INTERFERENCE IN THE RADIATIVE CAPTURE OF NEUTRONS*

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The interest in the shapes of resonances in the cross sections of nuclides for interactions with s-wave neutrons has now extended over a period of twenty years. In spite of the long and rather intense study of this problem in which the shapes of resonances attributed to scattering, fission, and radiative capture have been investigated extensively, the shapes associated with some processes have not been observed. One of these is the resonance capture which results in a single mode of radiative decay of the compound nucleus, i.e., decay by emission of the gamma ray to a particular energy level of this nucleus. If this can be considered to be a single-channel process in the compound nucleus model, the theory says definitely that the partial radiation widths which correspond to each mode of de-excitation should belong to a statistical population drawn from a χ^2 distribution with 1 degree of freedom, and the wave amplitudes associated with each mode should add coherently to give the cross sections of the particular process.[1] In other words, the process should be similar to the elastic scattering of neutrons in these particulars. Data already presented[2] indicate that the observed partial widths are consistent with the χ^2 distribution with 1 degree of freedom.

Here we are concerned with the second point. Coherent addition of the wave amplitudes is usually made apparent through interference effects. However, in contrast to the situation for scattering resonances, resonances which are caused predominantly by capture have shown none of the asymmetries associated with interference effects, the explanation being that the interference effects cancel because of the addition of very many interference terms of random signs. It is therefore apparent that an interference effect associated with radiative capture can be observed only if the study selects a single mode of decay, or only a very few.

The aim of the present experiment was to measure the relative intensity of individual capture gamma rays as a function of neutron energy in the vicinity of the Pt^{195} resonances at 11.9 and 19.6 ev, both of which are known[2] to have $J=1$.

The measurements were made with the Argonne fast chopper[3] operated at a speed of 15 000 rpm. The sample, a piece of normal platinum 6 in. × 12 in. × 0.080 in., was mounted 25 m from the chopper at an angle of about 22° to the beam. The over-all time-of-flight resolution of the system was 0.16 μsec/m. The capture gamma rays were detected by a NaI(Tl) scintillator, 6 in. long by 8 in. in diameter, whose output was fed to an analog-to-digital converter. All of the digitalized pulse heights and the time differences corresponding to the energies of the captured neutrons were recorded on magnetic tape in the ANL three-parameter analyzer.[4] In order to be able to correct for the effects of possible gamma-ray summing, two experiments were performed, one with the crystal $5\frac{3}{8}$ in. from the center of the sample, and another with the crystal $10\frac{3}{8}$ in. from the sample. However, both this series of experiments and others[5] performed for the purpose of determining partial radiation widths show that for platinum no such correction is necessary.

For the two Pt^{195} resonances being considered, the easiest transition to observe is the one directly from the initial state to the ground state. The relative intensity for this transition may be studied by means of the ratio R_0/R_γ, where R_0 is the intensity of pulses (in a given time channel) for which the height is in the neighborhood of the binding energy and R_γ is the intensity of pulses in a broad band at a much lower energy. It is assumed that, because of the complexity of the capture γ-ray cascade, R_γ is a measure of the rate of neutron capture. The experimental values for the ratio R_0/R_γ are shown in Fig. 1. The point (indicated by ×) shown for $E = 0.0253$ ev was the result of a separate experiment performed with the rotor of the chopper stationary. Although the quantity of interest in this experiment is the relative strength of the ground-state transition compared with the total capture in resonances of Pt^{195} with total angular momentum $J=1$, the ratio R_0/R_γ is a measure of the fraction of this transition in the total capture in all isotopes of platinum. However, over the energy region dominated by the 11.9- and 19.6-ev resonances, the difference between these ratios is not significant; the other isotopes make a significant difference only for the experimental point

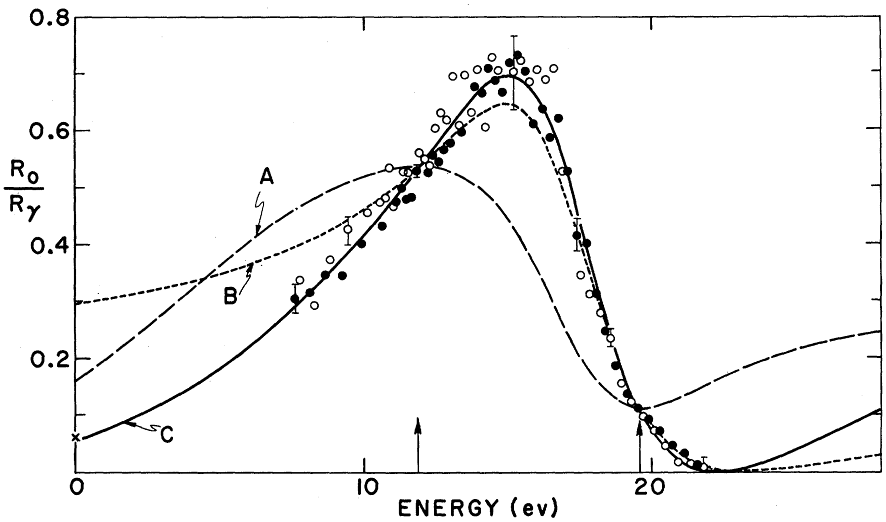

FIG. 1. The relative strength of the 7.92-Mev ground-state transition in Pt^{196} following neutron capture in platinum as a function of neutron energy. The open circles are the result of an experiment in which the distance from sample to detector was $10\frac{5}{8}$ in., the solid circles from one in which this distance was $5\frac{5}{8}$ in. The indicated errors are standard statistical errors. Curve *A* is the shape of the variation expected if no interference occurs between levels of the same *J*. Curve *B* shows the shape expected if the components associated with the resonances at 11.9 and 19.6 ev (indicated by arrows) interfere, and the contributions from other levels are ignored. Curve *C* is the expected shape if all of the levels listed in Table I are included and interference is allowed between all levels of the same *J*.

at thermal energy.

Along with the data shown in Fig. 1 are three curves computed on the basis of a simple multilevel formula[6] applicable to the present case in which $\Gamma \ll D$. Curve *A* shows the shape obtained on the assumption that no interference exists. Curve *B* was computed for the case of interference between the 11.9- and 19.6-ev resonances with no others included. Curve *C* shows the shape obtained if all resonances of the same *J* are allowed to interfere. The parameters used

Table I. The resonance parameters used in computing the curves of Fig. 1. The partial radiation widths $\Gamma_{\gamma 0}^*$, although of the order of magnitude of the absolute partial radiation width $\Gamma_{\gamma 0}$, must be considered meaningful only with respect to each other; the absolute values are of no importance here. The quantity in the last column is proportional to the wave amplitude.

E_0 (ev)	J	Γ_n^0 (ev)	Γ_γ (ev)	$\Gamma_{\gamma 0}^*$ (ev)	$\lvert\sigma_0\Gamma_{\gamma 0}^*\lvert E\rvert^{1/2}\Gamma^{-1}\rvert^{1/2}$
-13.6[a]	0	0.0302[a]	0.100[b]	0.0	0.0
or -13.0[a]	1	0.0092[a]	0.100[b]	≤0.00001	+3.2
11.9	1[c]	0.0034[d]	0.112[d]	0.00505[e]	+43.5
19.6	1[c]	0.0016[d]	0.100[d]	0.00095[e]	-15.9
67.4[f]	1[e]	0.0044	0.100[b]	0.0039[e]	-42.5

[a]Chosen so that the contribution to the thermal capture cross section would be consistent with the measured value for Pt^{195}.
[b]Assumed.
[c]See reference 2.
[d]John R. Waters, Phys. Rev. 120, 2090 (1960).
[e]See reference 5.
[f]See reference 7.

in the computation are listed in Table I. A few remarks about some of these parameters are relevant. Since the known positive energy levels do not account for the measured thermal capture cross section for Pt^{195}, a bound level needs to be included in the computations to obtain results consistent with the experimental data. On the assumption that $\Gamma_\gamma = 0.100$ ev, a set of parameters E_0 and $\Gamma_n{}^0$ was selected for this level, for each possible value of J, which provides the correct amount of capture at thermal energies. A value of the partial radiation width $\Gamma_{\gamma 0}$ and the sign of the wave amplitude were selected for the set with $J = 1$ that gave a proper fit to the data. (An equally good fit can be obtained with the opposite sign and correspondingly different $\Gamma_{\gamma 0}$.) Of course, $\Gamma_{\gamma 0} = 0$ for $J = 0$. No obvious choice can be made between these solutions, so all sets of parameters have been included in the table. There are known to be two resonances in Pt^{195} near 68 ev.[7] Studies of the capture gamma rays that result from neutron capture in these resonances suggest that only the higher energy resonance of the pair has $J = 1$.[5] An area analysis of some unpublished transmission data, under the assumption that $\Gamma_\gamma = 0.100$, leads to the estimate $\Gamma_n = 0.136$ ev for this resonance.

On the basis of the excellent agreement between the data and curve C and the obvious disagreement between the data and the curve A, it can be concluded that interference does occur between radiative transitions associated with neutron resonances of the same J. Curve B merely strengthens the argument by showing that the dominant features of the data (the maximum between the resonances and more importantly the minimum above) are accounted for by consideration of only the well-known nearby resonances and are not strongly dependent on the parameters of the less well-known distant resonances.

Since the number ν of channels available for this process of radiative capture to a particular final state has been the subject of much debate during the past few years, it is of interest to emphasize that the present results are consistent with a single-channel process. Furthermore, the improvement in the quality of the fit brought about by the inclusion of the 68-ev resonance strengthens the argument that $\nu = 1$, and certainly requires that ν be a number very near one, if not equal to it, since the interference between three neighboring levels would be very unlikely if the process could proceed through many channels.

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