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DETERMINATION OF ABOVE-ATMOSPHERE DIMENSIONS OF METEORITES

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SUMMARY

The absence of data on above-atmosphere dimensions of meteoritic bodies and the position of those specimens having fallen on Earth constitutes one of the most essential gaps in our knowledge of meteorites. The only method allowing to evaluate the above-atmosphere dimensions of meteorites is the study of the depth dsitribution of the formation rate of cosmogenous isotopes arising in nuclear interactions of cosmic rays with the meteoritic matter. The accuracy of the assumed method resides mainly in the precision of radiometric methods and the correctness of the adopted hypothesis on the constancy of spatial distribution of cosmic rays in the solar systems. The method is practically applied in the case of the Yardymlin iron shower.

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The basic source of cosmic matter is in meteorites. The matter of meteorites and of their parent bodies, i.e. the asteroids, varied in the course of the time of their existence (nearly 4.5 billion years) to a substantially lesser degree than the substance of the Earth. This is why meteorites constitute the most important source of information about the early stages of formation of solar system's bodies. Moreover, they are the only source of knowledge on temporal and spatial variations of cosmic rays, for the meteoritic matter stores the products of nuclear interactions.

One of the most essential gaps in our knowledge of meteorites is the lack of data on above-atmosphere (or pre-atmosphere) dimensions of meteoritic bodies, and the position of the specimens of these bodies having fallen on Earth. It is known only that a substantial part of meteoritic body invading the terrestrial atmosphere is lost at the expense of the ablation process.

The only method to determine the above-atmosphere dimensions of meteorites is the study of the distribution in depth of the formation rate of cosmogenous isotopes emerging in nuclear interactions of cosmic rays with the meteoritic matter. The foundation of this method lies in the existence of differences in the excitation functions, i.e., the dependence of formation cross sections on the particle energy $\sigma_{A_i} - f(E_{part})$ for the various groups of products of nuclear reactions.

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* OPREDELENIYE DOATMOSFERNYKH RAZMEROV METEORITOV

As follows from experiments on irradiation of iron targets by protons of various energies from 0.1 to 2.5 giga ev [1—5], all products of nuclear reactions may be divided into two groups :

1) isotopes with $\Delta A = A_{target} - A_{prod} \leqslant 10$; for them σ_{A_i} is constant in the indicated proton energy range (see curve 1 in Fig. 1);

2) isotopes with $\Delta A > 10$; for them there is observed a sharp increase of σ_{A_i} in the region $E_p < 1$ giga ev and a small variation for $E_p > 1$ giga ev, similarly to the curve 2, Fig.1).

The rate of formation of isotopes H_{A_i} at the i-th point, defined by the quantity r_i (distance from the surface) of the meteorite body of radius R_i, is a function of the intensity of primary cosmic radiation and secondary nucleo-active particles, which depend on r_i and R_i and on the quantities

$$\bar{\sigma}_{A_i} = \int_{E_0}^{E_\infty} \sigma_{A_i}(E) F(E) dE / \int_{E_0}^{E_\infty} F(E) dE; \tag{1}$$

$\bar{\sigma}_{A_i}$ depend on the form of the spectrum of nucleoactive particles and on the excitation functions of isotopes.

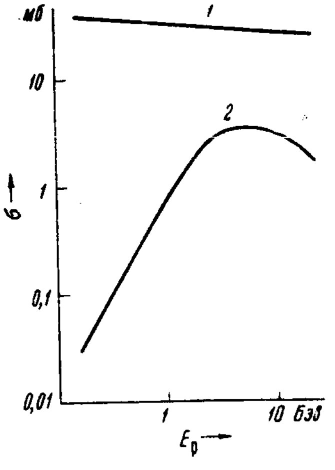

Fig.1. Excitation functions of V^{49} (curve 1) and Na^{22} (curve 2) in the reactions of protons with iron nuclei.

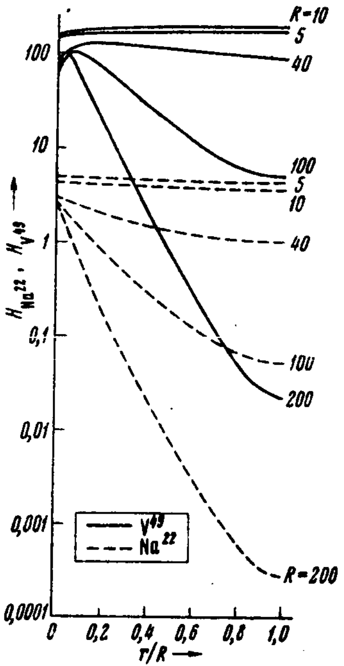

Fig.2. Distribution in depth of the formation rate of $H_{Na^{22}}$ and $H_{V^{49}}$ in iron meteorites with different R

In the model proposed by us in [6, 7], the values of $H_{A_i}(r_i, R_i)$ in iron meteorites are

$$H_{A_i}(r_i, R_i) = \frac{N}{A} [\bar{\sigma}_{A_i}^{\text{перв}} I_{\text{перв}} + \bar{\sigma}_{A_i}^{\text{ливн}} I_{\text{ливн}} + \\ + \bar{\sigma}_{A_i}^{p} I_p + \bar{\sigma}_{A_i}^{\pi} I_\pi + \bar{\sigma}_{A_i}^{n_1} I_{n_1} + \bar{\sigma}_{A_i}^{n_2} I_{n_2}], \tag{2}$$

$\bar{\sigma}_{A_i}$ is the mean non-weighted formation cross section of the isotope A ; the indices "перв ", "ливн ", p, π, n and n_2 are respectively related to the primary cosmic radiation, to shower particles ($E_p > 1$ giga ev , to fast protons, mesons and neutrons (0.1 giga ev $\leqslant E_p \leqslant$ 1 giga ev) and slow neutrons (0.001 giga ev $\leqslant E_p \leqslant$ $\leqslant$ 0.1 giga ev).

The role of particles of each form in the formation of the A_i-isotope is determined by the form of the spectrum of particles and the function $A_i = f(E)$. This is why the character of the depth distribution H_{A_i} in meteorites with different R_i for the isotopes of the two above indicated groups is different. This is clearly seen from the curves of Fig.2 obtained by us for the following parameters: $I_0 = 0.23$ particle/cm^2 sec·ster $= 0.386$ nucleons/cm^2 sec·ster according to the spectrum of primary radiation for the solar activity minimum by the 1953-1956 data [8] ; the spectrum form variation was taken into account for various r_i at the expense of ionization losses. The multiplicities of secondary mesons and protons were determined by their spectra obtained during photoplate exposure in the atmosphere [9]. In correspondence with these data it was admitted that the spectra of secondary particles are not dependent on either r_i or R_i . When determining $I_p(r_i, R_i)$ and $I_\pi(r_i, R_i)$, the ionization losses were taken into account. The multiplicity of neutrons was determined from the neutron spectrum in the atmosphere [10] at normalization to the value for $R = 26$ cm and $r = 13$ cm 11 . The multiplicities are $\bar{S}_{\text{ливн}} = 0{,}27$, $\bar{S}_p = 0{,}70$, $\bar{S}_\pi = 0{,}46$, $\bar{S}_{n_1} = 3{,}46$, $\bar{S}_{n_2} = 37{,}53$. It was assumed that the excitation functions are identical for protons, mesons and neutrons, and that the meteorite body had a spherical shape before entering the Earth's atmosphere.

From the course of the curves in Fig.2 substantial differences result in the absolute formation rates of Na^{22} and V^{49} and in their distribution in depth. It is most essential that the ratio $H_{V^{49}}/H_{Na^{22}}$ generally varies little on the surface of meteorites with various R_i (for example, for $R = 5$ cm it is equal to 28, for $R = 40$ cm — to 25 and for $R = 200$ cm —to 19), whereas for the centers these variations are substantial (for $R = 5$ cm they are 36.7; for $R = 40$ cm they are 80 and fir $R = 200$ cm they are 44). As R_i increases, there is observed a rise in the values of the ratio $(H_{A_i})_{surf}/(H_{A_i})_{cent}$; for example, if at $R = 5$ cm it is 0.85 for V^{49} and 1.07 for Na^{22} , we shall obtain at $R = 100$ cm respectively 11.4 for V^{49} and 51 for Na^{22}.

These peculiarities of H_{A_i} distribution in depth for isotopes with various excitation functions are still more clearly revealed in the graphs of Fig. 3 in the coordinates H_A and H_{A_1}/H_{A_2} , which represents a nomogram from mutually intersecting parallel lines corresponding to R_i = const and r_i / R_i = const.

Such a nomogram allows to determine the above-atmosphere radius of the meteoritic body and the distance of the sample investigated from its surface or center according to the activity of the respective isotopes in the given sample of iron meteorite. In order to exclude the possible temporal intensity variation of cosmic rays, isotope pairs with close decay periods should be chosen. Such are Na^{22} ($T = 2.58$ years) and V^{49} ($T = 330$ days) or Mn^{54} ($T = 291$ days) for freshly fallen meteorites and Be^{10} ($T = 2.5 \cdot 10^6$ years or Al^{26}($T = 7.4 \cdot 10^7$ years)* for meteorites having fallen five or more years back. According to the maximum value of Na^{22} activity and the average activity of V^{49} in the Arus Yardymlin iron shower [12] (point in Fig. 3), we determined the above-atmosphere radius and the weight of the meteoritic body having started that shower (see Table 1). Had the fallen body had the shape of a sphere of radius $R_{aft.\,atm.} = 15.6$ cm, its weight would

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* also Mn^{53} ($T \geqslant 2 \cdot 10^6$ years)

have been equal to 550 kg, value close to that of open specimens (150 kg). The difference between these weights is explained by the irregularity of melted layer's blowing off the surface of the body moving at cosmic velocity. The value of r for the specimen investigated was found to be 10.4 cm.

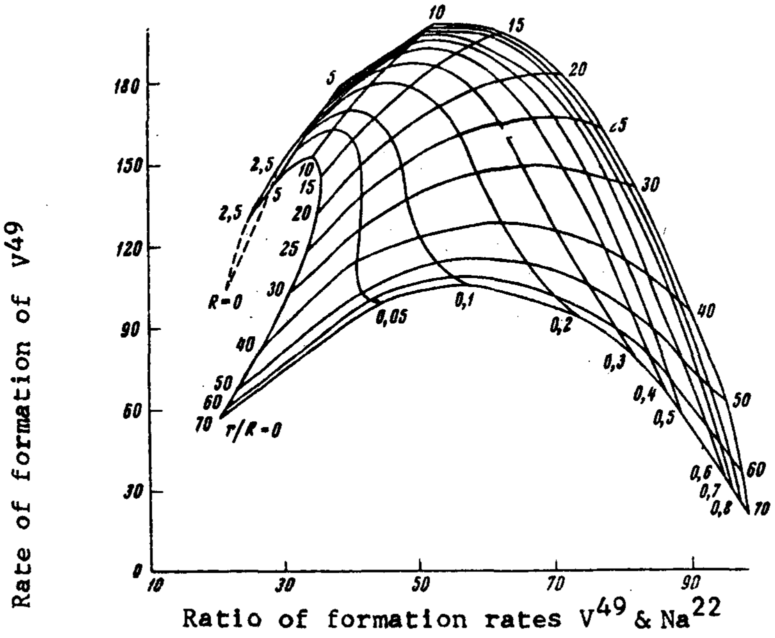

Fig. 3. Dependence of $H_{V}49$ on $H_{V}49 / H_{Na}22$ for various r_i and r_i / R_i

TABLE 1

Above-atmosphere dimensions of a meteoritic body fallen in the form of Yardymlin iron shower

R, cm	r / R	r, cm	R – r, cm	General weight, kg	Degree of ablation, %	Source
26	0.4	10.4	15.6	550	75	present work
39	0.6 – 0.4	23.4 – 15.6	15.6 – 23.4	1850	92	13

Our estimates of dimensions and weight of the meteortic body having fallen in the form of the Yardymlin iron shower differ from the data of [13], obtained on the basis of analysis of the dependences of ratios of He^3 / Ne^{21} and He^3 / He^4 contents on $H_{Ar^{38}}$, in the Arus specimen. The nomograms were constructed according to data on depth distribution of these isotopes in the Grant meteorite, whose cosmic age was, according to the Al^{36} / Cl^{36} method, equal to 600 million years. However, susbtantial discrepancies were revealed in [14] in the dependence of Cl^{36} and Ar^{36} on depth and in the values of cosmic ages for various areas of the Grant meteorite, apparently on account of spatial erosion which may distort to pattern of distribution in depth of stable isotopes. Nor can be excluded the possibility of temporal variation of cosmic rays which will lead to various effects on stable and radioactive isotopes.

The method proposed by us is devoid of these uncertainties. Its precision is determined mainly by the precision of radiometric determinations of low activities and the correctness of the adopted opinion on the constance of spatial distribution of cosmic rays in the solar system.

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**** THE END ****

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