PHYSICAL REVIEW C VOLUME 10, NUMBER 2 AUGUST 1974

γ-ray transitions in ^{48}Cr and ^{60}Zn

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(Received 28 January 1974)

The level structure of the $N = Z =$ even nuclei ^{48}Cr and ^{60}Zn was investigated. The levels were excited in the (^{3}He, n) reaction. By measuring direct γ radiation in coincidence with the outgoing neutrons information about the γ decay of the levels was obtained.

[NUCLEAR REACTIONS ^{46}Ti, ^{58}Ni (^{3}He, $n\gamma$), $E = 10$ MeV measured $E\gamma$, $I\gamma$, $n\gamma$ coin deduced ^{48}Cr, ^{60}Zn levels, J, π. Enriched targets. Ge(Li) detector.]

INTRODUCTION

Until recently nothing was known of the γ-ray transitions in the $N = Z =$ even nuclei ^{48}Cr and ^{60}Zn. These nuclei are hard to investigate with light-particle-induced reactions because of the low cross sections. Information about ^{48}Cr was obtained by the ^{46}Ti(^{3}He, n)^{48}Cr[1] and ^{50}Cr(p, t)^{48}Cr[2-4] reactions and, recently, the γ decay of levels excited by the ^{40}Ca(^{10}B, $pn\gamma$)^{48}Cr[5] reaction was investigated. The structure of ^{60}Zn was studied by neutron detection after the ^{58}Ni(^{3}He, n)^{60}Zn[6,7] reaction and with the ^{58}Ni(^{16}O, ^{14}C)^{60}Zn[8] reaction. ^{60}Zn is the heaviest $N = Z =$ even nucleus of which some level structure is known. Since no γ rays are reported from this nucleus, we investigate these nuclei with in-beam γ spectroscopy.

EXPERIMENTAL PROCEDURE AND RESULTS

^{48}Cr and ^{60}Zn levels were excited with the ^{3}He, n reaction on enriched self-supporting 2 mg/cm^2 foils of ^{46}Ti(^{46}Ti : 86.1%; ^{47}Ti : 1.6%; ^{48}Ti : 10.6%; ^{49}Ti : 0.8%; ^{50}Ti : 1.0%), and ^{58}Ni(^{58}Ni : 99%). Because of the large ^{48}Ti contamination experiments on natural Ti were also done. 10 MeV ^{3}He beams from the AVF cyclotron der Vrije Universiteit were used. Single γ spectra were measured with a Ge(Li) detector with an efficiency of 3.5%. The neutrons were detected with a 10 cm diam × 10 cm NE213 liquid scintillator. Neutron-γ separation was performed with the zero-crossover technique. For each observed neutron-γ coincidence, the energy of the γ ray, the height of the pulse from the neutron detector, and the time difference in the zero-crossover from neutron and γ pulses from the NE213 were dumped on magnetic tapes and afterwards analyzed.[9] The contribution of the (^{3}He, $pn\gamma$) reaction is relatively small. Moreover, for the assignment of the γ rays we had to select the energy of the outgoing neutron by setting software windows in the NE213 energy spectra during the analyses, which caused a further reduction of the (^{3}He, $pn\gamma$) contribution. γ rays were detected at 90° at a distance of 3 cm from the target. The neutron detector was located at 0° and at 3.5 cm from

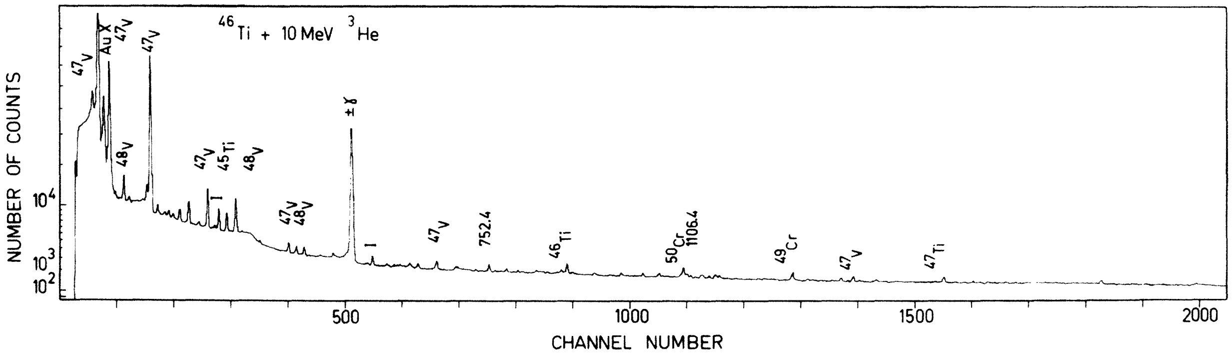

FIG. 1. 10-MeV ^{3}He on ^{46}Ti single γ spectrum. The beam was stopped in a gold backing.

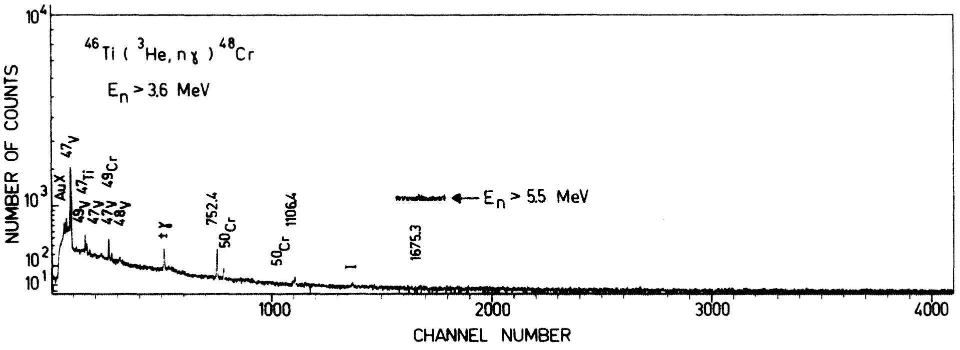

FIG. 2. γ spectrum coincident with neutrons with an energy above 3.6 MeV.

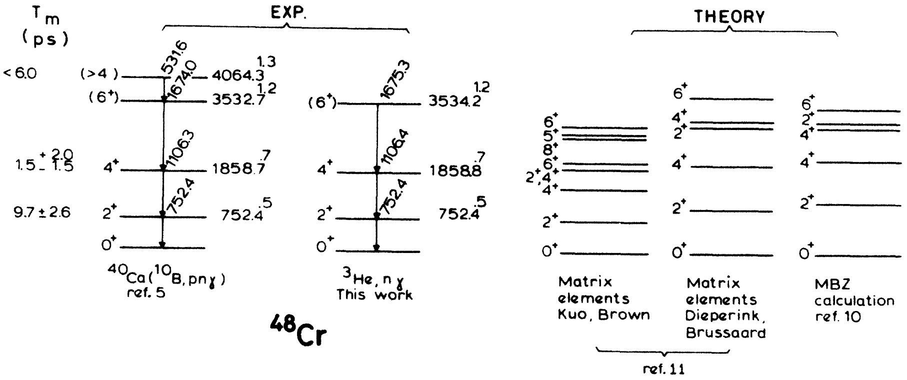

FIG. 3. Proposed level scheme of ^{48}Cr.

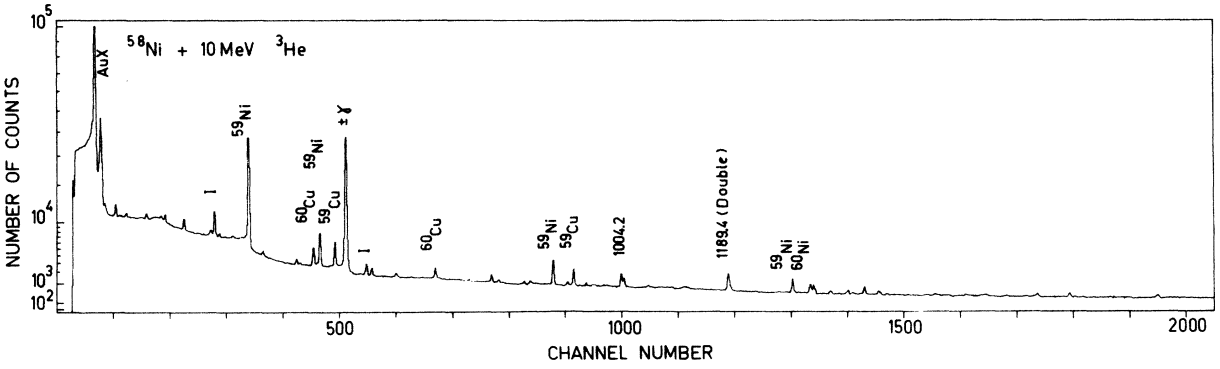

FIG. 4. 10-MeV ^{3}He on ^{58}Ni single γ spectrum. The beam was stopped in a gold backing.

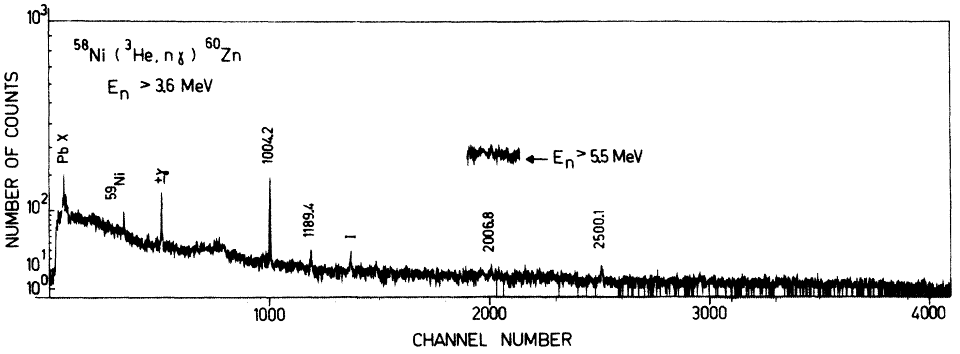

FIG. 5. γ spectrum coincident with neutrons with an energy above 3.6 MeV.

TABLE I. γ-ray energies and intensities of ^{48}Cr.

	^{48}Cr
E_γ (keV)	I_γ coincident with neutrons, $E_n > 3.6$ MeV
752.4 (0.5)	100
1106.4 (0.5)	18 ± 3
1675.3 (1.)	19 ± 2

TABLE II. γ-ray energies and intensities of ^{60}Zn.

	^{60}Zn
E_γ (keV)	I_γ coincident with neutrons, $E_n > 3.6$ MeV
1004.2 (0.5)	100
1189.4 (0.5)	17 ± 3
2006.8 (1.)	4 ± 2
2506.1 (1.)	23 ± 4

the target.

The single γ-ray spectrum from reactions with 10-MeV ^{3}He on ^{46}Ti is seen in Fig. 1. The γ spectrum coincident with neutrons with an energy above 3.6 MeV shows clearly the lines that belong to the ^{46}Ti(^{3}He, $n\gamma$)^{48}Cr reaction (Fig. 2). Energies and intensities are given in Table I. The proposed level scheme of ^{48}Cr, given in Fig. 3, is in excellent agreement with Ref. 5 except for the 532-keV transition. This γ ray could only be seen rather vaguely in their γ-γ coincidence spectra. The single γ-ray spectrum from reactions with 10-MeV ^{3}He on ^{58}Ni is shown in Fig. 4. In the spectrum of γ rays coincident with neutrons with an energy above 3.6 MeV, the γ rays that correspond to the ^{58}Ni(^{3}He, $n\gamma$)^{60}Zn reaction are shown (Fig. 5). Energies and intensities are given in Table II. With the assumption of a 4^+ state at 2193 keV one can assign 2^+ for the 4200.4-keV level. The proposed level scheme is given in Fig. 6.

Lifetime measurements on the first excited state of ^{60}Zn by means of the Doppler shift attenuation method could not be performed because the total energy shift, calculated from the kinematics with the necessary neutron detection at 0°, is only 1.7 keV.

Shell model calculations for ^{48}Cr have been performed by assuming a closed ^{40}Ca core with four protons and four neutrons in the $1f_{7/2}$ shell.[10,11] Different sets of matrix elements were used as indicated in Fig. 3. By assuming ^{56}Ni as an inert core, shell model calculations for ^{60}Zn were done with matrix elements derived from Yale-Reid[12] and Hamada-Johnston[13,14] potentials. Perazzo[13] also used the Auerbach and Argonne interaction. In Fig. 6, two of these calculations are compared with the experimental data. The wave functions of Singh[14] indicate that no simple shell model picture of ^{60}Zn exists. This calculation is the only one that reproduces correctly the first excited 0^+ state. The second 2^+ state below 4 MeV is predicted by Perazzo.[13] Unfortunately no transition probabilities are calculated for this level. Experimentally this level seems to decay preferentially to the 4^+ state. Upper limits for the $2_2^+ \to 0_2^+$ and the $2_2^+ \to 2_1^+$ transitions could not be extracted with a reasonable accuracy because of the low statistics of the 2006.8-keV γ ray.

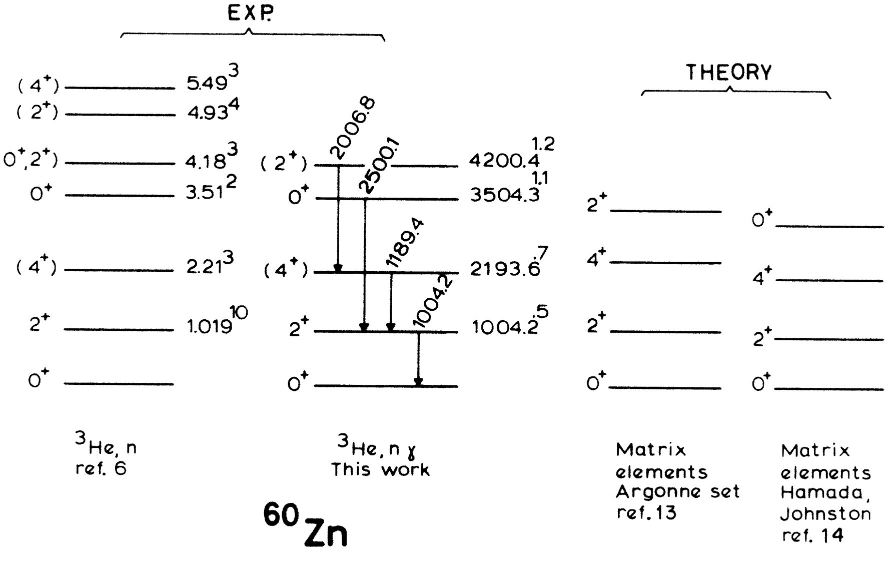

FIG. 6. Proposed level scheme of ^{60}Zn.

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