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Study the Matrix Elements of Pre – Equilibrium Nuclear Reactions

Omar Ahamed Muaffaq

Department of Physics - College of Sciences – Diyala University
omaralqadiry@yahoo.com

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Abstract

The matrix element have the main role in the transition rates of nuclear reactions. In the present work, different formulae of matrix elements for pre – equilibrium nuclear reactions have been tested wide ranges of energy, which ranged from 0 to 200 MeV. It's found that the two recent formulae of Koning with and without asymptotic value deviate at high energy with old one that was suggested by Kalbach. The differential cross section was calculated using these formulae and comparison between them and with available experimental were made. This comparison showed a good agreement between the studied matrix formulae and the experimental formulae.

Keywords: Matrix element, pre –Equilibrium, Nuclear Reactions the cross-Section, Kalbach and Koning Formulas

دراسة عناصر المصفوفة للتفاعلات النووية قبل – التوازن

عمر احمد موفق صفاء الدين

قسم الفيزياء- كلية العلوم - جامعة ديالى

الخلاصة

أن عنصر المصفوفة يعتبر القاعدة الأساسية في معدل الأنتقالات للتفاعلات النووية. في هذا العمل، تم اختبار صيغ مختلفة لعنصر المصفوفة للتفاعلات النووية لمنطقة ما قبل التوازن ولمدى طاقة واسع، والذي هو من 0 الى 200 مليون الكترون فولط. لقد وجد بأنه المعادلتان الأخيرتان لكوننك والتان تصفان عنصر المصفوفة في حالة المحاذاة وعدمها تنحرف عن الصيغة القديمة المقترحة بوساطة كالباخ. تم حساب المقطع العرضي التفاضلي للتفاعل بأستخدام الصيغ اعلاه وتم عمل مقارنة فيما بينها ومع ما متوفر من نتائج عملية. هذه المقارنة بينت توافقا جيدا بين صيغ عنصر المصفوفة المدروسة وبين النتائج العملية.

الكلمات المفتاحية: عناصر المصفوفة ، التفاعلات النووية قبل التوازن ، مساحة المقطع العرضي ، معادلات كالبيك وكوننك .

Introduction

Pre-equilibrium calculations depend on a wide set of parameters of different types, one of them is the matrix element. The emission rates in terms of a squared matrix element ($|M|^2$) have been used in many exciton model analyses. Slight variations among different formulae of matrix element give similar behavior of the squared matrix element (a decreasing function of both the excitation energy of a composite system and of its mass number). Therefore, there is no exact formulaused in calculations of a specific reaction.

In general, the matrix element is evaluated empiricallyand incorporate in the codes of the exciton model cross – section calculations.The most common form of $|M|^2$ is empirically in nature and is given for *N-N* interaction by the most popular form suggested by Kalbach [1].

$$|M|^2 = K\ E^{-1}A^{-3} \quad \text{………..(1)}$$

K is a constant has the values [2];K=100-110 MeV^{-3}which gives best results in the PEQAG code [2],whilein GNASH code [3],K has higher values of 130-160 MeV^{-3},$E$the total excitation energy, and A is the mass number. If excitation energy replaced by average excitation per-exciton energy€, the squared matrix element written by [4]:

$$|M|^2 = K\ e^{-1}A^{-3} \quad \text{………. (2)}$$

Where $e = \frac{E}{n}$ and have the values between 7 and 15 MeV.

As the residual interaction inside the nucleus is not same for like and unlike nucleus, the two-body transition rates are described by the matrices $|M_{\pi\pi}|^2, |M_{\nu\pi}|^2, |M_{\nu\nu}|^2$ where Dobes and Betak [5] used this different matrix elements depend on the nature of the interacting particles; proton – proton, neutron – neutron, and proton – neutron (pp, nn, pn), respectively. For the purpose of model calculation, one can write it as the average $|M|^2$ by [6] :

$$|M|^2 = \frac{K}{[A(20.9MeV + e)]^3} \quad (\text{MeV})^2 \quad \text{………} \quad (3)$$

Kalbach [6] found from experimentally calculations of transition rates,with energy up to 100 MeV, the new formula of average matrix element, which was given by:

$$|M_{ij}|^2 = K_{ij}A_a g_o^{-3}\left(\frac{E}{3A_a} + 20.9\right)^{-3} \quad (\text{MeV})^2 \quad \text{……….. (4)}$$

Where A_a projectile mass number and the constants $K_{ij} = K_{\pi\pi} : K_{\nu\pi} : K_{\nu\nu}$ has specific values 2000:900:900, respectively. The single-particle state density can be found from[5] as; $g_{\pi o} = \frac{Z}{15MeV}$, $g_{\nu o} = \frac{N}{15MeV}$.

Recently, KoningandDuijvestijn [7] adopted two new formulae. These formulae wee suggestedbased on thepotential of the optical model for neutrons and protons at range of energies depend onexperimental database consists of a complete set of continuum emission spectraof reactions for incident energy between 7 and200 MeV. However, the suggested semi-empirical expressions for thesquared matrix element can be given by;

$$|M|^2 = \frac{1}{A^3}\left[6.8 + \frac{4.2\times10^5}{\left(\frac{E^{tot}}{n}+10.7\right)^3}\right] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

For asymptotic behavior. Where$n$ is exciton states and E^{tot} is a composite nucleus energy. Thesecond formula suggested without asymptoticbeaviorfor energy range 10-60 MeV, and can be given as:

$$|M|^2 = \frac{1}{A^3}\left[\frac{8.1\times10^5}{\left(\frac{E^{tot}}{n}+14.4\right)^3}\right] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

However, in the present study, different formulae of the squared matrix element have been studied, and the comparison between the old and recent formulae with energy dependence.Further, The effects of these formulae of squared matrix element on the cross section of $^{56}Fe(p,\alpha)$ reaction at 120MeV have been illustrated.

Results and Discussions

In the exciton model, the square matrix element of the residual interaction that depending on the energy and mass number, is used to be regarded as effective as a single parameter for the residual two-body interactions responsible for energy equilibration in the composite nucleus. These have been determined phenomenologically by some theoretical models used for

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extending it to incident (or excitation) energies outside the range studied. The values of the mean square matrix elements may recover for approximations in other parts of calculation and coupled to the values of other model parameters. Using eq's (3), (5) and (6) a comparison made these equations at 120 MeV as in fig (1).

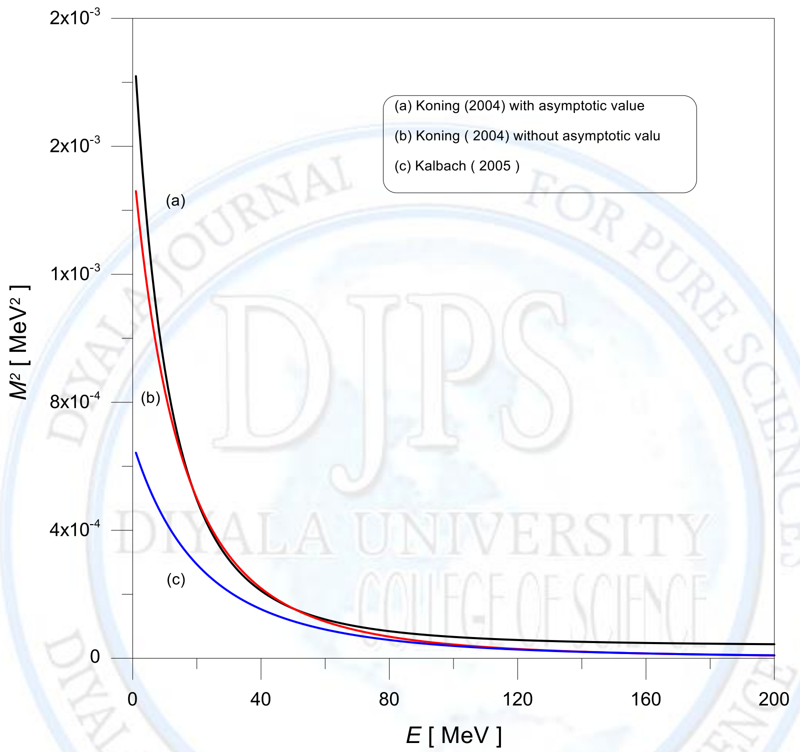

Fig 1. The squared matrix element *M^2* comparison for exciton number *n=3* using different formulafor nucleus ^{56}Fe.

The figure shows the behavior of matrix element parameterizations as a function of excitation energy for nucleus ^{56}Fe.At higher energies, the two expressions of low and high energies start to deviate leading to a difference by a factor approximately 3 at 160 MeV, while kalbach formula be match with low component at 90 MeV. The results of calculations with matrix elements for ^{56}Fe*(p, α)* spectra at 120 MeV are displayed in fig(2). A clear overestimation of the high-energy tail by the old matrix element parameterization is found and, consequently, an underprediction of the multiple pre-equilibrium component just above the evaporation peak. This is repaired by the asymptotic value in eq. (4). The explanation for the difference is that the larger damping width at the initial stage of the reaction leads to more emission at the higher stages, while leading to high-energy tail.

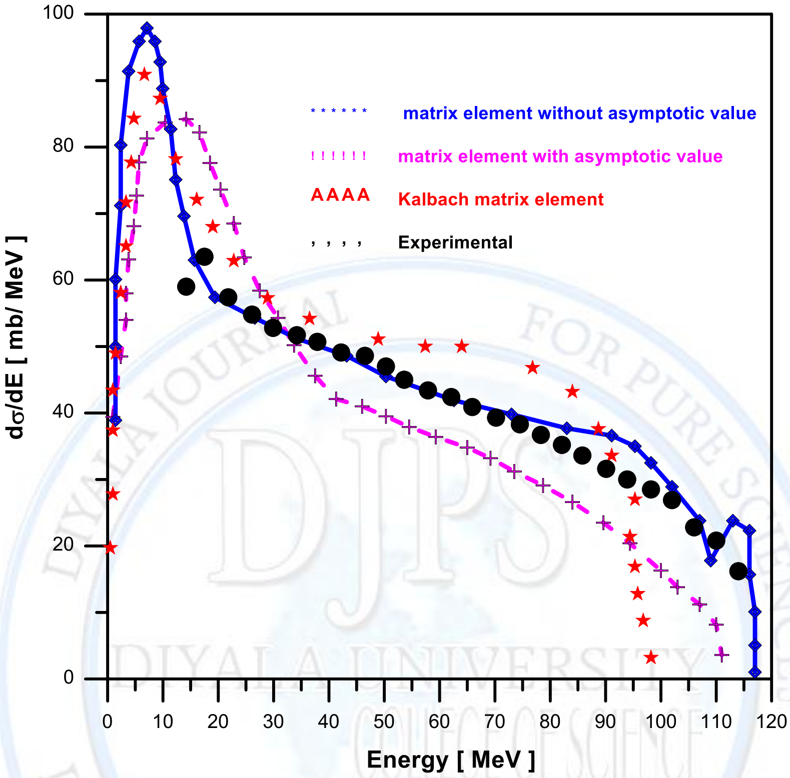

Fig (2) ^{56}Fe (p,α) reaction cross sections using different matrix elements in calculation at 120 MeV. Experimental data taken from

Conclusions

The analytical solution of transition rates needs a value for the squared matrix elements and different formula have been used at different energies to study its effective on the transitions rats. The differential cross section was calculated using these formulae

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