

Spectroscopic information from nuclear reactions

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The properties of nuclear states are investigated experimentally by means of nuclear reactions. It is necessary therefore to know the relation between the spectroscopic amplitudes, characterizing the nuclear structure, and the decay and partial widths, measured in nuclear reactions. The relations can be obtained on the basis of the continuum shell model¹⁾ which describes nuclear structure and nuclear reaction aspects with comparable accuracy.

For isolated resonance states R , the relation between the decay width Γ_R and the partial widths $\Gamma_{R,c}$, relative to the channels c , is

$$\Gamma_R = \sum_c \Gamma_{R,c} \quad (1)$$

Such a relation is usually used in analyzing the experimental data. Further,

$$\Gamma_{R,c}^{1/2} = \Gamma_R \sum_{c'} \gamma_{R,c'} I_{R,c,c'} \quad (2)$$

where $\gamma_{R,c'}$ are the spectroscopic amplitudes and $I_{R,c,c'}$ is an overlap integral between bound and scattering wavefunctions²⁾. For large spectroscopic amplitudes, the partial width is proportional to the squared spectroscopic amplitude as it is usually assumed. But for channels with small parentage, coupling to more favoured (open as well as closed) channels can change, according to eq. (2), the simple relation between partial widths and spectroscopic amplitudes drastically. Numerical calculations are performed for the isospin forbidden proton and neutron decay of the first $T = 3/2$ state in the $A = 13$ nuclei. Further, the disagreement between calculated and measured α -widths in heavy nuclei known for many years gives evidence of the existence of

favoured (closed) α -channels.

The wavefunction of an isolated resonance state R is¹⁾

$$\Omega_R = \phi_R + G_P H \phi_R \quad (3)$$

where ϕ_R is the traditional shell-model wavefunction, G_P the Green function in the continuum and H the Hamiltonian. The excitation of a resonance state in a nuclear reaction is therefore proportional to two terms: the traditional resonance reaction part via the first term of eq. (3) and the channel-resonance scattering via the second term. Nuclear reactions are suitable for an extraction of spectroscopic information if the direct reaction part relative to the resonance reaction part is small, since in such a case the channel resonance scattering is also small. Otherwise the influence of channel coupling cannot be neglected. It leads, for example, to neutron-shell effects in the radii of nuclear charge distributions.

For overlapping resonance states it is³⁾

$$\Gamma_R < \sum_c \Gamma_{R,c} \quad (4)$$

instead of eq. (1). It is therefore difficult to draw conclusions from lifetime measurements on partial widths. Problems appeared, indeed, in the interpretation of the lifetime data of e. g. ^{239}U . Furthermore, $\Gamma(E)$ decreases with energy after reaching a maximum⁴⁾ because of $\Gamma(E) \rightarrow 0$ for $E \rightarrow 0$ and $E \rightarrow \infty$ ⁵⁾. This fact is also not taken into account in the interpretation of the lifetime data on the basis of a statistical theory.

Another result of the continuum shell model calculations is the fact that external mixing of resonance states with equal spin and parity via the continuum becomes important when the resonance states begin to overlap. The collectivity of the lower- (higher) lying states is enlarged at the cost of the collectivity of the higher- (lower) lying states due to external mixing. Further, the resonance states repel each other. As a consequence, special types of structures may appear in the reaction cross section. While structures which are caused by only one resonance state appear at the resonance

energy E_R in all channels, this is not necessarily the case for structures which are generated by several overlapping resonance states. The centre of these structures may be shifted in the different channels because of the different partial widths. The "widths" of these structures are determined, to a great extent, by the distance of the single resonance states which lie close together by chance due to fluctuations in the level density. Structures of such a type may appear as intermediate-like ones in the reaction cross section or as substructures under a gross structure. The only condition is $\Gamma \leq D$ where Γ is the average width and D the average distance of the resonance states. If $\Gamma \ll D$ then finestructure resonances will be observed while for $\Gamma \gg D$ the external mixing is so strong that only a gross structure appears. Thus, conclusions on the level density can be drawn when substructures are observed in the reaction cross section with excitation of, e. g., isobaric analog resonances or in heavy ion reactions.

References

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