TWO-NEUTRON PICKUP STRENGTHS ON THE EVEN LEAD ISOTOPES THE TRANSITION FROM SINGLE-PARTICLE TO "COLLECTIVE"*

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The (p, t) reaction on ^{208}Pb, ^{206}Pb, and ^{204}Pb has been studied with 35 MeV protons. It is observed that the $L = 0$ ground-state cross section rapidly increases as one changes targets from ^{208}Pb to ^{206}Pb to ^{204}Pb while the cross section for other natural-parity transitions decreases. The observed cross sections are compared with predictions of the shell model and the pairing-vibration model. Both models are seen to describe some features of the data.

Both the shell model [1, 2] and the pairing-vibration model [3, 4] have been used to describe properties of the lead isotopes. In this note, the predictions of both these models are compared with the observed (p, t) strengths on ^{208}Pb, ^{206}Pb, and ^{204}Pb. These reactions have been studied with a 35 MeV proton beam from the MSU Cyclotron. The tritons were detected by either nuclear emulsions (with resolution of 15 keV, FWHM) or a position sensitive proportional counter [5] (resolution of 30 keV) in the focal plane of a spectrograph. In order to minimize uncertainties in the relative cross sections from isotope to isotope, the identical experimental set up was used to study the (p, t) reaction on all the Pb isotopes. To check these relative cross sections we also studied the (p, t) reaction on a natural lead target for which the ratio of the different isotopes is known. The uncertainty in relative cross section from isotope to isotope is estimated to be less than 8%. Reynolds et al. [6] have studied these reactions with resolution of 220 keV; where similar quantities are reported, our results are substantially in agreement with theirs.

Angular distributions to the lowest 0^+, 2^+, and 4^+ states excited in each nucleus are shown in fig. 1 along with the DWBA predictions for these angular distributions. The DWBA calculations used the code DWUCK [7] (in the zero-range approximation) with shell model wave functions describing the initial and final states. Proton parameters from ref. [8] and triton parameters (r_0 = 1.16 fm) from ref. [9] were used.

Our main interest in this note is in how the magnitude of the (p, t) cross section changes as one goes away from the ^{208}Pb closed core. In fig. 2 experimentally determined cross sections are compared with the predictions of the shell model for the transitions to ^{206}Pb and ^{204}Pb and with the simplest pairing-vibration model (described below) for transitions to the lowest 0^+, 2^+, and 4^+ states. The shell model calculations [1] used a complete six-orbit basis with two-body matrix elements based on those of Kuo and Herling [2]. The theoretical cross sections have been normalized to fit the lowest states of a given L-value observed in the ^{208}Pb(p, t)^{206}Pb reaction; then the same normalization was used to describe the other transitions to states of the same spin and parity. The relative cross section for different L-values is not predicted too well by the shell model; if $\sigma^{\exp}(\theta) = N^L \sigma_{\mathrm{DW}}(\theta)/(2L+1)$, then $N^{L=0}$ is about 70% larger than $N^{L\neq 0}$. This suggests that there are correlations absent in the calculated ground-state wave functions which are significant in the two-nucleon transfer pro-

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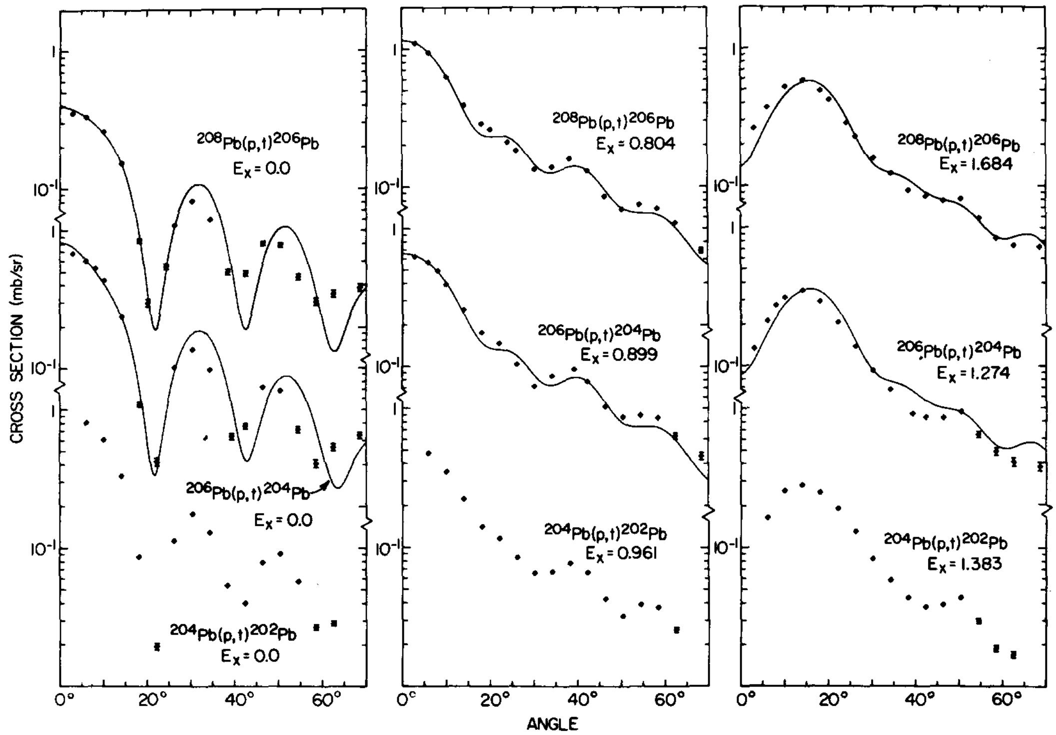

Fig. 1. The experimental and calculated angular distributions observed in the ^{A}Pb(p, t)$^{A-2}$Pb reaction. Each DWBA curve has been independently normalized to show the agreement between the shapes of calculated and observed angular distributions.

cess. Such correlations are predicted by Vary et al. [10].

The simplest pairing-vibration model in which the creation operators for the lowest 0^+, 2^+ and 4^+states in ^{206}Pb are treated as bosons was used. In this model, the strengths for the (p, t) transitions are proportional to the number of phonons in the final state. Hence, the (p, t) cross sections for transitions to the ground states of ^{206}Pb, ^{204}Pb, and ^{202}Pb are predicted to be in the ratio of 1:2:3, and the transition strengths to the lowest 2^+ and 4^+ states are predicted to be equal for all targets.

Examining fig. 2 one sees (1) the cross section for L = 0 transitions to the ground-state increases rapidly as one moves away from the ^{208}Pb closed core, (2) the cross sections to the lowest 2^+ and 4^+ states decrease as one moves away from the closed core, and (3) the strength to higher-lying natural-parity states generally decreases as one goes to the lighter isotopes. All these results indicate that the more neutron-deficient lead isotopes become "collective" in the sense that the (p, t) cross section becomes concentrated in the ground-state transition.

Comparison of experiment with the predictions of DWUCK using shell model wave functions for ^{208}Pb, ^{206}Pb, and ^{204}Pb (see fig. 2) indicates the shell model generally does very well where it has been applied. In particular, it not only predicts the observed trend of increasing ground-state cross sections and decreasing cross sections to the other natural-parity states as one goes from ^{208}Pb(p, t)^{206}Pb to ^{206}Pb(p, t)^{204}Pb, but it generally agrees in detail with experiment, with the exception of the strength to the second 4^+ state in ^{204}Pb where the observed cross section is considerably larger than predicted.

The simple pairing-vibration model is in qualitative agreement with the systematic behavior of the ground-state transitions. For the lowest 2^+ and 4^+ states, the experimental cross sections decrease significantly as the target mass decreases, whereas the pairing-vibration model predicts equal strengths with decreasing mass.

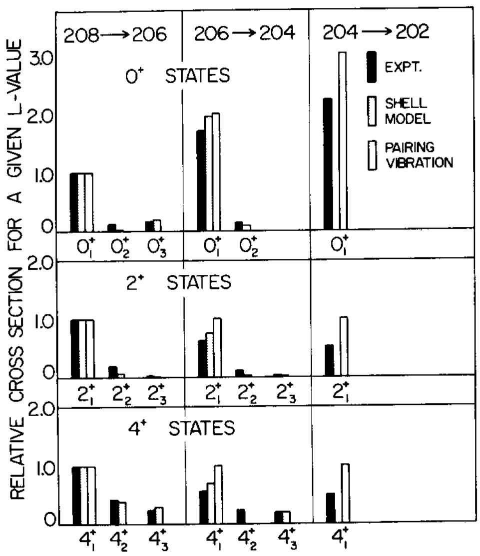

Fig. 2. Comparison of the experimental cross sections with the relative cross sections predicted by the shell model (for transitions to ^{206}Pb and ^{204}Pb) and the pairing-vibration model (for the transitions to the lowest 0^+, 2^+, and 4^+ states). Included here are all transitions to states which can be reliably associated with states predicted by the shell model plus the lowest 0^+, 2^+, and 4^+ states in ^{202}Pb. The excitation energy of the 0^+ states are (in keV) 0, 1167, 2314 and ^{206}Pb and 0, 1728 in ^{204}Pb; the 2^+ states are at 804, 1466, 1783 in ^{206}Pb and at 899, 1663, 1958 in ^{204}Pb; the 4^+ states are at 1684, 1997, 2929 in ^{206}Pb and 1274, 1563, 1816 in ^{204}Pb.

In the ^{204}Pb(t, p)^{206}Pb reaction [4], the 0^+ state at 5.64 MeV was observed to be strongly populated. In the pairing-vibration model, it is interpreted as a three-phonon state. Since the ^{208}Pb ground state is a zero-phonon state, this state should not be populated strongly in the ^{208}Pb(p, t)^{206}Pb experiment. No $L = 0$ transition at the energy of this state was observed in the experiment summarized here.

In fact, no state within 100 keV of this energy was populated with more than 3% of the ground-state strength.

The agreement between the pairing-vibration model and the experiment considered here is, in one sense, rather surprising. The shell model wave function for the ground state of ^{206}Pb is roughly 50% $(p_{1/2})^{-2}$. If a creation operator, $Z(^{206}\mathrm{Pb})$, for this ground state is defined, and the ground state of ^{204}Pb is defined as the state resulting when this ^{206}Pb creation operator acts twice successively on ^{208}Pb, the $(p_{1/2})^{-4}$ component vanishes because of the Pauli principle. This shell model results implies that the pairing-vibration model ignores a rather large effect. A simple calculation is suggested by this fact. Express $Z(^{206}\mathrm{Pb})$ in second-quantized notation, then define a four-hole state as $\psi(204) \equiv N Z(^{206}\mathrm{Pb}) \times Z(^{206}\mathrm{Pb}) | ^{208}\mathrm{Pb}\rangle$ where N is a normalizing constant; $\psi(204)$ is properly antisymmetrized. The overlap in this wave function with the shell model ground-state of ^{204}Pb has been computed, and that overlap is greater than 0.99. Thus, the shell model ^{204}Pb ground-state looks very much like the square of the ^{206}Pb ground-state even when the large Pauli effect is considered.

In conclusion, the present results indicate that both the shell model and pairing-vibration model describe features of the lead isotopes, and that there is an unusually large overlap (and agreement) in the predictions of these generally complimentary models.

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