Digest Journal of Nanomaterials and Biostructures Vol.13, No.4, October-December 2018, p. 1055-1061

EFFECT OF ENERGY AND MASS NUMBER ON ENERGY TRANSITION RATES IN PRE-EQUILIRIUM REGION

A. D. SALLOUM[a], J. F. MOHAMMAD[b], A. M. THEEBAN[a]
[a]*University of Baghdad, College of science for women, Physics Department, Iraq*
[b]*University of Anbar, College of education for pure Sciences, Physics Department, Iraq*

In this paper the behavior of a transition rates with increasing the excitation energy and mass numbers have been studied. The transition rates of creation, annihilation and inelastic scattering are studied with increasing the excitation energy for proton-proton, proton-neutron and neutron-neutron interactions, where it is found for all processes that the transition rates of creation increases with increasing energy and the transition rates of annihilation decreases with increasing the excitation energy while that for inelastic scattering does not affected by the increasing of excitation energy. Also All transition rates for proton-proton interaction are studied with three different values of mass numbers for ^{40}Ca,^{56}Fe and ^{90}Zr where it is found the transition rates for creation increases with increasing the mass number, the transition rates for annihilation increases with increases the mass number up to 40 MeV then become has the same values with different mass numbers and the transition rates for inelastic scattering decreases with increasing the mass number.

(Received August 16, 2018; Accepted November 2, 2018)

Keywords: Pre-equilibrium reactions, Exciton model, Transition rates

1. Introduction

Nuclear reaction models attempted to make the theoretical results in agreement with the experimental data. According to first studies, it was supposed two regions of nuclear reaction spectrum compound nucleus and direct reactions [1, 2]. The compound nucleus appears in the spectrum as a broad peak towards the low excitation energy [2]. Compound nucleus model was supposed by Niles Bohr in 1936, it supposed that when the nucleon become in touch with the nucleus it will absorbed of which, after that the incident nucleon will give its energy to one of nucleons in target i.e. the energy of the incident nucleon divide between them and the energy will transport to other nucleons by two body collision process, then the energy will distribute on all nucleons in target nuclei after completion energy distribution on all nucleons equally the nucleus attain to thermodynamic equilibrium after that the decay occurs by emitting particle and/or radiation [3]. The decay is dependent on excitation energy and good quantum numbers but independent of the mode of formation this is called independence hypothesis [3]. The direct reactions lie on the other side of the spectrum towards the high excitation energy as sharp peaks [4]. In direct reactions only a few numbers of particles contribute in reaction and the life time of this stage is about 10^{-22} Second, while in compound nucleus the whole particles contribute in reaction and its lifetime of this stage is about 10^{-16} Second. The smooth part of the spectrum that is represented by a slowly descending part between those two extreme cannot be interpreted neither by compound nucleus nor by direct reactions, but it was interpreted for the first time by J. J. Griffn [5], where he was considered it represents the particles emitted during equilibrium before the completion of energy distribution on all target nucleus and the compound nucleus is formed the life time of this stage is about 10^{-18} Second. This region, called pre-equilibrium nuclear reaction region and the emitted particles called pre-equilibrium or pre-compound particles [6-8]. In

*Corresponding author: jfm_67@yahoo.com

this paper the effect of mass number and energy on energy transition rates in the pre-equilibrium region have been studied.

2. Theory part

Griffin supposed the exciton model in order to explain the particle emission in the pre-equilibrium region. This model considered that all the nucleus are below the Fermi level before the excitation and when the incident particle hits the target nucleus and interact with one of the nucleons it will give it energy and excite it above the Fermi level, leaving behind a hole, the pair of nucleon or particle and hole (p, h) called exciton it is denoted by n. The energy will spread to all nucleons by two body collision process [9]. The energy transition can be expressed by transition rates of a system from one state to another [1]. There are three types of transition rates depending on the type of change in the exciton number i.e. $\Delta n = 0, \pm n$, when $\Delta n = +n$ it represents exciton creation, $\Delta n = -n$ it represents exciton annihilation and if $\Delta n = 0$ this means inelastic scattering. These types of exchanges cause transitions between only the adjacent states; therefore, transition rates can be calculated by Fermi golden rule [1, 10]

$$\lambda_{\Delta n}(n_i, E) = \frac{2\pi}{\hbar}|M|^2\, \omega_{\Delta n}(n_f, E) \tag{1}$$

$\lambda_{\Delta n}(n_i, E)$ is the transition rates of the exchange Δn, $|M|$ is the average (effective) matrix element of the interaction causing the transition and $\omega_{\Delta n}(n_f, E)$ is the density of final accessible states with n_f is the exciton number of the final state. William derived analytical expressions of the $\omega_{\Delta n}(n_f, E)$ [1, 11]

$$\omega_{+}(n_f, E) = \frac{g^3E^2}{n_f - 1} = \frac{g^3E^2}{n_i + 1} \tag{2}$$

$$g = \frac{A}{d} \tag{3}$$

$$\omega_{-}(n_f, E) = g\, p_i h_i\ (n_i - 2) = g\,(p_f + 1)(h_f + 1)n_f \tag{4}$$

Where p_i, h_i, p_f and h_f are the numbers of particles and the number of the holes of initial and final states respectively. In case of transition when $\Delta n = 0$

$$\omega_0(n_f, E) = g^2\, E\,(n_i - 1) = g^2\, E\,(n_f - 1) \tag{5}$$

Therefore, the transition rates will now be given as;

$$\lambda_{+}(n_i, E) = \frac{2\pi}{\hbar}|M|^2\, \frac{g^3E^2}{n + 1} \tag{6}$$

$$\lambda_0(n_i, E) = \frac{2\pi}{\hbar}|M|^2\, g^2\, E\,(n - 1) \tag{7}$$

$$\lambda_{-}(n_i, E) = \frac{2\pi}{\hbar}|M|^2\, g\, ph(n - 2) \tag{8}$$

The two-body interaction is described by matrix element $|M|$, and in the case of two-component system (which considers the protons and neutrons as distinguishable particles) there are three types of matrices element;

$|M_{\pi\pi}|^2$, $|M_{\pi\nu}|^2 = |M_{\nu\pi}|^2$ and $|M_{\nu\nu}|^2$; for proton-proton, proton-neutron and neutron-neutron interactions respectively. This leads to be three types of transition rates. Each of these matrices were found by Dobeš and Běták in the following formulae [5]

$$|M_{\pi\nu}|^2 = \frac{K}{ANZE} \tag{9a}$$

$$|M_{\nu\nu}|^2 = \frac{K}{AREN^2} \tag{9b}$$

$$|M_{\pi\pi}|^2 = \frac{K}{AREz^2} \tag{9c}$$

K is fitting parameter, R = a numerical factor that account for different ways of interaction between like and unlike particles. Its value is about 2.9 to 3.

3. Results and discussion

We have been studying the relation between transition rates and energy by figures for ^{56}Fe. These figures were drowned by Mat. Lab 2010. From Figs.1a, b, c, one can show that the transition rates of creation for proton-proton, proton-neutron and neutron-neutron interaction increase linearly with the energy. This behavior is expected because the increasing in energy will create new pairs of excitons.

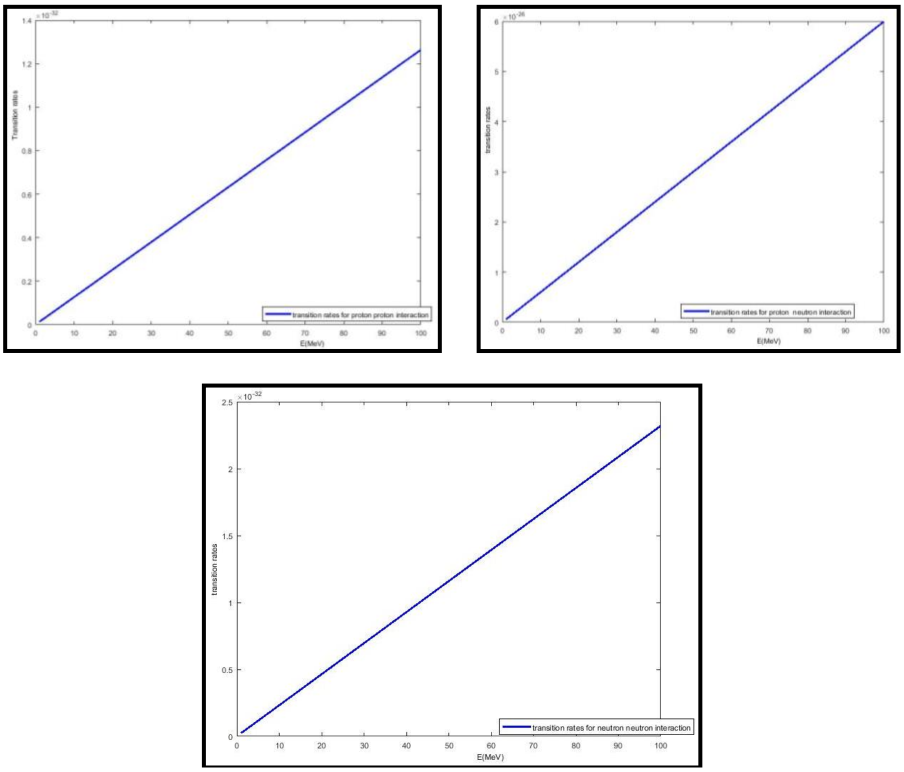

Fig. 1. Transition rate for ^{56}Fe. of a) proton-proton creation; b) proton-neutron creation; c) neutron-neutron creation;

Figs. 2 a, b, c give the relation between the transition rates of annihilation for proton-proton, proton-neutron and neutron-neutron interactions respectively. It's noted that the transition rates of annihilation decrease with increasing energy, because the increasing energy will increase the excitation of particles and lead to create a new pairs of excitons, therefore, the annihilation will decrease.

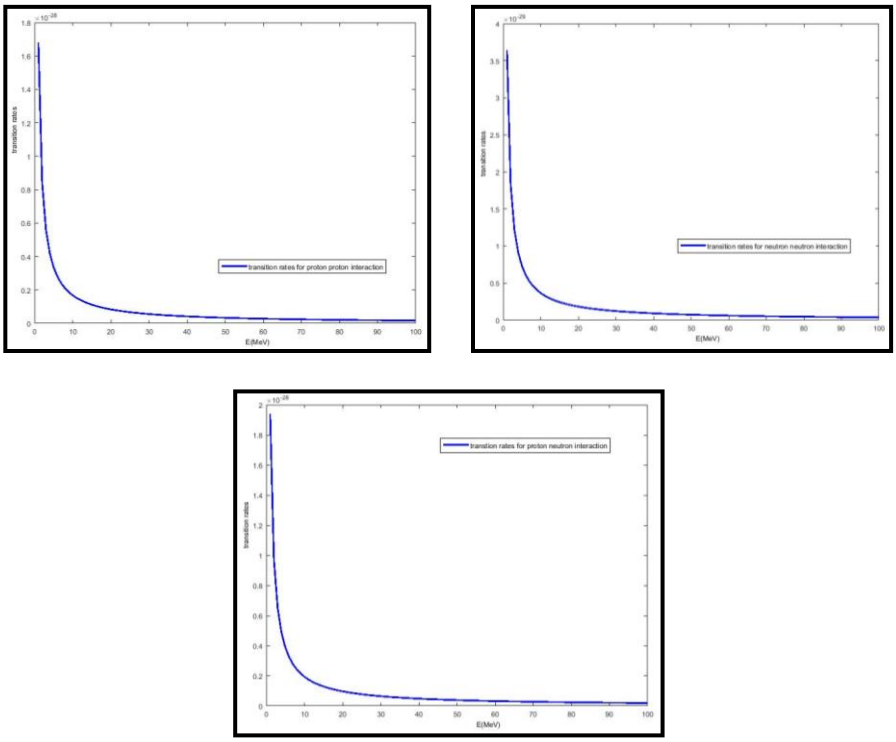

Fig. 2 Transition rate for ^{56}Fe of a) proton-proton annihilation; b) neutron-neutron annihilation; c) proton-neutron annihilation

Figs. 3 a, b, c show the relation between the transition rates of inelastic scattering and energy for, proton-proton, proton-neutron and neutron-neutron interactions respectively. They show that the transition rates of inelastic scattering don't change with changing energy.

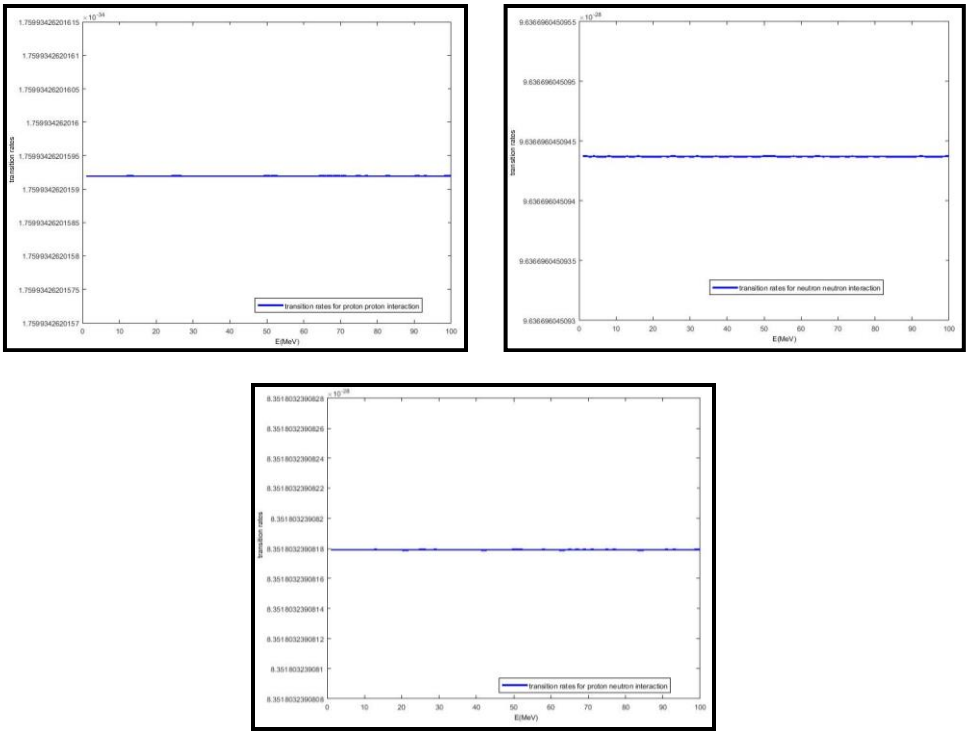

Fig. 3 Transition rate for ^{56}Fe of a) proton-proton inelastic scattering; b) neutron-neutron inelastic scattering; c) proton-neutron inelastic scattering

Fig. 4 gives a comparison between the transition rates of creation λ_+ for proton-proton interaction for three isotopes ^{40}Ca, ^{56}Fe and ^{90}Zr, it noted that λ_+ For proton-proton increase with the increasing mass number because λ_+ increase with increasing g which in turn increases with mass number A.

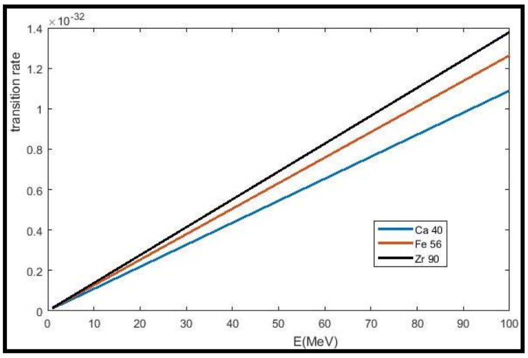

Fig. 4. Transition rate of creation for proton-proton interaction with different mass numbers.

Also the transition rates of annihilation λ_- for proton-proton interaction is compared in Fig. 5. Where one can see that there is small increasing in λ_- at energies up to 40 MeV, and then λ_- have the same values. This can be interpreted as the mass number increase transition rates of annihilation λ_- will increase because when the mass number increase the energy distributes on a larger number of nucleons and the share of each nucleon from energy will be less, hence the probability of occurrence the annihilation will be greater but with increasing the energy the probability of exciton creation will increase therefore λ_- become the same for different isotopes. Finally, figure 6 gives the change in transition rates of inelastic scattering λ_0 with different mass numbers, where it shows that λ_0 decrease with increasing the mass number because the creation process becomes dominant.

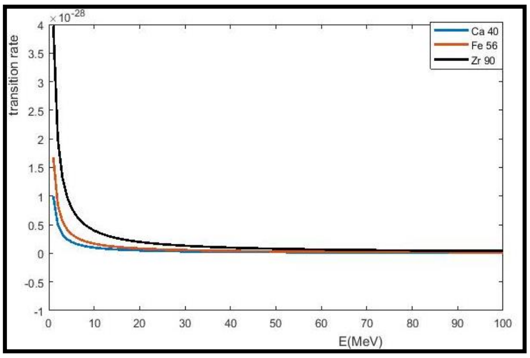

Fig. 5. Transition rates of annihilation λ_- for proton-proton interaction.

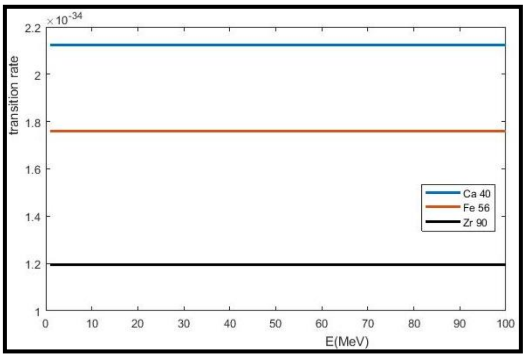

Fig. 6. The change in transition rates of inelastic scattering λ_0 with different mass numbers.

4. Conclusions

The creation processes increase with increasing the energy while the annihilation processes decreases and the inelastic scattering does not affected by energy increasing. Also, the creation processes increase with the increasing mass number, the annihilation processes, increase slightly with the mass number up to 40 MeV then become equal for all mass number values. Finally the inelastic scattering processes, decrease with the increasing mass number.

References

[1] E. Běták, P. E. Hodgson, University of Oxford, available from CERN Libraries, Geneva, reports ref. OUNP-98-02 (1998).
[2] T. Ericson, Adv. Phys. **9**, 425 (1960).
[3] S. N. Ghoshal, Phys. Rev. **80**, 939 (1950).
[4] S. T. Butler, Phys. Rev. **80**, 1095 (1950).
[5] J. J. Griffin, Phys. Rev. Lett. **17**, 478 (1966).
[6] P. E. Hodgson, Heavy ion collision proceedings of International Summer School, La Rabia, Spain, 220 (1992).
[7] E. Gadioli, E. Gadioli - Ebra, Nuclear theory for applications - 1980, IAEA - SMR 68/1, Vienna, **3** (1981).
[8] H. Jahn, Nuclear theory for applications - 1982, Vienna, IAEA - SMR **93**, 39 (1984).

[9] V. F. Weisskopf and D. H. Ewing, Phys. Rev. **57**, 472 (1940).
[10] C. Kalbach, Phys. Rev. C **33**, 818 (1986).
[11] A. A. Selman "Neutron Induced Preequilibrium Nuclear Reactions Using the Exciton Model" Ph. D. Thesis, University of Baghdad (2009).