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Short note

T-band phenomena in ^{183}Re

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Abstract. High-spin states in ^{183}Re have been studied using the ^{176}Yb(^{11}B,4n) reaction at 52 and 57 MeV. Two high-K bands have been observed directly by a time-correlated γ-γ coincidence measurement. One of the bands is built on an isomeric $K^\pi = \frac{25}{2}^+$ state at $E_x = 1908$ keV with a half-life of 0.82(2) ms. The other band, assigned as $K^\pi = \frac{29}{2}^-$ at $E_x = 2739$ keV, decays to the $\frac{25}{2}^+$ band. These bands are interpreted as three-quasiparticle structures, $\pi\frac{5}{2}^+[402] \otimes \nu\frac{9}{2}^+[624]\otimes\nu\frac{11}{2}^+[615]$ for the $\frac{25}{2}^+$ band and $\pi\frac{9}{2}^-[514]\otimes\nu\frac{9}{2}^+[624]\otimes\nu\frac{11}{2}^+[615]$ for the $\frac{29}{2}^-$ band. The $K^\pi = \frac{29}{2}^-$ band becomes strongly Coriolis mixed with increasing spin and is gradually changing into a low-K s-band structure.

PACS. 21.10.Tg Lifetimes – 23.20.Lv Gamma transitions and level energies

Nuclear rotational structures including high-j orbitals such as $i_{13/2}$ neutrons are strongly affected by rotation which results in interesting Coriolis mixing phenomena. In the $A \sim 180$ mass region, the neutron Fermi surface lies in the middle of the $i_{13/2}$ shell, and these neutrons contribute to the structure of both the s-band with $K \sim 0$ as well as to the t-band where the angular momenta are coupled to high-K as discussed by Frauendorf [1]. In the $N = 106$ isotones, ^{180}W, ^{181}Re, and ^{182}Os, the first back-bending of the ground state band has been interpreted as a crossing of the t-band, which in these cases consist of the high-K coupling of the $\frac{7}{2}^+[633]$ and $\frac{9}{2}^+[624]$ Nilsson orbitals [2] [3] [4]. In the $N = 108$ isotones, the corresponding band is formed by replacing the $\frac{7}{2}^+[633]$ neutron by a $\frac{11}{2}^+[615]$ neutron, enabling a $K^\pi = 10^+$ coupling [5]. In the $N = 108$ nucleus ^{183}Re, one-quasiparticle bands and a strongly populated 1.04(4) ms isomer at $E_x = 1908$ keV had been previously identified [6] [7] [8]. In this study, we report the observation of two bands above the isomer, which are assigned, respectively, to the $\frac{5}{2}^+[402]$ proton and $\frac{9}{2}^-[514]$ proton coupled to the $K^\pi = 10^+$ $i_{13/2}$ neutron configuration.

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High-spin states of ^{183}Re were populated via the ^{176}Yb(^{11}B,4n) reaction, and the γ-rays were detected using the NORDBALL array at Niels Bohr Institute Tandem Accelerator Laboratory. A γ-γ coincidence experiment was carried out with a self-supporting 5mg/cm^2 ^{176}Yb target and a DC beam at 57MeV. At this energy, only 20% of the fusion evaporation cross section leads to ^{183}Re, but a high angular momentum input is ensured. Figure 1 shows three rotational band structures which are three out of 12 different ones identified in this nucleus, and we shall in this paper confine the discussion to this subset.

Time-correlated γ-γ coincidence measurements were performed by use of a pulsed beam. The beam energy was reduced to 52 MeV to enhance the 4n channel yield and the pulsing regulated to cycles of 10μs beam burst and 2 ms beam off. Gamma-ray energies and their detection time relative to the start of the beam burst were recorded for every beam pulse. An event was defined with the condition that a γ-ray was detected within a beam burst and a γ-ray was detected immediately following in the off-beam period. Matrices of the type $\gamma_{\text{in beam}} - \gamma_{\text{off beam}}$ were constructed and spectra were projected from it by selection on either axis. Random coincidence events were reduced by a reduction of the beam intensity to about 50 pA.

Figure 2a shows a spectrum which is gated by off-beam γ-rays identified as the transitions below the isomer at

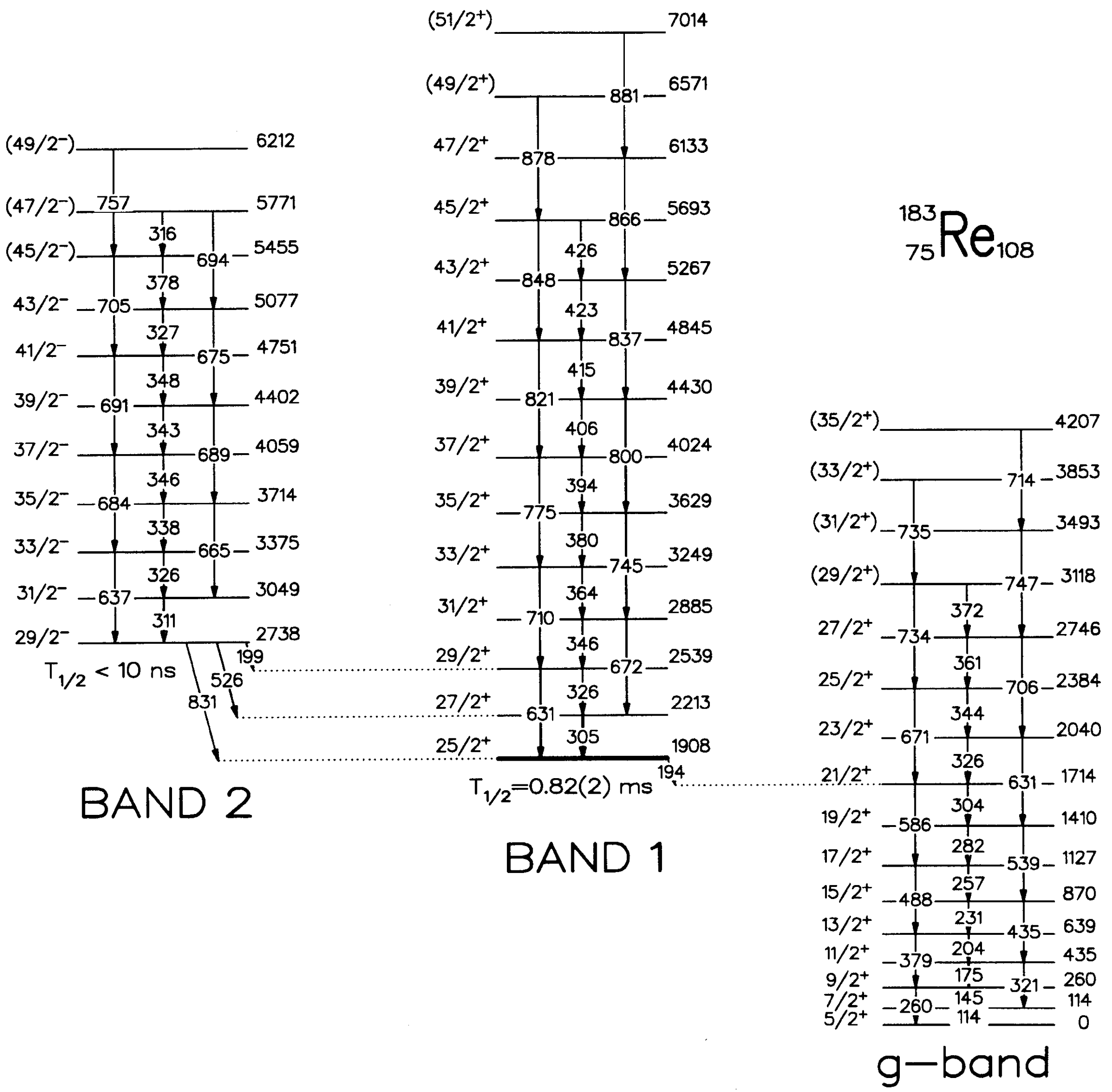

Fig. 1. The partial level scheme of ^{183}Re

E_x = 1908 keV. The strong transitions at 305, 311, 326, 526 and 631 keV assigned to Band 1 and 2 appear clearly. The spectrum of Fig. 2b results from gate selection on the in-beam transitions at 305, 311, 326, 526 and 631 keV belonging to Band 1 and 2. A complete spectrum of M1 and E2 transitions below $I = \frac{21}{2}$ in the ground band and a 194 keV γ-ray is observed.

The decay curves of the 194 keV and γ-rays identified in the spectrum of Fig. 2b show a half-life of $T_{1/2}$ = 0.82(2) ms. These observations establish the bandhead of Band 1 as a 0.82(2) ms isomer at E_x=1908 keV. The total conversion coefficient for the 194 keV transition depopulating the isomer is α_t=0.36(2). This is evaluated on the basis of the intensity balance at the 1714 keV level assuming pure M1 and E2 character for the 304 and 586 keV transitions respectively. This value agrees with the conversion electron measurements of [8] and the theoretical value for an E2 of α_t = 0.359, and confirms pure E2 character of the 194 keV transition. Hence $I^\pi = \frac{25}{2}^+$ is assigned to the 1908 keV isomeric level. BCS calculations including blocking and residual interactions [9] show that the $\pi\frac{5}{2}^+[402] \otimes \nu\frac{9}{2}^+[624] \otimes \nu\frac{11}{2}^+[615]$ configuration is the only three-quasiparticle state available at this excitation energy. Further evidence for this assignment comes from the experimental $B(\mathrm{M1})/B(\mathrm{E2})$ values of the three-quasiparticle band, deduced from measured in-band branching ratios and plotted in Fig. 3a. These are in good agreement with theoretical values for the proposed configuration, calculated using the semi-classical formula [10] [11] for the B(M1) value, shown in Fig. 3a as a solid line. An alignment $i_x = 1.5\hbar$ for the $\frac{9}{2}^+[624]$ neutron and 1.0 $\hbar$ for the $\frac{11}{2}^+[615]$ neutron has been used in the calculations.

Coincidence-time spectra between the 199 or 526 keV transition and some of the Band 2 transitions indicate a short lifetime, but it is close to the time resolution of

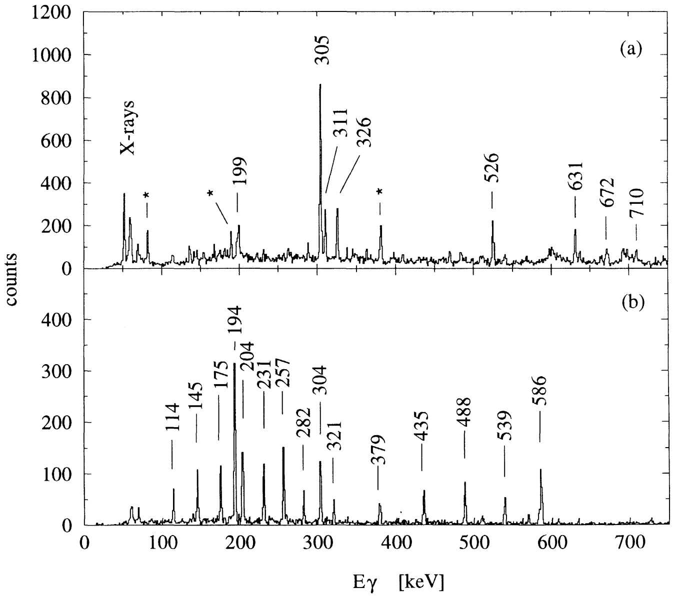

Fig. 2. **a** The in-beam sum spectrum gated by all off-beam γ-rays below the isomer, **b** The off-beam sum spectrum gated by in-beam γ-rays, 305, 311, 326, 526 and 631keV, belonging to Band 1 and 2. The stars, *, indicate well known contaminations from the random coincidences

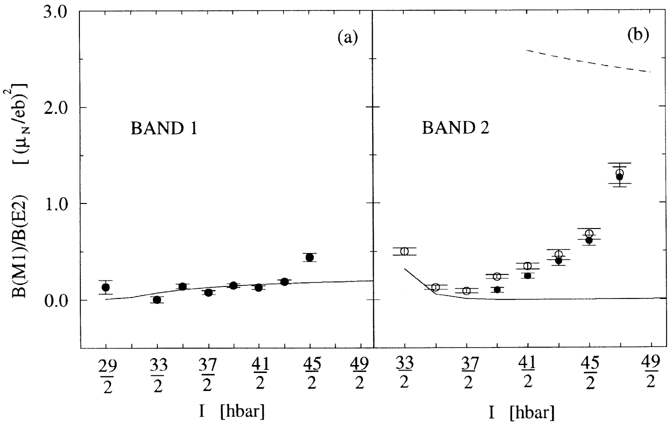

Fig. 3. **a** Experimental (filled circles) and theoretical (solid lines) values of B(M1)/B(E2) ratios for Band 1, **b** for Band 2. The open circles are experimental values assuming $K_{\text{eff}} = \frac{27}{2}$ for Band 2. The dashed line is the calculations for the rotational aligned configuration. A quadrupole moment $Q_0 = 6.5$ eb, $g_R = 0.3$ and alignments shown in the text have been used

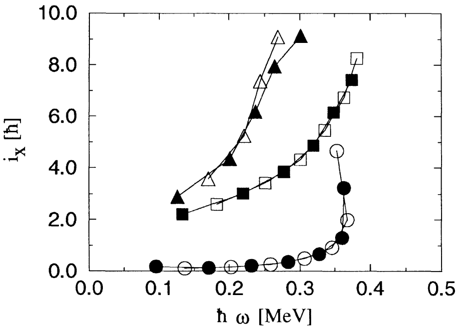

Fig. 4. Aligned angular momenta for the ground band (circles), Band 1 (squares) and Band 2 (triangles). Reference parameters: $J_0 = 30$ MeV$^{-1}\hbar^2$, $J_1 = 35$ MeV$^{-3}\hbar^4$

the system, therefore a limit of $T_{1/2} < 10$ ns is assigned for the 2738 keV level. DCO ratios of the 199 and 526 keV transitions indicate that the bandhead of Band 2 has $I = \frac{29}{2}$ or $\frac{25}{2}$. Since both Band 1 and 2 are strongly populated it is very likely that the two bands have roughly the same spin at the same excitation energy. Therefore we suggest the assignment of $I = \frac{29}{2}$ to the bandhead with a preference for negative parity since the intensity of the 831 keV transition is compatible with an M2, but much too weak for an E2 assignment. The bandhead at 2738 keV is assigned a three-quasiparticle configuration based on $\pi\frac{9}{2}^-[514] \otimes \nu\frac{9}{2}^+[624] \otimes \nu\frac{11}{2}^+[615]$. In fact this configuration is the only three-quasiparticle configuration to produce $K^\pi = \frac{29}{2}^-$ at this energy and the observed large alignment is consistent with the proposed configuration.

The B(M1)/B(E2) ratio for Band 2 deduced from experiment is shown in Fig. 3b together with a solid curve representing calculated values for the proposed configuration. An alignment of $i_x = 0.5\hbar$ for the $\frac{9}{2}^-[514]$ proton orbital and neutron alignments as for Band 1 have been applied. If a constant K-value of $\frac{29}{2}$ is used for Band 2, we obtain negative values of the mixing ratio square δ^2 when we deduce it from the experimental in-band branching ratios λ. Therefore B(M1)/B(E2) ratios in the interval $\frac{33}{2} \le I \le \frac{37}{2}$ can not be extracted, but values for higher spins are plotted with filled circles. Since both the $h_{11/2}$ proton and the two $i_{13/2}$ neutrons are affected by Coriolis mixing, we have introduced a smaller effective K-value for Band 2, and calculated a new set of B(M1)/B(E2) ratios. With $K_{\text{eff}} = \frac{27}{2}$ we obtain the ratios plotted as open circles in Fig. 3b. The alignment of all three bands is shown in Fig. 4 and Band 2 is seen to be perturbed most strongly by the Coriolis force. At the highest spin observed in the present work, almost full alignment of the $i_{13/2}$ neutrons and a significant signature splitting is apparent. This signifies a conversion from a strongly coupled high-K band at the bandhead to a rotational aligned band at higher spin states. This interpretation can explain the increasing trend of the B(M1)/B(E2) ratios in Fig. 3b where a dashed line represents the theoretically calculated ratios of rotational aligned band assuming $i_x = 0.5\hbar$ for the proton, $i_x = 10\hbar$ for the pair of $i_{13/2}$ neutrons and an effective K-value of $\frac{9}{2}$ for the band. Both the alignments and the B(M1)/B(E2) ratios suggest that at low spin, Band 2 appears as a strongly coupled high-K band, but as the first units of collective angular momentum are added, the angular momentum vector tilts away from the deformation axis, so that at intermediate spins Band 2 qualifies as a t-band. Finally, at the higher spins the angular momentum vector eventually aligns fully to the rotational axis, and the band qualifies as a s-band.

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