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$Ni^{62,64}(He^3,d)Cu^{63,65}$ Reaction*

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A 22-MeV He^3-ion beam was used to excite states in Cu^{63} and Cu^{65} by means of the (He^3,*d*) reaction on Ni^{62} and Ni^{64}. Levels were analyzed up to approximately 4 MeV of excitation. The angular distributions obtained in the forward-angle region were compared to predictions from a distorted-wave stripping calculation, and orbital angular-momentum transfers and spectroscopic factors were obtained. On the basis of this analysis, large fractions of the $2p_{1/2}$ and $1f_{5/2}$ proton single-particle strengths appear in the first few excited states of Cu^{63} and Cu^{65}. This result is in marked disagreement with the predictions of the simple excited-core model, but in fair to good agreement with more extended model calculations. The sums of the spectroscopic factors for each single-particle state are compared with predicted values. Angular distributions were also obtained in the backward-angle region, and provide strong evidence for a *j*-dependent effect for $l=1$ transitions. The possible importance of certain secondary-reaction mechanisms is examined briefly.

I. INTRODUCTION

The (*d,p*) stripping reaction has been the subject of numerous studies during the past decade or so. From these studies, a large body of information on neutron states has been obtained. While, in principle, analogous information on proton states can be obtained by observing the (*d,n*) reaction, technical difficulties associated with the detection of uncharged particles limit the usefulness of this reaction. It should be possible, however, to obtain this information by means of the (He^3,*d*) reaction, which is not subject to such a restriction. Several recent experimental studies[1–4] of the (He^3,*d*) reaction on medium-weight nuclei have demonstrated its usefulness for these purposes. The present paper reports the results of such a study on the Ni^{62} and Ni^{64} isotopes, leading to states in Cu^{63} and Cu^{65}. A brief description of the results from the $Ni^{62}(He^3,d)Cu^{63}$ reaction has appeared earlier[2]; a full report of a similar study[3] of the states of Cu^{59} and Cu^{61} is in preparation.

Considerable attention has been paid to the Cu^{63} and Cu^{65} nuclei in recent years. The first few states of these nuclei have usually been described in terms of models based upon the concept of core excitation,[5–7] in which a proton in one or more orbitals is coupled to the ground state or to one or more excited states of the Ni core.[8–13] Previous experiments[14–19] have emphasized the collective aspects of the excited states of the Cu nuclei. These experiments, while confirming many of the predictions of the model calculations, also yielded certain disagreements, particularly with the earlier models. The present experiment, in which the states of the Cu nuclei are examined by means of a reaction believed to emphasize primarily their single-particle aspects, was designed as a further test of the models. In its simplest form, the excited-core model predicts that for the (He^3,*d*) stripping reaction the cross sections of the core-excited states in the Cu nuclei will be negligible.

The data of the present experiment were interpreted by comparing the angular distributions to the predictions of a distorted-wave stripping calculation.[20] From this comparison the angular-momentum transfers and spectroscopic factors were obtained. With the aid of sum rules developed by French and Macfarlane,[21,22] these results were, in turn, compared with predictions for the total strength of each single-particle transition.

It has been shown recently[23] that in some cases the shapes of angular distributions from stripping and pickup reactions depend not only upon the orbital angular-momentum transfer *l*, but upon the total

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angular-momentum transfer j. The distinction between $p_{3/2}$ and $p_{1/2}$ angular distributions is probably the most readily apparent, but there are observed differences between the $l+\frac{1}{2}$ and $l-\frac{1}{2}$ components of other transitions as well. Similar j-dependent effects were observed in the present study.

II. EXPERIMENTAL PROCEDURE

He^3 particles, accelerated to 22 MeV in the Los Alamos variable-energy cyclotron, were passed through a 90° momentum-analyzing magnet and focused as a $\frac{1}{16}\times\frac{5}{32}$-in. vertical beam spot on a target at the center of a 20-in.-diameter scattering chamber. A gold-surface-barrier semiconductor system consisting of a thin ΔE transmission detector and a thick E detector, each obtained commercially, was mounted internally on an arm attached to an azimuth positioner. The angle between the detector system and the beam direction could be set and read remotely. A thermoelectric junction was used to cool the detectors, reducing their noise contribution and decreasing the rise time of their pulses. For the detection of deuterons from the (He^3,d) reaction, the ΔE detector was a totally depleted unit of 500-μ thickness, while the E detector was a lithium-drifted unit of 3-mm depth. Data from the elastic scattering of He^3 particles were also obtained; for the detection of these particles the ΔE and E detectors were of 100-μ and 500-μ thickness, respectively. The preamplified pulses from the detectors were fed into a mass-identification system.[24] Parallel circuitry provided amplification and coherent addition of the ΔE and E pulses; the summed pulses were then fed into a 400-channel pulse-height analyzer gated by the output of the mass-identification system.

The resulting spectra were read out as information on punched paper tape, printed paper tape, and plots. The punched paper tape was converted to punched IBM cards which were then used in a least-squares computer program[25] which fits a skewed Gaussian distribution plus an exponential tail to each peak in a pulse-height spectrum, and computes the area of each peak.

The self-supporting targets were produced by vacuum evaporation,[26] and had areal densities ranging between 150 and 600 $\mu g/cm^2$. The isotopic purity of the target material[27] was 98.7% in the case of Ni^{62}, and 98.6% in the case of Ni^{64}. Where contaminations from the smaller amounts of other Ni isotopes present in a target were important, their contributions were subtracted from the data.

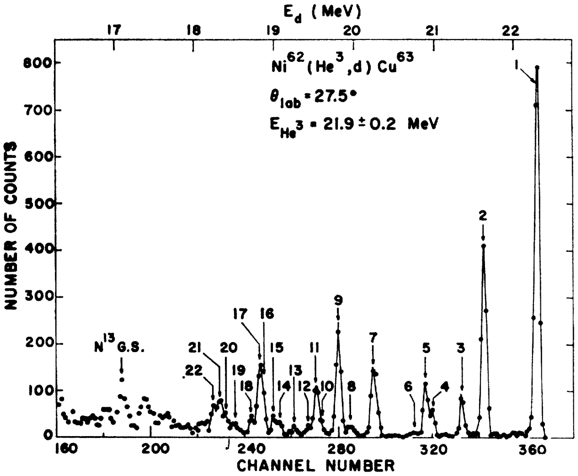

FIG. 1. Pulse-height spectrum of deuterons from the $Ni^{62}(He^3,d)Cu^{63}$ reaction. The curves through the datum points represent the results of a least-squares computer program which fits each peak with a skewed Gaussian distribution plus an exponential tail. The excitation energies corresponding to the numbered deuteron groups are given in Table I.

Absolute cross sections were determined within ±10% by observing the (He^3,d) reaction on a natural Ni target of known thickness, and also by measuring He^3 particles elastically scattered from the individual targets at small scattering angles, where the scattering cross section is nearly Coulomb.

The over-all energy resolution of the deuteron spectra varied between 70 and 90 keV, depending on target thickness and detector geometry. At forward angles, the geometry was set up to yield an angular resolution of 0.5° while at scattering angles greater than approximately 45° in the case of deuterons, and 70° in the case of elastically scattered He^3 particles, the angular resolution was approximately 1°. Zero scattering angle was determined to ±0.2°, while relative scattering angles were set to an accuracy of ±0.1°.

The He^3 beam passing through the target was collected in a Faraday cup, and the total charge for each experimental run was measured by means of a vibrating-reed electrometer current integrator.[28] The beam energy was determined by means of a slowing-down technique similar to that described by Northrop and Stokes.[29] In the present experiment, the error limit in the determination of the mean energy is estimated to be ±200 keV. The variation of the beam energy at the center of a target was less than ±50 keV over an entire angular distribution.

The energy scale of the deuteron spectra was obtained by reference to the positions of the first few states of the Cu nuclei, whose energies are well known,[30] and to the

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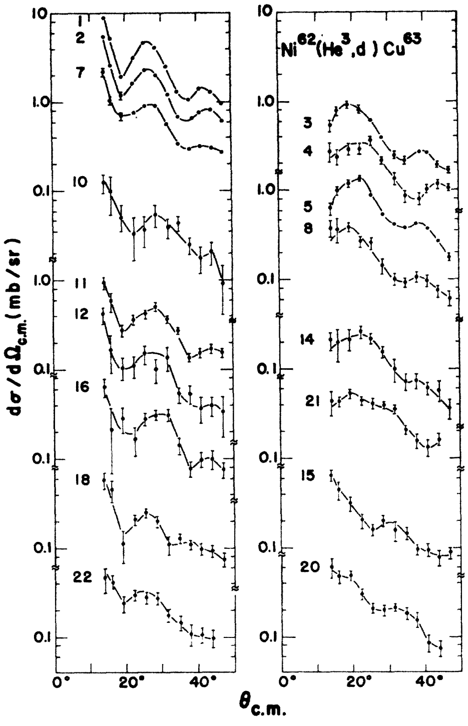

FIG. 2. Angular distributions of all but the weakest deuteron groups and groups 9 and 17 from the $Ni^{62}(He^3,d)Cu^{63}$ reaction, up to 4.1 MeV of excitation energy. The curves drawn through the experimental points are intended only as visual guides.

positions of the lower states in Al^{26} and Al^{27},[30] excited by means of the (He^3,d) reaction on Mg^{25} and Mg^{26}. In this manner, excitation energies were determined to within ±50 keV.

III. RESULTS

A. $Ni^{62}(He^3,d)Cu^{63}$ Reaction

The ground-state Q for the $Ni^{62}(He^3,d)Cu^{63}$ reaction is 0.633 MeV.[31] A typical energy spectrum for this reaction is shown in Fig. 1. States up to approximately 4 MeV of excitation were analyzed. Above this excitation energy the deuteron groups were too weak to be meaningfully analyzed. Figure 2 shows angular distributions of deuterons from all but the most weakly excited states and states 9 and 17.

In Fig. 3 are shown examples of $l=1$, 2, 3, and 4 transitions, together with results from the distorted-wave (DW) calculation. The present DW calculation employs the zero-range approximation, and does not include spin-orbit interactions in the incoming He^3 or outgoing deuteron channels. Optical-model parameters for the deuteron channels were obtained from set B of the analysis results of Perey and Perey.[32] The He^3 optical-model parameters were obtained from optical-model fits to angular distributions from the elastic scattering of He^3 particles from Ni^{62};[33] the set chosen for the present calculation used Saxon wells with the following parameter values: $V=140$ MeV, $r_{0R}=r_{\text{Coul}}=1.080$ F, $a_R=0.800$ F, $W=24.4$ MeV, $r_{0I}=1.542$ F, and $a_I=0.788$ F. The binding energy of the proton was set equal to its separation energy.[34] An integration cutoff radius of 4.7 F was used in the calculation, and the DW predictions were normalized to the experimental angular distributions at their peaks in the 20°–30° region. Allowing the integration to proceed to the origin yielded angular distributions whose shapes were very similar to those obtained from the 4.7-F cutoff calculation, and whose magnitudes in the region of interest differed by no more than 5%. A different set of He^3 optical-model parameters,[33] in which the real Saxon well had a depth of approximately 95 MeV, was also tried; when the 4.7-F cutoff radius was used the calculation predicted angular distributions very similar to those obtained with the deeper well, and magnitudes which differed by no more than a few percent. Integrating to the origin, however, yielded magnitudes which differed by up to 20%.

In order to determine the response of the DW calculation to small changes in the optical well parameters, the real and the imaginary well depths of the incident

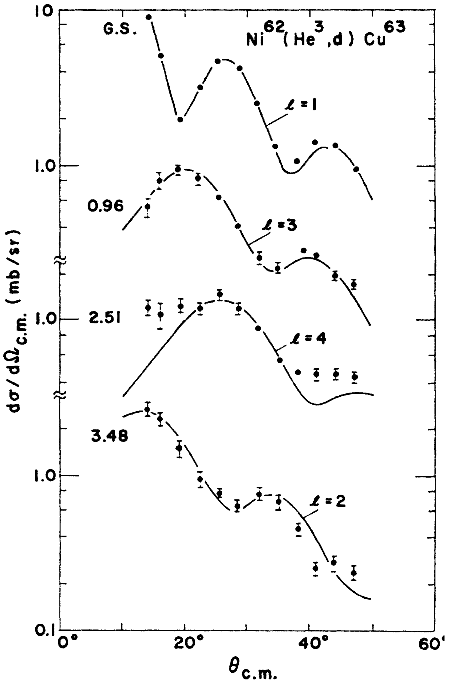

FIG. 3. Comparison of the predictions of the DW calculation with the angular distributions for group 1 (G.S.), group 3 (0.96 MeV), group 9 (2.51 MeV), and group 17 (3.48 MeV) from the $Ni^{62}(He^3,d)Cu^{63}$ reaction.

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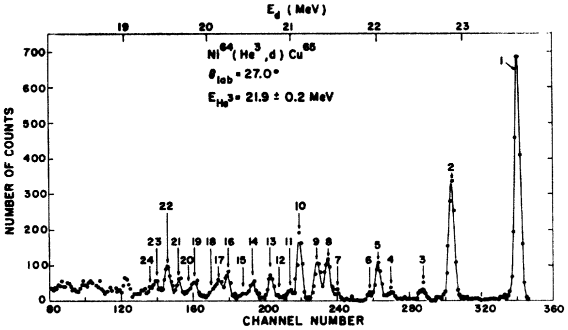

FIG. 4. Pulse-height spectrum of deuterons from the $Ni^{64}(He^3,d)Cu^{65}$ reaction. The excitation energies corresponding to the numbered deuteron groups are given in Table II.

and the outgoing particles were increased by 10% from their normal values. The increase in real well depth, whether for He^3 particles or for deuterons, had a negligible effect on the shapes and magnitudes of the predicted $l=1$ and $l=3$ angular distributions. The increase in the imaginary well depth, whether for He^3 particles or for deuterons, also affected the shapes of the $l=1$ and $l=3$ distributions negligibly, but decreased their magnitudes by approximately 5%. The lack of sensitivity to these changes in the real well depths should probably be considered as welcome. The dependence upon the imaginary well depths could have an effect on the spectroscopic factors for Cu^{65} relative to those for Cu^{63}, since the same optical well parameters were used for the $Ni^{64}(He^3,d)Cu^{65}$ reaction as for the $Ni^{62}(He^3,d)Cu^{63}$ reaction.

The DW calculation for $l=1$ and $l=3$ transitions is seen to predict very well the behavior of the respective angular distributions in Fig. 3. The angular distributions for group 9, at 2.51 MeV, and group 17, at 3.48 MeV, are not quite so well predicted; part of the reason for this is probably that there are transitions of other l values to nearby states which are unresolved from the principal states.

Transitions interpreted as $l=1$ are shown on the left-hand side of Fig. 2. The right-hand side of the figure includes the observed $l=3$ distributions and distributions 15 and 20, which have been interpreted as predominantly $l=2$ transitions. These latter two distributions apparently include small amounts of other l values as well. It also appears that distribution 21 is not a pure $l=4$ transition.

The relation between the cross section σ predicted by the DW calculation and the experimental cross section $d\sigma/d\Omega$ is given by

$$\frac{d\sigma}{d\Omega}=N\frac{2J_f+1}{2J_0+1}C^2S\sigma, \tag{1}$$

where N is a normalization factor that includes the overlap for the dissociation of the He^3 particle into a deuteron and a proton, J_0 and J_f are the spins of the initial and the final states, respectively, C is the isobaric-spin Clebsch-Gordan coupling coefficient, and S is the spectroscopic factor. From the study of the (He^3,d) reaction on nuclei with 28 neutrons,[4] we have obtained an average normalization factor of 3.8 for spinless-proton capture. This value is in good agreement with the value obtained by Bassel[35] from an analysis of the overlap of the internal wave function of the deuteron and the wave function of the proton in the He^3 nucleus. The effect of an $\mathbf{l}\cdot\mathbf{s}$ potential for the captured proton has been simulated by assuming a j dependence for N.[36] In the absence of specific calculations for the present cases, we have assumed a spin-orbit dependence represented by a 10% increase (decrease) in N for a $p_{3/2}$ ($p_{1/2}$) transition, and proportional to $(2l+1)$.[37]

Table I shows the values of C^2S obtained for the $Ni^{62}(He^3,d)Cu^{63}$ reaction. Previous experiments have determined the spins and parities of the ground state and the first three excited states.[14,30] All $l=3$ transitions to higher states were assumed to be $1f_{5/2}$ transitions. Similarly, all $l=1$ transitions to higher states were assumed to be $2p_{1/2}$ transitions, unless there was evidence from the back-angle data, to be discussed later, that a transition was $p_{3/2}$. Finally, $l=2$ and $l=4$ transitions were assumed to be $2d_{5/2}$ and $1g_{9/2}$ transitions, respectively.

B. $Ni^{64}(He^3,d)Cu^{65}$ Reaction

The ground-state Q for the $Ni^{64}(He^3,d)Cu^{65}$ reaction is 1.957 MeV.[31] A typical energy spectrum for this reaction is shown in Fig. 4. As in the case for Cu^{63}, states up to approximately 4 MeV in Cu^{65} were analyzed.

TABLE I. Results from the $Ni^{62}(He^3,d)Cu^{63}$ reaction.

Group	Excitation energy (MeV)	Assumed J^π	C^2S
1	0	$\frac{3}{2}-$	0.66
2	0.67	$\frac{1}{2}-$	0.70
3	0.96	$\frac{5}{2}-$	0.33
4	1.33	$\frac{7}{2}-$	0.057
5	1.41	$\frac{5}{2}-$	0.45
7[a]	2.06	$\frac{1}{2}-$	0.23
8	2.35	$\frac{5}{2}-$	0.10
9	2.51	$\frac{9}{2}+$	0.31
10	2.69	$\frac{1}{2}-$	0.013
11	2.78	$\frac{3}{2}-$	0.044
12	2.88	$\frac{1}{2}-$	0.031
14	3.23	$\frac{5}{2}-$	0.060
15	3.31	$\frac{5}{2}+$	0.015
16	3.43	$\frac{1}{2}-$	0.065
17	3.48	$\frac{5}{2}+$	0.070
18	3.58	$\frac{1}{2}-$	0.045
20	3.89	$\frac{5}{2}+$	0.019
21	3.98	$\frac{9}{2}+$	0.051
22	4.06	$\frac{1}{2}-$	0.059

[a] The present experiment provides evidence that this is a doublet, with an energy separation between the members of approximately 60 keV.

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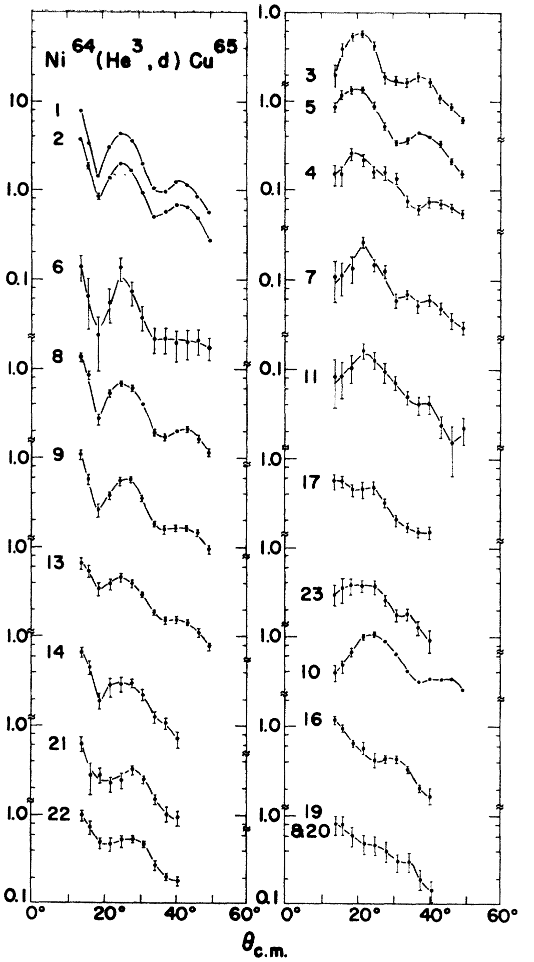

FIG. 5. Angular distributions of all but the weakest deuteron groups from the $Ni^{64}(He^3,d)Cu^{65}$ reaction, up to 4.2 MeV of excitation energy.

Angular distributions of all but the most weakly excited states are shown in Fig. 5. Distributions corresponding to $l=1$ transitions appear on the left-hand side of the figure, while $l=3$, 4, and 2 distributions are shown on the right-hand side. Again, as a consequence of inadequate energy resolution, some of the groups at higher excitation energies show impure distributions.

Table II shows the values of C^2S obtained for this reaction. The spins and parities of the first four states of Cu^{65} have been determined from previous experiments[14,30]; assignments to the other states have been made on the basis discussed for the $Ni^{62}(He^3,d)Cu^{63}$ reaction.

C. *j* Dependence of Angular Distributions

As mentioned in Sec. I, it has been shown recently in several direct reactions that angular distributions may depend not only upon the transferred orbital angular momentum l, but also upon the total transferred angular momentum j.[23] In particular, experimental differences in $p_{1/2}$ and $p_{3/2}$ distributions usually appear toward backward angles. Figure 6 shows the results from the present experiment for the ground state and first excited state of Cu^{63} and of Cu^{65}. Although the distributions closely resemble each other at forward angles (see Figs. 2 and 5) they begin to differ at approximately 50°, and by 90° the $p_{1/2}$ first-excited-state distribution is substantially out of phase with the $p_{3/2}$ ground-state

TABLE II. Results from the $Ni^{64}(He^3,d)Cu^{65}$ reaction.

Group	Excitation energy (MeV)	Assumed J^π	C^2S
1	0	$\frac{3}{2}-$	0.79
2	0.77	$\frac{1}{2}-$	0.75
3	1.11	$\frac{5}{2}-$	0.26
4	1.48	$\frac{7}{2}-$	0.054
5	1.62	$\frac{5}{2}-$	0.57
6	1.73	$\frac{1}{2}-$	0.032
7	2.10	$\frac{5}{2}-$	0.073
8	2.21	$\frac{1}{2}-$	0.21
9	2.33	$\frac{3}{2}-$	0.070
10	2.54	$\frac{9}{2}+$	0.29
11	2.65	$\frac{5}{2}-$	0.051
13	2.88	$\frac{3}{2}-$	0.051
14	3.08	$\frac{1}{2}-$	0.080
16	3.37	$\frac{5}{2}+$	0.038
17	3.48	$\frac{1}{2}-$ $\frac{5}{2}-$	0.07 0.08
19 20	3.8	$\frac{5}{2}+$ $\frac{9}{2}+$	0.02 0.04
21	3.95	$\frac{1}{2}-$	0.07
22	4.08	$\frac{1}{2}-$	0.13
23	4.19	$\frac{9}{2}+$	0.07

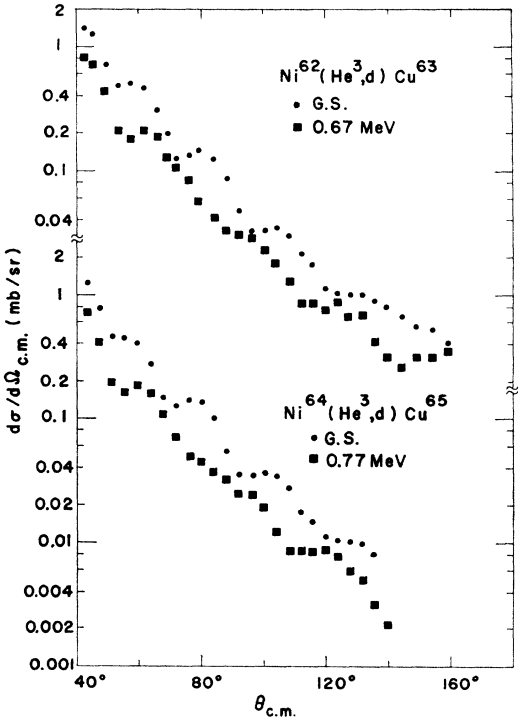

FIG. 6. Backward-angle distributions of deuterons from the ground state and the first excited state of Cu^{63} (top) and Cu^{65} (bottom).

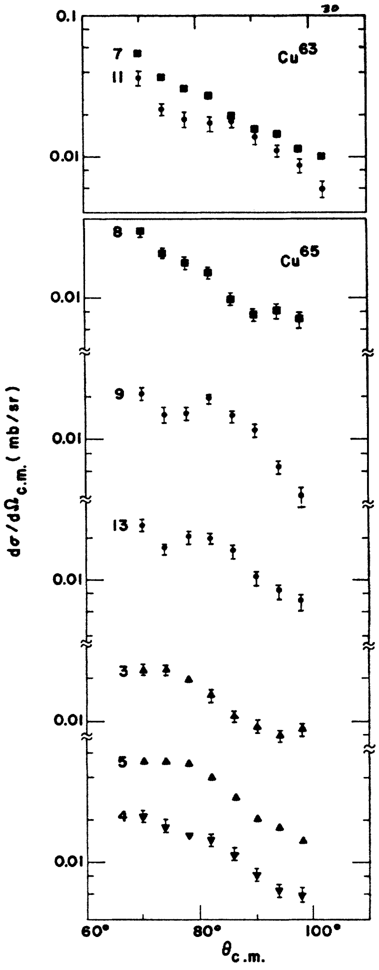

FIG. 7. Backward-angle distributions of deuterons from several states in Cu^{63} (top) and Cu^{65} (bottom).

distribution. A similar situation exists for the ground-state and first-excited-state transitions in the $Ni^{58}(He^3,d)Cu^{59}$ and $Ni^{60}(He^3,d)Cu^{61}$ reactions, as observed in this laboratory.

Figure 7 shows the results of the present experiment for those $l=1$ transitions which were sufficiently intense and adequately resolved to be studied in the angular region from approximately 70° to 110°. It seems reasonable to attribute the differences between distributions 7 and 11 for Cu^{63}, and between distribution 8 and distributions 9 and 13 for Cu^{65}, to the same mechanism that distinguishes the $p_{3/2}$ ground-state distribution from the $p_{1/2}$ first-excited-state distribution in these same nuclei. There is an apparent Q dependence which tends to push the maxima and minima of the distributions out to larger angles as Q decreases; this effect is also observed in Cu^{59} and Cu^{61}. A similar difference in the back-angle distributions of $l=1$ transitions has been observed in the (He^3,d) reaction on several other nuclei in this mass region.[4]

On the basis of these results, group 7 in Cu^{63} and group 8 in Cu^{65} are tentatively assigned to $p_{1/2}$ transitions, while group 11 in Cu^{63} and groups 9 and 13 in Cu^{65} are assigned to $p_{3/2}$ transitions. These assignments appear in Tables I and II. Except for the first two states, there is no additional information concerning the other $l=1$ transitions observed in the present study, and they are assigned to $p_{1/2}$ transitions. It is probable, however, as is discussed in the next section, that some are actually $p_{3/2}$ transitions.

There is also a difference between the angular distributions leading to the $\frac{5}{2}^-$ second excited state (distribution 3) and the $\frac{7}{2}^-$ third excited state (distribution 4) in both Cu^{63} and Cu^{65}, as can be seen most clearly in the 35° to 45° region of these distributions (Figs. 2 and 5). Toward backward angles, as shown for Cu^{65} in Fig. 7, the differences are not so apparent. (For completeness, distribution 5 is also shown in Fig. 7.)

From our (He^3,d) reaction studies on other isotopes in this mass region, occasional differences between transitions to $\frac{5}{2}^-$ and $\frac{7}{2}^-$ states have been observed, but the distinction is not so clear as it is in the $p_{1/2}$-$p_{3/2}$ cases. It is possible that in the case of the Cu isotopes, interfering reaction mechanisms are partly responsible for the different behavior of the angular distributions for the $\frac{7}{2}^-$ states (see Sec. IV).

The j dependence of angular distributions has been interpreted in terms of a diffraction model.[38,39] One might also expect that a DW calculation which includes spin-orbit effects in the incoming and outgoing channels would predict the j-dependent behavior. Preliminary calculations of this type by Bassel[35] reproduce the experimental behavior of the Cu^{63} $\frac{3}{2}^-$ ground-state distribution and the $\frac{1}{2}^-$ first-excited-state distribution quite well in the angular region between 90° and 160°, but in the region between 50° and 90° only the behavior of the $\frac{3}{2}^-$ ground-state distribution is well predicted.

IV. CONCLUSIONS

French and Macfarlane[21] have shown that for a proton-stripping reaction on an even-even target,

$$(2J_f+1)\sum(C^2S)=\langle p\rangle_j-(N-Z+1)^{-1}\langle n\rangle_j, \qquad (2)$$

where the sum extends over all fragments of the $T_f=T_0-\frac{1}{2}$ isobaric component of an l_j single-particle (SP) state. In Eq. (2), N and Z refer to the number of neutrons and protons, respectively, in the target nucleus, and $\langle p\rangle_j$ and $\langle n\rangle_j$ are the average number of proton and neutron holes, respectively, in the l_j orbit in the target nucleus. The value of $\langle n\rangle_j$ for the various orbits can be obtained from the (d,p) reaction studies of Fulmer *et al.*[40] From the value of C^2S for the $\frac{7}{2}^-$ third excited state in Cu^{63} and Cu^{65} (see Tables I and II), we have assumed that in the Ni nuclei the $f_{7/2}$ proton shell (8 protons possible) is approximately 6% empty, and that the next higher SP proton state, the $2p_{3/2}$ orbital

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TABLE III. Comparison of observed and predicted values of $\Sigma(C^2S)$; observed energy centroids.

	Cu^{63}			Cu^{65}		
	$\Sigma(C^2S)$ (obs)	$\Sigma(C^2S)$ (pred)	Centroid (MeV)	$\Sigma(C^2S)$ (obs)	$\Sigma(C^2S)$ (pred)	Centroid (MeV)
$p_{3/2}$	0.70	0.84	0.2	0.91	0.85	0.3
$p_{1/2}$	1.14	0.92	1.5	1.34	0.96	1.8
$f_{5/2}$	0.94	0.93	1.5	1.03	0.97	1.7
$g_{9/2}$	0.36	0.86	···	0.40	0.89	···
$d_{5/2}$	0.10	0.86	···	0.06	0.89	···

(4 protons possible), is approximately 12% filled. Table III compares the observed sum $\sum(C^2S)$ for each of the SP states with the values predicted by Eq. (2). If certain additional $l=3$ transitions are indeed $f_{7/2}$ instead of the assumed $f_{5/2}$ transitions, the predicted value of $\sum(C^2S)$ for the $p_{3/2}$ state would be lowered further.

From Table III it appears that for both Cu^{63} and Cu^{65} too much $p_{1/2}$ strength is observed relative to the total $p_{3/2}$ strength. If the present DW analysis is correct, and if all important $l=1$ transitions have been correctly identified, this suggests that a small fraction of the transitions assigned to the $p_{1/2}$ SP state are actually $p_{3/2}$ transitions. A reassignment of 20% of the sum $\sum(C^2S)$ for the $p_{1/2}$ state would increase the $p_{3/2}$ sum by 9% [because of the $(2J+1)$ statistical factor in Eq. (2) and the slight j dependence of N in Eq. (1)]. Such a reassignment would bring the observed values of $\sum(C^2S)$ for the $p_{1/2}$ and $p_{3/2}$ SP states in Cu^{63} into good agreement with the predicted values; for Cu^{65}, the agreement would be nearly within the experimental error. As mentioned in Sec. III, the results for Cu^{65} are also subject to an uncertainty arising from the optical-model parameters used. In view of the uncertainties in the analysis of the higher excited states and in the DW calculation, the results for the $p_{3/2}$ and $p_{1/2}$ SP states, as well as for the $f_{5/2}$ SP state, must be considered in acceptable agreement with the predicted values. It is worthwhile to note, also, that the more recent of the model calculations[8,9,12] predict that in Cu^{63} approximately 15% of the $p_{3/2}$ SP strength lies above the ground state, in good agreement with the reassignment proposed above.

Comparisons between the present results from the Ni^{62}(He^3,d)Cu^{63} reaction and the model predictions have been made in the literature.[2,9,41] (Improved data and DW analysis account for the differences between the values of C^2S in those references and in the present report.) It is clear that the present results require large amounts of $2p_{1/2}$ and $1f_{5/2}$ SP configurations in some of the lower excited states of Cu^{63} and Cu^{65}, in disagreement with the predictions of the simple excited-core model. The predictions of the more extended models, and especially that of Thankappan and True,[9] in which both dipole and quadrupole core-to-particle interactions are used, are in better quantitative agreement with the results of the present study.

From Table III, one may conclude that a large segment of the $1g_{9/2}$ SP state, as well as nearly all of the $2d_{5/2}$ SP state, lies at excitation energies higher than 4 MeV.

Table III also lists the observed energy centroids of the levels assigned to the $2p_{3/2}$, $2p_{1/2}$, and $1f_{5/2}$ SP states. These centroids may be in error by several tenths of an MeV, since any reassignment of levels, e.g., from the $2p_{1/2}$ SP state to the $2p_{3/2}$ SP state, will shift the associated centroids accordingly.

A final point remains to be discussed. Throughout this report, it has been assumed that the dominant reaction mechanism in the present experiment is a simple stripping mechanism. Because the excited-core models predict large amounts of core-excited configurations in the first few excited states of Cu^{63} and Cu^{65}, the question arises as to the importance of secondary reaction mechanisms,[42–44] e.g., one which excites the Ni target nucleus to a collective state, then couples a proton to this state. Recent quantitative calculations by Penny and Satchler[37] for the case of (He^3,d) reaction on Ni^{62}, however, have indicated that for nearly all the lower states of Cu^{63} the only important means of excitation is that of the simple stripping process. An exception is the $\frac{7}{2}^-$ third excited state; in the absence of any $f_{7/2}$ hole in the Ni^{62} ground-state wave function it would be reached only by a secondary reaction process. It is possible that the difference between the experimental angular distributions to the $\frac{7}{2}^-$ state and the $\frac{5}{2}^-$ states reflects the presence of interference from a competing reaction mechanism. Studies of the (He^4,t) reaction and the (d,He^3) reaction are in progress at this laboratory and should furnish additional information on the importance of other reaction mechanisms.

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