STRUCTURE IN THE RESONANCE NEUTRON CAPTURE IN ^{115}In †

C. Coceva,* F. Corvi,* P. Giacobbe,* and M. Stefanon*
Bureau Centrale de Mesures Nucleaires, EURATOM, Geel, Belgium, and Comitato Nazionale per l'Energia Nucleare, Centro di Calcolo, Bologna, Italy
(Received 23 January 1970)

Gamma rays from resonance neutron capture in ^{115}In were detected in the neutron energy range 40 eV-1 keV. The resonance energy dependence of the radiative transition intensities to the low-lying levels shows a nonstatistical structure. This structure is found to be correlated with the local neutron strength function.

In the last years several cases have been observed of partial failure of the statistical model in interpreting both thermal and resonance neutron capture data. Interpretations of these effects in terms of doorway states were advanced.[1-3] The result of the present experiment provides new information on the subject, suggesting that a role in the nonstatistical behavior of gamma decays following slow neutron capture may be played by components, in the compound nucleus state, of higher hierarchy than doorway states in the neutron channel.

The yield of the (n, γ) reaction in ^{115}In for resonance neutrons below 1 keV was measured by time-of-flight technique with about 1% resolution. The experiment was performed at the Bureau Centrale de Mesures Nucleaires–EURATOM Linac of Geel on a 50-m flight path. A sample of natural isotopic composition was used. Two NaI(Tl) detectors (with diameter and height both equal to 15 cm) were used to measure for each resonance of ^{115}In the intensity of emitted γ rays above a 4-MeV threshold, in an experimental setup like that of Coceva, et al.[4] To prevent detection of neutrons scattered from the sample, each crystal was shielded with a 2.5-cm thick boron-loaded polyethylene plate and with a 2-g/cm^2-thick layer of ^{10}B. The count rate due to scattered neutrons was determined in a separate run and was found to be in any case less than 1% of the counts due to captured neutrons. The gamma intensity above 4 MeV was normalized to the total capture intensity, which was assumed to be proportional to the yield obtained with an energy threshold of 1.6 MeV. The ratio R between the two intensities is then roughly proportional to the sum of all partial radiation widths above 4 MeV, corresponding to final states below 2.5-MeV excitation energy.

On the basis of the statistical model one should expect that, for a given nucleus, the values of R depend just on the spin of the resonances. This was confirmed in similar experiments on the even-Z, odd-N target nuclei of Ref. 4 where, apart from a clear grouping according to the two spin values of s-wave resonances, the R values fluctuate within narrow limits and do not show any energy dependence. In the case of ^{115}In ($Z = 49$, $I = \frac{9}{2}$), one would expect a very weak spin effect. In fact an odd-odd nucleus, such as ^{116}In, has a large number of low-lying states with a wide range of spin values. This reduces the influence of the initial spin on the decay chain.

The experimental R values for 56 ^{115}In resonances, in the range 40 eV-1 keV, are plotted against neutron energy in Fig. 1. The ^{115}In resonances were selected according to the isotopic assignment of the Columbia group.[5] In order to reduce the influence of p-wave resonances, the conditional probability theorem was used as in Bollinger and Thomas[6] to calculate for each resonance the probability of being excited by p-wave neutrons. Eleven resonances with a probability larger than 50% were then eliminated from the data presented here. Figure 1 shows no evidence of the double-peaked distribution characteristic of a spin effect. The relative spread of the R values, although rather large (≈30%), would not be definitely inconsistent with a reasonable number of degrees of freedom. However, the data show that the spread is due not to random fluctuations but to a systematic behavior consisting of a strong modulation as a function of resonance energy. The nonrandomness is rather evident. In the range 40-500 eV the test for randomness based on the number of the sequences of points lying systematically below or above the median gives a 1% probability level. Furthermore, a serial correlation analysis with lag 1 (i.e., correlation between adjacent values) performed in the same energy range gives a serial correlation coefficient $\rho = 0.41$ which falls at the 1% probability level for zero correlation. The systematic behavior of R indicates a structure in the decay probability of the capture states to low-excitation levels. The effect may be due to a recurrence in the capture states of components strongly coupled via electromagnetic interaction

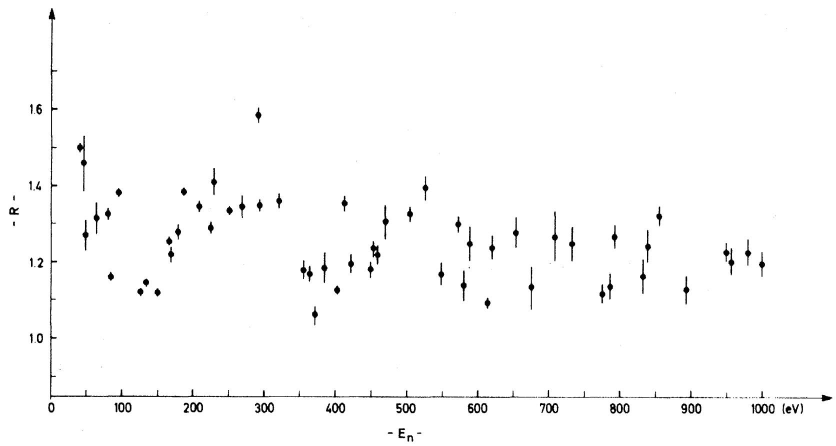

FIG. 1. Values R of the high-energy γ-ray intensity ($E_\gamma > 4$ MeV) normalized to the intensity above 1.6 MeV for ^{115}In neutron resonances between 40 eV and 1 keV. The vertical scale is in arbitrary units.

to low energy states. In other words, the effect should be related to doorway states in the outgoing channels. The amplitude of such states in the compound nucleus wave function will have a resonant behavior giving rise to the observed modulation. As the low-lying states are characterized by a small number of excitations, the same must hold for the components responsible for the hardening of the gamma spectrum. The spacing between these components should characterize the modulation of the R values. It must be pointed out that the intermediate structures observed up to now in the neutron strength function have widths two orders of magnitude larger than the width of the structure observed in the present experiment, which is about 200 eV. This is to be expected as the states directly coupled via electromagnetic radiation to states with excitation energy up to 2.5 MeV may be more complex than doorway states in the neutron channel. In Fig. 2 the R values averaged over 50-eV intervals are compared with the neutron strength function calculated in the same intervals from the $g\Gamma_n{}^0$ values of the Columbia group.[5] A similar structure appears in both histograms: The correlation coefficient between $\langle R\rangle$ and $\sum g\Gamma_n{}^0$, calculated over the whole energy range, is $\rho(\langle R\rangle, \sum g\Gamma_n{}^0) = 0.51 \pm 0.17$ and falls at the 2% probability level for zero correlation. Positive correlations between radiation and neutron widths were already observed[7,8] and the effect was explained in terms of channel capture. In the present case however such an explanation meets with some difficulties because of the following reasons:

(i) In a study of gamma decay from ^{115}In neutron resonances, Earle, Lone, and Bartholomew[9] found no evidence of correlation between the averaged partial widths and the corresponding (d,p) spectroscopic factors.

(ii) The correlation coefficient between single values of R and $g\Gamma_n{}^0$ is only $\rho(R, g\Gamma_n{}^0) = 0.14 \pm 0.13$, which is significantly lower than the correlation coefficient between the local averages reported above. Besides this, the value of $\rho(\langle R\rangle, \sum g\Gamma_n{}^0)$ in the interval 500-1000 eV is $\rho = -0.1 \pm 0.3$. In other words, the correlation is shown up by the local averaging and is limited to the range 40-500 eV (just where the structure in the R values was established). Both facts

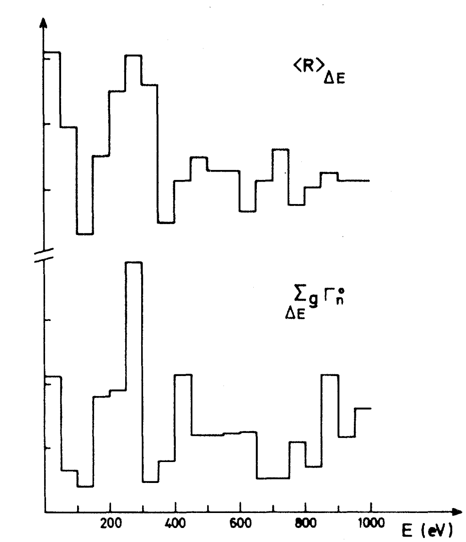

FIG. 2. The quantity $\sum g\Gamma_n{}^0$, which is proportional to the local neutron strength function, is plotted together with the average values $\langle R\rangle$ of the high-energy γ-ray intensities. Both quantities are calculated in neutron energy intervals $\Delta E = 50$ eV. The vertical scales are in arbitrary units.

indicate that the correlation is essentially connected with a short-range modulation.

A possible explanation may be given in terms of intermediate configurations if one assumes that the same state which is strongly coupled via gamma radiation to the low-lying states be also a significant step in the coupling between the resonances and the neutron channel.[3] This state should be an exceptionally long-lived doorway or, more probably, a state of higher hierarchy.

The shell-model level scheme indicates that high-energy ($E_\gamma > 4$ MeV) dipole radiation in ^{116}In should be mostly due to proton transitons between the $1g_{7/2}$ and $1g_{9/2}$ levels. Accordingly, in this mass region, strong $M1$ transitions are expected and have been found experimentally in the isotopes of tin[10] and also in the thermal and resonance neutron capture in ^{115}In.[9,11] We may therefore tentatively assume that the observed structure is due to the proton excitation coupled to a residual excitation of about 2 MeV. Under such assumption, one can estimate the order of magnitude of the intermediate level density by multiplying the density of states of ^{116}In at about 2 MeV by the degeneracy of the proton transition. If the spacing of levels at 2 MeV having the correct spin and parity is taken to be about 10 keV, one obtains a density of the order of 2.5 keV^{-1}, in agreement with the observed modulation.

It must be pointed out that one would expect the superposition of two independent structures corresponding to the two spin values. The data of Fig. 1 are not inconsistent with this possibility; however, this point might be clarified only after a spin determination of the resonances.

The authors are very grateful to G. Hacken of Columbia University for having supplied before publication the isotopic assignments and neutron widths of the In resonances.

---

†Work performed within a EURATOM–Comitato Nazionale per l'Energia Nucleare cooperation program for nuclear data measurement.

*Comitato Nazionale per l'Energia Nucleare, Ispra, Italy.

[1]G. A. Bartholomew, in *International Symposium on Neutron Capture Gamma Ray Spectroscopy, Studsvik, Sweden, August 1969* (International Atomic Energy Agency, Vienna, Austria, 1969), p. 553.

[2]K. Rimawi *et al.*, Phys. Rev. Lett. 23, 1041 (1969).

[3]A. M. Lane, Phys. Lett. 31B, 344 (1970).

[4]C. Coceva *et al.*, Nucl. Phys. A117, 586 (1968).

[5]G. Hacken *et al.*, Bull. Amer. Phys. Soc. 14, 494 (1969), and private communication.

[6]L. M. Bollinger and G. E. Thomas, Phys. Rev. 171, 1293 (1968).

[7]M. Beer *et al.*, Phys. Rev. Lett. 20, 340 (1967).

[8]M. A. Lone *et al.*, Phys. Rev. 174, 1512 (1968).

[9]E. D. Earle, M. A. Lone, and G. A. Bartholomew, in *International Symposium on Neutron Capture Gamma Ray Spectroscopy, Studsvik, Sweden, August 1969* (International Atomic Energy Agency, Vienna, Austria, 1969), p. 595.

[10]J. A. Harvey *et al.*, ANL Report No. 6797, 1963 (unpublished), p. 230; M. R. Bhat *et al.*, Phys. Rev. 166, 1111 (1968).

[11]A. Fubini *et al.*, in *International Symposium on Neutron Capture Gamma Ray Spectroscopy, Studsvik, Sweden, August 1969* (International Atomic Energy Agency, Vienna, Austria, 1969), p. 317.