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Short note

The γ-Decays of ^{210}Po-Levels from the (^{3}He, d$^*\gamma\gamma$)-Reaction

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Abstract. An in-beam experiment with the subcoulomb reaction ^{209}Bi(^{3}He, d$^*\gamma\gamma$)^{210}Po at 20.5 MeV was performed with two Euroball Cluster detectors in Cologne. It closed the gap between the low energy levels of the level-scheme and the high energy levels found in ^{209}Bi(^{3}He, d)^{210}Po and ^{208}Pb(^{4}He, t)^{210}Po particle experiments. New branchings have been found and the (^{3}He, d$^*\gamma\gamma$) reaction below the coulomb-barrier has been used successfully.

PACS. 21.10.Pc Single-particle levels and strength function – 23.20.Lv Gamma transitions and level energies – 25.55.-e 3H-,3He-, and 4He-induced reactions

The mass region around the doubly magic nucleus ^{208}Pb is one of the most important testing grounds for the nuclear shell model [1]. Although the excitations of ^{209}Bi(^{3}He, d)^{210}Po and ^{208}Pb(^{4}He, t)^{210}Po have been well investigated with methods of particle spectroscopy [2], the electromagnetic decay properties of these states are not known to the same extent. No γ-transitions depopulating the multiplet-levels above 4 MeV had been observed so far [3]. The observation of these high energy γ-transitions and thus the connection to the level-scheme has become possible due to the high efficiency of the Euroball Cluster detectors.

The experiment, performed at the Cologne FN-Tandem accelerator, used the ^{209}Bi(^{3}He, d$^*\gamma\gamma$)^{210}Po reaction at 20.5 MeV. We write d* to include the various exit channels of deuterons with spin 1 and 0 and the (pn)-channel, which we did not distinguish in particular. Thus we have d (S=1), d (S=0), (pn) $\subset$ d*. In order to reduce the competing fusion reaction (^{3}He, 2n) we chose a beam energy below the Coulomb-barrier. This reaction was also chosen to test the power of the subcoulomb stripping reaction in gamma decay studies. We were able to observe γ-spectra with only relatively few contaminations, which were mainly (^{3}He, p2n)^{209}Po ($\sim$50% compared with ^{210}Po), (^{3}He, 3n)^{209}At ($\sim$10%) and (^{3}He, 2n)^{210}At ($\sim$5%). These contaminations could easily be separated using $\gamma\gamma$-coincidences.

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The spectrometer used in this experiment consisted of two unshielded Euroball Cluster detectors at a distance to the target of only 8 cm. Each of the Euroball Cluster detectors, developed by a collaboration of groups from Cologne, Jülich, the company Eurisys, and the Euroball Collaboration [4] consists of seven high purity germanium detectors (segments) with an efficiency of 65% relative to a 3"x3" NaI detector. The setup was optimized to detect $\gamma\gamma$-coincidence events of high energy transitions. The close target-detector distance is possible, because our proton stripping reactions provide γ cascades of low multiplicities, which reduces the probability of multiple hits respective to fusion-evaporation reactions. With the two detectors we achieved a photopeak efficiency of $\approx$ 7% at 1333 keV, applying the nearest neighbour addback method as described in [5]. A schematic view of the setup can be seen in Fig. 1.

The granularity of the Euroball Cluster detector allows a quantitative analysis of γ-peaks due to sum-up events [6]. To obtain a good energy and efficiency calibration at high energies, in addition to the standard ^{226}Ra source we used ^{24}Mg (^{24}Mg(p,n)^{24}Al $\xrightarrow{\beta+}$ ^{24}Mg* $\xrightarrow{\gamma}$ ^{24}Mg) for calibration. This procedure [7] allows a highest quality energy calibration up to 7 MeV. Due to the different decay-multiplicities of ^{226}Ra, ^{24}Mg and ^{210}Po a systematic error in the efficiency calibration had to be taken into account. This error emerged to be less than 10%.

The $\gamma\gamma$-matrix of addback events contains 1.2 billion coincidence events from 40 hours of measuring. This data were analyzed to establish the coincidence relations and extend the levelscheme. We were able to find 14 new lev-

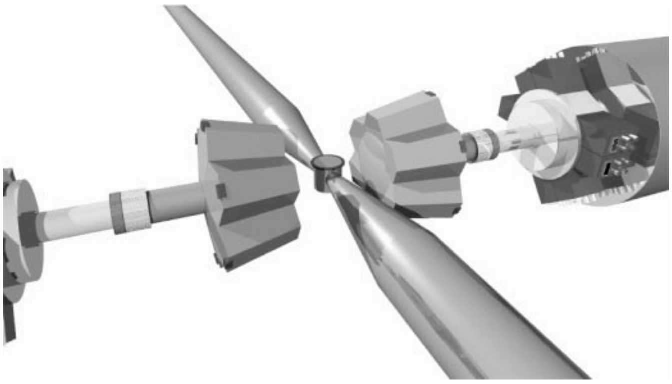

Fig. 1. Experimental setup: Two Euroball Cluster detectors in a distance of 8 cm from the target

Table 1. Comparison of sets of levels observed by different ^{210}Po reactions

	reaction	Ref.	levels
1:	^{209}Bi(^{3}He, d)	[3]	23
2:	^{208}Po(^{4}He, t)	[3]	31
3:	^{209}Bi(t, 2nγ)	[8]	45
4:	^{209}Bi(^{3}He, d$^*\gamma\gamma$)	this work	56

els and 39 new γ-transitions in ^{210}Po. The results of our analysis are shown in Fig. 2 and in Table 2. Furthermore, six levels previously observed only in particle experiments were connected to the level scheme by γ-transitions and thus the precision of the measured level energies could be improved.

This experiment gives a good evidence for the utility of the subcoulomb (^{3}He, d$^*\gamma\gamma$) reaction. The amount of new data is remarkable taking into account the previous knowledge of 61 levels [3]. A comparison of different reactions used to investigate states of ^{210}Po is given in Tab. 1.

In Fig. 2 the single particle excitations in ^{210}Po are compared with those of ^{209}Bi [2]. We see all states of these multiplets with exception of a (3^+) state at 4320 MeV. Because of the observed γ-transitions, it is now possible to improve several spin assignments. The 4553 keV state was (4^+,7^+) and is now assigned (7^+) due to the observed γ-transition to 8^+ states. Thus it belongs to the $h_{9/2}{\otimes}p_{3/2}$ mulitplet. The missing 4^+ could not be found.

The 3^- state at 2846 keV was assigned to the $h_{9/2} \otimes i_{13/2}$ multiplet, because it is the only 3^- in this region. The spin and parity of the 3^+ at 4592 keV assigned by [2] are put in some doubt because here an M3 would compete with possible E1, M1 and E2 transitions, which were not observed.

The fact, that the (^{3}He, pn)-reaction populated nearly all single-particle excitations may give a hint, that a subcoulomb stripping of one proton of the ^{3}He occured and the output-channel was a deuteron d (S=1) or an excited deuteron d (S=0), which would decay to the (pn)-channel. Furthermore, we observed spin transfers up to $6\hbar$.

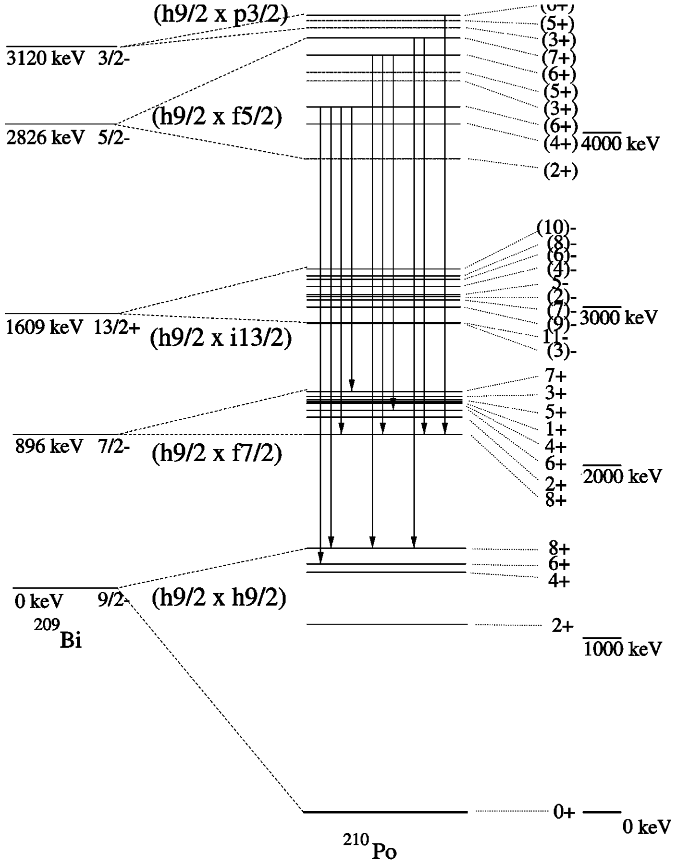

Fig. 2. New γ-transitions found in ^{210}Po. Only transitions which complete the 2-particles multiplets [2] are shown

Besides the construction of a levelscheme with the new γ-transitions, the decay branchings of the levels were found. To obtain high-quality branching ratios from our $\gamma\gamma$-matrices, we gate on transitions populating the level of interest. This was not possible for the new high energy levels. The branchings of these levels were found in the gate of the $2_1^+ \rightarrow 0_1^+$ 1181 keV transition. This includes additional systematic errors of about 30%.

The branchings will provide a useful test of the shell-model. There is still a need for further experiments to obtain spin and parity assignments, since some of the known spins are only tentative and our experimental setup offered no possibility to analyse angular distribution or correlation.

Summing up, this experiment attests the spectroscopic power of the subcoulomb (^{3}He, d$^*\gamma\gamma$)-reaction in conjunction with two Euroball Cluster detectors. Thus 56 new levels of ^{210}Po were observed up to an energy of 5 MeV.

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Table 2. New γ-transitions and energy-levels observed in ^{210}Po. If published energy E_p of the levels are given, the transition energies E_γ and the branchings are new. Initial and final spins (J_i, J_f) and the final levels E_f were taken from Ref. [3]. Changes from these values are marked with an asterix *. The relative intensities were calculated from all γ-transitions depopulating a level, seen in coincidence with the $2_1^+ \rightarrow 0_1^+$ transition. The given relative cross-sections I_{rel} are taken from the (^{3}He, d)-particle experiment [2]. The intensities and cross-sections are normalized to the 4141 keV level

E_i [keV]	E_p [keV]	J_i^π	J_f^π	E_γ [keV]	E_f [keV]	Branching	I_{rel}	$\sigma_{\mathrm{rel}40^\circ}$
3477.3_3			8+	1289.3_2	2188.0	100	9	
3637.5_2			3−	1250.7_2	2386.8	100	12	
3693.9_2			3−	1307.1_2	2386.8	100	5	
–	3792_2	(2+)						2
–	4027_1	4+						45
4029.1_3			8+	2602.4_3	1557.0	100	30	
4043.4_3			8+	1855.4_2	2188.0	100	25	
4105.1_3	4105_{10}		8+	1917.1_2	2188.0	100	5	
4141.1_4	4139_1	(6+)	8+	2665.5_4	1473.3	30_{10}	100	100
			7+	1702.5_2	2438.4	15_{10}		
			8+	1953.6_2	2188.0	30_{10}		
			8+	2583.8_3	1557.0	100_{20}		
			8+	2671.4_9	1473.3			
–	4237_{10}							
–	4320_1	(3+)						56
4329.5_4			6+	2003.5_3	2326.0	100	15	
–	4382_1	(5+)						88
4386.9_4			6+	2059.9_5	2326.0	40_{15}	55	
			8+	2199.3_3	2188.0	100_{10}		
4469.6_3	4469_1	(6+)	6+	2143.5_3	2326.0	10_8	120	170
			8+	2281.9_3	2188.0	20_{10}		
			8+	2913.1_3	1557.0	100_{15}		
4542.1_3		(4+)*	5+	2139.2_3	2403.3	60_{20}	35	
			3−	2159.8_3	2382.6	40_{10}		
			4+	2215.7_4	2326.0	50_{25}		
			6+	3115.6_6	1426.7	100_{30}		
4553.6_4	4553_1	(7+)*	8+	2365.6_4	2188.0	80_{20}	70	210
			8+	2997.9_6	1557.0	100_{20}		
4592.5_4	4591	(3+)	0+	4592.5_4	0.0	100		630
4621.5_3		(3+)*	5+	2207.9_3	2413.8	100_{30}	85	
			1+	2227.7_3	2393.8	30_{10}		
			4+	2238.8_4	2382.6	45_{15}		
			2+	2331.5_3	2290.1	50_{25}		
–	4624_1	(5+)						
4637.5_3			5+	2234.7_4	2403.3	60_{30}	90	
			4+	2255.1_3	2382.6	100_{15}		
			6+	2311.5_4	2326.0	25_{10}		
4644.9_5	4644_1	(6+)	8+	2456.9_5	2188.0	100	5	
4660.4_3			4+	2277.8_3	2382.6	75_{25}	50	
			6+	2334.1_4	2326.0	100_{40}		
4948.1_3			5+	2544.8_3	2403.3	50_{25}	45	
			6+	3474.9_5	1473.3	100_{50}		
4974.4_5			8+	2786.4_5	2188.0	100	10	
–	4991_1							80
4998.2_5			8+	2810.2_5	2188.0	100	2	

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