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The Study of Changing Occurs on Two Components Pairing Corrected Partial Levels Density Formulae in Pre-Equilibrium Nuclear Reaction Region with Different Isobaric Nuclei

Ali Dawoud Salloum[1], Zainab Adil Abdul-Raheem[2]

Abstract: ***Pairing correction of pre-equilibrium partial levels density (PLD) formula was added to PLD Ericson's formula in order to optimize the theoretical data and make it in agreement with experimental data. There are four types of pairing correction formulae, first type pairing correction, second type (improved pairing correction), third type (exact Pauli correction) and forth type (back shift energy correction). In this paper we studied the effect of different values of proton numbers and neutron numbers in isobaric nuclei on pairing corrected two components PLD formulae. Where we used three isobaric nuclei $^{40}_{20}Ca$, $^{40}_{19}K$ and $^{40}_{16}S$, the results of PLD of these nuclei for each type of pairing corrected formulae are compared. It is found that the change in Z and N causes a small change in PLD results in case of pairing correction from first type, in case of third type the change in PLD, increase and becomes more in case of forth type and there is no change in PLD results of the second type (improved pairing correction)***

Keyword: exciton model, nuclear levels density, pre-equilibrium region

1. Introduction

The emission of pre – equilibrium region in nuclear reaction was proposed when the old hypothesis which suppose that the nuclear spectra are made of two parts compound nucleus and direct reaction is not agreed with some of experimental data [1,2]

The pre – equilibrium emission was proposed by J.J Griffin in 1966 [3], Where, he supposed the exciton model that which considers the incident particle gives it energy to one the target nucleus and this will excite to a certain level leaving a hole behind a pair of particle and hole called exciton. By two body collision process more particles and holes are produced.

The level which contain particles are separated on those contain holes by fermi level which is defined as the energy value that lays half the way between the last filled and the first unfilled energy levels [4]

The partial levels density PLD of excitons i.e. for one level is given by Ericson's formula

$$\omega_1(n,E) = \frac{g^n E^{n-1}}{p!h!(n-1)!} \qquad (1)$$

$\omega_1(n,E)$ is the one component levels density (one component means when the protons and neutrons are considered as undistinguishable particles), E is the energy, g is the Sigle particle levels density which is given by

$$g = \frac{A}{d} \qquad (2)$$

A is the mass number and d is the distance between the energy space and its value about $13\ MeV$.
p and h are the particles number and hole numbers respectively, and n is the exciton number which equal n=p+h.
And when they are considered as distinguishable particles Ericson's formula becomes

$$\omega_2(n,E) = \frac{(g_\pi)^{n_\pi}(g_\nu)^{n_\nu}E^{n-1}}{p_\pi!h_\pi!p_\nu!h_\nu!(n-1)!} \qquad (3)$$

ω_2(n, E) is two components PLD and g_π, g_ν are Single particle level densities for protons and neutrons respectively. They are given by

$$g_\pi = \frac{Z}{A} g \qquad (4)$$

$$g_\nu = \frac{N}{A} g \qquad (5)$$

Where Z and N are the number of protons and neutrons respectively.

E is the energy and p_π, h_π are the numbers of proton particles and proton holes respectively, and p_ν, h_ν are the numbers of neutron particles and neutron holes respectively n_π is the number of proton excisions n_ν is the number of neutron exciton and is the total number of excitons is $n = n_\pi + n_\nu$ [5].

In order to improvement the data, many corrections are added to Ericson's formula in both cases one component and two components. These corrections are Pauli principle correction, spin correction, isospin correction, linear momentum correction, surface correction, active and passive holes correction and finally pairing correction which includes four types, we will discuss them in the next section [1, 4, 5].

In this paper the effects of the isobaric nuclei on all types of two components pairing correction formulae have been studied.

2. Theory

Pairing occurs between any two identical particles found in same quantum state in other words they have the same orbital quantum number $|\vec{l}|$ due to overlapping between wave functions of them that increases nucleon-nucleon coupling, therefore, this will cause loss part of excitation energy in dissociation the coupling. The coupling between particles (nucleons) in even – even nuclei is greater than those in even – odd or odd – even nuclei and in those nuclei is greater than that in odd – odd nuclei [4].

Pairing has been described by four methods

2.1 First Method

In this method the pairing effect on the two components PLD is given by [7]

$$\omega_2(n,E) = \frac{g_\pi^{n_\pi} g_\nu^{n_\nu}\left(E - P_2(\Delta) - B_{p_\pi,h_\pi,p_\nu,h_\nu}\right)^{n-1}}{p_\pi!\,h_\pi!\,p_\nu!\,h_\nu!\,(n-1)!}\,\Theta\left(E - P_2(\Delta) - B_{p_\pi,h_\pi,p_\nu,h_\nu}\right) \quad (6)$$

$P_2(\Delta)$ is the two – components pairing energy and $\Theta\left(E - P_2(\Delta) - B_{p_\pi,h_\pi,p_\nu,h_\nu}\right)$ is the Heaviside step function.

$$P_2(\Delta) = 2P_1(\Delta) \quad (7)$$

$$P_1(\Delta) = \frac{g(\Delta_0^2 - \Delta^2)}{4} \quad (8)$$

Where Δ_0 and Δ are the energy gap of the ground and excited states respectively [8,9].

$$\left.\begin{array}{ll} \frac{\Delta}{\Delta_0} = 0.996 - 1.76\left({}^{n}/_{n_c}\right)^{1.6}\left(\frac{E}{C_e}\right)^{-0.68} & if \quad E \geq E_{phase} \\ \frac{\Delta}{\Delta_0} = 0 & if \quad E < E_{phase} \end{array}\right\} \quad (9)$$

E_{phase} is the pairing energy of phase transition [6]

$$\left.\begin{array}{ll} E_{phase} = C_e\left[0.716 + 2.44\left(\frac{n}{n_c}\right)^{2.17}\right] & if \ \frac{n}{n_c} \geq 0.446 \\ E_{phase} = 0 & \text{otherwise} \end{array}\right\} \quad (10)$$

where n_c = critical exciton number, is the most probable exciton number that leads to emission, and given as follows [6]

$$n_c = 0.792\Delta_0 \quad (11)$$

C_e is the condensation energy given by the relation [7].

$$C_e = g\,\frac{\Delta_0^2}{4} \quad (12)$$

When the eq (10) is used, we must take into account that the minimum value of energy for applying these equations is the 'effective threshold energy' which means the threshold value of E_{phase} and it is given by [7].

$$\left.\begin{array}{ll} U_{th} = C_e\left[3.23\frac{n}{n_c} - 1.57\left(\frac{n}{n_c}\right)^2\right] & for \ \frac{n}{n_c} \leq 0.446 \\ U_{th} = C_e\left[1 + 0.627\left(\frac{n}{n_c}\right)^2\right] & for \ \frac{n}{n_c} > 0.446 \end{array}\right\} (13)$$

The value of Δ_0 can be obtained using the curve - fitting for almost all known nuclei by a relation known a Gilbert – Cameron formula [10, 11].

$$\Delta_0 = \Delta_{0\pi} + \Delta_{0\nu} \quad (14)$$

$\Delta_{0\pi}$ and $\Delta_{0\nu}$ are the energy gaps of ground states of protons and neutrons respectively [11].

$$\left.\begin{array}{l} \Delta_{0\pi} = 1.654 - 9.58Z \times 10^{-3} \\ \Delta_{0\nu} = 1.374 - 5.16N \times 10^{-3} \end{array}\right\} \quad (16)$$

N and Z are the neutron and proton number respectively.

$$B_{p_\pi,h_\pi,p_\nu,h_\nu} = A_{p_\pi,h_\pi,p_\nu,h_\nu}\sqrt{1 + \left(\frac{2g\Delta}{n}\right)^2} \quad (17)$$

$B_{p_\pi,h_\pi,p_\nu,h_\nu}$ is the modified Pauli blocking factor and $A_{p_\pi,h_\pi,p_\nu,h_\nu}$ is the unmodified Pauli plocking factor given by.

$$A_{p_\pi,h_\pi,p_\nu,h_\nu} = \frac{p_\pi(p_\pi+1) + h_\pi(h_\pi-3)}{4g_\pi} + \frac{p_\nu(p_\nu+1) + h_\nu(h_\nu-3)}{4g_\nu} \quad (18)$$

2.2 Second method

This method was suggested by Kalbach, it is also called improve pairing correction.

In this method the pairing correction is included in Pauli correction factor that given in the following equation [12]

$$A_k(p,h) = E_{th} - \frac{p(p+1) + h(h+1)}{4g} \quad (19)$$

E_{th} is the threshold excitation energy

$$E_{th}(p,h) = \frac{g(\Delta_0^2 - \Delta^2)}{4} + p_m\sqrt{\left(\frac{p_m}{g}\right)^2 + \Delta^2} \quad (20)$$

$$p_m = maximum\ (p,h)$$

Then, the two – components of improved pairing correction of PLD can be given as

$$\omega_2(n,E) = \frac{g_\pi^{n_\pi} g_\nu^{n_\nu}\left[E - A_k(p_\pi,h_\pi,p_\nu,h_\nu)\right]^{n-1}}{p_\pi!\,h_\pi!\,p_\nu!\,h_\nu!\,(n-1)!}\,\Theta\left(E - A_k(p_\pi,h_\pi,p_\nu,h_\nu)\right) \quad (21)$$

$$A_k(p_\pi,h_\pi,p_\nu,h_\nu) = A_k(p_\pi,h_\pi) + A_k(p_\nu,h_\nu) \quad (22)$$

$A_k(p_\pi,h_\pi)$ and $A_k(p_\nu,h_\nu)$ are calculated in the same way as $A_k(p,h)$.

2.3 Third method (Exact Pauli correction)

In this method the pairing correction added to the PLD with other corrections includes exact Pauli, improved pairing and finite well depth corrections

This correction in two components of PLD is [7]

$$\omega_2(n,E) = \frac{g_\pi^{n_\pi} g_\nu^{n_\nu}}{p_\pi!\,h_\pi!\,p_\nu!\,h_\nu!\,(n-1)!}\sum\sum\sum\sum(-1)^{i_\pi+j_\pi+i_\nu+j_\nu}\,C_{p_\pi}^{i}C_{h_\pi}^{j}C_{p_\nu}^{i}C_{h_\pi}^{j}C_{h_\nu}^{j}\left(E - E_{th} - i_\pi B_\pi - j_\pi F_\pi - i_\nu B_\nu - j_\nu F_\nu\right)^{n-1}\Theta\left(E - E_{th} - i_\pi B_\pi - j_\pi F_\pi - i_\nu B_\nu - j_\nu F_\nu\right) \quad (21)$$

where $C^{i}_{p_\pi} C^{j}_{h_\pi} C^{i}_{p_v} C^{j}_{h_v}$ are binomial coefficients given as

$C^{i}_{p_\pi} = p_\pi!/i!\,(p_\pi - i)!$, $C^{j}_{h_\pi} = h_\pi!$ /j! (h_π - j)!

$C^{i}_{p_v} = p_v!/i!\,(p_v - i)!$, $C^{j}_{h_v} = h_v!$ /j! (h_v - j)!

B_π and B_v are the binding energy for protons and neutrons respectively. F_π and F_v are the Fermi energy for the holes h_π and h_v respectively.

2.4 Forth correction (back shift correction)

This correction takes into account the interaction between the nucleons a part from the excitation energy goes as a kinetic energy of interacting nucleons, therefore, this part have been entered in the calculations as a correction called "Back shifted Fermi Gas" and the lost energy called energy back shift and it is denoted by S. This energy was added to PLD as correction [7]

$$\omega_2(n,E) = \frac{g_\pi^{n_\pi} g_v^{n_v}}{p_\pi!h_\pi!p_v!h_v!(n-1)!} \sum_{i_\pi=0}^{p_\pi} \sum_{j_\pi=0}^{h_\pi} \sum_{i_v=0}^{p_v} \sum_{j_v=0}^{h_v} (-1)^{i_\pi+j_\pi+i_v+j_v} C^{i}_{p_\pi} C^{j}_{h_\pi} C^{i}_{p_v} C^{j}_{h_v} (E - i_\pi B_\pi - j_\pi F_\pi - i_v B_v - j_v F_v - S)\, \Theta(E_{th} - i_\pi B_\pi - j_\pi F_\pi - i_v B_v - j_v F_v - S) \quad (22)$$

3. Results and Discussion

In this section, we will show the results of PLD for the all types of pairing of the isobaric nuclei $^{40}_{20}Ca$, $^{40}_{19}K$, $^{40}_{16}S$ and discuss them. Those results are gotten using MAT.LAB program. The numerical values those are used in calculations given in table (1).

Table 1: The numerical values which are used in the calculations

The quantity	The value
Maximum excitation energy	100
Exciton number and configurations	two components (3,2,0,0)
Maximum value of particles and holes p_m	5
Fermi energy for protons and neutrons respectively F_π, F_v	38 MeV
Binding energy for protons and neutrons respectively B_π, B_v	8 MeV
Back Shift energy S	5 MeV

Figure (1) shows the two components PLD of the first type pairing correction, where, it is noted that the PLD values for $^{40}_{20}Ca$ is the same for $^{40}_{19}K$ and the PLD values for $^{40}_{16}S$ are less them, but the difference is little between the PLD of $^{40}_{16}S$ and those of $^{40}_{20}Ca$ and $^{40}_{19}K$. This can be interpreted that the decrease in protons number Z causes decreasing with the value of g_π which given in eq. (4) and this lead to decrease the PLD.

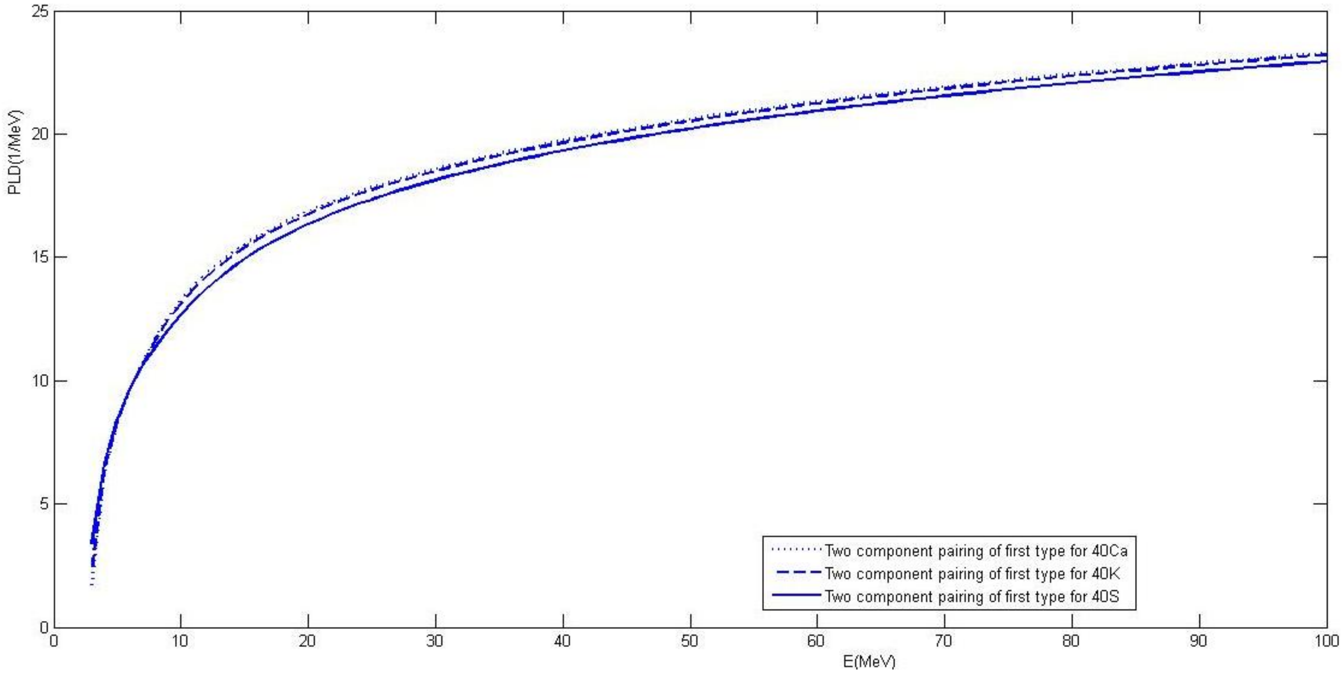

Figure 1: First type pairing correction for isobaric nuclei

Fig (2) shows the PLD of the second type (improved pairing) correction. One can see that the values of PLD for all isobaric nuclei are the same i.e. in case of improved Pairing the PLD does not change with changing Z and N.

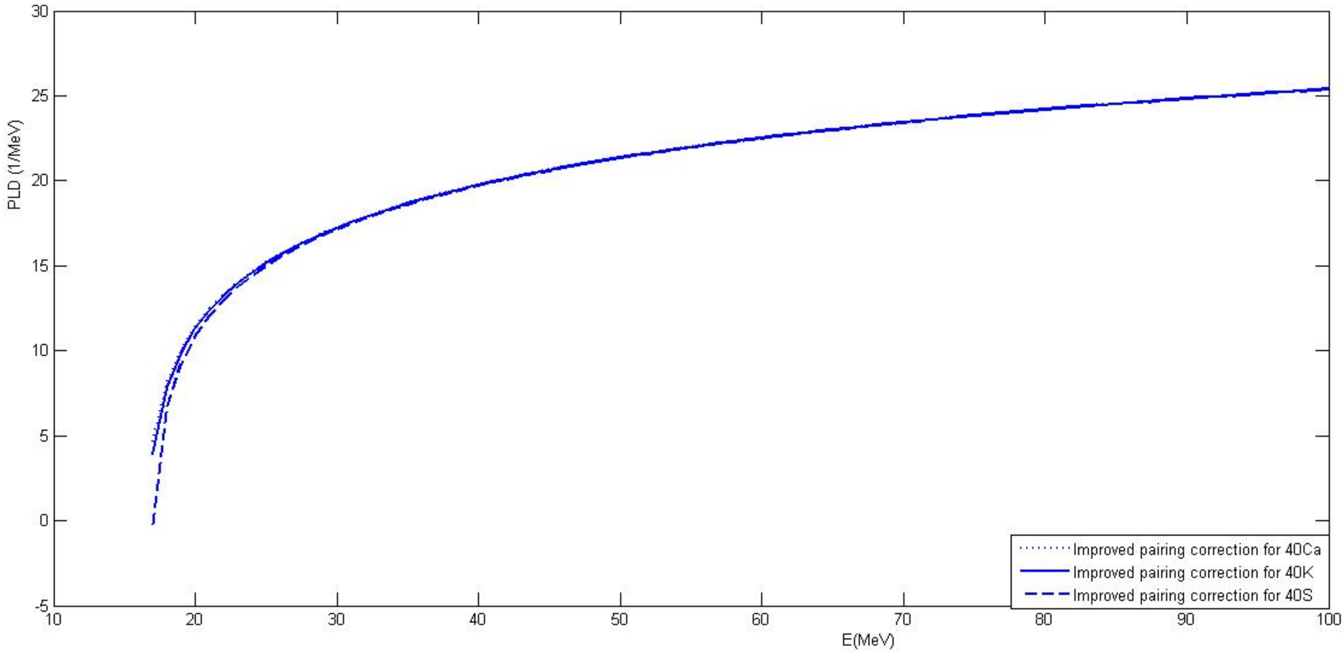

Figure 2: Second type pairing correction for isobaric nuclei

Figure (3) gives the PLD results for the third type (Exact Pauli correction). The PLD decrease clearly with decreasing Z due to decreasing in g_π value.

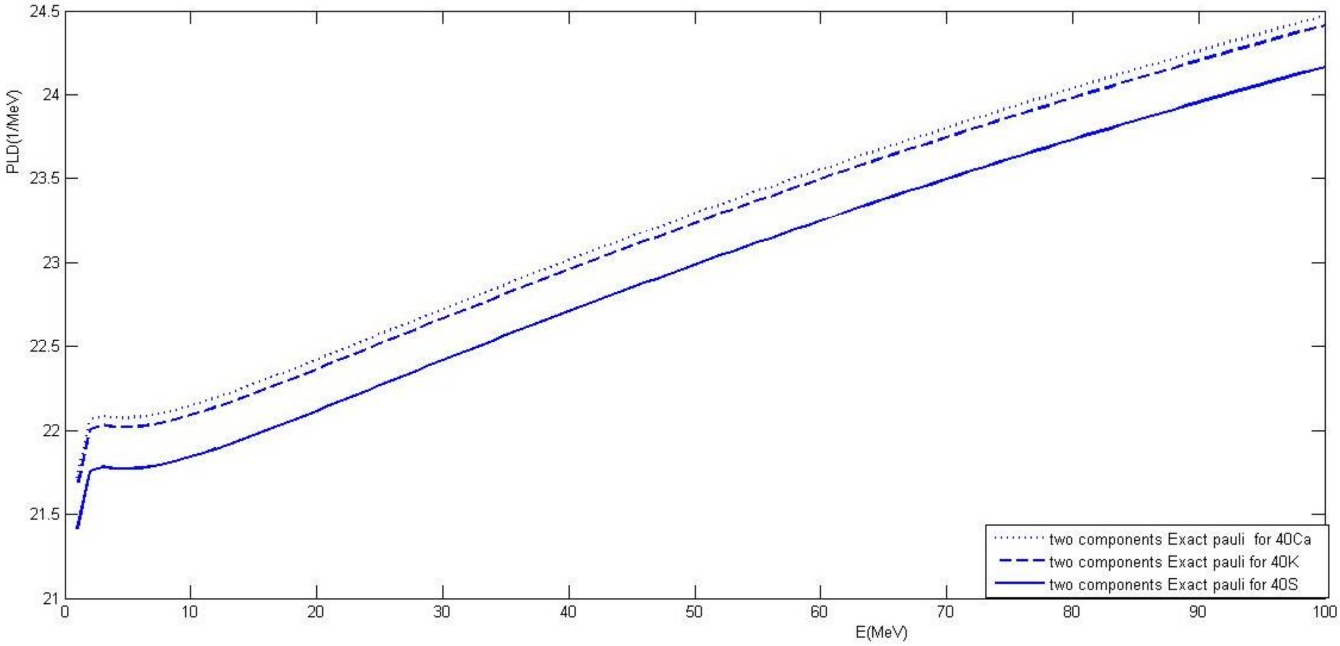

Figure 3: Third type pairing correction for isobaric nuclei

In figure (4) the PLD for the fourth type (Back shift correction) is shown. The PLD decrease with decreasing Z for the previous reason and the decreasing is more than the other type of pairing correction.

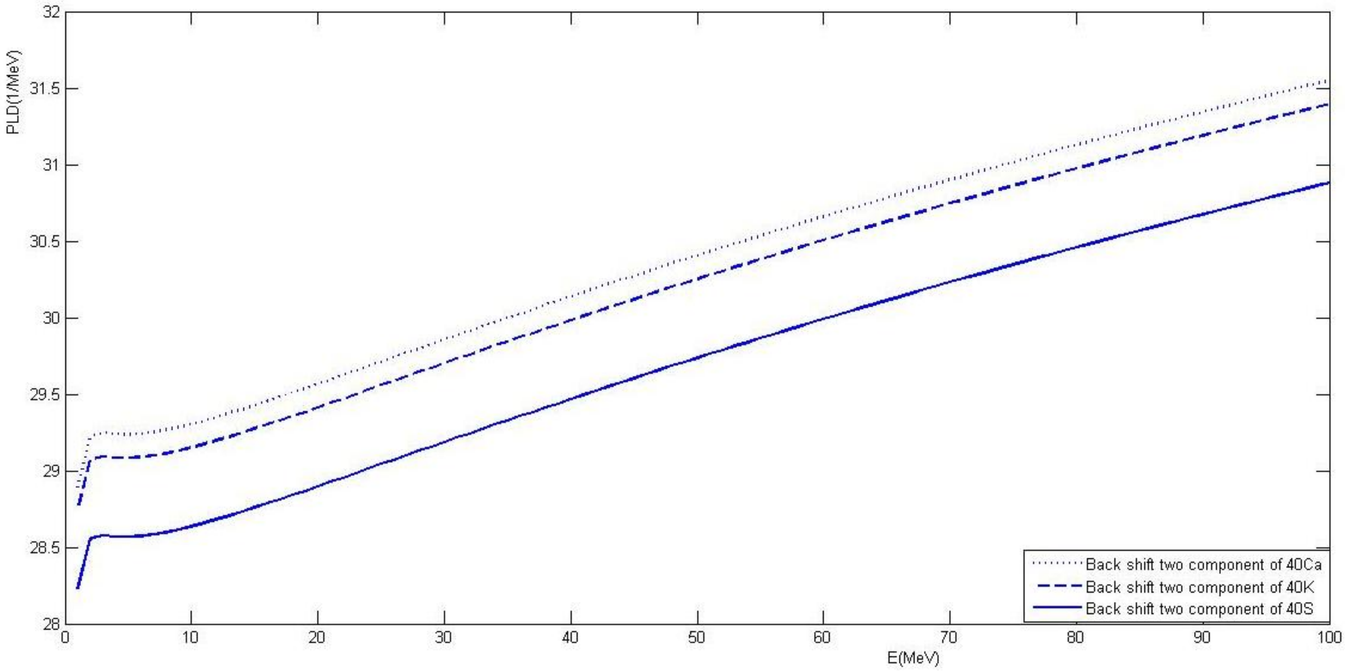

Figure 4: Forth type pairing correction for isobaric nuclei

4. Conclusion

In case of first type pairing correction there are small change in PLD values with changing Z and N , third type and fourth type affect with changing of Z and N in isobaric nuclei while the second type does not affect.

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