ON THE POSSIBLE EXISTENCE OF SUPERHEAVY ELEMENTS IN NATURE

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Abstract

Full Text

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PHYSICS

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Recently information has appeared on the theoretical possibility of the existence of superheavy long-lived transuranium elements (1-3). This question, from the physical point of view, has been covered by G. N. Flerov (1, 2) and V. M. Strutinskii (3). The chemical aspects of the problem were considered by V. I. Goldanskii at a general meeting of the Academy of Sciences of the USSR (March 1969). G. Seaborg' s review article (4) summarizes all the work known as of 1968 devoted to distant transuranium elements.

In Fig. 1, borrowed from work (1), are shown the existing in nature, synthesized, and possible isotopes which, apparently, may be studied in the future with different numbers of protons (Z) and neutrons (N) in the nucleus.

Fig. 1. Region of existence of isotopes. Protrusions **A** and **B** are due to nuclear fission. The outer contour, shown by a solid line, denotes the boundaries of the region of stability obtained on the basis of theoretical calculations

In Table 1, compiled on the basis of the data of S. G. Nilsson (5), are given the theoretically predicted maximum half-lives of isotopes of superheavy elements with atomic numbers from 106 to 116 and with neutron numbers from 178 to 189. As can be seen from this table, at least 18 isotopes may have half-lives of not less than 10^8 years. It follows from this that if these isotopes were synthesized in nature simultaneously with the known heavy elements, then some quantity of them should have been preserved in terrestrial matter. The largest half-life is predicted for the isotope eka-lead with mass 298 ($Z = 114$). This is substantiated

Table 1

Maximum theoretical half-lives of distant transuranium isotopes

Z N	178	179	180	181	182	183	184	185	186	187	188	189
116	1 µs	–	1 day		10^5 years		10^{11} years		10^{11} years		1 sec.	
115		–	10 µs		10 h.		1 day		10 sec.		10 µs	
114	1 µs	–	10^3 years	1 year	10^9 years	10^2 years	10^{16} years	100 days	10^{15} years	5 h.	10^{14} years	10 days
113		–	10 years		10^3 years		10^5 years		1 year		10 years	
112	10^{-2} sec.	–	1 day	10^2 years	10^6 years	10^4 years	10^{13} years	10^2 years	10^{13} years	100 days	10^{12} years	10 years
111		–	10 years		10^5 years		10^7 years		10^2 years		10^3 years	
110	1 µs	–	10 µs	10^4 years	10^3 years	10^9 years	10^{10} years	10^5 years	10^{10} years	10^2 years	10^9 years	10^4 years
109		–					10^{11} years		10^5 years			
108	10^3 years	–	1 sec.		1 year		10^8 years	10^9 years	10^8 years		10^7 years	
107		–										
106		–			10 days		10^7 years					

also the possibility of the existence of a second and third “island” of stability with the longest-lived elements eka-plutonium ($Z = 126$) and eka-eka-lead ($Z = 164$) (4).

The theoretical conclusions of physicists have received some confirmation thanks to the discovery of tracks of superheavy nuclei in photographic emulsions lifted into the stratosphere. These discoveries were made by P. Fowler (5), in an amount of approximately 1 track per 4 m^2 of photographic emulsion per day. The width of these tracks is such that P. Fowler identified them as tracks of transuranium elements with atomic numbers from 106 to 110. It should be noted, however, that the width of a track cannot serve as an unambiguous indication of the existence of superheavy nuclei. Nevertheless, these discoveries are very encouraging.

The general hardness of cosmic rays gives reason to suppose (and this follows from P. Fowler’ s experiments) that the overwhelming majority of superheavy nuclei will inevitably enter into nuclear reactions with atmospheric nuclei. It is apparently no accident that similar tracks were not observed in photographic emulsions placed on the Earth’ s surface. Nuclei with relatively low energy can “settle” on the surface of the Earth. Their lifetime must be thousands and millions of years. It is not difficult to show that, with the dimensions of our Galaxy of 10^5 light-years, and with a nuclear velocity of 1000 km/sec, their own flight time from the central parts of the Galaxy to the Solar System will be measured in millions of years. On the basis of these considerations, there remains no hope of finding short-lived superheavy nuclei on Earth.

In estimating the abundance of long-lived superheavy nuclei in terrestrial matter, one may proceed from a number of assumptions based on two different models. The first assumes the formation of superheavy nuclei in a single nucleosynthesis together with heavy ($M > 209$) nuclei, and therefore their abundance should be somewhat lower (provided they are relatively stable) than the cosmic abundance of, for example, bismuth or uranium-235. On average, for terrestrial matter this value may be 10^{-12}–10^{-14} g/g. The second model assumes that the original terrestrial matter did not contain such superheavy nuclei, and that the emergence of the latter became possible only at a certain stage of stellar evolution (in the most recent supernovae). Suppose that the influx of superheavy isotopes onto the Earth’ s surface began 4.5 billion years ago (the age of the Earth) and continued at a constant rate amounting to 0.25 particle per 1 m^2 per day. Then, taking into account that 10^5 g of superheavy nuclei fell onto the Earth’ s surface, with an area of 509 million km^2, over the entire time of its existence, and assuming that in the process of formation of the Earth’ s crust they were distributed down to a depth of 30 km (mass of the Earth’ s crust $5 \cdot 10^{25}$ g), their abundance in the Earth’ s crust on average is $2 \cdot 10^{-21}$ g/g.

Modern analytical techniques make it possible to identify several hundred thousand stable atoms. Analytical chemistry can provide for the processing of several hundred kilograms of any natural material in order to isolate microquantities of superheavy elements possessing unknown chemical properties.

In nature there may exist accumulations of one or another superheavy element. It is possible that they follow their electronic analogues. Proceeding from these considerations, some investigators are attempting to identify the tracks of fission fragments in old lead glasses, assuming that some of them belong to fission fragments of eka-lead. This problem is very difficult, since it is necessary to take into account fission events both of the lead itself

Table 2

Distant transuranium elements, their analogues, and an estimate of the feasibility of searching for them

Electronic analogues	Maximum stability, years	Geochemical associations	Relative ease of search	Note
W-106	10^7	Mo, W, Re	1	Lithophile *

Electronic analogues	Maximum stability, years	Geochemical associations	Relative ease of search	Note
Re-107	?	Mo, W, Re	?	Siderophile **
Os-108	10^8	Ru, Rh, Pd	3	»
Ir-109	10^{11}	Os, Ir, Pt	2	»
Pt-110	10^{10}	Os, Ir, Pt	1	»
Au-111	10^7		2	Chalcophile ***
Hg-112	10^{13}	Cu, Zn, Ga, Ge,	1	»
Tl-113	10^5	Ag, Cd, In, Sn,	1	»
Pb-114	10^{16}	Au, Hg, Tl, Pb	3	»
Bi-115	1 day	Sb, As, Bi	?	»
Po-116	10^{11}	Se, Te	2	»
At-117	?	Br, I	?	Lithophile
Rn-118	10^3	A, Kr, Xe	2	»
Fr-119	?	K, Cs, Cr, Ba	?	»
Ra-120	10^2	K, Cs, Cr, Ba	?	»
Ac-121	?	T, R	?	»
Th-122	?	U, Th	?	»
Pa-123	?	T, R	?	»
U-124	?	U, Th	?	»
Np-125	?	T, R	?	»
Pu-126	10^{10}	T, R	1	»

* Ions with 8 electron shells.
** Ions with 18 electron shells.
*** Ions with electron shells being built up.

as well as impurity elements, for example uranium, under the action of cosmic radiation, the neutron background of the Earth' s crust, spontaneous fission, etc. Moreover, the track method itself is indirect.

Since the expected abundance of superheavy elements is very small, it is expedient to search for them in concentrates of one or another analogue element. Table 2 gives the atomic numbers of distant transuranium elements and their electronic analogues. Next are indicated the half-life periods of the longest-lived isotope of these elements, as predicted by theory. Curly braces mark geochemical analogies. The table then gives the elements of geochemical associations (the most probable co-occurrence in nature). In the following column is indicated (purely preliminarily and qualitatively) the relative ease of searching for one or another eka-element, taking into account all possible geochemical, chemical, and physical factors on a three-point scale. Finally, the note indicates the affiliation of the eka-elements with the group of chalcophile, siderophile, or lithophile elements according to the classification of V. M. Goldschmidt.

As can be seen from Table 2, in purely silicate materials (lithophile elements) the probability of finding heavy transuranium elements is the smallest. From the geochemical point of view this probability is greatest for siderophile elements (elements of the iron group and the platinoids); however, from the standpoint of analytical chemistry, chalcophile elements (those having an affinity for sulfur) will probably prove preferable, since they are all readily volatile. In this connection, searches for superheavy elements in sulfide ore manifestations, various volcanic deposits, minerals of pegmatite veins, etc., may prove promising.

In addition to natural concentrators, wastes from metallurgical production can be used in searches for superheavy elements (for example, lead exhausts in the blast-furnace process). It is not impossible that ekaradon may be found in the heavy fractions of noble gases from cryogenic plants. Aerosols can also be investigated.

When superheavy (nonrelativistic) nuclei enter the atmosphere, there is a high probability of their adsorption on aerosols, which consist of cosmic, terrigenous, and industrial dust. In accumulations of such dust one may expect elevated concentrations of eka-elements. The place of such an accumulation of dust may be either deep-sea oceanic sediments (for example, red clays) or high-mountain glaciers. In the latter case it is possible to estimate the approximate abundance of eka-elements. On the basis of P. Fowler' s data, a maximum of 91 superheavy isotopes may fall on 1 m^2 of glacier surface. If the glacier has existed for 10,000 years and during this time has grown by 1000 m, then 1 m^3 of ice (together with suspended matter) contains on the order of 900 atoms of superheavy isotopes. Even if 90% of the eka-elements is carried away by meltwater, a sufficient quantity of them remains to attempt to isolate them, especially since no special analytical difficulties are foreseen in this case.

It is of great interest to investigate meteoritic and tektitic matter. The former—because the original association of elements in it has not been disturbed throughout its history. At the same time, meteorites contain a sufficient variety of minerals, including some unknown on Earth. Iron meteorites, in particular, represent a primary association of siderophile elements. The latter (tektites) are of interest mainly because of the enigmatic nature of their origin. Of still greater interest is the investigation of cosmic dust in pure form, in particular on such a natural accumulator of cosmic dust as the surface of the Moon.

It follows from the foregoing that finding superheavy elements in nature is a task of exceptional difficulty. However, the cost of searches for these elements will be considerably less than the cost of special accelerator equipment for the artificial synthesis of superheavy elements.

It is difficult to predict what practical consequences the discoveries of superheavy elements might lead to, but there can be no doubt that this would give a powerful impetus to the development of theoretical concepts, especially in nuclear physics.

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