Evidence for charge exchange coupling in ^{206}Pb$(t, p)^{208}$Pb

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(Received 25 June 1974)

Anomalies are observed in the excitation function of the ^{206}Pb$(t, p)^{208}$Pb reaction measured at 169° lab from 9 to 16 MeV. In addition to isospin forbidden analog resonances, anomalous behavior is observed near the threshold for the analogous (t, n) reaction. These results as well as previously reported data for other reactions are consistent with the interpretation of this latter anomaly as arising from charge exchange coupling.

[NUCLEAR REACTIONS ^{206}Pb(t,p), E =9–16 MeV; measured σ (E_t), θ =169°.]

Anomalies observed[1-4] in the excitation functions for a number of one and two particle transfer reactions on Pb isotopes have been attributed to isospin forbidden formation (or decay) of analog resonances. Possible mechanisms for this process have been given.[1,5] In Tamura's[5] direct reaction, coupled channel calculation the observed resonance behavior in the transfer reaction is attributed entirely to the proton channel. To date only qualitative fits to the data have been obtained. Stein *et al.*[4] pointed out that, in qualitative agreement with Tamura's theory, all of the observed anomalies can be correlated with the proton channel energy. The experimental data[1-4,6] strongly indicate that a *necessary* condition for anomalies in transfer reactions involving protons in the initial or final state is a resonance in the proton channel.

Another type of anomaly which has been observed[7-9] in transfer reactions in a number of cases for nuclei with $A \leq 100$ arises from charge exchange coupling. The main purpose of this paper is to present experimental results which provide evidence for the existence of this latter type of anomaly in the ^{206}Pb$(t, p_0)^{208}$Pb reaction. Coupling between the isospin analogous channels in ^{208}Pb$(p, p)^{208}$Pb has been observed,[10,11] but the existence of charge exchange coupling in transfer reactions in this mass region has not previously been reported.

As a continuation of earlier work[2,3] excitation functions for the ^{206}Pb$(t, p)^{208}$Pb reaction were measured from about 9 to 16 MeV in 100 keV steps at a laboratory angle of 169°. The triton beam was obtained from the Los Alamos Scientific Laboratory three-stage Van de Graaff facility. The target was enriched in ^{206}Pb and was about 100 keV thick at 12 MeV. Protons, deuterons, and tritons were identified and separated by means of a $\Delta E - E$ counter telescope in conjunction with an SDS 930 online computer.

The excitation function for the ^{206}Pb(t, p) reaction to the ground state of ^{208}Pb is shown in Fig. 1. The upper energy range of the excitation function is also shown expanded by a factor of 2. Most of the data points are an average of at least two separate runs. Data points in the region from 13.5 to 15.6 MeV are averages of three separate runs made over a period of three days. The vertical lines near the lower axis indicate the expected triton energies of known[12] analog resonances with the indicated spectroscopic designations. The large anomalies in the (t, p) reaction observed in the triton energy range between 10.9 and 12.5 MeV are attributed to these analog resonances. The two lower energy anomalies ($d_{5/2}$ and $s_{1/2}$) were previously observed[3] in the inverse reaction ^{208}Pb$(p, t_0)^{206}$Pb. The portion of the curve of most interest here is the region from about 12.5 to 15 MeV. The arrows shown near 13.45 MeV indicate the threshold energy for the ^{206}Pb$(t, n)^{208}$Bi reaction to the state in ^{208}Bi which is the analog of the ^{208}Pb ground state. In the region of this threshold the (t, p) excitation function shows a small anomaly which is consistent with a dip superimposed on the gradually decreasing cross section. Additional anomalous behavior occurs at somewhat higher energies. All of these features were present in each of the separate data runs. These anomalies near 13.45 MeV are in the energy region where effects of charge exchange coupling between the analogous (t, p) and (t, n) reactions would be expected.

It is of interest to correlate the (t, p) results with the ^{208}Pb$(p, p)^{208}$Pb measurements[10,11] in the corresponding proton channel energy region. The ^{208}Pb$(p, p)^{208}$Pb reaction does display an anomaly

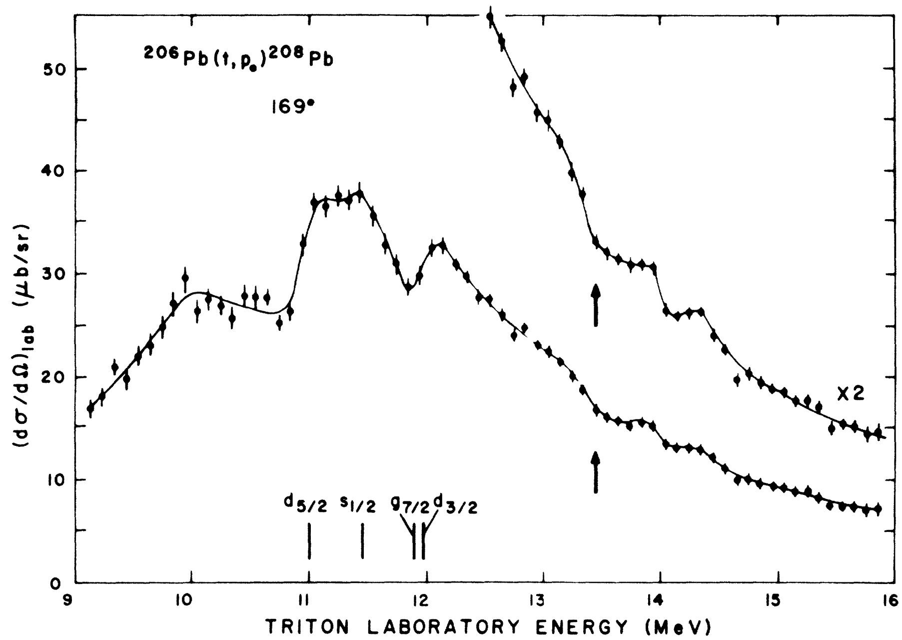

FIG. 1. Excitation function at 169° lab for the $^{206}Pb(t,p_0)\,^{208}Pb$ reaction. The high energy portion of the data is also plotted on a scale expanded by a factor of 2. The curves are drawn through the experimental points. The vertical lines near the horizontal axis indicate the expected energies of known analog resonances. The arrows at $E_t = 13.45$ MeV indicate the threshold for $^{206}Pb(t,n)\,^{208}Bi$ reaction to the analog of ^{208}Pb ground state.

which starts near E_p(c.m.) = 18.9 MeV, the threshold for quasielastic scattering, and extends upward in energy for 500 keV or so. The Yale group[10, 11] has attributed this anomaly in the elastic scattering to coupling between the (p,p) channel and the analogous (p,n) channel.

The anomalous behavior observed in $^{206}Pb(t,p)$-^{208}Pb near the triton energy of 13.45 MeV is almost certainly related to the anomaly in the proton channel at the corresponding energy, E_p(c.m.) = 18.9 MeV. Thus, if the proton anomaly arises from coupling to the analogous (p,n) channel, the (t,p) anomaly arises from coupling to the analogous (t,n) channel. Coupling between analogous channels in a two particle transfer reaction has been observed[13] in $^{98}Mo(p,t_0)^{96}Mo$. Hinrichs *et al.*[13] point out that anomalous behavior should be observed in *all* reactions involving a proton in entrance or exit channel when the proton channel energy is near the quasielastic threshold. Indeed, the published excitation functions in Ref. 4 for the $^{208}Pb(p,d)$ reaction to several different final states and for the $^{207}Pb(d,p)$ reaction to the ground state show small anomalies when the proton channel energy is near the quasielastic threshold, E_p(c.m.) = 18.9 MeV.

An interesting feature in the present case is that the Q values for both the $^{207}Pb(d,p_0)$ reaction and the $^{206}Pb(t,p_0)$ reaction are such that the "rule of thumb" ($Q > \frac{1}{4}\Delta E_c$) for observing[9, 14] charge exchange coupling in (d,p) reactions on lighter nuclei is satisfied. Also, assuming the anomaly is the result of charge exchange coupling, this case is the second example[9] of a ground state threshold cusp occurring on a descending cross section.

While all of the experimental data are consistent with the interpretation of the (t,p) anomaly near 13.45 MeV as arising from charge exchange coupling, it is not possible to completely rule out the possibility that it is the result of analog resonances in the proton channel. It is also possible that the effects seen are a combination of these two mechanisms. This latter possibility has been suggested[15, 16] to explain the results seen in $^{96}Zr(p,d)$ and $^{98}Mo(p,d)$.

In summary, this paper presents evidence for charge exchange coupling in transfer reactions involving the system $^{208}Pb + p$ in addition to the already reported charge exchange coupling observed[10, 11] in the elastic scattering. Although the coupling has been observed in several channels for a few other nuclei,[13, 15] the fact that ^{208}Pb is "doubly magic" should make the present case more amenable to theoretical calculation. Probably further experimental study including polarization[17] measurements would be worthwhile.

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†Work supported in part by a grant from Research Corporation.

‡Work performed under the auspices of the U. S. Atomic Energy Commission.

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