Are nuclei with $N \sim 43$ deformed?

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Abstract. The level schemes of $^{75}$Se and $^{79}$Kr have been established through gamma ray and conversion electron spectroscopy following $^{75}$As (p, n $\gamma$e) and $^{79}$Br (p, ny$\gamma$e) reactions. The data on these nuclei and the nuclei in the neighbourhood of this mass region are discussed and evidence is presented to show that the nuclei with $N \sim 43$ are deformed.

Keywords. (p, n $\gamma$e) reactions; Coriolis coupling; deformed nuclei.

1. Introduction

The recent observation of Bonn et al (1972), that the root mean square radius of $^{185}$Hg in its ground state is more than that of $^{187}$Hg, raised the question as to whether $^{189}$Hg is deformed. In this connection the high spin levels of $^{186}$Hg and $^{188}$Hg were studied by Proetel et al (1973) and Rud et al (1973) respectively by means of heavy-ion induced reactions. Proetel et al (1973) found that while the $2^+ \rightarrow 0^+$ and $4^+ \rightarrow 2^+$ level-spacings are equal, the levels of even spin from $6^+$ to $14^+$, which they studied, showed level spacings that can be fitted into a rotational band with an inertial parameter $\hbar^2/2I = 12$ keV. Rud et al. similarly concluded that $^{189}$Hg is deformed from levels of spin $\geq 6^+$ and supported their conclusion by measuring the $B(E2)$ values of the transitions between some of the levels of the rotational band. The inertial parameter as well as the measured $B(E2)$ values lead to a deformation parameter $\beta_2 = 0.28$. These results can be explained if the potential energy as a function of deformation has a second minimum at $\beta_2 = 0.28$ in these nuclei (Proetel et al 1973), the first minimum being at $\beta_2 = 0$ or a small negative value. Dickmann and Dietrich (1973) calculated such a potential energy curve on the Strutinsky-Nilsson model and found that the potential energy for light even Hg isotopes indeed has minima at $\beta_2 \sim -0.15$ and $\beta_2 \sim 0.28$. They also calculated the zero point energy and the most probable shape for these nuclei and concluded that the light even Hg isotopes have a stable deformation. The odd mass nuclei in this region may further stabilize the deformation and thus the observation of Bonn et al (1972) can be understood in terms of a deformation.

A similar situation seems to occur in the $^{78}$Se, $^{78}$Kr region. Recently Wyckoff and Draper (1973) have studied the high spin levels in $^{72-78}$Se and $^{78-84}$Kr. In
2. Experimental procedure and results

We have studied the excited states of $^{76}$Se and $^{79}$Kr through (p, n) reactions on $^{78}$As and $^{79}$Br respectively (Agarwal et al. 1973, 1974a, b) using the 5.5 MeV Van de Graaff accelerator at B.A.R.C., Trombay. The energies, the spins and parities and lifetimes of the levels were measured using a variety of techniques which included in-beam $\gamma$-ray, internal conversion electron spectroscopy and angular distributions of $\gamma$-rays. The details of the experiments together with the complete level schemes for $^{76}$Se and $^{79}$Kr will be published elsewhere. Here, we present the data only on a few levels which are relevant in the present context. Partial level schemes of $^{78}$Se, $^{77}$Se and $^{79}$Kr are shown in figure 1. The levels in $^{77}$Se are taken from the existing data (Nuclear Data 1966). Also shown in the figure are some of the high spin excited states in $^{79}$Se studied recently by Protop et al. (1973) by (a, xn) reactions on Ge isotopes.

3. Discussion

From figure 1, one observes that in all the three nuclei, three levels of spin $1/2^-$, $3/2^-$ and $5/2^-$, which can be fitted into a $K = 1/2^-$ rotational band, are seen. The inertial parameters $\hbar^2/2\mathcal{J}$ and the decoupling parameter $a$ are also shown in the
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$\begin{array}{c}
2395 (15/2^-) \\
1907 (13/2^-) \\
1592 (9/2^-) \\
1221 (7/2^-) \\
778 (5/2^-) \\
586 (3/2^-) \\
293 (1/2^-) \\
\end{array}$

$\begin{array}{c}
1490 (11/2^-) \\
1080 (9/2^-) \\
749 (7/2^-) \\
440 (5/2^-) \\
240 (3/2^-) \\
183 (3/2^-) \\
0 (1/2^-) \\
0 (3/2^-) \\
0 (1/2^-) \\
\end{array}$

$\frac{h^2}{2\mathcal{J}} \quad (\text{keV}) = 68 \\
\alpha = 0.44 \\
\delta = 0.33 \\
\delta' = 0.48$

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$\begin{array}{ccc}
75\text{Se} & 77\text{Se} & 79\text{Kr} \\
34 & 34 & 36 \\
\end{array}$

Figure 1. Partial level schemes of $^{75}\text{Se}$, $^{77}\text{Se}$ and $^{79}\text{Kr}$. The energy in keV and the spin and parity of each of the levels are marked. The $K = 1/2^-$ band in these nuclei and the $K = 3/2^-$ band in $^{75}\text{Se}$ are separately presented. The moment of inertia parameter $\frac{h^2}{2\mathcal{J}}$ and the decoupling parameter, $\alpha$, for these bands are shown. The results of a band mixing calculation between the $K = 1/2^-$ and $3/2^-$ bands in $^{79}\text{Se}$ are shown by dotted lines. The calculation was made using the parameters $\frac{h^2}{2\mathcal{J}} = 45$ keV, $\alpha = 0.4$ and the Coriolis coupling strength (Kerman 1956) $A_k = 60$ keV.

In $^{79}\text{Kr}$, there is also a level at 721 keV, which has tentatively been assigned a spin of $7/2^-$. This level fits into the $K = 1/2^-$ band. The levels at 287 (3/2$^-$), 428 (5/2$^-$), 749 (7/2$^-$), 1080 (9/2$^-$), 1490 (11/2$^-$), 1907 (13/2$^-$) and 2395 (15/2$^-$) in $^{75}\text{Se}$ can also be fitted into a rotational band with $K = 3/2^-$, as has been noted by Protop et al. (1973). However, the inertial parameter $\frac{h^2}{2\mathcal{J}}$ has a value of 65 keV for the $K = 1/2^-$ band while it is 35 keV for the $3/2^-$ band. This large difference in the moment of inertia for the two bands in the same nucleus can be understood on the basis of mixing of these two bands through a Coriolis interaction. A Coriolis coupling calculation with a common value of $\frac{h^2}{2\mathcal{J}} = 45$ keV and $\alpha = 0.4$ for the decoupling parameter for the $1/2^-$ band, reproduces the observed level energies reasonably well. The calculated energies of the levels are shown by dotted lines in figure 1. The moment of inertia and the decoupling parameter for the $K = 1/2^-$ bands in $^{77}\text{Se}$ and $^{79}\text{Kr}$ are similar (figure 1).

The $K = 1/2^-$ band assigned in these three nuclei can further be identified with the $(301 \downarrow) 1/2^-$ Nilsson orbit. The decoupling parameter for this band can be calculated from the Nilsson wave functions (Nilsson 1955) to be 0.7 to 0.8 for deformation ranging from $\beta_2 = 0.2$ to 0.4. The experimental value is in reasonable agreement with the calculated one. Similarly, the $K = 3/2^-$ band in $^{75}\text{Se}$ can be identified with the $(301 \uparrow) 3/2^-$ Nilsson orbital.
4. Conclusions

The following piece of evidence exist for concluding that the nuclei in the region with $N \approx 43$ are deformed:

(i) The energy spacings for levels with spin $I \geq 6^+$ for the even Kr and Se isotopes can be fitted into a rotational band.

(ii) The large $B(E2)$ values for the $2^+ \rightarrow 0^+$ transitions in the even Kr and Se isotopes and the large quadrupole moments for the ground states of $^{78, 79}$Se.

(iii) The observation of three $K = 1/2^-$ rotational bands with consistent moments of inertia and decoupling parameters.

(iv) The $K = 3/2^-$ band observed by Protop et al. (1973) in $^{79}$Se.

(v) The potential energy curve calculation by Tanaka and Tomoda (1973) which shows a potential minimum for $\beta_2 = +0.35$.

It will be interesting to study the high spin levels in the odd mass Se and Kr isotopes in order to see whether more rotational bands could be identified.

The positive parity levels have not been discussed in the present work. They will be discussed elsewhere (Agarwal et al 1974 a, b). However, it may be mentioned that Sanderson (1973) has recently made a Coriolis coupling calculation for the positive parity levels and concluded that the energy levels could be fitted well by a deformation parameter $\beta_2 \sim 0.3$ in agreement with the conclusion of the present work. Scholz and Malik (1968) made similar Coriolis coupling calculations for the odd proton nuclei in this region and found reasonable agreement between the calculated and the observed levels.

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