REGULARITY IN ENHANCEMENT PHENOMENON OF ALLOWED BETA-TRANSITIONS TO EVEN-EVEN NUCLEI

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Abstract

Recent attempts to understand the beta-decay process based on log *ft* values are mentioned. An up-to-date analysis of all allowed beta-transitions gives quite a few nuclei which show enhancement. Further study of these enhancements reveals a systematic trend in excitation energy, decay process and the existence of these even-even nuclei.

Introduction

Recent years have seen a rapid development of the theoretical understanding of the properties of the low-lying states of even nuclei. Most important in this respect have been the single-particle shell model (in the refined version) and the collective model. Within the framework of these has come a significant insight into the nuclear properties of medium-weight and deformed nuclei.

In the case of medium-weight nuclei the low-lying excited states have been understood as vibrational states which are characterised by a level sequence having a spin sequence 0^+, 2^+ and 2^+ $(2')$ for the ground state, first excited state and second excited state, respectively. Davydov and Fillipov[1] have shown that these levels can be considered as rotational states of an asymmetric rotor.

Many attempts have been made to understand the characteristics of these low-lying levels. These levels can result from a beta-decay process from the parent nucleus to the daughter nucleus followed by gamma-transitions between these low-lying excited levels. The character of gamma-ray was investigated by Kraushaar and Goldhaber[2] and by Scharff-Goldhaber and Weneser,[3] who obtained very useful conclusions as regards the multipolarity of gamma-transitions, transition-probabilities and energy-ratio of the 2′ to 2 state.

In the beta-decay process it is of interest to know about the nuclear matrix element M which is defined as $M = \int \psi_f^* H \psi_i$ where ψ_f and ψ_i are the wave-functions of the final and initial states in beta-decay, respectively. The nuclear matrix element, a measure of the overlap of the initial and the final state wave-functions, can be calculated theoretically if one has the knowledge of the wave-functions ψ_f and ψ_i. In cases where ψ_f and ψ_i are not known the matrix element can be computed by experimentally obtained value of log *ft*, which is a measure of the inverse of the square of the nuclear matrix element, M.

Beta-transitions have been classified as allowed or forbidden transitions depending on the log *ft* value. An analysis of log *ft* values for the 2′ to 2 states by Sakai[4] has brought to light the hindrance phenomenon in allowed transitions. Further, an extension[5] of this method of analysis to higher 2^+ levels and other excited states such as 4^+, has shown an enhancement in these beta-transitions. Both the hindrance and enhancement phenomena can be qualitatively related to the excitation mechanism of the various excited levels. One such attempt[6] to throw light on the excitation mechanism of 0^+ excited state has resulted in the interesting interrelationships for the log *ft* values. A promising approach to understand the hindrance and enhancement phenomena quantitatively has been made by Sakai and Yoshida[7] from the point of view of the paring correlation theory.

Our recent analysis[8] of the up-to-date data on allowed beta-transitions to 2′ and 2 states has prompted us to propose an empirical relation connecting log *ft* values and ratio of the excitation energy of these states. In this analysis we find hindrance to be general feature in allowed beta-transitions, but one cannot neglect the enhancement shown in quite a few cases. Here we have focused our attention on these exceptions to learn more about them.

B. Experimental Data Compilation

The nuclei which show enhancement are collected from recent publications, the guiding principle being that the transition to the 2′ state will have a lower log *ft* value than that to the 2 state, and are given in Table I. The experimental values in Table I, include the errors on log *ft* values and the excitation energies of the 2′ and 2^+ state, which have been carefully evaluated.

TABLE I

Parent Nucleus		Daughter Nucleus	E (2) Mev.	log ft (2)	E (2′) Mev.	log ft (2′)	Reference
$_{17}Cl_{17}{}^{34}$	$\xrightarrow{\beta^+}$	$_{16}S_{18}{}^{34}$	$2 \cdot 13 \pm 0 \cdot 002$	$5 \cdot 82 \pm 0 \cdot 02$	$3 \cdot 30 \pm 0 \cdot 004$	$4 \cdot 82 \pm 0 \cdot 02$	*a*
$_{21}Sc_{23}{}^{44}$	$\xrightarrow{\beta^+}$	$_{20}Ca_{24}{}^{44}$	$1 \cdot 16 \pm 0 \cdot 008$	$5 \cdot 33 \pm 0 \cdot 02$	$2 \cdot 28 \pm 0 \cdot 006$	$5 \cdot 12 \pm 0 \cdot 01$	*b*
$_{25}Mn_{31}{}^{56}$	$\xrightarrow{\beta^-}$	$_{26}Fe_{30}{}^{56}$	$0 \cdot 845 \pm 0 \cdot 003$	$7 \cdot 15 \pm 0 \cdot 12$	$2 \cdot 657 \pm 0 \cdot 005$	$5 \cdot 5 \pm 0 \cdot 14$	*c*
$_{29}Cu_{31}{}^{60}$	$\xrightarrow{\beta^+}$	$_{28}Ni_{32}{}^{60}$	$1 \cdot 3325 \pm 0 \cdot 0003$	$7 \cdot 45 \pm 0 \cdot 03$	$2 \cdot 159 \pm 0 \cdot 003$	$6 \cdot 37 \pm 0 \cdot 02$	*a*
$_{29}Cu_{33}{}^{62}$	$\xrightarrow{\beta^+}$	$_{28}Ni_{34}{}^{62}$	$1 \cdot 172 \pm 0 \cdot 003$	$7 \cdot 18 \pm 0 \cdot 12$	$2 \cdot 048 \pm 0 \cdot 003$	$5 \cdot 68 \pm 0 \cdot 08$	*a*
$_{51}Sb_{65}{}^{116}$	$\xrightarrow{\beta^+}$	$_{50}Sn_{66}{}^{116}$	$1 \cdot 272 \pm 0 \cdot 005$	$5 \cdot 21 \pm 0 \cdot 01$	$2 \cdot 20 \pm 0 \cdot 006$	$4 \cdot 82 \pm 0 \cdot 02$	*d*

Note.—The error estimates on excitation energies are assigned using the results of Van Patter (ref. *e*). In order to incorporate the errors on log ft values, the log ft values are re-evaluated taking into account the errors on disintegration energies, branching-ratios and half-life. In this re-evaluation use was made of Feenberg and Trigg's curves(Ref. *f*) and the nomogram of Moszkowaski (Ref. *g*).

(*a*) *LandoltBornstein, Energy Levels of Nuclei, A = 5 to A =* 257 [(Springer-Verlag, Berlin, 1961).

(*b*) Dillman, L. T. and Kraushaar, J. J., *Nuclear Physics*, 1962, **42**, 383.

(*c*) Pettersson, B. G., Hamilton, J. H. and Thun, J. E., *Ibid.*, 1961, **22**, 131.

(*d*) Fettweis, P. and Vervier, J., *Phys. Lett.*, 1962, **3**, 36.

(*e*) Van Patter, D. M., *Nucl. Phys.* 1959, **14**, 52.

(*f*) Feenberg, E. and Trigg, G., *Rev. Mod. Phys.*, 1950, **22**, 399.

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C. ANALYSIS OF DATA AND RESULTS

From Table I, the following conclusions can be drawn:

1. In all these nuclei which show enhancement in log ft value for 2′ state, the excitation energy for the 2′ state is greater than 2 Mev.

   The levels of these nuclei are populated *via* β^+ emission and electron capture process with the exception of Fe^{56}, which has been established as a rotational nucleus.

2. The enhancements occur in only those nuclei which have either neutrons or protons in closed or are near closed shell (differing only by 2 units).

3. The study[5] of the log *ft* values for the allowed beta-transitions from various other parent levels to the excited states of the common daughter nucleus indicates that the enhancement persists in the higher excited states of some of the nuclei given in Table I.

4. Such a regularity in excitation energy of the 2′ state, existence of these nuclei near closed shells and the consistent enhancements to the other higher excited states, is not found in other nuclei of the periodic table.

In conclusion, we hope that the theoretical developments based on these regularities will help to bring out this comparatively weaker phenomenon of enhancements.

References

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