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POLAR COUPLING COEFFICIENTS FOR COSMIC RAY MULTIPLE NEUTRONS WITH ENERGIES UP TO 15 GeV

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Values of α and k for polar coupling coefficient functions between 1966—1968 are submitted. They are determined on the basis of geomagnetic effects of the cosmic ray nucleonic component. The geomagnetic latitude dependence of neutrons of the multiplicity 1, 2,...≥6 is approximated by the following analytical expression $N(R_c, h_0) = N(0, h_0)\{1 - \exp(-\alpha R_c^{-k})\}$.

КОЕФФИЦИЕНТЫ ПОЛЯРНОЙ СВЯЗИ ДЛЯ МНОЖЕСТВЕННЫХ НЕЙТРОНОВ КОСМИЧЕСКОГО ИЗЛУЧЕНИЯ С ЭНЕРГИЯМИ ВПЛОТЬ ДО 15 ГеВ

В работе преставлены значения параметров α и k для функции коеффициентов полярной связи за 1966—68 гг. Эти коеффициенты определены на основе геомагнитных эффектов нуклонной составляющей космического излучения. Зависимость нейтронов с множественностью 1, 2,...≥6 от геомагнитной широты апроксимируется следующим аналитическим выражением:

$$N(R_c, h_0) = N(0, h_0)\{1 - \exp(-\alpha R_c^{-k})\}.$$

I. INTRODUCTION

Primary cosmic ray charged particles considerably change their direction of motion when entering into the geomagnetic field. This change is especially considerable in the case of low energy particles. During the transition through the Earth's atmosphere the primary cosmic ray is transformed, it generates secondary particles in dependence on the energy of the primary particles. It means that the individual secondary cosmic ray components are variously sensitive to the primary spectrum energetic intervals. The progress in computing methods from the observed variations to the primary ones at the Earth's atmosphere boundary and searching secondary variations in dependence on the energy of the primary particles made it possible to observe primary cosmic ray variations with the help of the secondary cosmic rays registered by experimental equipment on the Earth.

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In i-th cosmic ray component global intensity (neutronic, mesonic,...) at the point with the threshold rigidity R_c at the atmospheric level with the pressure h_0 can be expressed as

$$N^i_{R_c}(h_0) = \int_{R_c}^{\infty} D(R)\, m^i(R, h_0)\,\mathrm{d}R, \tag{1}$$

where $D(R)$ is the primary particle rigidity differential spectrum, $m^i(R, h_0)$ is the integral multiplicity giving the number of the i-th type particles at the level with the pressure, h_0 generated by one primary nucleon with the rigidity R, R_c is the threshold rigidity $(R = pc/Ze)$.

In principle three factors can be changed: R, $D(R)$, and $m^i(R, h_0)$. Then in the general case we have for the intensity variations $N^i_{R_c}(h_0)$:

$$\delta N^i_{R_c}(h_0) = \int_{R_c}^{\infty} \delta D(R)\, m^i(R, h_0)\,\mathrm{d}R - \delta R_c m^i(R, h_0)\, D(R) + \int_{R_c}^{\infty} \delta m^i(R, h_0)\, D(R)\,\mathrm{d}R. \tag{2}$$

For relative variations:

$$\delta N^i_{R_c}(h_0)/N^i_{R_c}(h_0) = \int_{R_c}^{\infty} \delta m^i(R, h_0)/m^i(R, h_O)\, W^i_{R_c}(R, h_0)\,\mathrm{d}R - \delta R_c W^i_{R_c}(R, h_O) + \int_{R_c}^{\infty} \delta D(R)/D(R)\, W^i_{R_c}(R, h_0)\,\mathrm{d}R, \tag{3}$$

where the functions:

$$W^i_{R_c}(R, h_0) = D(R)\, m^i(R, h_O)/N^i_{R_c}(h_0) \tag{4}$$

are the so-called coupling coefficients between primary and secondary variations. They interpret the registration equipment differential sensitivity to the various energies of the primary spectrum. They are defined for every cosmic ray component registered by some experimental equipment.

The various possible cosmic ray variations connected with Eq. (3) can be divided into three groups:

1st group — connected with the generation integral multiplicity change. Here belong cosmic ray intensity variations of atmospheric origin — meteorological effects (the first term on the righthand side of Eq. (3)).

2nd group — connected with the threshold rigidity change as a consequence of geomagnetic disturbances (the second term on the right-hand side of Eq. (3)).

3rd group — connected with the primary rigidity spectrum change of the particles outside the Earth (e.g. the supplement flow in consequence of particle generation during strong chromospheric flares in the Sun). This is the most considerable variation group of an origin outside the Earth (the third term on the right-hand side of Eq. (3)).

II. POLAR COUPLING COEFFICIENTS DETERMINATION METHOD

Differentiating Eq. (1) according to R_c and using definition (4) for the coupling coefficients we have:

$$W^i_{R_c}(R, h_0) = -\partial \ln N^i_{R_c}(h_0)/\partial R_c. \tag{5}$$

The expression on the right-hand side of the equation represents the cosmic ray i-th component latitude effect. It means that up to energies of ~15 GeV, which are sensitive to the Earth's geomagnetic field for any cosmic ray component, the coupling coefficients can be determined on the basis of geomagnetic data.

From now on the polar coupling coefficients $W^i_0(R, h_0)$ will be used; they are interconnected with $W^i_{R_c}(R, h_0)$ as follows [1]:

$$W^i_0(R, h_0) = W^i_{R_c}(R, h_0)\, N^i_{R_c}(h_0)/N^i_0(h_0). \tag{6}$$

From Eqs. (5) and (6) for $W^i_0(R, h_0)$ there follows:

$$W^i_0(R, h_0) = -\partial\{N^i_{R_c}(h_0)/N^i_0(h_0)\}/\partial R_c. \tag{7}$$

Experimental data of the measured latitude dependence are best approximated by the relation:

$$N^i_{R_c}(h_0) = N^i_0(h_0)\,\{1 - \exp(-\alpha R_c^{-k})\}. \tag{8}$$

Then for $W^i_0(R, h_0)$, using relation (7), there holds:

$$W^i_0(R, h_0) = \alpha k R^{-(k+1)} \exp(-\alpha R^{-k}). \tag{9}$$

From the last relation it can be seen that the coupling coefficients are known if the parameters α and k are known. They will be determined by the least square method. By minimization of Eq. (8) for the parameters α and k one gets:

$$k = n\sum_{i=1}^{n} \ln R_i \ln\ln\{N^i_0(h_0)/[N^i_0(h_0) - N^i_{R_i}(h_0)]\} - \sum_{i=1}^{n} \ln R_i \sum_{i=1}^{n} \ln\ln\{N^i_0(h_0)/[N^i_0(h_0) - N^i_{R_i}(h_0)]\}/\left(\sum_{i=1}^{n} \ln R_i\right)^2 - n\sum_{i=1}^{n} \ln R_i^2, \tag{10}$$

$$\alpha = \exp\left(\sum_{i=1}^{n} \ln R_i \sum_{i=1}^{n} \ln R_i \ln\ln\{N^i_0(h_0) - N^i_{R_i}(h_0)]\} - \sum_{i=1}^{n} \ln\ln\{N^i_0(h_0)/[N^i_0(h_0) - N^i_{R_i}(h_0)]\}\left(\sum_{i=1}^{n} \ln R_i\right)^2 \Big/ \left(\sum_{i=1}^{n} \ln R_i\right)^2 - n\sum_{i=1}^{n} \ln R_i^2\right).$$

III. POLAR COUPLING COEFFICIENTS BETWEEN 1966—1968

In the past few years an electronic apparatus for measuring local multiple neutrons in the producer of the neutron detector was constructed as an improvement of the experimental equipment for the registration of the cosmic ray nucleon component [2, 3, 4]. The apparatus permits to observe neutrons of the multiplicity 1, 2,..., n and to determine by help of Eq. (3) variations of a primary character. For this purpose it is inevitable to know the coupling coefficients for each multiple group. They can be determined by the above described method.

Experimental data used in the analysis were obtained by the Japanese expedition to the Syowa station in the Antarctic [5]. Time intervals used (year, day, month); 1966: 1/–2, 3/12—15/12, 22/12—26/12; 1967: 15/2—28/2, 1/3—7/3, 14/3——29/3, 3/4—18/4; 1968: 19/2—29/2, 7/3—22/3, 28/3—31/3, 1/4—10/4. During the mentioned period no outstanding nonstationary changes were registered by the world neutron supermonitor network in the intensity of the galactic cosmic ray radiation — as Forbush decreases or sudden increases caused by the supplement particle flow from the Sun. Taking into account that short time periods were used in the analysis, the multiplicity $N^i_0(h_0)$ was chosen as the normal level for the considered periods and for the groups of multiple neutrons; this multiplicity corresponds to the registration in the polar region. Thus multiplicity time variations are restricted to the minimum.

The total neutron multiplicity daily averages and the multiplicity of each group of multiple neutrons are corrected with respect to the barometric pressure and the factor connected with the registration of multiple neutrons threshold rigidity R_c [6].

Table 1

	1966		1967		1968	
	α	k	α	k	α	k
N^i	0.82	7.69	0.62	4.92	0.93	10.67
N^{m_1}	0.86	8.13	0.64	4.88	1.00	11.85
N^{m_2}	0.93	9.34	0.67	5.37	1.06	14.15
N^{m_3}	0.87	8.63	0.64	5.66	0.98	12.97
N^{m_4}	0.73	6.86	0.61	5.90	0.84	10.63
N^{m_5}	0.62	6.06	0.45	4.67	0.69	8.01
$N^{m_{\geq 6}}$	0.54	6.53	0.31	4.25	0.63	5.41

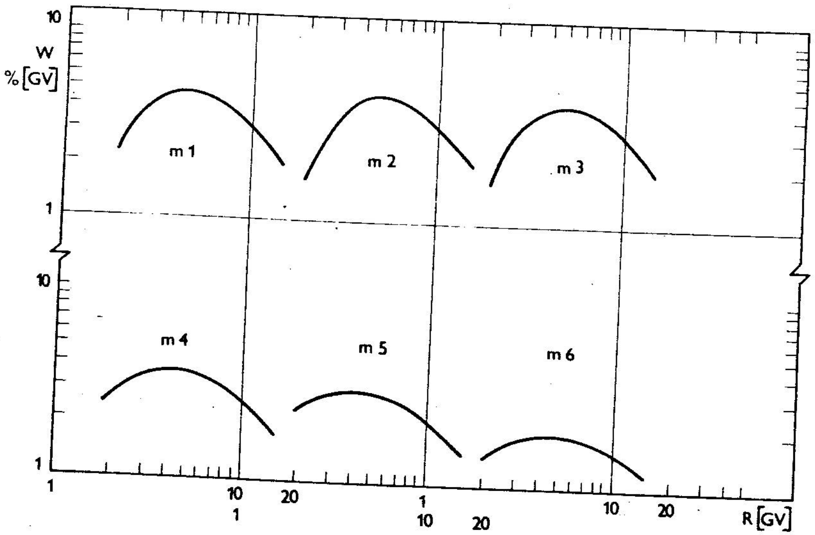

Fig. 1. The latitude dependence polar coupling coefficient functions of neutrons of the multiplicity 1, 2,..., 6 for 1966 year.

The values of the threshold rigidity R for vertically incident particles were computed on the basis of the Finch-Leaton geomagnetic field model and are taken from [7].

The values of the parameters α and k and for the functions of polar coupling coefficients for the total multiplicity N' and the multiplicities of multiple neutrons $N^{m_1}, N^{m_2}, \ldots N^{m\geq 6}$ determined by help of Eq. (10) are listed in Table 1.

The standard deviation of the values α, resp. k, listed in this Table is 0.05, resp. 0.02.

IV. DISCUSSION

From the study of the time variations of the neutron multiplicity $\bar{m} = \sum_{m=1}^{\infty} mN^m / \sum_{m=1}^{\infty} N^m$ in the neutron monitor with sufficient statistics in dependence on the total multiplicity during the period of the Forbush decreases or the intensity increases during solar flares the anticorrelational character of the neutron multiplicity is known [8]. The polar coupling coefficient functions provide the use of the individual multiple neutron group data in the study of primary time variations. Assuming that in Eq. (3) δR_c, $\delta m^i(R, h_0) = 0$, the primary particle

rigidity spectrum can be used in the power from $\delta D(R)/D(R) = aR^{-\gamma}$, and using (6) for the relative variations of the multiple neutrons one gets:

$$[\delta N^i_{R_c}(h_0)/N^i_0(h_0)]\, A^i_{R_c} = a \int_{R_c}^{\infty} R^{-\gamma} W^i_0(R, h_0)\, dR, \qquad (11)$$

where $A^i_{R_c} = N^i_{R_c}(h_0)/N^i_0(h_0)$ are auxiliary functions; the index $i = m_1, m_2, \ldots, m_{\geq 6}$ determines a multiple neutron group. The unknown coefficients a and γ of the primary spectrum can be determined by solving Eq. (11), using pairs of cosmic ray stations with different threshold rigidities.

From the definition (4) there follows the connection between the changes of the coupling coefficients and the change of solar activity. Let $D_{min}(R)$ and $D_{max}(R)$; $N^i_{0\,min}(h_0)$ and $N^i_{0\,max}(h_0)$; $W^i_{0\,min}(R, h_0)$ and $W^i_{0\,max}(R, h_0)$ be primary spectra and multiplicities of individual multiple neutron groups and polar coupling coefficients for periods of the minima and maxima of the solar activity. Assuming that $W^i_{0\,min}(R, h_0)$; $D_{min}(R)$ and $D_{max}(R)$ are known and using definition (4), one gets:

$$W^i_{0\,max}(R, h_0) = N^i_{0\,min}(h_0)\, D_{max}(R)/N^i_{0\,max}(h_0)\, D_{min}(R) [W^i_{0\,min}(R, h_0)].$$

The last expression can be generalized for the determination of the coupling coefficients for an optimal time interval with the help of data observed by the world neutron monitor network.

The computation was done on the computer TESLA 200 using the program COUPCO.

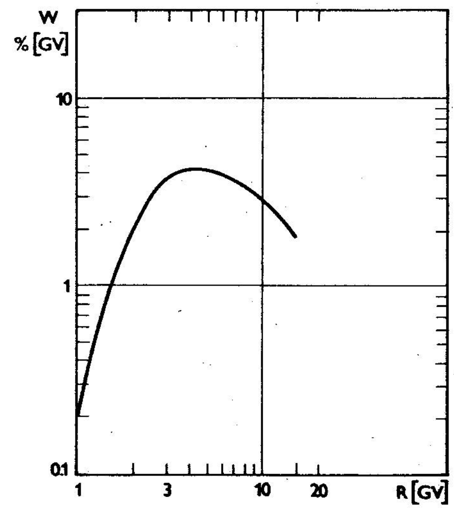

Fig. 2. The latitude dependence polar coupling coefficient function of the total neutron component for 1966 year.

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