PROTON-CHANNEL ANALOG RESONANCES AND WEAK COUPLING IN THE $^{206}Tl(d,p)^{206}Tl$ REACTION †

W. R. WHARTON, R. A. HINRICHS, G. W. PHILLIPS and J. G. CRAMER
Department of Physics, University of Washington, Seattle, Washington, USA

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Proton resonance structure was observed in the $^{205}Tl(d,p)$ reaction at single-particle energies for outgoing protons leading to all strongly excited states below 3 MeV excitation in ^{206}Tl. Decay of the isobaric analog of the ^{207}Tl ground state was not observed.

Recent studies of (d, p) reactions on $^{206,207,208}Pb$ [1-3] have revealed the presence of isobaric analog resonances (IAR) in proton channels populating both the ground state and excited states of the final nucleus. The resonances occur in each channel at the same outgoing proton energies but at different energies in the compound nucleus determined by the sum of the excitation energy of the final state and the resonant proton energy. These results have led to a weak-coupling interpretation in which the parent analog states can be described as a neutron in a single-particle orbit coupled to an excited core closely resembling the particular final state reached in the (d, p) transition. Similar effects have been observed in the study of IAR in the (p, p') reaction [4] which can strongly excite only collective states. The observance of weak coupling in the (d, p) reaction may be a source of spectroscopic information not obtainable from the (p, p') reaction.

In the present work we have studied IAR excited in the (d, p) reaction on ^{205}Tl with the object of investigating the conditions under which weak coupling applies. Previous studies have been limited to the lead isotopes which have a closed proton shell. ^{205}Tl has a proton hole in the $3s_{\frac{1}{2}}$ shell and therefore has twice as many states to couple for each neutron configuration. We have measured excitation functions leading to all strongly excited states of ^{206}Tl. A deuteron beam from the University of Washington's FN tandem accelerator was used, and outgoing protons were observed with two Si(Li) detectors placed at $\pm 160^{\circ}$. Excitation functions for all strongly excited states below 3 MeV show resonance structure at outgoing proton energies between 16 and 18 MeV. Some of these are shown in fig. 1. Prominent resonance structure is observed near proton energies of 16.7 MeV, corresponding to groups of IAR in ^{207}Pb with the proton resonating in the $3d_{\frac{5}{2}}$ and/or $4s_{\frac{1}{2}}$ shells, and 17.4 MeV, corresponding to groups of IAR in ^{207}Pb with the proton resonating in the $2g_{\frac{7}{2}}$ and/or $3d_{\frac{3}{2}}$ shells. The shape of the resonances is similar to those seen in $^{206}Pb(d,p)$ [2]. The excitation functions of excited states above 3 MeV have little resonance structure at these proton energies (see fig. 1b). This is symptomatic of a breakdown in weak coupling. The strongly excited states above 3 MeV primarily have configurations with a neutron in the same $3d_{\frac{5}{2}}$, $4s_{\frac{1}{2}}$, $2g_{\frac{7}{2}}$, or $3d_{\frac{3}{2}}$ shells in which a proton at these energies resonates. Therefore weak coupling is not valid because of strong correlations between nucleons in the same shell.

To investigate cases where the outgoing proton resonates in other shells, we studied the same IAR which appear in the low-lying excited states of ^{206}Tl. These IAR should have alternative decay channels where the proton is resonating in the $3p_{\frac{1}{2}}$, $2f_{\frac{5}{2}}$ and $3p_{\frac{3}{2}}$ shells (see fig. 2). These channels populate states of ^{206}Tl above 3 MeV with a neutron in the $3d_{\frac{5}{2}}$, $4s_{\frac{1}{2}}$, $2g_{\frac{7}{2}}$, or $3d_{\frac{3}{2}}$ shell. The excitation functions for two such groups of states at 4.24 and 5.05 MeV are shown in fig. 1a. Only in the latter is there evidence of weak resonance structure, and this appears at deuteron energies of 13.5 and 14.9 MeV, corresponding approximately to the energy of an outgoing proton resonating in the $3p_{\frac{1}{2}}$ and $3p_{\frac{3}{2}}$ shells, respectively. The single-particle decay widths for a proton resonating in these shells, when

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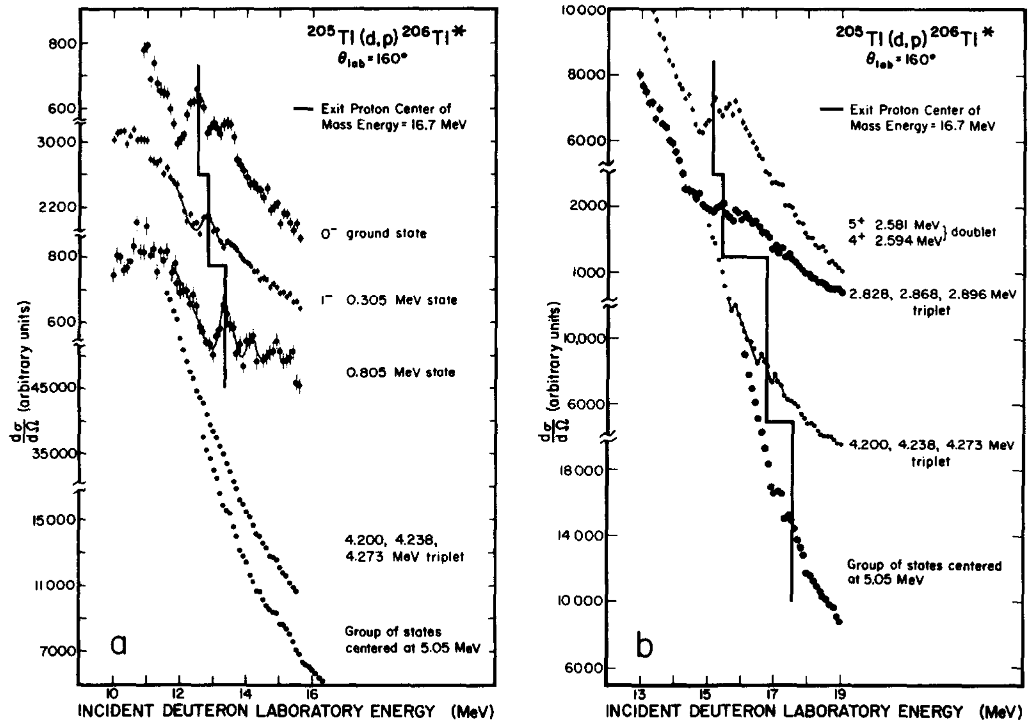

Fig.1.a) ^{205}Tl(d, p)^{206}Tl excitation functions at 160° to various final states in ^{206}Tl, showing resonance structure at the same outgoing proton energy indicated by the solid line.
b) A continuation of a) for higher excited states of ^{206}Tl.

multiplied by the number of nucleons in each shell, is comparable to the single-particle decay widths for a proton resonating in the 3d$_{5/2}$, 4s$_{1/2}$, 2g$_{7/2}$ and 3d$_{3/2}$ shells. The weakness or absence of visible resonance structure in the 4.24 and 5.05 MeV excitation functions is attributed to two things. 1) The direct (d,p) cross section is much larger to the states at 4.24 MeV and 5.05 MeV than for the low-lying excited states of ^{206}Tl.
2) The resonance cross section is expected to be at least a factor of four smaller for the states at 4.24 and 5.05 MeV than for the low-lying excited states of ^{206}Tl. This is because the sum of the spectroscopic factors between the parent analog states in ^{207}Tl and the final state in ^{206}Tl coupled to a nucleon in the 3d$_{5/2}$, 4s$_{1/2}$, 2g$_{7/2}$ and 3d$_{3/2}$ shells has an upper limit of 1 for each shell or a total upper limit of 4. However, the sum of the spectroscopic factors between the parent analog states in ^{207}Tl and the final state in ^{206}Tl coupled to a nucleon in the 3p$_{1/2}$, 2f$_{5/2}$, 3p$_{3/2}$, 1i$_{13/2}$, 2f$_{7/2}$ and 1h$_{9/2}$ shells has a total upper limit of 1. Furthermore, some of this spectroscopic strength is distributed into the 1i$_{13/2}$, 2f$_{7/2}$ and 1h$_{9/2}$ shells where the resonating proton width for the IAR is negligible.

We have also searched for the isobaric analog of the $\frac{1}{2}^+$ ground state of ^{207}Tl. The comparable experiment on a lead target is not possible because a $0^+ \rightarrow 0^+$ transition by deuteron capture is prohibited by angular momentum and parity selection rules. The isobaric analog of the ^{207}Tl g.s. should occur at the same deuteron energy in all channels and should only appear in the excitation functions for the low-lying states of ^{206}Tl with the proton resonating in the 3p$_{1/2}$, 2f$_{5/2}$ or 3p$_{3/2}$ shells. The IAR of the ^{207}Tl g.s. was calculated to be within a few hundred keV of E_d = 7.5 MeV. We could obtain an excitation function only for the 0.305 MeV state of ^{206}Tl because of contaminate peaks in our spectra. No resonance structure was observed although the spectroscopic factor between the 0.305 MeV state and the ^{207}Tl ground state is expected to be nearly 1. The formation of the analog of the ^{207}Tl g.s. requires a spin flip of either the captured neutron or proton. The proton and neutron must be captured in the same shell with opposite spin orientations although their spins are aligned in the deuteron. Such a spin flip is not needed to form

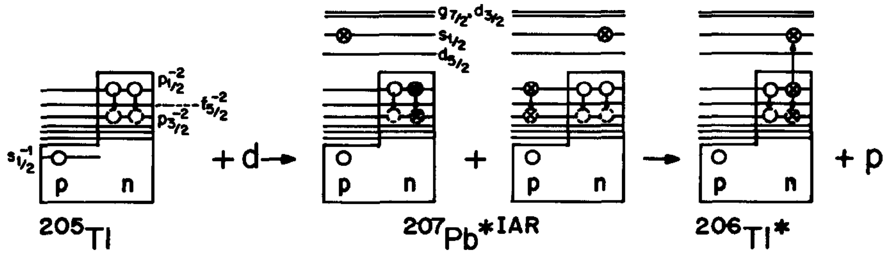

Fig. 2. Simple shell model schematic of the ^{205}Tl(d, p) reaction going through the isobaric analog of a $\pi(3s_{\frac{1}{2}})^{-1}\nu(es_{\frac{1}{2}})\nu(j)^{-1}$ state in ^{207}Tl where $j = 3p_{\frac{1}{2}}$, $2f_{\frac{5}{2}}$, $3p_{\frac{3}{2}}$, etc. Dotted circles with arrows represent one of several alternative locations of the holes or particles; ⊗ represents a nucleon, which can be associated with the deuteron in the entrance channel and/or the proton in the exit channel.

the other IAR which have been observed in the (d, p) reactions.

The (d, p) reaction through IAR is isospin forbidden in the entrance channel, and the isospin violating mechanism for formation of the IAR is not well understood. Coulomb excitation of the deuteron into the 0^+, $T = 1$ singlet state has been proposed as a possible reaction mechanism [1], however, this mechanism requires a spin-flip and would be expected to strongly excite the analog of the ^{207}Tl g.s. Another possible mechanism is the approach of Tamura [5] which assumes a direct stripping of a neutron followed by a final-state interaction between the proton and the residual nucleus. The non-observance of the analog of the ^{207}Tl g.s. is consistent with spin-flip being of minor importance in this reaction mechanism.

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