M1 transitions in ^{169}Lu and neighbour nuclei*

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The enhanced M1 transitions in odd-Z *[1]* nuclei provide the possibility of studying the matrix elements which are related to the currents associated with the nucleonic motion in the nucleus and therefore directly connected with the nuclear single particle and collective angular momenta and their coupling schemes *[2]*. In the present studies the nucleus ^{169}Lu has been re-investigated with the NORDBALL detector array and the $^{154}Sm(^{19}F, 4n)^{169}Lu$ reaction, extending the present knowledge *[3]* up to, and beyond the strongly pronounced up-bends for the $\frac{1}{2}$[541], $\frac{7}{2}$[404], $\frac{1}{2}$[411], $\frac{5}{2}$[402] and $\frac{9}{2}$[514] configurations. In the two bands based on the $\frac{7}{2}^{+}$[404] and $\frac{9}{2}^{-}$[514] orbitals both signatures are well established. The K-forbidden M1 transitions between $\frac{5}{2}^{+}$[402] and $\frac{1}{2}^{+}$[411] bands are observed and interpreted in terms of a pronounced mixing due to the proximity of the states at $I \sim 13/2$ belonging to these bands. Another striking feature observed in the present studies (not considered here) is that states in the $\frac{1}{2}^{+}$[411] band with $\alpha = -\frac{1}{2}$ decay systematically by E1 transitions in competition to the E2 intraband transitions (refs.*[4]* and *[5]*). Besides the connections with the [541] band, the [411] band is coupled via M1 transitions with the decay sequence associated with the $\frac{5}{2}^{+}$[402] Nilsson configuration. These M1 transitions from the $\alpha = +\frac{1}{2}$ signature partner of the $\frac{5}{2}^{+}$[402] to the $\alpha = -\frac{1}{2}$ signature partner of the $\frac{1}{2}^{+}$[411] band are seen when gating on both decay sequences and have to be understood as due to a mixing of the states belonging to the two sequences considered, which at low spin are quite close in energy. In the present study the [402] sequence was extended from $I^{\pi} = \frac{15}{2}^{+}\hbar$, *[3]* to $I^{\pi} = \frac{45}{2}^{+}(\frac{49}{2}^{+})$ as illustrated on the partial level scheme in fig.1. However, due to the mixing between the $\alpha = +\frac{1}{2}$ signature partners of the $\frac{1}{2}^{+}$[411] and $\frac{5}{2}^{+}$[402] bands the character of favoured $\frac{5}{2}^{+}$[402] band could be closer to being the unfavoured signature partner of the $\frac{1}{2}^{+}$[411] band. Similarly as in the even-even neighbours a large interaction between the ground band and s-band with a pair of $i_{13/2}$ quasineutrons aligned is appearing. Correspondingly, the all

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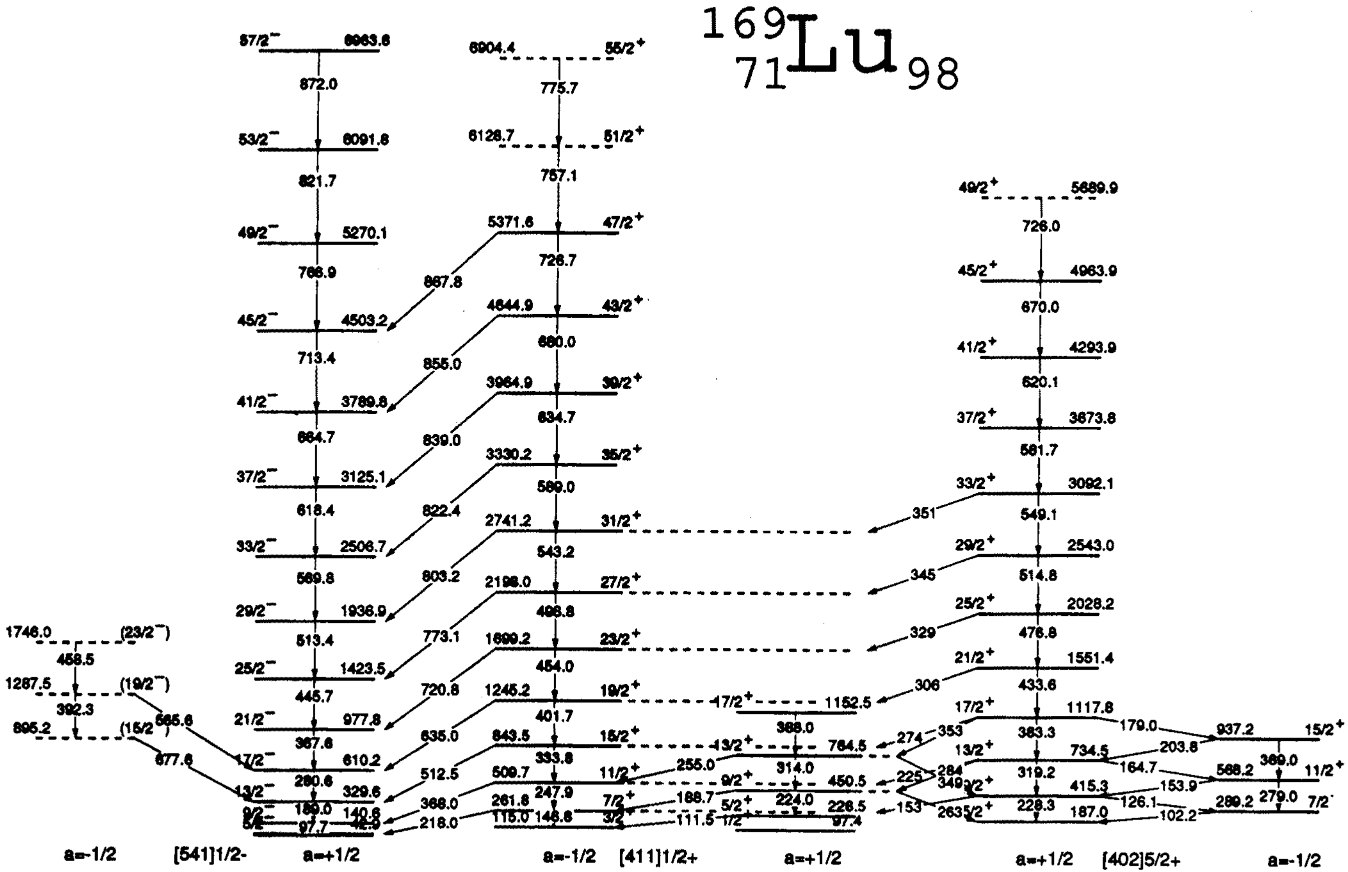

Figure 1: The partial level scheme of ^{169}Lu showing states populated in the $^{154}Sm(^{19}F,4n)$ reaction at 85 MeV. The assignment [9] of the bands to Nilsson orbitals is based mainly on the systematics of level energies of neighbouring odd-Z even-N nuclei.

observed alignment curves for the various quasiproton configurations in ^{169}Lu show gentle up-bends. The $\frac{7}{2}^+$[404] and $\frac{9}{2}^-$[514] configurations are both positive sloping in the Nilsson diagram. The atypical behaviour of the two N=4 $\frac{5}{2}^+$[402] and $\frac{1}{2}^+$[411] Nilsson orbitals could be connected with a pronounced mixing between them (cf. the observation of the linking intense K-forbidden M1-transitions as well as E2 transitions between them). The $\frac{5}{2}^+$[402] orbital is rather "oblate-driving", while $\frac{1}{2}^+$[411] Nilsson state seems to be a deformation independent. It is interesting, however, to note that the band crossing connected to the $\frac{1}{2}^+$[411] orbital is delayed and rather close to that observed for the "prolate-driving" $\frac{1}{2}^-$[541] orbital. Using the experimental branching, λ and mixing δ ratios for the ΔI = 1 transitions connecting the two signatures of the decay sequences, the ratios of the reduced magnetic dipole and electric quadrupole transition probabilities are extracted. Results for decay sequences associated with the $\frac{7}{2}^+$[404] and $\frac{9}{2}^-$[514] Nilsson states in ^{169}Lu are shown as a function of spin in fig.2. The measured ratios are clearly configuration dependent. The magnetic dipole transition rates depend on quasiproton configurations, while such dependence is not expected for $B(E2, I \rightarrow I-2)$ values which mainly reflect the nuclear shape. The configuration and spin dependence are therefore assumed to reflect mainly the behaviour of the magnetic dipole operator. We calculate the B(M1)/B(E2) ratios using a particle-rotor model, in which one-quasiproton $(\pi h_{11/2})$ $((\nu g_{7/2}))$ configurations and one-quasiproton plus two-quasineutron $(\pi h_{11/2})(\nu i_{13/2})^2$ $((\pi g_{7/2})(\nu i_{13/2})^2)$ configurations are included. In the calculation $B(E2: I \rightarrow I-2)$ values are estimated by assuming $(Q_t)^2 = 50b^2$, while moments of inertia are adjusted so as to reproduce the observed level scheme as much as possible. We comment that the increase of the the calculated ratio for lower angular momentum (i.e. $I_i \leq 21/2$) comes from the decrease of $B(E2: I \rightarrow I-2)$ values due to high-K values of the present bands, and not from the increase of $B(M1: I \rightarrow I-1)$ values. The increase of B(M1) values at the S-band crossing (around $I_i \sim 33/2$) can be easily recognized in the fig.2. Similar behaviour was observed for the B(M1)/B(E2) ratios of the e.g. [514] decay sequences associated with lowest $\pi h_{11/2}$ configurations for $^{161-167}Lu_{90-98}$, $^{157}Ho_{90}$ and $^{159}Tm_{90}$ nuclei (*refs.[1,6,7,8]*).

The high M1 transition rates ($\sim 1000 mW.u.$) above the crossing point may be also understood on the basis of a semi-classical consideration developed by Dõnau and Frauendorf *[9]*. In such a picture the M1 radiation is generated by the magnetic moment μ rotating around the space-fixed angular momentum I. Thus, the effective component of μ is perpendicular to I, and the square of $\mu_\perp$ is proportional to the reduced magnetic dipole transition probability $B(M1, I \rightarrow I-1)$. After the first band crossing where the two neutrons align, the total angular momentum has an extra component and the dynamic moment $\mu_\perp$ is icreasing considerably.

Calculations of the two bands, $\frac{1}{2}^+$[411] and $\frac{5}{2}^+$[402], are performed using a particle-rotor model in which one-quasiproton configurations are those with $N_t = 4$ in a modified oscillator potential. We have found that using a given moment of inertia of the core it is not possible to obtain a band-crossing so that at higher angular momentum the members of

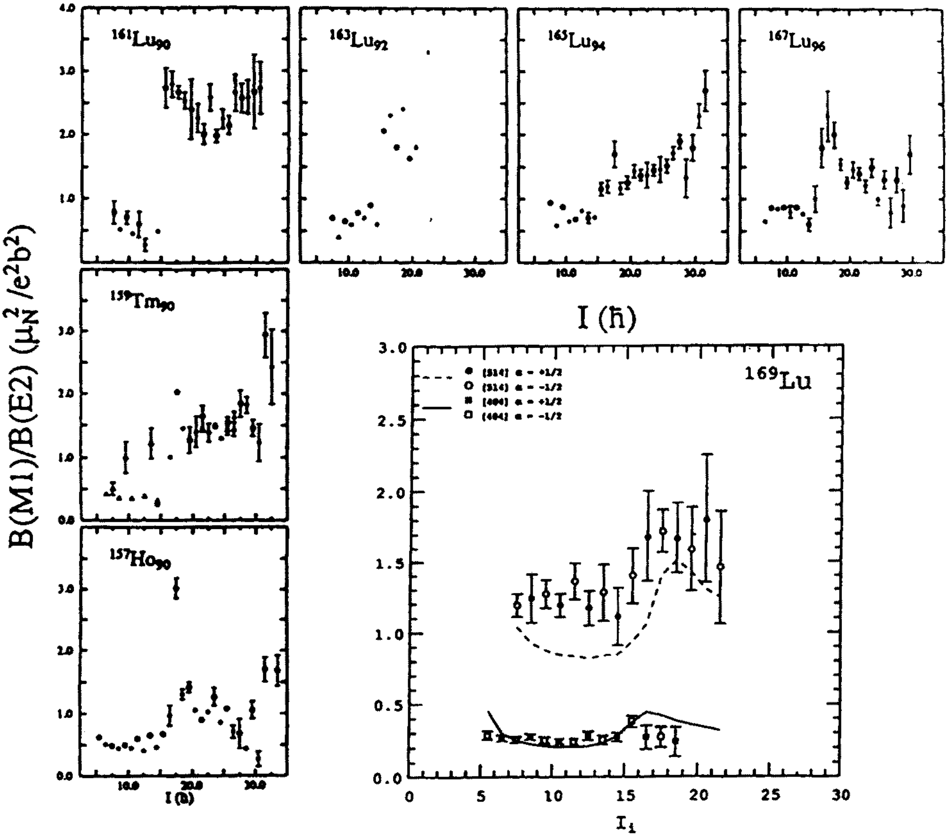

Figure 2: Spin dependence of the ratio of reduced transition probability, $\frac{B(M1,I\to I-1)}{B(E2,I\to I-2)}$ for the decay sequences based on the $\frac{9}{2}^-$[514] and $\frac{7}{2}^+$[404] Nilsson orbitals. Data for $^{157}Ho_{90}$, $^{159}Tm_{90}$, and $^{161-167}Lu_{90-96}$ odd-Z nuclei for the decay sequence based on the $\frac{9}{2}^-$[514] orbital are taken from ref.*[6]*.

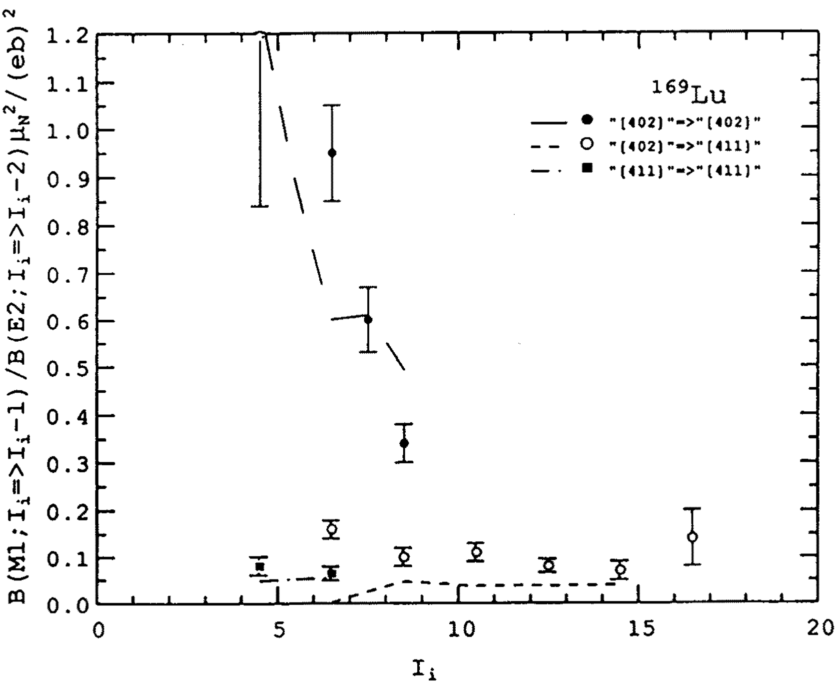

Figure 3: Spin dependence of the ratio of reduced transition probability, $\frac{B(M1, I\rightarrow I-1)}{B(E2, I\rightarrow I-2)}$ for the decay sequences based on $\frac{5}{2}^+[402]$ and $\frac{1}{2}^+[411]$ Nilsson orbitals. The solid, dash and dash-dot lines represent the values calculated with a particle rotor model.

the $\frac{1}{2}^+[411]$ band become lower than those of the $\frac{5}{2}^+[402]$ band. However, in a large range of angular momentum (i.e. $I \leq 33/2$) the wave functions of the resulting states with (I=1/2 mod 2) are found to be considerably mixed. This mixing produces the calculated B(M1) values of the transitions between the "402" and the "411" band (fig.3). The value of ε =0.255 is used in the calculation of wave functions, in order to obtain the observed near-degeneracy of the states of the two bands in the region of I=9/2 $\sim$ 13/2 when the standard (κ, μ) parameters are used. A plot of excitation energies for the observed $\frac{5}{2}^+[402]$ and $\frac{1}{2}^+[411]$ bands of ^{169}Lu, with a rigid rotor term subtracted, is presented in fig.4. For low spin states portion of both bands the appearing mixing tendency is illustrated in this figure, especially around spin $\frac{13}{2}$.

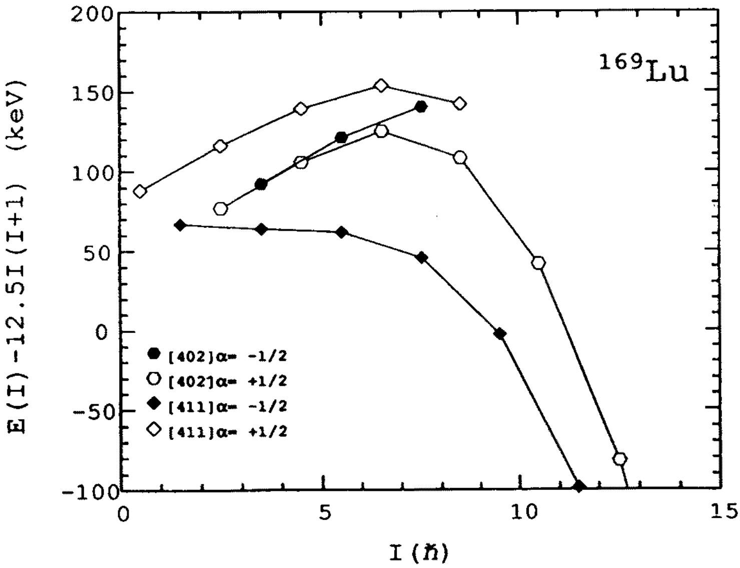

Figure 4: Excitation energies of observed levels belonging to the [411] and [402] Nilsson configurations in ^{169}Lu, with a rigid rotor term corresponding to $J_0 = 40MeV^{-1}\hbar^2$ subtracted for the purpose of display. The figure illustrates the "proximity" of these two bands.

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