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

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

\textbf{INTRODUCTION}

Until recently nothing was known of the \gamma-ray transitions in the $N=Z$ even nuclei $^{48}\text{Cr}$ and $^{60}\text{Zn}$. These nuclei are hard to investigate with light-particle–induced reactions because of the low cross sections. Information about $^{48}\text{Cr}$ was obtained by the $^{46}\text{Ti}($$^3\text{He}, n$)$^{48}\text{Cr}$ and $^{51}\text{Cr}$(p,$t$)$^{49}\text{Cr}$ reactions and, recently, the \gamma decay of levels excited by the $^{46}\text{Ca}$(B,$p\gamma$)$^{48}\text{Cr}$ reaction was investigated. The structure of $^{60}\text{Zn}$ was studied by neutron detection after the $^{58}\text{Ni}($$^3\text{He}, n$)$^{60}\text{Zn}$ reaction and with the $^{58}\text{Ni}($$^{16}\text{O}, ^{14}\text{C}$)$^{60}\text{Zn}$ reaction.

$^{60}\text{Zn}$ 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.

\textbf{EXPERIMENTAL PROCEDURE AND RESULTS}

$^{48}\text{Cr}$ and $^{60}\text{Zn}$ levels were excited with the $^3\text{He}, n$ reaction on enriched self-supporting 2 mg/cm$^2$ foils of $^{46}\text{Ti}$($^{46}\text{Ti}$: 86.1\%; $^{47}\text{Ti}$: 1.6\%; $^{48}\text{Ti}$: 10.6\%; $^{49}\text{Ti}$: 0.8\%; $^{50}\text{Ti}$: 1.0\%), and $^{58}\text{Ni}$($^{58}\text{Ni}$: 99\%). Because of the large $^{48}\text{Ti}$ contamination experiments on natural Ti were also done. 10 MeV $^3\text{He}$ 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 $\times$ 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.\textsuperscript{9} The contribution of the $(^3\text{He}, p\gamma)$ 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 $(^3\text{He}, p\gamma)$ contribution.

\textbf{FIG. 1. 10-MeV $^3\text{He}$ on $^{46}\text{Ti}$ single $\gamma$ spectrum. The beam was stopped in a gold backing.}
FIG. 2. $\gamma$ 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 $\gamma$ spectrum. The beam was stopped in a gold backing.

FIG. 5. $\gamma$ spectrum coincident with neutrons with an energy above 3.6 MeV.
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, $n\gamma$)$^{46}$Cr reaction (Fig. 2). Energies and intensities are given in Table I. The proposed level scheme of $^{46}$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 $^{50}$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 $^{50}$Ni($^3$He, $n\gamma$)$^{50}$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 $^{46}$Cr have been performed by assuming a closed $^{46}$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 $^{50}$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$^+_2 \rightarrow 0^+_1$ and the 2$^+_2 \rightarrow 2^+$ transitions could not be extracted with a reasonable accuracy because of the low statistics of the 2006.8-keV γ ray.

![Diagram](https://example.com/diagram.png)

**FIG. 6.** Proposed level scheme of $^{60}$Zn.
10S. Pittel, University of Pittsburgh, private communication to Shepard, Graetzler, and Kraushaar.