INVESTIGATION OF NEUTRON-PROTON HOLE STATES IN Tl^{206} BY THE REACTION $Pb^{208}(d, \alpha)Tl^{206}$*

M. B. Lewis and W. W. Daehnick
Nuclear Physics Laboratory, University of Pittsburgh, Pittsburgh, Pennsylvania
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The neutron-hole, proton-hole states of Tl^{206} have been studied by the direct reaction $Pb^{208}(d, \alpha)Tl^{206}$ with 17-MeV deuterons. The experimental resolution of 15 keV or better permitted the detection of many two-hole states, most of them previously unknown. For most levels L values could be extracted from the comparison of microscopic distorted-wave Born approximation (DWBA) calculations with experimental angular distributions. The experimental level energies and J^π assignments (or limits) are compared with recent calculations by Kuo and are found to be in good agreement.

The study of odd-odd nuclei is fundamental to the understanding of the neutron-proton interaction in nuclear matter. The two-body wave functions of the neutron-proton type are distinctive in that they are sensitive to the $T=0$ as well as the $T=1$ components of the two-nucleon force. Odd-odd nuclei in the lead region are of special importance since the doubly magic Pb^{208} ground state appears from recent data to be the best vacuum (i.e., inert) state of any nucleus and serves as an ideal nuclear core for single-particle orbitals.[1]

The direct reaction $Pb^{208}(d, \alpha)Tl^{206}$ is ideally suited for the excitation of the theoretically most important levels in Tl^{206}, i.e., those formed by coupling single proton-hole and neutron-hole orbitals in the doubly magic Pb^{208} core. The few single-nucleon-exchange reactions reaching levels of this important, but poorly known nucleus, such as the reactions[2] $Tl^{205}(d,p)Tl^{206}$ or $Pb^{207}(t, \alpha)Tl^{206}$, populate only some of the two-hole states of interest. Early calculations[3] for Tl^{206} had not been able to explain the limited information available for this nucleus up to that time. For example, these calculations predict the splitting of $[s_{\frac{1}{2}}^{-1}p_{\frac{1}{2}}^{-1}]_{J=0}$ and $[s_{\frac{1}{2}}^{-1}p_{\frac{1}{2}}^{-1}]_{J=1}$ to be ≈ 60 keV, whereas experimentally it appears to be 304 keV. Calculations by Kim[3] predict 16 two-hole levels below 2.5 MeV, whereas at least 32 such levels have been excited in the reaction $Pb^{208}(d, \alpha)Tl^{206}$ (a partial list is given in Fig. 1).

Recent shell-model calculations by Kuo[4] with realistic forces (Hamada-Johnston), 11 single-hole orbitals, and the inclusion of core polarization as a perturbation have yielded a spectrum of high level density even below 2-MeV excitation containing many states with very appreciable configuration mixing (see Fig. 1).

The direct (d, α) reactions are expected to excite all $T_<$ states with a proton-neutron-hole component with the exception of $J^\pi = 0^+$ states, states of pure $(j^2)_{\text{even}}$ configuration, and states of such configuration as to give rise to coherent cancellation of the amplitude of the deuteron radial form

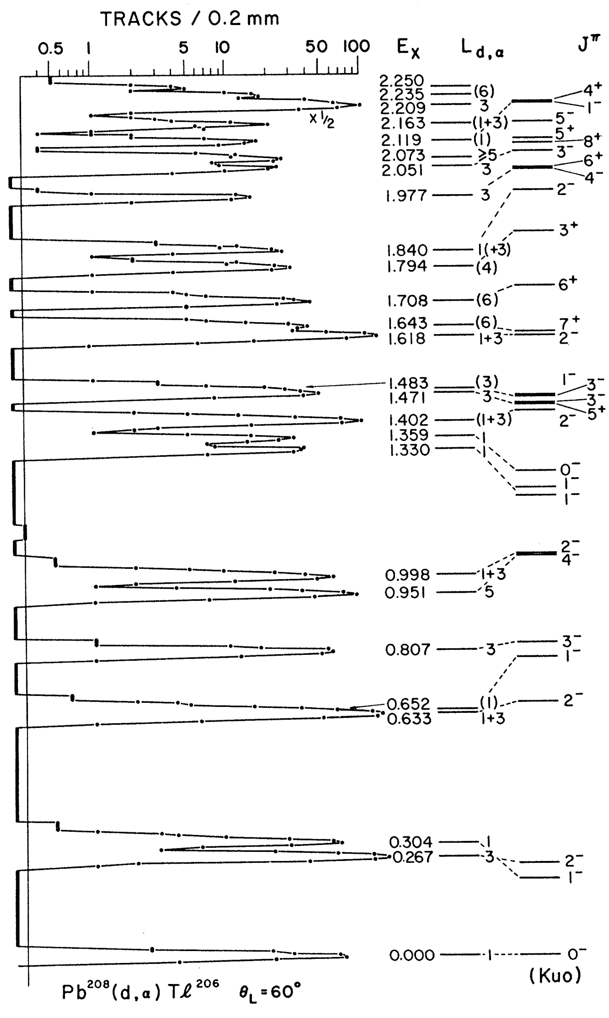
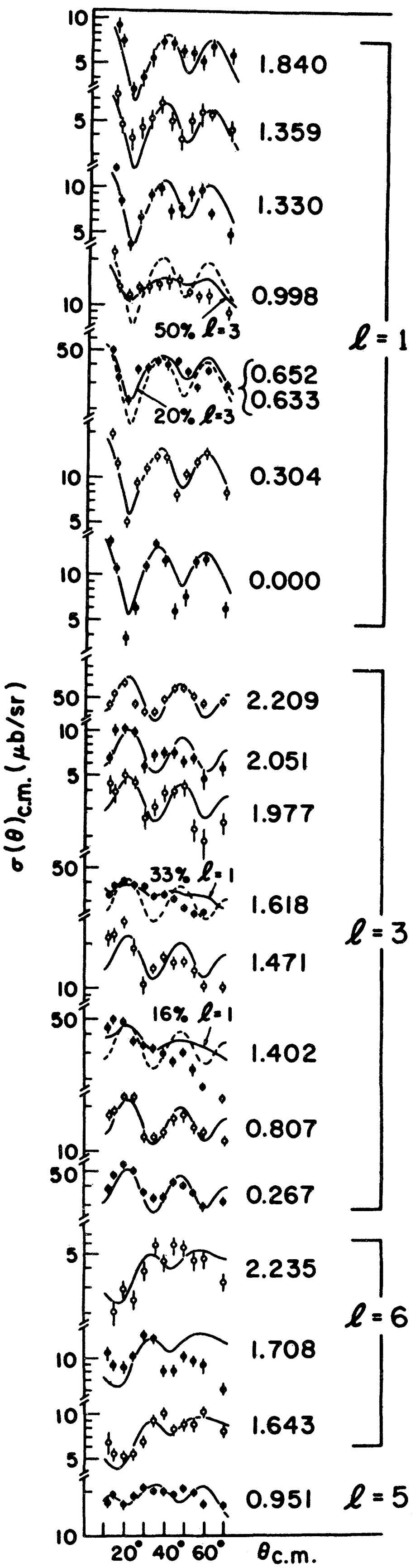


FIG. 1. A typical $Pb^{208}(d, \alpha)Tl^{206}$ spectrum as observed with the split-pole spectrograph at $E_d = 17$ MeV and $\theta_{\text{c.m.}} = 60°$. The excitation energies listed have estimated errors of ±5 keV for $E < 1$ MeV and ±10 keV elsewhere. Numbers to the right of the level energies are the observed L transfers. On the extreme right is the Tl^{206} spectrum calculated by Kuo (Ref. 4).



factor.[5] Kuo's calculations do not predict 0^+ or pure $(j^2)_{\text{even}}$ configurations for Tl^{206}, and total cancellation effects are expected to be small. Hence we expect to see nearly all predicted two-hole levels in the $\text{Pb}^{208}(d,\alpha)\text{Tl}^{206}$ experiment. Figure 1 shows a comparison of theory with the low-lying levels seen in this work. Many of these levels shown are reported here for the first time and are expected to have configurations in which both neutron and proton are in excited hole orbitals. It is apparent that the (d,α) spectrum is just as rich in levels as the calculated one, save for a possible few that – in spite of the 15-keV experimental resolution – are not sufficiently resolved.

A one-to-one correlation for calculated and observed levels has been attempted in Fig. 1. For most (d,α) angular distributions the L transfer could be extracted with confidence as shown in Fig. 2. The curves drawn in Fig. 2 are DWBA predictions.[6] For each L assignment, spin and parity are restricted to $L-1 \leq J \leq L+1$ and $\pi = (-1)^L$. In addition, predicted J_{odd}^- and J_{even}^+ must be excited via pure $L=J$ transfers. In regions of considerable configuration mixing, we generally expect J_{odd}^+ and J_{even}^- levels to be reached by a mixture of two L ($L=J-1$ and $L'=J+1$) values.[7]

The correlation between calculated and observed levels is further suggested by the relative intensities of the L transfer. For example, calculations[8] based on the configuration mixed wave functions of Kuo indicate intense $L=3$ dominance over $L=1$ for exciting the 0.267-MeV level, while $L=1$ should be dominant for the 0.633-MeV level, even though both states are $J^\pi = 2^-$. Other examples, too numerous to mention here, can be cited at higher excitation.

We conclude that the agreement between Kuo's calculations and experiment is especially significant since it indicates that a large configuration space is necessary to describe even the lowest lying states of Tl^{206}. The importance of configuration mixing in Tl^{206} is in contrast to the recent study of those particle-hole states[9] in Bi^{208} excited via single-nucleon-transfer reactions and compared with calculations of Kim and Rasmussen[10]

FIG. 2. Experimental cross sections and DWBA calculations grouped according to L value. The experimental absolute scale error is about 20%. The DWBA cross sections were arbitrarily normalized to the data. Deuteron form factors were computed on a microscopic basis, and finite-range and nonlocal corrections were included (Ref. 6).

in a more limited configuration space. A more detailed and quantitative discussion of the data as well as a presentation of data for higher excited states will be published elsewhere.

The authors are indebted to T. T. S. Kuo for permission to present his as yet unpublished calculations for Tl^{206}. Also, we wish to thank F. Rybicki for helpful discussions and permission to use the Drisko-Rybicki microscopic-form-factor code[6] for our DWBA calculations.

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STRANGENESS $S=-2$ BARYON RESONANCE*

J. Alitti, V. E. Barnes, E. Flaminio, W. Metzger,‡ D. Radojičić,§ R. R. Rau, C. R. Richardson,‖ and N. P. Samios
Brookhaven National Laboratory, Upton, New York

and

D. Bassano, M. Goldberg, and J. Leitner†
Syracuse University, Syracuse, New York
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Evidence is presented confirming the existence of the $\Xi(1815)$ baryon with strangeness $S=-2$ as well as two new Ξ resonances with masses 2030 ± 10 MeV and 2430 ± 20 MeV, respectively. It is speculated that the $\Xi(2030)$ is a member of a $\frac{5}{2}^+$ octet, and an SU(3) analysis of the decay rates of the conjectured states is in reasonable agreement with the experimental data.

Baryons of strangeness quantum number $S=-2$ have typically been difficult to observe. For many years the $\Xi(1320)$ and $\Xi(1530)$ were the only definitely known states. Two Ξ resonances at masses 1815 MeV[1-4] and 1930 MeV[2,3] have been suggested for some time, the first supported by considerably stronger evidence than the second. Recently we have given positive evidence for the 1930-MeV state.[5] In this Letter we present confirmatory evidence for the 1815-MeV state (our mass $M=1830\pm10$ MeV and width $\Gamma=55^{+40}_{-20}$ MeV) as well as evidence for two new $S=-2$ states with masses $M_1=2030\pm10$ MeV and $M_2=2430\pm20$ MeV, and widths $\Gamma_1=45^{+40}_{-20}$ MeV and $\Gamma_2=150^{+60}_{-40}$ MeV. At the conclusion of this Letter we speculate, as have others, that the $\Xi(1815)$ is a member of an SU(3) octet having spin and parity $J^P=\frac{3}{2}^-$.[6] Furthermore, the $\Xi(2030)$ could be a member of a new SU(3) octet with $J^P=\frac{5}{2}^+$.

Our data come from a study of K^-p interactions at 3.9-, 4.6-, and 5.0-BeV/c K^- momenta. The exposures have been made using the Brookhaven National Laboratory (BNL) 80-in. hydrogen bubble chamber, which was situated in an electrostatically separated particle beam at the alternating-gradient synchrotron. In the combined 4.6- and 5.0-BeV/c exposures, there are approximately 18 event/μb and at 3.9 BeV/c, about 10 event/μb. The final states of direct interest in the study are

$$\Lambda^0K^-K^+,\ 458\text{ events;} \tag{1}$$

$$\Sigma^0K^-K^+,\ 218\text{ events;} \tag{2}$$

$$\Sigma^-\bar{K}^0K^+,\ 82\text{ events;} \tag{3}$$

$$\Xi^-\pi^+\pi^-K^+,\ 267\text{ events.} \tag{4}$$

All the above are four constraint (4C) production fits except Reaction (2) which is a 2C fit. Events