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Mass and low-lying energy levels of ^{69}Cu

B. Zeidman and J. A. Nolen, Jr*

Argonne National Laboratory, Argonne, Illinois 60439

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The $(d, {}^3\mathrm{He})$ reaction on ^{64,66,68,70}Zn was investigated at $E_d = 23.3$ MeV and angular distributions measured for low-lying states. The mass excess of ^{69}Cu is found to be -65.75 ± 0.01 MeV, about 190 keV less stable than tabulated mass values. A partial level scheme for ^{69}Cu based on the systematics of the $(d, {}^3\mathrm{He})$ reaction and the energy levels of the lighter odd mass Cu isotopes is suggested. Spectroscopic factors for proton pickup from the zinc isotopes are also presented.

[NUCLEAR REACTIONS $^{64,66,68,70}\mathrm{Zn}(d, {}^3\mathrm{He})$ $E_d = 23.3$ MeV; measured $\sigma(\theta)$, deduced l DWBA analysis. ^{69}Cu mass measured, level scheme suggested.]

During the course of a $(d, {}^3\mathrm{He})$ study of the even Zn isotopes investigating the systematics of the "single" proton states in the Cu isotopes, a 190-keV discrepancy in the tabulated mass of ^{69}Cu was noted.[1] Although this information was included in data compilations,[2] the mass of ^{69}Cu has not been suitably adjusted in the mass tables.[3] In the present paper, not only is this tabulated discrepancy noted, but a partial level scheme with spins and parities for ^{69}Cu is suggested. Angular distributions and spectroscopic factors for low-lying states populated in the $(d, {}^3\mathrm{He})$ reactions on ^{64,66,68,70}Zn targets are also presented.

EXPERIMENTAL

The experiment was performed at the ANL 60″ cyclotron which provided a 23.3-MeV dueteron beam with an energy spread full width at half maximum (FWHM) of ~20 keV. The detector consisted of a ΔE-E surface barrier detector telescope composed of a 100-μmΔE detector and a 300-μm E detector followed by a 500-μm anticoincidence counter. Particle identification (PI) was obtained by analog multiplication. Data was displayed in a two-parameter mode, PI vs total energy $(E + \Delta E)$ where complete separation between ^{3}He and ^{4}He was observed. Projection of the ^{3}He data upon the energy axis yielded spectra such as those of Fig. 1, where measured resolution is <50 keV. The system included pile-up rejection and dead-time correction capability.[4]

The targets consisted of isotopically enriched zinc metal, ~150 μg/cm^2 thick, supported by 10-μg/cm^2 carbon substrates. The enrichment of ^{64,66,68}Zn exceeded 98%, but the ^{70}Zn target was ~75% enriched, the balance being roughly equally distributed between the other even zinc isotopes.

Normalization of the data at the various angles utilized current integration and a fixed solid state monitor detector set on the peak for elastic scattering of deuterons. Absolute cross sections were determined from measurements of target thickness, solid angle, and current integration and also by comparison with elastic deuteron scattering, taken simultaneously, together with optical model calculations. Although the two methods agreed to within 15%, the comparison to elastic scattering was adopted since the inherent sources of possible error were considerably smaller. The errors in the absolute cross section are estimated to be <10%.

The energy calibration, determined on both ab-

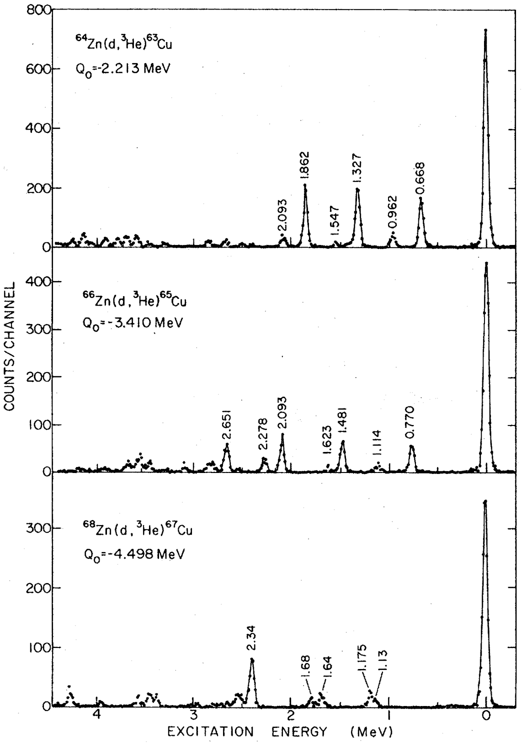

FIG. 1. Spectra for $^{64,66,68}\mathrm{Zn}(d, {}^3\mathrm{He})$ at 21° lab.

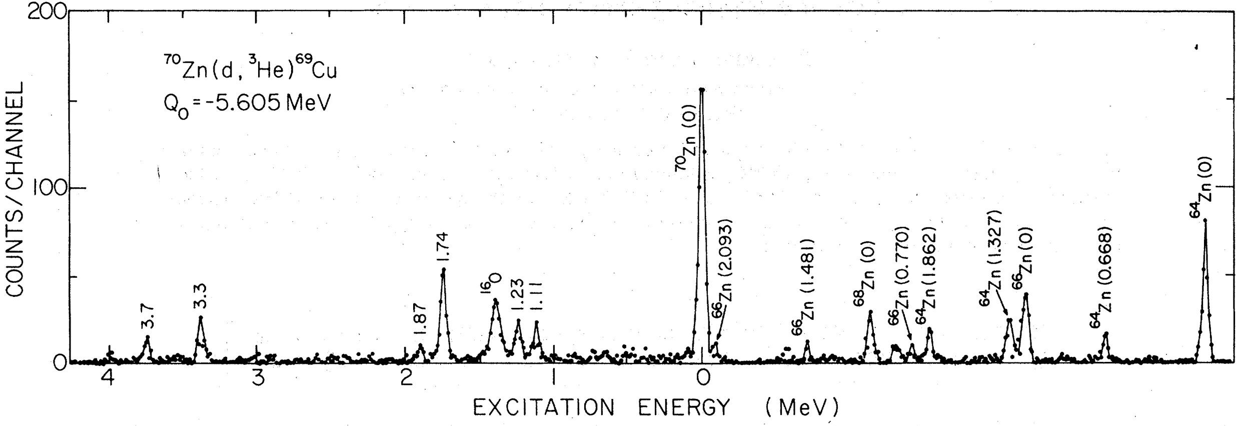

FIG. 2. Spectrum of ^{70}Zn(d, ^{3}He) at 21° lab. Peaks resulting from other zinc isotopes are indicated.

solute and relative bases, is discussed in the next section.

RESULTS

Typical (d, ^{3}He) spectra obtained with the various targets are displayed in Figs. 1 and 2. The angle was chosen so as to enhance the cross sections for the $l = 3$ transitions relative to those for $l = 1$ transitions.

The energy calibration was determined approximately with the use of α particles from the decay of ^{241}Am and elastic scattering of deuterons from Zn isotopes at various angles. These measurements were consistent with the Q values derived from the mass tables for spectra from the (d, ^{3}He) reactions on ^{64}Zn, ^{66}Zn, and ^{68}Zn targets. A more precise calibration, most reliable over the range $Q \approx -2$ to -8 MeV for (d, ^{3}He), is obtained from the spectra for the ^{70}Zn(d, ^{3}He)^{69}Cu reaction. Because of the admixtures of the other zinc isotopes in this target, a number of peaks of known excitation energies,[2] and hence Q values, are clearly identifiable in the spectra, e.g., Fig. 2. Assuming the most intense peak in the spectrum to be that of the ^{70}Zn(d, ^{3}He)^{69}Cu ground state reaction, we obtain $Q_0 = -5.605 \pm 0.010$ MeV. This value is in disagreement with the latest mass tabulation[3] from which a $Q_0 = -5.415 \pm 0.070$ MeV would be obtained. Since the masses of ^{70}Zn and the oth-

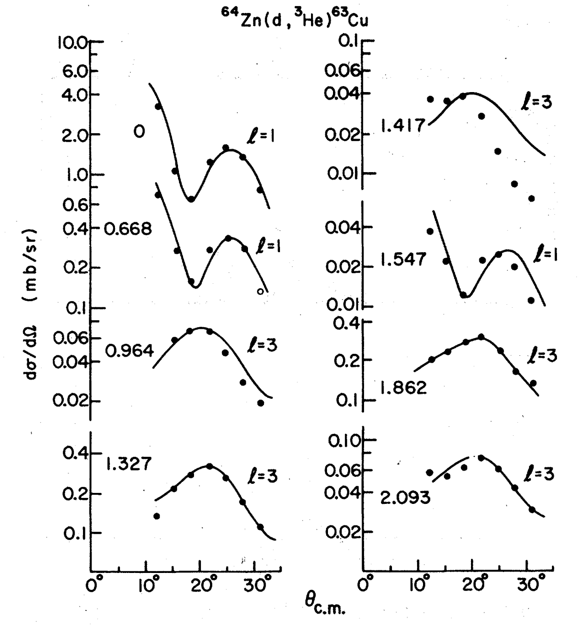

FIG. 3. Angular distributions for low-lying levels in the ^{64}Zn(d, ^{3}He) reaction.

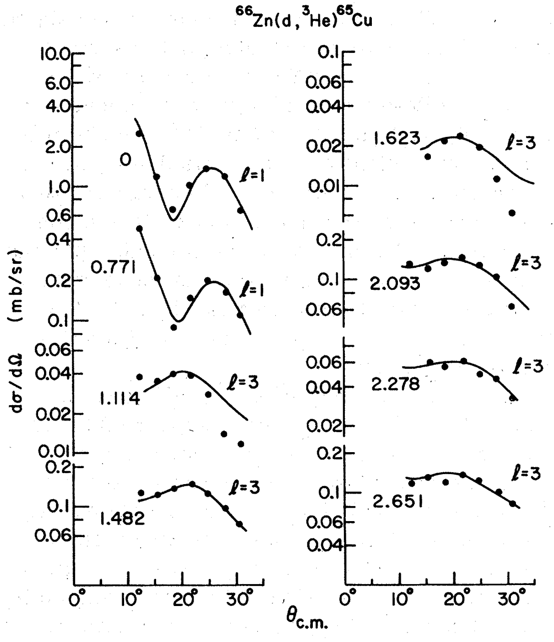

FIG. 4. Angular distributions for low-lying levels in the ^{66}Zn(d, ^{3}He) reaction.

TABLE I. Parameters used in DWBA calculations. The appropriate units are MeV and fm.

	V	W	W_D	r_c	r	a_v	r'	a_w	V_{so}	λ
d	105	0	15	1.3	1.02	0.86	1.4	0.65	6.0	
^{3}He	175.5	21.9	0	1.4	1.14	0.71	1.6	0.83	0	
p	adj			1.25	1.2	0.7				25

er target nuclei are well determined, this implies an error in the mass of ^{69}Cu. The present measurements yield a mass excess for ^{69}Cu of −65.750 ± 0.01 MeV, approximately 190 keV less stable than listed.

Angular distributions over the range 12°–30° for the prominent, low-lying levels in each of the final nuclei are shown in Figs. 3–5. This angular range is sufficient to unambiguously deduce l values in the present mass region, and allows extraction of spectroscopic factors from comparison with DWBA calculations. Since the spins of the low-lying states in ^{63,65,67}Cu are known from other sources,[2] the solid lines in Figs. 3–5 are DWBA calculations using the code JULIE with spin orbit coupling; the parameters being listed in Table I. The systematics discussed below provided the basis for the spins used in the calculations for ^{69}Cu levels. Spectroscopic factors obtained from the relation $d\sigma/d\omega = 2.95C^2S\sigma_{\text{JULIE}}$ are listed in Table II along with the spins used in the calculation.

DISCUSSION

Since the 190-keV discrepancy between the present result and the tabulated mass of ^{69}Cu exceeds the quoted uncertainty (70 keV) and is in a direction so as to provide less binding for ^{69}Cu, it is necessary to examine the bases for both the previous and present values.

The tabulated mass excess is based upon measurements of the gross β spectrum in the decay of ^{69}Cu.[5] The authors, however, report that the presence of ^{68}Cu and ^{63}Zn in their sample interfered seriously with an accurate determination of the end point in the β spectrum. As a result, it is reasonable to assume that their quoted uncertainty was underestimated.

Nevertheless, since the direction of the discrepancy implies that the present ground state transition measured here could correspond to a transition to an excited state, the systematics of the Zn(d, ^{3}He) reactions should be examined. The low-

TABLE II. Spectroscopic factors from Zn(d, ^{3}He)Cu reactions leading to final states in Cu. The excitation energies are in MeV. The spins for ^{69}Cu are based upon the present work; for other nuclei, the spins have been assigned previously.

	Level	j	C^2S		Level	j	C^2S
^{63}Cu	0	$\frac{3}{2}^-$	1.6	^{65}Cu	0	$\frac{3}{2}^-$	1.7
	0.668	$\frac{1}{2}^-$	0.43		0.770	$\frac{1}{2}^-$	0.44
	0.964	$\frac{5}{2}^-$	0.50		1.114	$\frac{5}{2}^-$	0.55
	1.327	$\frac{7}{2}^-$	1.5		1.481	$\frac{7}{2}^-$	1.2
	1.417	$\frac{5}{2}^-$	0.2		1.623	$\frac{5}{2}^-$	0.39
	1.547	$\frac{3}{2}^-$	0.045		2.093	$\frac{7}{2}^-$	1.5
	1.862	$\frac{7}{2}^-$	1.7		2.278	$\frac{7}{2}^-$	0.73
	2.093	$\frac{7}{2}^-$	0.45		2.651	$\frac{7}{2}^-$	1.8
	2.673	$\frac{7}{2}^-$	0.35				
^{67}Cu	0	$\frac{3}{2}^-$	1.9	^{69}Cu	0	$\frac{3}{2}^-$	1.3
	1.13	$\frac{5}{2}^-$	0.3		1.11	$\frac{1}{2}^-$	0.46
	1.17	$\frac{1}{2}^-$	0.26		1.23	$\frac{5}{2}^-$	1.5
	1.67	$\frac{7}{2}^-$	0.90		1.74	$\frac{7}{2}^-$	2.7
	2.34	$\frac{7}{2}^-$	3.1		1.87	$\frac{7}{2}^-$	0.45

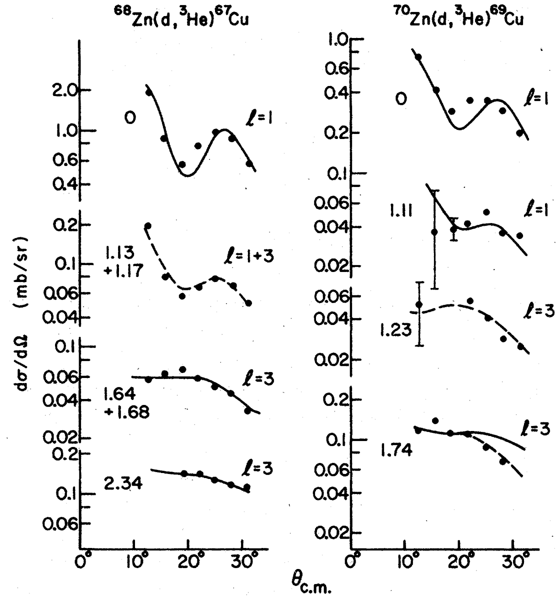

FIG. 5. Angular distributions for ^{68}Zn(d, ^{3}He) and ^{70}Zn(d, ^{3}He).

lying levels of $^{63-69}$Cu are shown in Fig. 6. It is seen that there is a smooth progression of the level sequence which can be continued to ^{69}Cu, and the ground $\frac{3}{2}^-$ state is well isolated. The log-ft for the β decay is indicative of an allowed transition. In addition, the (d, ^{3}He) spectroscopic factor for the ground state is consistent with those for the other ground state reactions measured. On these bases, it is suggested that the spin and parity of ^{69}Cu is $\frac{3}{2}^-$, as are the other odd Cu isotopes, and there is no other state within 300-keV excitation. These arguments rule out the possibility of a ground state doublet so that the measured Q value corresponds to the ground state transition.

The spectroscopic factors listed in Table II and the systematic progression of level sequences observed in Fig. 6 provide a means for possible spin assignment of some low-lying states in ^{69}Cu. The $\frac{3}{2}^-$ ground state is discussed above. The 1.11-MeV level is $l = 1$ ($J^\pi = \frac{1}{2}, \frac{3}{2}^-$) and the systematics prefer a $\frac{1}{2}^-$ assignment. The level at 1.73-MeV excitation is $l = 3$ and the spectroscopic factor is so large that a $\frac{7}{2}^-$ assignment is strongly suggested. From the systematics, a $\frac{7}{2}^-$ assignment is also most probable for the 1.87-MeV level.

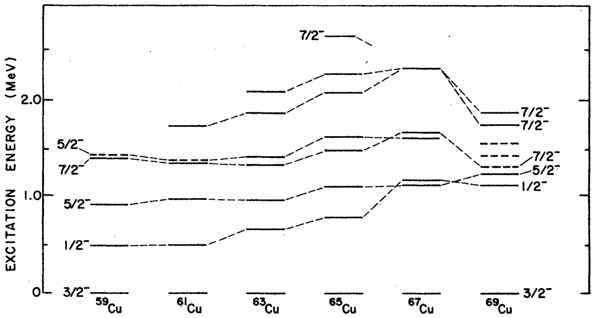

FIG. 6. Level schemes for the Cu isotopes. The levels for ^{59}Cu to ^{67}Cu are from the literature. The levels for ^{69}Cu are proposed here.

TABLE III. Spectroscopic factor sums for each spin in Cu isotopes.

Nucleus	$\Sigma\frac{3}{2}^-$	$\Sigma\frac{5}{2}^-$	$\Sigma\frac{1}{2}^-$	$\Sigma\frac{7}{2}^-$
^{63}Cu	1.65	0.7	0.43	4.0
^{65}Cu	1.7	0.94	0.44	5.2
^{67}Cu	1.9	0.3	0.26	4.0
^{69}Cu	1.3	1.5	0.46	3.15

The peak at 1.23-MeV excitation, however, does not clearly correspond to a single level in the other odd Cu isotopes. In addition, the peak is slightly broader than the others in the spectrum. If all of the strength is assumed to arise from a $\frac{5}{2}^-$ transition, the spectroscopic factor is substantially larger than the $\frac{5}{2}^-$ transitions in the other Cu isotopes. Moreover the summed $\frac{7}{2}^-$ strength is somewhat lower than in the other nuclei (see Table III). It therefore seems probable that a $\frac{5}{2}^-$, $\frac{7}{2}^-$ doublet exists near 1.23 MeV and the strength is distributed between these states. There is also evidence for several other weak states at 1.31-, 1.43-, and 1.56-MeV excitation that, based on systematics, probably have $\frac{7}{2}^-$ or $\frac{5}{2}^-$ spins and parities. The presence of oxygen in the target obscured these states at several angles and makes any assignment difficult. Other peaks are seen at excitations of 3.0, 3.3, 3.7, and 3.95 MeV, that may correspond to pickup from the $2s, 1d$ shell. However, the angular distributions for these levels were sufficiently ambiguous that no l values could be assigned.

The summed spectroscopic strengths of $p_{3/2}$, $p_{1/2}$, $d_{5/2}$, and $f_{7/2}$ for each isotope are listed in Table III. Except for the previously discussed ambiguity in the assignment of $\frac{5}{2}^-$ and $\frac{7}{2}^-$ strength in the 1.23-MeV peak, there is consistency among the various targets. If we arbitrarily were to make the $f_{7/2}$ strength in ^{69}Cu equivalent to the other Cu isotopes, the $f_{5/2}$ strength would also be consistent. It is evident, however, that in ^{68}Zn, there is somewhat more $(p_{3/2})^2$ and less $(f_{5/2})^2$ configuration than in the other Zn isotopes. The sum of the spectroscopic strengths for $p_{3/2}$, $p_{1/2}$, and $f_{5/2}$ exceeds 2 for all targets, indicating an unfilled $f_{7/2}$ shell and the presence of sizable residual interactions.

In conclusion, we have more reliably measured the mass of ^{69}Cu, and proposed a partial level scheme for this nucleus. It is also seen that these data are consistent with systematic trends observed in other Cu isotopes.

Note added in proof. A measured value of -65.734 ± 0.013 MeV for the mass excess of ^{69}Cu confirms the present result. T. S. Bhatia *et al.* annual report, 1977, Max-Planck Institute für Kernphysik—Heidelberg (unpublished), p. 107.

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