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Differential cross section comparison calculated from Kalbach and Iwamoto-Harada models for alpha emission in pre-equilibrium region

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Abstract: α-cluster cross section production by proton/neutron induced reactions was calculated at different energies using Kalbach PRECO6 program and an analysis in the framework of pre-equilibrium exciton model made with Iwamoto-Harada [IH] model depend on pickup mechanism. Comparison with our calculation give remarkable agreement with experimental data. The cross section have been estimated for the targets ^{54}Fe, ^{63}Cu, ^{120}Sn with different energies.

Keywords: α-Cluster, PRECO6, Pre-Equilibrium, Iwamoto-Harada

1. Introduction

The mechanism of the emitted particle in the nuclear reaction is an important to provide information about nucleus. The exciton model [1] is one of many models used to explain nuclear emission before equilibrium. This model assumes the reaction proceed via a gradation of states characterized by exciton pairs of particle-hole (p-h). The evaluation of p-h excitons can be described by the master equation which is first proposed by Kalbach and Blann [2] in the spin-independent formulation of this model:

$$\frac{d\sigma}{dE} = \sigma_R \sum_n \tau_n W_x^c(n, E, \varepsilon_x) \quad (1)$$

where σ_R is the cross section for the creation of the composite particle, τ_n is the time spent by a nucleus in the n-exciton state, E excitation energy, ε_x is the energy of ejectile particle and the particle (x represent π for proton and ν for neutron) emission rate is [3]:

$$W_x^c(n, E, \varepsilon_x) = \frac{2s_x+1}{\pi^2 \hbar^3} \mu_x \varepsilon_x \sigma_{inv}(\varepsilon_x) \frac{\omega(p-1,h,U)}{\omega(p,h,E)} R_x(p) \quad (2)$$

where μ_x and s_x are the reduced mass and spin of ejectile, respectively $\sigma_{inv}(\varepsilon_x)$ is the inverse cross section and $U=E-B_x-\varepsilon_x$ is the energy of residual nucleus and the factor $R_x(p)$ represent charge composition of the excitons with respect to the ejectile. Replacing the exciton number of the residual nucleus (p-1, h) for nucleon emission by $p-p_x$, h to write cluster emission rate where the cluster formed by p_x of the total of p excited particles[3]. Nevertheless Ribansky and Oblozinsky [4] improve this case butting the term $\gamma_x \times \omega(p_x, 0, \varepsilon_x + B_x)/g_x$ instead of p_x where γ_x is formation probability of the emitted cluster. Thus the emission rate will be:

$$W_x^c(n, E, \varepsilon_x) = \frac{2s_x + 1}{\pi^2 \hbar^3} \mu_x \varepsilon_x \sigma_{inv}(\varepsilon_x) \frac{\omega(p - p_x, h, U)}{\omega(p, h, E)} \times \gamma_x \frac{\omega(p_x, 0, \varepsilon_x + B_x)}{g_x} R_x(p) \quad (3)$$

The addition of γ_x formation probability to the emission rate was discussed by reference [12]. Also, the calculated results for nucleon induced alpha particle emission was compared with many researchers [6] and the results showed that there are some large conflict among calculated values and experimental data especially in pre-equilibrium process that dominate above 20 MeV. Pre-equilibrium emission of cluster has two opposite mechanisms; pre-formed α-particle that treated as a single exciton [5] and coalescence model that assuming forms a cluster in the course of a reaction from excitons [6] and applied more generally for all type of light complex particles. On the other hand, phenomenological models [7,8]are proposed to describe nuclear reactions for nucleon and cluster induced reaction and emission by fitting many variables parameters to experimental energy spectra. Further, Iwamoto and Harada (IH) clustering exciton model [12] depending on original coalescence model allowed them to describe the form of a cluster not only from exciton, but also from unexcited nucleons below Fermi level. This model improved the pickup mechanism within the exciton model framework and calculate formation probability factor quantumly. PRECO code constructed by Kalbach [11] is a computational framework to calculate different parameters such as cross section from statistical and pre-equilibrium processes, and emission spectrum with angular distribution and its capable to estimates the contribution of secondary emissions and its effects to the emission spectrum.

The present work is adopted to compare between Kalbach [11] and IH model for α-particle emission by nucleon induced reactions at energies 14, 29 and 62 MeV on some target nuclei (^{54}Fe, ^{63}Cu, ^{120}Sn) and comparisonthese calculations with available experimental works which can take from EXFOR (the all experimental data were taken from this library)[12].

2. Results and Conclusions

The spectra of α-particle have been measured for the targets ^{54}Fe, ^{63}Cu, and ^{120}Sn with different energies. “Fig.1” shows the spectra of α-particle emission of ^{54}Fe induced by proton at energy 29 MeV. The behavior of the curves of this figure become smooth and show comparatively small differential cross section if compare with other light charge particle like proton, calculated by Kalbach model(in the frame work of Preco-6). The spectra in general have showed high energy tail.

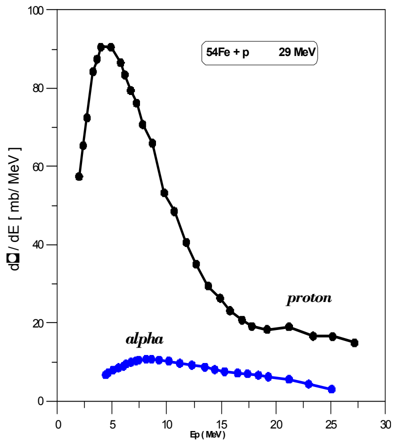

Figure 1. The differential cross section of α-particle compared with proton for ^{54}Fe nucleus.

In “Fig.2”(a and b) the results of incident proton (and emitted α) are compared with experimental data [12] for ^{54}Fe nuclide at 29 MeV and for ^{120}Sn at 62 MeV. The overall results of ^{54}Fe “Fig2.a” illustrated that the IH model explains the experimental results very well comparing with Kalbach model, whereas for ^{120}Sn results “Fig2.b", Kalbach model give good behavior with experimental one.

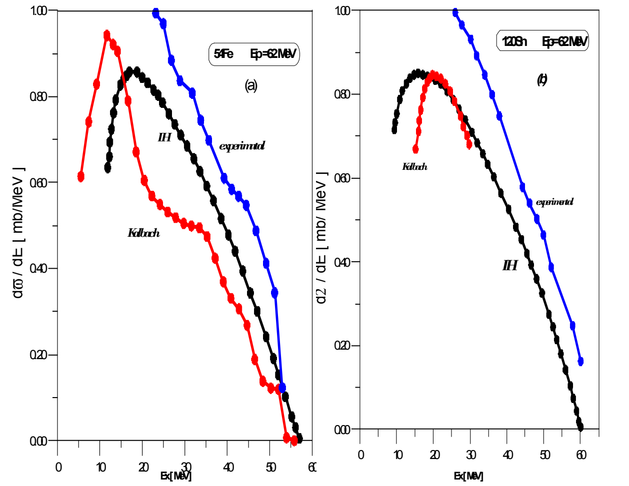

Figure2. Differential cross section of the (a)^{54}Fe(p,α) reaction at 29 MeV and (b)^{120}Sn (p,α) reaction at 62MeV. Solid line for IH, dot one for Kalbach and dash line for experimental data.

Analyzing pre-equilibrium spectra of α-particle in “Fig.2” for IH model, which depends on the formation probability of α-particle calculated by overlap integral wave functions, gives relatively smaller values rather than calculated data estimated by Kalbach model for ^{54}Fe nucleus at 62 MeV. The high-energy tail of the emission spectra of Kalbach was clear for ^{54}Fe not for ^{120}Sn. Similar result was found for ^{54}Fe (p,α) at energy 29MeV as illustrated in “Fig.3”.

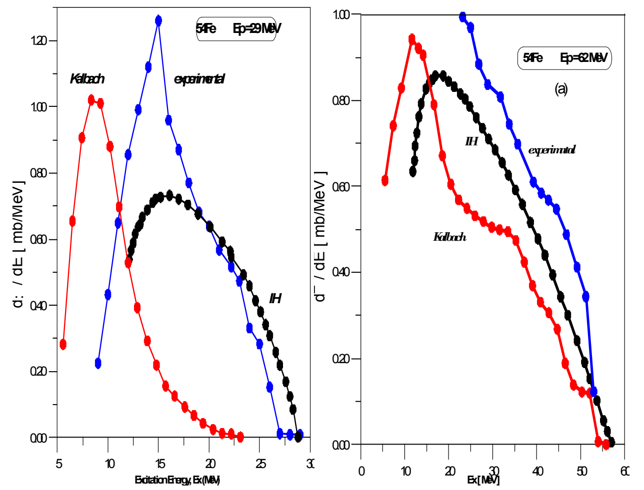

Figure 3. ^{54}Fe+p reaction differential cross section at 29MeVand 62 MeV.

The neutron induced reactions studied by Kalbach model at energies up to 14 MeV for ^{54}Fe and ^{63}Cu nuclei were showed in “Fig’s. 4”. At lower energy range, the data are more sensitive to pairing and shell structure effects, so all the components (pickup, exciton model and evaporation) of the calculated ^{54}Fe(n,α) spectrum overvalue the experimental data but overall behavior of the results seem good. At higher incident energies, there is a spread of 7-9 MeV in the experimental beam energy that causes a broadening and smoothing of the measured spectra. For ^{63}Cu at the same energy range the spectra of Kalbach dominated on the experimental data.

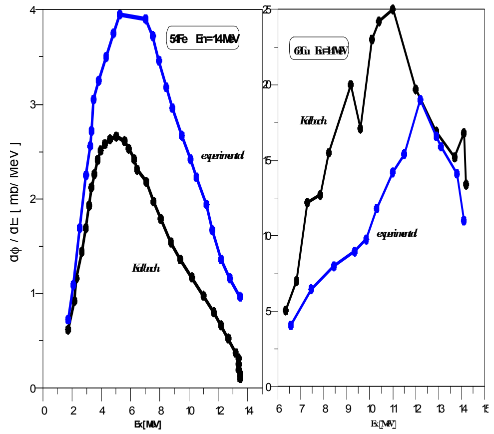

Figure 4*.* *^{54}Fe (n, α) and ^{63}Cu(n, α) reactions at energy 14 MeV calculate by Kalbach (solid) comparing with experimental (dash).*

Study of the structure of α-particle component comparing with other structure of ^{54} Fe(p, α) reaction into the particle-hole state of the parent nucleus will done. Because of this nucleus even-even and have *sd* shell for proton and *pf* for neutron, it is a good sample to study the effect of transform from the closed shell to open one. Since a closed shell nucleus is supposed to be quite a stable entity, the correlation among the valence nucleons alone responsible for a variety of facts known about this nuclei. Calculated results by Kalbach, "Fig.5a", was compared with IH model " Fig.5b". It is clear from this figure, the very high-lying state 2p-2h is most dominate to the high-energy alpha spectra in Kalbach that cause a more strength toward higher excitation energies. In IH the two component show law cross section with relative dominated of 2p-2h and as energy becomes decrease, the contribution from 2p-1h becomes more effective and the slope of the spectra decreased. In other words, the shell effects were appeared nicely in Kalbach model but IH model was failed in illustrating it. This is because the Kalbach model takes into account the shell effects on the partial level density (PLD), whereas IH model depends on William Formula for PLD which takes the Pauli effect only in its formation [13].

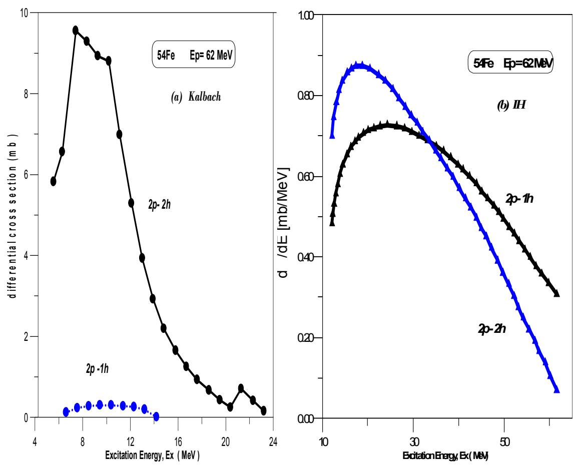

Figure 5*. Differential cross section calculations of configurations 2p-2h and 2p-1h for (a) Kalbach and (b) IH models in ^{54}Fe nucleus.*

3. Conclusions

In this work, the differential cross section of alpha particle emitted by nucleon induced reactions is calculated for the nuclei;^{54}Fe, ^{63}Cu,^{120}Sn.The calculations of this work have been made in the framework of the pre-equilibrium nuclear reaction region usingKalbach model (PRECO-6) comparing with IH model and experimental data. We found that IH model have a cross section in small range compare with Kalbach for all choice nucleus. Since exciton model applied to many experimental data and has had much success, studied during the pre-equilibrium stage give a small exciton number as it clear in analysis of PRECO-6. But there remain some opacity in the formulation of the composite particle emission to explain it by PRECO-6 as the transformation from the closed shell to open shell and how would other shell-model type correlations affect the ground state strength in the ^{54}Fe case?

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