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CORIOLIS INTERACTION BETWEEN THREE NILSSON BANDS IN Pa

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By comparing new experimental results with calculations, it is shown that the levels above the $\frac{1}{2}^-[5,3,0]$ ground-state band in ^{233}Pa and ^{231}Pa may be interpreted as resulting from the $\frac{1}{2}^+[6,6,0]$, the $\frac{3}{2}^+[6,5,1]$, and the $\frac{5}{2}^+[6,4,2]$ bands involved in a three-band Coriolis interaction.

Interpretation of several states between 80 and 400 keV in ^{233}Pa as due to a three-band Coriolis interaction was first suggested by Browne and Asaro.[1] New information just available from measurements of the ^{237}Np α and ^{233}Th β^- decays[2,3] will be presented here as strongly confirming this hypothesis. Also, we present results of a calculation showing that the very uncommon deformation of one of the observed rotational bands can be caused by a three-band Coriolis interaction, with very acceptable values for the interaction parameters.

In Fig. 1 the alpha feeding of the levels in ^{233}Pa is shown.[4] The α hindrance factors indicate that the 86.4- and the 238.2-keV levels (level energies as following from the present work) are fed by unhindered alpha transitions and therefore contain considerable percentages of the Nilsson level $\frac{5}{2}^+[6,4,2]$, assigned to the ^{237}Np ground state.[5]

In an earlier proposal the 86.4-keV level was interpreted as the $\frac{5}{2}^+[6,4,2]$ state and the 238.2-keV level as the $\frac{5}{2}^+$ member of the $\frac{3}{2}^+[6,5,1]$ rotational band, mixed with the former state by Coriolis interaction. The failure of this model to explain the very low values of the hindrance factors of the alpha transitions to the 212.4-keV level and to the remarkable doublet at 103.7 and 108.5 keV led Browne and Asaro to the new model mentioned above.

In the meantime, our experiments have shown that a level at 94.6 keV is fed by an allowed, hindered or a first-forbidden, unhindered (ah or 1u) beta transition from ^{233}Th. This 94.6-keV level decays to the ground state, to the 6.7-keV level (Fig. 2), and more strongly, by low-energy conversion electrons,[6] to the 86.4-keV level. We found this level to be in coincidence also with the alpha transitions feeding the 103.7- and 108.5-keV doublet; this explains the lack of gamma-ray transitions from this doublet to the $\frac{1}{2}^-[5,3,0]$ band. Taken together these findings make it at-

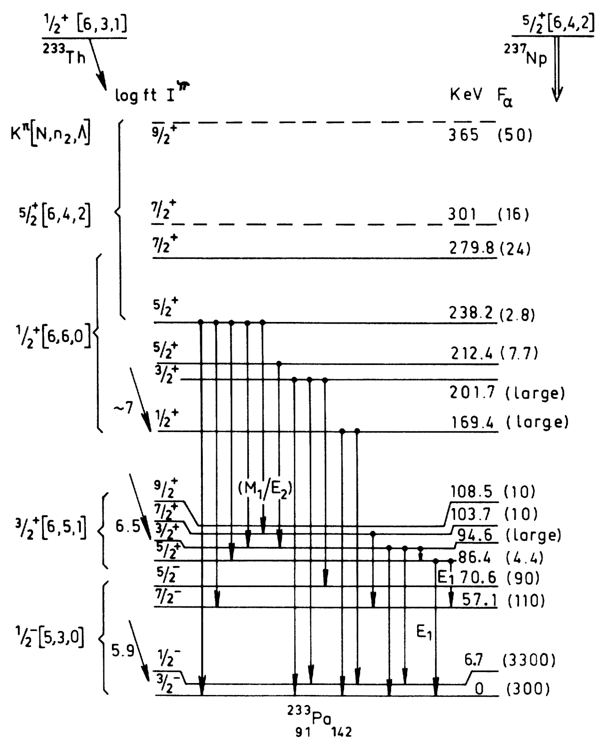

FIG. 1. Level scheme of ^{233}Pa as found from the decays of ^{233}Th and ^{237}Np presented as far as of interest for the accompanying discussion. The hindrance factors F_α refer to the α decay of ^{237}Np.

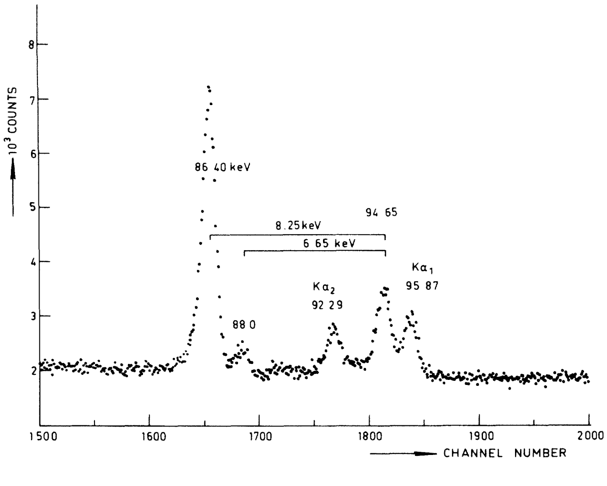

FIG. 2. A part of the gamma-ray spectrum following the decay of ^{233}Th taken with a thin Si(Li) detector by M. de Bruin of the Reactor Institute, Delft, The Netherlands.

tractive to consider this cluster of the four levels near 100 keV as a very deformed rotational band.

Analogy with its isotopes ^{235}U and ^{237}Pu allows a choice between the $\frac{7}{2}^-[7,4,3]$ and the $\frac{1}{2}^+[6,3,1]$ Nilsson assignments for the ground state of ^{233}Th.[5] The ah or 1u beta feeding to the ground-state band in ^{233}Pa limits the choice to the last possibility.[7] But then the data presented above allow only a spin $\frac{3}{2}$ for the 94.6-keV level. Since the $\frac{5}{2}^+$ assignment for the 86.4-keV level is quite firm, the band considered is indeed unusually deformed. Moreover, this band cannot be interpreted anymore as the $\frac{5}{2}[6,4,2]$ rotational band. We strongly confirm the suggestion of Browne and Asaro to assign this deformed band as the $\frac{3}{2}^+[6,5,1]$ one. Its deformation cannot be explained by a two-band Coriolis interaction. The evident third candidate, which can also be involved in Coriolis interaction with this $\frac{3}{2}^+[6,5,1]$ band, is the $\frac{1}{2}^+[6,6,0]$ rotational band.

In the decay of ^{233}Th a 169.4-keV level is rather strongly fed by a direct beta transition. A 201.7-keV level also is found, which is decaying directly to the ground-state band. Spin assignments $\frac{1}{2}$ and $\frac{3}{2}$ suggests themselves for these levels. Together with the 212.4- and 279.8-keV levels, the former levels can then form the $\frac{1}{2}^+[6,6,0]$ band. Such an interpretation also explains the lack of alpha feeding to the lowest two levels of this band by the ^{237}Np α decay. (These lower levels are found in the gamma-ray spectrum following this alpha decay, but are presumably fed by converted transitions originating in the higher levels.) The other three levels, given in Fig. 1, are interpreted as the $\frac{5}{2}^+[6,4,2]$ band.

These above-mentioned data are just sufficient for calculating the parameters of a three-band Coriolis interaction. With the aid of the expressions given by Davidson,[8] we find $\hbar^2/2J$ very nearly equal to 7.0 keV for all the three rotational bands. The band with $K=\frac{1}{2}$ has a decoupling parameter nearly equal to zero. The interaction parameters between the $K=\frac{1}{2}$ and $K=\frac{3}{2}$ and between the $K=\frac{3}{2}$ and $K=\frac{5}{2}$ bands were both found to be about 19.1 keV. The lowest levels of the undisturbed bands are at 106 keV for the $K=\frac{3}{2}$ hole state and at 171 keV for the $K=\frac{5}{2}$ particle state (the $I=\frac{1}{2}$ state of the $\frac{1}{2}^+[6,6,0]$ band is of course not shifted).

Comparing known[9] levels in ^{231}Pa with the levels in ^{233}Pa, analogy in the decay characteristics points to spin assignments $\frac{5}{2}$, $\frac{7}{2}$, and $\frac{3}{2}$ for the states at 84.2, 101.4, and 102.3 keV, respectively, in ^{231}Pa. The fact that here even two rotational levels are pressed below the $\frac{3}{2}^+$ ground state of this band is probably connected to the fact that the $\frac{5}{2}^+[6,4,2]$ assignment in ^{231}Pa has to be given to a level with an energy much lower than its similar one in ^{233}Pa: The level in ^{231}Pa is at 183.5 keV.

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