

## RECENT TRENDS IN FAST NUCLEON CAPTURE STUDIES

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The refined direct-semi-direct theory for fast nucleon capture, which involves the complex coupling interaction between the incident nucleon and the vibrating target nucleus, satisfactorily reproduces the experimental data. To understand the origin of imaginary part of the coupling interaction, further investigations, experimental and theoretical, are called for.

With the appearance of a new generation of nucleon radiative capture data, namely the excitation functions for fast neutron capture to particular final states of the residual nucleus, it was possible to make a further step in the theoretical description of observed data. The original direct-semi-direct (DSD) model<sup>1,2)</sup> assumed that two processes are important in the fast nucleon capture reaction; direct dipole capture in the average nuclear field and semi-direct-capture connected with the dipole excitation of the target nucleus by inelastic scattering of the incoming nucleon to a single-particle bound state, in the first step, and with the radiative deexcitation of the target nucleus, in the second step. This model has now been refined by allowing the coupling between the incident nucleon and the vibrating target nucleus to be complex<sup>3)</sup>. The imaginary coupling was introduced in a semi-phenomenological way. The parameters attributed to it were taken from the imaginary part of the symmetry optical potential in the same way as the parameters of the real coupling were in accordance with the real part of the symmetry optical potential.

The transition amplitude is obviously the sum of the direct transition matrix element and the semi-direct one and it is usually written as

$$T_{\gamma, \text{nucl}}^{\nu} = \langle \phi_{n\ell jm}(x_0) | D^{\nu}(x_0) | \chi_i^{(+)}(x_0) \rangle + \frac{1}{E_{\gamma} - E_R + -i\Gamma_R} \langle \phi_{n\ell jm}(x_0) | V^{\nu}(x_0) | \chi_i^{(+)}(x_0) \rangle \quad (1)$$

where  $\chi_i^{(+)}(x_0)$  is the scattering state of the incident nucleon,  $\phi_{nljm}(x_0)$  is the final bound single particle state of the same nucleon,  $E_\gamma$  is  $\gamma$ -ray energy,  $E_R$  and  $\Gamma_R$  are (approximately) the position and the width of the giant dipole resonance in the target nucleus,  $D^V(x_0)$  is the single-particle dipole operator and  $V^V(x_0)$  the incident nucleon-target nucleus vibration coupling interaction or the form factor. In the refined model the latter is given; in the case of incident neutron for instance,

$$\text{by } V^V(x_0) = \text{const} \cdot r_0 \left[ \frac{V_1}{4} \cdot f(r_0) - i \frac{W_1}{4} \cdot 4b \frac{d}{dr_0} f(r_0) \right] \quad (2)$$

Here  $V_1$  and  $W_1$  are the strength of the real and imaginary part of the symmetry potential,  $f(r_0)$  is the Saxon-Woods form factor and  $b$  the diffuseness of the imaginary term. (In analysis  $V_1$  and  $W_1$  are usually treated as free parameters).

The meaning of the imaginary term has been traced back into the formal derivation of the model on the basis of Feshbach's unified reaction theory<sup>4)</sup>. By assuming that there is no coupling between the intermediate collective dipole states which are explicitly taken into account, that these intermediate states radiatively decay directly that the contribution of other complicated states to the transition amplitude is negligible, and by energy averaging the transition amplitude, we obtain the expression:

$$T_{\gamma, \text{nucl}} = \langle \Psi_f | D | \Psi_i^{(+)} \rangle + \sum_d \frac{\langle \Psi_f | D | d \rangle \langle d | H_{dP} | \Psi_i^{(+)} \rangle}{E - E_d(E) - i \Gamma_d(E)} \quad (3)$$

Here  $H_{dP}$  is a complex effective operator, defined by

$$H_{dP} = H_{dP} + H_{dq} \frac{1}{E - H_{qq} + \frac{1}{2} i \Gamma} H_{qP} \quad (4)$$

and  $H_{dP}$  corresponds to real coupling of the elastic channel with an intermediate state  $|d\rangle$ ,  $H_{qP}$  to real coupling of the elastic channel with a complicated state, etc. The meaning of the other symbols can be recognized from equation (1). Although it looks straightforward to understand the origin of the imaginary coupling interaction (like an effect of the indirect coupling of the incident channel with the intermediate state) we are still far from knowing the truth.

It is trivial to say that recent trends in fast nucleon capture studies are directed toward better understanding of the capture reaction mechanism, but it is not trivial to say that trends are directed toward the understanding of the origin of the imaginary coupling. Its phenomenological success offers us a possibility of deepening our understanding of the reaction dynamics. One may, of course, defend another standpoint on this question, but finally it turns out that in case we need the same thing: qualitatively new experimental results, the extension of the DSD model, systematic numerical analysis, and some theoretical estimates and tests.

The existing experimental data are effected by relatively large errors. The excitation functions are known only at a definite solid angle. Also possible contributions of transitions to final states being of different structure than (single particle state, target nucleus ground state) are not known. By getting rid of these deficiencies the values obtained for free parameters  $V_1$  and  $W_1$  would be more reliable. Some experimental data on angular distributions have already appeared<sup>5)</sup>.

The generalization of the DSD model (for example, the introduction of intermediate states of collective quadrupole type, whose effects have been observed in recent preliminary measurements of  $\gamma$ -ray angular distributions) will help to improve further our knowledge of free parameters. The first step in this direction has been made already<sup>6)</sup>.

In order to obtain reliable parameter values, systematic analysis of capture data, based on the refined and generalised DSD model should be carried out. There is no systematic analysis available at the present time, but a partial analysis based on the refined DSD model will be published soon<sup>7)</sup>.

The confrontation of these values of free parameters with the results of theoretical estimates for the indirect excitation of the model intermediate state will necessarily lead to a better knowledge of the origin of the imaginary coupling. Tests for the validity of the assumptions present in the derivation of the generalized DSD model will help further in assessing its true limitation. It might be hoped that from all

these results a valuable contribution toward more complete understanding of the radiative capture mechanism will be obtained.

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