EPJ Web of Conferences **123**, 02001 (2016)
Heavy Ion Accelerator Symposium 2015
DOI: 10.1051/epjconf/201612302001

A dipole band above the I^{π}= 31/2^{-} isomeric state in ^{189}Pb

D. M. Cullen[1,a]

[1] *School of Physics and Astronomy, University of Manchester, Manchester M13 9PL, United Kingdom*

Abstract. This contribution focuses on the new observation of a dipole band built upon an I^{π}=31/2^{-} isomeric state in ^{189}Pb, identified using recoil-isomer tagging at the University of Jyväskylä, Finland. This is the lightest odd-mass Pb isotope in which a dipole band is known. By comparison with the heavier-mass dipole bands, the dipole band in ^{189}Pb was deduced to be based upon a $\pi(s_{1/2}^{-2}h_{9/2}i_{13/2})_{11^-} \otimes \nu(i_{13/2}^{-1})_{13/2^+}$ configuration. However, in the ^{189}Pb dipole band, the initial aligned angular momentum was larger than that exhibited by the dipole bands in the heavier-mass isotopes. This may be evidence for a reduced repulsive proton/neutron-hole interaction in ^{189}Pb.

1 Introduction

Dipole bands are a common feature of the neutron-deficient odd-mass Pb isotopes [1–8]. These bands exhibit a structure which resembles a strongly-coupled rotational band, however, the nuclear shape is approximately spherical and the strongly-coupled structure has strong $M1$- and weak $E2$-transitions.

Dipole bands in this region are known to originate from the coupling of protons in the $h_{9/2}$ orbital to neutron holes in the $i_{13/2}$ orbital [8–10]. The projections of the neutron and proton states are nearly perpendicular at the band-head because of the repulsive particle-hole interaction. Therefore, at the band-head the total angular momentum, I, points in a direction somewhere between the individual proton and neutron angular momentum. The higher-angular momentum states are formed by the stepwise alignment of the respective neutron and proton angular momentum with I in the shears mechanism [8, 10].

An isomeric state with a mean lifetime of 32 μs was first discovered in ^{189}Pb by Baxter *et al.* [11] but was not definitely linked into the lower-spin states. Subsequently, Dracoulis *et al.* were able to firmly link this state into the lower states and to define its spin and parity to be I^{π}=31/2^{-} from electron conversion measurements at the Australian National University [9]. Dracoulis *et al.* also first proposed that this isomeric state was a shears-mode band-head state.

The present contribution describes the results of a new experiment which was performed at the University of Jyväskylä to establish the transitions which were built up on this isomeric state.

[a] e-mail: dave.cullen@manchester.ac.uk

2 Experiment

High-spin states were populated in ^{189}Pb with a ^{86}Kr beam at 355-MeV on a 500 μg/cm^2 ^{108}Pd target at the University of Jyväskylä. The beam current was ~10-pnA for a total of ~150 hours. The prompt gamma-rays were detected with the Jurogam-II detector array of 39 Compton suppressed germanium detectors with a total photo-peak efficiency of ~ 6% at 1.3 MeV. The recoiling nuclei passed through the RITU spectrometer [12] and implanted into a double-sided silicon strip detector. Subsequent gamma-ray decays were detected with the GREAT Planar- and Clover-focal plane germanium detectors [13]. All events were time stamped by the trigger-less data readout system [14]. The TDR data was used to perform recoil-isomer tagging by allowing the correlation of prompt Jurogam-II gamma-ray events at the target position with delayed GREAT Planar and Clover gamma-ray events at the focal plane. The full details of the experiment can be found in [15].

3 Results

In the analysis, several prompt-delayed matrices were constructed for events which were separated in time by up to 60 μs (~3 half-lives of the ^{189}Pb isomeric state). By gating on the known [9, 11] delayed gamma rays in ^{189}Pb, six new prompt transitions of energies 206-, 335-, 389-, 413-, 419- and 435-keV were established to lie above the 32 μs proposed dipole band-head state in ^{189}Pb. In addition, a prompt gamma-gamma matrix was constructed gated by delayed gamma rays detected up to 60μs (~3 half-lives of the ^{189}Pb isomeric state) after a recoil implant at the focal plane. This matrix was used to determine the coincidence relationships and placements of the gamma rays in the level scheme based on intensity measurements. In addition, the total intensity flow through particular levels was

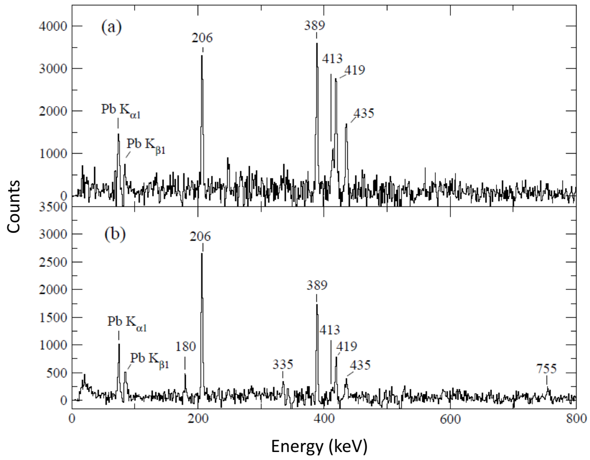

Figure 1. (a) Sum of prompt gates (206-, 389-, 419- and 435-keV) placed in a prompt gamma-gamma matrix gated by delayed gamma rays detected up to 60 μs (~3 half-lives of the ^{189}Pb isomeric state) after a recoil implant at the focal plane. (b) Prompt gamma-ray spectrum from a sum of delayed gates on the known transitions (142-, 267-, 272-, 530-, 609-, 811-, 819-, 911-, and 1142-keV) which depopulate the 32 μs isomeric state in ^{189}Pb [9, 11].

used to estimate electron-conversion coefficients. The latter measurements along with angular correlation measurements were used to estimate the spins and parities of the levels. The full details of this analysis are published in Ref. [15]. Figure 1(a) shows a sum of individual prompt gates (206-, 389-, 419- and 435-keV) placed in this matrix. The labelled transitions are all in coincidence with each other and also the Pb Kα1 and Kβ1 X rays. Figure 1(b) shows a prompt gamma-ray spectrum gated by a sum of delayed gates on the known ^{189}Pb transitions (142, 267-, 272-, 530-, 609-, 811-, 819-, 911-, and 1142-keV) which depopulate the 32-μs isomeric state [9, 11] The spectrum shows the relative intensity of the newly established prompt transition sequence which feeds the isomeric state. Figure 1(b) shows the same sequence of gamma rays as Fig. 1(a) along with additional 180- and 755-keV transitions. These two transitions are not in coincidence with the main sequence and are thought to directly feed the isomeric state.

Figure 2 shows the sequence of transitions established in the present work to lie above the known 32 μs isomeric state [9, 11] in ^{189}Pb and the best estimates for the spins and parities of the levels

4 Discussion

In order to better interpret the structure of the newly established dipole band in ^{189}Pb, Figure 3 shows a comparison of the aligned angular momentum, i_x, as a function of rotational frequency for this band in comparison with the most intense dipole bands in the odd-mass ^{191}Pb-^{199}Pb isotopes [1, 3–5, 16]. Each band in the figure has been plotted assuming $K = 11$ and has a reference band with Harris Parameters $J_0 = 10\ \hbar^2$/MeV and $J_1 = 30\ \hbar^4$/MeV^3 subtracted in accordance with Ref. [1].

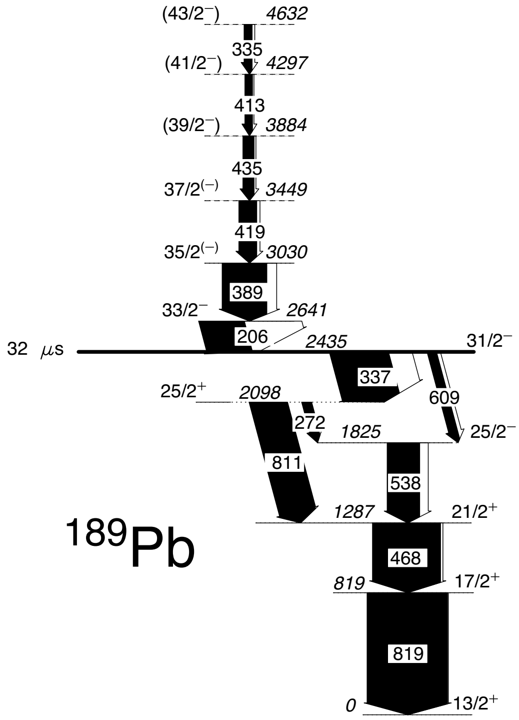

Figure 2. Partial level scheme of ^{189}Pb, showing the new transitions established in this work to form a dipole-band built upon the known 32 μs isomeric state [9].

In this region, the dipole bands are known to be built upon a configuration at low rotational frequencies and a configuration at higher rotational frequencies above the first band crossing [1, 3–5, 16]. The first crossing takes place at rotational frequencies around 0.30-0.36 MeV and involves the alignment of two $i_{13/2}$ neutrons with a corresponding 8-9$\hbar$ gain of aligned angular momentum, see Fig. 3.

Figure 3 shows that the new dipole band in ^{189}Pb (filled circles) follows this general aligned angular momentum trend associated with the higher-mass neighbouring isotopes. However, the initial aligned angular momentum of the new dipole band in ^{189}Pb, like that of the dipole band in ^{191}Pb is ~2$\hbar$ larger than that of the neighbouring dipole bands. This increased initial aligned angular momentum in the two lightest mass dipole bands in the Pb nuclei, may suggest that the states in these nuclei are subject to a smaller repulsive proton/neutron-hole interaction. Such a reduced repulsive interaction could permit the angular momentum of the neutrons to contribute more to the total aligned angular momentum at low rotational frequencies. At higher rotational frequencies, this effect would become less noticeable as the proton and neutron-hole orbits align. A theoretical study of this effect would be necessary to fully interpret these differences.

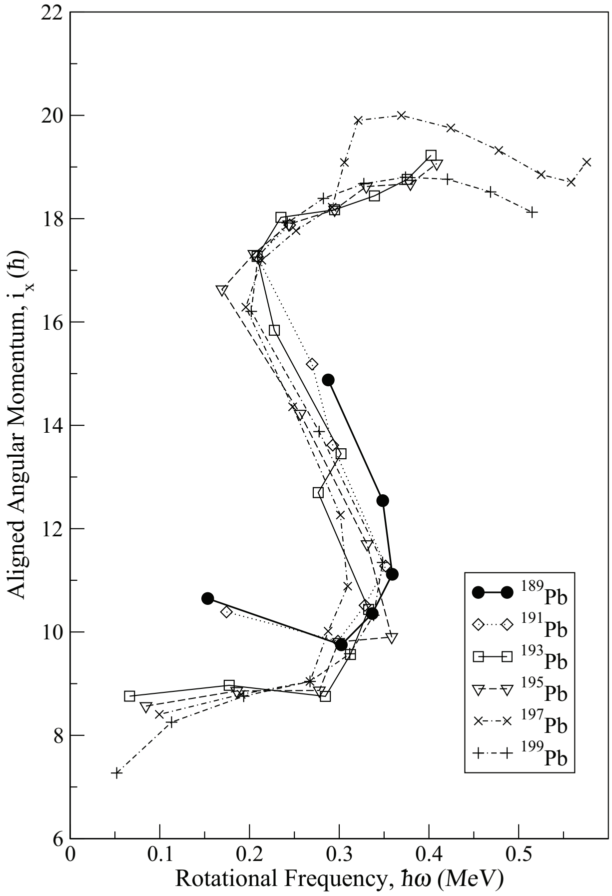

Figure 3. Aligned angular momentum systematic behaviour for the most intense dipole bands in the odd-mass $^{191-199}$Pb isotopes [1, 3–5, 16] along with the new dipole band in ^{189}Pb established in this work (filled circles). Note that the spins of the states in the dipole band in ^{191}Pb have been raised by $1\hbar$ in this figure.

Acknowledgements

I had the privilege of knowing, collaborating with and respecting George Dracoulis for nearly 20 years. This work on ^{189}Pb was initiated after discussions with George. Unfortunately George could not make it to the actual experiment but gave useful comments on the early stages of the work. Without George's original discovery of the $31/2^{-}$ isomer, this work would not have been possible. I remain indebted to and will miss him. This work was supported by the UK STFC through a standard Grant EP/E02551X/1.

References

[1] N. Fotiades *et al.*, Phys. Rev. C **57**, 1624 (1998).
[2] L. Ducroux *et al.*, Z. Phys. A **356**, 241 (1996).
[3] M. Kaci *et al.*, Z. Phys. A **354**, 267 (1996).
[4] A. Görgen *et al.*, Nucl. Phys. **A683**, 108 (2001).
[5] G. Baldsiefen *et al.*, Nucl. Phys. **A574**, 521 (1994).
[6] G. D Dracoulis, A. P. Byrne, and A. Baxter, Phys. Lett. B **432**, 37 (1998).
[7] G. D. Dracoulis *et al.*, Phys. Rev. C **67**, 051301(R) (2003).
[8] R. M. Clark and A. O. Macchiavelli, Annu. Rev. Nucl. Part. Sci. **50**, 1 (2000).
[9] G. D. Dracoulis, G. J. Lane, T. Kibédi, and P. Nieminen, Phys. Rev. C **79**, 031302 (2009).
[10] H. Hübel, Prog. Part. Nucl. Phys. **54**, 1 (2005).
[11] A. M. Baxter *et al.*, Phys. Rev. C **71**, 054302 (2005).
[12] M. Leino *et al.*, Nucl. Instrum. Methods B **99**, 653 (1995).
[13] R. D. Page *et al.*, Nucl. Inst. Meth. B **204**, 634 (2003).
[14] I. Lazarus *et al.*, IEEE Trans. Nucl. Sci. **48**, 567 (2001).
[15] D. Hodge *et al.*, Phys. Rev. C **92**, 054312 (2015).
[16] D. L. Balabanski *et al.*, Phys. Rev. C **83**, 014304 (2011).