# $\gamma$-ray transitions in $^{48}$Cr and $^{60}$Zn

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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 $\gamma$ radiation in coincidence with the outgoing neutrons information about the $\gamma$ 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, $J$, $\pi$. Enriched targets. Ge(Li) detector.]

## INTRODUCTION

Until recently nothing was known of the $\gamma$-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 $\gamma$ 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 $\gamma$ rays are reported from this nucleus, we investigate these nuclei with in-beam $\gamma$ 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 $\gamma$ 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-$\gamma$ separation was performed with the zero-crossover technique. For each observed neutron-$\gamma$ coincidence, the energy of the $\gamma$ ray, the height of the pulse from the neutron detector, and the time difference in the zero-crossover from neutron and $\gamma$ 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 $\gamma$ 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. $\gamma$ 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

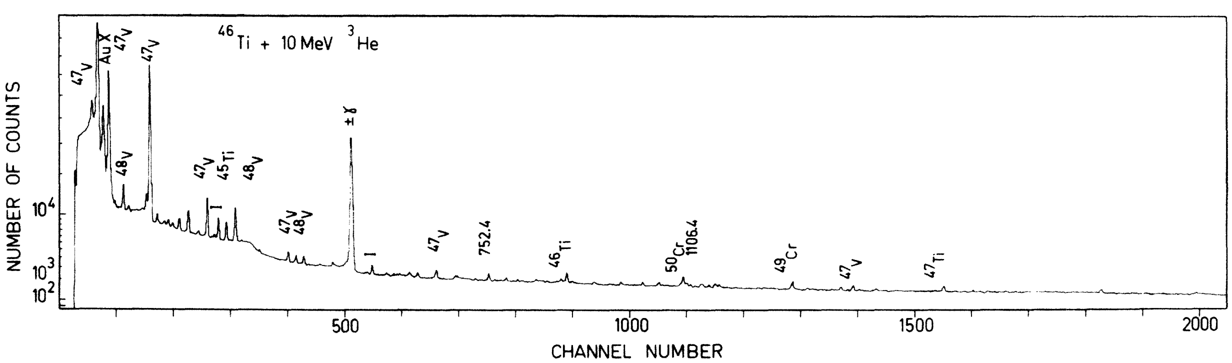


FIG. 1. 10-MeV $^3$He on $^{46}$Ti single $\gamma$ spectrum. The beam was stopped in a gold backing.

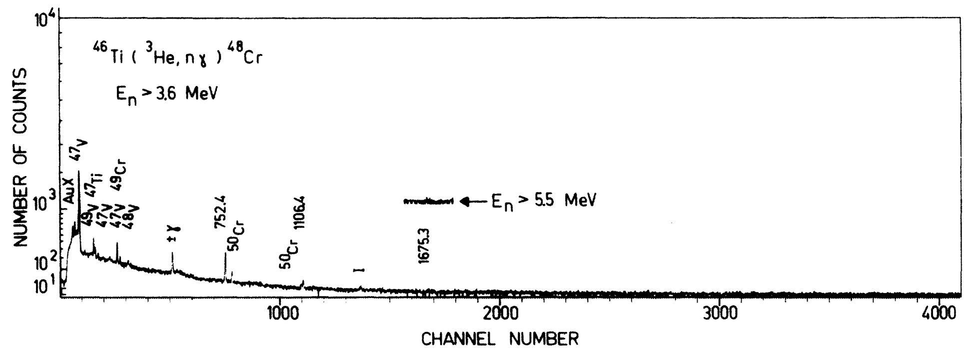


FIG. 2. γ spectrum coincident with neutrons with an energy above 3.6 MeV.

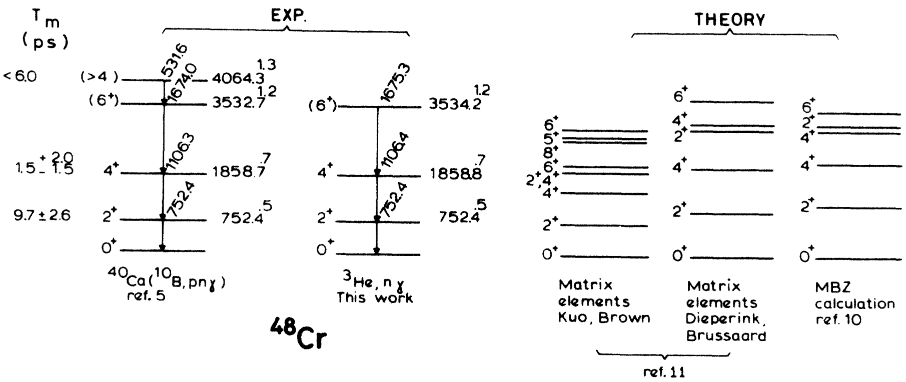


FIG. 3. Proposed level scheme of $^{48}$Cr.

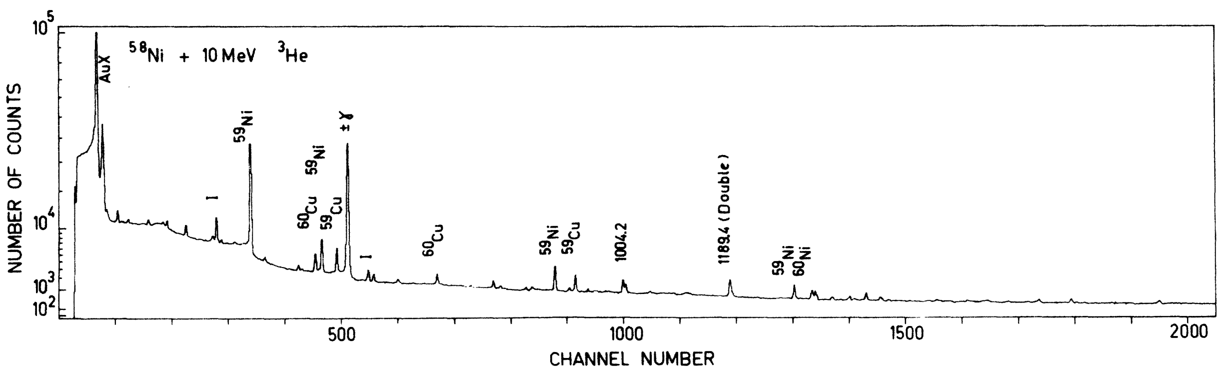


FIG. 4. 10-MeV $^{3}$He on $^{58}$Ni single γ spectrum. The beam was stopped in a gold backing.

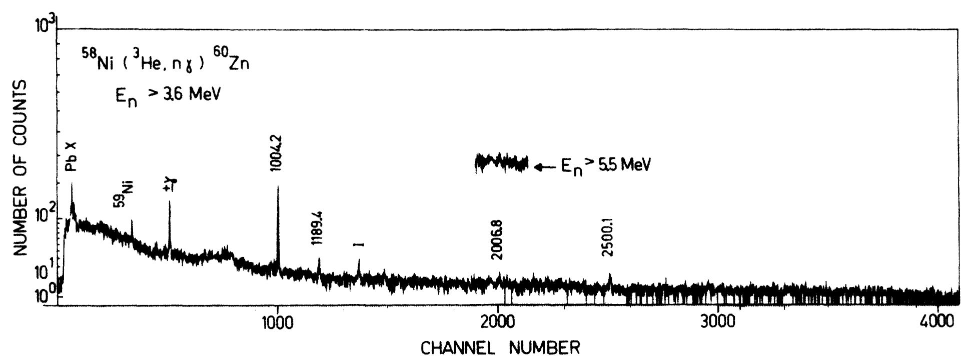


FIG. 5. γ spectrum coincident with neutrons with an energy above 3.6 MeV.

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

| $E_\gamma$ (keV) | $^{48}$Cr $I_\gamma$ 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.

| $E_\gamma$ (keV) | $^{60}$Zn $I_\gamma$ 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 $2_2^+ \rightarrow 0_2^+$ and the $2_2^+ \rightarrow 2_1^+$ transitions could not be extracted with a reasonable accuracy because of the low statistics of the 2006.8-keV γ ray.

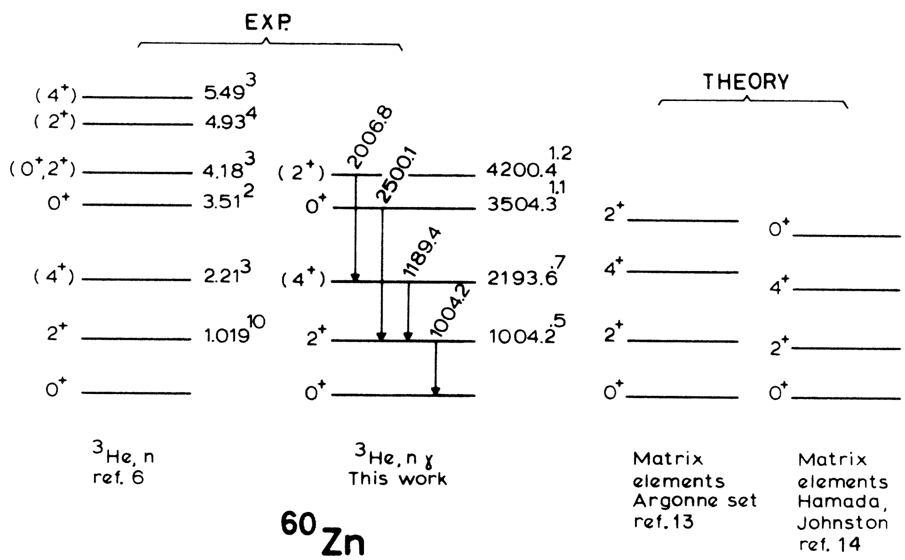


FIG. 6. Proposed level scheme of $^{60}$Zn.

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