Population of the 2.37-MeV 0+ Level in ^{66}Zn by ^{66}Cu

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The decay of ^{66}Cu to ^{66}Zn has been studied with Ge(Li) detectors. The following γ rays were observed (energies in keV and intensities in parentheses): 833.0±1.0 (1.7±0.4), 1039.2±0.2 (100), and 1332.5±1.5 (0.032±0.006). These depopulate the following levels in ^{66}Zn: 1039.2±0.2, 2+; 1872.2±1.0, 2+; and 2371.7±1.5, 0+. The spin of the 2372-keV level was determined to be zero by γ-γ directional correlation studies of the 1039.2–1332.5-keV cascade. The A_2 and A_4 values obtained are 0.49±0.32 and 1.16±0.44, respectively.

INTRODUCTION

THE level structure of ^{66}Zn has been studied by inelastic scattering[1–5] and pick-up reactions[5] as well as from the decays[6–8] of ^{66}Cu and ^{66}Ga. The results of the most recent experiments[1–8] are shown in Table I.

Reaction studies[2,5] have indicated a 0+ level at 2383 KeV. From energy considerations it was thought to be a member of a two-phonon triplet.[2] A level at 2372.3 keV is populated[6,7] by β decay from the 0+ ground state of ^{66}Ga. The spin and parity[6] were assigned as 0+ or 2− with 0+ strongly favored. This state[6,7] at 2372.3 keV is most probably the same state reported at 2383 keV in reaction studies.[2] A 0+ level has been established[9] recently at 1655.7 keV in ^{68}Zn populated by electron capture from the 1+ ground state of ^{68}Ga. Consideration of these data led us to study the β decay of the 1+ ground state of ^{66}Cu to search for population of a 0+ state with an energy in the range of 2370–2380 keV in ^{66}Zn. A level at 2371.7 was observed to be populated by ^{66}Cu and its spin determined to be 0 from directional correlation measurements.

EXPERIMENTAL PROCEDURES

Sources of ^{66}Ni ($T_{1/2}$=55 h) which decays 100% to the ground state of ^{66}Cu ($T_{1/2}$=5.1 min) were used in this work. The ^{66}Ni activity was prepared by utilizing a neutron flux of 2.45×10^{15} n/cm^2 sec for the successive capture two neutrons by ^{64}Ni. Targets consisted of isotopically enriched ^{64}Ni (98.56%) metal. After the irradiation, the target was dissolved in nitric acid and silver carrier added. The solution was then neutralized and made slightly acidic with hydrochloric acid, and the ^{110m}Ag contamination was removed by precipitating silver chloride. The hydrochloric acid was removed by fuming the solution in the presence of sulphuric acid. The solution was then diluted, neutralized with ammonium hydroxide and made strongly alkaline with an excess of ammonium hydroxide. The ^{66}Ni was plated onto a platinum screen to isolate it from the ^{24}Na contamination. The ^{66}Ni was then removed from the platinum electrode with hot HCl and the solution was passed through a Bio.Rad AG-1 anion-exchange column to remove ^{58}Co and ^{60}Co contaminations. The eluate from the column was evaporated down to incipient dryness, treated with nitric acid to destroy organic material, and then treated with HCl to convert the nickel to the chloride. The ^{66}Ni was then taken up in 0.1M HCl. Sources were prepared from this solution.

A 15-cc Ge(Li) detector and a 4096 channel analyzer were used for singles measurements. The resolution of the system was 6.0 keV (FWHM) at 1333 keV at the counting rates used in this work. The 15-cc Ge(Li) detector and a 2×2-in.^{2} NaI detector were used for the coincidence and directional correlation measurements. The system was calibrated for energy measurements with the following transitions[10]: 569.63±0.08; 1063.50±0.06; 1769.71±0.13; 661.595±0.076; 897.96±0.10; 1836.08±0.07; 1173.226±0.040; 1332.483±0.046 from the decays of ^{207}Bi, ^{137}Cs, ^{88}Y, and ^{60}Co. The calibration standards were mixed with the ^{66}Ni source for three of the singles runs to obtain the energies of the 833.0 and 1039.2-keV transitions as accurately as possible.

The directional correlation apparatus has been used to measure several well-known correlations and is described briefly elsewhere.[11] Data were taken at 90°,

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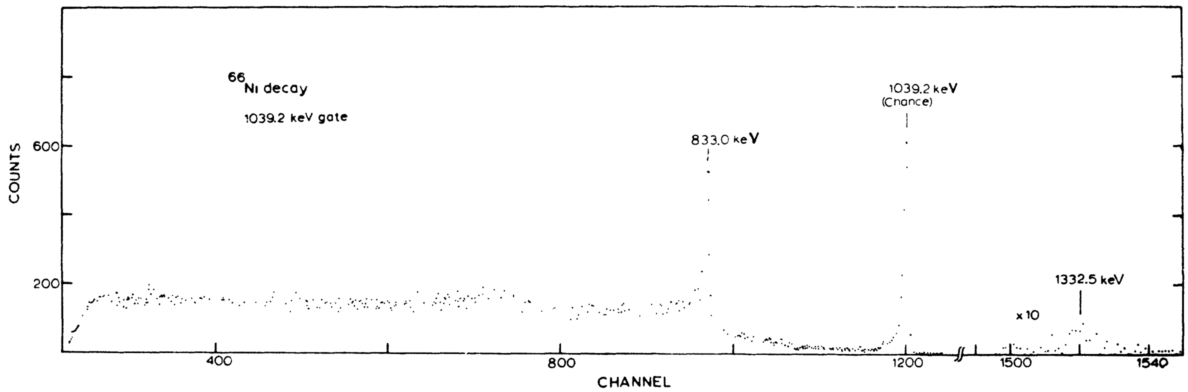

FIG. 1. Typical coincidence spectra of ^{66}Cu taken with a 15 cc Ge(Li) detector and a NaI detector with its gate set on 1039 keV.

135°, and 180°. The NaI-detector gate was set on the 1039-keV peak. The signals from the two detectors generated a fast coincidence signal to open the memory of a Nuclear Data 4096 channel analyzer to the pulses from the Ge(Li) detector. The solid-angle correction for the NaI detector was taken from tables[12] while the similar correction for the Ge(Li) detector was experimentally determined by measuring known correlations. The data at the three angles were used to determine the coefficients in the expression for the directional correlation corrected for solid angles $W(\theta)=1+A_2P_2+A_2P_4$.

RESULTS AND DISCUSSION

Figure 1 shows a typical coincidence γ-ray spectrum of ^{66}Ni. The energies and intensities of the transitions assigned to the decay of ^{66}Cu are shown in Table II. The important new feature is the transition at 1332.5 keV which was observed in both singles and coincidence spectra. This transition has been observed in the decay[6,7] of ^{66}Ga but not in the decay[8] of ^{66}Cu. The upper limit on the 1872-keV crossover transition (0.01) set in this work is the same as that found by Freedman *et al.*[6]

The energy of the 1039.2-keV transition was determined in three runs in which the calibration sources were mixed with the ^{66}Ni source. The 833.0-keV peak is almost obscured by the Compton edge of the 1039-keV peak, consequently the peak must be reconstructed to obtain its energy and intensity. The peak was reconstructed by using the 1039.2-keV peak as a standard. Obtaining the energies and intensities of the 1332.5-keV transition was complicated by the presence in the source of ^{60}Co, which has transitions at 1173.226 and 1332.483 keV. In the singles measurements, the 1332.483-keV transition of ^{60}Co was un-

TABLE I. Energy levels observed in ^{66}Zn below 2.5 MeV are given. The modes of excitation, spin, and parity assignments are given. The energies are in keV.

(α,α')[a]	(p,p')[b]	(d,d')[c]	(p,p')[d]	(p,p') (p,t)[e]	^{66}Ga decay[f]	^{66}Ga decay[g]	^{66}Cu decay[h]
1040±20,	1037±2,	1040,	1040±50,	1040,	1039.3,	1039.0±0.1,	1040,
2+	2+	2+	2+	2+	2+	2+	2+
1800±100,	1865±3,	1830,	1830±10,	1870,	1872.8,	1872.6±0.3,	1870,
2+	2+	2+	2+	2+	2+	2+	2+
	2382±9,		2340±20,	2370,	2372.3,	2372.3±0.4,	
	0+		(0+)	0+	(0+, 2−)	0+	
	2462±9,	2410,	2410±10,	2460			
	(4+)	4+	4+				

[a] Reference 1.
[b] Reference 2.
[c] Reference 3.
[d] Reference 4.
[e] Reference 5.
[f] Reference 6.
[g] Reference 7. No discussion of the spins of these three states was given in Ref. 7. These assignments were presumably taken from reaction data.
[h] Reference 8.

[12] M. J. L. Yates, in *Alpha-, Beta- and Gamma-ray Spectroscopy*, edited by K. Siegbahn (North-Holland Publishing Co., Amsterdam, 1965), p. 1691.

TABLE II. Energies and relative γ intensities of transitions in ^{66}Zn from the decay of ^{66}Cu.

Present work		^{66}Ga[a]
Energy (keV)	Intensity	Energy (keV)
833.0±1.0	1.7±0.4	833.6±0.3
1039.2±0.2	100	1039.0±0.1
1332.5±1.5	0.032±0.006	1333.3±0.4
1872	<0.01	

[a] Reference 7.

resolved from the 1332.5-keV transition in ^{66}Ni. The intensity of the transition in ^{66}Ni was obtained by determining the contribution of ^{60}Co to this peak. The ^{60}Co contribution was determined to be 50% of the composite peak from the intensity of the 1173-keV transition and the relative intensities of the 1173.2- and 1332.5-keV ^{60}Co peaks measured in the same geometry as the ^{66}Ni run. The relative intensity of the 1332.5 to the 833.0-keV transition was also determined from the coincidence data. The detectors were placed face to face so that directional-correlation effects on the intensities should be a minimum. The average of the relative intensities of the 833.6- to 1332.5-keV transition obtained from the coincidence data, 55±7 is in good agreement with the average of the relative intensities as determined from the singles measurements, 53±18. The resolution of the complex peak in the singles spectrum at 1332.5 is identical with that obtained for the 1173.2-keV peak. The transition in ^{66}Ni is assigned an energy of 1332.5±1.5 keV where the error limit was determined by estimating the possible separation of two equal intensity transitions without noticeably changing the line resolution.

The coincidence data establishes that the 1332.5-keV transition is in coincidence with the 1039.2-keV transition. Therefore, the level observed at 2372 keV from the ^{66}Ga decay also is popultaed by ^{66}Cu. In order to establish the spin of the state observed at 2371.7 keV, directional correlation measurements were made on the 1332.5–1039.2-keV cascade. The directional-correlation coefficients, A_2 and A_4, were determined as discussed above.

After correction for the finite solid angle, the normalized coefficients were found to be $A_2=0.49\pm0.32$ and

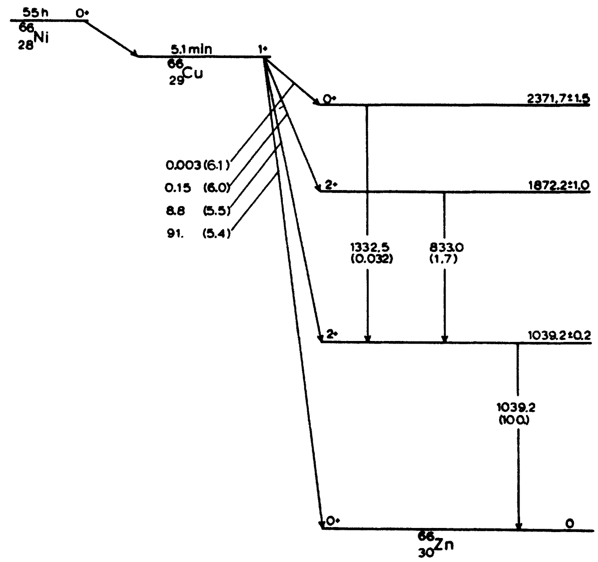

FIG. 2. The decay scheme of ^{66}Cu to ^{66}Zn. The γ-ray intensities are given relative to the 1039.2-keV transition, which has an absolute intensity of 9.0% per decay. The relative β feeding to the ground state was taken from other work [G. Friedlander and D. E. Alburger, Phys. Rev. **84**, 231 (1951)].

$A_4=1.16\pm0.44$. The errors are estimated to be one standard deviation. These values are consistent only with a 0-2-0 assignment (theoretical $A_2=0.36$, $A_4=+1.1$) for the 1332.5–1039.2-keV cascade. Thus, the 2371.7-keV level is uniquely determined to have spin zero. Based on nuclear systematics the parity is assigned as even.

The decay scheme is shown in Fig. 2. The additional information obtained here is the population of a level at 2371.7-keV in ^{66}Zn by ^{66}Cu and the verification by a directional correlation experiment that the spin is zero. The other levels have been observed[8] previously in the decay of ^{66}Cu.

One notes that the log ft of transitions to the excited 0+ state is considerably higher than the log ft for decay to the 0+ ground state but similar to that of the second-excited 2+ state. The log ft values in the decay of ^{66}Cu have been compared to the allowed log ft values to similar states in ^{68}Zn, ^{80}Se, and ^{80}Kr in a recent survey.[13]

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