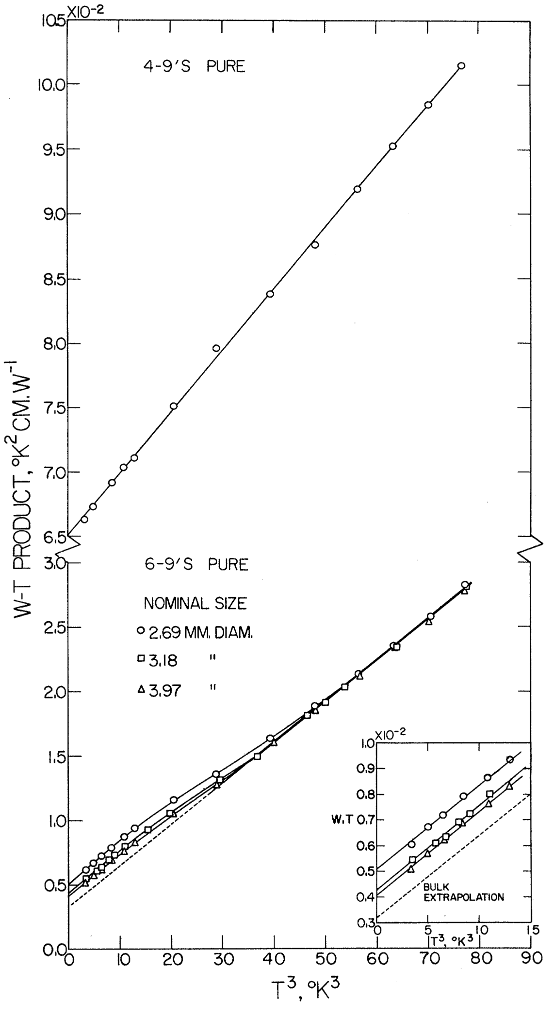

FIG. 1. Plot of WT against T^3 for A-axis crystals of different sizes. The top curve, which is for a less pure specimen, shows no boundary-scattering effects.

to a group of electrons from a limited portion of the Fermi surface, the range of temperatures for which l_{ep}/d varies from 1 to $\gg 1$ may be much smaller than that for the entire surface. The validity of Matthiessen's rule for these specimens provides another indication that the additional resistance due to boundary scattering is caused by a small fraction of the conduction electrons.

The assertion that the nonlinear part of the graph of WT versus T^3 is due to boundary scattering is further supported by the fact that an identical curve for an A-axis specimen of 99.99% gallium with $d = 3.175$ mm shows no deviation from a straight line (see top curve in Fig. 1). If we multiply the intercept obtained from the dotted line in Fig. 1 with the Lorentz number, we obtain a value of ρ which agrees reasonably well with the bulk residual resistivity value of Yaqub and Cochran.[5] This provides further evidence that the straight line for $T \geqslant T_1$ represents the bulk behavior.

The authors would like to acknowledge with thanks many helpful comments by Dr. Sung.

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*Research sponsored by the Air Force Office of Scientific Research, Office of Aerospace Research, U. S. Air Force, under Grant No. AF-AFOSR-1051-66.

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SPECTROSCOPY OF ODD-ODD NUCLEI WITH DIRECT (d, α) REACTIONS*

W. W. Daehnick and Y. S. Park
Nuclear Physics Laboratory, University of Pittsburgh, Pittsburgh, Pennsylvania
(Received 3 November 1967)

Until recently, two major obstacles impeded the successful investigation of heavier odd-odd nuclei by direct nuclear reactions: the need for very good experimental resolution, due to the high level densities of odd-odd nuclei, and the reduced usefulness of single-nucleon transfer reactions. The resolution necessary for medium-weight nuclei and the first 20 to 40 excited states is now easily obtained. The combination of tandem Van de Graaffs and modern magnetic spectrometers allows total resolving powers of 2000 and better[1,2] without the excessive loss in counting rate that used to restrict earlier high-resolution work. Generally, however, there remains a large ambiguity in the assignment of total angular momentum (J_f) for the final states if the target nucleus has nonzero J_i. Hence quantum numbers of odd-odd nuclei are most uniquely assigned in deuteron-transfer reactions on even-even targets, since $\vec{J}_{\text{final}}=\vec{j}_{\text{transfer}}=\vec{l}+\vec{1}$, provided that l or j transfers can be recognized experimentally. Previous studies[3-7] indicate that the dominant l value in a deuteron-transfer transition can possibly be identified from the angular distribution; and as long as at least one contributing l value is recognized, J_f for odd-odd residual nuclei is immediately restricted to no more than three values. The important possibility of obtaining detailed structure information for the nuclear wave function from two-nucleon transfers between states of known quantum numbers has been discussed in detail previously.[3,8]

This note focuses on the question of the extent to which direct deuteron-transfer reactions, in particular of the type (d, α) and (α, d), can uniquely determine J, π, and T of unknown levels in odd-odd nuclei. Since $T=0$ for deuterons and alpha particles, we expect $\Delta T=0$ for all one-step (d, α) reactions. Hence T_{final} is known immediately, provided the transitions in question are not too weak, have differential cross sections which resemble those of other direct deuteron transfers, and do not fluctuate with bombarding energy. These conditions eliminate most two-step and more complicated (d, α) transitions that can excite forbidden isospin (and parity) states. Two-step reactions cannot be ruled out if a given cross section is more than an order of magnitude lower than those of typical direct transitions.[9] For low energies and light elements, even strong (d, α) transitions may be nondirect and have important compound contributions.[3] Empirically, in (d, α) studies for elements lighter than Ca^{40}, alpha energies should be well above 20 MeV. For heavier targets the bombarding energy may be lowered safely. For instance, for $\text{Cu}^{63}(d, \alpha)\text{Ni}^{61}$ we find no significant fluctuations, even at back angles, for alpha energies from 16 to 20 MeV.[4]

The parity assignment $\pi_f=\pi_i(-1)^l$ follows from zero-range distorted-wave Born-approximation (DWBA) calculations; however, it is not necessarily correct for complex projectiles. As is shown for finite-range calculations,[10] it holds only if the transferred particles are in a relative s state with regard to the complex projectiles. The latter condition is well met for the deuteron transfer in one-step (d, α) and (p, He^3) reactions. This leads to a great simplification in the interpretation of (d, α) and (α, d) reactions on $J^\pi=0^+$ targets. Since $\vec{j}=\vec{l}+\vec{1}$, we have either $l=j$ or $l=j\pm 1$. Hence $(J_{\text{odd}})^-$ and $(J_{\text{even}})^+$ states can only be excited by pure-l deuteron transfers, and we expect regularly structured angular distributions that can be fitted by empirical curves or calculations for $l=j=J_f$. On the other hand, $(J_{\text{odd}})^+$ and $(J_{\text{even}})^-$ states in odd-odd nuclei may be excited by exactly two l contributions which generally differ in magnitude, according to

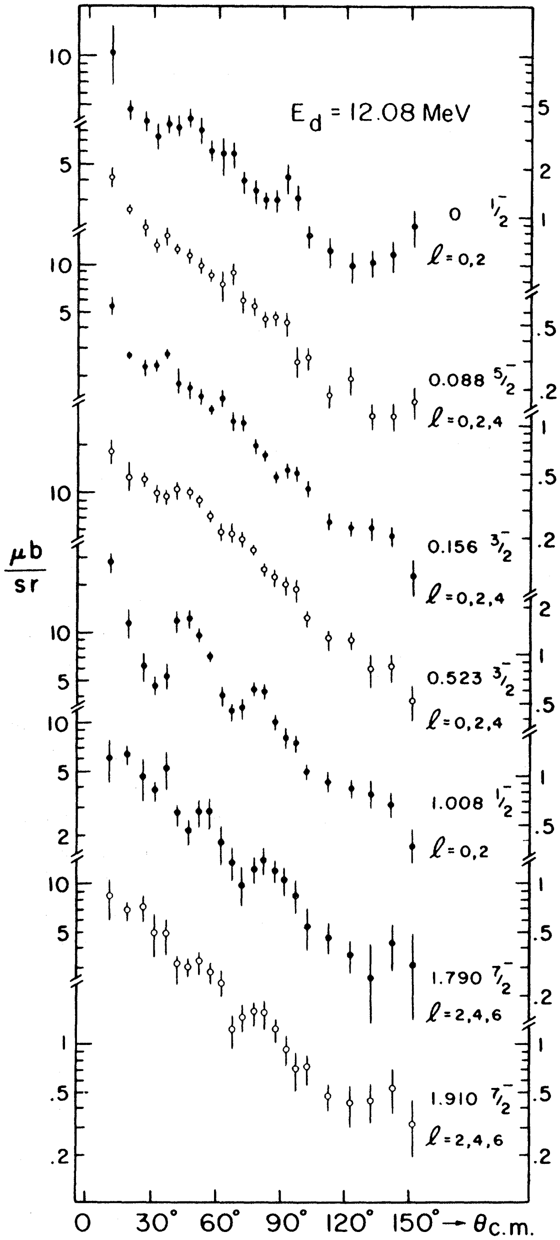

FIG. 1. Differential cross sections for $\text{Cu}^{65}(d, \alpha)\text{Ni}^{63}$ transitions to well-resolved final states. All random errors are included in the error bars. The absolute cross-section scale is accurate to about 20%.

the structure of the initial and final states. Hence the latter angular distributions will tend to be atypical and less structured. If both contributing l transfers can be identified or if one contribution in (d, α) reactions is $l=0$ (1^+ state), $(J^\pi)_f$ can be assigned with certainty. At present some ambiguity remains if for nuclear structure reasons only one of two allowed l values contributes noticeably. One might then be tempted to assign $J_f = j = l$, while possibly $j = l \pm 1$.

Experience to date with about forty $\mathrm{Zn}^{68}(d, \alpha)$ and $\mathrm{Zn}^{66}(d, \alpha)$ angular distributions[11] shows that pure l transfers result in characteristic angular distributions and that two l values contribute visibly in about half of all observed transitions. Hence the pure l transfers for the other half are strongly suggestive of $l=j$. This interpretation is supported by the angular distributions for $\mathrm{Cu}^{65}(d, \alpha)\mathrm{Ni}^{63}$ shown in Fig. 1. Since $(J^\pi)_i = \frac{3}{2}^-$ for Cu^{65}, two or more l contributions are allowed. Known values of J^π and the permitted l transfers are listed in Fig. 1. In the $\mathrm{Cu}^{65}(d, \alpha)\mathrm{Ni}^{63}$ transitions no pure l transfer is seen, although all final states are well resolved. (Total experimental resolution for the data reported in this Letter is 12 keV.) This should be compared with angular distributions for the transitions to well-resolved low-lying states in the odd-odd isotope Cu^{66} shown in Fig. 2. Three different and distinctly structured types of angular distributions are immediately apparent.

Except for the 1^+ ground state, no confirmed J^π assignments for Cu^{66} were available. A high-resolution $\mathrm{Cu}^{65}(d, p)\mathrm{Cu}^{66}$ experiment was performed[11] in order to check and supplement J^π limits (listed in Fig. 2) of earlier experiments of marginal resolution.[12] The use of a (d, p) sum rule[13] for $f_{5/2}$ spectroscopic factors allowed fairly unambiguous (d, p) spin assignments of 2^+, 4^+, and 3^+ for the states at 0.183, 0.272, and 0.589 MeV, respectively. Thus, four "known" J^π assignments could be used to identify $l=0$, $l=2$, and $l=4$ angular distributions empirically. Zero-range DWBA calculations based on a deuteron transfer model were made with the Oak Ridge code JULIE,

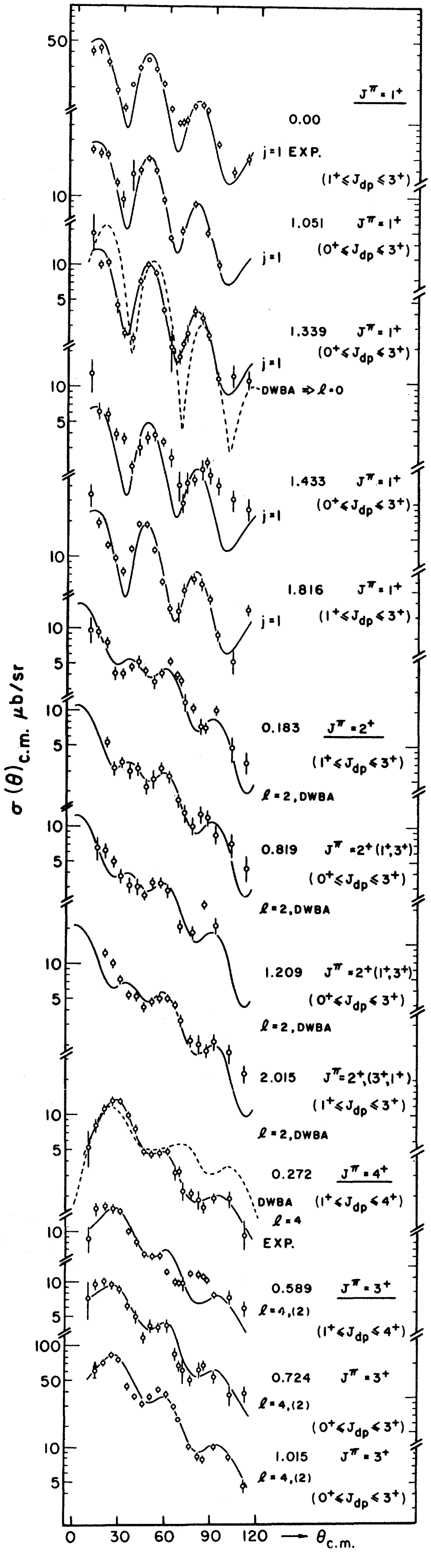

FIG. 2. Differential cross sections and new J^π assignments for $\mathrm{Zu}^{68}(d, \alpha)\mathrm{Cu}^{66}$ transitions. Note that in contrast to Fig. 1 all angular distributions show a pronounced structure. The dotted curves and the curves for $l=2$ are DWBA predictions. The solid curves are explained in the text.

and are shown in Fig. 2. The calculations gave good qualitative agreement with experiment for $l=0$ and $l=4$ (dotted curves) and very good agreement for $l=2$, without the use of cutoffs or finite-range corrections. This agreement is taken as an affirmation of the empirical choice of three typical curves ($l=0$, 2, and 4), which are then used unchanged (solid lines) to identify the dominant l value and a possible l admixture for the transitions shown. Transitions with $l=0$ contributions can only go to $J^\pi=1^+$ states, and the corresponding assignments are considered very reliable. The pure $l=2$ transitions are tentatively assigned as leading to 2^+ states, but $(1^+, 3^+)$ are not firmly excluded. The one 4^+ assignment seems well justified, and the 3^+ assignments are considered reliable on the basis of significant $l=2, 4$ mixing, and the good agreement with $J_{d,p}$ limits.

One of us (W.W.D.) wishes to acknowledge informative conversations with Dr. Austern and Dr. Drisko, and the hospitality of the Aspen Institute for Humanistic Studies, where part of this study was performed.

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*Work supported by the National Science Foundation.

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PARTICLE-CORE COUPLING IN THE LEAD NUCLEI*

Nelson Stein, C. A. Whitten, Jr., and D. A. Bromley
Wright Nuclear Structure Laboratory, Yale University, New Haven, Connecticut

(Received 20 November 1967)

The particle-core weak-coupling model has been used to describe certain states of odd-mass nuclei by relating them to excited states of adjacent even-even nuclei.[1] According to this model, the extra particle or hole in an odd-mass nucleus may couple to excitations of the even core to form multiplets at about the same energy as the excitation in the even nucleus, and with very similar properties. This description is expected to be valid provided that the coupling does not alter significantly the nature of the core state. A good example of such a state is the collective electric octupole excitation in the lead region, occurring as single states in Pb^{206} and Pb^{208}, a doublet in Pb^{207}, and a complex multiplet in Bi^{209}, all in the vicinity of 2.6 MeV.[2] Among the interesting questions relevant to this model are (1) the extent to which it is valid as the excitation energies of both the particle and core increase, (2) the nature of the core states to which it may be applied, and (3) the nature of the particle-core interaction. In addition, information pertaining to these questions is also important for the "doorway theory" of nuclear reactions because particle-plus-core excitations may occupy the crucial position of doorway states, and hence constitute the first step toward bridging the gap between broad single-particle excitations and narrow states in the compound nucleus.[3] The purpose of this Letter is to present experimental results which indicate the existence, at intermediate energies in the lead nuclei, of particles in excited states coupled to various excitations of the core, and to show how the isobaric analogs of these states are selectively excited by proton scattering. The experiments are part of a study of isobaric analog resonances currently in progress at this laboratory using the Em-