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A SEARCH FOR THE TRACKS OF HEAVY AND SUPERHEAVY COSMIC RAY NUCLEI IN OLIVINES FROM METEORITES

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The present paper contains the results of experiments aimed at investigating the charge spectrum of galactic cosmic ray nuclei with the view of detecting the nuclei of superheavy elements.

These investigations have been in progress since 1967: first by using nuclear emulsions and subsequently with polymer track detectors exposed in balloons or orbiting satellites [1,2]. Over the past decade only 23 tracks have been detected due to the $86 \leq Z \leq 96$ nuclei with no events recorded in the region of $Z > 100$.

The studies on the abundance of the $Z \geq 50$ nuclei, performed by Price and coworkers with a thick stack of plastics exposed on the orbiting space station "Skylab" in 1974-75 seem to be most informative (Fig.1a). The abundance of the Th-U group nuclei was obtained in that experiment to be the $2\text{-}5 \times 10^{-7}$ th fraction of the abundance of the Fe nuclei for $E \geq 300$ MeV/n [2,3]. A total of 7 nuclei with Z ranging from 90 to 96 have been recorded. It is evident that the SHE abundance is much lower than that of Th-U nuclei; therefore the possibility of detecting such nuclei in these experiments was practically eliminated. For SHE searches it is necessary to increase by a few hundred times the number of the detected nuclei with $Z \geq 90$. A possible solution to the problem is to reveal the tracks of cosmic ray nuclei in olivine crystals taken from meteorites. The main advantage of such crystals is their ability to record and store the tracks of cosmic ray nuclei with $Z \geq 23$ for up to a hundred million years [4]. According to some estimates, for a period of 10^8 years about 2×10^4 nuclei of the Th-U group have passed through one square centimeter of the meteorite surface. Possessing high energies ($\geq$500 MeV/nucleon) such nuclei can pass a distance of several centimeters until they stop in meteoritic matter. At the end of their range they produce zones of defects about 1 mm long, which are observable after chemical etching under an optical microscope with a magnification factor of 100x-500x. The account of nuclear interactions and the decline of the energy spectrum shows that most of the nuclei have been stopped in a layer situated 1-2 cm from the preatmospheric surface(5).However, in passing the earth's atmosphere the meteorite loses a ~ 5 cm surface layer (6,7) in which ~ 90% of nuclei with $Z \geq 50$ have been stopped.We determined the depth of location of crystals (7,8) by investigating the density of the tracks due to the Fe group nuclei. The density of the Fe nuclei tracks

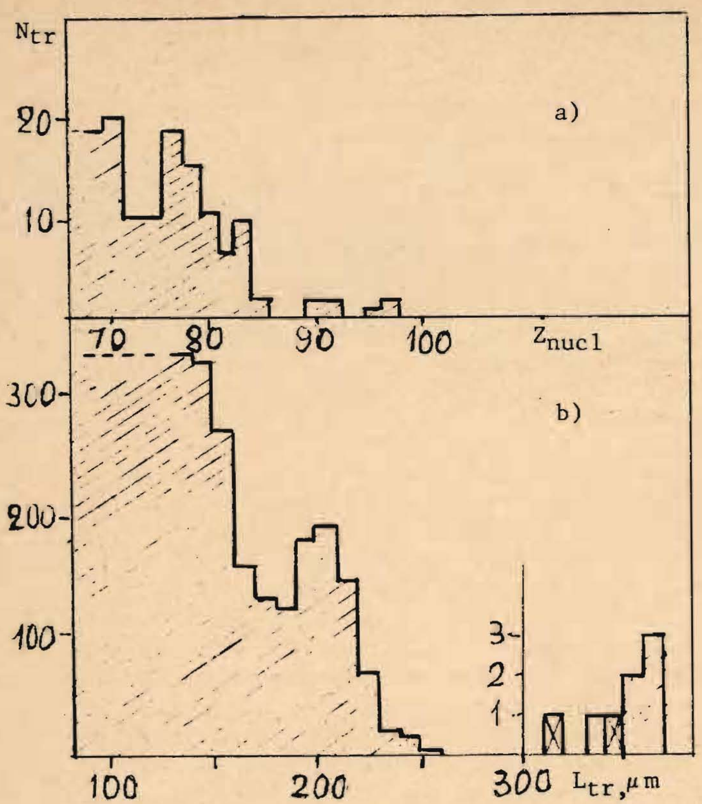


Fig.1. Results of track studies to search for SHE nuclei in cosmic rays. a) The atomic number Z distribution of the nuclei detected in a stack of polymer detectors exposed in the space station "Skylab" (2); b) The distribution of the etchable lengths of tracks due to the $Z \geq 50$ nuclei in olivines from meteorites. The tracks were annealed for 32 hours at a temperature of 430°. The low-energy parts of the two tracks marked with crosses reached beyond the crystal surface.

in Marjalahti and Eagle Station pallasites turned out to lie in the range $10^{10}-10^{11}$ cm^{-3}. Such a high density of the tracks indicates that these crystals may contain up to 10^3 cm^{-3} of tracks due to the Th-U group nuclei. Thus, despite the fact that a large amount of information turns out to be lost, our technique allows us to increase by many times the sensitivity of SHE searches compared with the level achieved with nuclear emulsions and plastics (1-3). The identification of cosmic ray nuclear charges was made using the correspondence between the vol-

ume etchable track length and the atomic number of the nucleus (5,8). The identification of the nuclei was complicated because of the partial fading of the tracks in cosmic space. This fading leads to a difference in the lengths of tracks of different age for nuclei with equal Z (9). The search for the tracks of the heaviest nuclei and their identification were very difficult because of the high density of tracks due to the Fe group nuclei. Therefore we employed the technique of controlled annealing of the tracks (10). The heating of the crystals to 430°C followed by a 32-hour exposure at this temperature led to the entire disappearance of the etchable tracks of the Fe group nuclei and to the independence of track lengths of the age for the $Z \geq 50$ nuclei tracks (11).

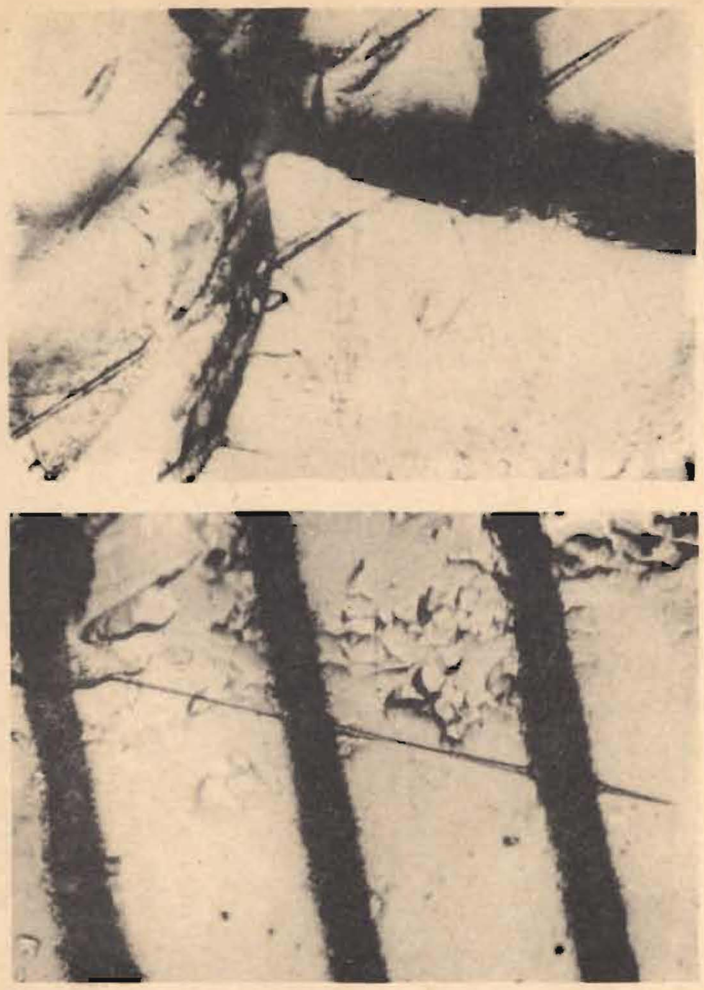
According to the estimates made in the framework of the model of Katz and Kobetich [12,13] the etchable lengths of unannealed tracks of the nuclei of Xe, U and element with $Z = 114$ are equal to 230 μm, 1160 μm and 1830 μm, respectively. The annealing procedure was controlled by following the changes in the lengths of tracks due to Xe, Pb and U nuclei after the irradiation of the crystals at the accelerator. After annealing the full etchable length of tracks due to Xe nuclei was equal to 26.5 ± 1.3 μm. Using this as a calibration one, it is possible to calculate, in the framework of the more accurate variant of the Katz-Kobetich model proposed by V.A.Ditlov [13] the tracks of U nuclei to decrease to 210-230 μm and those of the $Z = 114$ nuclei to 340-380 μm.

To etch the tracks having the entire lengths enclosed in the crystal volume it is necessary to introduce the etchant into the crystal volume. For this purpose the crystals were exposed to laser pulses formed with certain duration, amplitude and shape. In the laser irradiated crystals a system of microcracks is formed (fig.2a) which provide the penetration of the etchant inside the crystal [11,14]. The etching of olivines was carried out by an etchant [15] during about 4 days at a temperature of 100°C in a hermitically sealed volume.

In experiments with abbealed crystals a total of 12 cm^3 of olivines mainly from Marjalahti meteorite have been scanned. The results of these measurements are plotted in fig.1b. From this figure it follows that the distribution of track lengths contains a pronounced group of tracks 190-220 μm long as well as eight 310-360 μm tracks.

The spectrum of track lengths presented in fig.1b allows one to advance the hypothesis that the nuclei of superheavy elements with $Z \geq 110$ may be present in cosmic rays.

In fact, the group of 190-220 μm tracks is evidently due to the U nuclei. The minimum located in the region of the 160-180 μm tracks can be explained as being due to small lifetimes of atomic nuclei with $83 < Z < 90$. The increase in the



a)

b)

Fig.2. a) Photograph of the annealed olivine crystal bombarded with a laser beam. b) Photograph of the annealed olivine crystal bombarded with ^{60}Ni ions through a system of slits.

number of 120-150 μm tracks agrees with the relatively high abundance of the Pt-Pb group. The abundance of the nuclei responsible for the 190-220 μm tracks is equal to $1\text{-}2\times10^{-7}$ relative to the iron abundance. This result for the same nuclear energy range agrees with the Th-U abundance in cosmic rays, obtained in experiments using track and electronic detectors placed in balloons and satellites [1-3].

The anomalous tracks 310-360 μm long form a group far from the Th-U group. In the track spectrum such a group corresponds to nuclei with $Z = 110\text{-}114$ [16]. The absence of 260-310 μm tracks in the spectrun can naturally be explained by the short lifetimes of the $96 < Z < 110$ nuclei.

The assumption that the group of 310-360 μm tracks corresponds to the $Z > 110$ nuclei is confirmed by our data on a difference in the etching rate for different parts of the tracks [16], as well as by the coincidence of the directions of the 310-360 μm tracks with the maximum of the angular distribution of the tracks due to the $Z \geq 50$ nuclei in the same crystals.

Thus the data presented in fig.1b permit an estimate of the abundance of the SHE nuclei in cosmic rays, which is equal to the $(3\text{-}10)\times10^{-3}$th fraction of the Th-U group abundance, i.e., a factor of $10^3\text{-}10^4$ higher than the limit of the SHE concentration in Solar system matter obtained in studying the spontaneous fission activity of stony meteorites such as Allende and others [17]. This difference may have two natural explanations: the difference in the Solar system age equal to 4.6×10^9 years and the cosmic ray age of about 10^7 years, and the uniqueness of the nucleosynthesis event in the Solar system and the continuity of this process in the universe.

The proposed SHE abundance is in agreement with optimistic estimates for nucleosynthesis occurring in the r-process. According to some predictions [18], the SHE concentration in cosmic rays amounts to the $10^{-1}\text{-}3\times10^{-4}$th fraction of the Th-U abundance. The latest estimates taking into account the r-process cut-off due to delayed fission predict either a factor of 10-500 decrease in the SHE nuclei yield [19,20], or the absolute forbiddenness for SHE synthesis [21]. Discrepancies in the obtained estimates indicate that the experimental solution of the problem of SHE existence and abundance is rather important for understanding the nucleosynthesis process.

Positive evidence for the assignment of the observed tracks to the SHE nuclei would be provided by the observation of spontaneous fission fragment tracks at the end of these nuclei ranges. It is rather likely that during the average age of nuclear tracks in Marjalahti meteorite equal to about 10^8 years the SHE nuclei which had stopped in olivine might have undergone spontaneous fission. Because of the threshold properties of olivine the SHE nucleus had stopped at a distance of about 10 μm from the end of the etchable track. Model experiments demonstrate that the annealing technique used in our experiments is capable of increasing this distance to about 25 μm and, at the same time, of decreasing from ~18 μm to 12-15 μm the length of tracks due to spontaneous fission fragments. At present work is in progress to develop the technique of revealing the tracks of fission fragments by using the thermal-neutron induced fission of the ^{235}U nuclei.

Naturally, to detect SHE spontaneous fission it is necessary to increase the number of tracks. A considerably larger number of tracks should be obtained in the 310 μm - 360 μm group, this requiring a higher rate of scanning and measuring. One of the possibilities is shown in fig.2b. It involves the bombardment of the crystals with $Z \geq 30$ ions through a multi-slit collimator. As a result of such a bombardment, the efficiency of revealing tracks becomes higher, and crystal scanning easier, thus providing conditions required for the automatisation of track measurements.

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Перелыгин В.П., Стеценко С.Г., Флеров Г.Н. E7-85-245

Поиск следов тяжелых и сверхтяжелых космических ядер в оливинах из метеоритов

Представлены результаты исследования следов ядер космических лучей с $Z \geq 50$ в кристаллах оливина из метеоритов. При обработке кристаллов применялась методика контролируемой термической регрессии следов ядер. В приведенном спектре длин следов ядер с $Z \geq 50$ выделяются группы длиной 190÷230 мкм, отнесенные к Th–U, и аномально протяженных следов 310÷360 мкм. Обсуждается предположение о существовании в космических лучах ядер сверхтяжелых элементов /СТЭ/ с $Z \geq 110$.

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Perelygin V.P., Stetsenko S.G., Flerov G.N. E7-85-245

A Search for the Tracks of Heavy and Superheavy Cosmic Ray Nuclei in Olivines from Meteorites

The results of investigating the tracks of cosmic ray nuclei with $Z \geq 50$ in olivine crystals from meteorites are presented. The obtained spectrum of track lengths for the $Z \geq 50$ nuclei exhibits two pronounced groups of tracks: 190–230 μm tracks, attributed to nuclei ranging from Th to U, and abnormally long 310–360 μm tracks. The hypothesis that the nuclei of superheavy elements with $Z \geq 110$ may be present in cosmic rays is discussed.

The investigation has been performed at the Laboratory of Nuclear Reactions, JINR.

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