THE N=82 GAP IN ^{146}Gd FROM β-DECAY STUDIES OF Tb ISOTOPES

J. Styczen[+], P. Kleinheinz, M. Piiparinen[++]
Institut für Kernphysik, KFA Jülich, Jülich, Germany

J. Blomqvist
Research Institute of Physics, Stockholm, Sweden

Abstract

A β-decay study of 23 s ^{146}Tb suggests a $(\pi h_{11/2}\ \nu d^{-1}_{3/2})$ 5^- configuration for this activity. In its decay we have identified a $\pi h_{11/2} \rightarrow \nu h_{9/2}$ GT decay branch which populates neutron particle-hole states in ^{146}Gd. From the results we conclude that the N=82 single particle energy gap is less than 4 MeV. Neutron one-particle two-hole and two-particle one-hole states in ^{145}Gd and ^{147}Gd were identified in the β-decays of 29 s ^{145}Tb and 1.6 h ^{147}Tb.

There exists quite detailed knowledge on the proton ph states in ^{146}Gd. These levels are strongly populated in the yrast decay[1], and their excitation energies are in accord with the ≈ 3.5 MeV Z=64 energy gap as derived from the difference of the ^{147}Tb and ^{146}Gd single proton separation energies. On the other hand it is well known that pairing is important at Z=64, and from an analysis of single proton quasi-particle energies[2,3] in the neighbouring ^{145}Eu and ^{147}Tb isotones a value of ∿ 2.5 MeV was derived for the energy gap in the single particle spectrum.

From the single neutron separation energies one obtains for ^{146}Gd an N=82 gap of ≈ 3.7 MeV, but nothing so far is known on the ^{146}Gd neutron particle hole excitations which should occur at about that excitation. Furthermore, the excitation energies in the neighbouring isotopes with one neutron lifted across N=82 (1p2h states in ^{145}Gd and 2p1h states in ^{147}Gd), which are crucial to determine the gap in the neutron single particle energies, are also not known. These states have in general low spin and are therefore not populated in in-beam experiments. However, it was possible to locate such neutron ph excitations in the three Gd isotopes through β-decay studies of ^{145}Tb, ^{146}Tb, and ^{147}Tb, which we will report here.

The parent activities were produced through (α,xn) reactions (x = 8, 9, 10) in bombardments of ^{152}Gd and ^{151}Eu targets with α-particle beams between 90 and 130 MeV from our cyclotron. Gamma-ray singles and two-detector coincidence measurements with various coaxial and planar Ge detectors were carried out during 20 to 40 sec beam pauses following similar irradiation periods during which the detectors were blocked.

Our results for ^{146}Tb decay are shown in Fig. 1. In contrast to earlier studies[4,5] we find negligible feed to the 3^- 1st excited state and the coincidence results locate three new levels in ^{146}Gd above 3.4 MeV.

From the shell model one expects for the ^{146}Tb parent nucleus a $\pi h_{11/2}\ \nu d^{-1}_{3/2}$ configuration which can couple to $I^\pi = 4^-, 5^-, 6^-$ or 7^-, where the πν residual interaction will be repulsive for the two extreme spins. The strong feeding of the $\pi h_{11/2}\ d^{-1}_{5/2}$ states at about 3 MeV excitation proceeds through the allowed $\pi d^{-1}_{5/2} \rightarrow \nu d^{-1}_{3/2}$ GT transition. Excellent agreement of the β-branchings to the $(\pi h_{11/2} d^{-1}_{5/2})4^-, 5^-$, and 6^- states with theoretical ratios unambigously classifies the ^{146}Tb parent state as $I^\pi = 5^-$.

The clearly observed 1579 - 3140 keV coincidences establish a new level at 4719 keV. We attribute the feeding β-branch to the other expected GT transition, $\pi h_{11/2} \rightarrow \nu h_{9/2}$, which systematically occurs with essentially equal log ft value in other Tb isotopes in this region. This classifies the 4719 keV state as $(h_{9/2} d^{-1}_{3/2})4^-$ neutron particle hole excitation. Only the 5^- multiplet member is predicted to be also fed in β decay, but 14 times weaker than the 4^- state.

A weak 1297 - 1844 keV parallel decay branch proceeds from the 4^- state, where the transition ordering is determined from ^{144}Sm(α,2n) excitation function measurements[6] close to threshold. We interprete the intermediate 3423 keV level as $\nu f_{7/2} d^{-1}_{3/2}$ state, which is the lowest neutron particle hole excitation in ^{146}Gd. Its energy should be equal to the N=82 gap at Z=64, except for small contributions of collective or nucleon-nucleon interactions. The nearagreement with the ≈ 3.7 MeV N=82 gap as derived from the neutron separation energy difference is in accord with this view.

In our spectra we also observe weakly the known[6] 1972 keV $2^+ \rightarrow 0^+$ transition, and a 1059 keV line in coincidence with it. As no connecting transitions to any of the strongly β-fed levels could be found it remains unclear how the 2^+ state is fed. Most likely it is directly populated in β decay of a low spin ^{146}Tb isomer involving the $d_{3/2}$ (or $s_{1/2}$) proton particle, which is possibly produced at the present bombarding energies via precompound particle emission. Such a low spin ^{146}Tb activity has been identified[7] following β decay of ^{146}Dy.

The ^{145}Tb activity was previously not known. The mass identification was derived from excitation function and from X-ray coincidence measurements, and the ^{145}Tb half life was found as $T_{1/2}$ = 29 ± 4 sec. This value is in agreement with an independent determination[8] reported in a recent abstract.

The ^{145}Tb decay scheme is shown in Fig. 2. From systematics we attribute $I^\pi = 11/2^-$ to its ground state. Levels in ^{145}Gd have previously been investigated[9] through the ^{144}Sm(α,3n) reaction, but the energy levels observed in this study above 750 keV are not populated in ^{145}Tb decay. However, most of the levels seen in β decay have been observed in concurrent ^{144}Sm(^{3}He,2n)γ and e^- measurements[10] which gave the spin-parity assignments shown in Fig. 2 for the levels between 1 and 2 MeV. The transition multipolarities quoted in the figure are also from the in-beam work. Our β-decay branchings are in accord with the $11/2^-$ ^{145}Tb parent spin. Strongly fed in β-decay is the 2382 keV ^{145}Gd level, and the log ft = 4.2 suggests a $\nu h_{9/2}\ j_0^{-2}$ configuration. The other 1p2h state, the $\nu f_{7/2} j_0^{-2}$ level at 1273 keV is known from the in-beam work[10].

+ On leave from Institute of Nuclear Physics, Cracow, Poland
++ A.v. Humboldt fellow 1978-80, on leave from Univ. of Jyväskylä, Finland

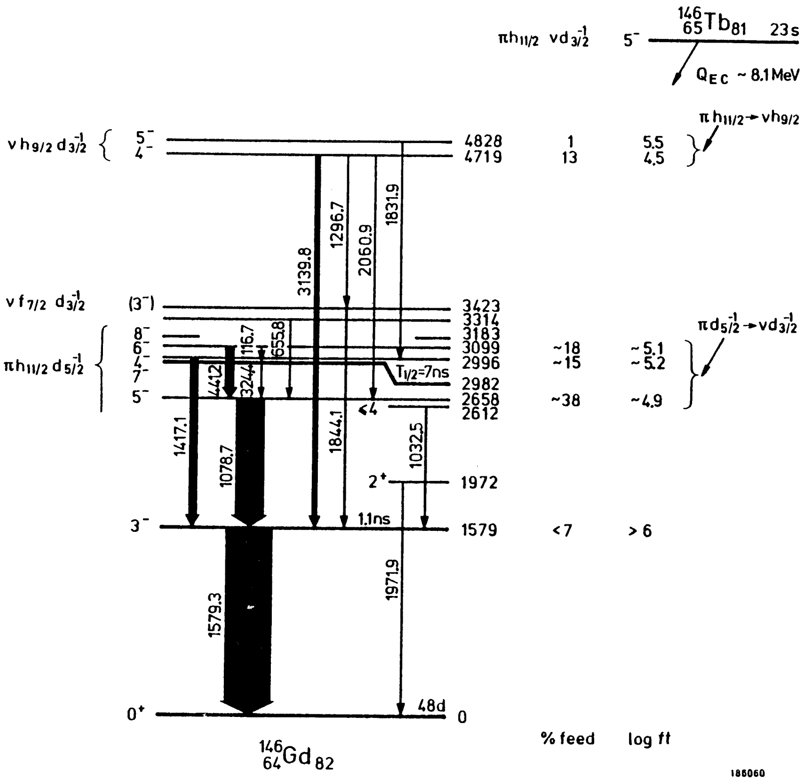

Fig. 1: Decay scheme of 23 s ^{146}Tb. For feeding of 1972 keV 2^+ state see text.

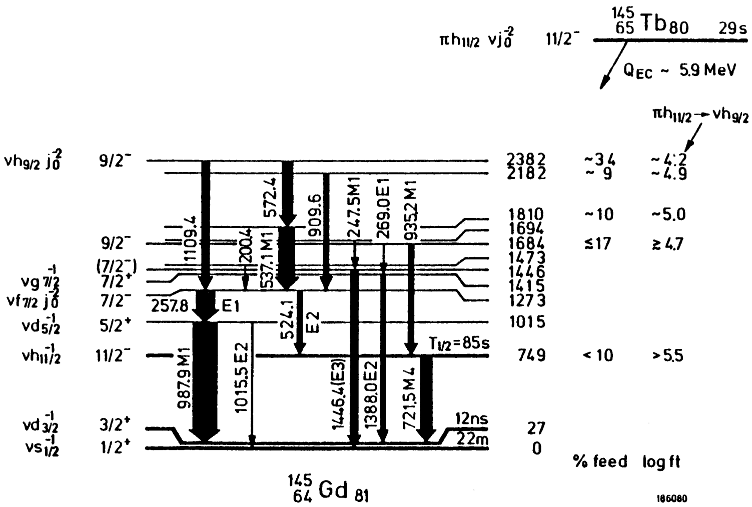

Fig. 2: Decay scheme of 29 s ^{145}Tb. The Q_{EC} value is derived from comparison with ^{147}Tb. It is assumed that the 0^+ neutron hole pair of ^{145}Tb will not affect the QEC ($\pi h_{11/2} \rightarrow \nu h_{9/2}$) value. The transition multipolarities are from the (^3He,3n) reaction study[10].

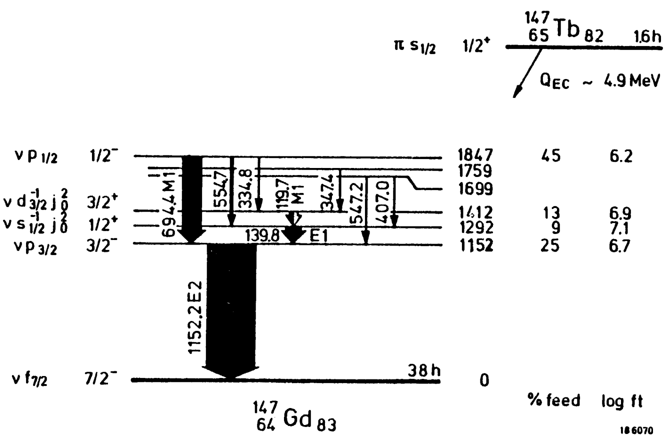

Fig. 3: Decay scheme of 1.6 h ^{147}Tb. The Q_{EC} value is from Ref. 11, assuming that the $1/2^+$ and $11/2^-$ ^{147}Tb β-activities lie close[3] in energy.

Our data on 1.6 h ^{147}Tb β decay are given in Fig. 3. The energy levels are in agreement with those reported[4] earlier, but the new $1/2^+$ assignment[3] for 1.6 h ^{147}Tb, together with new data on transition multipolarities lead to a revision of ^{147}Gd spin parity assignments. In addition to the $\nu p_{3/2}$ state at 1152 keV now also the $\nu p_{1/2}$ level is identified at 1847 keV. We interpret the 1292 and 1412 keV levels respectively as $\nu s_{1/2}^{-1} j_0$ and $\nu d_{3/2}^{-1} j_0^2$ 2p1h excitations.

In conclusion, the present β decay studies have located neutron particle hole states in ^{146}Gd which suggest a gap of less than 4 MeV in the neutron single particle energies. Although one would not expect that pairing at N=82 is equally significant as at Z=64[2,3] it will be interesting to analyse the present results for the three Gd isotopes within the pairing theory.

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