EPJ Web of Conferences 66, 02110 (2014)
DOI: 10.1051/epjconf/20146602110
© Owned by the authors, published by EDP Sciences, 2014

Study of ^{207}Tl$_{126}$ Produced in Deep-Inelastic Reactions

E. Wilson[1, a], Zs. Podolyák[1], B. Fornal[2], R. V. F. Janssens[3], M. Bowry[1], M. Bunce[1], M. P. Carpenter[3], C. J. Chiara[3,4], N. Cieplicka[2], A. Y. Deo[5], G. D. Dracoulis[6], H. Grawe[7], C. R. Hoffman[3], R. S. Kempley[1], F. G. Kondev[8], G. J. Lane[6], T. Lauritsen[3], M. W. Reed[1,6], P. H. Regan[1,9], C. Rodríguez Triguero[10], B. Szpak[2], P. M. Walker[1], and S. Zhu[3]

[1] *Department of Physics, University of Surrey, Guildford, GU2 7XH, UK*
[2] *H. Niewodniczański Institute of Nuclear Physics, PL-31342 Kraków, Poland*
[3] *Physics Division, Argonne National Laboratory, Argonne, IL 60439, USA*
[4] *Department of Chemistry and Biochemistry, University of Maryland, College Park, MD 20742, USA*
[5] *Department of Physics, University of Massachusetts Lowell, Lowell, MA 01854, USA*
[6] *Department of Nuclear Physics, Research School of Physics and Engineering, Australian National University, Canberra, ACT 0200, Australia*
[7] *GSI Helmholtzzentrum für Schwerionenforschung GmbH, D-64291 Darmstadt, Germany*
[8] *Nuclear Engineering Division, Argonne National Laboratory, Argonne, IL 60439, USA*
[9] *National Physical Laboratory, Teddington, TW11 0LW, UK*
[10] *School of Computing, Engineering and Mathematics, University of Brighton, Brighton, BN2 4GL, UK*

Abstract. Deep-inelastic collisions of a ^{208}Pb beam on a ^{208}Pb target were performed using the ATLAS accelerator at Argonne National Laboratory. The Gammasphere detector array was used for the detection of prompt and delayed gamma-rays of the reaction products. ^{207}Tl is one proton away from the ^{208}Pb doubly-magic nucleus. Its low-energy level structure is dominated by the single proton-hole states $\pi s^{-1}_{1/2}$, $\pi d^{-1}_{3/2}$, and $\pi h^{-1}_{11/2}$. The $11/2^-$ state is isomeric with $T_{1/2}$= 1.33(11) s. The reaction partner of ^{207}Tl is ^{209}Bi, which has a relatively well established level scheme compared to ^{207}Tl. Cross-coincidences between these two nuclei were used to confirm or establish levels above the $11/2^-$ isomeric state in ^{207}Tl. These states are obtained via breaking of the neutron core. Angular correlation analysis was performed on known transitions in ^{208}Pb, proving the applicability of this method for multipolarity assignment.

1 Introduction

The nuclei in the area to the 'south-east' of doubly-magic ^{208}Pb have comparatively little known about their spectroscopic properties [1–4]. The study of this area, enclosed by Z≤82 and N≥126, is useful for improving current theoretical models, and may also have an impact on understanding the production of heavy elements in the r-process. An experiment was performed where several of these nuclei were populated via deep-inelastic collisions.

Here we concentrate on the structure of ^{207}Tl. ^{207}Tl is a one proton-hole nucleus, with a low-energy level structure dominated by the single proton-hole states $\pi s^{-1}_{1/2}$, $\pi d^{-1}_{3/2}$, and $\pi h^{-1}_{11/2}$. This mass

a. e-mail: emma.wilson@surrey.ac.uk

This is an Open Access article distributed under the terms of the Creative Commons Attribution License 2.0, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Article available at http://www.epj-conferences.org or http://dx.doi.org/10.1051/epjconf/20146602110

region is characterised by the presence of a low-lying octupole vibration of the ^{208}Pb core. For example, the first excited state of ^{208}Pb at 2614 keV, has a spin-parity of 3^-, and decays via a collective E3 transition to the ground state. In ^{207}Tl, the octupole phonon coupled to the $\pi h^{-1}_{11/2}$ state forms an yrast state decaying through a 2465 keV transition, which has an E3 character [5]. Breaking of the N=126 neutron core must occur to observe states of higher spin and energy than this state. Similar states have been observed in, for example, ^{206}Hg, ^{209}Bi, ^{207}Pb, and ^{209}Pb [1, 6, 7].

2 Experimental Methods

The experiment was performed at Argonne National Laboratory using the ATLAS accelerator, wherein a beam of ^{208}Pb impinged a thick target of ^{208}Pb. The ^{208}Pb beam had an energy 20% above the Coulomb barrier (1446 MeV), and the target thickness was 75 mg/cm^2. Deep-inelastic collision was the dominant reaction. The highly excited reaction products emitted γ-rays, which were detected by the Gammasphere array. More details can be found in reference [8]. All products were stopped within the target, so Doppler correction is not needed. The beam pulsing was such that a sub-nanosecond beam pulse occurred once every 82.5 ns, of which four out of five were deflected, leading to a beam-off period of 412 ns. Preliminary analysis showed no evidence of isomeric states in this time window in ^{207}Tl, therefore all results presented here are from analysis of the prompt data.

2.1 Deep-Inelastic Collisions

In deep-inelastic collisions, nucleons are exchanged between the nuclei of the beam and the target such that the resulting target-like nucleus has a number of greater or fewer nucleons, and *vice versa* for the beam-like reaction partner nucleus. This leads to cross-coincidences in reaction partners, such that transitions from one nucleus are in coincidence with those from the other [9]. For instance, the nucleus of interest in this paper, ^{207}Tl, has one less proton than ^{208}Pb, while its reaction partner, ^{209}Bi, has one more proton than ^{208}Pb. Neutron evaporation may also occur, consequently a nucleus may have more than one reaction partner. Deep-inelastic collisions populate yrast and near-yrast states preferentially.

2.2 Angular Correlations

The use of γ-ray angular correlations to assign spins and multipolarities is well documented, see, for example, references [10–12]. The angular correlation of two γ-rays is described by the following equation:

$$W(\theta) = 1 + A_{22}P_2(cos\theta) + A_{44}P_4(cos\theta) \quad (1)$$

where θ is the angle between the two detected γ-rays, and P_2 and P_4 are Legendre polynomials. The A_{kk} coefficients can be caluclated using the tables in reference [13].

3 Results

Cross coincidences between ^{207}Tl and ^{209}Bi were used to identify transitions in ^{207}Tl by gating on the well-known transitions in the reaction partner. A spectrum gated on known transitions in ^{209}Bi, 246 keV and 500 keV, is shown in Figure 1. The known transitions in ^{207}Tl [5, 6], such as the 2465 keV E3 transition, as well as several transitions identified for the first time in this experiment, are visible in the spectrum. The transition energies and intensities are listed in reference [8]. The majority of these transitions originate from excited states produced via core excitations.

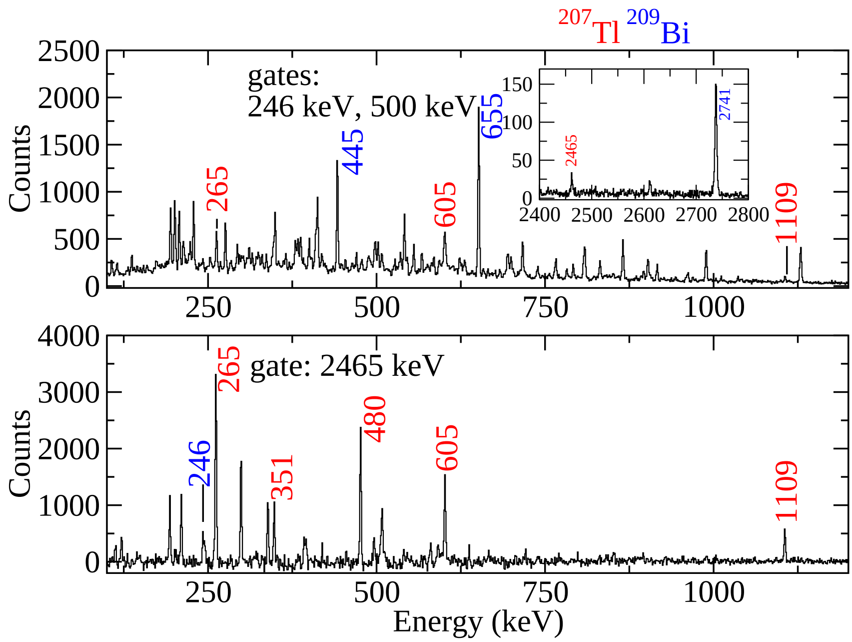

Figure 1. Spectra obtained from a $\gamma\gamma\gamma$ cube, the upper panel spectrum being obtained by gating on 246 keV and 500 keV, which are known transition in ^{209}Bi. The inset shows the region between 2400 keV and 2800 keV, such that the 2465 keV peak from the ^{207}Tl reaction partner is visible. The spectrum of the lower panel was obtained by gating on this 2465 keV transition. Highlighted are transtions from either of these, clearly showing cross-coincidences in reaction partners.

The multipolarities of these transitions will be determined from angular correlations. The technique was tested on well-known and high-intensity γ-rays in ^{208}Pb. The original orientation of the nuclei as produced in the reaction was neglected, and it was assumed that intermediate transitions do not have a significant effect on the angular correlation. Preliminary results are shown for two cases in Figure 2. These results show that the 1413 keV transition has E3 character, while the 583 keV transition is E2 in nature. This confirms the previously established multipolarities [14], and also that the two assumptions listed above are valid.

4 Conclusion

Several transitions in the single-proton hole nucleus ^{207}Tl have been identified, allowing the level scheme to be extended to higher spins and energies. Coincidence relationships and intensity balances are being considered in building the level scheme. Angular correlations analysis, and comparisons with shell model calculations, will aid spin-parity assignments.

This work is supported by the US Department of Energy, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357, and by the Science and Technology Facilities Council (STFC), UK. The contributions of the Argonne National Laboratory technical staff are gratefully acknowledged.

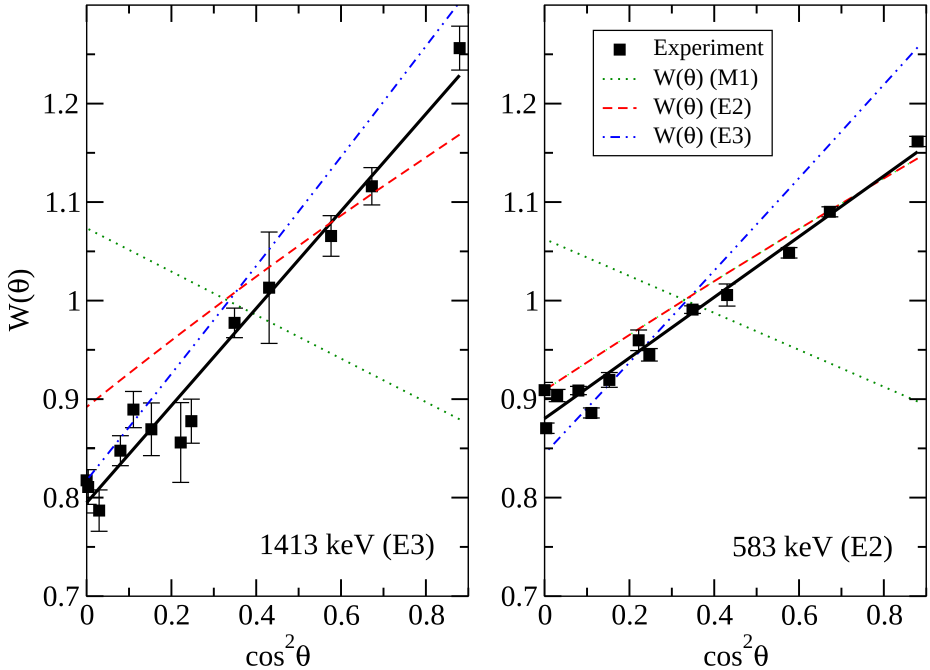

Figure 2. Angular correlations between the 2614 keV E3 transition and the 1413 keV γ-ray (left panel), and the 583 keV γ-ray (right panel). The data points are the experimental values, found for different angles, while the thick black line is the fit to the data. Theoretical lines are also shown, considering different multipolarities.

References

[1] B. Fornal *et al.*, Phys. Rev. Lett. **87**, 212501 (2001)

[2] S. J. Steer *et al.*, Phys. Rev. C **84**, 044313 (2011)

[3] N. Al-Dahan *et al.*, Phys. Rev C **80**, 061302 (2009)

[4] A. Gottardo *et al.*, Phys. Rev. Lett. **109**, 162502 (2012)

[5] M. Rejmund *et al.*, Eur. Phys. J. A **8**, 161 (2000)

[6] F. G. Kondev and S. Lalkovski, Nucl. Data Sheets **112**, 707 (2011)

[7] M. J. Martin , Nucl. Data Sheets **63**, 723 (1991)

[8] E. Wilson *et al.*, Acta Phys. Pol. B **44**, 381 (2013)

[9] R. Broda, J. Phys. G.: Nucl. Part. Phys. **32**, R151 (2006)

[10] S. Zhu *et al.*, Phys. Rev. C **85**, 034336 (2012)

[11] A. Krämer-Flecken *et al.*, Nucl. Instrum. Methods A **275**, 333 (1989)

[12] G. D. Dracoulis *et al.*, Phys. Rev. C **71**, 044326 (2005)

[13] W. D. Hamilton (ed.) *Electromagnetic Interactions in Nuclear Spectroscopy* (North Holland, Amsterdam, 1975) 890-897

[14] M. J. Martin, Nucl. Data Sheets **108**, 1583 (2007)