# HIGH-SPIN STATES IN $^{60}Cu$ AND A SIMPLE SHELL-MODEL DESCRIPTION OF THE $J^{\pi} = 6^-$ AND $9^+$ STATES IN THE ODD-ODD Cu ISOTOPES

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ABSTRACT

A level scheme of the nucleus $^{60}Cu$ is deduced from the $^{58}Ni(\alpha,pn\gamma)$ reaction. The $J^{\pi} = 6_1^-$ and $J^{\pi} = 9_1^+$ states in the odd-odd Cu isotopes are described as $(\pi p_{3/2},\nu g_{9/2})_{6^-}$ and $(\pi g_{9/2},\nu g_{9/2})_{9^+}$ states.

Few reliable results concerning the $^{60}Cu$ level scheme are known [1]. Hoffman et al. [2] have given a tentative decay scheme of $^{60}Cu$ based on the $^{58}Ni(\alpha,pn\gamma)$ reaction at 22 MeV. An high-spin state, probably $(\pi g_{9/2},\nu g_{9/2})_{9^+}$, has been located at 5990 keV [3] using the very selective reaction $(\alpha,d)$ on a $^{58}Ni$ target. Some other states are also strongly excited in this reaction[3,4] but no $J^{\pi}$ assignments were proposed.

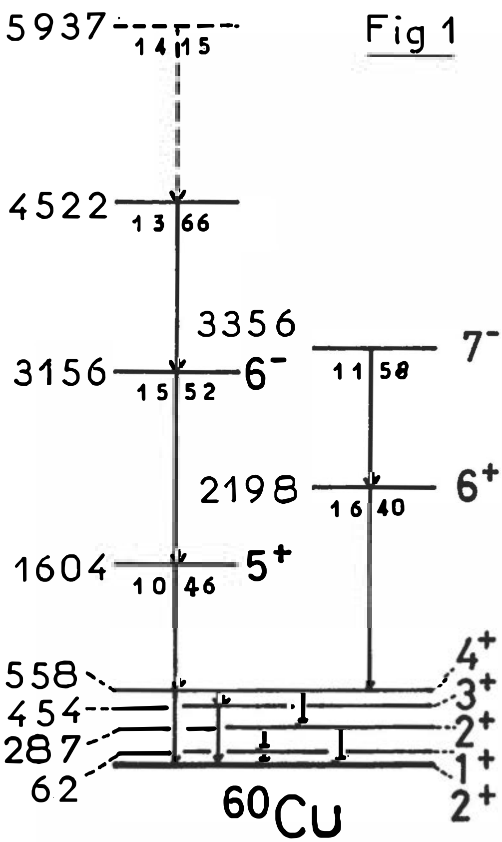



Fig 1

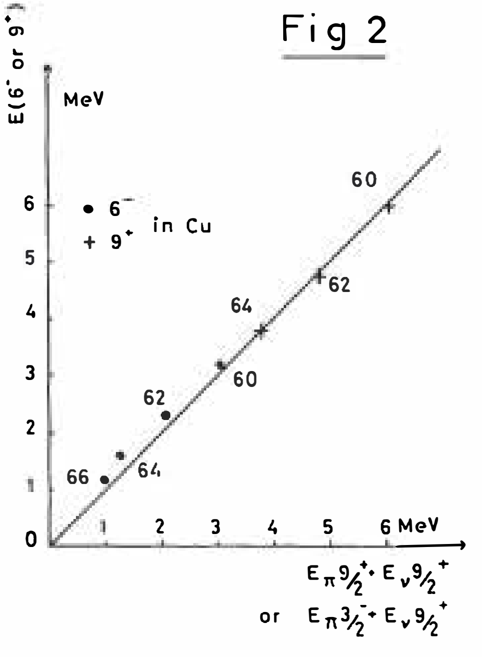
The $^{60}Cu$ level scheme presented here (fig. 1 ) is deduced from the $^{58}Ni(\alpha,pn\gamma)$ reaction studied by means of $\gamma$-spectroscopy techniques ($\gamma$-$\gamma$ coincidence and angular distribution measurements at $E_{\alpha} = 32$ MeV, yield function measurements in the range of 24 to 40 MeV and electronic timing measurements). No isomeric state ($T_{1/2} > 2$ ns) has been observed in $^{60}Cu$ using this reaction. We have established the $J^{\pi} = 5^+$ and $6^-$ character for the levels at 1604 keV and 3156 keV. These states are similar to the 1371 keV ($J^{\pi} = 5^+$) and 2296 keV ($J^{\pi} = 6^-$) levels in $^{62}Cu$ [5] and have also been strongly excited in the $(\alpha,d)$ reaction [3,4]. Shell-model calculations [6] have shown that the $J^{\pi} = 5^+$ state has mainly $(f_{5/2})^2_{5^+}$ character ; for the $J^{\pi} = 6^-$ state we propose a $(\pi p_{3/2},\nu g_{9/2})$ configuration.

The $(\pi g_{9/2},\nu g_{9/2})_{9_1^+}$ states in the odd-odd Cu, observed in the $(\alpha,d)$ reaction are generally also excited in fusion-evaporation reactions, particularly in the $(\alpha,pn\gamma)$ reaction. In $^{64}Cu$, we have recently performed an angular distribution measurement of the 609 keV $\gamma$ transition (L = 1) which allows us to assign $J^{\pi} = 9_1^+$ to the 3799 keV level [7].

If the $J^{\pi} = 9^{+}$ states in $_{Z+1}Cu_{N+1}$ have $(\pi g_{9/2}, \nu g_{9/2})_{9^+}$ character and the $J^{\pi} = 9/2^{+}$ states in $_{Z+1}Cu_{N}$ and $_{Z}Ni_{N+1}$ are pure $(\pi g_{9/2})$ and $(\nu g_{9/2})$ states, respectively, then the excitation energy of the $J^{\pi} = 9^{+}$ state is given by the following relation :

$$E_x(_{Z+1}Cu_{N+1};9^+) = E_x(_{Z+1}Cu_N;9/2^+) + E_x(_ZNi_{N+1};9/2^+) + \langle \pi g_{9/2},\nu g_{9/2}|V_{residual}|\pi g_{9/2},\nu g_{9/2}\rangle_{9^+} - B.E.(_{Z+1}Cu_{N+1}) + B.E.(_{Z+1}Cu_N) + B.E.(_ZNi_{N+1}) - B.E.(_ZNi_N).$$

A similar relation can be obtained for the $J^{\pi} = 6^{-}$ states assumed to arise from the coupling of a $p_{3/2}$ proton with a $g_{9/2}$ neutron. For the $\langle \pi g_{9/2},\nu g_{9/2}|V|\pi g_{9/2},\nu g_{9/2}\rangle_{9^+}$ matrix element the value of -1.12 MeV is deduced from the position of the known $J^{\pi} = 9^{+}$ states in $^{62,64}Cu$, the $J^{\pi} = 9/2^{+}$ states in $^{61,63}Ni$ and $^{61,63}Cu$ and the binding energies [8] involved (taken to be negative). With this empirical value of the proton-neutron matrix element we predict the $J^{\pi} = 9^{+}$ in $^{60}Cu$ at 6.0 MeV in good agreement with the ($\alpha$,d) result [3] and in $^{66}Cu$ at 3.4 MeV excitation energy. From the position of the known $J^{\pi} = 6^{-}$ states in $^{60,62,64,66}Cu$, the $J^{\pi} = 9/2^{+}$ states in the adjacent odd-even Ni and Cu isotopes the empirical value of -0.87 MeV is deduced for the $\langle \pi p_{3/2},\nu g_{9/2}|V|\pi p_{3/2},\nu g_{9/2}\rangle_{6^-}$ matrix element.




The consistency of the results shows that the configurations considered are indeed rather pure and, moreover, that valuable information about the residual interaction can be deduced from the position of these high-spin states.

The figure 2 shows the correlation between the excitations energies of the $6^{-}$ and $9^{+}$ states and the $g_{9/2}$ single particle energies.

Such a simple shell model description has also been satisfactorily applied to other two-nucleon, high-spin states in many nuclei [9].

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