Direct reaction model analysis of continuum region in one particle transfer reaction

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Abstract

Single particle strength in (p, d) reaction has been studied with 65 MeV polarized protons. From the study of level assignment at low excitation energy region, realistic function of spreading width has been extracted. A calculation method of cross section in direct reaction continuum is proposed using the strength function and DWBA calculation and the results of comparisons between the calculation and experimental data are described.

1. Introduction

In one particle transfer reaction at low projectile energy, the continuum spectra which appear succeeding the discrete region (direct reaction continuum) have been studied with several methods. Due to its structureless there has not been a decisive one. A few methods were proposed to make approach toward this problem. In these methods, cross section in this energy region was considered as incoherent sum of the direct reaction components which would preserve the sum rule limit of each shell orbit.

An approach proposed by Lewis was to treat the direct reaction continuum spectra as a damping of deep hole states on that assumption and it reproduced the direct continuum spectra measured in ^{209}Bi(p, d)^{208}Bi at 62 MeV by using the spreading width and single-hole energies[1].

Recently, from the studies of level assignment in Ni isotopes at low excitation energy region, more realistic function of spreading width has been extracted. In this study, a calculation method of direct reaction continuum by using the extracted strength function and DWBA calculation is proposed as following of the Lewis's approach.

2. Experiment

The experiment was carried out at Research Center for Nuclear Physics (RCNP), Osaka University using the AVF cyclotron which provided the 65 MeV polarized protons. The accelerated protons were bombarded onto the ^{48}Ca,^{58,64}Ni targets. The emitted deuterons were momentum-analyzed in the focal plane of the spectrograph RAIDEN viewed with the focal plane detector system Kyushu. Measured excitation energy regions were 0–10 and/or 20 MeV and measured angles were at 5–45 laboratory angles. Fig.1 shows double differential cross sections $d^2\sigma/d\Omega dE$ and analyzing powers A_y obtained after summing up over the energy bin of 500 keV in ^{58}Ni target.

3. Direct Reaction Model Analysis

The theoretical calculation is based on the assumption that the direct continuum is considered as incoherent sum of the direct reaction components which would preserve the sum rule limit of each shell orbit. In calculation, direct process is only considered in order to investigate the direct continuum since the process is expected to be dominant at excitation energy region (

Ex<5 MeV). The double differential cross sections is expressed by

$$\frac{d\sigma}{d\Omega}(E) = \sum_{\ell,j} C^2 S_{\ell,j}(E) \times \left.\frac{d\sigma}{d\Omega}\right|_{\ell,j}^{DWBA}(E) \tag{1}$$

with

$$C^2 S_{\ell,j}(E) = \sum C^2 S_{\ell,j} \times f_{\ell,j}(E) \tag{2}$$

and σ is the DWBA cross section calculated with the code DWUCK[2], a non-symmetry Lorentz function[3,4] that gives a strength distribution of the single-hole states;

$$f_{\ell,j}(E) = \frac{n_0}{2\pi} \frac{\Gamma(E)}{\left(|E - E_F| - E_R^{\ell,j}\right)^2 + \frac{\Gamma^2(E)}{4}} \tag{3}$$

where E_F is the Fermi energy calculated by an empirical formula[5] and n_0 is a normalization factor adjusted to fill the sum rule on the ℓ, j orbit. $\Gamma(E)$ is a spreading width expressed by

$$\Gamma(E) = \frac{\varepsilon_0 \left(E - E_F\right)^2}{\left(E - E_F\right)^2 + E_0^2} + \frac{\varepsilon_1 \left(E - E_F\right)^2}{\left(E - E_F\right)^2 + E_1^2} \tag{4}$$

where ε_0, ε_1, E_0 and E_1 are constants that express effects of the nuclear damping in the nucleus[6]. The parameters used are $\varepsilon_0 = 19.4$ MeV, $\varepsilon_1 = 1.40$ MeV, $E_0 = 18.4$ MeV and $E_1 = 1.60$ MeV. The sum rule of the spectroscopic factor and the resonance energy E_R are estimated for each ℓ, j orbit by the BCS theory. Single particle energies used in the BCS calculation are calculated by a prescription[7]. Isobaric analog states (IAS) were observed in the excitation energy regions larger than 12.535, 5.162 and 11.729 MeV for ^{48}Ca, ^{58}Ni and ^{64}Ni, respectively. The sum rule of the spectroscopic factor of neutron orbits for $T \pm 1/2$ isospin states are estimated with simple shell model prediction[8]

$$\sum C^2 S = \begin{cases} n_n - \dfrac{n_p}{2T+1} & \text{for} \quad T_< = T - \frac{1}{2} \quad \text{states} \\ \dfrac{n_p}{2T+1} & \text{for} \quad T_> = T + \frac{1}{2} \quad \text{states} \end{cases} \tag{5}$$

where n_n and n_p are the number of neutrons and protons for each ℓ, j orbit , respectively and T is the target isosipn. The calculated results are plotted in Fig.1.

4. Results and Discussion

From a comparison of the calculated spectra and experimental ones in Fig.1, it is found that the spectral shape is considerably well reproduced at forward angles for all the targets while the direct continuum spectra ($E_x > 5$ MeV) are appreciably underestimated at backward angles. As for the analyzing power A_y, all the targets show the same results in which positive A_y are observed at around the ground state and negative A_y in the higher excitation energy regions at forward angles (5, 8 deg.). The direction and magnitude of A_y in the higher excitation energy regions become positive and large with angles. It should be noted that A_y is perfectly positive at overall excitation energies in backward angle spectra more than 29 deg.. The calculation reproduce the polarization and the magnitude well. This tendency is indicating the validity of this calculation method.

Fig.2–5 shows angular distributions of the cross sections obtained after summing up over the excitation energy bin of 5 MeV. In the discrete region (E_x<5 MeV) the theoretical cross sections are smaller than that of experiment at all the measured angles for all targets but their distributions are in good agreement with the experimental ones. The normalization factors extracted after scaling the theoretical cross sections to the experimental ones are 1.17, 1.40 and

1.15 for ^{48}Ca, ^{58}Ni, and ^{64}Ni, respectively. The factors are very close values in all the target nuclei.

At continuum regions (E_x=5–10 MeV), the same factors are applied for ^{58,64}Ni nuclei since the distributions are similar to that of descrete regions while ^{48}Ca data doesn't show such a systematic results. In the normalized distributions for ^{58,64}Ni, theoretical cross sections are appreciably small at backward angles. It is expected that the contributions from the other reaction processes such as multi-step process become important at this excitation energy regions.

5. Conclusion

In this study, double differential cross sections and analyzing powers of direct reaction continuum were calculated with the spreading widths and single-particle energies which were determined through the experimental studies. Spectral shape is well reproduced and the abusolute values ofcross sections are in good agreement with experimental ones. It is found that in direct reaction contiuum contributions from the processes such as multi-step process become large at backward angles.

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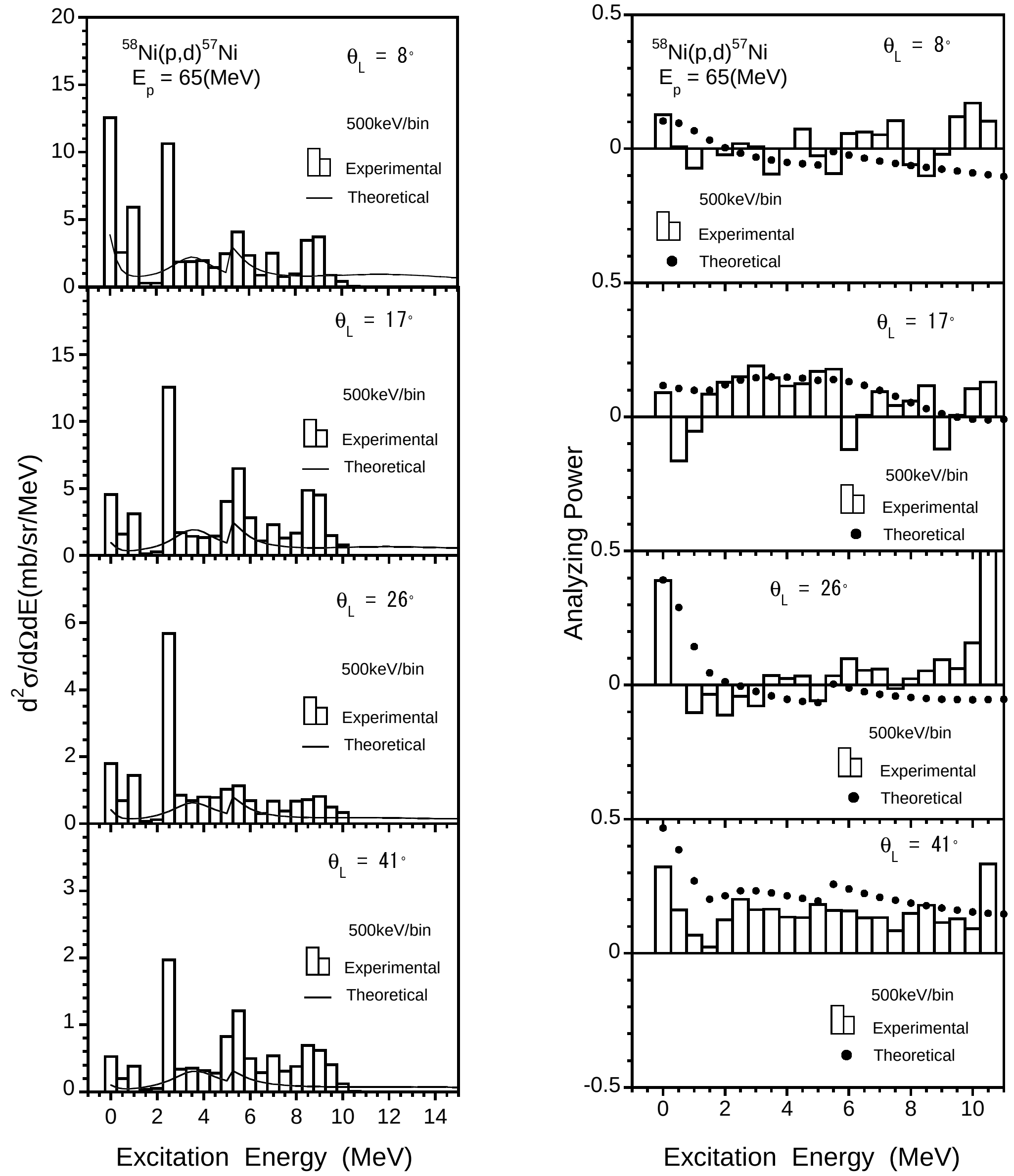

Figure 1: Double differential cross section (left) and Analyzing Power (A_y) from a ^{58}Ni target.

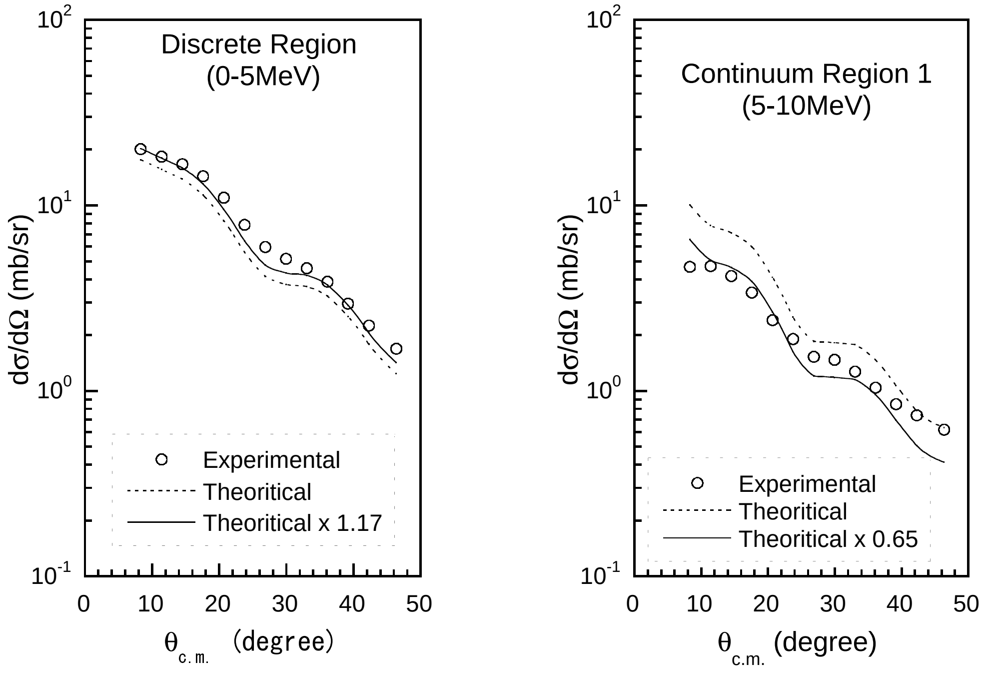

Figure 2: Angular distributions of summed cross sections from a ^{48}Ca target. Ex=0–5 MeV (left) and 5–10 MeV(right).

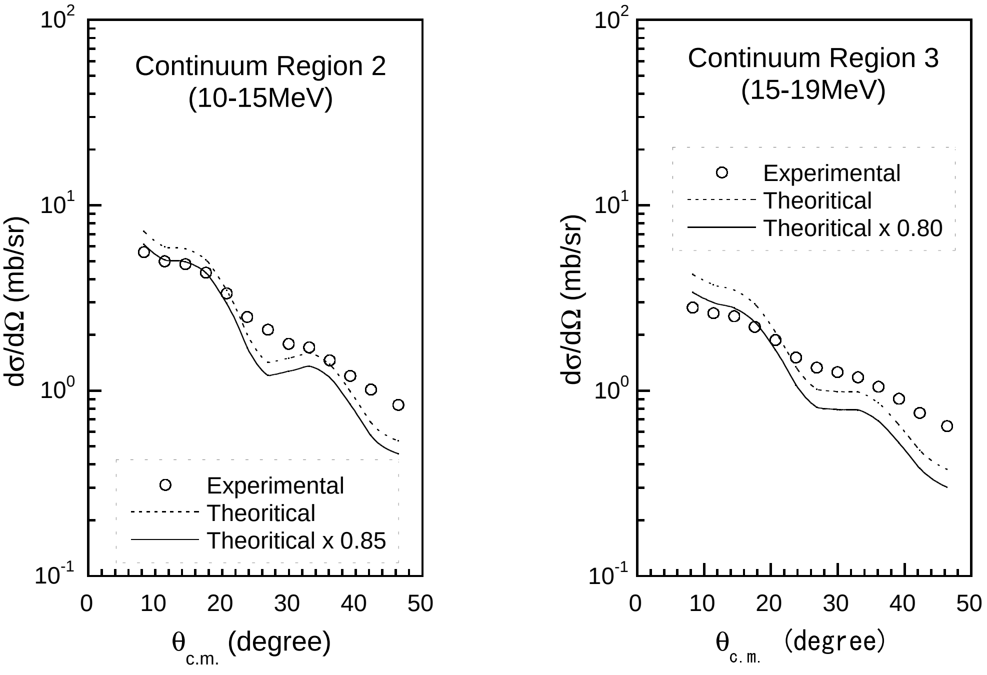

Figure 3: Angular distributions of summed cross sections from a ^{48}Ca target. Ex=10–15 MeV (left) and 15–19 MeV(right).

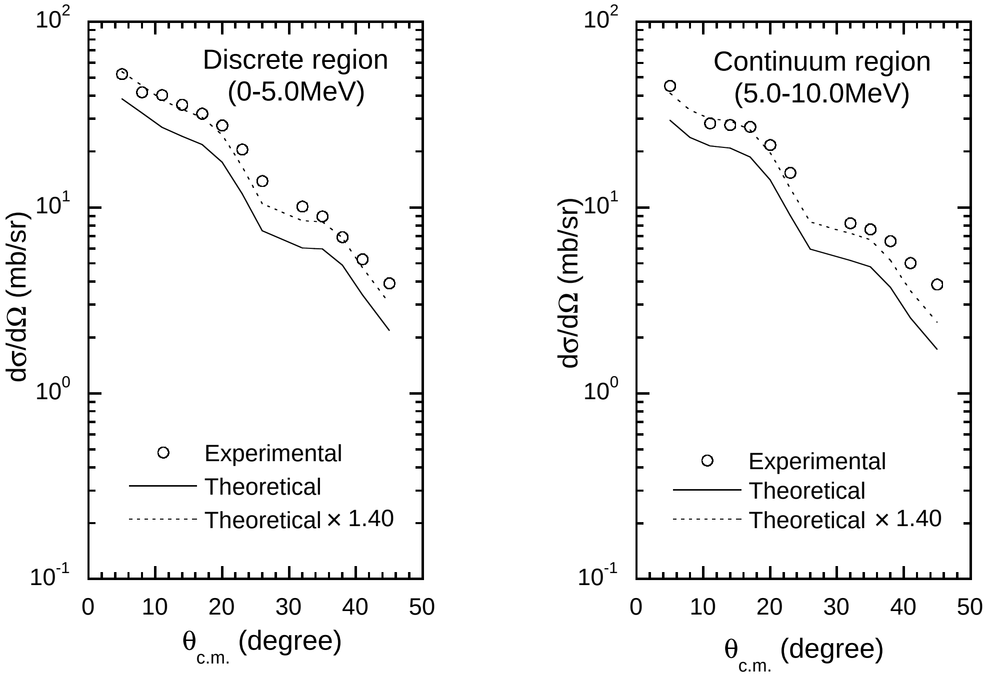

Figure 4: Angular distributions of summed cross sections from a ^{58}Ni target. Ex=0–5 MeV (left) and 5–10 MeV(right).

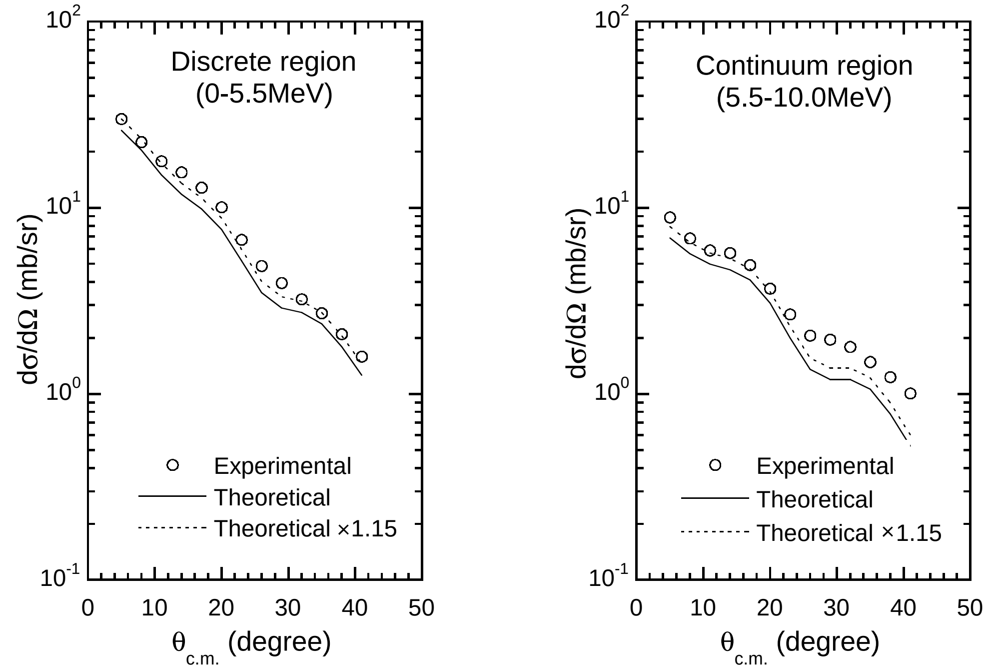

Figure 5: Angular distributions of summed cross sections from a ^{64}Ni target. Ex=0–5.5 MeV (left) and 5.5–10 MeV(right).