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Uncertainties on gamma-ray energies and intensities measured in the decay of ^{83}Sr

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We analyze once again the γ singles spectra and γ-γ-t coincidence spectra following the β^++EC decay of ^{83}Sr. Multipeaks are carefully separated and many γ transition cascades are clearly obtained in the work. As a complement to our previous work, the uncertainties on γ-rays energies, γ-rays intensities and deduced level energies in the β^++EC decay of ^{83}Sr are given now.

Keywords: Uncertainty on γ-ray energy; uncertainty on γ-ray intensty.

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In our previous work,[1] approximately 190 γ-rays including 94 new γ-rays and 19 new levels were assigned to the β^+ + EC decay of ^{83}Sr. Among the approximately 190 γ-rays, 180 ones were placed in the decay scheme which incorporates all the observed γ transitions except seven relatively weak ones, but no uncertainties on γ-ray energies and intensities were given. Therefore, we analyze once again the γ singles in the multispectra mode and γ-γ-t coincidence spectra, by paying particular attention to the hardly decomposed γ-ray multiplets.

Details of the experimental procedure and main results can be found in Ref. 1, but some important points may be mentioned here for completeness. The summed singles spectra are analyzed carefully with a computer program which fits each peak with an adjustable lines shape (approximately Gaussian), then the centroid channel and peak area are used to derive the γ-ray energy, intensity and their uncertainties. Many weak γ-rays which are not identified or barely assigned in each individual spectrum can be clearly identified in the summed singles spectrum. The relative intensities of γ-rays, including the energies of that below 60 keV, are determined from the summed spectrum without anti-Compton suppression. The energies of γ-rays above 60 keV are obtained from Compton-suppressed spectra.

The uncertainties of the γ-rays energy and intensity include the contributions from the counting statistics, the systematic uncertainty of the energy calibration and relative efficiency calibration, respectively, and the normalization procedure. For the singles spectrum, the systematic uncertainty of the energy calibration is 0.04 keV when the γ-rays energy is below 200 keV or over 2000 keV, otherwise it is 0.03 keV, while the systematic uncertainty of the relative efficiency calibration is 3% when the γ-rays energy is less than 250 keV and 2% when the γ-rays energy is larger than 250 keV. For the coincidence spectrum the systematic uncertainty of energy calibration is 0.1 keV and that of relative efficiency calibration is 5%. Now the uncertainties on γ-rays energies and intensities of all the γ-rays assigned to the decay of ^{83}Sr are added, as shown in Tables 1 and 2. The reported uncertainties refer to the last significant digits.

Because both the energy resolution of spectrometer and the statistical fluctuation of counts have been largely improved, compared to the previous works, coupled with the use of detailed spectral decomposition method, the accuracy of energy measurement is improved by over three times. By decomposing the multiple peaks, a number of new γ-rays are discovered. The background and contaminants at very low radioactive level are mainly ^{85}Sr, ^{83}Rb, ^{84}Rb, ^{131}Ba, ^{60}Co, ^{40}K, ^{137}Cs, etc. The energies and uncertainties of all 41 excited levels (see Table 1) are obtained by the method of least squares. Table 2 is the same as Table 1 in our previous paper,[1] but now the uncertainties are added. It should be noted here that we provide I_γ in this paper, but in Fig. 2 of our previous paper[1] the data next to the γ-rays energy are the transition intensities, as implied by the words "Intensities: $I_{(\gamma+ce)}$ per 100 parent decays", where I_{ce} (I_{ce} denotes the intensity of internal-conversion electron) is obtained from the calculations. The measured energy region is between 30 keV and 2650 keV, thus the 42.08 keV γ-ray can be detected and its uncertainty is also given, as shown in Table 1, but not the 5.23 keV γ-ray.[2]

All the intensities of the γ-rays are normalized to an intensity of 100 for the 762.61 keV γ transition. An additional measurement of the relative intensity of the 511 keV annihilation radiation (from which the total β^+ decay intensity can be obtained) is performed, with the ^{83}Sr source sandwiched between two lead plates of 3 mm thickness each, to produce total annihilation. The relative (β^+ + EC) decay strength (normalized to intensity of 762.61 keV γ transition) to each excited level can be obtained from intensity balance. By using theoretical $I_{\beta+}/I_{\rm EC}$ values, the relative β^+ intensity of each excited level can be calculated. The relative intensity

Table 1. The uncertainties of energies and relative intensities of γ-rays assigned to the decay of ^{83}Sr and placed in the decay scheme and the deduced uncertainties of level energies.

E_x (keV)	I^π	E_γ (keV)	I_γ	E_x (keV)	I^π	E_γ(keV)	I_γ	E_x (keV)	I^π	E_γ (keV)	I_γ
2189.545 23	9/2+	2147.42 6	0.564 12			1492.78 5	0.065 5			678.31 4	0.153 6
		1765.84 5	0.059 3	1798.475 18	(5/2)+	1798.46 4	0.101 4			438.16 3	2.90 6
		1452.50 7	0.027 3			1793.23 6	0.038 2			159.65 4	0.373 19
		1395.95 9	0.031 3			1756.38 4	0.075 3	1201.955 18	(5/2,7/2)+	1201.94 3	0.423 9
		1384.83 4	0.344 9			1374.86 4	0.180 5			1159.87 3	5.14 10
		1151.97 9	0.017 6			1233.94 5	0.067 3			778.38 3	6.58 13
		1086.67 4	0.098 5			993.78 3	1.23 3			737.3 3	0.020 1
		987.60 9	0.032 3			715.35 3	0.339 12			637.39 7	0.057 4
		764.92 5	0.217 6			555.63 13	0.027 5	1102.81 4	9/2-	1102.73 4	0.110 4
		494.1 5	0.050 3	1749.252 18	(5/2+,7/2)	1749.20 4	0.091 4			365.5 2	0.025 8
2134.705 24	(5/2,7/2)+	2134.67 6	0.093 3			1707.15 5	0.077 3	1096.459 24	(9/2)+	1054.33 3	0.726 16
		2092.46 17	0.005 1			1325.62 4	0.256 7			673.04 6	0.074 7
		1711.12 4	0.111 5			1184.54 10	0.018 3			291.61 7	0.087 9
		1397.56 9	0.041 3			944.51 3	0.443 11	1083.132 23	(1/2,3/2)+	659.53 3	0.810 18
		1330.03 9	0.026 3			652.78 3	0.281 7	1037.65 3	11/2+	995.55 4	0.545 12
		1038.23 4	0.301 7			547.3 4	0.030 1			243.9 4	0.050 2
		838.78 12	0.018 6			506.4 2	0.26 3	1035.118 23	(3/2,5/2)	1035.04 4	0.128 4
		768.90 8	0.026 3	1695.334 24	(7/2,9/2)+	1653.22 4	0.254 7			1029.63 17	0.011 2
		537.12 7	0.034 8			1271.81 4	0.233 7			935.79 6	0.052 5
2094.98 5	(5/2+,7/2,9/2)	2052.93 7	0.028 1			890.60 3	0.449 11			645.74 4	0.185 10
		1290.23 11	0.016 2			657.68 4	0.323 8			611.4 2	0.021 4
		892.96 7	0.048 3			599.12 13	0.018 7			568.00 7	0.013 5
2089.725 19	(5/2,7/2+)	2089.71 5	0.400 9			493.45 5	0.196 11			470.69 9	0.026 8
		2047.64 5	0.322 7			270.8 2	0.030 1			298.02 5	0.092 6
		1666.16 4	0.281 8	1649.35 4	(5/2,7/2,9/2)-	1649.40 5	0.086 3	1010.20 3	(3/2,5/2,7/2)-	1010.18 4	0.129 5
		1525.22 26	0.005 1			1084.76 7	0.040 3			1004.96 4	0.094 4
		1352.46 10	0.034 5			827.81 14	0.015 5			445.69 7	0.058 5
		1285.02 4	0.306 8			795.34 5	0.076 3	907.947 22	(3/2,5/2)	907.94 5	0.723 22
		993.22 5	0.167 17			639.13 8	0.051 4			902.64 4	0.182 5
		846.87 4	0.193 5	1614.76 4	(5/2+,7/2,9/2+)	1572.70 5	0.043 2			808.60 4	0.168 5
		812.32 13	0.021 3			1191.10 13	0.014 2			518.5 2	0.11 2

Table 1. (*Continued*)

E_x (keV)	I^π	E_γ (keV)	I_γ	E_x (keV)	I^π	E_γ(keV)	I_γ	E_x (keV)	I^π	E_γ (keV)	I_γ
		723.72 13	0.016 3			1050.24 4	0.318 7			484.5 5	0.020 2
		394.47 12	0.026 4			877.63 5	0.082 3			440.85 8	0.042 5
2056.93 4	(5/2+,7/2+, 9/2)	2014.83 4	0.145 4			371.9 3	0.022 6			343.4 3	0.030 2
		1319.84 11	0.013 2	1606.20 5	(3/2,5/2,7/2)	1606.07 14	0.008 2	853.953 19	(3/2,5/2)	853.98 4	0.27 2
		1252.30 5	0.049 5			1600.97 9	0.020 2			848.66 3	0.592 13
		1019.25 4	0.176 7			1506.91 8	0.022 2			754.56 5	0.103 4
2036.40 10	(5/2,7/2)	2030.99 15	0.008 1	1597.577 20	(5/2,7/2)	1597.59 4	0.111 5			289.53 5	0.122 7
		1647.21 15	0.012 2			1592.31 5	0.039 2	821.61 3	(3/2,5/2)	821.59 4	0.023 3
		1612.70 12	0.034 3			1208.17 5	0.062 3			816.34 4	0.168 5
		1231.85 12	0.008 3			1173.88 4	0.171 7			722.28 7	0.044 3
1951.918 13	5/2+	1951.93 3	2.71 5			792.97 4	0.122 4	804.692 15	7/2+	804.67 3	0.308 7
		1946.66 5	0.065 2			395.62 4	0.209 10			762.61 3	100
		1562.53 3	6.07 12	1424.71 4	(9/2+)	1382.73 5	0.131 4			381.09 5	6.71 20
		1528.34 4	0.332 8			630.88 5	0.087 8	793.78 4	13/2+	751.71 4	0.193 5
		1387.38 5	0.085 3	1374.71 6	(3/2,5/2)	1275.34 8	0.029 3	737.102 18	7/2-	737.07 3	0.875 19
		1214.79 3	0.850 19			907.62 10	0.021 8			731.84 3	0.296 7
		1147.17 3	4.29 9	1365.88 4	(5/2+,7/2,9/2)	1323.78 4	0.477 12			695.06 15	0.019 7
		1130.25 4	0.139 6			561.22 6	0.073 4			172.5 1	0.059 6
		1097.96 3	0.868 19			328.4 2	0.020 1	564.522 17	(3/2,5/2,7/2)-	564.54 4	0.295 9
		1043.93 3	1.171 25			269.5 4	0.040 2			559.30 3	0.735 18
		941.94 10	0.031 3	1295.96 3	(5/2,7/2)	1295.96 3	0.457 11	467.09 5	(1/2,3/2)	461.82 7	0.072 7
		916.79 3	0.470 11			906.55 4	0.30 2	423.599 13	5/2+	423.61 3	5.43 11
		868.84 5	0.063 6	1277.50 3	(3/2,5/2,7/2)	1277.49 4	0.134 5			418.37 3	15.74 32
		749.96 5	0.141 4			1272.39 10	0.061 7			381.52 3	52.5 13
		709.13 6	0.054 3			887.90 6	0.050 3	389.396 16	3/2-	389.37 3	5.59 11
		674.41 4	0.164 6			713.00 12	0.023 3			384.18 4	0.294 8
		577.18 8	0.031 9	1242.817 15	(5/2)+	1242.82 4	0.271 7			290.09 3	1.368 25
		354.32 4	0.203 15			1237.56 3	0.755 17	99.344 21	(3/2)-	94.12 3	1.41 8
		345.80 8	0.029 10			1200.75 6	0.142 5	42.077 15	9/2+	42.08 4	6.13 19
		153.55 10	0.043 5			853.42 4	0.20 2	5.243 14	3/2-		
1916.38 5	(5/2,7/2)	1916.4 2	0.010 2			819.23 3	2.80 6				
		1911.12 4	0.112 4			775.77 12	0.021 3				

Table 2. The uncertainties of energies and relative intensities of γ-rays assigned to the decay of ^{83}Sr but not placed in the decay scheme.

E_γ (keV)	758.20 10	856.81 12	1498.60 17	1608.90 18	1709.45 18	1777.90 4	1873.69 4
I_γ	0.08 3	0.017 3	0.005 2	0.007 2	0.013 2	0.082 4	0.108 5

of β^+ decay to the ground state is calculated by subtracting the relative β^+ intensity to excited levels from the measured total β^+ decay intensity, and the relative (β^++EC) decay intensity (47 ± 9) to the ground state is also calculated using theoretical $I_{\beta+}/I_{\mathrm{EC}}$ value. The renormalization coefficient (0.299 ± 0.015) and (β^++EC) branching ratio for each level are then obtained.

In summary, in order to study the decay of nuclei with very complex decay scheme, the present paper focuses on the process of analyzing the spectrum, the peak position and fitting interval determined by automatic peak searching code are checked and verified. The nonlinear least square method is adopted to perform curve fitting. Practice proves that manual control of the process of decomposing the complex multiple peaks is effective and necessary. This ensures the accuracy of γ-rays energy and relative intensity and then the deduced level energy is greatly improved.

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