On the basis of our calculations we arrive at the following conclusions:

1. The transitions ($^3\!/_2 1 \rightarrow {}^1\!/_2$) and ($^5\!/_2 1 \rightarrow {}^1\!/_2$) [besides the transition ($^5\!/_2 3 \rightarrow {}^3\!/_2 2$)] have the greatest reduced probability among all the abovementioned E2 transitions. This is in agreement with the experimental results on Coulomb excitation (for W^{183}, see reference 6). If the nuclear shape deviates strongly from the axially symmetric one, the transitions ($^3\!/_2 2 \rightarrow {}^3\!/_2 1$) and ($^5\!/_2 2 \rightarrow {}^5\!/_2 1$) also become pronounced.

2. If the nucleus deviates little from the axially symmetric shape, all M1 transitions between the rotational levels of the nucleus have small reduced probabilities. If, however, the nuclear shape is far from being axially symmetric, the transitions ($^5\!/_2 2 \rightarrow {}^5\!/_2 1$) and ($^5\!/_2 3 \rightarrow {}^3\!/_2 2$) become important.

3. It follows from (5) and (6) that all magnetic transitions to the ground state should be very weak as compared to the electric transitions.

4. According to Davydov,[1] we have $\gamma \approx 27°$ for the nucleus W^{183}. From Fig. 1 we then obtain for the ratio of the reduced transition probabilities for the transitions ($^1\!/_2 \rightarrow {}^5\!/_2 2$) and ($^1\!/_2 \rightarrow {}^3\!/_2 2$) the value $(6/4)(4/2.3) = 2.6$. This is in good agreement with the estimate based on the experimental results of Alder et al.[6]

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ALPHA DECAY OF Th^{229}. *INTERACTION OF NUCLEAR LEVELS*

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THE α decay of Th^{229} has not been investigated heretofore. Nor is anything known concerning the structure of the levels of the daughter nucleus Ra^{225}.

We have investigated the α decay of Th^{229} with a magnetic α spectrometer;[1] the spectra of conversion electrons of Ra^{225} accompanying the α decay of Th^{229} were investigated with a high-aperture toroidal β spectrometer[2] and an α-β coincidence circuit. The measurements were carried out with the isotope Th^{229}, obtained by chemical separation of thorium from U^{233} that was aged for a long time.

The investigation of the α spectrum of Th^{229} disclosed 12 α lines. The energies of the α lines and the intensities of the corresponding transitions are listed in the table, which contains also the hindrance coefficients (ratio of the transition intensity, calculated from the formula for even-even nuclei, to the observed intensity).

In the investigation of the spectrum of the conversion electrons we observed approximately 100 conversion lines that could not yet be fully interpreted. We separated reliably the γ transitions with energies 17.2, 42.8, 69.9, 75.5, 137.2, 156.6, 193.4, and 210.5 kev. The 29.1, 31.6, 56.8, 58.9, 85.0, 132.1, 154.4, 179.6, 242.0 kev and a few other transitions are less reliable.

A comparison of the data obtained with both instruments suggests the existence of a Ra^{225} level with excitation energy ~ 3 kev. Whether this level becomes populated in α decay of Th^{229} and at what probability is still unknown. Apparently the γ transitions from high levels occur mainly at this level rather than at the ground level of Ra^{225}.

The α decay to the ground state of Ra^{225} appears to be strongly forbidden ($\eta = 330$). The more likely transition is that to the 214.5-kev level ($\eta = 1.5$). The spin of this level should therefore equal the spin of the ground state of Th^{229}, i.e., $^5\!/_2$. Located above this level are several others, some of which have small η. The Ra^{225} nucleus lies in a region sufficiently far from closed shells. The investigated nuclei in this region are prolate. It is natural to assume that

α line	α-line energy, Mev	Transition intensity, percent	η	α line	α-line energy, Mev	Transition intensity, percent	η
α_0	5.048	6.7	330	α_{156}	4.894	10.7	25
α_{20}	5.028	~0.2	~10^4	α_{214}	4.837	58.2	1.5
α_{45}	5.003	~0.1	~10^4	α_{246}	4.806	11.4	7
α_{78}	4.971	3.4	200	α_{264}	4.788	1.0	40
α_{88}	4.961	6.0	100	α_{302}	4.751	1.5	20
α_{125}	4.925	0.25	~10^3	α_{376}	4.678	0.4	25

Ra^{225} is also prolate, and its level spectrum should therefore contain rotation bands. Such bands are usually determined from the multipolarities of the γ transitions between levels and from the energy variation, described by the well known formula

$$E_{\rm rot} = (\hbar^2/2J)\{I(I+1) - I_0(I_0+1)\}. \qquad (1)$$

As already mentioned, we have not yet succeeded in interpreting the γ spectrum, and comparison with (1) does not enable us to separate a single rotation band in the Ra^{225} spectrum. One can assume that the interaction between levels of very high density has caused them to shift and to deviate from (1).

An important auxiliary method, which can be employed for the analysis of the problem, is to study the α decay intensities at the rotational levels. These intensities behave, generally speaking, in an irregular manner. For α transitions at the levels of the principal rotation band (the band beginning with the level for which $\eta \approx 1$) there exists, however, the well known formula of Ter-Martirosyan,[3] which has been experimentally confirmed with good accuracy (see, for example, reference 4).

The population of the level with energy 214.5 kev, the transition to which is facilitated, is 58.2% (see table). Assuming a value of 43 kev for the energy of the first rotational level of Ra^{225} (the energy value is taken from the level spectrum of Th^{229}, the daughter nucleus of U^{233}, and is characteristic of the entire adjacent region of nuclei) and putting $K = 5/2$ we find that the levels $(I = 7/2;\ K = 5/2)$ and $(I = 9/2;\ K = 5/2)$ should have populations ~ 10 and ~ 1.0% respectively.

It follows from the table that the required region contains only one level with a population of ~ 10%, α_{246}. Its excitation energy is, however, less than expected, merely 31.6 kev (relative to the α_{214} level).

The only possible level with $I = 9/2$ and $K = 5/2$ is α_{302}, with 1.5% population. The excitation energies of these two levels, however, do not fit the rotation formula (1).

We thus arrive at one of two possible conclusions:

1. The levels of the principal rotation band has an anomalously small population (smaller than theoretical by a factor of several times ten) and therefore do not appear in the α spectrum. This case appears to us, however, to be very unlikely, since no noticeable deviations from the Ter-Martirosyan formula have yet been observed. 2. The α_{246} level is shifted because of interaction with the α_{264} level.

As is known, interaction between levels should manifest itself particularly strongly only when their spins coincide and their K differ by unity. Since the spin of α_{246} is $7/2$, we must assume that the α_{264} level also has $I = 7/2$; inasmuch as this level is not a rotation satellite, its K also equals $7/2$. The selection rules with respect to K are thus automatically satisfied.

The "unshifted" position of the α_{246} level cannot exceed $(246+264)/2 = 255$ kev. Its excitation level lies in this case between 32 kev (observed value) and 41 kev. The upper value is in sensible agreement with the data for other nuclei.

The α_{302} level is apparently also shifted.

Let us indicate in conclusion that this interpretation raises a difficulty connected with a great difference in the α-populations of the interacting levels.

The investigation of the Ra^{225} levels will be continued by an improved procedure.

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ANGULAR DISTRIBUTION OF LONG-RANGE ALPHA PARTICLES, CONNECTED WITH THE FISSION PROCESS

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WE investigated the complex fission of U^{235} by thermal neutrons with thick photographic emulsions. In the experiments we used type P-8 photographic plates, prepared in our laboratory. The emulsion used had good discriminating ability with respect to tracks of fragments, α particles, and protons.

Cases in which a track of a long-range α particle was connected with the fission point were counted. We selected those cases, in which both the fragments and the α particle stopped in the emulsion. For approximately 600 such cases we calculated the ranges of all particles and the angles between the α particle and the fragments. The distribution of α particles by ranges, corrected for the probability of their exit from the emulsion, for the angular distribution of the α particles (Fig. 1), and for the asymmetry of fission were in good agreement with the results given in other papers.[1,2]

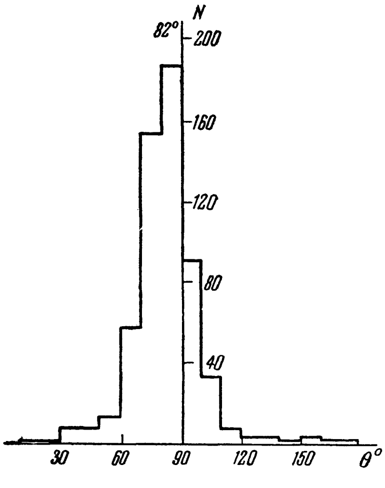

FIG. 1. Angular distribution of particles about the direction (shown by an arrow to the left) of light fission fragment.

Reference 1 proposes a mechanism whereby the production of a long-range α particle is considered as the scattering, under the influence of Coulomb forces, of three particles produced as the result of vibrations of a drop of nuclear liquid, in which the fourth harmonic, which is responsible for the triple fission, has a noticeable amplitude. Such a scheme explains satisfactorily the following: a) That the most probable angle of emission of an α particle deviates noticeably from 90° towards the lighter fragment. In fact, it is seen from Fig. 1 that the maximum in the angular distribution is located near 82° from the light fragment. b) That the energies of the α particles are close in order of magnitude to the total of the Coulomb barriers of the fragments.

Within the framework of this scheme, one would also expect the angle of emission of an α particle to be related to the asymmetry of the fragment, i.e., deviations from the most probable value in the angular distribution (82°) should result either from a more symmetrical fission (towards 90°), or a more asymmetric one (towards smaller angles). In addition, the angle of emission of the α particle should not be greater than 90° relative to the light fragment.

The experimental data,* however, indicate lack of agreement with the expected results.

1. There is a considerable number of cases when the α particle is emitted more than 90° from the track of the light fragment. Furthermore, it has been noted that the angular distribution broadens with increasing range of the α particle. If the graph shown in Fig. 1 is broken up into three parts for three α-particle ranges (up to $100\,\mu$, from 100 to $200\,\mu$, and above $200\,\mu$ of range in photographic emulsion), the graphs obtained (see Fig. 2) differ noticeably from each other. The half-width of the distribution curve increases with range, and at maximum range the angular distribution for the α particles becomes nearly isotropic. On the other hand, almost no angles greater than 90° are observed for α particles with ranges less than $100\,\mu$. Thus, the greater the energy of the α particle, the more independent its behavior in the field of two heavy fragments.

2. To estimate the influence of the magnitude of the mass asymmetry on the α-particle emission angle we can employ, with a certain degree of approximation, the value of the asymmetry of the fragment ranges provided we neglect the difference in v(R) of the light and heavy fragments. The mean values of R_L/R_H for α particles emitted at angles both greater and less than 82°