FIRST OBSERVATION OF $T_> = 45/2$ INNER HOLE STATES IN ^{207}Pb

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The first four isobaric analog states in ^{207}Pb, $T_> = 45/2$, were found around $E_x = 20$ MeV with the reaction ^{208}Pb(τ, α) ^{207}Pb at 102 MeV incident energy. The excitation energies, widths and angular distributions were measured. Spectroscopic factors were deduced by DWBA analysis.

The experimental investigation of neutron inner hole states in heavy nuclei has been of special interest in the last few years. The corresponding states show up in the energy spectra of neutron pick-up reactions as more or less fragmented gross structures riding on top of a continuous background [1]. In addition, fairly narrow states have also been observed at higher excitation energy in several medium heavy nuclei [2]. Such states were identified as the $T_> = T_0(\text{target}) + 1/2$ component of the neutron inner hole state. Their strengths can be directly compared to those of the parent proton hole states and those of the corresponding $T_<$ states.

In general, the observation of deep hole states gets more difficult as one moves to heavier nuclei. The different subshells come closer and their respective contributions strongly interfere already at low excitation energy. In addition, the $T_>$ states are expected at very high excitation energy on top of a continuum of $T_<$ states having very high density. Mixing through the Coulomb force introduces a spreading width in addition to the natural width due to the allowed proton decay channels. Moreover, the $T_>$ strength becomes a very small fraction $(1/2\ T_0 + 1)$ of the total hole strength and decreases with increasing neutron excess. In the lead region isobaric analog states (IAS) were never observed, so far, by pickup reactions. In the present ^{208}Pb(τ, α) ^{207}Pb experiment performed at 102 MeV incident energy, we were able to identify four $T = 45/2$ states, analogues of the first corresponding proton hole states in ^{207}Tl.

The experiment has been performed at the ISN Grenoble with the ^{3}He beam delivered by the variable energy cyclotron. Scattered particles were momentum analyzed by the QSD magnetic spectrometer. Their impact position in the focal plane was measured with a delay line proportional chamber and particle identification was accomplished by measurement of energy loss (ΔE) in an ionization chamber (10 cm active depth) and time of flight (T.O.F.) relative to RF bursts. Displaying ΔE versus T.O.F. allowed a clean identification of d, t, τ and α-particles. Self-supporting targets of enriched (98.7 %) ^{208}Pb were used. Spectra were taken from 1.9° to 20.9° laboratory angles. With only two settings of the spectrometer magnetic field it was possible to investigate 30 MeV excitation energy in the ^{207}Pb spectra. An overall energy resolution of 100 keV was achieved for the measurements at 4.7° and 10.2° which benefited of better beam adjustments and statistics (180 keV at all other angles). Spectra from C and Mylar targets were recorded at all angles for calibration in the highest excitation energy region of the

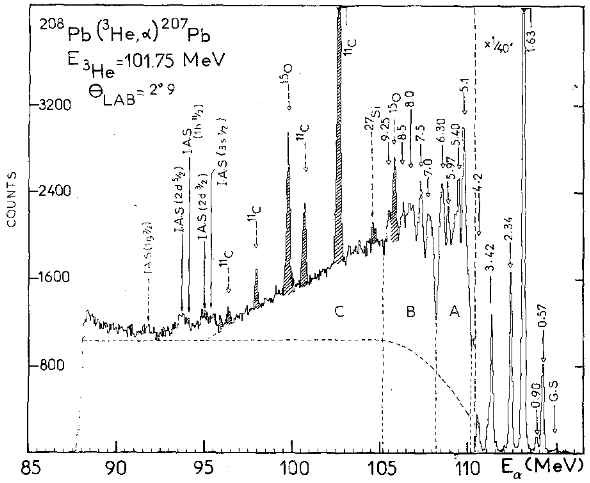

Fig. 1. Experimental spectrum at 2.9° of α-particles from the ^{208}Pb(^{3}He, α)^{207}Pb reaction.

of the ^{207}Pb spectra and for an estimate of contributions from ^{16}O impurities in the target.

A typical spectrum covering the whole energy region investigated is shown in fig. 1. Besides the well known low-lying levels, two isolated strongly fragmented broad structures with rather large cross sections are centered at 5.6 and 8.2 MeV. The continuum then slowly decreases till $E_x \approx 20$ MeV where two small and fairly narrow structures with clear contribution of two peaks in each of them can be seen. The identification of those peaks as the analog states rests on four arguments: (i) their location, (ii) their relative spacing, (iii) their small width, and (iv) their angular distribution.

The excitation energies and widths are best determined using the 100 keV energy resolution spectra recorded at 4.7° and 10.2°. The contributions of ^{11}C and ^{15}O peaks, indicated by hatching in fig. 2 were first carefully subtracted. The spectra were then unfolded using a Breit–Wigner shape for the natural width and a gaussian shape for the experimental contribution to the overall width. The resultant fits are presented in fig. 2. The extracted excitation energies and widths of the four peaks are shown in table 1. Measurements at other angles, although suffering of poorer statistics gave similar results.

The experimental Coulomb energy displacements (ΔE_c) are found somewhat smaller ($\approx$ 60 keV) than the value of 18710 keV calculated using the semi-empirical formula of ref. [3]: $E_c = (1430\,\bar{Z}/A^{1/3} - 992)$ keV, where $\bar{Z}$ is the average charge of the isobaric pair.

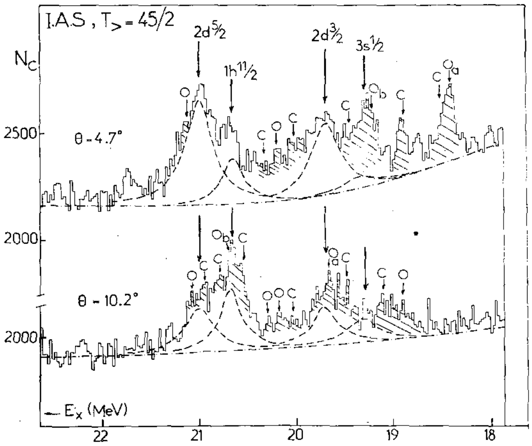

Fig. 2. Parts of the α-spectra showing the isobaric analogue states.

The widths measured in the present pickup experiment are comparable to those of known IAS found at about the same excitation energy in scattering or charge exchange reactions on nearby nuclei [4]. It is interesting to note that the width of the $1h_{11/2}$ IAS is found substantially smaller than those of the $2d_{3/2,5/2}$ states. More precise measurements on high purity targets are needed to confirm this point and to gain better information on the $3s_{1/2}$ state.

The cross sections corresponding to the analog states were extracted using simple gaussian shapes. The experimental angular distributions are compared in fig. 2 with zero-range DWBA predictions. The optical model parameters taken from ref. [5] were tested by fitting the angular distributions on low-lying levels (fig. 2). The corresponding angular distributions calculated for the four analog states agree reasonably well with the experimental data, supporting therefore their assignments as the first $3s_{1/2}$, $2d_{3/2}$, $1h_{11/2}$ and $2d_{5/2}$ $T_>$ hole states. The absolute spectroscopic factors were extracted with a normalization constant of 23, using the neutron form factors computed in a standard well (r_0 = 1.25 fm, a = 0.65 fm, λ = 25) with the usual separation energy prescription. The resulting values are rather large as compared to the shell model sum rule predictions, but no clear conlusion can be presently

Table 1
Isobaric analog states $T_> = 45/2$ in ^{207}Pb.

E_x(exp.) (^{207}Pb) (keV)	ΔE_C(exp.) (keV)	Γ (keV)	*nlj*	$(2T_0+1)\,C^2S_n$ I	$(2T_0+1)\,C^2S_n$ II	$2j+1$	C^2S_p [a]	E_x(^{207}Tl) (keV)
19280 ± 60	18630 ± 60	350 ± 60	3s 1/2	3.6	1.35	2	1.26–4.5	0
19640 ± 30	18640 ± 30	350 ± 40	2d 3/2	9	3.15	4	3.4 –8.5	351
20640 ± 30	18650 ± 30	225 ± 40	1h 11/2	13.5	6.75	12	7.38–22.6	1341
21000 ± 30	18677 ± 30	350 ± 40	2d 5/2	6.75	3.15	6	3.13–10.7	1674

I: Standard separation energy method.
II: Lane's coupled equations; the isospin term is $\frac{4V_1'}{A}\,\frac{e^x}{(1+e^x)^2}\,t\cdot T$ with $V_1' = 142$ MeV.

[a] Experimental proton spectroscopic factors from ref. [6].

drawn from the direct comparison with the spectroscopic factors of the parent hole states (see table 1). A more reliable treatment of the form factor in $N>Z$ nuclei requires the introduction of an isospin dependent potential which couples the $T_>$ neutron and proton wave functions [7]. By assuming a pure surface shape for this potential, as generally prescribed, and solving Lane's equations, smaller $T_>$ neutron spectroscopic factors are indeed obtained. It should however be pointed out that smaller spectroscopic factors are also found, by using the same procedure, for proton pick-up reactions. In addition, the choice of a surface shaped isospin potential in heavy nuclei may be questioned. A careful study of the effects of all the other parameters on the predicted absolute cross sections, as well as more precise experimental determinations are clearly needed for quantitative conclusions.

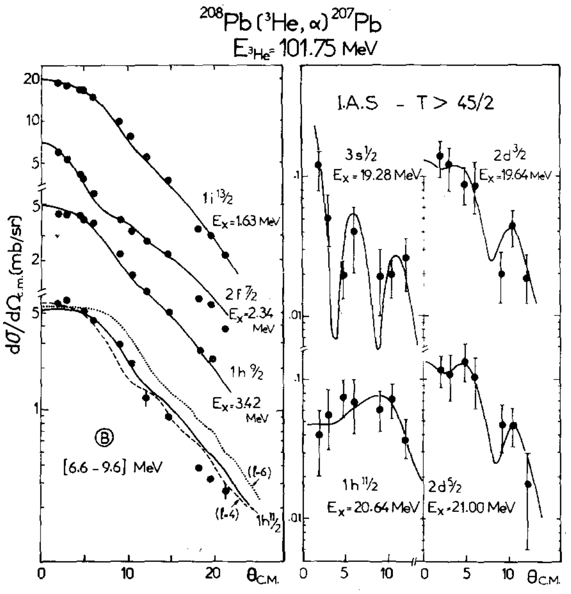

Fig. 3. Experimental and DWBA angular distributions of IAS states. On the left side, low-lying levels and region B angular distributions.

The detailed results and discussion concerning the $T_<$ part of the ^{207}Pb spectra ($E_x < 20$ MeV) indicated as regions A, B and C in fig. 1 will be presented in another paper [8]. We wish to emphasize the following points connected to the present discussion: (i) the centroids of the $3s_{1/2}$, $2d_{3/2,5/2}$ and $1h_{11/2}$ hole strengths are all predicted [9] around 6–10 MeV excitation energy; but only large-l orbitals are sufficiently well matched in the present reaction to give large cross sections; (ii) the known low-lying levels ($E_x < 4.5$ MeV) do not exhaust the $1h_{9/2}$ and $1i_{13/2}$ strengths, the corresponding missing strength is thus expected in region A in a weak-coupling picture, (iii) the fine structures showing up clearly in region B do not significantly modify the overall B angular distribution, which is best reproduced assuming $l = 5$ transfer as shown in fig. 3. We thus conclude, in agreement with previous results [1] that most of the strength centered around $E_x = 8.3$ MeV may be attributed (with ≈ 40% of the total strength) to the $T_<$ counterpart of the $T_>$ $1h_{11/2}$ hole state.

In conclusion, the first $3s_{1/2}$, $1d_{3/2}$, $1h_{11/2}$ and $1d_{5/2}$ IAS in ^{207}Pb were identified using the (^{3}He, α) reaction at 102 MeV incident energy. We measured their excitation energies, widths and spectroscopic factors. New information was also gained on the location and fragmentation of the $1h_{11/2}$ $T_<$ inner hole strength. The present results demonstrate the power of pick-up reactions for further study of IAS in heavy nuclei.

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