High spin states in ^{95}Sr

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Twenty new γ transitions in ^{95}Sr were identified from γ-γ-γ coincidences in the spontaneous fission of ^{252}Cf. New bands, based on a previously known isomeric state, $T_{1/2}$=23.6(24) ns, have been built up to a $(31/2^+)$ state. The states in these bands show a close similarity in transition energies to the ground band of the neighboring ^{94}Sr, which has a spherical shape. This similarity is interpreted as the weak coupling of the $1g_{7/2}$ neutron particle to the levels of the $^{94}_{38}$Sr$_{56}$ core.

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In the weakly deformed Zr and Sr isotopes between the two shell gaps of N=50 and 56, a comparison of the excitation patterns is necessary to extract information on the hole and particle residual interactions between the valence neutrons and protons. The high spin states in ^{91,92,93}Sr [1,2], ^{89,90}Sr [3,4], ^{94}Sr [5], and ^{92,93,94,95}Sr [6] have been so far interpreted from this viewpoint. An abrupt change from a spherical to a deformed shape takes place as the neutron number increases from N=56 to N=64. Also, the coexistence of spherical and deformed shapes has been observed in ^{96,97,98}Sr [5,7,8], and in ^{98,99,100}Zr [5,8]. The nucleus ^{96}Sr has a spherical ground state with deformed excited states [8] while in ^{93,94}Sr only the spherical ground state [8] has been observed. The ground and first excited states in ^{97}Sr have spins and parities of $1/2^+$ and $3/2^+$, respectively. The $1/2^+$ ground state in ^{97}Sr has a spherical shape as discussed in Ref. [8] and high spin states in ^{97}Sr with a very deformed shape of $\beta_2 \approx 0.4$ were reported recently [7]. For the ground and first excited states in ^{95}Sr, $1/2^+$ and $(1/2^+, 3/2^+)$ were assigned [9] without any information on the deformation. It is interesting to identify the high spin states in ^{95}Sr with N=57 in order to look for neutron particle states originating from $1g_{7/2}$ orbitals excited from the N=56 subshell gap. In the present work, 20 new γ transitions and two new bands in ^{95}Sr are reported from γ-γ-γ coincidences in the spontaneous fission of ^{252}Cf. Weakly coupled bands based on a $1g_{7/2}$ neutron configuration are reported in ^{95}Sr, for the first time, in the Sr and Zr region.

In the present work, the measurements were carried out at the Lawrence Berkeley National Laboratory by using a spontaneously fissioning ^{252}Cf source inside the Gammasphere array [10]. A ^{252}Cf source of strength $\approx$62 μCi was sandwiched between two Fe foils of thickness 10 mg/cm^2 and was mounted in a 7.62-cm diameter plastic (CH) ball to ab-

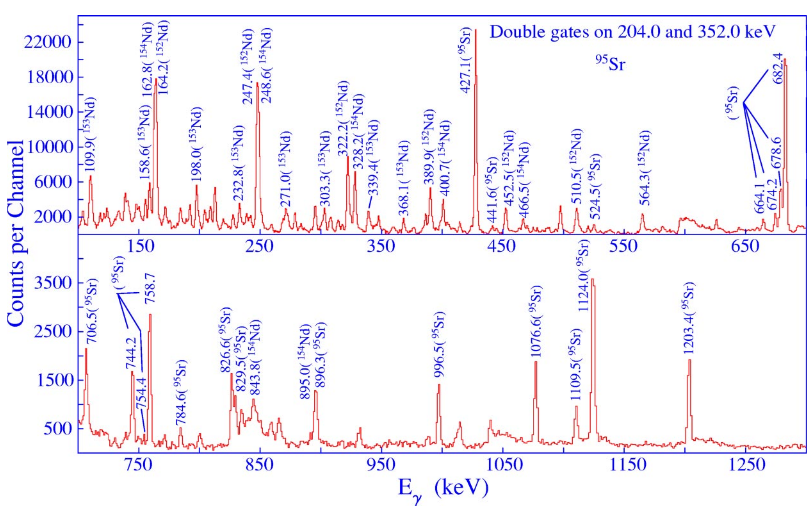

FIG. 1. (Color online) Coincidence spectra with double gates set on 204.0- and 352.0-keV transitions in ^{95}Sr.

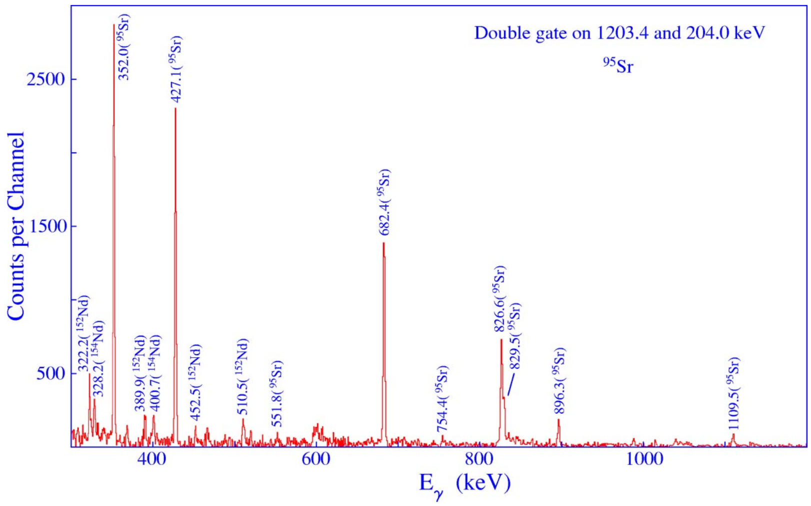

FIG. 2. (Color online) Coincidence spectrum with double gates set on 1203.4- and 204.0-keV transitions in ^{95}Sr.

sorb β rays and conversion electrons. The source was placed at the center of the Gammasphere array which, for this experiment, consisted of 102 Compton suppressed Ge detectors. A total of 5.7×10^{11} triple and higher fold coincidence events were collected. The coincidence data were analyzed with the RADWARE software package [11]. The width of the coincidence time window was about 1 μs. The ordering of transitions in bands is based on relative intensities, coincidence relationships, and the feeding and decaying intensity balances for levels.

The partner fragments of ^{95}Sr in spontaneous fission of ^{252}Cf are ^{154}Nd$(3n)$, ^{153}Nd$(4n)$, and ^{152}Nd$(5n)$. When we set double gates on two known transitions belonging to ^{152,153,154}Nd, the previously known 352.0-, 204.0-, and 652.4-keV transitions in ^{95}Sr from the β decay work [12] are clearly seen in our spectra. But we did not see the 886.1-keV transition between the 1238.5- and 352.0-keV states as seen in the β^- decay from the $5/2^-$ state of ^{95}Rb. By double gating on these three known transitions (352.0-, 204.0-, and 685.4-keV transitions [12]) we observed several new transitions belonging to ^{95}Sr. Also, by comparing coincidence spectra with double gates on one transition in ^{95}Sr and another on a transition in one of Nd partner isotopes, 20 new transitions in ^{95}Sr were identified.

The 352.0-keV and 204.0-keV transitions have $M1$ and $E2$ multipolarities [12], respectively. According to those properties, the spins and parities of the first and second excited states in Fig. 2 were assigned as $(3/2^+)$ and $(7/2^+)$ [9] in the present work. The log ft values to these states from the β^- decay of ^{95}Rb [12] also support these spins and parities [12]. The log ft value to the 1238.5-keV state is >7.6 [12] which is a first forbidden (unique) case or $\Delta I=0^-$, 1^-, or 2^- for the β^- decay from the $5/2^-$ state of ^{95}Rb. Therefore the spin and parity of $(9/2^+)$ is assigned to this state in the present work. This spin and parity assignments would make the 886.1-keV transition an $M3$ which is unlikely and is consistent with its nonobservation.

In Fig. 1, we show the coincidence spectrum with a double gate on the 352.0- and 204.0-keV transitions in ^{95}Sr. In Fig. 1 there are several weak peaks which are very hard to assign to any particular isotope. Some of them may be from the background coincidences and some of them from different isotopes which are not identified in the present work. However, the transitions assigned to ^{95}Sr are clearly established by comparing several different coincidence spectra. Figure 2 shows a spectrum in coincidence with the 1203.4- and 204.0-keV transitions. In Fig. 2, the peaks corresponding to the transitions of ^{95}Sr are clearly seen with the double

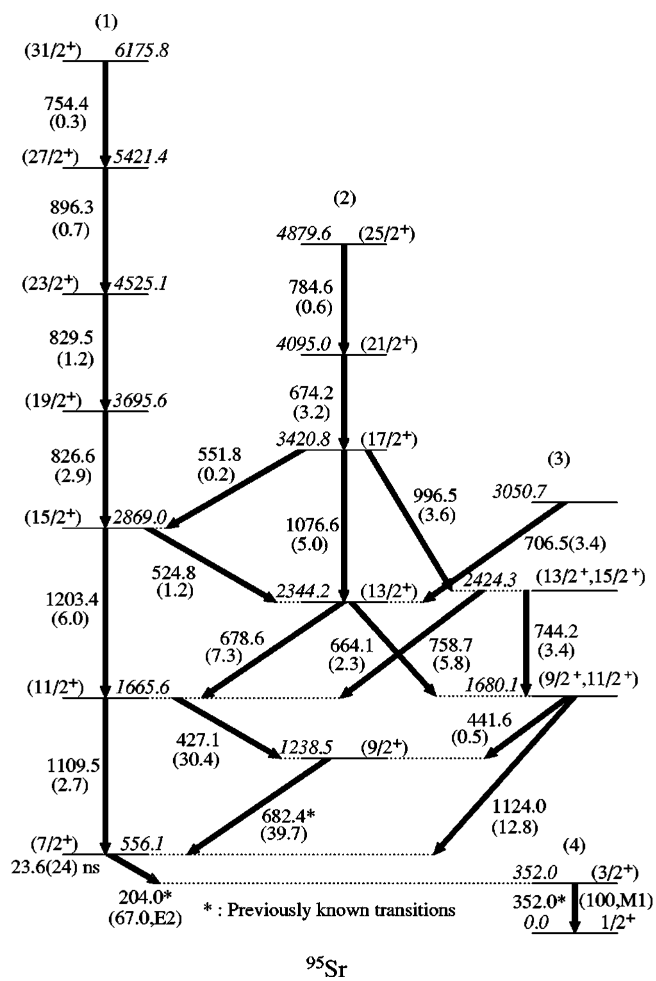

FIG. 3. High spin states in ^{95}Sr. The intensity errors range from 5% for the strong transitions to 30% for the weak transitions. The intensities of the transitions are shown in parentheses.

TABLE I. Transition energies and intensities in ^{95}Sr. The intensity errors range from 5% for the strong transitions to 30% for the weak transitions. All of spins and parities except $1/2^+$ are, tentatively, assigned in the present work.

E_γ(keV)	Relative I_γ	$I_i^\pi \rightarrow I_f^\pi$	E_γ(keV)	Relative I_γ	$I_i^\pi \rightarrow I_f^\pi$
204.0	67.0	$(7/2^+) \rightarrow (3/2^+)$	352.0	100	$(3/2^+) \rightarrow 1/2^+$
427.1	30.4	$(11/2^+) \rightarrow (9/2^+)$	441.6	0.5	
524.8	1.2	$(15/2^+) \rightarrow (13/2^+)$	551.8	0.2	$(17/2^+) \rightarrow (15/2^+)$
664.1	2.3		674.2	3.2	$(21/2^+) \rightarrow (17/2^+)$
678.6	7.3	$(13/2^+) \rightarrow (11/2^+)$	682.4	39.7	$(9/2^+) \rightarrow (7/2^+)$
706.5	3.4		744.2	3.4	
754.4	0.3	$(31/2^+) \rightarrow (27/2^+)$	758.7	5.8	
784.6	0.6	$(25/2^+)(21/2^+)$	826.6	2.9	$(19/2^+) \rightarrow (15/2^+)$
829.5	1.2	$(23/2^+) \rightarrow (19/2^+)$	896.3	0.7	$(27/2^+) \rightarrow (23/2^+)$
996.5	3.6		1076.6	5.0	$(17/2^+) \rightarrow (13/2^+)$
1109.5	2.7	$(11/2^+) \rightarrow (7/2^+)$	1124.0	12.8	
1203.4	6.0	$(15/2^+) \rightarrow (11/2^+)$			

gates on 1203.4- and 204.0-keV transitions in ^{95}Sr. By using the relative intensities and coincidence relationships, the four levels observed in β decay along with new high spin states in ^{95}Sr observed in the present SF work are shown in Fig. 3. We identified clearly only three transitions observed in β decay work [12] namely the 352.0-, 204.0-, and 682.4-keV transitions. Many other transitions reported in β^- decay work [12] are not shown in Fig. 3 because they are not seen in our SF data. New transitions belonging to ^{95}Sr are shown in Figs. 1 and 2. The relative transition intensities are shown in Table I and in Fig. 3.

Ideally, one would like to have γ-γ angular correlation measurements to determine the multipolarities. The Eurogam collaboration has made a few angular correlation measurements [13,14]. In their cases, the fission fragments were stopped in a KCl salt pill, a diamagnetic medium in which the perturbing magnetic or electric fields at the stopped fission nuclei should be small. In all our Gammasphere experiments, we have stopped the fragments in metallic foils such as Fe and Ni, which could have large residual perturbing fields [2]. Because of this situation, spin and parity assignments for high spin states in ^{95}Sr are tentative in the present work.

In this mass region, according to the Nilsson deformed shell model [12], the $2d_{5/2}$, and $1g_{7/2}$ orbitals are below and above the $N=56$ spherical subshell gap, respectively. In our previous work on ^{93}Sr, the bands were interpreted as originating from the weak coupling of the $2d_{5/2}$ neutron hole to the levels of the $N=56$ ^{94}Sr core [2]. Since ^{95}Sr has one neutron in the $1g_{7/2}$ near spherical orbital, the levels in ^{95}Sr can be thought of as arising from the weak coupling of the $g_{7/2}$ neutron to the ^{94}Sr core [2]. On this basis, the spins and parities to bands −1 and −2 are assigned. The $E2$ assignments to the transitions in the bands are based on the fact that the transition energies in bands −1 and −2 in ^{94}Sr are similar to those in ^{93,94}Sr. A comparison of the level energies in ^{93,94,95}Sr is shown in Fig. 4. Since the band head energy of band −1 in ^{94}Sr is 556.1 keV above the ground state energies of ^{93,94}Sr, a value of 556.1 keV is subtracted from each level energy in band −1 for comparison as shown in Fig. 4. Then bands −1 and −2 of ^{95}Sr will have a spherical shape similar to that of a ground state rotational band of ^{94}Sr. Bands −1 and −2 are extended up to $(31/2^+)$ and $(25/2^+)$, respectively. The spins and parities of the levels in band −3 are tentatively assigned based on the decay and feeding pattern of the levels.

In summary, 20 new γ transitions in ^{95}Sr were observed, for the first time, by using the SF source of ^{252}Cf and Gammasphere. States in ^{95}Sr, based on the previously known isomeric state at 556.1 keV, are established up to an excitation

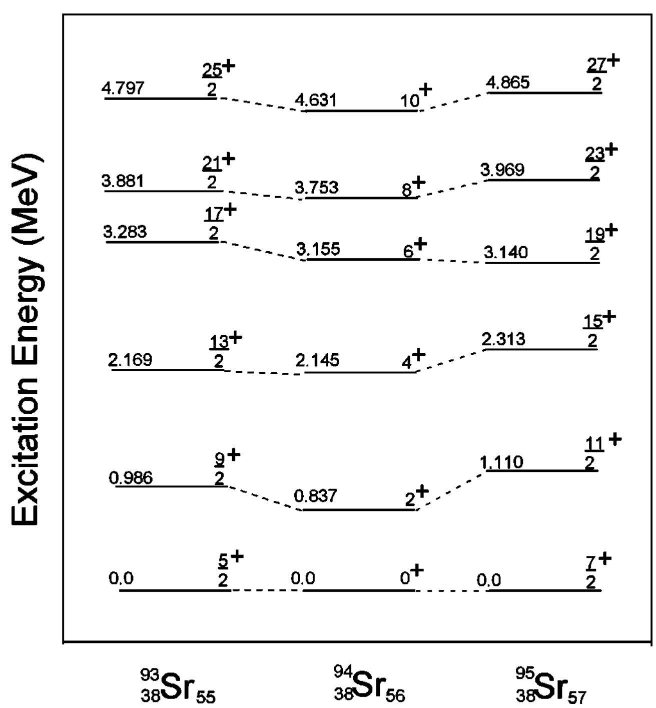

FIG. 4. Comparison between the experimental excited energies in ^{95}Sr, ^{93}Sr [2], and ^{94}Sr [2,5]. A value of 0.5561 MeV is subtracted from each level energy in band −1 in ^{95}Sr to normalize it with the values in ^{93,94}Sr.

energy of 6175.8 keV $[(31/2^+)]$. These bands show a close similarity in transition energies to the ground band of the neighboring ^{94}Sr which has a spherical shape. This similarity leads to an interpretation of the ^{95}Sr levels as arising from the weak coupling of the $1g_{7/2}$ neutron to the levels of the $^{94}_{38}$Sr$_{56}$ core.

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