FLUCTUATIONS IN PARTIAL RADIATION WIDTHS*

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One of the main efforts of slow-neutron spectroscopy has been to measure and interpret the distribution of partial widths for elastic scattering, radiative capture, and fission in neutron resonances. Continuing improvements in experimental techniques have now made it feasible to investigate the distribution for another kind of width, the partial width for individual radiative transitions. Of special interest is the distribution of the widths Γ_{ij} for high-energy transitions to some single low-energy state from the many closely spaced states i that are formed by capture of s-wave neutrons in resonances with a particular value of the total angular momentum J.

The published experimental evidence concerning the distribution of the partial radiation widths appears to be contradictory. Kennett et al.[1] and Bird et al.[2] find evidence that the distribution of partial widths for transitions in Mn^{56} and Hg^{200} are broad. In contrast, Hughes et al.[3] have reported results for W^{184} which are interpreted as indicating that the partial radiation widths fluctuate only slightly. We have attempted to clarify the experimental evidence by performing a more extensive and refined set of measurements than those previously reported. The experimental objective of our study was to observe the high-energy end of resonant-capture gamma-ray spectra in enough detail to be able to determine the probabilities of transitions not only to the ground state but also to one or more of the low-energy states of the compound nucleus. These transition probabilities were obtained from the pulse-height spectra of a single large (4 in. × 4 in.) NaI(Tl) scintillator of good quality and from the spectra associated with coincident counts in two crystals. To achieve a high intensity of gamma rays from resonant capture, the Argonne fast chopper was used with the exceptionally short flight path of 6.7 m. As a result, the neutron time-of-flight resolution was poor (~0.4 μsec/m) and only a few resonances could be studied in each nuclide.

Our most reliable spectra for isolating individual transitions result from capture in resonances of the even-odd target nuclides Pt^{195} and Hg^{199}. An example of the pulse-height spectra recorded is given in Fig. 1. By unfolding these spectra we obtain relative probabilities of transitions to the ground state and to the first excited state. When necessary, these results were checked by coincidence measurements. The data obtained are summarized in Table I. The relative widths ρ_{ij} are obtained under the assumption that the number of detector pulses having a height greater than about 1.5 Mev is proportional to the number of neutrons captured. This assumption depends on the belief that the multiplicity of γ rays is approximately constant for resonances in a single nuclide, a belief that was confirmed experimentally for the nuclides studied. The errors given for the ρ_i are principally estimates of systematic uncertainties resulting from an incomplete knowledge of line shapes for single γ rays. When they

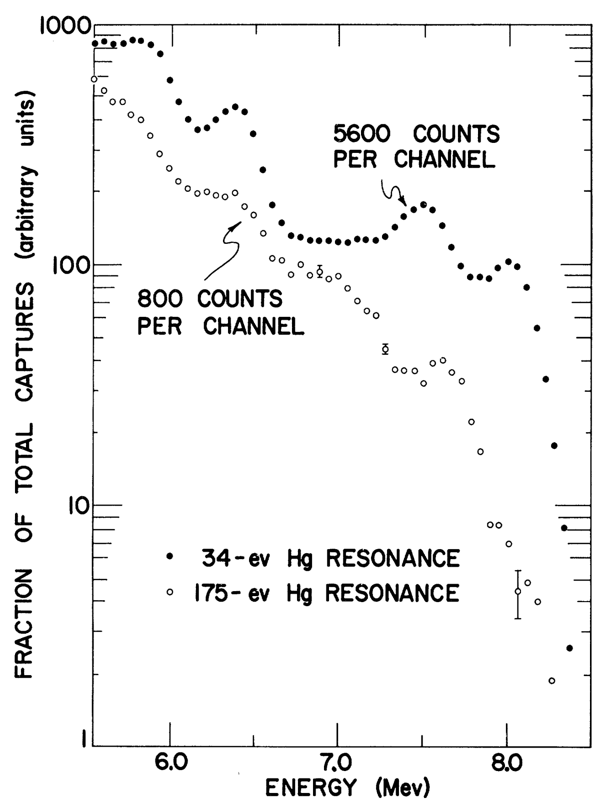

FIG. 1. Pulse-height spectrum of γ rays resulting from neutron capture in the 34- and 175-ev resonances of Hg^{199}. The ground-state transition at 8.03 Mev is clearly seen for the 34-ev resonance. In contrast, this transition for the 175-ev resonance is lower by more than an order of magnitude. Also of interest is the large difference in intensity between transitions to the ground state and the first excited state (7.66 Mev) of the 175-ev resonance.

are listed, the absolute values of partial widths Γ_{ij} were obtained by normalizing our data on gamma rays from thermal capture to those tabulated by Bartholomew.[4]

In general, the spin assignments of the resonances studied are not known from measurements independent of the gamma-ray spectra. Thus the spin assignments must be made on the basis of the characteristics of the high-energy spectra.[5] For s-wave capture in Pt^{195} and Hg^{199}, the compound nuclide is formed in either a 0^- or a 1^- state. An observation of a moderately strong transition to either the 0^+ ground state or the 2^+ first excited state was taken as evidence for an $E1$ transition and hence for an initial state having $J=1$.

The data of Table I are summarized in graphical form in Fig. 2, where the integral distribution of the ratio $R_{ij}=\rho_{ij}/\rho_{(i+1)j}$ is plotted. Since the distribution of R is the same as that of R^{-1}, we use the value that is less than unity. In an effort to obtain a quantitative measure of the distribution of the partial radiation width Γ_{ij}, we follow the Porter-Thomas procedure[6] of assuming the correct distribution to be a χ^2 distribution with ν degrees of freedom, i.e.,

$$dF=\frac{(\nu/2)^{\nu/2}}{\Gamma(\nu/2)}x^{\nu/2-1}e^{-\nu x/2}dx, \qquad (1)$$

where $x=\Gamma_i/\bar{\Gamma}$ and $\Gamma(\nu/2)$ is the well-known Γ function. The dashed curves in Fig. 2 show the fraction of cases for which R_{ij} is greater than the specified value, the fraction being computed from Eq. (1) for several values of ν. The qualitative comparison of the experimental data of Fig. 2 with the calculated distributions indicates clearly that the correct value of ν is a small number. To obtain a more quantitative estimate of ν, the data for Pt and Hg have been treated by the method of

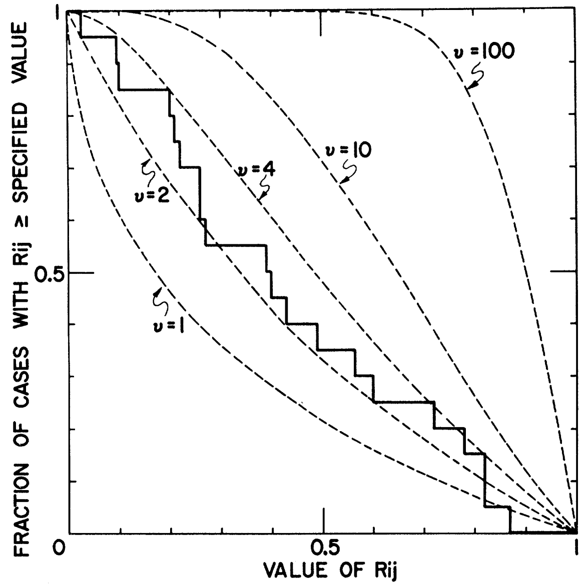

FIG. 2. The integral distribution of width ratios $R_{ij}=\rho_{ij}/\rho_{(i+1)j}$. The solid curve represents the experimental data; the dashed lines are calculated curves for various values of ν.

Table I. Partial widths for high-energy radiative transitions. The superscripts 0 and 1 on ρ and Γ refer to the ground state and first excited states, respectively. The energies of first excited states are W^{184}, 111 kev; Pt^{196}, 354 kev; Hg^{200}, 368 kev. The values of ρ for different nuclides are normalized in an arbitrary way with respect to each other and should not be compared; however, for each resonance $\rho^1/\rho^0=\Gamma^1/\Gamma^0$.

Target nuclide	Resonance energy (ev)	J	$(\rho^0+\rho^1)$	ρ^0	ρ^1	Γ^0 $(10^{-6}$ev)	Γ^1 $(10^{-6}$ev)
Hg^{199}	-2	(0)		<0.03	0.31±0.11	<90	800
	34	1		3.52±0.03	0.26±0.06	9000	670
	130	(1)		0.35±0.19	0.32±0.17	900	820
	175	1		0.09±0.06	1.25±0.12	230	3100
Pt^{195}	12	1		1.78±0.07	<0.1		
	20	1		0.46±0.05	0.18±0.03		
	68	1		0.76±0.06	0.43±0.10		
W^{183}	7.6	1	2.53±0.11	2.25±0.15	0.28±0.09		
	27	1	1.48±0.08	0.23±0.10	1.25±0.09		
	41	1	0.75±0.16	0.26±0.10	0.49±0.12		
	46	1	1.62±0.10	1.27±0.40	0.35±0.09		

maximum likelihood,[7] which allows both ν and the mean values $\bar{\rho}_i$ to be unknown parameters to be determined from the data. By this treatment we find with 80 % probability that $0.7 \leq \nu < 4$, the most probable value being 2.4.

The wide fluctuations observed in the partial widths given in Table I are probably consistent with the data of Bird et al.,[2] but seem flatly contradictory to the observation of Hughes et al.[3] of a "deviation from the mean of only 20 %" in the widths for ground-state transitions from the states of W^{184}. Therefore, in an effort to resolve the discrepancy and to check on the possibility that ν differs from nuclide to nuclide, we also have studied the gamma-ray spectra from capture in resonances of W^{183}. Because of the small separation (111 kev) of the first excited state from the ground state in W^{184}, these spectra are much harder to resolve into individual transition probabilities than are the spectra for Pt^{196} and Hg^{200}. The quantity that can be obtained with greatest certainty is the sum $(\rho^0 + \rho^1)_i$ of relative widths for transitions to the ground state and the first excited state. The values obtained for this sum (listed in Table I) exhibit a surprising degree of uniformity. However, by examining the pulse-height spectra for W^{184} with great care, we are able to deduce approximate values of individual widths and then we find strong evidence for a broad distribution. Treating these data in the same way as those for Pt^{196} and Hg^{200} we obtain $0.6 < \nu < 6$; again the most probable value is 2.4. This result is entirely consistent with that given by the data for Pt^{196} and Hg^{200}. We conclude from our study of W^{184} that the partial widths reported by the Brookhaven group[3] for "ground-state transitions" are in reality the sum of widths for transitions to two low-energy states; this summing, combined with a statistical accident, accounts for the uniformity of their results.

Although our values for the partial radiation widths fluctuate widely, it is of theoretical importance to determine quantitatively whether or not the data are consistent with what would be expected for a single-channel process,[6] for which $\nu = 1$. This question was studied by means of a Monte Carlo calculation which allowed us to take into account our inability to observe very weak transitions. Assuming the experimental values of the partial widths to be a sample drawn from a population that obeys the Porter-Thomas distribution ($\nu = 1$), we find that there is a 30 % chance of obtaining an estimate of ν that is greater than our experimental value. Thus we conclude that the experimental data are in good agreement with a distribution having $\nu = 1$.

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ELECTRON CAPTURE DECAY OF ORIENTED NUCLEI

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Recent developments in the theory of beta decay[1] implying that the Hamiltonian is not invariant with respect to space inversion and charge conjugation (and perhaps also time reversal), have suggested new types of experiments which might yield information concerning the beta-decay interaction. In this paper we suggest an experiment on oriented nuclei, the results of which should enable one to make a choice between the ST and VA variants.

The angular distribution of recoil nuclei from the decay by electron capture of oriented nuclei has been computed by Treiman[2] and Frauenfelder et al.[3] The angular distribution function is

$$F(\theta) = \frac{1}{4\pi}\left[1 - \frac{\langle J_z \rangle}{J}\frac{B_+}{1+b}\cos\theta\right],$$