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ENERGY DECREASE LAWS AND ELECTRON PRODUCTION RATES IN THE GENERALIZED MODEL OF IONIZATION PROFILES DUE TO THE COSMIC RAY CHARGED PARTICLES IN PLANETARY IONOSPHERES AND ATMOSPHERES WITH 5 ENERGY INTERVAL APPROXIMATION OF THE IONIZATION LOSSES FUNCTION

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Abstract

An analytical and numerical approach for penetration and ionization of cosmic ray nuclei with charge Z in the planetary ionospheres and atmospheres is considered in this paper. The electron production rates are calculated using new formulas, which couple the five main energy intervals in the ionization losses function (dE/dh). This is a five interval function, which performs better approximation of the measurements and experimental data in comparison with previous results for four interval ionization losses function. The geomagnetic cut-off rigidities and the energy decrease laws for the different intervals are used for creation of an intermediate transition energy region, which performs the coupling of the five main intervals in the ionization losses function. A new sixth energy interval for charge decrease in lower energies is taken into account. The case of vertical cosmic ray penetration is considered. The corresponding energy decrease laws and initial energy interval boundary values are evaluated.

Key words: *cosmic rays, ionization model, planetary ionospheres and atmospheres, space weather*

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Energy decrease laws and boundary crossings

The calculation of energy decrease laws over the boundaries of the ionization losses function energy intervals is very important for the creation of improved electron production rate model. The formulas which describe this kind of cosmic ray particles kinetic energy decrease will be derived as follows.

Boundary crossing between energy intervals 1 and 2. We assume that the initial kinetic energy of cosmic ray particles before penetration in the atmosphere is $0.15<E_k<E_a$. Boundary crossing occurs if $\widetilde{h}_2 < \widetilde{h}(h)$. The following condition is fulfilled: $\widetilde{h}(h) < \widetilde{h}_1(E_{21}(h) = kT) + \widetilde{h}_2$ The final energy, corresponding to E_k and $\widetilde{h}(h)$ is $E_{21}(h)$.

$$(1) \qquad \widetilde{h} = \widetilde{h}_1 + \widetilde{h}_2 = \int_{E_{21}(h)}^{0.15} \frac{AdE}{2570 \times E^{0.5}} + \int_{0.15}^{E_k} \frac{AdE}{1540 \times E^{0.23}} =$$

$$\frac{A}{1285}\left(0.15^{0.5} - E_{21}^{0.5}(h)\right) + \frac{A}{1540 \times 0.77}\left(E_k^{0.77} - 0.15^{0.77}\right)$$

The transformed equation which contains the unknown variable $E_{21}(h)$ is the following:

$$(2) \qquad \frac{1285}{A}\widetilde{h} = 0.15^{0.5} - E_{21}^{0.5}(h) + \frac{1285}{1540 \times 0.77}\left(E_k^{0.77} - 0.15^{0.77}\right)$$

The final energy after the CR particles penetration in the atmosphere at altitude h is:

$$(3) \qquad E_{21}(h) = \left[0.15^{0.5} + \frac{1285}{1540 \times 0.77}\left(E_k^{0.77} - 0.15^{0.77}\right) - \frac{1285}{A}\widetilde{h}\right]^2$$

Boundary crossing between energy intervals 2 and 3. The condition $\widetilde{h}_3 < \widetilde{h}(h)$ for fixed $E_a < E_k < 200$ MeV/n causes interval boundary crossing of the energy E_a. The final energy $E_{32}(h)$ after penetration of CR particles at height h for traveling substance path $\widetilde{h}(h) < \widetilde{h}_2(E_{32}(h) = 0.15) + \widetilde{h}_3$ is calculated as follows:

$$\widetilde{h} = \widetilde{h}_2 + \widetilde{h}_3 = \int_{E_{32}(h)}^{E_a} \frac{AdE}{1540 \times E^{0.23}} + \int_{E_a}^{E_k} \frac{dE}{231 \frac{Z^2}{A} E^{-0.77}} = \tag{4}$$

$$\frac{A}{1540 \times 0.77}\left(E_a^{0.77} - E_{32}^{0.77}(h)\right) + \frac{A}{231 \times 1.77 \times Z^2}\left(E_k^{1.77} - E_a^{1.77}\right)$$

Equation (4) is transformed with the purpose to be solved towards the unknown variable $E_{32}(h)$:

$$\frac{1540 \times 0.77}{A}\widetilde{h} = E_a^{0.77} - E_{32}^{0.77}(h) + \frac{1540 \times 0.77}{231 \times 1.77 \times Z^2}\left(E_k^{1.77} - E_a^{1.77}\right) \tag{5}$$

The final energy $E_{32}(h)$ after CR penetration at height h is therefore defined with the following expression:

$$E_{32}(h) = \left[E_a^{0.77} + \frac{1540 \times 0.77}{231 \times 1.77 \times Z^2}\left(E_k^{1.77} - E_a^{1.77}\right) - \frac{1540 \times 0.77}{A}\widetilde{h}\right]^{1/0.77} \tag{6}$$

Boundary crossing between energy intervals 3 and 4. The condition $\widetilde{h}_4 < \widetilde{h}(h)$ causes the interval boundary crossing of the energy 200 MeV/n for initial kinetic energy of particles $200 < E_k < 850$ MeV/n. From the relation $\widetilde{h}(h) < \widetilde{h}_3(E_{43}(h) = E_a) + \widetilde{h}_4$ it follows that

$$\widetilde{h} = \widetilde{h}_3 + \widetilde{h}_4 = \int_{E_{43}(h)}^{200} \frac{dE}{231 \frac{Z^2}{A} E^{-0.77}} + \int_{200}^{E_k} \frac{dE}{68 \frac{Z^2}{A} E^{-0.53}} = \tag{7}$$

$$\frac{A}{231 \times Z^2 \times 1.77}\left(200^{1.77} - E_{43}^{1.77}(h)\right) + \frac{A}{68 \times Z^2 \times 1.53}\left(E_k^{1.53} - 200^{1.53}\right)$$

The transformed equation (7) has the form:

(8) $$\frac{231\times1.77\times Z^2}{A}\tilde{h} = 200^{1.77} - E_{43}^{1.77}(h) + \frac{231\times1.77}{68\times1.53}\left(E_k^{1.53} - 200^{1.53}\right)$$

The corresponding final kinetic energy $E_{43}(h)$ which characterizes the CR penetration in the atmosphere for intervals 3 and 4 from (1) in [1] is:

(9) $$E_{43}(h) = \left[200^{1.77} + \frac{231\times1.77}{68\times1.53}\left(E_k^{1.53} - 200^{1.53}\right) - \frac{231\times1.77\times Z^2}{A}\tilde{h}\right]^{1/1.77}$$

Boundary crossing between energy intervals 4 and 5. This case follows from the condition $\tilde{h}_5 < \tilde{h}(h)$. It is valid for $850<E_k<5000$ MeV/n with the relationship $\tilde{h}(h) < \tilde{h}_4(E_{54}(h) = 200) + \tilde{h}_5$. The penetrating CR particles cross the boundary 850 MeV/n:

(10) $$\tilde{h} = \tilde{h}_4 + \tilde{h}_5 = \int_{E_{54}(h)}^{850} \frac{dE}{68\frac{Z^2}{A}E^{-0.53}} + \int_{850}^{E_k} \frac{dE}{1.91\frac{Z^2}{A}}$$

Equation (10) is solved towards the unknown variable $E_{54}(h)$ which presents the final kinetic energy for this case, namely

(11) $$E_{54}(h) = \left[850^{1.53} + \frac{68\times1.53}{1.91}\left(E_k - 850\right) - 68\times1.53\frac{Z^2}{A}\tilde{h}\right]^{1/1.53}$$

Boundary crossing between energy intervals 5 and 6. The next energetic interval boundary in (1) from [1], which is crossed, has the value 5000 MeV. This case takes place, when $\tilde{h}_6 < \tilde{h}(h)$ and $5000<E_k<5\times10^6$ MeV/n. The condition $\tilde{h}(h) < \tilde{h}_5(E_{65}(h) = 850) + \tilde{h}_6$ is also valid:

(12) $$\tilde{h} = \tilde{h}_5 + \tilde{h}_6 = \int_{E_{65}(h)}^{5000} \frac{dE}{1.91\frac{Z^2}{A}} + \int_{5000}^{E_k} \frac{dE}{0.66\frac{Z^2}{A}E^{0.123}}$$

The final kinetic energy $E_{65}(h)$ is calculated as follows:

$$(13) \qquad E_{65}(h)=5000-1.91\frac{Z^2}{A}\widetilde{h}+\frac{1.91\left(E_k^{0.877}-5000^{0.877}\right)}{0.66\times 0.877}$$

Initial energies for interval boundaries

The initial kinetic energies of the interval boundaries are needed for formation of intermediate transition regions between energetic intervals in the improved cosmic ray ionization model.

***Boundary between energy intervals 1 and 2*: 0.15 MeV/n.** It is assumed that $\widetilde{h}$ generates the condition $E_{0.15,2}(h)<E_a$ in the following expression:

$$(14) \qquad \widetilde{h}=\int_{0.15}^{E_{0.15;2}(h)}\frac{AdE}{1540E^{0.23}}=\frac{A}{1540\times 0.77}E^{0.77}\Big|_{0.15}^{E_{0.15;2}(h)}=$$

$$\frac{A}{1540\times 0.77}\left(E_{0.15;2}^{0.77}(h)-0.15^{0.77}\right)$$

The unknown variable for the initial energy $E_{0.15;2}(h)$ is calculated from (14):

$$(15) \qquad E_{0.15;2}(h)=\left[0.15^{0.77}+\frac{1540\times 0.77}{A}\widetilde{h}\right]^{1/0.77}$$

It creates the upper boundary of the intermediate region between energy intervals 1 and 2 in (1) from [1].

***Boundary between energy intervals 2 and 3*: E_a.** It is assumed that the value of $\widetilde{h}$ generates the condition $E_{E_a,3}(h)<200$ MeV/n in the next equation:

$$(16) \qquad \widetilde{h}=\int_{E_a}^{E_{E_a,3}(h)}\frac{dE}{231\frac{Z^2}{A}\cdot E^{-0.77}}=\frac{E_{E_a,3}^{1.77}(h)-E_a^{1.77}}{231\frac{Z^2}{A}\times 1.77}$$

The initial value of E_a in interval 3 is obtained from equation (16):

(17) $$E_{E_a,3}(h) = \left[E_a^{1.77} + 231\frac{Z^2}{A} \times 1.77 \times \widetilde{h} \right]^{1/1.77}$$

***Boundary between energy intervals 3 and 4*: 200 MeV/n.** It is assumed that the value of $\widetilde{h}$ generates the condition $E_{200,4}(h) < 850$ MeV/n in the next equation:

(18) $$\widetilde{h} = \int_{200}^{E_{200,4}(h)} \frac{dE}{68\frac{Z^2}{A}E^{-0.53}} = \frac{E_{200,4}^{1.53}(h) - 200^{1.53}}{68\frac{Z^2}{A} \times 1.53}$$

The corresponding initial energy $E_{200,4}(h)$ is calculated from equation (18):

(19) $$E_{200,4}(h) = \left[200^{1.53} + 68 \times 1.53 \times \frac{Z^2}{A} \times \widetilde{h} \right]^{1/1.53}$$

***Boundary between energy intervals 4 and 5*: 850 MeV/n.** It is assumed that the value of $\widetilde{h}$ generates the condition $E_{850,5}(h) < 5000$ MeV/n in the next equation:

(20) $$\widetilde{h} = \int_{850}^{E_{850,5}(h)} \frac{dE}{1.91\frac{Z^2}{A}} = \frac{E_{850,5}(h) - 850}{1.91\frac{Z^2}{A}}$$

The corresponding initial energy value $E_{850,5}(h)$ is calculated from equation (20):

(21) $$E_{850,5}(h) = 850 + 1.91\frac{Z^2}{A}\widetilde{h}$$

***Boundary between energy intervals 5 and 6*: 5000 MeV/n.** It is assumed that the value of $\widetilde{h}$ generates the condition $E_{5000,6}(h) < 5 \times 10^6$ MeV/n in the next equation:

$$(22) \qquad \widetilde{h} = \int_{5000}^{E_{5000,6}(h)} \frac{dE}{0.66\frac{Z^2}{A}E^{0.123}} = \frac{E_{5000,6}^{0.877}(h) - 5000^{0.877}}{0.66\times\frac{Z^2}{A}\times 0.877}$$

The corresponding initial energy value $E_{5000,6}(h)$ is calculated from equation (22):

$$(23) \qquad E_{5000,6}(h) = \left[5000^{0.877} + 0.66\times\frac{Z^2}{A}\times 0.877\times\widetilde{h}\right]^{1/0.877}$$

Energy decrease laws in internal regions, corresponding to energy intervals 1-6

These energy decrease laws are used for calculation of the ionization losses and the electron production rate in the internal regions of all 6 energy intervals in (1) from [1]. It means, that both the initial energy E_k and the final energy $E_i(h)$ belong to the corresponding energy interval i, $i\in\{1,\ldots,6\}$ from (1) in [1].

Energy interval region 1. The condition $\{E_k, E_1(h)\}\in[kT, 0.15]$ MeV/n is fulfilled. E_k is the initial energy and $E_1(h)$ is the final energy for this case of energy decrease law.

$$(24) \qquad \widetilde{h} = \int_{E_1(h)}^{E_k} \frac{AdE}{2570\times E^{0.5}} = \frac{A\left(E_k^{0.5} - E_1^{0.5}\right)}{1285}$$

The final energy $E_1(h)$ is calculated from equation (24) as follows:

$$(25) \qquad E_1(h) = \left[E_k^{0.5} - \frac{1285}{A}\widetilde{h}\right]^2$$

Energy interval region 2. The condition $\{E_k, E_2(h)\}\in[0.15, E_a]$ MeV/n is fulfilled. E_k is the initial energy and $E_2(h)$ is the final energy for this case of energy decrease law.

$$(26) \qquad \widetilde{h} = \int_{E_2(h)}^{E_k} \frac{AdE}{1540\times E^{0.23}} = \frac{A\left(E_k^{0.77} - E_2^{0.77}(h)\right)}{1540\times 0.77}$$

The final energy $E_2(h)$ is calculated from equation (26) as follows:

$$(27) \qquad E_2(h) = \left[E_k^{0.77} - \frac{1540}{A}\times 0.77\times\widetilde{h}\right]^{1/0.77}$$

Energy interval region 3. The condition $\{E_k, E_3(h)\} \in [E_a, 200]$ MeV/n is fulfilled. E_k is the initial energy and $E_3(h)$ is the final energy for this case of energy decrease law.

$$\widetilde{h} = \int_{E_3(h)}^{E_k} \frac{dE}{231\frac{Z^2}{A}E^{-0.77}} = \frac{E_k^{1.77} - E_3^{1.77}(h)}{231\frac{Z^2}{A}\times 1.77} \tag{28}$$

The final energy $E_3(h)$ is calculated from equation (28) as follows:

$$E_3(h) = \left[E_k^{1.77} - 231\frac{Z^2}{A}\times 1.77\times \widetilde{h}\right]^{1/1.77} \tag{29}$$

Energy interval region 4. The condition $\{E_k, E_4(h)\} \in [200, 850]$ MeV/n is fulfilled. E_k is the initial energy and $E_4(h)$ is the final energy for this case of energy decrease law.

$$\widetilde{h} = \int_{E_4(h)}^{E_k} \frac{dE}{68\frac{Z^2}{A}E^{-0.53}} = \frac{E_k^{1.53} - E_4^{1.53}(h)}{68\times\frac{Z^2}{A}\times 1.53} \tag{30}$$

The final energy $E_4(h)$ is calculated from equation (30) as follows:

$$E_4(h) = \left[E_k^{1.53} - 68\times 1.53\times\frac{Z^2}{A}\times \widetilde{h}\right]^{1/1.53} \tag{31}$$

Energy interval region 5. The condition $\{E_k, E_5(h)\} \in [850, 5000]$ MeV/n is fulfilled. E_k is the initial energy and $E_5(h)$ is the final energy for this case of energy decrease law.

$$\widetilde{h} = \int_{E_5(h)}^{E_k} \frac{dE}{1.91\times\frac{Z^2}{A}} = \frac{E_k - E_5(h)}{1.91\times\frac{Z^2}{A}} \tag{32}$$

The final energy $E_5(h)$ is calculated from equation (32) as follows:

$$E_5(h) = E_k - 1.91\times\frac{Z^2}{A}\times \widetilde{h} \tag{33}$$

Energy interval region 6. The condition $\{E_k, E_6(h)\} \in [5000, 5\times10^6]$ MeV/n is fulfilled. E_k is the initial energy and $E_6(h)$ is the final energy for this case of energy decrease law.

$$\widetilde{h} = \int_{E_6(h)}^{E_k} \frac{dE}{0.66\times\frac{Z^2}{A}E^{0.123}} = \frac{E_k^{0.877} - E_6^{0.877}(h)}{0.66\times\frac{Z^2}{A}\times0.877} \tag{34}$$

The final energy $E_6(h)$ is calculated from equation (34) as follows:

$$E_6(h) = \left[E_k^{0.877} - 0.66\times0.877\times\frac{Z^2}{A}\times\widetilde{h}\right]^{1/0.877} \tag{35}$$

Electron production rate in 5 energy intervals with charge decrease in the ionization losses function

The improved CR ionization model includes the electron production rate terms in 6 energy intervals of the ionization losses function and 5 intermediate transition region terms between the basic intervals. The lower boundary of integration E_{min} is chosen as the maximum of the atmospheric cut-off and the geomagnetic cut-off rigidity [1, 2]. The case of vertical penetration of cosmic rays is considered. This improved model can be extended to the 3-dimensional case in the Earth environment with introduction of the Chapman function [1, 2], which takes into account the Earth sphericity. Then all possible combinations of initial and final energy intervals of CR penetration must be included.

***Lower boundary of integration E_{min}*:** The following case of lower integration boundary is assumed [1, 2]:

$$kT \le E_{A1}(h) \le E_{min} \le 0.15 < E_a \text{ MeV/n} \tag{36}$$

The next equation presents the corresponding electron production rate. $\rho(h)$ is the neutral density [1], Q is the energy for formation of one electron-ion pair [2]. Formula (1) from [1] is taken into account.

$$q(h) = \frac{\rho(h)}{Q}\left\{2570\int_{E_{min}}^{0.15} D(E)[E_1(h)]^{0.5}dE + 2570\int_{0.15}^{E_{0.15,2}(h)} D(E)[E_{21}(h)]^{0.5}dE + \right. \tag{37}$$

$$1540 \int_{E_{0.15,2}(h)}^{E_a} D(E)[E_2(h)]^{0.23} dE + 1540 \int_{E_a}^{E_{E_a,3}(h)} D(E)[E_{32}(h)]^{0.23} dE +$$

$$231 \times Z^2 \int_{E_{E_a,3}(h)}^{200} D(E)[E_3(h)]^{-0.77} dE + 231 \times Z^2 \int_{200}^{E_{200,4}(h)} D(E)[E_{43}(h)]^{-0.77} dE +$$

$$68 \times Z^2 \int_{E_{200,4}(h)}^{850} D(E)[E_4(h)]^{-0.53} dE + 68 \times Z^2 \int_{850}^{E_{850,5}(h)} D(E)[E_{54}(h)]^{-0.53} dE +$$

$$\int_{E_{850,5}(h)}^{5000} D(E)\frac{dE}{dh}[E_5(h)] dE + \int_{5000}^{E_{5000,6}(h)} D(E)\frac{dE}{dh}[E_{65}(h)] dE +$$

$$0.66 \times Z^2 \int_{E_{5000,6}(h)}^{\infty} D(E)[E_6(h)]^{0.123} dE$$

The ionization losses function in interval 5 with final energies $E_5(h)$ from (33) and $E_{65}(h)$ from (13) is calculated with the following formula:

$$(38) \qquad -\frac{1}{\rho}\frac{dE}{dh}[E_5(h)] = -\frac{1}{\rho}\frac{dE}{dh}[E_{65}(h)] = 1.91 \times Z^2$$

Conclusion

For many practical purposes of space weather, e.g., for the impact of cosmic rays on the ozone layer and formation of clouds in the troposphere, it is important to know precisely the cosmic ray induced ionization, its distributions and its variations with location, time, solar and geomagnetic activity. For this goal mainly two types of models are created: 1) analytical and 2) numerical.

In the present work a generalized *analytical* CR ionization model is proposed. A model of this type can be formed for every altitude, azimuth and zenith angle in the middle atmosphere and the lower ionosphere. Some combinations of energy intervals will arise which will cause the derivation of corresponding new formulas for energy integration in the model of the electron production rate with multi-interval ionization losses function, which was presented in this paper. The full 3D integration with introduction of the Chapman function [1, 2] can then be done which will provide higher accuracy of the electron production rate model. The coupling of the energy intervals of the ionization losses function are done.

The computational procedure will choose logically the respective lower boundary and mathematical expression for third energy integration which corresponds to the ionization losses function energetic interval, the atmospheric cut-off or geomagnetic cut-off rigidity.

The integration over the full altitude-zenith-azimuth surface will be performed with account to the local Chapman function value which corresponds to the travelling substance path for the point which is calculated. These values differ from one another which will increase the number of interval combinations and the complexity of the electron production rate model.

The improved model can be realized on PC [1, 3]. It will possess higher accuracy [1, 4]. It can be applied for practical calculations [4-6]. The cosmic ray flux measurements [7, 8] are taken into account in the improved ionization model. This improved model includes a new 5 energy interval approximation of the ionization losses function, which is more adequate to experimental data [1, 9]. The charge decrease *Z* of particles in the additional second energy interval (interval 2 in (1) from [1]) is taken into account.

The analytical and numerical results in this work are important for the study of solar-terrestrial processes and space weather. Our results can explain quantitatively a lot of interesting phenomena in the terrestrial environment, as for example the appearance of abnormal ionization in the Earth's atmosphere and the lower ionosphere associated with solar cosmic ray flux enhancement on 23 February 1956 [10]. This is the most powerful and the greatest solar proton event which is observed up to now. One first corresponding evaluation of this event is given in the monograph [2].

The second type of CR ionisation models are the *numerical* models and codes. A simulation of extensive air showers with application of the CORSIKA (Cosmic Ray Simulations for KASKADE) programming system is made in [11]. The variation of atmospheric depth profile on different time scales is shown in [12]. The formation of the Pfotzer maximum of the electron production rate from cosmic rays is presented in [13-15]. But these investigations could not explain satisfactorily the first experimental data obtained yet more than 70 years ago.

The cosmic ray intensities in the stratosphere were measured for the first time in 1933 by the group of the Nobel price winner (1923) Robert Millikan [15]. The cosmic ray ionization at high altitudes was determined in 1934 by the group of another Nobel price winner (1927) Arthur Compton [16].

For better agreement between the experiments and the models our group began to model the ionization profiles in the whole atmosphere [17, 18]. Cosmic ray induced ionization rates q produced by galactic cosmic rays (GCR) in the Earth's atmosphere are obtained on the basis of a recent model using Monte Carlo simulations and parameterization of the primary spectrum. The simulations are carried out with CORSIKA 6.52 code using FLUKA 2006 and QGSJET II hadronic interaction subroutines. The energy deposit of GCR proton induced air showers is estimated. The ionization profiles for minimum and maximum of solar activity are calculated on the basis of the previously defined and obtained cosmic ray induced ionization yield function Y and parameterization of the cosmic ray spectrum [19, 20].

For our simulations we used the recent version CORSIKA 6.52 code [21] with corresponding hadronic interaction models FLUKA [22] and Quark Gluon String with JETs QGSJET [23]. The FLUKA 2006 code is used for simulation of hadronic interaction below 80 GeV/nucleon and QGSJET for hadronic interaction above 80 GeV/nucleon, respectively. The choice to use FLUKA hadronic interaction model is based on the recommendation of CORSIKA authors [24]. The hadronic event generator FLUKA is used only for the description of inelastic interactions below energy of several 100 GeV [25]. Within FLUKA these collisions are handled by different hadronic interaction models above, around and below the nuclear resonance energy range.

All these investigations require the efforts of big international collectives and collaborations [26]. One such collaboration is the Working Group 2 of Action 724 to European Co-operation in the field of Scientific and Technical Research - COST 724 "Developing the Scientific Basis for Monitoring, Modelling and Predicting Space Weather".

References

1. Velinov P. I. Y., L. N. Mateev, H. Ruder. Aer. Space Res. in Bulgaria (in this issue)
2. Velinov P., G.. Nestorov, L. Dorman. Cosmic Ray Influence on the Ionosphere and on Radio-Wave Propagation. Sofia, BAS Publ. House, 1974.
3. Press W. H., B. P. Flannery, S. A. Teukolsky, W. T. Vetterling. Numerical Recipes in C++ - The Art of Scientific Computing. Cambridge, Cambridge University Press, 2002.
4. Usoskin I., K. Alanko-Huotari, G. Kovaltsov, K. Mursula. J. Geophys. Res., **101**, 2005, A12108.
5. Johnson R. E. Energetic Charged-Particle Interactions with Atmospheres and Surfaces, Berlin, Springer-Verlag, 1990.
6. Usoskin I. G., G. A. Kovaltsov. J. Geophys. Res., **111**, 2006, D21206.
7. Neher H. V. J. Geophys. Res., **76**, 1971, 1637-1651.

8. Van Allen J. A. Ch. 14 in "Physics and Medicine of the Upper Atmosphere". Univ. New Mexico Press, 1952.
9. Sternheimer R. Interaction of Radiation with Substance. In: Fundamental Principles and Methods of Particle Detection. Methods of Experimental Physics, Vol. V, A. Nuclear Physics, New York-London, Academic Press, 1961.
10. Bailey D. K. Proc. IRE, **47**, 1959, 2, 255-266.
11. Keilhauer B., J. Bluemer, R. Engel, H. O. Klages, M. Risse. Astroparticle Physics, **22**, 2004, 249-261.
12. Wilczynska B., D. Gora, P. Homola, J. Pekala, M. Risse, H. Wilczynski. Astroparticle Physics, **25**, 2006, 106–117.
13. Stozhkov Y. I. The role of cosmic rays in the atmospheric processes. J. Phys. G: Nucl. Part. Phys. **29**, 2003, 913-923 doi:10.1088/0954-3899/29/5/312, http://www.iop.org/EJ/abstract/0954-3899/29/5/312
14. Ziegler J. F. IBM J. Res. Develop. **42**, 1998, 1, 117.
15. Bowen I. S., R. A. Millikan. Cosmic-ray intensities in the stratosphere. Phys. Rev., **43**, 1933, 9, pp. 695-700. http://authors.library.caltech.edu/5451/
16. Compton A. H., R. J. Stephenson. Cosmic-Ray Ionization at High Altitudes, Phys. Rev., **45**, 1934, 7, pp. 441-450, http://adsabs.harvard.edu/abs/1934PhRv...45..441C
17. Velinov P. I. Y., A. Mishev. Compt. rend. Acad. bulg. Sci., **60**, 2007, 5, 495 - 502.
18. Mishev A., P. I. Y. Velinov. Compt. rend. Acad. bulg. Sci., **60**, 2007, 5, 513 - 518.
19. Mishev A., P. I. Y. Velinov. Compt. rend. Acad. bulg. Sci., **60**, 2007, 7, 725 - 734.
20. Velinov P. I. Y., A. Mishev. Compt. rend. Acad. bulg. Sci., **60**, 2007, 9, 947 - 956.
21. Heck D. et al., CORSIKA: A Monte Carlo Code to Simulate Extensive Air Showers. Report FZKA 6019 Forschungszentrum Karlsruhe, 1997.
22. Fasso A. et al., 2003. The physics models of FLUKA: status and recent developments, Computing in High Energy and Nuclear Physics 2003 Conference (CHEP2003), La Jolla, CA, USA, March 24-28, 2003, (paper MOMT005), eConf C0303241.
23. Kalmykov N, S. Ostapchenko, A. Pavlov. Nuclear Physics B - Proc. Suppl **52**, 1997, 17.
24. Heck D. et al., 2003. Influence of Low-Energy Hadronic Interaction Programs on Air Shower Simulations with CORSIKA. Proc. 28th Int. Cosmic Ray Conference, Tsukuba (Japan), 279-282.
25. Heck D. Low-Energy Hadronic Interaction Models. Proc. XIIIth Int. Symp. on Very High Energy Cosmic Ray Interactions, Pylos, Greece (2004) Nucl. Phys. B (Proc. Suppl.), 151, 2006.
26. Usoskin I., L. Desorgher, P. I. Y. Velinov, M. Storini, E. Flueckiger, R. Buetikofer, G. A. Kovalstov. Solar and Galactic Cosmic Rays in the Earth's Atmosphere. Progress Report of Working Group 2 of COST 724 Project. Acta Geophys., **66**, 2007 (in press)

ЗАКОНИ ЗА НАМАЛЕНИЕ НА ЕНЕРГИЯТА И СКОРОСТ НА ЕЛЕКТРОННАТА ПРОДУКЦИЯ В ОБОБЩЕНИЯ МОДЕЛ НА ЙОНИЗАЦИОННИ ПРОФИЛИ ОТ ЗАРЕДЕНИТЕ ЧАСТИЦИ НА КОСМИЧЕСКИТЕ ЛЪЧИ В ПЛАНЕТНИТЕ ЙОНОСФЕРИ И АТМОСФЕРИ С АПРОКСИМАЦИЯ НА ФУНКЦИЯТА НА ЙОНИЗАЦИОННИТЕ ЗАГУБИ ВЪРХУ 5 ЕНЕРГИЙНИ ИНТЕРВАЛА

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Резюме

В настоящата статия е разгледан един аналитично-числен метод за описание на проникването и йонизацията от ядра на космическите лъчи със заряд Z в планетните йоносфери и атмосфери. Скоростта на електронната продукция се изчислява с нови формули, които съчетават петте основни енергийни интервала на функцията на йонизационните загуби (dE/dh). Тя е 5 - интервална функция, която осъществява по-добра апроксимация на измерванията и експерименталните данни в сравнение с предходни резултати за 4 - интервална функция на йонизационните загуби. Геомагнитните прагове на отрязване и законите за намаление на енергията за различните интервали се използват за създаване на междинна преходна област на енергията, която осъществява съчетаване на петте основни интервала на функцията на йонизационните загуби. Въвежда се един нов шести енергиен интервал за намаление на заряда в ниските енергии. Разглежда се вертикално проникване на космическите лъчи. Изчислени са съответните закони за намаление на енергията и началните стойности на границите на енергийните интервали.