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Band Structure of the Transitional Nucleus ^{218}Ra*

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The Ra isotopes offer an excellent opportunity to investigate the gradual increase in collectivity in nuclei beyond the double magic ^{208}Pb starting from ^{214}Ra, at the closed neutron N=126 shell, up to the well deformed ^{228}Ra nucleus. Considerable interest has focused on the structure of the low lying bands with negative parity observed in most of the even-even actinide isotopes. One of the most common interpretation of these bands is in terms of a rotational band built onto a harmonic octupole vibration (Peker, 1981).

^{218}Ra is situated in the transitional region between the spherical and the deformed nuclei, with six protons and four neutrons outside the closed shell. Until now, only scarce experimental information has been available about nuclei in this region ($216< A\leq 220$), limited to a few excited states in ^{217}Ra and ^{220}Ra, which were identified in alpha decay experiments (Lederer, 1978). No excited state in ^{218}Ra was known. We attempt, therefore, to contribute to the understanding of this region by studying these transitional nuclei via (HI, xn) reactions.

High-spin states of ^{218}Ra were populated by the ^{208}Pb(^{13}C, 3n)^{218}Ra reaction. The ^{13}C ions were accelerated by the Munich MP Tandem to energies between 65 and 70 MeV. Gamma rays were assigned to ^{218}Ra on the basis of the excitation functions and γ-X ray coincidences. $\gamma-\gamma$-coincidence data were used to construct the level scheme. Angular distributions and linear polarization measurements were performed in order to deduce spin and parities. Time spectra obtained from pulsed beam measurements do not reveal any delayed transitions with lifetimes greater than 2 ns. A detailed description of these experiments will be published elsewhere (Fernández Niello, 1982).

The level scheme of ^{218}Ra, shown in Fig. 1, has been established up to spin $I^{\pi}=17^{-}$. The excited levels can be grouped into two bands, one with positive parity and the other with negative parity. An interesting feature in ^{218}Ra is the presence of strong interband E1 transitions. Not only the negative parity band but also the ground state band is deexcited via E1 transitions, which in both bands compete with E2 transitions. Concerning the B(E1) to B(E2) branching ratios, it is

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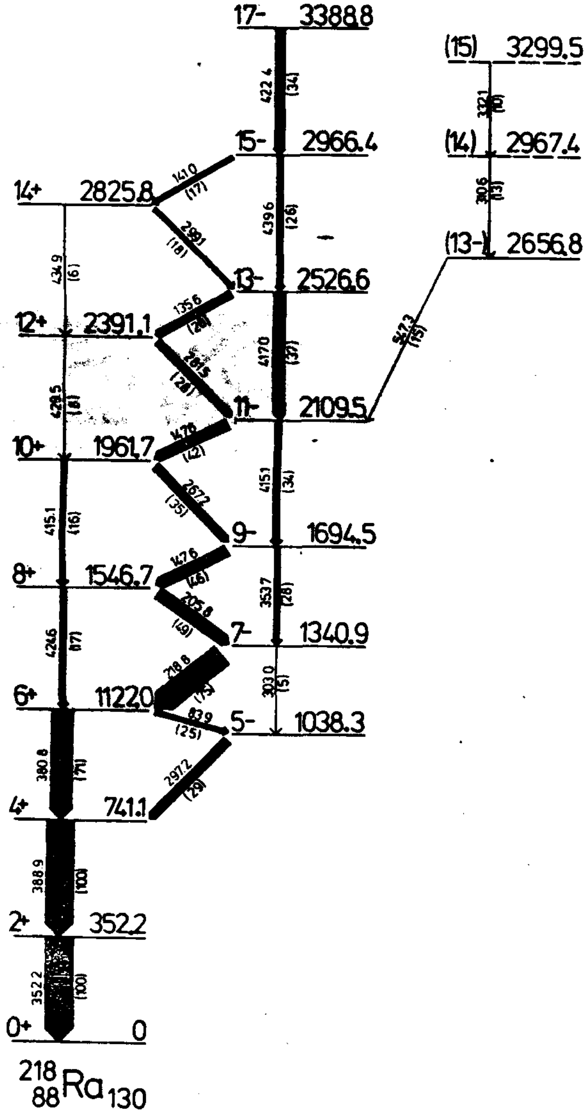

Fig. 1 Level scheme of ^{218}Ra

striking to observe that their values are remarkably constant for all levels of both bands (Table 1). According to the Grodzins relation (Grodzins, 1962) one can estimate a value of 20 single particle units for the B(E2; $2^+ \to 0^+$) transition probability in ^{218}Ra, in good agreement with the systematic trend in this region. This B(E2) value would yield hindrance factors for the E1 transitions of the order of 10^{-3}.

TABLE 1: B(E1)/B(E2) branching ratios for the de-excitation of levels in ^{218}Ra

Level energy (keV)	I^π	B(E1)/B(E2) (10^{-6} fm^{-2})
1122	6^+	3.7 ± 0.8
1341	7^-	2.8 ± 0.6
1547	8^+	3.5 ± 0.4
1694	9^-	2.2 ± 0.4
1962	10^+	1.1 ± 0.2
2109	11^-	3.6 ± 0.4
2391	12^+	1.8 ± 0.3
2527	13^-	2.9 ± 0.4
2826	14^+	1.3 ± 0.3
2966	15^-	2.9 ± 0.4

The positive parity band fits well into the systematic of even Ra isotopes. Figure 2 displays the gradual transition of the even-parity level patterns of these nuclei, from the lighter isotopes where single particle structure dominates to the heavier nuclei with rotational behaviour. The almost equidistant level spacing in the positive parity band of ^{218}Ra suggests a vibrational structure of this nucleus.

The negative parity band, possessing only odd spin members, has been observed from $I^\pi=5^-$ to $I^\pi=17^-$. Band members with smaller spins are not populated in this reaction. An octupole vibrational origin is predicted for such bands in other Ra isotopes (Peker, 1981), although the two phonon octupole states were not observed in alpha decay experiments (Kurcewicz, 1977). An alternative explanation (Möller, 1972) suggesting a stable octupole deformation for these states also seems improbable, since it would impose large hindrance factors on the interband E1 transitions. This contradicts the observation of no additional retardation in the E1 transitions in ^{218}Ra.

The vibration-like pattern of the positive and the negative parity bands and the collective features observed in ^{218}Ra stimulated us to interprete our results in terms of the SU(5) limit of the interacting boson approximation (Arima, 1976). In this limit the ground state band is built considering only quadrupole bosons, and their energies are given by the equation

$$E_{gsb}(I=2n_d) = \varepsilon_d n_d + c_4 \frac{n_d(n_d-1)}{2}$$

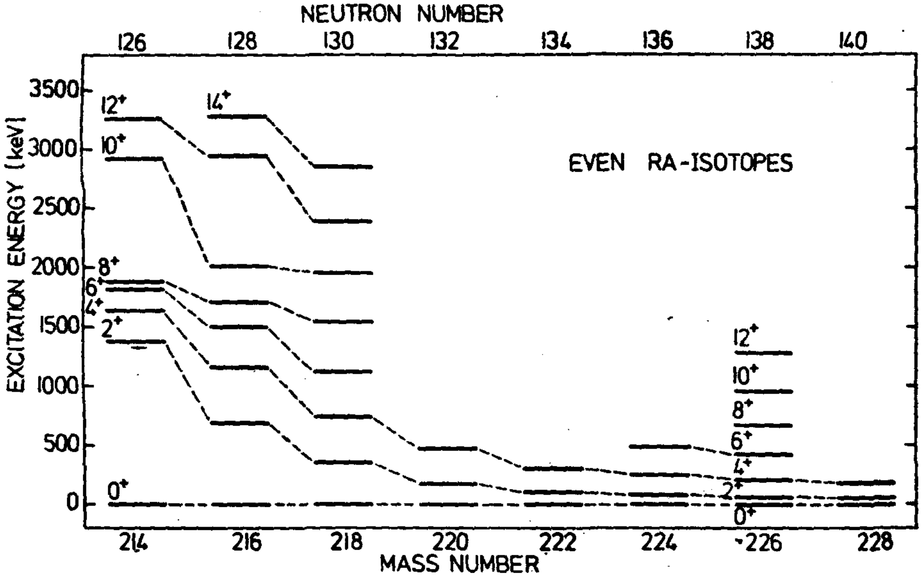

Fig. 2 Spectra of positive parity states in even Ra isotopes. The experimental data are taken from Horn (1979), Lönnroth (1981), Fernândez Niello (1982), Lederer (1978), Zimmermann (1980), Kurcewicz (1976, 1977)

where n_d represents the number of d-bosons (L=2), ε_d their excitation energy and c_4 the coupling between them. Within the framework of this model, the negative parity states are formed by coupling one octupole boson to the quadrupole bosons. We will use the "totally aligned band" whose energies are

$$E_{ovb}(I=2n_d+3) = E_{gsb}(2n_d)+\varepsilon_f+n_d x_5$$

where ε_f and x_5 are adjustable parameters. Using these expressions we obtain a good fit to the experimental level scheme (Fig. 3). The deduced parameters are ε_d = 361.2 keV, c_4 = 14.7 keV, ε_f = 649.7 keV and x_5 = -15.1 keV.

The IBA also gives a simple formula for the branching ratios in the deexcitation of the negative parity band

$$\frac{B(E1,I=2n_d+3 \rightarrow I'=2n_d+2)}{B(E2,I=2n_d+3 \rightarrow I'=2n_d+1)} = \frac{n_d+1}{7\cdot n_d}\cdot C$$

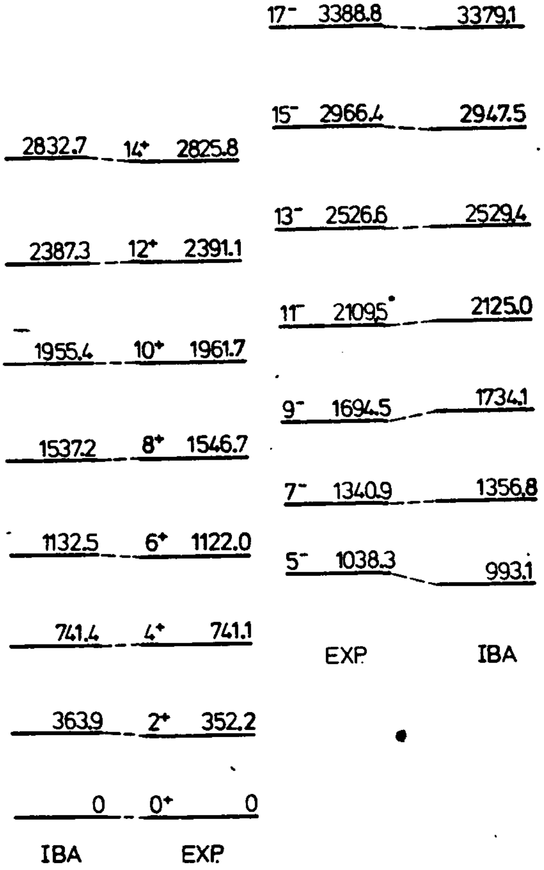

Fig. 3 Comparison between the experimental level energies and the IBA predictions

where C is a constant. However, within this approximation of the IBA, E1 transitions from the positive to the negative parity band are inhibited since they involve the simultaneous annihilation of two quadrupole bosons. In a refined version of the model (perturbative treatment of symmetry breaking terms) these E1 transitions do appear but with rather low intensity. This is in striking contrast to the experiment. Consequently, it turns out that the interacting boson approximation in the vibrational limit fails to explain all the experimental data observed in ^{218}Ra.

Finally, it was recently proposed that alpha-clustering effects should be important in the structure of transitional actinide nuclei (Iachello, 1982). Indeed, this model predicts very small hindrance factors for the E1 transitions. In order to draw definite conclusions in this respect it is certainly necessary to investigate the transitional region in more detail.

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