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ONSET OF DEFORMATION IN NEUTRON-RICH KRYPTON ISOTOPES

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Abstract: Beta-decay properties of neutron-rich ${}_{35}$Br isotopes confirm the predicted smooth onset of quadrupole deformation for $Z<37$ already below $N=60$. The observed increase of the energy of the first 2^+ state in the $N=56$ nucleus ^{92}Kr may indicate octupole softness.

During the last decade, extensive studies have been devoted to the level structures of neutron-rich nuclei around $A=100$. For ee-isotopes in this region, already the behaviour of the first 2^+ levels (see Fig. 1) indicates the well-known transition from spherical to deformed shapes as neutrons are added beyond $N=58$, with an extremely sharp transition for ${}_{40}$Zr and ${}_{38}$Sr (see, e.g. [1,2]). The suddeness of this transition has been interpreted as an effect of the spherical $Z=40$ shell gap which can locally reinforce the $N=56$ spherical gap (see the 2^+ peak for ^{96}Zr) to delay the shape transition until the $Z=38$, $N=60$ gaps at large deformation can reinforce each other. As the proton number moves away from 40, the influence of the spherical $N=56$ subshell should quickly disappear. While for the heavier elements (${}_{42}$Mo to ${}_{46}$Pd) the $E(2^+)$, indeed, decrease more gradually indicating a smooth onset of deformation, so far no experimental data were available for lighter elements (${}_{34}$Se, ${}_{36}$Kr) with $N>54$. The region around $Z=36$, $N=56$ is of particular interest because of the predicted octupole softness [2-4].

With the halogen beams available at the mass separators OSTIS (ILL-Grenoble) and ISOLDE (CERN-Geneva), we have started a systematic investigation of β-decay properties of heavy Br isotopes in order to check the above predictions for $Z<37$ nuclei. At both facilities UC-graphite targets were used which were connected to negative-surface ion sources with a LaB$_6$ ionizer [5,6]. Spectroscopic information was obtained from multiscaling of delayed neutrons and β-particles to derive $T_{1/2}$ and P_n values, and from γ-singles and γγ-coincidence measurements to establish partial decay schemes.

The most surprising result is the observation of an increase of $E(2^+)$ in ^{92}Kr by about 60 keV relative to ^{90}Kr indicating a gap at $N=56$ for $Z=36$ (see Fig. 1). On the one hand, this increase appears small compared to the 830 keV in the double semi-magic ^{96}Zr; on the other hand, however, the effect in ^{92}Kr is remarkable when regarding the $E(2^+)$ trends in the isotones with $Z=(40\pm2)$ and $Z=(40+4)$. Already in ^{98}Mo and ^{94}Sr the increase of the $E(2^+)$ has with 9 keV, respectively 22 keV become very small; and in the ${}_{44}$Ru isotopes, one observes a decrease of the $E(2^+)$ by about 110 keV when going from $N=54$ to 56. Based on this behaviour the effective $N=56$ gap in ^{92}Kr has to be considered even stronger than the apparent increase of $E(2^+)$.

One is now forced to question why a subshell gap exists in ^{92}Kr while it has more or less disappeared in the other $N=56$ isotones around ^{96}Zr. For the double semi-magic ^{96}Zr there is consistent interpretation that the spherical gaps in both the proton and neutron systems give a particularly low shell energy for the spherical shape [1,2]. With the proton shell structure dominating over the neutron shell structure [2], already for isotopes in close vicinity to $Z=40$ the spherical $N=56$ is not strong enough to resist a change to deformed shapes below $N=60$. As can be seen from the neutron SP levels for ^{92}Br in Fig. 1, the spherical gap is now replaced by a deformed $N=56$ gap around $\varepsilon_2=0.2$. Hence, our original interpretation [7] was that the increase of $E(2^+)$ in ^{92}Kr may be due to this locally occuring deformed gap.

We have compared the experimental β-decay properties of ${}^{91-94}$Br with shell-model predictions from the Lund RPA code [8]. The main results of this comparison are that (i) the observed changes in the shape of the β-strength function (S_β) as well as in $T_{1/2}$ and P_n confirm a smooth onset of deformation already below $N=60$, and that (ii) the latter properties seem to be very sensitive to deformation, thus allowing to limit ε_2 already from $T_{1/2}$ and P_n (see Tab. 1). When comparing the two odd-mass isotopes ^{91,93}Br and the two even-mass nuclei ^{92,94}Br, for both pairs a decrease of the experimental $T_{1/2}$ by about a factor of five is observed. This is - similar to the situation in the respective ${}_{37}$Rb isotones [9] - mainly due to the increase of the $\nu g_{7/2}$ →

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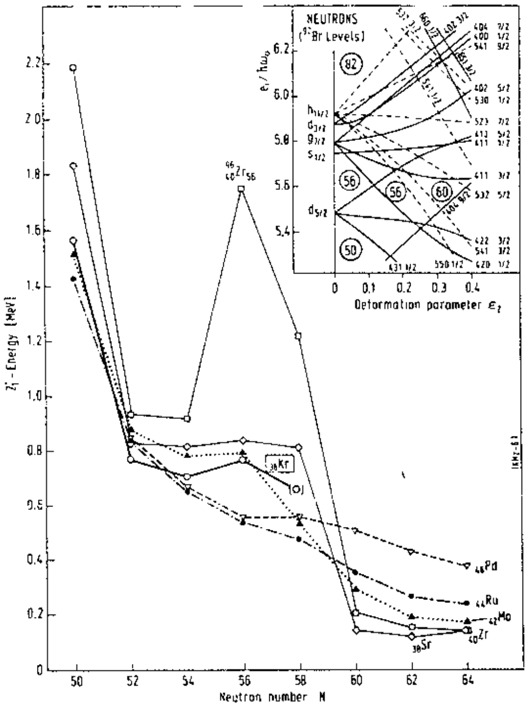

Fig. 1: Systematics of $E(2^+)$ of heavy $_{36}Kr$ to $_{46}Pd$ isotopes. The insert shows the Nilsson neutron SP levels for ^{92}Br as a function of quadrupole deformation.

$\pi g_{9/2}$ GT strength around 3.5 MeV beyond the $d_{5/2}$ closure at N=56. The somewhat less pronounced drop of the $T_{1/2}$ for the Br isotopes compared to their Rb neighbours reflects the onset of the deformation-related fragmentation and reduction of the above GT strength in $^{93}Br_{58}$ and $^{94}Br_{59}$. In the Rb isotopes this latter change of S_β occurs only at N=60 [9].

Let us now have a closer look into the $^{92}Br/^{92}Kr$ system. From both, the experimental S_β and the combination of $T_{1/2}$ and P_n (see Tab. 1), the predicted deformation of $\varepsilon_2 \approx 0.2$ for ^{92}Kr [1,2] can be excluded. For this case our RPA calculations give the lowest GT strength at about 2.3 MeV with a log(ft)≈3.6, whereas in experiment no β-branch with a log(ft)<6.0 could be identified. Agreement with experiment is only obtained for a narrow near-spherical range, where $T_{1/2}$ and P_n are reproduced and the lowest GT strength is predicted at about 3.1 MeV with a log(ft)≈5.3. All other GT decay goes to levels above $B_n \approx 5.4$ MeV. The low-lying strength may correspond to a group of levels observed around 3 MeV with a cumulative log(ft)≈5.9. Further support for a near spherical $^{92}Br/^{92}Kr$ system may come from the theoretical ground state configuration of $\nu s_{1/2}$, $\pi f_{5/2}$ for ^{92}Br yielding a most probable $J^\pi = 2^-$. This spin would be consistent with the experimental log(ft)≈6.0 for first-forbidden β-decay to the first 2^+ level at 769 keV in ^{92}Kr. It would also be consistent with a log(ft)≈6.8 for the second 2^+ level at 1447 keV and a log(ft)≈9.5 for a ff-unique transition to the 4^+ member of the 2-phonon-triplet at 1357 keV. Additional indication for a low ^{92}Br spin ($J \leq 3$) comes from the observation of a strong β-delayed-neutron branch to the $5/2^+$ g.s. of ^{91}Kr.

Tab. 1: Comparison of experimental $T_{1/2}$ and P_n values for $^{91-94}Br$ with RPA shell-model predictions for different quadrupole deformation.

Isotope	Experiment		RPA Shell Model		
	$T_{1/2}$ [ms]	P_n [%]	$T_{1/2}$ [ms]	P_n [%]	Def. ε_2
$^{91}_{35}Br_{56}$	510 ± 20	25.5 ± 3.5	892	26.8	0
			628	21.8	0.05
			202	8.0	0.10
			43	3.2	0.20
$^{92}Br_{57}$	310 ± 10	32 ± 4.5	1830	100	0
			439	23.6	0.025
			41	4.2	0.10
			78	13.7	0.20
$^{93}Br_{58}$	102 ± 10	10 $\pm^{5}_{3}$	19	2.9	0
			92	10.7	0.10
			41	5.4	0.20
$^{94}Br_{59}$	70 ± 20	30 ± 10	19	8.9	0
			35	7.8	0.25
			93	34.9	0.275
			107	25.3	0.30

Summarizing, we conclude that in contrast to our earlier belief [7] and most model predictions, the N=56 isotone ^{92}Kr seems to be quasi-spherical. This now raises again the question about an interpretation of the observed increase of $E(2^+)$ in this nucleus.

Bengtsson et al. [2] noted that their Strutinsky type potential-energy calculations could not describe the properties of nuclei around Z=36, N=56. They suggested to consider the octupole degree of freedom to obtain the required lowering of the g.s. energies. Although no octupole equilibrium deformation is predicted in this mass region [2-4], softness with respect to octupole distortions is expected which should be enhanced for spherical shapes [4]. Hence, octupole instability may be responsible for the observed lowering of the g.s. energy, i.e. the N=56 gap in ^{92}Kr. A more convincing argument would, however, be the identification of low-lying $\pi = -$ states. And, indeed, we have evidence for a 3^- level at 1805 keV. The spin assignment is based on the $E(3^-)$ systematics in this region [3], as well as on β- and γ-branching arguments. In the N=56 neighbours ^{94}Sr and ^{96}Zr the lowest 3^- level lies at about 1.9 MeV, close to the energy of our 3^- candidate in ^{92}Kr. Similar to the situation in ^{94}Rb decay (3^- to 3^- β-branch with a log(ft)≈7.0), the 2^- to 3^- β-branch is with a log (ft)≈6.8 rather slow. Although the J^π involved would suggest "allowed" β-decay, it does not occur as GT branch in our RPA model.

Further experiments - in particular a determination of the multipolarities of the γ-transitions deexciting the 3^- level - are foreseen at CERN-ISOLDE in order to confirm our interpretation of octupole instability in $^{92}Kr_{56}$.

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