Fine structure of β-decay strength functions

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Analysis of the spectrum of delayed protons of ^{147}Dy and of data in the literature on the decay schemes shows that the spacings between the levels, which are intensely populated by Gamow-Teller β transitions, are not random quantities. They instead vary in a regular fashion with the mass number of decaying nuclei.

During the decay of nuclei far from the stability valley, β transitions may populate a very large number of excited states of the daughter nucleus. The energy dependence of the density of reduced probabilities of the β transitions determines the strength function of the β decay, S_β. A study of the total-absorption spectra of cascade γ-ray

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transitions has shown[1] that the strength functions S_β are clearly of a resonance nature. At large excitation energies these resonances consist of a large number of closely spaced levels, which are not resolved by a total-absorption spectrometer.

In an effort to study the fine structure of S_β, we have carried out an analysis of the energy intervals between the levels which are intensely populated by Gamow-Teller β transitions during the decay of ^{147}Dy, an emitter of delayed protons. The proton spectrum is measured with a resolution $\approx$30 keV. The proton transitions which are observed in this spectrum correspond to excitation energies of the ^{147}Tb daughter nucleus from 3.8 to 6.5 MeV. Measurements of the total-absorption spectra of cascade γ-ray transitions have shown[3] that the resonance in S_β has an energy $\approx$4 MeV, so that the structure of the proton spectrum should reflect the structure of S_β in the resonance region. An important point is that in the decay of ^{147}Dy the intensity of proton transitions to excited states of the ^{146}Gd daughter nucleus is negligibly low, so that the proton energies are related unambiguously to the energies of β transitions. The delayed-proton spectrum of ^{147}Dy has a pronounced fine structure. When the barrier penetrability is taken into account, the proton transitions which are the most intense turn out to be those with energies of 2.0, 2.18, 2.54, and 3.26 MeV. The distances between levels are respectively 0.18, 0.36, and 0.72 MeV. The intervals between many other lines in the spectrum are also multiples of 0.18 MeV. Figure 1 shows the autocorrelation function of the delayed-proton spectrum, as found from the

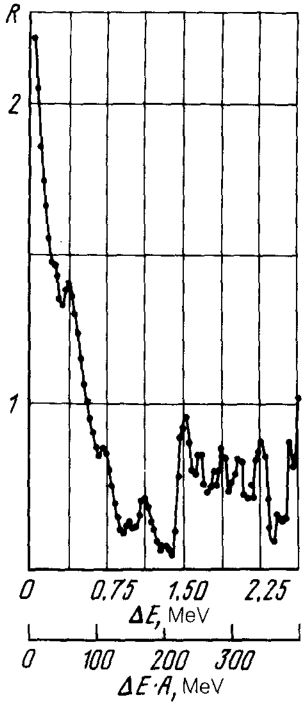

FIG. 1. Autocorrelation function of the spectrum of delayed protons for the decay of ^{147g}Dy.

formula

$$R(\Delta E)=\frac{\sum\limits_{i=1}^{N-k} S(i)S(i+k)}{\sum\limits_{i=1}^{N-k} S(i)\ \sum\limits_{i=1}^{N-k} S(i+k)}\,(N-k),\quad \Delta E=k\delta\ , \tag{1}$$

where δ is the width of the channel in the spectrum. We see from this figure that the function R has maxima at energies which are multiples of 0.375 MeV, indicating the existence of corresponding correlations in the positions of the intense peaks in the spectrum. An important point is that the selection rules on allowed Gamow-Teller β transitions in the β^+ decay of ^{147g}Dy cause a preferential filling of levels with an isospin $T=17/2$, which have the spin and parity $J^{\pi}=1/2^+$, $3/2^+$. However, the centrifugal barrier suppresses proton transitions from levels with spin 3/2 by an order of magnitude. Consequently, the observed correlations in the proton spectrum should primarily reflect correlations in the energies of levels with the quantum numbers $T=17/2$, $J^{\pi}=1/2^+$; they cannot be explained in terms of a splitting of spin or isospin multiplets.

After discovering such surprising correlations in the delayed-proton spectrum, we decided to study the distances between levels which are intensely populated by β transitions, working from the extensive data on decay schemes in the literature.[4] To

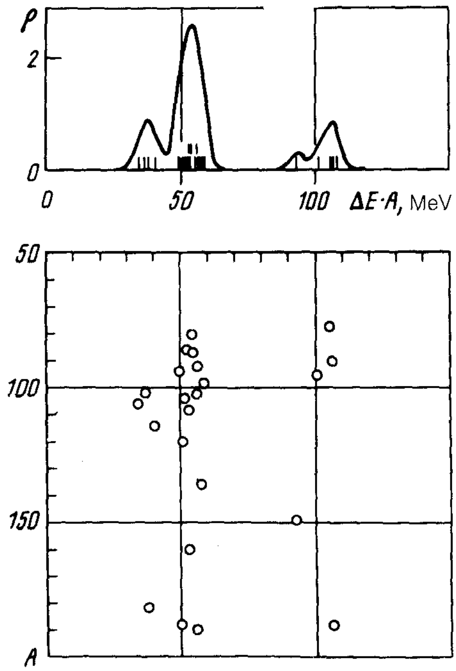

FIG. 2. Distribution of values of $\Delta E\times A$ for $0^+\rightarrow 1^+$ Gamow-Teller β transitions. The probability density ρ was found by convolving a discrete distribution with a Gaussian function.

eliminate cases of an isospin splitting of levels, we considered heavy nuclei with $A > 65$.

In the decay of even-even nuclei, the allowed Gamow-Teller transitions excite levels with the single definite value $J^{\pi} = 1^{+}$. Choosing levels with $\log ft \leqslant 5.5$ in the decay scheme—corresponding to allowed Gamow-Teller transitions—we determine the energy intervals (ΔE) between them. We first considered levels with the minimum value of $\log ft$ for the given scheme and the high-lying states. It turned out that the values of ΔE characterizing the fine structure of S_{β} decrease with increasing mass number A. Plotting $\log \Delta E$ versus $\log A$, we found that the points cluster around straight lines with a slope of A^{-1}, so that the value of the product $\Delta E \times A$ is essentially independent of A (Fig. 2). The probability for a random bunching of points (Fig. 2) near the values $\Delta E \times A = 53$ and 105 MeV is no greater than 10^{-4}, according to our estimates. A more detailed analysis of the decay schemes of even-even nuclei (we considered 70 decay schemes and 220 Gamow-Teller β transitions without additional selection rules) showed that the intervals encountered most frequently are $\Delta E = 2\hbar\omega_0/nA$, where $\hbar\omega_0 = 53$ MeV; $n = 1,2,3,4,$; and A is the mass number. Again in Fig. 2 we see a group of points near the values $\Delta E \times A = 36 \text{ MeV} = (2/3)\hbar\omega_0$; in Fig. 1 we see maxima corresponding to values of $\Delta E \times A$ which are multiples of $27 \text{ MeV} = (1/2)\hbar\omega_0$.

We also studied the decay of odd-odd nuclei with $J^{\pi} = 1^{+}$, i.e., the $1^{+} \rightarrow 0^{+}$ Gamow-Teller β transitions. In the β decay of these nuclei, both the ground state of the daughter nucleus and the 0^{+} excited states are intensely populated. Twenty-six decay schemes containing $1^{+} \rightarrow 0^{+}$ β transitions with $\log ft < 6.3$ not only to the ground state but also to excited states are given in the tables of Ref. 4 for nuclei with $A > 65$. Figure 3 shows the distribution of the values of $\Delta E \times A$. We see from this figure that the points again group around values that are multiples of 52 MeV (marked by the arrows). We estimate the probability for a random bunching of the values of $\Delta E \times A$ to be no greater than 10^{-3}.

We believe that these results demonstrate convincingly that the distances between levels which are intensely populated by Gamow-Teller β transitions are not random quantities but instead depend in a regular way on the mass number A; specifically, we have $\Delta E = \hbar\omega/A$. For the most intense transitions, the values of $\hbar\omega$ are multiples of the quantity $\hbar\omega_0 = 53 \pm 5$ MeV. For the weaker transitions, intervals $\Delta E = 2\hbar\omega_0/nA$ are frequently found. Curiously, a set of fractional resonant frequencies of this sort is

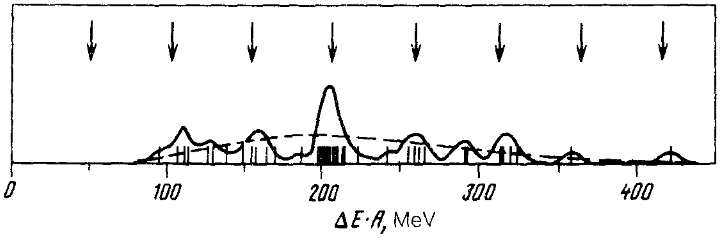

FIG. 3. Distribution of the values of $\Delta E \times A$ for $1^{+} \rightarrow 0^{+}$ Gamow-Teller β transitions. The arrows show the values of $\Delta E \times A$ which are multiples of 52 MeV.

characteristic of the combinational excitation of parametric resonances,[5] so we do not rule out the possibility that the regular behavior which we have discovered in the fine structure of S_β may be related to the parametric excitation of some hypothetical elementary mode with a frequency $\hbar\omega_0$ equal to $53/A$ MeV. We wish to stress that we were unable to find a dependence of $\hbar\omega_0$ on the spin, isospin, or deformation of the nuclei or a magic-number effect. We believe that the behavior which we have found here does not conform to existing nuclear theory.

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