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Lifetimes of levels in ^{64}Zn from Doppler shift measurements via the ^{61}Ni(α, n)^{64}Zn reaction

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The levels of ^{64}Zn have been investigated via the ^{61}Ni($\alpha, n\gamma$)^{64}Zn reaction up to 3.4 MeV excitation. The level scheme which has been obtained includes most of the previously reported levels. The lifetimes of 18 levels in ^{64}Zn have been measured by the Doppler shift attenuation method at bombardment energies between 6.4 and 8.0 MeV.

[NUCLEAR REACTIONS ^{61}Ni($\alpha, n\gamma$), E_α=6.4–8.0 MeV, enriched targets, measured $E_\gamma, I_\gamma, \Delta E_\gamma(\tau)$ confirmed ^{64}Zn levels, deduced τ.]

I. INTRODUCTION

In recent years, the doubly even ^{64}Zn nucleus has been the subject of several investigations.[1-3] Many levels have been found up to an excitation energy of about 6 MeV. Moreover, spin-parity assignments have been made for most of the levels up to approximately 3 MeV in excitation. Therefore, it appears useful to get experimental information concerning the γ-ray transition probabilities. The present work was undertaken in order to measure the lifetimes of the excited states of ^{64}Zn by using the Doppler shift attenuation method (DSAM).

II. EXPERIMENT

The mean lifetimes of a number of states in ^{64}Zn were measured following the ^{61}Ni($\alpha, n\gamma$) ^{64}Zn reaction ($Q \approx 3.9$ MeV). The targets employed were self-supporting foils of nickel enriched to 97% in mass 61. The target was bombarded with ^{4}He^{++} ions from the Lyon University Van de Graaff accelerator at energies ranging from 6.4 to 8.0 MeV. The γ rays were detected in a 60 cm^3 Ge(Li) detector with 3.5 keV resolution (full width at half maximum) at 1332 keV. Single spectra were recorded at about 40° and 150° with respect to the beam direction. To monitor gain shifts, γ rays from ^{88}Y and ^{88}Zr sources were counted simultaneously with the reaction γ rays. The recorded spectra were analyzed with the help of the SAMPO program[4] in order to determine the centroid shifts. The Doppler shifts were measured at a beam energy of a few hundred keV above the reaction threshold for each level. In that case the initial mean velocity of the recoiling nucleus is practically insensitive to the angular distribution of the outgoing neutron. Moreover, the extraction of lifetimes is not disturbed too much by possible γ-ray cascades populating the levels.

The $F(\tau)$ curves were calculated in the framework of the Lindhard-Scharff-Schiøtt (LSS) theory[5] according to the formalism of Blaugrund.[6] An uncertainty for the attenuation curve was obtained by assigning a 15% uncertainty to the nuclear stopping power. The component of the initial average recoil velocity of the ^{64}Zn ions in the beam direction was obtained from the kinematics by assuming that the angular distribution of the outgoing neutrons is isotropic in the center of mass system.

III. RESULTS

In the present investigation, most of the previously known ^{64}Zn levels were identified up to 3.4 MeV. The γ spectrum at $\theta = 90°$ is shown in Fig. 1. Most of the transitions could be ascribed to ^{64}Zn, ^{64}Cu, ^{61}Ni, or to well-known background lines. Only a few weak lines remain unidentified.

In Table I is given the list of excited levels in

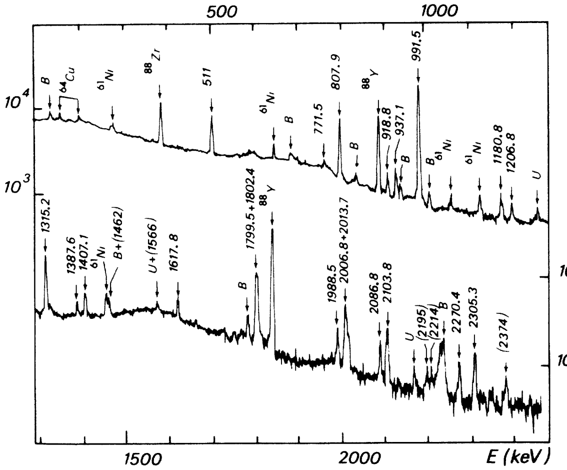

FIG. 1. Experimental γ spectrum of the reaction ^{61}Ni($\alpha,n\gamma$) ^{64}Zn at $\theta = 90°$ and $E_\alpha = 8$ MeV. The peak labeled with B corresponds to well-known background lines. Unidentified peaks are denoted by U.

TABLE I. Mean shifts, attenuation factors, and mean lifetimes for transitions deexciting the nuclear levels of ^{64}Zn. The uncertain weak transitions are indicated inside parentheses.

Level (keV)	E_γ (keV)	I_γ rel. [b]	ΔE_γ (keV)	E_α [a] (MeV)	$F(\tau)$	τ (fs)
991.5	991.5	3800	0.13 ± 0.03	6.4	0.025 ± 0.007	2700^{+800}_{-500}
1799.4	807.9	1000	0.12 ± 0.03	7.0	0.026 ± 0.007	2600^{+800}_{-500}
	1799.5	390	0.26 ± 0.07		0.026 ± 0.007	2600^{+800}_{-500}
1910.3	918.8	150	0.10 ± 0.03	7.0	0.020 ± 0.006	3400^{+1500}_{-800}
2306.7	1315.2	660	0.88 ± 0.10	7.6	0.114 ± 0.013	630^{+140}_{-100}
2609.3	1617.8	88	0.50 ± 0.18	7.6	0.053 ± 0.020	1400^{+800}_{-500}
2736.5	937.1	250	0.14 ± 0.04	7.6	0.026 ± 0.008	3000^{+1200}_{-700}
	1745	≈ 25				
2793.9	1802.4	200	9.9 ± 0.5	7.6	>0.90	< 13
2980.2	1180.8	100	<0.20	8.0	<0.03	>2500
	1988.5	63	<0.20		<0.02	>3800
3005.7	1206.8	45	3.8 ± 0.5	8.0	0.53 ± 0.07	81^{+25}_{-17}
	2013.7	75	9.0 ± 2.0		0.75 ± 0.17	32^{+30}_{-23}
	3005.7	50	11.0 ± 2.0		0.60 ± 0.12	65^{+20}_{-15}
2998.3	2006.8	165	<0.50	8.0	<0.040	>1500
3078.3	771.5	60	0.20 ± 0.10	8.0	0.040 ± 0.020	2000^{+1500}_{-800}
	2086.8	60	0.38 ± 0.15		0.031 ± 0.012	2500^{+1400}_{-800}
3094.3	2103.8	97	3.9 ± 0.5	8.0	0.31 ± 0.04	190^{+40}_{-30}
3187.0	(1276)	≈ 10		8.0		
	1387.6	60	1.0 ± 0.3		0.12 ± 0.04	580^{+300}_{-180}
	(2195)	≈ 15				
3206.5	1407.1	68	1.20 ± 0.30	8.0	0.15 ± 0.04	470^{+200}_{-120}
	(2214)	≈ 10				
3261.9	(1462)	≈ 20		8.0		
	2270.4	40	11.4 ± 1.0		0.85 ± 0.08	20^{+11}_{-12}
3296.8	2305.3	65	2.1 ± 0.3	8.0	0.15 ± 0.02	450^{+100}_{-80}
(3365)	(1566)	≈ 15		8.0		
	(2374)	≈ 10				
	3364	20	15 ± 3		0.75 ± 0.15	37^{+28}_{-22}
(3425)	(3425)	≈ 15	20 ± 3	8.0	>0.90	< 15

[a] Energy of the incident ^{4}He^{++} beam.
[b] Relative intensities at $E_\alpha = 8$ MeV.

^{64}Zn and the corresponding γ-ray transitions. The proposed level scheme is shown in Fig. 2. Up to the level at 2793 keV the spin-parity assignments are obtained from previous distorted wave Born approximation analysis[1,2] or angular correlation measurements.[3] It should be noted that the levels at 2609 and 2793 keV are possibly connected to the 2^+ 1799 keV level. As a matter of fact, those transitions (indicated by dashed lines) may have been masked by the strong transitions of 807.9 and 991.5 keV, respectively. However, a careful analysis of those peaks indicated that the possible 809.9 and 994.5 keV transitions must have intensities lower than 40 and 140 (units of Table I), respectively. States with $J^\pi = 3^-$ and 4^+ have been predicted at about 3.02 and 3.11 MeV, respectively, using the

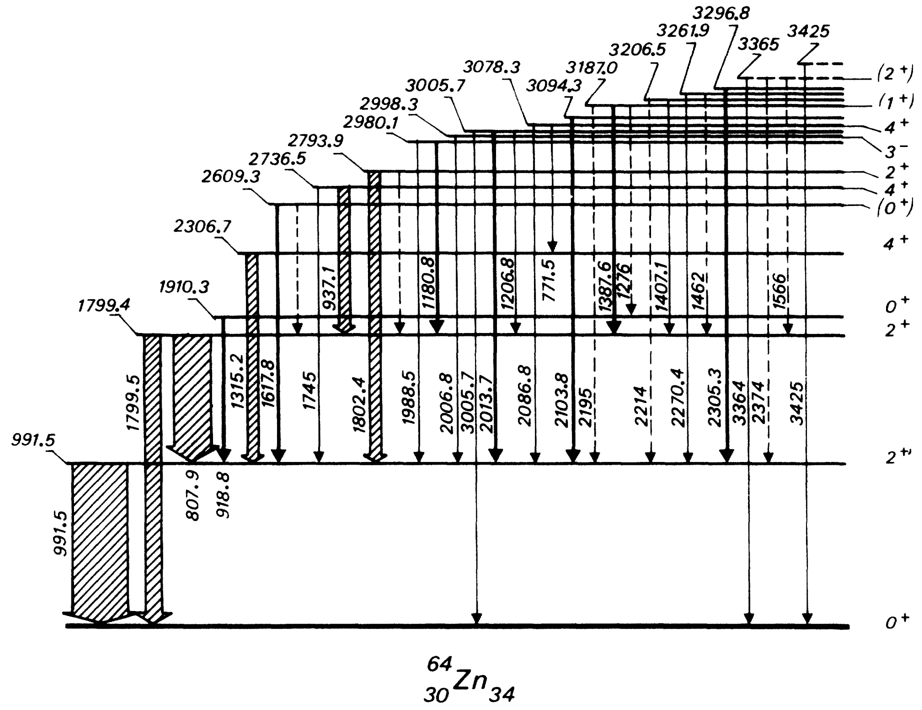

FIG. 2. Proposed level scheme of ^{64}Zn resulting from the present investigation.

($\alpha\alpha'$) and (t,p) reaction data.[1,2] Those states were finally associated with the 2998 and 3078 keV levels on the evidence of γ-γ angular correlation experiments.[3] Unfortunately, no evidence is available for the assignments of the 2980 and 3006 keV levels which were also observed via the (p,p') reaction. The high lying levels of our scheme are also excited with the (p,p') reaction. The very weak or uncertain transitions are indicated by dashed lines.

In the following columns of Table I are given the measured $F(\tau)$ and the deduced mean lifetimes for each level. It should be noted that the lifetime of the first excited state is in good agreement with previous measurements[1,7] ($T_{1/2}=1.75$ ps, $\tau=2.52$ ps). Those results are discussed in the next section.

TABLE II. Electromagnetic transition rates for some transitions in ^{64}Zn. The reduced transition probabilities are given in Weisskopf units.

Level	I^π	Transition	Mult.	T_{exp}/T_W
991.5	2^+	991.5	$E2$	20.4
1799.4	2^+	807.9	$E2$	42.3
		1799.4	$E2$	0.30
1910.3	0^+	918.8	$E2$	23.6
2306.7	4^+	1315.2	$E2$	21.3
2609.3	0^+	1617.8	$E2$	3.4
2736.5	4^+	937.1	$E2$	21.8
		1745	$E2$	0.10
2793.9	2^+	1802.4	$E2$	>213
		1802.4	$M1$	>0.45
2998.3	3^-	2006.8	$E1$	$<5.2\times10^{-5}$
3078.3	4^+	771.5	$E2$	42.5
		2086.8	$E2$	0.31

IV. DISCUSSION

From the measured branching ratios, the level lifetimes presented in Table I, and the expected multipolarities, we can deduce the reduced transition probabilities. Their values in Weisskopf units (W.u.) are given in Table II for some ^{64}Zn states. The $B(E2)$ value of the one-phonon state is about the same as in ^{66}Zn and ^{68}Zn.[7-9] The $B(E2)$ values of the levels at 1799 (2^+), 1910 (0^+), and 2306 (4^+) are in the range expected for the two-phonon state. Those results can be compared to the values deduced from the lifetimes measured in ^{66}Zn.[9] The $B(E2)$ corresponding to the 4^+ state is of the same order of magnitude (43 W.u.) but there is a strong deviation for the 2^+ state due to the surprising large $B(E2)$ value in ^{66}Zn (468 W.u.). A three-phonon state interpretation can be suggested for the 2736 keV state (4^+) which decays primarily to the 2^+ two-phonon level. The very short lifetime of the 2793 keV level should be noted. The reduced transition probability values suggest that the 1802 keV transition is not pure $E2$ but rather ($E2+M1$). The $B(E1)$ value of the 2998 keV level is lower by at least a factor of 10 than those deduced from measured lifetimes of the first 3^- states in ^{66}Zn and ^{68}Zn.[9]

In conclusion, it seems difficult at present to achieve a theoretical understanding of this experiment. The calculation of sufficiently realistic wave functions for Zn isotopes is now required to make full use of the experimental data.

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