# PHYSICS

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## Abstract

## Full Text

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# SPONTANEOUS FISSION OF Th$^{232}$ AND THE STABILITY OF NUCLEONS

The conservation of the number of nucleons is one of the fundamental properties of matter. Up to the present, no processes have been observed in which a nucleon decays into lighter particles. However, the possibility of such processes cannot be completely excluded. From the fact that stable nuclei exist it follows only that the lifetime of the nucleon is very large.

The attempt undertaken by F. Reines et al. ($^1$) to estimate experimentally the lower limit of the nucleon lifetime is therefore of considerable interest. From an analysis of the pulse spectrum obtained in a large scintillator placed underground at a depth of 30 m, the authors concluded that the lifetime of a bound nucleon with respect to decay into lighter particles is $> 10^{22}$ years. It was also pointed out there that, from data on the spontaneous fission of long-lived nuclei, in particular Th$^{232}$, an independent estimate of the lifetime of a bound nucleon can be obtained. In doing so the authors assume that the energy left in the nucleus upon decay of a nucleon is sufficient to cause fission of the nucleus with high probability. However, they used an underestimated value of the fission half-life of Th$^{232}$, $1.4 \cdot 10^{18}$ years ($^2$).

In work ($^3$), using a multilayer ionization chamber, it was shown that the probability of spontaneous fission of Th$^{232}$ is at least 100 times smaller than that indicated in work ($^2$).

It was of interest, after substantially increasing the sensitivity of the method, to attempt to determine the half-life for spontaneous fission of Th$^{232}$. An increase in the sensitivity of the method can be achieved both by increasing the total amount of active material and by reducing the background. It proved possible to ensure a significant reduction of the background by using a proportional counter as the detector of fission fragments. A substantial advantage of the proportional counter is that the magnitude of the pulse in it (owing to gas amplification) is considerably greater than the pulse in a multilayer chamber, as a result of which an amplifier with a small gain factor, of the order of 100, can be used. This increases the ratio of the signal to the level of noise and interference at the amplifier input.

The counters used were made of thin-walled aluminum tubes 200 cm long and 12 cm in diameter, with a total working cathode surface of 8000 $cm^2$. Thorium in the form of $ThO_2$ oxide, with a small addition of Bakelite varnish, was applied to the inner surface of semicylindrical channels, which were mounted on the cathode of the counter. Nichrome threads 50 $\mu$ in diameter, fixed to covers —insulators made of Plexiglas—served as the anode. The counters were filled with methane to a pressure of 50 mm Hg; the methane was purified beforehand by freezing in a trap cooled with liquid nitrogen. The counters had a wide proportionality region; the gas amplification coefficient was $\sim 10^3$ at a voltage of 1200 V,

the characteristics of the counter did not change appreciably over several months of operation.

To increase the total amount of active working substance, several counters of the same type were used. For each counter there was a preamplification stage and a discriminator that made it possible to cut off pulses from $\alpha$-particles. Pulses from fission fragments were then fed to a common amplifier. The pulses from fission fragments were recorded through three channels with different levels of amplitude discrimination. Battery power ensured continuous operation of the amplifier and recording circuit for many hundreds of hours.

Special attention was paid to reducing the background due to spontaneous fission of a possible uranium impurity. The presence of even $10^{-3}\%$ of uranium in thorium could imitate spontaneous fission of $Th^{232}$ with a period of $\sim 10^{21}$ years. The usual methods for determining the uranium content are not applicable to such concentrations. We used, as in Ref. (3), activation analysis based on the fission of $U^{235}$ by thermal neutrons. A radium-beryllium source placed in paraffin was used as the source of thermal neutrons. A small multilayer chamber was used for analysis of the samples. However, in determining uranium concentrations below $10^{-3}\%$, additional difficulties arose. When samples of thorium from different batches were irradiated with neutrons, a certain number of pulses was invariably recorded. The result did not change even after chemical purification of the thorium from uranium. This fact is apparently connected with the fission of $Th^{232}$ by thermal neutrons, with a cross section of the order of 0.04 millibarn, which limits the determination of natural uranium impurity in thorium to concentrations $> 10^{-3}\%$.

For further control of the purity of the thorium, an indicator amount ($10^{-3}\%$) of $U^{233}$ was introduced into it, since the fission cross section of $U^{233}$ for thermal neutrons is large and the period of spontaneous fission is small. It was shown that, as a result of purifying thorium by selective sorption of uranium on an ion-exchange column, the amount of $U^{233}$, and consequently also of natural uranium in thorium, decreased by at least a factor of 100, i.e., to $< 10^{-5}\%$.

In recording spontaneous fission with a half-life $> 10^{20}$ years, the background due to fission of thorium by cosmic rays becomes significant. Preliminary measurements showed that the thorium fission effect decreased by approximately a factor of 10 at a depth of 8 m relative to measurements at the earth’ s surface, in agreement with the results of Ref. (3). To reduce still further the background due to cosmic rays, the measurements of spontaneous fission in the present work were carried out underground at a depth of 36 m.

An additional danger could also be posed by neutrons produced in the surrounding material, for example by $(\alpha, n)$ reactions or by spontaneous fission of uranium contained in it. To eliminate the background associated with fission of uranium by neutrons, the counters were surrounded by a 5-cm-thick layer of paraffin with boron.

The amount of working substance was determined by counting the fission events of thorium by neutrons from a $(\mathrm{Po} + \mathrm{Be})$ source.

As a result of measurements over 7000 g • h, not a single event of spontaneous fission was recorded. It follows from the result obtained that, if $\mathrm{Th}^{232}$ does undergo spontaneous fission, then its half-life is greater than $10^{21}$ years. The lower limit of the half-life, equal to $10^{21}$ years, is an order of magnitude greater than that obtained in Ref. (3) and substantially greater than the value calculated from Svyatetskii' s formula (4).

It follows from the data obtained that the lifetime of a bound nucleon with respect to decay into lighter particles is more than $2 \cdot 10^{23}$ years, if it is assumed that, as a result of the decay of a nucleon, the thorium nucleus undergoes fission.

Using the method described above for recording rare events of

fission, experiments were also carried out to search for transuranium elements in monazite minerals. For this purpose, monazites from various deposits with ages greater than $10^9$ years were studied. The monazites were first purified of uranium by a chemical method. For the content of $\mathrm{Pu}^{244}$, whose half-life for spontaneous fission is $2.5 \cdot 10^{10}$ years ($^5$), a value of $< 10^{-10}\%$ was obtained.

In conclusion, the authors express their gratitude to the Directorate of NIFI-2 of Moscow State University for the opportunity provided to carry out the measurements.

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*Note: Figure translations are in progress. See original paper for figures.*