TWO-NEUTRON CAPTURE REACTION IN THE INTERACTION BETWEEN N^{14} *AND NUCLEI OF SOME ELEMENTS**

V. A. KARNAUKHOV, G. M. TER-AKOP'YAN, and V. I. KHALIZEV

Submitted to JETP editor September 13, 1958

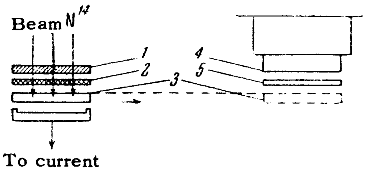
J. Exptl. Theoret. Phys. (U.S.S.R.) **36**, 748-750 (March, 1959)

Targets made of LiF, Al, and Cu were irradiated with ~ 92-Mev N^{14} ions. The radioactive isotope N^{16} was identified among the reaction products by its decay period and by the beta-particle energy. It is concluded that N^{16} is formed through "capture" of two neutrons from the target by the bombarding particle.

In many investigations of the interaction between heavy particles (C, N, O) with nuclei[1-6] there were observed the so called "capture" and "stripping" reactions, in which the bombarding particle captures a neutron, proton, or α particle from the target nucleus, or else adds such a particle to it. A detailed investigation of the "stripping" of a neutron in the bombardment of various targets by N^{14} ions $[Z^A(N^{14}, N^{13})Z^{A+1}]$[3,6] indicates that reactions of this type occur, in all probability, in the case of glancing collision between the interacting nuclei, without formation of a compound nucleus. The energy transferred in this case is small. This causes, in particular, the kinetic energy (and consequently the range) of the N^{13} nuclei not to differ much from the kinetic energy and range of the N^{14} ions. The large range of the reaction products of "stripping" and "capture" makes it possible to separate them from the reaction products of the decay of the compound nucleus, without having to resort to radiochemical methods.[6]

It appears to us that to investigate the mechanism of interaction between heavy particles and nuclei in the case of glancing collisions it is advisable to study not only the foregoing reactions, but also the "stripping" and "capture" of two neutrons. A detailed investigation of this process may yield useful information on the structure of the periphery of the nucleus, particularly on the character of the interaction of the outer neutrons. The possibility of "capture" of two neutrons follows from the work of Alkhazov et al.,[7] who observed the formation of N^{16} in the irradiation of LiCl by 15.6-Mev N^{14} ions. However, the results obtained do not lead to definite conclusions concerning the mechanism by which this isotope is produced.

It was the purpose of this investigation to observe the "capture" of two neutrons in the interaction between accelerated N^{14} ions and nuclei of several elements.



The experiments were performed with the internal beam of the 150-cm cyclotron of the U.S.S.R. Academy of Sciences. Five-charge N^{14} ions with energy ~ 92 Mev were used to bombard targets of LiF, Al, and Cu. The figure shows the arrangement of the experiment. The thickness of the targets 1 was chosen such that the nitrogen ions were emitted by the target at an energy of ~ 55 Mev. Placed behind the layer of the investigated substance was a 9-μ gold foil, 2, in which the short-range reaction products were absorbed. No nuclear reactions were produced in the gold itself, since the energy of the N^{14} ions (55 Mev) was not enough for this. Placed beyond that was a tantalum plate, 3, which collected both the beam and the reaction products that passed through the gold foil. The collector was moved periodically to a luminescent beta-particle counter 4, with a thick stilbene crystal (30 mm in diameter and 30 mm high), so that the counting could start 5 seconds after the end of the irradiation. The counter, placed in a magnetic shield, was 2 meters away from the target. To reduce the background due to beta particles with energies less than 1.0 Mev, a 1.5-mm aluminum absorber, 5, was placed in front of the crystal. The electronic circuitry employed comprised a single-channel amplitude analyzer, which determined the beta-particle energy and simultaneously measured the drop in

*The results of this work were reported in the survey paper by G. N. Flerov at the All-Union Conference on Nuclear Reactions at Low and Medium Energies (1957).

activity with time. The beam intensity was measured when the collector was near the counter. The ion current amounted to $0.1 - 0.3\,\mu a$. The intensity of the beam was stable enough throughout the experiments for quantitative estimates of the cross sections.

The irradiation of each target (LiF, Al, Cu) resulted in a beta activity with a half-life $T = 7.5 \pm 1$ sec and a maximum beta-particle energy $E_{max} > 7$ Mev.

In the experimental setup used, the only nuclei that could proceed from the target to the tantalum collector were those formed by "stripping" or "capture." The registration of isotopes — decay products of the compound nucleus — was excluded, since they were absorbed in the gold-foil shield. The fact that irradiation of targets having so wide a range of atomic numbers produced the same activity also indicates that this activity is obviously connected with the decay of the isotope that is produced by the "stripping" or "capture" reactions. An analysis of the possible products of such reactions leads to the conclusion that the observed beta activity must be attributed to the decay of the N^{16} nucleus ($T = 7.35$ sec., $E_{max} = 10.4$ Mev) which is formed by "capture" of two neutrons by the N^{14} nitrogen from the target nucleus.

Target	LiF		Cu		Al
	Li	F	Cu^{63}	Cu^{65}	
Q, Mev	+0.55	−6.65	−5.86	−4.37	−11.06
Relative yield of β activity with $T \approx 7.5$ sec.	100		30		3

A characteristic feature of the reaction that occur during glancing collisions, as already mentioned, is the large range of the nuclei formed from the bombarding particle. To disclose more clearly this feature of the mechanism of N^{16} production, an experiment was performed, in which we used a thinner target made of copper, covered on the collector side with a gold foil $15\,\mu$ thick. The yield of N^{16} per single copper atom was reduced here by $20 - 40\%$. For comparison we indicate that 2 or $3\,\mu$ of gold are sufficient to absorb completely the decay products of the compound nucleus formed upon fusion of the gold and copper nuclei.[8] No beta activity with a half-life of approximately 7.5 sec. was observed in a control experiment in which a gold target of equivalent thickness was irradiated.

The table lists a relative yield of the observed beta activity for various targets, referred to one atom of the investigated matter. The table also lists the values of Q, the difference in the binding energy of two neutrons in N^{16} and in the target nucleus:

$$Q = E_{2n}(N^{16}) - E_{2n}(Z^A).$$

(In the calculation of this quantity we used the data of reference 9 on the binding energy of the nuclei). It is seen that as Q decreases the activity yield decreases. This variation serves as further confirmation of the conclusions concerning the production of N^{16}. It must be noted that in the case of LiF target, the N^{16} nucleus appears obviously mostly as the result of the interaction of the nitrogen N^{14} with lithium.

What attracts attention is the absence of this effect in the bombardment of a gold target, although in this case the reaction of "capture" of two neutrons is energetically quite feasible. This is obviously connected with the fact that the produced N^{16} nuclei are so strongly deflected in the field of a target nucleus away from the direction of the bombarding-particle beam, that they do not fall on the collector.

The cross section of the reaction that leads to the appearance of the radioactive N^{16} upon interaction of N^{14} with lithium, averaged over the ion energy in the interval from ~ 92 to ~ 55 Mev, amounts to $\sim 5 \times 10^{-28}$ cm^2. This quantity must be considered as the lower limit of the cross section for the "capture" of two neutrons by a N^{14} nucleus, since the production of N^{16} in the excited state at sufficiently high excitation leads to the evaporation of a neutron: $N^{14} + 2n \rightarrow N^{16*} \rightarrow N^{15} + n$. This circumstance may also cause the yield of N^{16} to decrease with increasing energy of bombarding particles, owing to the increase in the average excitation energy of the nitrogen nucleus in the "capture" of the two neutrons.

The authors are grateful to Prof. G. N. Flerov for continuous attention in the work, and also to the cyclotron crew members, headed by Yu. M. Pustovoĭt, for ensuring correct operation of the apparatus.

[1] K. F. Chackett and I. H. Fremlin, Phil. Mag. **45**, 735 (1954).

[2] Chackett, Chackett, and Fremlin, Phil. Mag. **46**, 1 (1955).

[3] H. L. Reynolds and A. Zucker, Phys. Rev. **101**, 166 (1956).

[4] Reynolds, Scott, and Zucker, Phys. Rev. **102**, 237 (1956).

[5] H. L. Reynolds and A. Zucker, Phys. Rev. **106**, 251 (1957).

[6] Volkov, Pasyuk, and Flerov, J. Exptl. Theoret. Phys. (U.S.S.R.) **33**, 595 (1957), Soviet Phys. JETP **6**, 459 (1958).

[7] Alkhazov, Gangarskii, and Lemberg, J. Exptl. Theoret. Phys. (U.S.S.R.) **33**, 1160 (1957), Soviet Phys. JETP **6**, 892 (1958).

[8] Parfanovich, Rabin, and Semchinova, J. Exptl. Theoret. Phys. (U.S.S.R.) **31**, 188 (1956), Soviet Phys. JETP **4**, 99 (1956).

[9] A. H. Wapstra, Physica **21**, 367 (1955).

Translated by J. G. Adashko
138