Hindrance Factors of Allowed $1^+ \to 0^+$ Decays in Even-Even Nuclei with $A = 66$–80

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Recent work with solid-state detectors on the log*ft* values of allowed decays from 1^+ ground states to 0^+ and 2^+ states in four even-even nuclei ($66 \leq A \leq 80$) is surveyed. Decays to the first excited 2^+ and second excited 2^+ states are successively hindered over transitions to the 0^+ ground states. Transitions to the excited 0^+ states proceed at rates that are generally hindered even more than those to the second 2^+ levels in these nuclei. Relative $B(E2)$ values from the excited 2^+ states in ^{66}Zn and ^{68}Zn are compared.

I. INTRODUCTION

In a study of hindrance phenomena in allowed β transitions from odd-odd nuclei ($60 < A < 140$) with 1^+ ground states, Sakai[1] reported that in 24 and 14 cases the transitions to the first 2^+ and the second 2^+ excited states, respectively, were successively hindered (the average increases in log*ft* values for decays to the first 2^+ states over the 0^+ ground states and for decays to the second 2^+ over the first 2^+ were found to be 0.58 and 0.48, respectively), but decays to the first excited 0^+ states proceeded at rates essentially equal to that of the ground state. There were only three cases where knowledge of excited 0^+ states in these nuclei were available then. In a more recent study of vibrational and rotational nuclei, Sakai[2] again repeats this earlier conclusion[1] about the *ft* values of allowed decays to 0^+ states and supports it by work to be published.[3]

In the past few years, there has been considerable interest in locating 0^+, 2^+, and 4^+ states at about twice the energy of the first excited 2^+ states in vibrational even-even nuclei. Such triplet states could be considered as two-phonon vibrations. Hsu and French,[4] however, in applying microscopic models to vibrational states in even-even nickel isotopes pointed out that the 0^+ members of the two-phonon states were pushed up high in energy and that there were no natural candidates for low-energy 0^+ two-phonon states. Such conclusions have helped call into question the usefulness of the phonon vibrational model. More systematic information on the properties of the 0^+ states would be helpful in clarifying our understanding of these nuclei.

II. RELATIVE HINDRANCE FACTORS OF ALLOWED DECAYS TO EXCITED 0^+ AND 2^+ STATES

In the past few years, the Vanderbilt group has been interested in the properties of even-even vibrational nuclei with $A = 60$–80 to obtain detailed information of the properties of levels at about twice the first excited state for comparison with theory. The levels in ^{66}Zn, ^{68}Zn, ^{80}Se, and ^{80}Kr have been carefully studied[5–7] with solid-state detectors and with directional-correlation techniques to establish 0^+ states in each of these nuclei. The present paper presents comments on these papers in light of the work of Sakai.

The log*ft* values of the allowed transitions from the 1^+ ground states of ^{66}Cu, ^{68}Ga, and ^{80}Br are the primary quantities of interest in this paper. The measured log*ft* values for the decays of these nuclei are given in Table I. The conclusion of Sakai[1] about the successive hindrances of the first and second excited 2^+ states holds in each case as evidenced by the increasing log*ft* values. The log*ft* values for decays to the excited 0^+ states, however, indicate that the allowed decays to these states proceed at rates not only much slower than those to the ground states but in two cases slower than those to the second excited 2^+ states, in contrast to other reports.[1–3] On closer inspection, it appears possible that of the first three $1^+ \to 0^+$ decays surveyed,[1] the decay schemes may not be sufficiently well known to really support the conclusion that decays to the excited 0^+ states proceed at the same rate as to the ground state.

The log*ft* value to the excited 0^+ state in ^{68}Zn is unusually large for an allowed transition. This large value suggests that the excited 0^+ and second excited 2^+

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[2] M. Sakai, Nucl. Phys. **A104**, 301 (1967).
[3] M. Sakai and E. der Mateosian (to be published) (quoted in Ref. 2).
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[5] H. K. Carter, J. H. Hamilton, and J. J. Pinajian, Phys. Rev. **178**, 1743 (1969).
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TABLE I. Logft values for allowed decays of ^{66}Cu, ^{68}Ga, and ^{80}Br which all have 1^+ spin and parity in their ground states. The logft values were taken from Refs. 5, 6, and 7, respectively.

Parent	Decay mode	Daughter	Level populated (keV)	Spin parity	logft
^{66}Cu	β^-	^{66}Zn	ground state	0^+	5.4[a]
			1039.2	2^+	5.5[a]
			1872.2	2^+	6.0
			2371.7	0^+	6.1
^{68}Ga	β^+, EC	^{68}Zn	ground state	0^+	5.2
	β^+, EC		1077.4	2^+	5.4
	β^+, EC		1655.7	0^+	6.8
	EC		1883.4	2^+	5.8
	EC		2338.7	2^+	5.7
	EC		2823.8	2^+	5.1
^{80}Br	β^+, EC	^{80}Se	ground state	0^+	4.5
	β^+, EC		665.6	2^+	4.9
	EC		1477.6	0^+	5.5
^{80}Br	β^-	^{80}Kr	ground state	0^+	5.6
			616.2	2^+	5.8
			1255.6	2^+	6.3
			1320.2	0^+	6.3

[a] G. Friedlander and D. E. Alburger, Phys. Rev. **84**, 231 (1951).

states are not of the same character and so should not be considered as members of a two-phonon triplet. Such a conclusion supports the calculations of Hsu and French[4] where the low-lying 0^+ states in the nearby nickel isotopes were not found to be two-phonon in character. The differences in logft values to the excited 0^+ and second 2^+ states in ^{66}Zn, ^{80}Se, and ^{80}Kr are too small to make such a conclusion there. Lifetime measurements would be helpful in establishing whether these 0^+ states are collective or more quasiparticle in nature.

Another interesting feature of the Zn nuclei concerns the second excited 2^+ states. Transitions from these states to the first 2^+ states are measured[8,9] to be 94 and 80% $E2$ in ^{66}Zn and ^{68}Zn. One finds the ratios of the $B(E2)$ values from the second 2^+ state to the first 2^+ state to that of the second 2^+ state to the ground state to be >8000 in ^{66}Zn and 45 ± 5 in ^{68}Zn. This same $B(E2)$ ratio for the third excited 2^+ state in ^{68}Zn is 1390 ± 700. Hsu and French[4] point out that absence of a ground-state transition is not evidence of a two-phonon state. The markedly different $B(E2)$ values to the ground state from the second 2^+ state in ^{66}Zn and ^{68}Zn suggest that these states are different in character too.

By including pairing plus quadrupole interactions, Futami and Sakai[10] were able to explain the observed increase in logft to the first excited 2^+ state over that to the 0^+ ground state in the decay of 1^+ odd-odd nuclei. They did not extend their work to higher excited states. Systematic knowledge of the ft values to and relative transition probabilities from excited 0^+ and second excited 2^+ states in even-even nuclei as surveyed in this paper should provide sensitive tests of models of these vibrational nuclei.

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