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Searches for superheavy elements in nature: Cosmic-ray nuclei; spontaneous fission

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Abstract

There is little chance that superheavy nuclei with lifetimes of no less than 100 million years are present on the stability island discovered at present. Also, pessimistic are the results of estimates made about their nucleosynthesis in r-process. Nevertheless, the search for these nuclei in nature is justified in view of the fundamental importance of this topic. The first statistically significant data set was obtained by the *LDEF* Ultra-Heavy Cosmic-Ray Experiment, consisting of 35 tracks of actinide nuclei in galactic cosmic rays. Because of their exceptionally long exposure time in Galaxy, olivine crystals extracted from meteorites generate interest as detectors providing unique data regarding the nuclear composition of ancient cosmic rays. The contemporary searches for superheavy elements in the earth matter rely on knowledge obtained from chemical studies of artificially synthesized superheavy nuclei. New results finding out the chemical behavior of superheavy elements should be employed to obtain samples enriched in their homologues. The detection of rare spontaneous fission events and the technique of accelerator mass spectrometry are employed in these experiments.

Keywords: Superheavy nuclei; Nucleosynthesis; Cosmic rays; Spontaneous fission

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1. Introduction

Soon, after the first predictions indicating that nuclei in the vicinity of the magic numbers $Z = 114$ and $N = 184$ might have high fission barriers [1,2], the possibility of the existence of superheavy elements (SHEs) in nature became a focus of attention. Beginning with great interest roused by the announced observation of one or two tracks of atomic nuclei with $Z = 110$ among the traces of cosmic rays detected in the emulsions exposed at high altitudes in Earth atmosphere (see in [3]), more than one hundred papers on searches for SHEs in nature were published within a ten-year period. Approximately the same number of papers discussed various experimental aspects of this problem. These activities made evident that one encounters here an extremely complicated task, requiring great efforts from any team taking it on. The majority of researchers who were initially attracted by the possibility of discovering a new island of nuclear stability abandoned this problem after one or two attempts. Only a few groups remained engaged in the task, applying sensitive techniques. The state of affairs attained in this field by the beginning of the 1980s has been discussed in several review papers [4–8].

At the present time, when we are witness to the discovery of a real region $Z = 108$–118, $N = 169$–177 nuclei [9–12] that are truly a part of the long-sought island of stability, interest to the possible occurrence of long-lived superheavy nuclei in nature revives. The decay properties of the discovered superheavy nuclei confirm the basic concept of closed neutron and proton shells occurring in the region of very heavy elements. Most probably, the magic numbers $Z = 114$ and $N = 184$ determine the stability island. Detailed properties obtained for the more than 50 nuclei, making the neutron-deficient slope of the stability island, were employed extensively for fitting theory predictions. The ground-state energy values and the heights of fission barriers of heavy and superheavy nuclei were analyzed recently within various approaches (macroscopic–microscopic, extended Thomas–Fermi plus Strutinski integral (ETFSI), and relativistic mean-field (RMF)) (see [13] and the references therein) and making use of self-consistent mean-field (SMF) models with effective Skyrm interaction (see Ref. [14]). The obtained nuclear masses grant accuracy for the estimated α-decay half-lives within a factor of less than 100. Considerable diversity is evident among the predicted barrier heights [14–19] and the collective inertia calculated in a multidimensional deformation space. This diversity leads to discrepancies in the predicted spontaneous-fission lifetimes of up to a factor of 10^5. Different theory papers predict that α decay is the main decay mode for the even–even nuclei with $Z \geq 114$, $N \approx 184$ (the expected α-decay half-life times make no more than 1 s). These predictions assign the longest lifetimes to the isotopes of elements with atomic numbers of $Z = 108$–112 (Hs, Mt, Rg, Ds, Cn) lying in the β-stability valley. The common expectation is that spontaneous fission should be the most probable decay mode in this domain, limiting the lifetime of the most long-lived even–even nuclei with atomic numbers of $Z = 108$–112 to a few years.

The large uncertainties inherent to these predictions and the poor knowledge of hindrance factors imposed to the spontaneous fission of odd-proton (and/or odd-neutron) nuclei leave room for the possibility that one or perhaps two isotopes of $Z = 108$–112 elements could be sufficiently long-lived to allow for the survival of a small, but detectable, fraction of these nuclei since the time of the last nucleosynthesis event in which these nuclei could have been created. This would require a half-life on the order of 10^8 years or longer.

The possibility that nuclei of certain SHEs may be produced in the astrophysical r-process has been the subject of numerous calculations. The majority of authors who considered this subject in the 1970s reached negative conclusions about such a possibility. However, some authors claimed that the formation of SHE nuclei is possible [20–22]. Ultimately, a reasonable conclusion at that

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