Photon Scattering Experiments on the Quasistable, Odd-Odd Mass Nucleus ^{176}Lu [D]

S. Walter, F. Stedile, J.J. Carroll, C. Fransen, G. Friessner, N. Hollmann, H. von Garrel, J. Jolie, O. Karg, F. Käppeler, U. Kneissl, C. Kohstall, P. von Neumann-Cosel, A. Linnemann, D. Mücher, N. Pietralla, H.H. Pitz, **G. Rusev**, M. Scheck, C. Scholl, **R. Schwengner**, V. Werner, K. Wisshak

Published in Phys. Rev. C 75 (2007) 034301, 1-6

The quasistable odd-odd-mass nucleus ^{176}Lu is of special interest in nuclear structure physics and, moreover, in nuclear astrophysics. This isotope is one of the only nine known stable or quasistable naturally occurring odd-odd mass nuclei. It has a ground-state spin of $J_0^\pi = 7^-$ ($K = 7$) and decays by β^- decay with a halflife of about $4 \cdot 10^{10}$ a [1, 2] to ^{176}Hf. In addition, a low-lying $J^\pi = 1^-, K = 0$ isomer occurs in ^{176}Lu at an excitation energy of 122.9 keV with a halflife of only 3.635 h, which decays also by β^--transitions to ^{176}Hf. Such large spin differences of low-lying levels are common features in heavy odd-odd nuclei and originate from aligned and antialigned couplings of the unpaired protons and neutrons in high-spin Nilsson orbits. In the case of ^{176}Lu these orbits are the $\pi 7/2^+[404]$ and $\nu 7/2^-[514]$ orbits [3]. Because of the long halflife of 40 Ga and the fact that the isotope is shielded against an r-process synthesis, ^{176}Lu was suggested to be an appropriate s-process chronometer [4, 5, 6]. However, answering the question to what extent ^{176}Lu may serve as a cosmic clock or represents rather a stellar thermometer is complicated because of its nuclear structure and depends critically on a possible photoexcitation of the 1^- isomer and its subsequent short-lived 3.635 h β-decay within the photon bath of a stellar s-process scenario [6, 7, 8, 9, 10, 11]. Therefore, the electromagnetic coupling between the ground state and the low-lying isomeric state via low-lying intermediate states (IS) is of fundamental importance for the nucleosynthesis of ^{176}Lu and for tests of stellar models [6, 12, 13]. The possible coupling of these states is illustrated in Fig. 1. IS can be determined from the kinks in the yield curves observed in photoactivation experiments using bremsstrahlung photon beams (see, e.g., Ref. [14]). However, in such experiments the energy determination is limited to an accuracy of about 30 keV. On the other hand, in photon-scattering experiments the excitation energies of such IS can be measured with accuracies of better than 1 keV.

Photon-scattering experiments on ^{176}Lu were performed at the bremsstrahlung facility of the Stuttgart University [15]. Measurements using electron beams of 2.3 and 3.1 MeV delivered by the Dynamitron accelerator were carried out to achieve an optimum sensitivity, in particular in the low-energy range of astrophysical interest.

As a result of the present experiments a total of 29 transitions in ^{176}Lu have been found in the energy range from 1.3 MeV to 2.9 MeV and their transition strengths have been determined. For the lowest proposed IS at 838.6 keV an upper limit for the scattering-cross section integral of $I_s < 1.5$ eVb, corresponding to a minimum lifetime of $\tau \approx 1.5$ ps can be given. This limit is consistent with the result of a GRID measurement [9].

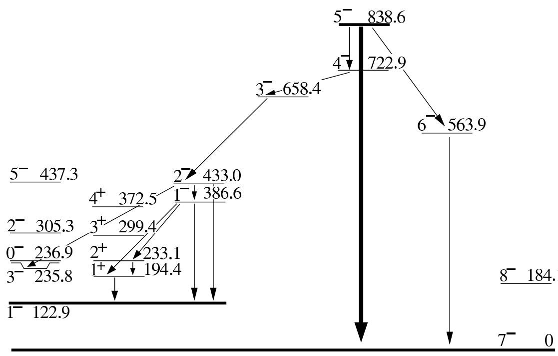

Fig. 1 *Level scheme showing a possible coupling between the ground state of ^{176}Lu and the isomer at 122.9 keV via the IS at 838.6 keV with a spin of 5^- and quantum number $K = 4^-$ (taken from Ref. [8]).*

[1] G.F. Grinyer, J.C. Waddington et al., Phys. Rev. C 67 (2003) 014302

[2] Y. Nir-El and G. Haquin, Phys. Rev. C 68 (2003) 067301

[3] M. S. Basunia, Nucl. Data Sheets 107 (2006) 791

[4] J. Audouze, W.A. Fowler and D. N. Schramm, Nature 238 (1972) 8

[5] M. Arnould, Astron. & Astrophys. 22 (1973) 311

[6] F. Käppeler, H. Beer and K. Wisshak, Rep. Prog. Phys. 52 (1989) 945

[7] N. Klay, F. Käppeler et al., Phys. Rev. C 44 (1991) 2801

[8] N. Klay, F. Käppeler et al., Phys. Rev. C 44 (1991) 2839

[9] C. Doll, H.G. Börner et al., Phys. Rev. C 59 (1999) 492

[10] K.T. Lesko, E.B. Norman et al., Phys. Rev. C 44 (1991) 2850

[11] J. Vanhorenbeeck, J.M. Lagrange et al., Phys. Rev. C 62 (2000) 015801

[12] F. Käppeler, Prog. Part. Nucl. Phys. 43 (1999) 419

[13] D. Belic, C. Arlandini et al., Phys. Rev. Lett. 83 (1999) 5242; Phys. Rev. C 65 (2002) 035801

[14] D. Belic, J. Besserer et al., Nucl. Instr. Meth. A 463 (2001) 26

[15] U. Kneissl, H.H. Pitz and A. Zilges, Prog. Part. Nucl. Phys. 37 (1996) 349