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FLUCTUATIONS OF NUCLEAR CROSS SECTIONS IN THE "CONTINUUM" REGION

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The assumption that the matrix elements of the compound nucleus are randomly distributed with respect to phase and magnitude has in recent years been very successful for the understanding of the fluctuations of the partial widths and the distribution of the level spacings of slow-neutron resonances.[1-3]

The purpose of this note is to examine the nontrivial consequences of this assumption in the so-called "continuum" region, in which the compound states overlap owing to the short lifetime of the compound nucleus. It is shown that (1) cross sections fluctuate in that region even though a large number of intermediate states are excited, (2) the formation and decay of the compound nucleus are independent only on the average and, (3) the fluctuations can be used to determine the lifetime of the compound nucleus in the "continuum" region.

Consider the compound-nucleus reaction proceeding from the initial state $|\alpha\rangle$ -- i.e., the target nucleus and the incident wave-- to the final state $|\alpha'\rangle$, a particular state of the final nucleus and the corresponding emitted wave. We assume the experiment to be performed with infinitely good energy resolution in the incident beam. The scattering matrix $S_{\alpha\alpha'}$ can be divided into two parts, one, S_{α}, leading into the compound nucleus, and one, $S_{\alpha'}$, leading out of the compound nucleus. The intermediate compound states $|i\rangle$

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of energy E_i are excited with probability amplitudes $f(E,E_i)$ which are approximately of the Lorentzian type

$$|f(E,E_i)|^2 \propto \frac{1}{(E-E_i)^2 + \Gamma^2/4}. \tag{1}$$

The "width" Γ is related to the lifetime τ of the compound nucleus by $\Gamma = \hbar/\tau$ by the uncertainty principle. Equation (1) expresses that the compound states within a region of the order of Γ are excited simultaneously and must be treated coherently; we therefore call Γ the coherence energy. The reaction cross section $\sigma_{\alpha\alpha'}$ can be written

$$\sigma_{\alpha\alpha'} \propto \left| \sum_i \langle \alpha | S_\alpha | i \rangle f(E,E_i) \langle i | S_{\alpha'} | \alpha' \rangle \right|^2. \tag{2}$$

The matrix elements $\langle \alpha | S_\alpha | i \rangle$ and $\langle i | S_{\alpha'} | \alpha' \rangle$, and consequently their product, have random phases. If the coherence energy Γ encompasses a large number of intermediate states $|i\rangle$, the sum in Eq. (2) consists of a large number of terms of random phases and becomes a random number, the real and imaginary part of which have Gaussian distributions. Therefore, if transitions to different final states are compared under otherwise identical conditions, the transition-matrix elements are independently random, because the factors $\langle i | S_{\alpha'} | \alpha' \rangle$ are uncorrelated and have uncorrelated phases. The partial cross sections $\sigma_{\alpha\alpha'}$ therefore fluctuate essentially like neutron widths in spite of the large number of compound states excited.

Furthermore, intermediate states $|i\rangle$ are excited essentially only within the coherence energy Γ. If the incident energy is changed by an amount much larger than Γ, the intermediate states are entirely different. The matrix element, thus the cross section, is different from its previous value, in general. On the other hand, if the energy change is small compared with Γ, essentially the same states are excited; the matrix element and cross section

are practically unchanged. Therefore we conclude that a partial reaction cross section will fluctuate as a function of incident energy with a typical period of the order of the coherence energy Γ. Because Γ is directly related to the compound nucleus lifetime, these fluctuations, in principle, provide a means for measuring the extremely short lifetimes of highly excited nuclei.

We point out that the usual statement of independence of formation and decay of the compound nucleus is not valid in this type of experiment: the fluctuations do not occur at the same excitation energy, if the same compound nucleus is formed by different means. In the "continuum" region this independence is a consequence of averaging over many residual states, or over an energy interval much larger than the coherence energy.

A more exact discussion should include angular momentum. The main results remain unchanged. For the partial total cross sections, states of opposite parity contribute independently, slightly reducing the amplitude of the fluctuations. The partial angular distribution and polarization fluctuate as functions of the incident energy over energy regions of the order of Γ.

The total reaction cross section is usually a sum of a large number of fluctuating partial cross sections, $\sigma_{\alpha\alpha'}$, and it will therefore usually have fluctuations of small amplitude only. When only few exit channels are available, the fluctuations are appreciable and occur also in the total cross section. Fluctuations in the total cross section have been observed by Cranberg[4] with high-resolution neutrons on Ti, and Fe. At 2.5-Mev incident neutron energy and 2-kev resolution the total cross section exhibits a fine structure, which, for Fe, has a half-width of 5 kev, corresponding to an approximate lifetime of 10^{-18} sec. The expected spacing of levels of spin 1/2 is indicated to be of the order of a few kev by slow-neutron resonances; the spacings of all excited states are considerably smaller.

REFERENCES

1. C. E. Porter and R. G. Thomas, Phys. Rev. 104, 483.

2. E. P. Wigner, in Proceedings of the Conference on Neutron Physics by Time of Flight, Gatlinburg, 1956, ORNL-2309.

3. L. Landau and Y. Smorodinsky, Lectures on the Theory of the Atomic Nucleus, Moscow, 1956.

4. Dr. L. Cranberg (private communication). See also L. Cranberg et al., in Proceedings of the Conference on Neutron Physics by Time of Flight, Gatlinburg, 1956, ORNL-2309, p. 148.

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