PRECOMPOUND EMISSION IN (n,2n) REACTIONS

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Neutron-induced reactions in the incoming energy region of 4-24 MeV have been investigated in a number of nuclei ranging from A=45 to 209 using precompound and compound-nucleus reaction processes. Special attention has been paid to the influence of the precompound process in these reactions. Inclusion of the precompound mechanism in primary-neutron emission is necessary to account for the (n,2n) reaction cross section.

During the last decade, in addition to compound-nucleus and direct reaction processes, precompound processes have been widely used to calculate fast-neutron-induced reactions. The presence of precompound processes in reactions such as (n,n′), (n,p) and (n,α) was observed in the early investigation of the precompound reaction mechanism. The influence of precompound processes on reactions with sequential emission of particles ((n,2n), (n,np), (n,pn), (n,3n)...) was not so pronounced as to be evident from simple observations. Therefore, these reactions were treated mostly using the compound-nucleus model.

Initiated by the work of the Dresden group[1], the precompound mechanism has been continuously included in sequential emission of particles in neutron-induced reactions.

Holub and Cindro[2] have indicated the presence of precompound mechanism in (n,2n) reactions from a systematic deviation of the simple semiempirical evaporation prediction from experimental data. Since then, (n,2n) reactions have been widely investigated using precompound and compound-nucleus processes[3].

In the present investigation, neutron-induced reactions have been calculated in the incoming energy range of 4-24 MeV using the Weisskopf-Ewing compound-nucleus evaporation model and the precompound (preequilibrium) exciton model. The analysis has been performed for 12 nuclei covering the wide mass region with A ranging from 45 to 209. The aim of this work is to draw a conclusion on the systematic influence and the absolute magnitude of the precompound mechanism in the

presence of other possible reaction mechanisms in fast-neutron-induced reactions, investigating simultaneously a number of possible reaction channels. In this contribution we have confined ourselves to the competition of the compound and precompound mechanisms.

Our intention was to use in the calculations the models free of adjustable parameters, or the parameters had to be defined from other independent sources. Most of the input parameters are common to the compound-nucleus evaporation model and the precompound exciton model. These are: separation energies, level-density parameter, reaction and inverse cross sections. The values of these parameters were consistently taken the same in both models. The choice of their values was based upon an independent analysis performed for the same nuclei, in the same energy region, using only the Weisskopf-Ewing compound-nucleus calculations for the same neutron-induced reactions[4]. This analysis[4] shows the degree up to which the compound-nucleus Weisskopf-Ewing model alone could explain the mechanism of various fast-neutron-induced reactions, and the most appropriate choice of the input parameters. This analysis has already pointed out the necessity for a consistent inclusion of precompound processes in a general description of the reactions studied.

The precompound exciton model was used in its closed form to describe the precompound emission of primary particles in all reaction channels present at a given incoming neutron energy. Although the precompound mechanism is included only in the emission of primary particles, the presence of this mechanism changes not only the spectra of primary particles but also the spectra of all other particles emitted in sequence after the emission of primary particles. At higher excitation energies it would be necessary to include precompound processes also in the emission of secondary particles. The precompound component was calculated using the Griffin closed-form expression for the exciton model[5] with the Pauli correction, as suggested in Ref. 6 and the depletion of states included in the expression for the precompound-emission cross section. Details of the model

and the expressions used in the present calculations are discussed elsewhere.[7]

The only free parameter in the precompound exciton model is the absolute average value of the two-body squared matrix element $\overline{|M|^2}$. Its dependence on mass number and excitation energy could be approximated as

$$\overline{|M|^2} = K \cdot A^{-3} E^{-1} .$$

The parameter K remains free and its value should be obtained by comparison of the calculated precompound cross section with experimental data. The best way to determine the value of K is to compare the calculated precompound cross sections with the experimental ones when the precompound mechanism is dominant. In neutron-induced reactions the precompound mechanism is dominant for (i) the high-energy tail of the primary-neutron spectrum and (ii) the (n,p) cross section at incoming energies $E_n > 14$ MeV for heavy nuclei. The average best-fit value for the parameter K extracted from the above comparison was 700 MeV^3. Using this value, we compared the calculated evaporation + precompound (n,2n) and (n,3n) cross sections with the experimental excitation functions for the nuclei ^{45}Sc, ^{55}Mn, ^{56}Fe, ^{59}Co, ^{89}Y, ^{93}Nb, ^{103}Rh, ^{169}Tm, ^{175}Lu, ^{181}Ta, ^{197}Au and ^{209}Bi. For all these nuclei we used a consistent set of input parameters as follows:

- separation energies from Wapstra and Gove[8],
- level-density parameter a from Gilbert and Cameron[9],
- neutron reaction cross sections from the Bersillon-Cindro optical potential[4],
- Proton and alpha-particle reaction cross sections from Mani et al.[10] and Huizenga and Igo[11], respectively.

The parameters appearing only in the precompound component were the following:

- the single-particle level density g was calculated as

$$g = \frac{6}{\pi^2} a ,$$

  where the level-density parameter a was calculated as already mentioned,
- the initial exciton number $n_o = 3$,

- the parameter K was the free parameter, and its value was determined as described.

The analysis performed shows that the inclusion of the precompound reaction mechanism is necessary for a consistent description of the reaction mechanism of neutrons with nuclei excited to an energy higher than 15 MeV. At an excitation energy of about 30 MeV, the precompound mechanism governs approximately 50% of the total cross section. The calculated cross sections were in satisfactory agreement with the experimental ones when the precompound mechanism was included only for primary particles with K=700 MeV^3. Good fits to experimental data were obtained simultaneously for (n,n_1) spectra, (n,p), (n,2n) and (n,3n) excitation functions.

For some nuclei (^{89}Y, ^{103}Rh, ^{197}Au and ^{209}Bi) it was necessary to vary the value of K from 700 MeV^3 in order to obtain good fits to experimental data. This was due to the structure effects of the respective nuclei. One of the consequences of structure effects is the departure of the level-density parameter a from its average trend. As the transition rates depend on parameters a and K, the departure of a from its average trend, while keeping K constant, causes the departure of the transition rate from its average value. Since the physical nature of the model does not allow for a structure-dependent value of transition rates, structure effects introduced by a are cancelled by variation of K.

REFERENCES

1. U. Herrmann, D. Seeliger, K. Seidel, ZfK (Dresden) 271, 80 (1974).
2. E. Holub and N. Cindro, Phys. Lett. 56B, 143 (1975).
3. B.P. Bayhurst, J.S. Gilmore, R.J. Prestwood, J.B. Wilhelmy, B.A. Erkkila and R.A. Hardekopf, Phys. Rev. C12, 451(1975).
   L.R. Veeser, E.D. Arthur and P.G. Young, Phys. Rev. C16, 1792 (1977).
   A. Chatterjee, S.K. Gupta, Phys. Rev. C18, 2118 (1978).

4. E. Holub, N. Cindro, O. Bersillon, J. Jary, Z. Phys. A289, 421 (1979).
5. J.J. Griffin, Phys. Rev. Lett. 17, 478 (1966).
6. C. Kalbach, Z. Phys. A283, 401 (1977).
7. E. Holub, Thesis, University of Zagreb (1979).
E. Holub and N. Cindro, Proc. 2nd Int. Symp. on Neutron Induced Reactions, Smolenice (ČSSR) (1979), and to be published.
8. A.H. Wapstra and N.B. Gove, Nuclear Data Tables 9, 303 (1973).
9. A. Gilbert and A.G.W. Cameron, Can. J. Phys. 43, 1446 (1965).
10. G.S. Mani, M.A. Melkanoff, I. Iori, CEA (France) Report 2379 (1963).
11. J.R. Huizenga and G. Igo, Nucl. Phys. 29, 462 (1962).