$\gamma$-decay of the particle-hole states with the highest spins in $^{208}$Pb

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Received: 6 August 1992

Abstract. $^{208}$Pb has been excited with inelastic heavy ion scattering of 350 MeV $^{64}$Ni and 420 MeV $^{82}$Se on a thick $^{208}$Pb target. With $\gamma - \gamma$ coincidence measurements 2 new decays of the $10^+$ isomer, namely a 34.5 keV $E2$-transition to $8^+$ and a 857.7 keV $E3$ transition to $7^-$ have been found and the wavefunctions of the participating levels deduced. An observed gamma cascade of 295.3, 348.0, 865.4 and 340.2 keV on top of the $10^+$ isomer is assigned to the particle-hole states with the highest spins $14^-$ $\rightarrow$ $13^+$ $\rightarrow$ $12^+$ $\rightarrow$ $11^+$ $\rightarrow$ $10^+$.

PACS: 21.10.Hw; 21.60.Cs; 23.20.Lv; 25.70.Cd

Introduction

The high spin states near the yrast line in $^{208}$Pb are quite pure particle-hole states composed of the few configurations that are possible for these spins. Two particle-two hole states are typically 2 MeV higher and should not mix much. Highly elaborated experiments with inelastic electron [1–5] and proton [6–11] (including polarized protons) scattering and charged particle transfer [12] have been performed, in order to find these levels and determine their structure. Simultaneously, because the structure is relatively well known, the reactions on $^{208}$Pb are used to understand the reaction mechanism and determine free parameters in the reaction theory as the effective charge and magnetic quenching in electron scattering. More fundamental problems might also be accessible in this way; Hintz et al. [13] discussed changes of the nucleon mass and nucleon-nucleon interaction as a function of nucleonic density from a comparison of $(e,e')$ and $(p,p')$ [3, 4, 6, 8, 9]. $\gamma$-spectroscopy of these levels can bring the mostly separated fields together and the combination of experimental data that are sensitive to quite different aspects of nuclear structure together with a very good theoretical basis by the shell model for $^{208}$Pb is particularly interesting. Therefore we tried $\gamma$-spectroscopy with inelastic heavy ion scattering at energies above the Coulomb barrier but below the additional energy, that is needed to form a compound nucleus [15]; the reactions therefore reach from quasi elastic to deep inelastic processes.

Experiments

Beams of 350 MeV $^{64}$Ni and 420 MeV $^{82}$Se from the VICKSI accelerator hit a thick $^{208}$Pb target (98.7% enriched) that stops the reaction products in approximately 2 ps. $\gamma$-rays emitted after this time from the nuclei at rest give narrow lines, while at shorter times they are so much Doppler broadened that they cannot be detected. $\gamma - \gamma$ coincidences have been measured with the Osiris spectrometer consisting of 11 Compton suppressed Ge-detectors and an inner ball of 48 BGO-scintillators for sum energy and multiplicity. The separation between the beam pulses from the VICKSI accelerator was 69 ns for $^{64}$Ni and 90 ns for $^{82}$Se and the time of all Ge-detector signals was measured relative to the 1 ns wide beam pulses.
Decay of the $10^+$ isomer

The half-life of the lowest $10^+$ state has been measured as $T_{1/2} = 500(50)$ ns and its main decay by a 284.5 keV transition to $8^+$ observed [14]. Here we report on two new decay modes of the $10^+$ isomer. Figure 1 shows the levels of $^{208}$Pb close to the yrast line. Delayed coincidences show a 250.0 keV line in coincidence with the 1413.2 keV $8^+\rightarrow5^+$ transition (Fig. 2) and a cascade of 840.0 and 857.7 keV on top of the $5^+$ level. The 250.0 keV transition is known as $8^+\rightarrow7^+$ and the 840.0 keV line as $7^+\rightarrow5^+$ from unpublished $^{208}$Bi($t,\gamma$) - data [16] of the experiment described in [14]. The 857.7 keV transition fits exactly the energy difference from $10^+$ to $7^+$ and is therefore a new $E3$-decay of the $10^+$ isomer. The occurrence of the 250.0 keV line implies an unobserved 34.5 keV transition from the $10^+$ isomer to the $8^+$ state. The short interval between beam pulses of the present experiment did not allow to verify the correct lifetime of the new isomeric decays, but there is no reason to suspect another isomer. Intensities of all transitions below the isomer have been evaluated from delayed coincidences using the measured efficiency of the Ge-detectors. Branching ratios and $\gamma$-transition rates have then been calculated from the measured lifetime and the theoretical conversion coefficients and are presented in Table 1.

The decay of the $10^+$ isomer is discussed with the help of Table 2. It shows the three relevant components of the wave functions and the transition strengths. All other configurations can be approximately disregarded as they are small and simultaneously the transition matrix elements are weak. The strength of all proton components

**Table 1. Decay properties of the $T_{1/2} = 500(50)$ ns $10^+$ isomer at 4.89541(10) MeV in $^{208}$Pb**

<table>
<thead>
<tr>
<th>$E_\gamma$ (keV)</th>
<th>Branch total %</th>
<th>$\alpha$ (total)</th>
<th>$\lambda_\gamma$ (1/s)</th>
<th>$B(E\lambda)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>284.48(5)</td>
<td>65(5)</td>
<td>0.137</td>
<td>7.9(12)$\times 10^5$</td>
<td>$B(E2) = 0.35(5) e^2 fm^4$ 0.0048(7) W.u.</td>
</tr>
<tr>
<td>(34.5)</td>
<td>23.5(80)*</td>
<td>1010</td>
<td>3.2(13)$\times 10^2$</td>
<td>$B(E2) = 5.4(22) e^2 fm^4$ 0.07(3) W.u.</td>
</tr>
<tr>
<td>857.72(10)</td>
<td>11.5(20)</td>
<td>0.02</td>
<td>1.6(3)$\times 10^3$</td>
<td>$B(E3) = 826(140) e^2 fm^6$ 0.32(5) W.u.</td>
</tr>
</tbody>
</table>

*From the intensity of the following 250 and 283 keV lines