THE LEVEL SCHEMES OF Sr and Y ISOTOPES IN THE MASS CHAINS A = 95, 97 and 99

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Abstract

The fission product separator Ostis at the Institut Laue-Langevin at Grenoble (France) was used for the investigation of the β-decays and the level schemes of short-lived Rb, Sr and Y isotopes with A = 95, 97 and 99.

The studies in the mass chains 95 and 97 were made using a surface ionization source to provide Rb isotopes whereas the mass chain 99 was investigated using an high temperature ion source.

The study of these nuclei close to ^{98}Sr and ^{100}Zr where a shape coexistence was evidenced is of great interest. Single γ-ray and conversion electron spectra, and prompt and delayed γ-γ and β-γ coincidences were measured. The level schemes of ^{95}Sr, ^{95}Y, ^{97}Sr and ^{97}Y were established or extended and a preliminary level scheme is given for ^{99}Y.

1. Introduction

Two transitional regions around A = 100 and A = 146 are accessible by the fission process. The spectroscopy of even-even nuclei reveals a different behaviour : whereas in the heavier group a smooth transition from spherical to deformed shapes is observed, the lighter one is characterized by an abrupt onset of large deformations and shape coexistence (^{100}Zr and ^{98}Sr).

Up till now only few information is available for odd nuclei around A = 100. Recently the spins and moments of the ground states of Rubidium isotopes have been measured by new spectroscopic methods[1-2]). The large quadrupole moment observed for ^{97}Rb [2]) reveals a large deformation comparable to the neigh bouring even-even nuclei. But these measurements do not allow an unique Nilsson assignment and more spectroscopic data are needed for a better understanding of this whole transitional region.

In this contribution, results concerning the level schemes of odd Strontium and Yttrium ranging in mass from A = 95 to A = 99 are presented.

2. Experimental Techniques

Samples of mass separated fission products were obtained from the Isol-system Ostis installed at an external neutron beam of the high flux reactor of the Institute Laue-Langevin in Grenoble[3]). The separator can be equipped with two kinds of ion sources : a thermoionization source delivering nearly isotopically pure samples of Rb and Cs isotopes and a recently developed high-temperature source[4]) which allows also Sr, Ba and rare earth elements to be ionized. The measurements in the mass chains A = 95 and A = 97 were performed with the first source whereas ^{99}Y was studied with the later one. The mass separated ions were deposited on a moving tape installed between the detectors. By adjusting the speed of the tape the different elements of a β-decay chain could be enhanced. By performing γ and conversion electron singles, γ-γ coincidence as well as β-γ and β-e$^-$ delayed coincidence measurements rather detailed decay schemes were established. Standard Ge(Li), Ge(HP) and Si(Li) detectors were used for these measurements.

3. Experimental Results

Whereas some information has been obtained on the level schemes of ^{95}Y and ^{97}Y from radio-activity and nulear reactions very little is known about the schemes of odd Sr isotopes with mass A ≥ 95 and on ^{99}Y. The new results of this work will be presented below isotope by isotope.

3.1 ^{95}Sr Level Scheme

The β decay of ^{95}Rb has been reported by several groups. A mean value for the half-life $T_{1/2}$ = 377 ms is obtained, but sparse and even contradictory informations have appeared in the literature on the level scheme of ^{95}Sr. In the present work about 230 γ-lines could be attributed to the decay of ^{95}Rb. The coincidence relationships allowed the construction of a scheme of 57 excited levels comprising about 97% of the activity.

The large number of transitions and the high density of levels cannot be discussed in detail in the frame of a conference. A discussion of the whole scheme will be given elsewhere. Only the characteristic features are displayed Fig.1. The intensity of the β branches has been determined from a filiation measurement assuming the absolute intensity I_γ = 0.19 ± 0.02 for the 954.2 keV γ-ray of ^{95}Zr (ref.[5]) and Pn = 8.9% (ref.[6]).

The scheme is characterized by the presence of many excited states up to 4660 keV, more than the neutron binding energy. Above 1439 keV one can distinguish three well separated groups of levels, two groups with rather low β feeding at about 2100 keV and 4200 keV and the third one at about 3500 keV with a strong β feeding (∿ 50% of the beta intensity). The logft calculated with a Qβ of 9260 keV[7]) indicate that the β branches feeding the levels of the groups at 2100 and 4200 keV are first forbidden whereas the levels at 3500 keV are fed by allowed ones. With the spin and parity assignment $I^\pi = 5/2^-$ found for the ground state of ^{95}Rb (ref.[1-2]) we have to admit the existence of a group of 13 negative parity states between 3366 and 3635 keV (the β$^-$ strength function deduced from these feedings will be compared to a theoretical prediction in the contribution of Kratz et al. at this conference).

The measured K conversion coefficient for the 204 and 352 keV γ-lines are in agreement with a multipolarity E2 and M1, respectively. The half-life of the 204 keV γ-line was found to be

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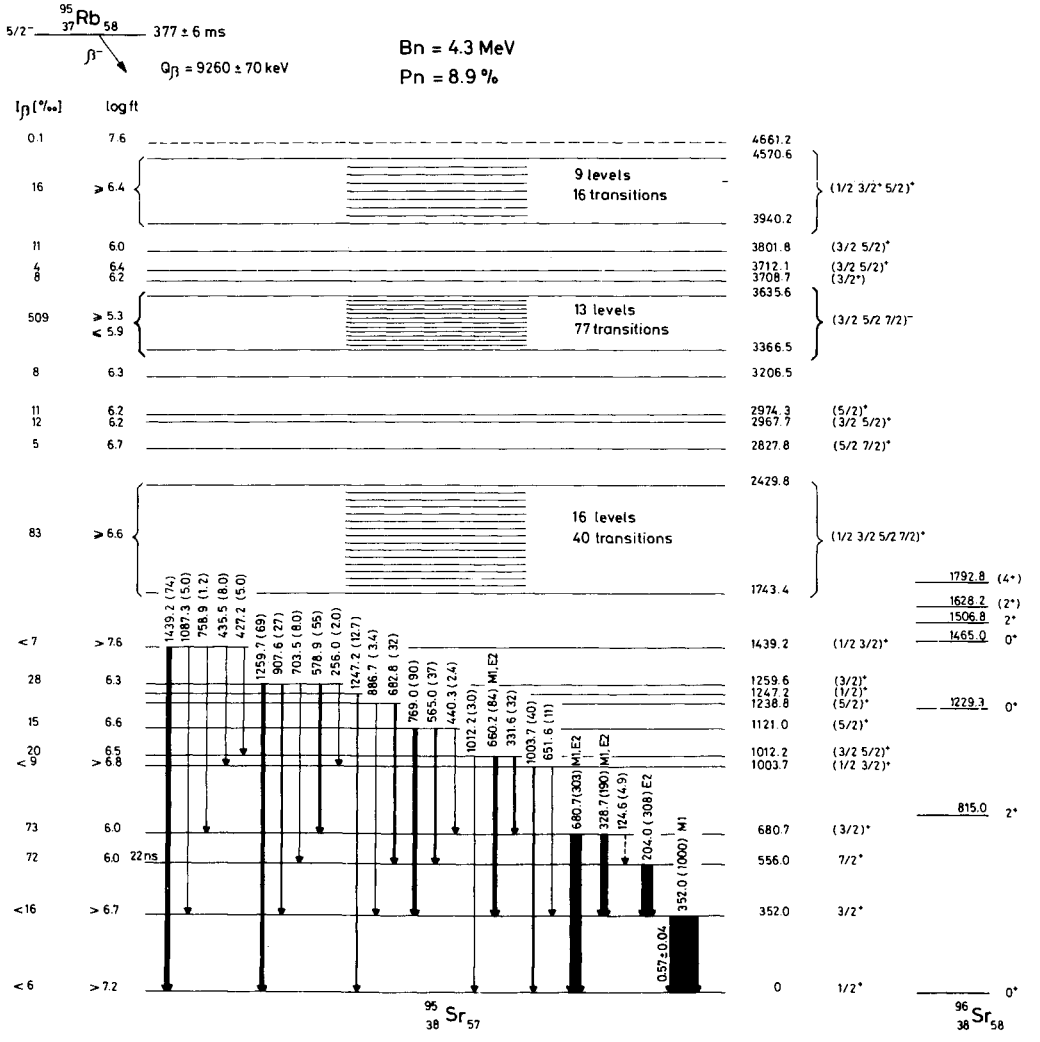

Fig. 1 Level scheme of ^{95}Sr

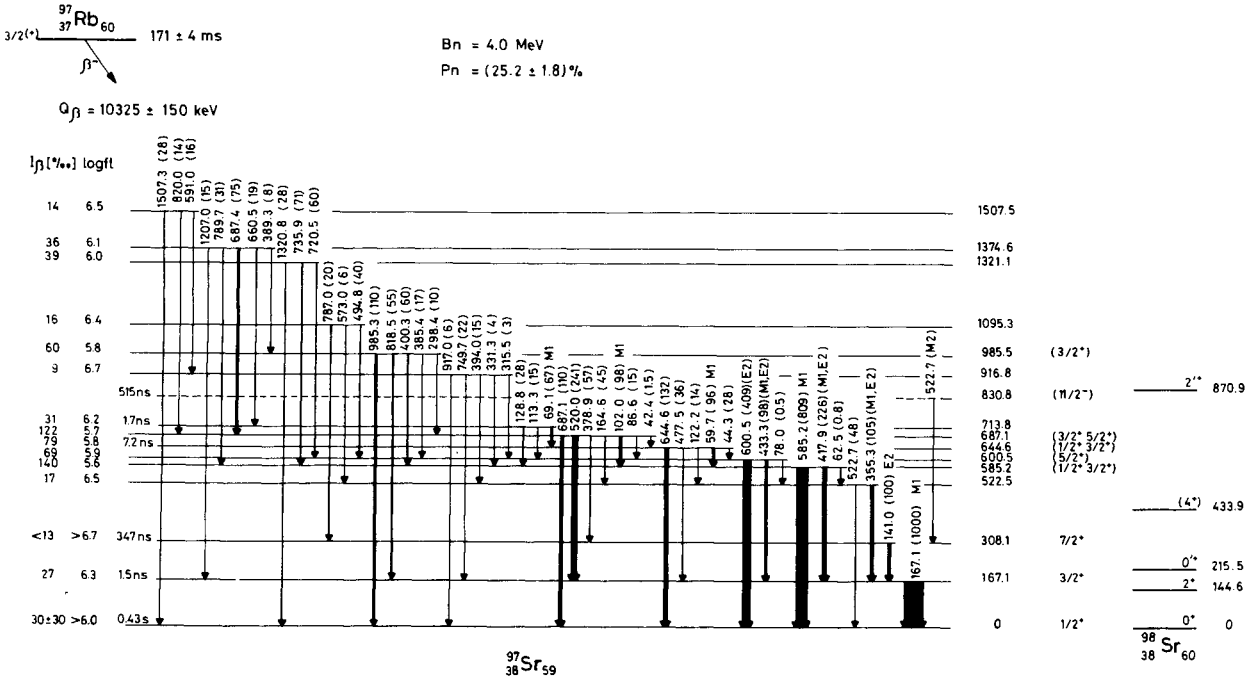

Fig. 2 Level scheme of ^{97}Sr

$T_{1/2}$ = 22 ± 3 ns in agreement with Fogelberg[8]). This value corresponds to the single particle Weisskopf estimate for a E2 transition. This E2-M1 sequence for the deexcitation of the two first excitated states corresponds to the one found in the isotone ^{97}Zr (ref.[9-10]). These levels are interpreted as arising from the neutron states $s_{1/2}$, $d_{3/2}$ and $g_{7/2}$. The higher excited states up to 1439 keV may then be interpreted by the coupling of these neutron states with the first 2^+, $0'^+$ and $2'^+$ excited states of the neighbouring even Sr isotopes.

3.2 ^{97}Sr Level Scheme

A mean value for the half-life of ^{97}Rb $T_{1/2}$ = 171 ms is obtained by several groups but no decay scheme was proposed. In the decay scheme shown Fig.2 nearly all the γ-lines observed were placed (about 94% of the γ activity). Compared to the decay scheme of ^{95}Sr we observe that the β decay feeds strongly levels at 650 keV instead of 3500 keV and that the feeding of states above 1.5 MeV seems to be negligable. Some very weak γ-lines were observed up to 2.5 MeV but could not be placed in the decay scheme. The intensity of the β branches have been determined from a filiation measurement assuming the absolute intensity Iγ = 0.928 (ref.[11]) for the 743.4 keV γ-line of ^{97}Nb and Pn = 25.2% (ref.[12]). By delayed coincidence techniques several life-times greater than 1 ns were detected. The half-life $T_{1/2}$ = 347 ± 12 ns of the 141 keV transition (in good agreement with Clark et al.[13]) fits into the systematic of E2 transition deexciting the $7/2^+$ state in ^{95}Sr and ^{97,99}Zr (Fig.6). This multipolarity was confirmed by the conversion electron measurements. The half-life of the 167.1 keV transition was found to be $T_{1/2}$ = 1.5 ± 0.7 ns in the β-delayed neutron decay of ^{98}Rb. The two levels at 644.6 keV and 713.8 keV have unexpected long half-lives of 7.2 ns and 1.7ns, respectively. The level at 644 keV may correspond to the level at 667 keV ($T_{1/2}$ = 10.2 ns) in ^{99}Zr (Ref.[14]) (see Fig.6). We can also remark that the scheme of these two isotones are very similar. The long-lived level at 830.8 keV was only populated in the fission process and could be the $11/2^-$ state[15]).

For some intense γ-lines the K conversion coefficient was measured. The values obtained indicate M1/E2 character. Due to the small difference of the theoretical α_K for M1 and E2 transitions and poor statistics above 400 keV no value for the E2 admixtures can be given. A special case is the γ-line at 600.5 keV. Compared with the close intense γ-line at 585.2 keV of nearly pure M1 character the α_K obtained for this line seems to indicate an E2 multipolarity. From these results a tentative spin and parity assignment could be made for some of the excited states.

The logft calculated with a Qβ of 10.325 keV (ref.[7]) show that the β branches feeding the levels at about 650 keV are allowed and indicate a positive parity for the ground state of ^{97}Rb. This new result combined with the spin I = 3/2 and magnetic and quadrupole moments measured by Thibault et al.[2]) allows to fix an unique Nilsson orbital [431 3/2] for the ground state of ^{97}Rb.

3.3 ^{95}Y Level Scheme

The decay of ^{95}Sr ($T_{1/2}$ = 25.1 s) has been studied by Herzog and Grimm[16]) who proposed a decay scheme mainly based on sum rule considerations. In the present work 85 γ-lines representing about 90% of the γ activity were placed in a scheme of 34 excited states based on coincidence relationships (Fig.3). The K conversion coefficient of the 260.6 keV γ-line indicate a M2 multipolarity. This γ-line has first been observed in delayed γ-rays coincidence with fission fragments deexciting an isomeric level at 1087.4 keV ($T_{1/2}$ = 57 ± 2 μs)[17]). As the 826.8 keV level has $I^\pi = 5/2^-$ (ref.[18]) we can assign spin and parity $I^\pi = 9/2^+$ to this isomeric level, in analogy with the odd Y isotopes. The intensity of the β branches was determined from the filiation measurement used for the decay of ^{95}Rb. To some levels with logft < 6.0 (calculated with Qβ = 6060 keV [19]) we can attribute positive parity. A tentative spin assignment was derived from the logft values and the γ deexcitation to the known first excited states.

3.4 ^{97}Y Level Scheme

The decay of ^{97}Sr ($T_{1/2}$ = 435 ± 30 ms) has already been studied with the separators Josef and Lohengrin[10]). In the present work the level scheme of ^{97}Y was extended (Fig.4). Some γ-lines in the energy range 2-3 MeV not seen in coincidence must deexcite higher levels to the ground state. This represents about 10% of the γ-intensity arriving at the ground state and was taken into account in calculating the β feeding of the levels. Contrary to the previous result[10]) no β feeding to the ground state was obtained. This can be explained by the different experimental conditions: whereas at Ostis all the elements of the mass chain 97 are obtained by β decay from Rb, at Josef and Lohengrin all the elements are collected according to their independent fission yield. This enters into the calculation and introduces additional errors. The levels above 1900 keV are characterized by strong β feeding and low logft values (the logft are calculated with Qβ = 7450 keV (ref.[19]). These levels with positive parity are depopulated by strong E1 transitions to the $1/2^-$ ground state and by γ-ray cascades via the 652.2 keV E2 transition to the $9/2^+$ isomeric state at 667.5 keV. In combining the logft values and the conversion electron measurements with the population of the $1/2^-$ and $9/2^+$ states a tentative spin and parity assignment can be proposed for several excited states.

3.5 ^{99}Y Level Scheme

For the decay of ^{99}Sr a half-life of $T_{1/2}$ = 290 ± 40 ms (ref.[20]) was measured but no information on the decay scheme has been reported up till now. With the new high temperature ion source about 25 γ-lines could be attributed to the decay of this nucleus. The γ-γ coincidence measurements led to the establishment of the decay scheme shown Fig.5.(A preliminary level scheme was given in [21]). Contrary to the other odd Y isotopes we observe a considerable lowering of the excited states indicating a change in the structure of ^{99}Y.

In a previous paper[14]) we proposed a spin and parity $I^\pi = 1/2^-$ for the ground state of this nucleus and a possible $9/2^+$ beta isomer from systematic of the odd Y isotopes. But all attempts to find this isomer failed. New filiation measurement performed at Ostis and assuming the absolute intensity Iγ = 56% (ref.[14]) for the 469.1 keV γ-line of ^{99}Nb gives a stronger ground state β feeding of ^{99}Zr (about 33%) than in [14]). This indicates an allowed β branch to the $1/2^+$ and $3/2^+$ states. Therefore spin and parity $I^\pi = 1/2^+$ or $3/2^+$ have to be assigned to the ground state of ^{99}Y. But by analogy with the isotone ^{97}Rb the spin 3/2 seems the most reasonable choice.

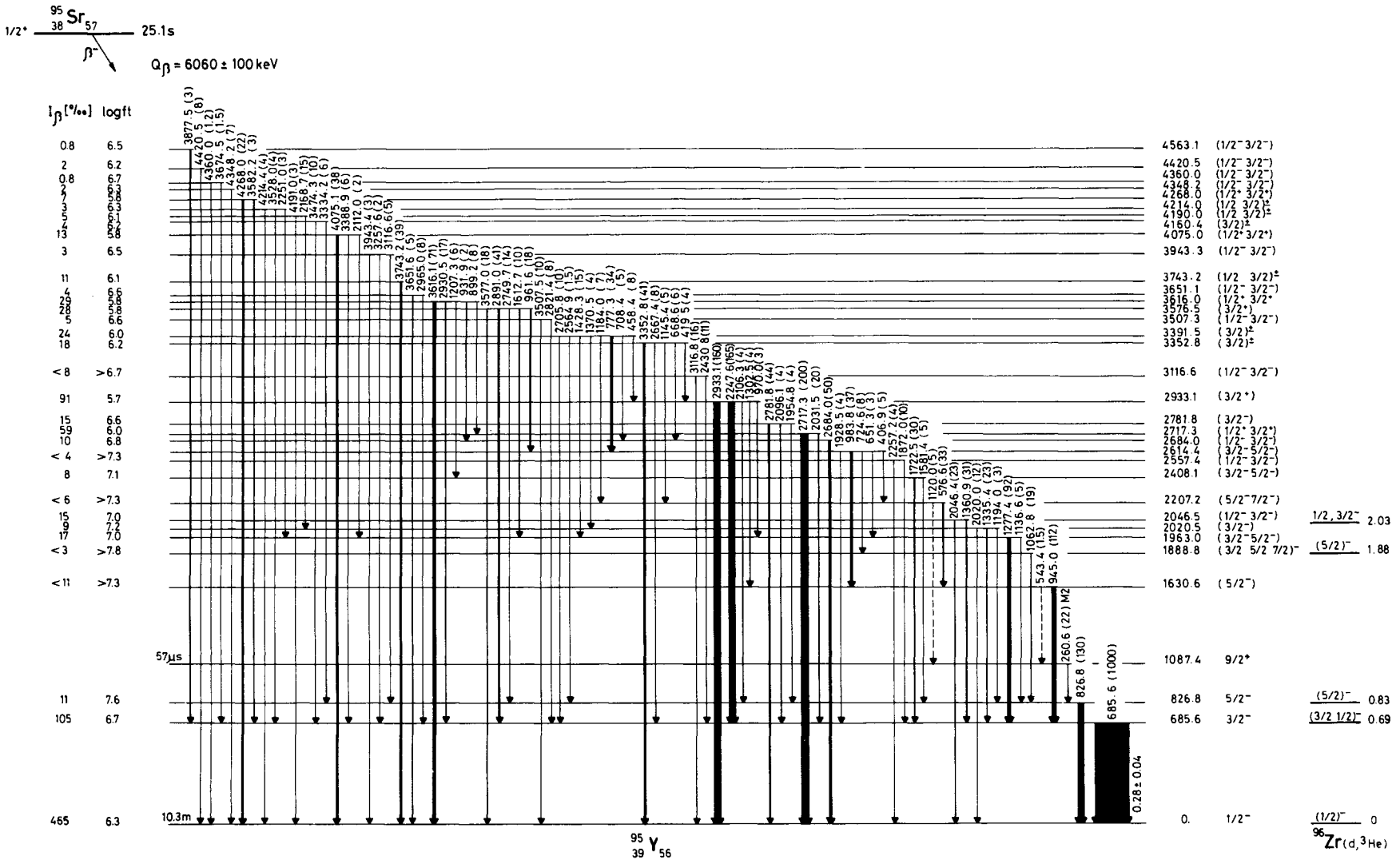

Fig. 3 Level scheme of ^{95}Y

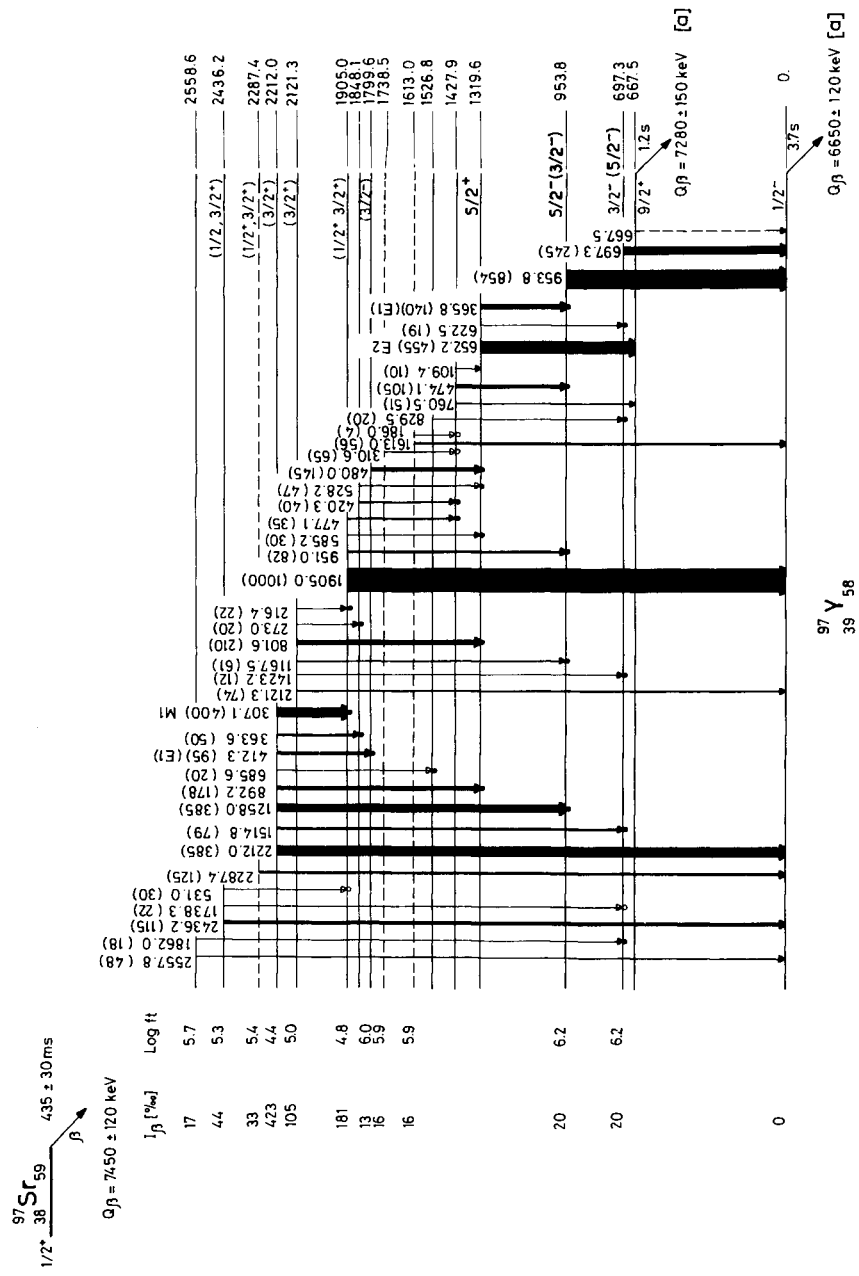

Fig. 4 Level scheme of ^{97}Y
[a] from ref.[19])

From the absolute intensity of the 125 keV γ-line found in the filiation measurement ($I_{\gamma abs}$ = 0.19 ± 0.03) the ground state β feeding of ^{99}Y is calculated as about 60%. This value is certainly overestimated due to the incomplete knowledge of the decay scheme but it must be rather strong. The logft ≳ 5.0 of this β branch leads to the assignment I^{π} = 3/2$^+$ or 5/2$^+$ for the ground state of ^{99}Sr.

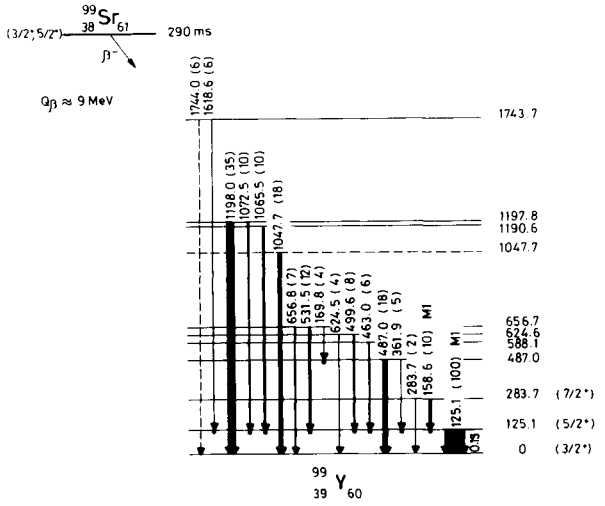

Fig. 5 - Level scheme of ^{99}Y.

4. Discussion

4.1 Odd neutron nuclei ^{95}Sr and ^{97}Sr

The ground state and the two first excited states of ^{95}Sr and ^{97}Sr are analogous to the corresponding ones in ^{97}Zr (see Fig.6), where they are interpreted as the shell model configurations $s_{1/2}$, $d_{3/2}$ and $g_{7/2}$ (ref[9]). This systematic behaviour shows the rather spherical nature of these three states. In contrast, isomeric states at about 600 keV were observed in ^{97}Sr as well in ^{99}Zr (ref.[14]). The strongly hindered deexcitation of these states to the low energy spherical ones shows these two groups of states are different in nature. In analogy with the even-even neighbouring nuclei ^{98}Sr and ^{100}Zr we could postulate these isomeric states have a different shape as the spherical ground state.

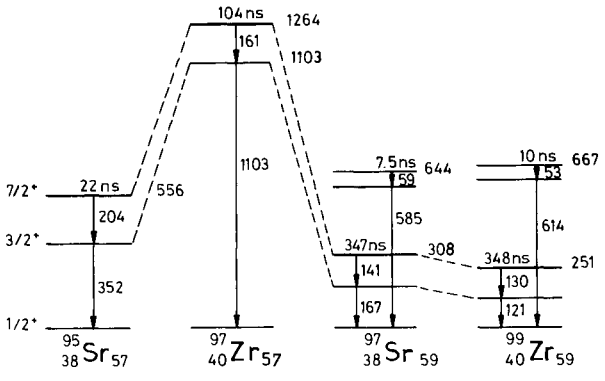

Fig. 6-Low lying excited states of ^{95}Sr and ^{97}Sr compared with those of ^{97}Zr and ^{99}Zr.

4.2 Odd proton nuclei ^{95}Y, ^{97}Y and ^{99}Y

The negative parity states below 1 MeV in ^{95}Y and ^{97}Y can be placed into the level systematics of the lighter odd mass Yttrium nuclei.

In ^{97}Y a positive parity system based on the 9/2$^+$ is observed. The level spacing of these states at 667.5 keV (9/2$^+$), 1319.6 keV (5/2$^+$) and 1905.0 keV (1/2$^+$, 3/2$^+$) is characteristic of the weak coupling with a vibrational core.

By adding two neutrons a strong coupling of the $g_{9/2}$ with the deformed core is observed in ^{97}Rb. The positive parity found for the ground state fixes an unique Nilsson orbital assignment [431 3/2]. The large quadrupole moment measured by[2]) confirms the large deformation of the ground state of ^{97}Rb.

Spin and parity assignment I^{π} = 3/2$^+$ to the ground state of ^{99}Y (Cf section 3.5) suggests that the structure of this state is analogous with the one of ^{97}Rb. This then leads to the assumption of a comparable deformation for both nuclei. The deformation of ^{99}Y can be seen from the different features of its decay scheme compared to the lighter odd Yttrium isotopes (See Fig.3,4). The level spacing of the two first excited states as well as the mode of deexcitation of the level at 283 keV suggests the existence of a rotational band built on the ground state. In order to confirm this assumption we have calculated the ratio $K(g_K - g_R)/Q_0$ from the branching ratio of the deexcitation of the level at 283 keV to the ground and first excited state in the framework of the rotational model. The obtained value of 0.44 is comparable with the number of 0.70 derived from the magnetic and quadrupole moments measured in ^{97}Rb (ref.[2]). The last value of 0.70 was calculated under the assumption g_R = Z/A.

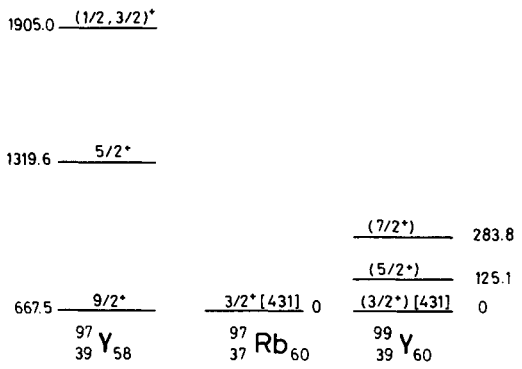

Fig. 7

The abrupt change in the coupling mode of the orbit $g_{9/2}$ with the core as a function of deformation is shown Fig.7.

If our assumption is correct this would be the first rotational band observed in an odd mass nucleus in the A ≳ 100 region. But more spectroscopic data would certainly be of great interest to confirm this result. Finnaly the spin and parity assignment I^{π} = 3/2$^+$ or 5/2$^+$ for the ground state of ^{99}Sr (see section 3.5) may correspond to the Nilsson orbits [411 3/2] or [413 5/2] respectively.

5. Conclusion

In this contribution new results on odd neutron and odd proton nuclei near N = 60 at the abrupt onset of deformation were presented. Although some of the results are preliminary a positive parity for the ground state of ^{97}Rb and the existence of a rotational band in the corresponding nucleus ^{99}Y could be suggested. It is a challenge for the future to extend detailed spectroscopic work further into the region $Z \leq 40$ and $N \approx 60$ with low fission yields.

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DISCUSSION

W. Andrejtscheff:

1) Please elaborate on your statement about possible shape coexistence in ^{99}Zr.

2) If the 125 keV level in ^{99}Y is of rotational type it should have a lifetime in the region of 1 ns. The attempt to measure the lifetime might provide some useful information.

B. Pfeiffer:

1) By comparing the first excited states of ^{97}Sr and ^{99}Zr with those of ^{97}Zr we concluded on a spherical nature of the low excited states. The rather long half-lives of M1/E2 transitions of 600 keV might arise from differences in the shape of the levels connected by these transitions. As ^{98}Sr and ^{100}Zr, for which shape coexistence has been reported, are the neighbours one is tended to relate these observations.

2) A first attempt has already been made, but due to technical problems no result was obtained. The experiment will be repeated in the near future.