

CORRELATIONS BETWEEN NEUTRON AND GAMMA WIDTHS

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There is a special merit in the study of radiative capture reactions that sets it apart from studies of other reactions. This is the insight that one obtains from the data into the interplay of "compound nucleus" and "direct" reaction mechanisms. Quite generally, the presence of a "direct" process in a reaction implies a special feature (channel correlations) for the compound nucleus resonances. It is only in capture reactions that the effect is strong enough, and the resonance data is good enough for the feature to be observed. In fact, until lately, the feature was seen only in neutron capture; recently it has been found in proton capture.

Although the title of the talk is "Correlations of Neutron and Gamma Widths", we will inevitably be lead into related areas, especially (1) capture in the energy region above resonances (i.e. fast capture at incident energies above 1 MeV); it is here that we see "direct" reactions most vividly, (2) correlations of gamma widths with final state neutron spectroscopic factors; such correlations emerge from the theory along with those involving neutron resonance widths, and it would be artificial to discuss one without the other.

The contents of the talk are as follows:

Basic Formal Theory: This displays the essential relation between correlations of resonance parameters and direct reactions.

The Simplest Example of Correlations: Analogue States: An analogue state often dominates the strength-function of several different channels in an energy region in which the analogue is fragmented into a large number of fine structure resonances. In this situation, strong correlations between resonance parameters are expected, and are observed. In the idealised case of no backgrounds, the correlations will be 100%.

The presence of background strength weakens the correlations. One can define a "mixed" strength function for any two channels containing the correlation between them. A generalisation of Robson theory gives the energy-dependence of this quantity in terms of 3 parameters. Two of these parameters are determined by the two normal strength functions, and thereby a check is obtained on the general structure of the theory.

One curious feature of the data at the  $\frac{3}{2}^-$  analogue in  $^{44}\text{Ca}+p$  is apparent conflict with the statistics usually believed to be obeyed by nuclear resonance parameters, i.e. Gaussian distributions, viz. an observed correlation arises entirely because of phases, not magnitudes, of the two reduced width amplitudes involved.

Correlations in Neutron Capture-Experimental: There has been a definite reduction in the amount of significant new data in the last five years. The major new items are the first correlations in proton capture, viz. in  $^{60}\text{Ni}+p$ , and the confirmation of correlations in M1 neutron capture (in the mass region  $A = 22-36$  particularly, but also for  $A \sim 56$ ). In neutron E1 capture, the main sources of new data are: (1) Confirmation of resonance correlations of neutron and total E1 widths for  $^{51}\text{V}$ ,  $^{54}\text{Fe}$ ,  $^{55}\text{Mn}$  (2) Thermal  $^{136}\text{Xe}$  capture agrees well in absolute cross-section with theoretical estimates based on the dominance of channel capture. (3) Correlations are found in even and odd Er isotopes, also in  $^{173}\text{Yb}$ . (4) Data on  $^{100}\text{Mo}$  for three  $\frac{3}{2}^-$  resonances does not agree with the valence model.

Theory of E1 Neutron Capture Correlations: Although generally correlations are expected when any non-compound nucleus process occurs, there remains the quantitative problem of predicting actual magnitudes. Since statistics are not good enough to observe correlations  $\rho$  of  $\leq 0.1$ , there is no guarantee, a priori, that observable correlations will be found, even when direct reactions occur. In fact, they do, at least for final states which have a

significant fraction of their parentage in the target ground state. The main theoretical problem is to understand why, for certain nuclei, where  $\rho$  is large ( $\geq 0.8$ ), the value of  $\rho$  is not weakened by excited target states which certainly occur in the final states. The answer seems to lie in a threshold effect which reduces such components in the initial states, i.e. the resonances:

Theory of Non-Compound Nucleus E1 Capture: Ideally, in any given nucleus, one could diagonalise  $l^-$  excitations from a given shell-model state, including continua, and see whether all E1 strength is collected in the GDR, or whether some involving low  $l$  is left in the threshold region (as indicated by the data). In the absence of such ambitious calculation, plausible simplified models are used. One such model is the recent one by Dietrich and Kerman, which essentially suggests that all E1 strength is lost to the GDR, and is returned to the threshold region by damping-spreading of the GDR. We show that there are other, formally equivalent, ways of rewriting the exact distribution, and that these suggest that the D-K hypothesis is not the only one; in fact, we know that it fails for low- $l$  values (because of the observed correlations).

Decoupling for Low  $l$ -values near Threshold: In order to obtain guidance as to which model is correct, and to take account of threshold decoupling, in the most economical way, we set up a two-state R-matrix theory. One sees that, even if the normal E1 strength is completely taken into the GDR, there is a channel contribution that will usually be uncoupled, and can account for the magnitude of observed correlations and cross-sections.

Theory of Non-Compound Nucleus M1 Capture: A theory of M1 capture was recently given, with numerical evaluation for  $^{29}\text{Si}+n$ . We reassess the estimates in the light of recent new theoretical and experimental estimates

of collective M1 strength of nuclei. Generally these reduce the strength, thereby reducing M1 capture. However the original estimate is restored if one also replaces the estimate of particle-target M1 coupling by more recent values. A new theoretical prediction in the M1 case is that strong final state correlations should be accompanied by strong initial state correlations, despite the fact that the process is semi-direct not direct.