in the ongoing energy loss calculations. All calculations of the interaction of fast electrons with atomic structures and the appearance of the corresponding radiation produced by the energy losses of electrons for radiation begin with its preliminary evaluation.

Pair formation. In quantum electrodynamics, pair formation is an inverse process of bremsstrahlung of fast electrons. From Detail Equilibrium Principle

$$\sigma_{pair}(k,E) = \sigma_r(k,E)\left(\frac{E}{k}\right)^2 \quad . \tag{24}$$

Then if v=E/k, where E is the energy of the electron created.

$$\sigma_{pair}(k,E) = 4\alpha Z^2 r_e^2 G(k,v) \quad . \tag{25}$$

$G(k,v)$ presented in readable form in (Haykava, 1974). The full cross section after integration of the $\sigma_{pair}(k,E)$ ire in a formula:

$$\begin{cases} \sigma_{pair}(k) = \int_{mc^2}^{k-mc^2} \sigma_{pair}(k,E)dE = 4\alpha Z^2 r_e^2 \cdot \\ \cdot \frac{7}{9} ln\frac{2k}{mc^2} - \frac{109}{54} \\ 3{,}423\ MeV \ll k \ll 35\ MeV \\ \frac{7}{9}\ln\left(191 Z^{-\frac{1}{3}}\right) - \frac{1}{54} \\ 35 MeV \ll k \end{cases} \quad . \tag{26}$$

In the first formula, the left edge of the interval is bounded by the energy values 3.423 MeV. From these relations in 1m is produced 1 positron. In all light channel full number of positrons is 10^7. If position of devices is near current tube the γ-flyers have been detected positrons and γ-quants from annihilation between positrons and electrons.

The mean cross section $\sigma_{pair}(k)$ of pair formation varied in air in the illumination is $10^{-25}cm^2 \le \sigma_{pair}(k) \le 10^{-24}cm^2$. The mean distance of pair formation in air l is $l = \frac{1}{\sigma_{pair}(k)} \approx (10^3 - 10^4)\ cm$. We emphasize that positrons do not annihilate immediately, because they need to experience sufficient deceleration up to thermal velocities. In other words, it is not always possible to attribute γ-flares before a lightning discharge.

In this chapter, we presented the radiation loss of fast relativistic electrons and pair production, and the possible source of γ-ray flashes. From the presented relations the following conclusions can be drawn.

The presence of huge gradients of the potential of the electric field in the places of formation of the lightning head leads to an unusual course of the process of formation of the radiation spectrum before the formation of the lightning discharge itself.

The calculations carried out in the article show that the presence of γ-radiation bursts and the simultaneous absence of an optical manifestation before a lightning discharge indicates that the electrons become ultra-relativistic after a thousand collisions. During this time, the ionized fraction of the gas does not have time to enter the recombination process.

This is possible in the absence of dust fractions and other pollutants, which absorb the electrons that are created and at the same time accelerate the coagulation rate. At the same time, the formation of raindrops is accelerated.

The spectroscopic properties of media that penetrate fast electrons are well studied, and the formulas used are simpler for all energy loss modes considered. In contrast to the extensive list of laboratory physical and extra-atmospheric astrophysical media used in lightning, the applicability of the Maxwell-Boltzmann velocity distribution is not applicable. Namely, all electrons move in one direction in the longitudinal direction, in the transverse direction they are distributed according to Maxwell. At relativistic velocities, the energy fraction of the transverse component of the electron velocities decreases sharply, and all velocities are already in a narrow angular opening. The bremsstrahlung and synchrotron in the ultra-relativistic mode of electron motion in flashes have several peculiarities. They consist in the fact that the possibility and spectrum of synchrotron radiation are limited by the values of the magnetic field of the Earth (or the corresponding planets), while the bremsstrahlung is determined by the influence of the Coulomb field of the nucleus. In the intervals given by us, synchrotron radiation can give rise to soft X-ray quanta. That is, under the conditions considered, synchrotron radiation does not produce γ quanta.

3. The detection in the exoplanets

The existence of a new generation of infrared satellites with its sensitivity is suitable for the search for exoplanets at a new level. In exoplanets with illumination in a short time have been IR excess production. In experiments with exoplanet identification, we propose to use IR photometric observation. The character of short-time IR pulses is specific for energy losses in an exoplanet atmosphere. The very fact of identifying the presence of planetary atmospheres is based on the registration of specific lines of polyatomic and diatomic molecules. These lines are of an electronic vibrational nature. The EXOMOLE project (Giovanna et al., 2007) used this approach and provided valuable information about the presence of polyatomic molecules on exoplanets. The very presence of lightning in planetary atmospheres speaks to their multiphase nature. That is, gas, solid particles and turbulent updrafts are present at the same time. The work function of electrons from the surface of solid particles of methane or its various mixtures with other chemical components of exoplanet atmospheres. The lower the work function emitted from the surface of the solid particle, the higher the probability of electron emission from its surface. In combination with active atmospheric activity, the power of lightning discharges has no fundamental limitations. Of great value in lightning is the backlight, which contains a large amount of scattered radiation. When lightning storms show significant activity, the exoplanet begins to "shine" with much greater intensity in the scattered radiation. The maximum intensity of radiation produced by lightning discharges is in the ultraviolet, as observed in the Earth's atmosphere. The planet Uranium can be used as a standard for the scattering of ultraviolet radiation, the atmosphere is practically composed of CH4 and NH3 molecules. Scattering by other molecules and small particles of different chemical composition is described by the classical Mie theory. Under normal conditions, the intensity of the scattered emission is given by the formula

$$I = \frac{9\pi^2(1-cos^2\theta)}{2r^2\lambda^4}\left(\frac{n_1^2-n_0^2}{n_1^2+2n_o^2}\right)^2 V^2 I_0 \ . \qquad (27)$$

The cross section registers mainly the illumination with $\theta \approx \pi/2 n_1$ are the refractive coefficients. n_0 are the gas phases, V is the molecular volume, $I_0$is the source illumination (from the illumination). The Rayleigh scattering cross section has a simple form:

$$C_s = \frac{8\pi^3(n^1-1)^2}{3N^2\lambda^4} \approx 10^{-17} cm^2 \text{ (For } CH_4) \ . \qquad (28)$$

Within order of magnitude, molecules CN_4, NH_3, C_2H_2, H_2O these same cross sections lead to effective scattering of the. The detected large exoplanets are probably composed of H_2 molecules and He atoms. For the planets of the solar system we used the next molecular data, which are presented in Table 2. The column header is: μ is molar masses n is refractive index. J, S, N, U are Jupiter, Saturn, Neptune, and Uran in percent of the corresponding chemical composition.

Table 2. The optical parameters, percent contention, and molecular data for big Sun System planets

μ(g/mol)	n	J	S	N	U
$\mu_H = 2.06$	1,00139	86%	96%	80%	72%
$\mu_{He} = 4.0026$	1,000035	13,9%	3,26	19%	26%
$\mu_{CH_4} = 16{,}04$	1,000441	0,1%	0,1%	0,1%	2%
$\mu_{NH_3} = 17{,}03$	1,000375	0,1%	0,1%	0,1%	0,1%
$\mu_{N_2} = 28{,}013$	1,000297	0,1%	0,1%	0,1%	0,1%
$\mu_{H_2O} = 18{,}015$	1,33	0,1%	0,1%	0,1%	0,1%

The glow of all planets without exception is due to incoming streams of light energy from external sources. Most of the discovered exoplanets are close to their parent star. This causes large temperature gradients and contributes to the occurrence of intense storms (Helling et al., 2012), (Berger et al., 2010), (Christensen, 2009). The presence of cloud layers in the atmospheres is associated with the upper layers of their exospheres, where the total gas pressure is close to the pressure at sea level on Earth. This causes large temperature gradients and contributes to the occurrence of intense storms. The presence of cloud layers in the atmospheres is associated with the upper layers of their exospheres, where the total gas pressure is close to the pressure at sea level on Earth. The possible presence of lightning in the presence of thunderstorms leads to additional "illumination" of the atmosphere (Wilkins, 2022), (Neuber et al., 2019). In this case, laboratory experiments are of interest, where spectra of spark discharges were obtained in media with the chemical composition shown in the table. Surprisingly, the obtained spectra have a maximum in the ultraviolet and with the presence and emission lines of the marked atoms and molecules. However, the maximum of the energy distribution is in the UV. In this case the Raleigh scattering of the present molecules is sufficient. In order to detect an exoplanet, it is necessary, as a contrast, to create a brightness variability on its surface in a narrow band of the spectrum, which is not characteristic for the variability of a star. The irregularity of the lightning discharge variability has several peculiarities. First of all, we notice their time interval. The structure of the flashes requires a detailed study. In this case, it is interesting to carry out laboratory experiments to obtain spectra of spark discharges in media with the chemical composition shown in the table. Surprisingly, the obtained spectra have a maximum in the ultraviolet and with the presence and emission lines of the marked atoms and molecules. However, the maximum of the energy distribution is in the UV. In this case the Raleigh scattering of the present molecules is sufficient. In order to detect an exoplanet, it is necessary, as a contrast, to create a brightness variability on its surface in a narrow band of the spectrum, which is not characteristic for the variability of a star. The irregularity of the lightning discharge variability has several peculiarities. First of all, we notice their time interval. The structure of flashes requires a detailed study. The sequence of physical processes during the formation of a lightning discharge can have its peculiarities for different chemical compositions of the exoplanet's atmosphere. Usually these are molecules and atoms from a Table 2. As an example, we can note cases of variability in the appearance of molecular lines and bands on a time scale in optical and IR spectral regions. This method requires the development of a new instrumental approach and is beyond the scope of this article.

4. Discussion

Lightning discharges in the atmospheres of planets provide an opportunity for local diagnostics of their state and help to check and calibrate the instruments we are developing. In particular, for a binary detector in the γ and optical ranges, the simultaneous presence of different fluxes was important. The γ-ray lightning spectra discovered by Japanese physicists using detectors at the Fukushima nuclear power plant required detailed consideration of the positron sources. We were involved in the separation of the whole set of channels of nuclear transformations and interactions of relativistic electrons with atmospheric atoms considered in this work and in (Doikov M., 2022). A big surprise was the appearance of a γ-flare, recorded by flashes several microseconds before the start of the discharge and its glow in the optics. The detection and study of this phenomenon required the development of a new generation of multichannel spectrographs. The work of (Doikov M., 2022) is devoted to this problem. At present it has become possible to integrate a commercial optical spectrograph into the design of the detector manufactured by us with access to the speed of LabView for its further synchronization with the γ-detector. Currently, the main efforts are focused on the development of the electronic unit of the mock-up γ-spectrograph. In order to diagnose lightning on other planets, it is necessary to thoroughly study their spectral and photometric variability. The structure of the variability of the energy fluxes, their temporal evolution, and the variability of the brightness of the spectral lines are important for identifying exoplanets with atmospheres with thunderstorm activity. The presence of traces of nuclear reactions involving protons and α-particles makes it possible to reconsider the sources of entry into the atmosphere of the Earth and other planets with thunderstorm activity of isotopes of CNO – elements and new sources of induce γ-ray emissions (Doikov D., 2020) with their participation. The role of lightning in the formation of planetary ionospheric activity should also be reconsidered (Doikov M., 2022). Lightning modulates collective oscillations in the ionosphere at infrasonic frequencies, and these oscillations are recorded by special ground stations. The limited timescales of lightning discharge processes and the energy intervals at which lightning hard radiation is formed provide important information about the environment. Despite the non-relativistic average speed of the electrons of a lightning discharge in the lengths of their one run, their speed quickly reaches relativistic values. According to the second part, the increase in velocity in the non-relativistic regime, taking into account collisions with the main component of the atmosphere with nitrogen molecules and atoms. In the range of ionization and radiation losses of kinetic energy accelerated by an external electric field of a given layer of the atmosphere, it becomes possible to form spectral lines and molecular bands located in the zone of maximum sensitivity of modern spectrographic equipment. The selection and planning of the equipment and observation sites are due to the fact that the base stations are located at relatively high altitudes in the mountainous terrain of the Rhodope Mountains. In particular, the building of the branch of the Faculty of Physics and Technology is located at an altitude of 800 m above sea level. The well-equipped Rozhen Observatory (1800 m above sea level) is also located nearby. In this case, the detection equipment is located near the lightning current, which eliminates the influence of additional distorting factors.

5. Conclusion

This paper considers the motion of relativistic particles in a quiescent atmosphere. Contrary to the results of traditional lightning observations, it was considered that the γ-burst starts before the main optical flash caused by collisions of relativistic electrons. In an external electric field, charged particles accelerate between pair collisions, and the loss of kinetic energy during collisions has the following characteristics Typically, charged particles undergo classical collisions, ionization losses, bremsstrahlung losses, and radiation due to the inverse Compton effect. We have also singled out the energy losses for radiation caused by the production of electron-positron pairs. To determine the efficiency of the kinetic energy losses for γ radiation, we considered the cross section for the production of electron-positron pairs. In this case, the source of γ quanta is the annihilation of newly formed thermalized positrons with thermal electrons. In contrast to the formation of positrons as a result of the decay of proton-rich nuclei, positrons in vapors do not have sufficiently low initial velocities. It takes some time for them to slow down. In our work we have obtained the following results:

1. Starting from zero, the particle moves in a non-relativistic regime with increasing velocity up to 10^5 m/s. γ-rays quants appear only in the relativistic regime of motion. In our case, the appearance of primary γ quants before a lightning discharge can be attributed to the formation of electron-positron pairs and further annihilation of positrons. The calculations performed in the article show small values of the cross sections and the productivity of the γ-quanta.

2. Then, with the onset of a lightning discharge, radiation arises due to the excitation of bound and correspondingly unbound transitions. Mainly the energy distribution in lightning spectra is UV part. Under these conditions, a plasma channel is created along which the accelerated motion of low-energy electrons occurs. Simultaneously, protons, and partially helium nuclei (α-particles) are carried out.

3. After the appearance of the plasma channel, the formation of two currents in opposite directions is shown. Electrons usually move from the Earth's surface toward the clouds or between the clouds. The flow of positive protons and alpha particles toward the Earth or between the clouds. The relativistic electron current should be a source only of background γ-ray quanta after 1 thousand collisions with atmospheric atoms.

4. In this state, after 10 thousand collisions, protons and α-particles acquire relativistic speed and energy and begin to participate in the nuclear transformations of lightning.

5. The currents consisting of the mentioned positive particles participate in nuclear transformations similar to the fission reactions leading to the brewing of proton-rich isotopes. Calculations of the induced γ radiation, carried out in our previous works, have shown that the isotope ${}^{13}_{7}N$ is formed most efficiently by the reaction $\alpha + {}^{14}_{7}N \rightarrow {}^{13}_{7}N + n + \alpha + \gamma$. After the formation of ${}^{13}_{7}N$ the decay is observed in the form of the reaction ${}^{13}_{7}N \rightarrow {}^{13}_{6}C + e^{+}$. Assuming these, we conclude that in illumination is possible to isolate γ-radiation produced by two processes, positron annihilation and the formatted by stimulated emission.

6. The photonuclear reaction with γ-quanta we plan to present in the next paper in volcano lighting.

It should be emphasized that lightning is of interest to us as a natural laboratory for the calibration of monitor-type γ-spectrographs.

References

Berger et al.: 2010, *Ap.J*, **709**, 332.

Christensen et al.: 2009, *Nature*, **457**, 167.

Doikov D.N.: 2020, *Odessa Astron. Publ*., **33**, 28.

Doikov M.D.: 2022, *Odessa Astron. Publ*., **35**, 24.

Doikov D.N., Doikov M.D.: 2023, *Astron. & Astrophys. Trans*. (in press)

Giovanna T., Alfred Vidal-Madjar, Mao-Chang Liang et al.: 2007, *Nature*, **448**, 169.

Gurevich A.V., Zybin K.P.: 2001, *Usp. Phys. Nauk*, **171**, № 11, 1177.

Haykava S.: Origin of Cosmic Rays, M.: MIR, 1974, v. 2, 343 p.

Helling C. et al.: 2012, *PSS Sp.Iss.: Outer Planets*, VIII July 10, arXiv:1207.1907 VI[astro-ph. EP], 8 Jul. 2012.

Neuber T. et al.: 2019, *Science*, **367**, Issue 6474, 183, https://doi.org/ 10.1126/ science.aax3872.

Petrov N.I.: 2021, *Scientific Rep.*, **11**:19824, https://doi.org/10.1038/s41598-021-99336-3.

Tanaka S., Yamano N., Hata K. et al.: 1994, *Proc. of 8th Int. Conf. on Rad. Shielding*, Arlington, April 24-28, 2, 965; Am. Nucl. Soc. Inc. https://wwwndc.jaea.go.jp/ftpnd/sae/acl.html

Sigmund P.: 2014, Particle Penetration and Radiation Effects, v. **2**, Springer., Switzerland, 603 p.

Wilkins A.: 2022, *New Scientists*, 26 May 2022.