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Short note

High-spin levels in ^{147}Tb

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Abstract. The high-spin states of ^{147}Tb have been studied with regard to their spins. The data were obtained by in-beam γ-ray spectroscopy using the reaction ^{120}Sn(^{31}P,4n)^{147}Tb at 152 MeV performed at the OSIRIS spectrometer in Berlin. We obtained multipole mixing ratios for 60 transitions, and level spins up to $67/2\hbar$ are introduced.

PACS. 21.10.Hw Spin, parity and isobaric spin – 23.20.Gq Multipole mixing ratios – 25.70.Gh Compound nucleus – 27.60.+j $90 \leq A \leq 149$

The neutron magic nucleus ^{147}Tb is a suitable system for testing the spherical shell model at high spins and has been object of former studies [1–4]. Apart from its closed neutron shell this nucleus has just one extra proton to the closed subshell at $Z = 64$.

We performed an experiment with the OSIRIS spectrometer at the HMI in Berlin in order to extend former studies to higher spins. This detector array consisted of a BGO inner ball for γ-ray multiplicity and sum energy determination surrounded by 12 compton-suppressed Ge spectrometers. The VICKSI accelerator provided a beam energy of 152 MeV for the ^{120}Sn(^{31}P,4n)^{147}Tb reaction. The thick target consisted of a 2 mg/cm^2 layer of ^{120}Sn on a 13 mg/cm^2 ^{197}Au backing.

A total of 770 million double γ–γ events were collected. By choosing gating conditions on sum energy and multiplicity the data provided 505 million counts with a ^{147}Tb share of 40 %. The data were sorted into various γ–γ-correlation matrices from which we obtained experimental DCO ratios, that allowed assignments of spins and multipole mixing ratios δ_{exp} [5,6]. For some transitions a DCO analysis was not possible, but we obtained additional information about several γ-ray characteristics from angular distributions of our coincidence projection spectra.

Up to the $27/2^+$ level at 3421 keV and for two negative parity states ($27/2^-$ and $29/2^-$) all the spins and multipole orders but no δ-values were known from [1–3]. Therefore, we were compelled to use only pure E transitions, which have $\delta = 0$, as the basis of our DCO analysis (Table 1). We used ten multipolarities, which were in accorance with Méliani et al. [3], but we took no advantage of further spins and multipolarities given in their work. Altogether, spin assignments for about 50 levels and mixing ratios of 60 transitions were evaluated and are shown in Fig. 1. A complete listing of the experimental mixing ratios is given in Table 2.

The strongest cascade extends from the $27/2^-$ state (3839 keV) to a $67/2^{(+)}$ level at 13774 keV with a change of parity at the 285 keV transition ($49/2^{(+)} \rightarrow 47/2^{(-)}$). This change is possible for any parallel decay path, as both

Table 1. Basic ^{147}Tb transitions for DCO analysis. Level energies of ^{147}Tb are given relative to the $11/2^-$-isomer ($T_{1/2}$ = 1.8 min) at 51 keV. Transition characteristics accord to [1–3]

E_γ [keV]	I_γ	E_i [keV]	J_i^π	char.
257.4(1)	82777(516)	2991.9	$23/2^+$	E2
285.2(1)	61249(479)	8986.4	$49/2^{(+)}$	E1
404.5(1)	110485(752)	3139.2	$25/2^+$	E2
696.9(1)	191394(1175)	2734.5	$21/2^+$	E2
699.3(1)	47000(600)	3838.5	$27/2^-$	E1
918.8(1)	66968(948)	9905.2	$53/2^{(+)}$	E2
989.4(1)	62555(1134)	8701.1	$47/2^{(-)}$	E2
1037.0(1)	27112(508)	4457.6	$29/2^-$	E1
1081.3(1)	37936(710)	10986.4	$57/2^{(+)}$	E2
1407.6(1)	35239(595)	5246.1	$31/2^-$	E2

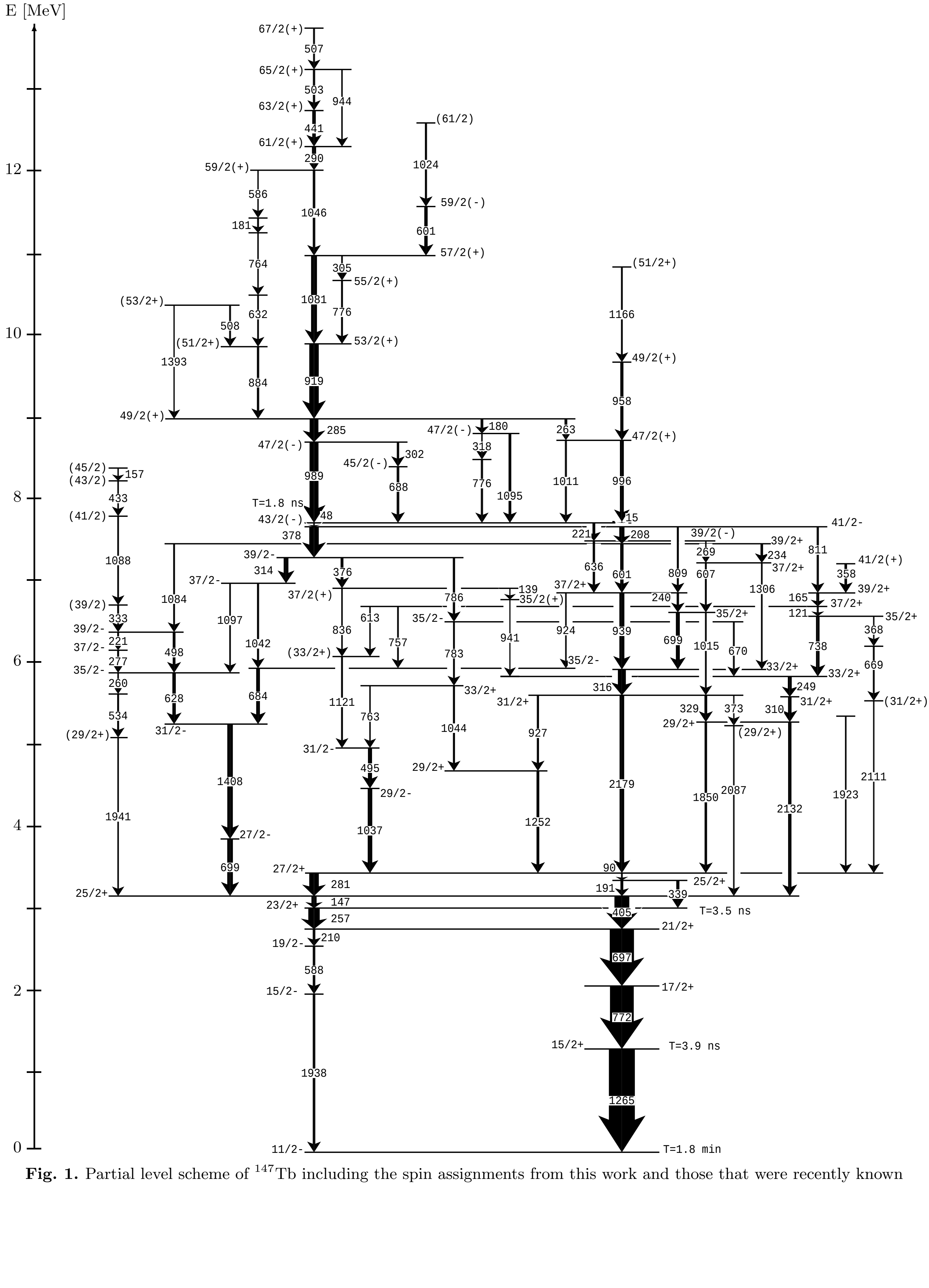

Fig. 1. Partial level scheme of ^{147}Tb including the spin assignments from this work and those that were recently known

Table 2. Transitions in ^{147}Tb and their mixing ratios δ_{exp} except for some stretched $E2$ transitions with $\delta = 0$ below the isomer at 7712 keV (628, 786, 939, 1044, 2132, and 2179 keV). Intenities of doublets (given without errors) had to be calculated

E_γ [keV]	I_γ	E_i [keV]	→	E_f [keV]	J_i^π	→	J_f^π	char.	δ_{exp}
120.8(1)	6140(142)	6687.6	→	6567.3	$37/2^+$	→	$35/2^+$	M1/E2	-0.25 ± 0.10
139.2(2)	1805(109)	6910.1	→	6771.1	$37/2^{(+)}$	→	$35/2^+$	M1/E2	-0.20 ± 0.10
147.4(1)	32500	3139.2	→	2991.9	$25/2^+$	→	$23/2^+$	M1 (from [3])	0.05 ± 0.05
165.5(1)	13918(221)	6853.1	→	6687.6	$39/2^{(+)}$	→	$37/2^{(+)}$	M1/E2	-0.05 ± 0.05
180.0(2)	14300	8986.4	→	8806.6	$49/2^{(+)}$	→	$47/2^{(-)}$	E1 (from [3])	0.00 ± 0.05
208.2(1)	32061(289)	7664.0	→	7455.9	$41/2^-$	→	$39/2^+$	E1	$0.00^{+0.05}_{-0.02}$
221.2(2)	9400	7711.9	→	6151.2	$43/2^{(-)}$	→	$39/2^{(-)}$	E2	$0.00^{+0.05}_{-0.02}$
234.4(1)	10956(217)	7455.9	→	7221.7	$39/2^+$	→	$37/2^+$	M1/E2	0.08 ± 0.04
240.1(1)	9380(219)	6854.3	→	6614.3	$37/2^+$	→	$35/2^+$	M1/E2	0.04 ± 0.04
249.0(1)	21997(268)	5829.6	→	5580.8	$33/2^{(+)}$	→	$31/2^{(+)}$	M1/E2	0.05 ± 0.05
263.1(1)	12661(225)	8986.4	→	8723.1	$49/2^{(+)}$	→	$47/2^{(+)}$	M1/E2	0.17 ± 0.02
277.1(1)	9854(242)	6151.2	→	5874.1	$37/2^-$	→	$35/2^-$	M1/E2	-0.25 ± 0.05
281.4(1)	67764(453)	3420.7	→	3139.2	$27/2^+$	→	$25/2^+$	M1/E2	-0.05 ± 0.05
289.6(1)	23719(307)	12322.4	→	12032.8	$61/2^{(+)}$	→	$59/2^{(+)}$	M1/E2	-0.17 ± 0.07
301.6(2)	9000	8701.1	→	8399.5	$47/2^{(-)}$	→	$45/2^{(-)}$	M1/E2	0.05 ± 0.05
304.6(2)	3764(446)	10986.4	→	10681.6	$57/2^{(+)}$	→	$55/2^{(+)}$	λ=1	0.00 ± 0.10
310.0(1)	18489(341)	5580.8	→	5270.7	$31/2^{(+)}$	→	$29/2^+$	M1/E2	0.05 ± 0.05
314.1(1)	28745(382)	7285.7	→	6971.7	$39/2^-$	→	$37/2^-$	M1/E2	0.27 ± 0.03
316.1(1)	54656(484)	5915.7	→	5599.6	$33/2^+$	→	$31/2^+$	M1/E2	0.20 ± 0.05
328.9(1)	12567(329)	5599.6	→	5270.7	$31/2^+$	→	$29/2^+$	M1/E2	0.10 ± 0.10
332.8(1)	5559(263)	6705.1	→	6372.3	$(39/2)$	→	$39/2^-$	λ=1	0.00 ± 0.10
357.7(1)	11200(271)	7210.8	→	6853.1	$41/2^{(+)}$	→	$39/2^{(+)}$	M1/E2	-0.05 ± 0.05
375.8(1)	13293(311)	7285.7	→	6910.1	$39/2^-$	→	$37/2^{(+)}$	λ=1	0.00 ± 0.05
378.1(1)	67143(796)	7664.0	→	7285.7	$41/2^-$	→	$39/2^-$	M1/E2	0.05 ± 0.05
433.0(3)	3179(536)	8226.3	→	7793.3	$(43/2)$	→	$(41/2)$	λ=1	-0.07 ± 0.07
441.2(1)	18824(567)	12763.6	→	12322.4	$63/2^{(+)}$	→	$61/2^{(+)}$	M1/E2	-0.34 ± 0.08
495.4(1)	23223(388)	4953.2	→	4457.6	$31/2^-$	→	$29/2^-$	M1/E2	0.05 ± 0.05
498.2(1)	12692(329)	6372.3	→	5874.1	$39/2^-$	→	$35/2^-$	E2	$0.00^{+0.15}_{-0.05}$
503.4(1)	8848(568)	13267.0	→	12763.6	$65/2^{(+)}$	→	$63/2^{(+)}$	M1/E2	-0.80 ± 0.55
506.6(2)	5842(419)	13773.6	→	13267.0	$67/2^{(+)}$	→	$65/2^{(+)}$	M1/E2	-0.85 ± 0.45
508.3(2)	5633(423)	10378.8	→	9870.5	$(53/2^+)$	→	$(51/2^+)$	M1/E2	0.02 ± 0.12
601.4(2)	16800	11587.8	→	10986.4	$59/2^{(-)}$	→	$57/2^{(+)}$	(E1)	-0.10 ± 0.10
607.2(3)	5869(668)	7221.7	→	6614.3	$37/2^+$	→	$35/2^+$	M1/E2	0.20 ± 0.05
636.3(1)	9385(373)	7490.5	→	6854.3	$39/2^{(-)}$	→	$37/2^+$	(E1)	$0.00^{+0.05}_{-0.15}$
669.8(3)	5020(600)	6499.3	→	5829.6	$35/2^-$	→	$33/2^{(+)}$	(E1)	$0.00^{+0.10}_{-0.15}$
683.8(1)	20611(416)	5929.9	→	5246.1	$35/2^-$	→	$31/2^-$	E2	0.00 ± 0.01
698.6(1)	18765(315)	6614.3	→	5915.7	$35/2^+$	→	$33/2^+$	M1/E2	0.55 ± 0.13
737.5(1)	19108(477)	6567.3	→	5829.6	$35/2^{(+)}$	→	$33/2^{(+)}$	M1/E2	-0.10 ± 0.05
757.3(2)	4679(295)	6687.6	→	5929.9	$37/2^+$	→	$35/2^-$	E1	0.00 ± 0.10
771.8(1)	182257(1153)	2037.6	→	1265.5	$17/2^+$	→	$15/2^+$	M1/E2	0.10 ± 0.05
776.4(2)	6000	10681.6	→	9905.2	$55/2^{(+)}$	→	$53/2^{(+)}$	(M1/E2)	-0.15 ± 0.20
782.8(2)	5525(338)	6499.3	→	5716.4	$35/2^-$	→	$33/2^+$	E1	$0.00^{+0.20}_{-0.02}$
811.0(2)	7936(542)	7664.0	→	6853.1	$41/2^-$	→	$39/2^{(+)}$	(E1)	$0.00^{+0.10}_{-0.05}$
884.1(1)	4045(452)	9870.5	→	8986.4	$(51/2^+)$	→	$49/2^{(+)}$	(M1/E2)	1.00 ± 0.10
926.7(2)	7961(375)	5599.6	→	4672.4	$31/2^+$	→	$29/2^+$	M1/E2	0.12 ± 0.05
941.5(2)	5158(379)	6771.1	→	5829.6	$35/2^{(+)}$	→	$33/2^+$	λ=1	0.05 ± 0.05
957.8(1)	15611(446)	9680.9	→	8723.1	$49/2^{(+)}$	→	$47/2^{(+)}$	(M1/E2)	0.29 ± 0.09
996.4(1)	21900(465)	8708.3	→	7711.9	$47/2^{(+)}$	→	$45/2^{(-)}$	(E1)	-0.04 ± 0.06
1041.7(2)	7373(390)	6971.7	→	5929.9	$37/2^-$	→	$35/2^-$	M1/E2	-0.05 ± 0.05
1046.4(2)	10609(402)	12032.8	→	10986.4	$59/2^{(+)}$	→	$57/2^{(+)}$	M1/E2	1.12 ± 0.44
1094.8(1)	12476(445)	8806.6	→	7711.9	$47/2^{(-)}$	→	$43/2^{(-)}$	E2	$0.00^{+0.30}_{-0.05}$
1166.1(2)	5183(330)	10847.0	→	9680.9	$(51/2^+)$	→	$49/2^{(+)}$	(M1/E2)	0.28 ± 0.03
1251.9(1)	12847(440)	4672.4	→	3420.7	$29/2^+$	→	$27/2^+$	M1	0.00 ± 0.05
1850.0(2)	10383(362)	5270.7	→	3420.7	$29/2^+$	→	$27/2^+$	M1/E2	-0.90 ± 0.15

the transition at 180 keV ($49/2^{(+)} \rightarrow 47/2^{(-)}$) and the one at 996 keV ($47/2^{(+)} \rightarrow 45/2^{(-)}$) revealed vanishing mixing ratios. The 221 keV and the 636 keV transition constituted the only accessible path to the 1.8 ns isomer at 7712 keV (reported in [6]), for which we assigned a spin and parity of $43/2^{(-)}$. This negative parity assignment and assignments for levels further above are somewhat unsure, as $\delta = 0$ allows no distinction between $M1$ and $E1$ character. But attributing this isomer to the lower lying isomer at $23/2^+$ backens our determination.

Below the 48 keV transition depopulating the isomer we obtained three multipole orders that differ from those given in [3]. The 684 keV turned out to be a stretched $E2$, whereas the 1042 and 378 keV transitions showed $M1/E2$ character. Thus, we assign a spin of $35/2^-$ to the level at 5930 keV and $41/2^-$ to the one at 7664 keV.

We also obtained spins for the second strongest transition sequence ranging from the $(51/2^+)$ level at 10847 keV to the well known $27/2^+$ state (3421 keV) and being of positive parity. Furthermore we gained spins for a couple of negative parity states between $39/2^-$ and $31/2^-$ in agreement with [3] and evaluated new spin assignments for several other levels beside the strongest cascades.

A detailed interpretation of the ^{147}Tb states and configurations will be given in a forthcoming article.

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