RATIO OF ISOMERIC AND GROUND STATE YIELDS OF Zn^{69} *PRODUCED IN VARIOUS NUCLEAR REACTIONS*

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The ratio of the amounts of Zn^{69} produced in the isomeric and ground states in the $Zn^{68}(dp)Zn^{69}$, $Ga^{69}(np)Zn^{69}$, and $Ga^{71}(d\alpha)Zn^{69}$ reactions was studied. In the first reaction the relative yield of the isomeric state initially increases with increasing deuteron energy, and then remains constant (at about half the ground-state yield). In the second reaction, the ratio is 1.4 for 14-Mev neutrons; in the third reaction it is about 0.5 for 6 to 8 Mev deuterons. The results are discussed on the basis of various reaction mechanisms (direct interactions like stripping, and compound nucleus formation).

It was shown in various papers[1,2] that when thermal neutron capture can result in formation of the isomeric and ground states of the final nucleus, there is preferential formation of the final state whose spin is closer to that of the initial nucleus.

The suggestion has been made that in reactions with faster particles the probabilities of formation of the isomeric and ground states should be proportional to the statistical weights of these states,[2,3] but this hypothesis is not always in agreement with the experimental data.[3] The apparent explanation is that the probabilities of formation of the final nucleus in various states depend to a considerable extent on the reaction mechanism. If the reaction proceeds via formation of a compound nucleus, then for low energies of the initial particles there should be preferential formation of those states of the final nucleus whose spin differs least from that of the initial nucleus, since the influence of the centrifugal barrier will lead to preferential formation of states of both the compound and final nucleus whose spins are close to that of the target nucleus. With increasing energy of the primary particles, the influence of the centrifugal barrier decreases, and there is an increase in the number of competing cascade transitions and the number of possible excited states in which the final nucleus is formed. This should make the populations of the isomeric and ground states of the final nucleus proportional to the statistical weights of the states. In reactions which proceed via direct interaction, the most probable process may lead to final states with all sorts of spin values, so that the ratio of the populations of the isomeric and ground states should be characteristic for the particular reaction and have entirely different numerical values for different reactions.

In order to determine the relative importance of direct interactions and compound nucleus formation, we undertook an experiment to find the ratio σ^*/σ of the yields in the isomeric and ground states of Zn^{69} formed in various nuclear reactions. Zn^{69} is a β^- emitter with a half life of 57 min, and has an isomeric state which decays to the ground state with a half life of 13.8 hr. Since these periods are markedly different, one can find the ratio σ^*/σ by analysis of the decay curve obtained by counting β particles in a Geiger counter which is not sensitive to γ-rays. Previous to this, measurements have been made of ratios of isomeric to ground state of Zn^{69} formed from thermal neutron capture[1] in Zn^{68} ($\sigma^*/\sigma = 0.29$), and of Zn^{69} produced in the $Ge^{72}(n,\alpha)Zn^{69}$ reaction with 14-Mev neutrons[4] ($\sigma^*/\sigma = 1.1$).

We have studied the $Zn^{68}(d,p)Zn^{69}$, $Ga^{69}(n,p)Zn^{69}$, and $Ga^{71}(d,\alpha)Zn^{69}$ reactions. The deuteron irradiations were done inside the cyclotron chamber. The energy spread of the deuterons in the cyclotron and the effect of target thickness gave an overall energy spread of the order of 0.5 Mev. We should therefore expect several excited states of the compound nucleus to be produced. The targets were irradiated with neutrons in a neutron generator with a tritium target. In both the neutron and deuteron irradiations several interfering activities are produced, so it was necessary to separate the zinc by radiochemical methods.

The ratios σ^*/σ found for Zn^{69} from the $Zn^{68}(d,p)Zn^{69}$ reaction for various deuteron en-

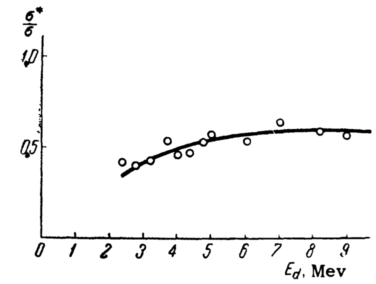

FIG. 1. Ratio σ^*/σ of probabilities of formation of Zn^{69} in isomeric and ground states from the Zn^{68} (d, p) Zn^{69} reaction, as a function of deuteron energy.

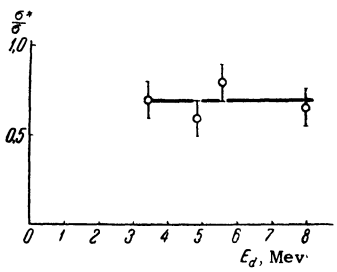

FIG. 2. Ratio σ^*/σ of probabilities of formation of Zn^{69} in isomeric and ground states from the Ga^{71} (d, α) Zn^{69} reaction, as a function of deuteron energy.

ergies are shown in Fig. 1. From the curve of Fig. 1 we see that with increasing deuteron energy the ratio σ^*/σ tends toward a constant value of ~ 0.5, and that there is a relative drop of the probability of formation of Zn^{69} in the isomeric state only at low energies. Such a dependence is completely understandable. The target nucleus has spin 0, and in Zn^{69} the ground state has spin $1/2$ while the isomeric state has spin $9/2$. Reactions like (d, p) should proceed with high probability via the stripping mechanism; for low deuteron energies the entry of the neutron into the nucleus into a $9/2$ level is hindered by the centrifugal barrier, so this naturally results in a relative decrease in the yield of Zn^{69} in the isomeric state.

For the Ga^{69}(n, p)Zn^{69} reaction we found the ratio σ^*/σ only for 14-Mev neutrons. It was 1.4, so in this case formation of the isomeric state is more probable. In the Zn^{68}(d, p)Zn^{69} reaction, at the highest deuteron energies the same compound nucleus Ga^{70} is formed with approximately the same excitation as in the second reaction. The marked difference in the ratio σ^*/σ for the two cases shows that in these processes, or in any case in one of them (probably the first) the principal reaction mechanism is not related to formation of a compound nucleus.

The values of σ^*/σ found for the Ga^{71}(d, α)Zn^{69} reaction at various deuteron energies are shown in Fig. 2; they are all equal to ~ 0.5 within the limits of accuracy of the measurements. A different reaction, Ge^{72}(n, α)Zn^{69}, which leads to formation of Zn^{69} via the compound nucleus Ge^{73}, was studied by Levkovskii.[4] For 14-Mev neutrons he found $\sigma^*/\sigma = 1.1$. The energies of excitation of the compound nucleus are the same in the Ga^{71}(d, α)Zn^{69} reaction with 6-Mev deuterons and in the Ge^{72}(n, α)Zn^{69} reaction with 14-Mev neutrons, while the values of σ^*/σ differ by more than a factor of two. From this we must conclude that at least one of these reactions proceeds mainly via a mechanism which is not related to compound nucleus formation.

In the reactions Zn^{68}(d, p)Zn^{69} and Ga^{71}(d, α)Zn^{69}, for which we have measured σ^*/σ as a function of energy of the incident particles, this ratio remained almost constant. It therefore seems most reasonable to assume that the processes we have studied proceed mainly via direct interactions, where for each type of primary particle and target nucleus there are certain processes which have high probability and which lead to formation of definite final states which are characteristic for the particular reaction and depend very little on the energy of the incident particles.

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[2] E. der Mateosian and M. Goldhaber, Phys. Rev. 108, 766 (1957).

[3] Meadows, Diamond and Sharp, Phys. Rev. 102, 190 (1956).

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