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Note

The Structure of the $K^{\pi}=2^{-}$ State in ^{182}W as Viewed from the g_R- and g_K-Factors

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The level structure of ^{182}W has been established through a number of experiments on the β decays of ^{182}Ta, ^{182}Re and on nuclear reactions. As seen in Fig. 1 this nucleus exhibits many rotational bands. Theoretical investigations on this nucleus

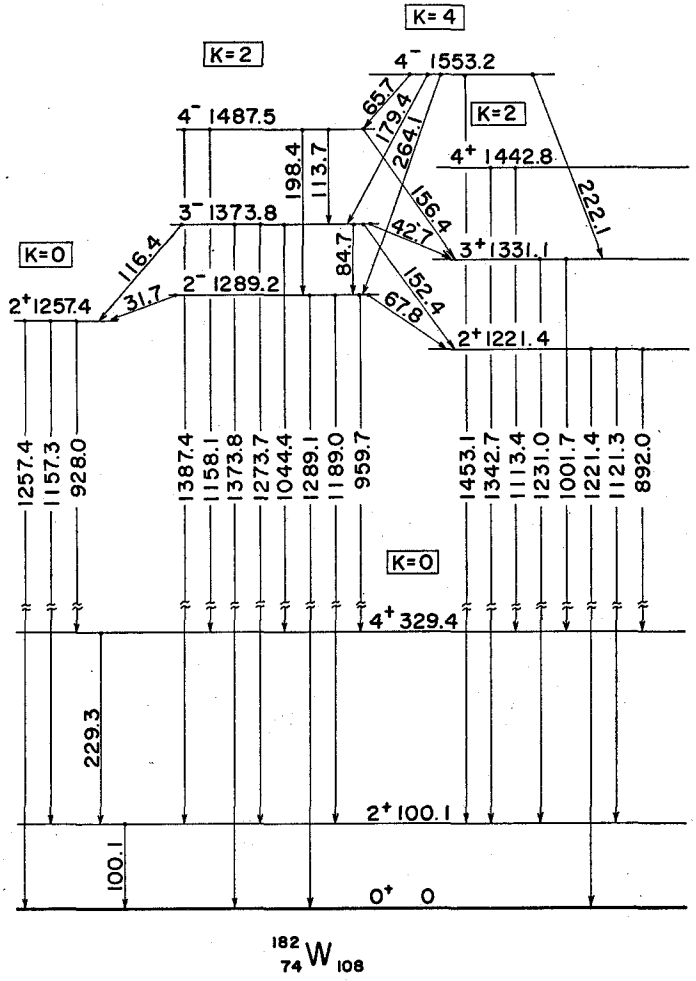

Fig. 1. Partial decay scheme of ^{182}W

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have been made with rather successful results. As for the non-rotational collective states two representative calculations based on the microscopic theory have been made by Solovev[1] and Neergård and Vogel.[2] However, the microscopic structure of the 2^- state at 1289 keV presented by them shows some descrepancy. Solovev has shown that the 2^- state contains an almost pure two-quasiparticle configuration, while Neergård and Vogel have obtained a more collective structure. In this paper we have attempted to clarify the origin of this descrepancy and to show, on the basis of microscopic theories, that the experimental g_K- and g_R-factors are both well explained by the pure two-quasiparticle configuration, which is only briefly discussed in the earlier work.[3]

Through the g-factor measurements by the present authors on the 2^- 1298 keV and the 3^- 1374 keV levels (the first two members of the $K^\pi=2^-$ band), the g_K-, and g_R-factors of this band have been determined as[3]

$$g_K=1.05\pm0.12, \tag{1}$$

$$g_R^{2^-}=0.48\pm0.09. \tag{2}$$

The microscopic structure obtained by Solovev is the 97.5% pp{[514] ↑ −[402] ↑ }, while Neergård and Vogel obtained that

$$\begin{aligned} &65\%\ \mathrm{pp}\{[514]\uparrow-[402]\uparrow\},\\ &9\%\ \mathrm{nn}\{[615]\uparrow-[503]\uparrow\},\\ &10\%\ \mathrm{nn}\{[624]\uparrow-[512]\uparrow\}. \end{aligned}$$

Since the contribution of the last two components to the g_K-factor is negligibly small, it is enough to take account of the proton two-quasiparticle state for the calculation of the g_K-factor. Accordingly, the Solovev's configuration gives the g_K-factor of about 0.98, while that of Neergård and Vogel yields $g_K=0.65$. This indicates that our experimental g_K-factor prefers the former configuration.

The difference between the predictions by Solovev and by Neergård and Vogel may in some part be originated in the parameters employed by them, but substantially its cause should be attributed to the blocking effect; in the calculation by Solovev the collectivity of the RPA state has been largely reduced because the above proton two-quasiparticle state falls considerably by the blocking effect as compared with other two-quasiparticle states. However, since the energy of two-quasiparticle state is highly sensitive to the parameters of the Nilsson potential, it is interesting to examine whether similar effect occurs in the case of the Nilsson potential adopted by Neergård and Vogel. After the pairing calculations with the same parameters adopted by Neergård and Vogel, we obtained the following results:

$$\Delta=0.215\ \hbar\omega$$

$$\Delta_{\alpha\beta}=0.000\ \hbar\omega$$

$$E_\alpha+E_\beta=1.75\ \mathrm{MeV} \tag{3}$$

$$\mathfrak{E}_{\alpha\beta}-\mathfrak{E}_0=1.26\ \mathrm{MeV}, \tag{4}$$

where

$$E_\mu=\sqrt{(\varepsilon_\mu-\lambda)^2+\Delta^2}\,. \tag{5}$$

In the above expression $\Delta_{\alpha\beta}$ and Δ are the gap parameters with and without blocking, ε_α and ε_β are the single particle energies of the [402]↑ and [514]↑ orbitals, $\mathfrak{E}_{\alpha\beta}$ is the total energy with the α and β states blocked and $\mathfrak{E}_0$ is the energy of the quasiparticle vacuum state. This calculation shows that the blocking effect reduces the energy of the above two-quasiparticle state by about 0.5 MeV. Even the nearest neighboring two-quasiparticle state has the energy of 2.28 MeV which is about 1 MeV higher than the pp{[514]↑ −[402]↑} state. Therefore, the mixing amplitude of other two-quasiparticle states as described in the paper by Neergård and Vogel is expected to be very small. The above description is also supported by the fact that the value $\mathfrak{E}_{\alpha\beta}-\mathfrak{E}_0=$ 1.26 MeV is in good agreement with the experimental value 1289 keV.

Next, we would like to show the g_R-factor (2) obtained by us is successfully explained by the microscopic theory. The g_R-factor $g_R^{2^-}=0.48\pm0.09$ is about twice as large as the value of the ground-state band:[3]

$$g_R^{g^-}=0.230\pm0.009. \tag{6}$$

Similar trends can be seen in the fact that the moment of inertia of the 2^--state band $\mathscr{I}^{2^-}$ is less than that of the ground-state band $\mathscr{I}^g$:

$$\frac{2}{\hbar^2}\mathscr{I}^g=60\ \mathrm{MeV}^{-1} \tag{7}$$

$$\frac{2}{\hbar^2}\mathscr{I}^{2^-}=71\ \mathrm{MeV}^{-1}, \tag{8}$$

as deduced from the level spacings.

According to the cranking model the moment of inertia of the doubly even ground state (seniority $v=0$) is expressed as follows:[4]

$$\mathscr{I}^g=2\hbar^2\sum_{\mu\nu}\frac{<\mu|j_x|\nu>^2}{E_\mu+E_\nu}(U_\nu V_\mu-V_\nu U_\mu)^2, \tag{9}$$

where U_μ and V_μ are the usual BCS parameters with no state blocked. However, as described above our calculation supports that the 2^- state is predominantly a two-quasiparticle state, so that one must take this state as the basis state in the cranking-model calculation on the g_R-factor. The result of our derivation of the moment of inertia for such a state is as follows:

$$\begin{aligned}\mathscr{I}^{\alpha\beta}=2\hbar^2\Bigg\{&\sum_{\nu\neq\alpha,\beta}\Bigg[\frac{<\alpha|j_x|\nu>^2}{\mathfrak{E}_{\beta\nu}-\mathfrak{E}_{\alpha\beta}}(U_\nu^{\alpha\beta}U_\alpha^{\beta\nu}+V_\nu^{\alpha\beta}V_\alpha^{\beta\nu})^2\prod_{\rho\neq\alpha,\beta,\nu}(U_\rho^{\alpha\nu}U_\rho^{\alpha\beta}+V_\rho^{\alpha\nu}V_\rho^{\alpha\beta})^2\\&+\frac{<\beta|j_x|\nu>^2}{\mathfrak{E}_{\alpha\nu}-\mathfrak{E}_{\alpha\beta}}(U_\nu^{\alpha\beta}U_\beta^{\alpha\nu}+V_\nu^{\alpha\beta}V_\beta^{\alpha\nu})^2\prod_{\rho\neq\alpha,\beta,\nu}(U_\rho^{\beta\nu}U_\rho^{\alpha\beta}+V_\rho^{\beta\nu}V_\rho^{\alpha\beta})^2\Bigg]\\&+\sum_{\nu,\nu'\neq\alpha,\beta}\frac{<\nu|j_x|\nu'>^2}{\mathfrak{E}_{\alpha\beta\nu\nu'}-\mathfrak{E}_{\alpha\beta}}(U_\nu^{\alpha\beta}V_{\nu'}^{\alpha\beta}-V_\nu^{\alpha\beta}U_{\nu'}^{\alpha\beta})^2\prod_{\rho\neq\alpha,\beta,\nu,\nu'}(U_\rho^{\alpha\beta\nu\nu'}U_\rho^{\alpha\beta}+V_\rho^{\alpha\beta\nu\nu'}V_\rho^{\alpha\beta})^2\\&+\frac{<\beta|j_x|\alpha>^2}{\mathfrak{E}_0-\mathfrak{E}_{\alpha\beta}}(U_\alpha V_\beta-V_\alpha U_\beta)^2\prod_{\rho\neq\alpha,\beta}(U_\rho U_\rho^{\alpha\beta}+V_\rho V_\rho^{\alpha\beta})^2\Bigg\},\end{aligned} \tag{10}$$

where $U^{\mu\nu}$ and $V^{\mu\nu}$ are the U- and V-coefficients with the μ and ν states blocked. In the above expression the term enclosed by the bracket corresponds to one-quasiparticle transitions ($v=2\rightarrow v=2$, $\Delta v=0$) and the remaining two terms correspond to $\Delta v=2$

($v=2\rightarrow v=4$ and $v=2\rightarrow v=0$) transitions. According to Nilsson and Prior[4] the collective gyromagnetic ratio can be expressed approximately as

$$g_R=\mathscr{I}_p/(\mathscr{I}_p+\mathscr{I}_n) \tag{11}$$

where $\mathscr{I}_p$ and $\mathscr{I}_n$ are the proton and neutron contributions to the moment of inertia.

In the present calculation we employed the parameters given by Gustafson *et al.*[5] for the Nilsson potential; $\kappa=0.0637$, $\mu=0.60$ for protons and $\kappa=0.0637$, $\mu=0.42$ for neutrons. The pairing calculations were made on Z and N lowest levels for Z protons and N neutrons, respectively, and the pairing strength parameter G was determined from the equation

$$G=[17.83\pm 12.17\,(N-Z)/A]/A \tag{12}$$

where the upper sign holds for protons and the lower for neutrons. The ground-state moment of inertia for the proton part calculated on the basis of Eq. (9) using the above parameters is

$$\frac{2}{\hbar^2}\mathscr{I}_p^g=11.2\ \mathrm{MeV}^{-1} \tag{13}$$

when $\beta=0.215$.

The experimental $\mathscr{I}_p^g$ and $\mathscr{I}_n^g$ values can be deduced by combining Eqs. (6), (7) and (11) as

$$\frac{2}{\hbar^2}\mathscr{I}_p^g=13.8\pm 0.6\ \mathrm{MeV}^{-1} \tag{14}$$

$$\frac{2}{\hbar^2}\mathscr{I}_n^g=46.2\mp 0.6\mathrm{MeV}^{-1}\,. \tag{15}$$

Our calculated value of $\mathscr{I}_p^g$ is in rather good agreement with the experimental $\mathscr{I}_p^g$ value.

The moment of inertia of the 2^- two-quasiparticle state $\mathscr{I}_p^{2-}$ was calculated by using Eq. (10) to be

$$\frac{2}{\hbar^2}\mathscr{I}_p^{2-}=28.2\ \mathrm{MeV}^{-1}\,. \tag{16}$$

The increase of the calculated proton moment of inertia is, therefore, 17.0 MeV^{-1}. However, since the calculated value of the ground-band moment of inertia is 19% less than the experimental value, it may be reasonable to normalize the calculated value to the experimental one. Then we expect

$$\frac{2}{\hbar^2}\Delta\mathscr{I}_p=21.0\ \mathrm{MeV}^{-1} \tag{17}$$

for the increase of the proton moment of inertia, and

$$\frac{2}{\hbar^2}\mathscr{I}_p^{2-}=34.8\ \mathrm{MeV}^{-1} \tag{18}$$

for the proton moment of inertia of the 2^- state. If the neutron moment of inertia for the 2^- state is equal to that for the ground state, the total moment of inertia should be

$$\frac{2}{\hbar^2}\mathscr{I}^{2-}=81.0\ \mathrm{MeV}^{-1}\,, \tag{19}$$

and the g_R-factor of the 2^- state be

$$g_R^{2-}=0.430\,. \tag{20}$$

Although this value is slightly less than our experimental value (2), the agreement between these two values is satisfactory.

According to Günther *et al.*[6] it is suggested that the quadrupole moment of the 2^- state Q_0^{2-} is less than that of the ground state by 9%. This 9% decrease in the value of Q_0 yields a decrease of about 10% in $\mathscr{I}_n$, while a negligibly small change in $\mathscr{I}_p^{2-}$ is expected according to the calculations on the basis of the cranking-model formulae (9) and (10). This situation implies that the agreement of the theoretical g_R^{2-}-factor and $\mathscr{I}^{2-}$ value with the experimental values should be improved by the small change in the Q_0 value.

If the 2^- state contains the two-quasiparticle state of pp{[514]↑ −[402]↑} by only 65% as predicted by Neergård and Vogel, the theoretical $\mathscr{I}_p$ value should become considerably small as compared with the pure two-quasiparticle case. Moreover, the remaining neutron two-quasiparticle components in the 2^- state should contribute to the increase of the neutron moment of inertia $\mathscr{I}_n$ and, therefore, the calculated g_R^{2-}-factor would get a further reduction.

As a conclusion it can be said that our experimental g_K- and g_R-factors both support an assignment of almost pure pp{[514]↑ −[402]↑} configuration to the 2^- state.

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