Analyses of nucleon spectra in heavy ion reactions

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We discuss uncertainties in extracting precompound neutron spectra and multiplicities by commonly used methods.

Many works have analyzed nucleon spectra resulting from heavy ion reactions with the assumption that the spectra may be represented by several sources moving with a constant (fictive) velocity with isotropic emission in each moving frame. Results of these distributions have been used to deduce precompound decay parameters in heavy ion reactions[1-3] and in deducing prefission precompound and evaporation neutron multiplicities.[4] In the latter case, additional physical properties were deduced from the results.

We wish to point out in this paper that while there is no reason why the constant velocity source argument should be valid for precompound decay, there are good arguments to believe that it should not. First, consider the case of a nucleon induced reaction (Fig. 1). Experimental results are shown for the ^{209}Bi (p,p') reaction,[5] as well as results calculated with the hybrid precompound decay model.[6] For the latter, we show the contribution from the first term ($n=3$), for which the incident proton has scattered once with the target nucleons, and for all higher order scattering processes ($n>3$).

The nucleons emitted following a single scattering event might well give a spectrum characteristic of the nucleon-nucleon center of mass system. However, we would expect a different distribution of velocities for nucleons emitted after two or more intranuclear scattering events. The assumption of a single source velocity would most likely introduce an error in the lower nucleon energies; Fig. 1 demonstrates that these are the result of multiple scattering. Unfortunately, this is also the region of energy where compound evaporation nucleons may dominate, thereby decreasing sensitivity of the analysis to this problem.

An additional problem in resolution into compound versus precompound components is that an arbitrary mathematical form is *assumed* to represent the precompound component; one such form used is

$$N(\epsilon)\alpha\epsilon e^{-\epsilon/k} . \quad (1)$$

For example, in Ref. 4 for the case of ^{16}O+ ^{142}Nd at 207 MeV beam energy, a value of $k=5.5$ was deduced for Eq. (1), which was used to deduce the precompound neutron multiplicity. Let us proceed by a different, equally arbitrary but more physical approach, instead of assum-

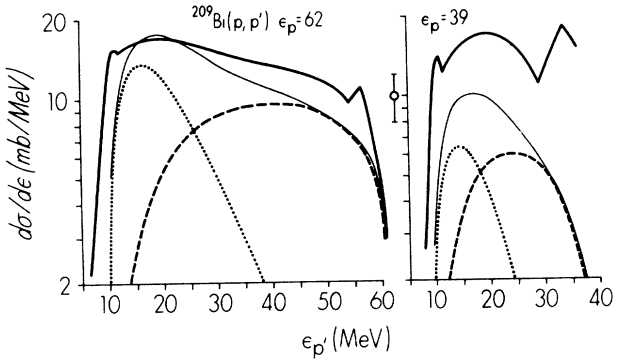

FIG. 1. Experimental and calculated ^{209}Bi (p,p') spectra for 62 and 39 MeV incident protons. The heavy solid curve is the experimental result from Ref. 5. The dashed curve is the first term ($n=3$) of the geometry dependent hybrid model; all higher order terms are included in the dotted curve. The thin solid curve is the sum of all calculated components.

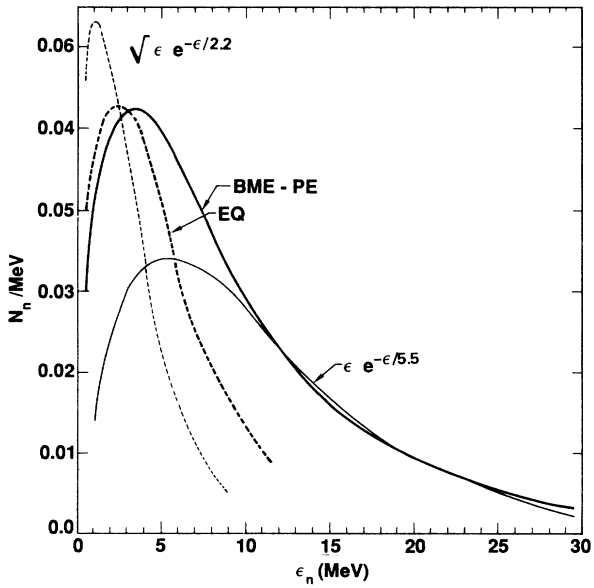

FIG. 2. Comparison of calculated equilibrium and precompound neutron spectra. The heavy solid curve is the precompound result of the Boltzmann master equation (BME) with $n_0=16$; the thin solid curve is the result of Eq. (1) with $k=5.5$ The heavy dashed curve is the BME equilibrium result; the thin dashed curve is the result of the expression indicated.

ing the validity of Eq. (1). To do so, we run the Boltzmann master equation[1] for an initial exciton number of 16, so that we get emission contributions following all nucleon scattering processes. The results are shown in Fig. 2, compared with the values from Eq. (1), as reported in Ref. 4.

It may be seen that for neutron energies above 12 MeV both approaches are in excellent agreement with each other, and with the experimental results of Gavron *et al.*[4] However, at lower energies, there is a considerable discrepancy in the predicted multiplicity of precompound neutrons. At the very least, we may conclude that the precompound neutron multiplicity deduced from data is dependent on the method of extraction. We must use caution in using the constant source velocity parametrization to integrate experimental spectra or to extract precompound neutron multiplicities. Nuclear model codes may be useful in estimating uncertainties when this is done. Our conclusion is that caution must be exercised to estimate uncertainties in these precompound phenomena when attempting to unfold experimental results; it should be recognized that both the constant velocity assumption, and the acceptance of Eq. (1) are likely to be in error, and the uncertainties due to these errors should be considered when physical parameters are deduced from results of such analyses.

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