proceed through (a) compound nucleus formation, (b) spin-orbit interaction, (c) nonsimultaneous, multiple-phonon excitation, and (d) a direct exchange process. Other mechanisms could contribute which have not been considered here.

On the basis of existing evidence concerning shapes of angular distributions and energy dependence of cross sections, processes (a) and (b) do not seem to contribute significantly. Indication of interference in the angular distributions suggests contributions from both (c) and (d). Clearly, to make a more quantitative analysis of these possible reaction mechanisms, more experimental information is needed. On the basis of existing data, however, production of unnatural-parity states in (α, α') scattering is surprisingly intense, since their production by most "first-order" processes is forbidden is forbidden by parity conservation. Thus the study of these levels in even-even nuclei is a potentially powerful tool for investigation of "second-order" reaction processes.

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EFFECT OF EXCHANGE ON L TO K CAPTURE RATIOS*

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Two years ago, Robinson and Fink[1] called attention to a systematic discrepancy between observed and predicted L to K electron capture ratios. Many experiments have since been performed to investigate this discrepancy. The observed L to K ratio has been found[2-5] to exceed by 5 to 25 percent the predicted L to K ratio for all nine of the precisely measured allowed electron captures with Z between 18 and 36. The calculations reported in this note remove the systematic disagreement between theory and experiment by including atomic states in the description of the radioactive system.

Following the suggestions of Benoist-Gueutal[6] and Odiot and Daudel,[7] we have generalized the usual allowed theory of electron capture to include atomic variables in the initial and final states. Using closure to sum over all possible final states of the outer electrons, we find[8-10]

$$\frac{\lambda_{L_I}}{\lambda_K} \cong \left(\frac{\lambda_{L_I}}{\lambda_K}\right)^0 \left\{\frac{1-[2R_{1s}(0)/R_{2s}(0)]\langle 1s'|2s\rangle}{1-[2R_{2s}(0)/R_{1s}(0)]\langle 2s'|1s\rangle}\right\}, \quad (1a)$$

where

$$(\lambda_{L_I}/\lambda_K)^0 = [q(2s')R_{2s}(0)/q(1s')R_{1s}(0)]^2 \quad (1b)$$

is the usual[11] L_I to K capture ratio, $\langle 1s'|2s\rangle$ is the overlap of the final $1s'$ electron state with the initial $2s$ electron state, and $R_{1s}(0)/R_{2s}(0)$ is the ratio of the electron radial wave functions evaluated at the nuclear surface.

An L_I capture can occur in two important ways: (a) direct annihilation of a $2s$ electron and (b) annihilation of a $1s$ electron with the initially present $2s$ electron jumping into the final $1s'$ shell. The probability of the direct process, (a), is proportional to $R_{2s}^2(0)$; the probability of the exchange process, (b), is proportional to $R_{1s}^2(0)\langle 1s'|2s\rangle^2$. The interference between amplitudes for direct and exchange decay is proportional to $-2R_{1s}(0) \times R_{2s}(0)\langle 1s'|2s\rangle$, the minus sign arising from the exclusion principle. The interference between direct and exchange amplitudes for K capture produces a term proportional to $-2R_{1s}(0)R_{2s}(0) \times \langle 2s'|1s\rangle$. Hence, the bracketed expression in

Table I. Electron overlap integrals.

Z	Elements	$-\langle 1s'\|2s\rangle$	$+\langle 2s'\|1s\rangle$
16	S-P	0.034	0.028
17	Cl-S	0.032	0.024
18	Ar-Cl	0.030	0.025
19	K-Ar	0.029	0.025
20	Ca-K	0.027	0.024

Eq. (1a), which we denote by X_{th}, represents an interference between direct and exchange modes of decay.

In Table I, we list values of $\langle 1s'|2s\rangle$ and $\langle 2s'|1s\rangle$ that were calculated with self-consistent-field wave functions.[12] Accurate self-consistent wave functions are unfortunately not available for many cases of experimental interest. However, the five cases listed in Table I yield values of X_{th} satisfying

$$X_{th} \cong 1 + (4 \pm 0.4)Z^{-1}, \qquad 16 \leq Z \leq 20. \tag{2}$$

We have used Eq. (2) to estimate the exchange correction in cases for which self-consistent wave functions were not available.

The measured values of X are listed in Table II; they were obtained by dividing the observed[2-5] L_I to K ratios by the values expected on the basis of the usual theory.[11] The exchange corrections, X_{th}, which are also listed in Table II, are in good agreement with the measured values, except for Zn^{65}.[13] The L to K capture ratio of V^{49}, which has not yet been measured,[14] is predicted to differ from the usual theoretical value by about 17 percent.

Table II. X_{exp} = (observed L/K capture ratio)/(usual theoretical L/K capture ratio). The uncertainty in X_{th} is about $\pm 0.4Z^{-1}$.

Decay	X_{exp}	X_{th}
$Ar^{37} \rightarrow Cl^{37}$	1.22 ± 0.04	1.22
$V^{49} \rightarrow Ti^{49}$		1.17
$Cr^{51} \rightarrow V^{51}$	1.18 ± 0.05	1.17
$Mn^{54} \rightarrow Cr^{54}$	1.19 ± 0.07	1.16
$Fe^{55} \rightarrow Mn^{55}$	1.13 ± 0.05	1.15
$Co^{57} \rightarrow Fe^{57}$	1.14 ± 0.2	1.15
$Co^{58} \rightarrow Fe^{58}$	1.18 ± 0.04	1.15
$Zn^{65} \rightarrow Cu^{65}$	1.23 ± 0.07	1.13
$Ge^{71} \rightarrow Ga^{71}$	1.08 ± 0.05	1.13
$Kr^{79} \rightarrow Br^{79}$	1.08 ± 0.05	1.11

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[8]A detailed account of this work is being prepared for publication elsewhere. It will include a discussion of the effect of exchange in electron emission as well as an evaluation of the effect of imperfect atomic overlap on allowed electron and positron emission probabilities and on total electron capture rates. The effect of imperfect atomic overlap largely cancels out of the electron capture ratio.

[9]Odiot and Daudel[8] used an 18-electron wave function for the initial atom and a 17-electron wave function for the daughter atom to evaluate the Ar^{37} L to K ratio. They predicted a ratio of 0.10, in good agreement with recent experiments. However, Odiot and Daudel assumed that only one final atomic state contributed significantly to the L_I-capture probability and only one (but different) final atomic state contributed significantly to the K-capture probability. This assumption is probably not correct, but a closure argument can be

used to justify their procedure for calculating capture ratios.

[10]In writing Eq. (1a), we have made use of the usual convention that all $R_{nS}(0)$ and $R_{nS'}(0)$ are real. The exact expression (reference 9) is, of course, independent of all phase conventions.

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[13]All quantities that appear in Eq. (1a), except $\langle 1s'|2s\rangle$ and $\langle 2s'|1s\rangle$, are known to an accuracy of the order of one percent. Since the L_I to K ratio depends only slightly (~1 percent) on $\langle 2s'|1s\rangle$ one can use precision measurements of L to K ratios to determine experimentally the electron overlap integral $\langle 1s'|2s\rangle$. It will be interesting to see if the method of self-consistent fields can predict these integrals accurately.

[14]I am grateful to Professor R. W. Fink for bringing this interesting example to my attention.

DEMONSTRATION OF A POLARIZED He^3 TARGET FOR NUCLEAR REACTIONS*

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This Letter reports the results of nuclear scattering from a polarized target of He^3 gas. The results to be described show that it is possible to prepare a polarized He^3 target, which is suitable for use in nuclear experiments with beams of fast charged particles, by using the optical pumping techniques of Walters, Colegrove, and Schearer.[1]

It is known that strong nuclear spin-orbit forces act when He^4 is scattered by He^3 near to the $\frac{7}{2}^-$ resonant state, at 4.53-MeV excitation, in Be^7. The scattering has been observed and the data have been phase-shift analyzed[2]; the polarization of the He^3 particles, after scattering, has been deduced from the scattering phase shifts.[3] The calculated polarization was found to be quite large at certain scattering angles and bombarding energies so that large azimuthal scattering asymmetries are to be expected for a polarized He^3 target. These facts provide a natural means for testing the He^3 gas target for polarization.

Figure 1 shows a schematic diagram of the apparatus. The basic principles of the production of He^3 polarization have been given in reference 1. Briefly, the method is as follows: Metastable $2\,^3S_1$ He^3 atoms are formed in the He^3 cell by a weak electric discharge. When circularly polarized $2\,^3S_1$-$2\,^3P_0$ resonance radiation, directed along a small applied magnetic field, is absorbed by the metastable $2\,^3S_1$ atoms, they become polarized. This polarization is transferred, by collisions involving exchange of metastability, to the more numerous ground-state atoms. In equilibrium the ground-state atoms attain the same polarization as the met-

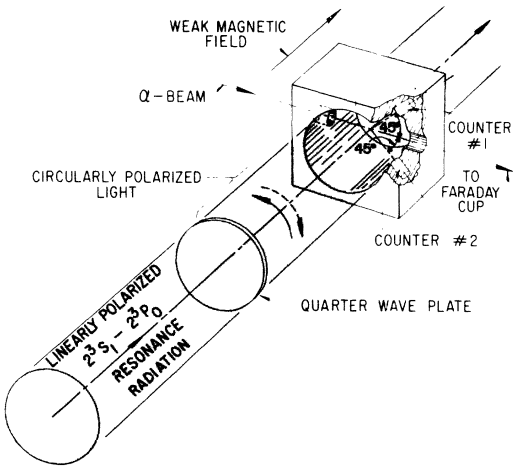

FIG. 1. Schematic diagram of the He^3 target. The alpha beam enters and leaves through thin metal foils. The particle counters are mounted inside the scattering chamber, which is constructed of brass with Pyrex light windows.