Excitation Energy Systematics of the Effective Single Particle Level Densities in Pre-equilibrium Processes in (n, p) Reactions at 14.8 MeV Incident Energies

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Introduction

The results of analysis of the global data for the energy-integrated angular distributions (EIAD) and for the angle-integrated energy spectra (AIES) for the protons emitted from the (n, p) reactions at 14.8 MeV, carried out with computer code PRECO-D2 based on semi-empirical model of Kalbach [1] for the pre-equilibrium reactions, provided the semi-empirical mass systematics of the single particle level densities $g_c^{(Exp)}$ effective in the composite systems, and $g_R^{(Exp)}$,in the residual nuclei, over a wide range of masses. The results were compared with theoretical calculations with Shlomo's theory [2-5] developed on the basis of Green function approach. The theoretical values $g^{Th}{}_{Rp}(\varepsilon_{pf})$ and $g^{Th}{}_{Rn}(\varepsilon_{nf})$ in the residual nuclei, and $g^{Th}{}_{Cp}(\varepsilon_p)$ and $g^{Th}{}_{Cn}(\varepsilon_n)$ in the composite systems, for the neutrons and protons ,respectively, were calculated using single-particle nuclear potential strengthV_0 as an adjustable parameter. The calculations for protons also included the Coulomb potential. The total theoretical values were taken as $g^{TTh}{}_R(\varepsilon_f) = g^{Th}{}_{Rp}(\varepsilon_{pf}) + g^{Th}{}_{Rn}(\varepsilon_{nf})$, and $g^{TTh}{}_C(\varepsilon) = g^{Th}{}_{Cp}(\varepsilon_p) + g^{Th}{}_{Cn}(\varepsilon_n)$. The excitation energies of the single particle levels were defined with reference to ε =0 value. The excitation energy systematics of the effective single particle level densities, so extracted are discussed in light of the previously reported results in literature.

Analysis procedure

The details of the analysis of the EIAD and AIES data using code PRECO-D2 have been described elsewhere [1]. The calculations of theoretical single particle level densities using Shlomo's model are described in details in literature [2-5].The single–particle nuclear interaction potential is assumed to be finite trapezoidal potential:

$$V(r) = \begin{cases} V_0 & for\, r < R - D \\ \dfrac{\{1-(r-R)/D\}V_0}{2} & for\, R - D \le r \le R + D \end{cases} \tag{1}$$

with the following parameters:

$$V_0 = V_0^I + 33t^3(N-Z)/A(MeV),\ D = \pi d$$
$$(d = 0.7\, fm),\ \ R = R_V/(1+(D/R)^2)^{1/3},$$
$$R_V = 1.12A^{1/3} + 1.0(fm) \qquad (2)$$

V_0^I was used as an adjustable parameter from 40 to 50 MeV and t^3 was 1 for a neutron and -1 for a proton. The value R in Eq (1) is determined by iteration. For the protons, Coulomb potential $V_c = Ze^2/R_c$, with R_c=1.12 $A^{1/3}$, was added to V_0.. For single particle level densities $g^{T\,Th}{}_C(\varepsilon)$, for ε > 0, the results obtained for finite trapezoidal potential well were corrected by subtracting the contribution due to the free-gas level density $g_{free}(\varepsilon)$ [2-5]

Results of analysis

The $g^{TTh}{}_R(\varepsilon_f)$ single particle level

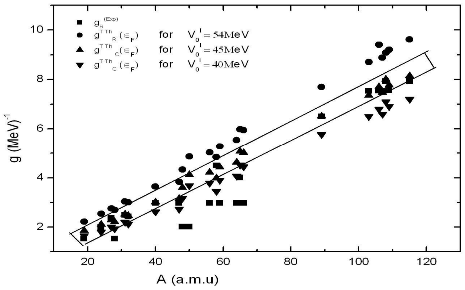

Fig. 1 The values of $g^{T\,Th}{}_R(\varepsilon_f)$ for V^I_0 =54 ,45 and 40 MeV and their comparison with $g^{(Exp)}{}_R$ as a function of mass number A of different target nuclei.

densities were calculated with V^I_0 = 54, 45 and 40 MeV. The results are presented in Fig. (1) along with the values of $g_R^{(Exp)}$ for different values of A. The results with V^I_0 =45 MeV seem to reproduce the experimental values more closely than those with other potential values. The $g^{T\,Th}_C(\varepsilon)$ level density for ε=14.8 MeV were also calculated with V^I_0=54,45 and 40 MeV. The values of $g^{TTh}_C(\varepsilon)$, $g^{Th}_{Cp}(\varepsilon_p)$ and $g^{Th}_{Cn}(\varepsilon_n)$ with V^I_0=45 MeV along with $g_c^{(Exp)}$ are plotted in Fig. 2 as a function of mass number A of the target nuclei . The theoretical values seem to follow the same general trend as that of $g_c^{(Exp)}$, however, the experimental values are, in general , somewhat (about 10 %) higher than the respective theoretical values, and remain somewhat higher, even than the theoretical values, obtained with V^I_0=54 MeV

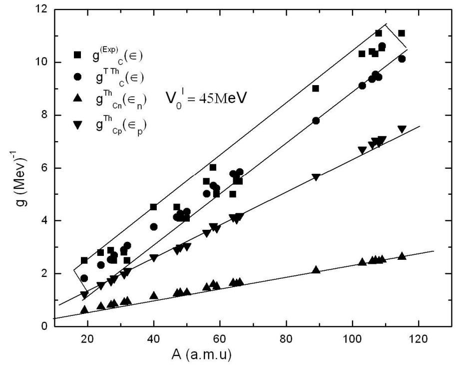

Fig.2 The value of $g^{T\,Th}_C(\varepsilon)$, $g^{Th}_{Cn}(\varepsilon_n)$ and $g^{Th}_{Cp}(\varepsilon_p)$ at ε_n =14.8 MeV and ε_p=ε_n-V_c with V^Io =45 MeV and their comparison with $g^{(Exp)}_C(\varepsilon)$

Discussion and Conclusions

The $g_C{}^{(Exp)}$ values are found to be consistently , significantly larger, than the respective $g_R{}^{(Exp)}$ values , suggesting that $g_C^{(\,Exp)}$ values correspond to higher excitation energies than those for the respective $g_R{}^{(Exp)}$ values Theoretical results provide excitation energies of the single particle level densities g(ε) with reference to ε =0 value. To develop, general trends of excitation energy dependence, of the single particle levels, their excitation energies should be expressed with reference to the depth of potential, $-V_0$ for neutrons, and $-V_0$ + V_C for protons. We have already expressed excitation energies of the $g^{T\,Th}_R(\varepsilon_f)$ as ε_f with respect to potential well depth(ε_{nf} =| V_0 | - B.E. of last neutron; and ε_{pf} =| V_0 | – B.E. -V_c.. The excitation energie ε for $g^{TTh}_C(\varepsilon)$ ($\varepsilon_n = \varepsilon_{in}$ + $|V_0|$;and $\varepsilon_p = \varepsilon_n - V_c$) when expressed with respect to potential depth, becomes around $\varepsilon=\varepsilon_{in}$ + $|V_0|$. Here ε_{in} is around 14.8 MeV. With these modifications, the excitation energy dependence for $g^{TTh}_C(\varepsilon)$, $g^{Th}_R(\varepsilon_f)$ and for $g_c^{(Exp)}$ and $g_R{}^{(Exp}$ can be expressed as :

$g^{TTh}_C(\varepsilon) / g^{T\,Th}_R(\varepsilon_f) = [(\varepsilon_{in} +| V_0 |)/\varepsilon_f]^{1/2} f(\varepsilon_{in})_{th}$

$g_c{}^{(Exp)}/ g_R{}^{(Exp)} = [(\varepsilon_{in} +| V_0 |)/\varepsilon_f]^{1/2} f(\varepsilon_{in})_{exp}$,

The $g^{T\,Th}_R(\varepsilon_f)$'s were found to have nearly the same values as the $g^{TTh}_C(\varepsilon_f)$'s for the respective composite systems. The factors $f(\varepsilon_{in})_{th}$ with V^I_0=45 MeV and $f(\varepsilon_{in})_{exp}$ for different targets may depend upon projectile energies, and here are found to vary slowly increasing from 0.8 to 1.0 and 1.0 to 1.2, respectively, with mass number of the targets. Similar trends were reported earlier [6-7] also in pre-equilibrium reactions studied with protons having incident energies varying from about 50 to 200 MeV.

Present results support earlier conclusions [6, 7] that the g_C effective in pre-equilibrium processes , corresponds to excitation energies, which are not only much greater than Fermi energies, but are also positive , and increase with projectile energy, in a systematic way, governed by a well defined analytical expression.

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