Journal of Engineering and Applied Sciences 1 (3) : 211-214, 2006

Analysis of Continuum Spectra for ^{64}Ni(p,d)^{63}Ni Reaction at 65 MeV

S.A. Sultana
Bangladesh Open University, Gazipur-1705, Bangladesh

Abstract: The ^{64}Ni(p,d)^{63}Ni reaction has been studied with an incident energy of 65 MeV polarized protons. Continuum regions are treated here with an analysis method using the direct reaction model. The double differential cross section-energy spectra are reproduced well using the DWBA-based cross sections and the asymmetrical Lorentzian form strength response function having energy-dependent spreading widths. The results of comparisons between the calculated and experimental spectra are described here.

Key words: Continuum Spectra, MeV, ^{64}Ni(p,d)^{63}Ni

INTRODUCTION

In the single-neutron pickup reactions, the continuum spectra which appear succeeding the discrete region have not been studied so easily. Due to its structureless there has not been a decisive one[1]. Varieties of theoretical models have been proposed to study the continuum spectra for one nucleon transfer reaction[2-4], which cannot reproduce well the experimental data[5,6].

From the above points of view, it is indispensable to develop a theoretical model which can reproduce well the continuum spectra in the direct reaction regions. Therefore, an approach such as proposed by Lewis[7] is suggested to be employed, in parallel with the prediction models described by Crawley[8] and Gales *et al.*[9], to analyze such a continuum in a systemic way.

In agreement with Lewis, Matoba *et al.*[10,11] have advanced an analysis using an asymmetrical Lorentzian shaped strength function having energy-dependent spreading widths and DWBA based cross sections, to describe the reaction process ruling the low-lying spectrum. This method has been successfully applied for the (p,d) reactions on ^{48}Ca and ^{58,60,62,64}Ni at 65 MeV[12], ^{96}Mo at 50[13] and ^{100}Mo at 21 and 50 MeV[14,15]. But in the case of ^{64}Ni, no detail analysation has been shown for the continuum spectra in the direct reaction region.

The present work is concerned with the (p,d) reaction on ^{64}Ni using a polarized proton beam of 65 MeV. The cross-sections are estimated here as an incoherent sum of many shell-orbits constituents based on the Distorted-wave Born Approximation (DWBA). The calculated results are compared with the experimental ones, as we know that there are no available theoretical results in the direct reaction regions so no comparison is possible here with other theoretical results.

Experiment: The experiment was performed with a beam of polarized protons of energy 65 MeV by the Kyushu University group at the Research Center for Nuclear Physics (RCNP), Osaka University using the AVF cyclotron. The emitted deuterons were momentum-analyzed in the focal plane of the spectrograph Raiden[16] viewed with the focal plane detector system Kyushu[17]. The angular distributions of cross sections and analyzing powers were measured over the laboratory angles 5^0-41^0. The target was self-supporting, isotopically enriched (97.9% of ^{64}Ni) and of thickness 0.526 mg cm^{-2}.

Theoretical calculations: In the present method, the theoretical calculations of the double differential cross-sections have been done by considering a direct reaction model as an incoherent sum of the direct reaction components, which are based on DWBA predictions and expressed as below

$$\frac{d^2\sigma}{d\Omega dE} = 2.30\sum_{l,j}\left[\frac{C^2s_{l,j}(E)}{2j+1}\times\left(\left.\frac{d\sigma}{d\Omega}\right|_{l,j}^{DW}(E)\right)\right] \qquad (1)$$

where $d\sigma/d\Omega|_{l,j}^{DW}(E)$ is the cross-section calculated by a DWBA code Dwuck[18] and $C^2S_{l,j}$, the spectroscopic factor expressed as

$$C^2S_{l,j}(E) = \left(\sum C^2S_{l,j}\right)\times f_{l,j}(E) \qquad (2)$$

where $\sum C^2S_{l,j}$ is the sum of the spectroscopic factors of all the predicted states and the distribution of strength function over the spectra is obtained by using an asymmetric Lorentzian function[10,11,19]

$$f_{l,j}(E) = \frac{n_0}{2\pi}\frac{\Gamma(E)}{\left(|E-E_F|-E_{l,j}\right)^2+\Gamma^2(E)/4} \qquad (3)$$

and

$$\int_0^{\alpha} f_{l,j}(E)dE = 1 \qquad (4)$$

where n_0 is the renormalization constant and E_F the Fermi energy. The Fermi energy can be calculated by using an empirical formula given in[20]. The sums of spectroscopic factors and the centroid energies ($E_{l,j}$) for J = l±1/2 shell orbits have been estimated by using BCS calculations. In these calculations, single particle energies required to calculate the centroid energy are calculated by the prescription of Bohr and Mottelson[21]. Spreading width (Γ) is expressed by a function proposed by Brown and Rho[22] and by Mahaux and Sartor[19], as,

$$\Gamma(E) = \frac{\varepsilon_0 (E - E_F)^2}{(E - E_F)^2 + E_0^2} + \frac{\varepsilon_1 (E - E_F)^2}{(E - E_F)^2 + E_1^2} \qquad (5)$$

where ε_0, ε_1, E_0 and E_1 are constants which express the determined as, effects of nuclear damping in the nucleus[10]. The estimated parameters[10] are

$$\begin{aligned} \varepsilon_0 &= 19.4 \text{ (MeV)}, E_0 = 18.4 \text{ (MeV)} \\ \varepsilon_1 &= 1.40 \text{ (MeV)}, E_1 = 1.60 \text{ (MeV)} \end{aligned} \qquad (6)$$

The sum rule of the spectroscopic factors of nucleon orbits for T±1/2 isospin states are estimated with a simple shell model prescription[23]

$$\sum c^2 s_{l,j} = \begin{cases} n_n(l,j) - \frac{n_p(l,j)}{2T+1} & \text{for } T_< = T - \frac{1}{2} \\ \frac{n_p(l,j)}{2T+1} & \text{for } T_> = T + \frac{1}{2} \end{cases} \qquad (7)$$

Here n_n (l, j) and n_p (l, j) are the numbers of neutrons and protons, respectively for each l, j orbit and T is the isospin of the target nucleus.

RESULTS AND DISCUSSION

The comparisons between the theoretical and experimental double differential cross section and analyzing power are shown in Fig. 1 and 2. The experimental and theoretical results are given by the histograms and solid lines, respectively for laboratory angles of 5°-41°. The measured energy spectrum of double differential cross section and analyzing power were converted to 500 KeV wide energy spectra. Menet potential[24] has been used here for protons, while for deuteron an adiabatic potential based on the Becchetti proton and neutron potentials[25] were constructed for the DWUCK-4 calculation.

From the comparison between the calculated spectra and experimental ones in Fig. 1 and 2, it is found that the spectral shape is overall well reproduced at all angles, in both direction and magnitude. It is a little overestimated at very forward angle, e.g., 5^0, whereas, a litttle underestimated at very backward angle, e.g., 41^0. It is thus possible that for the backward angles, there may be some contributions from the pre-equilibrium reaction process. As for the analyzing power, it is well reproduced for 5^0 and 17^0 angles but considerably well reproduced for 29^0

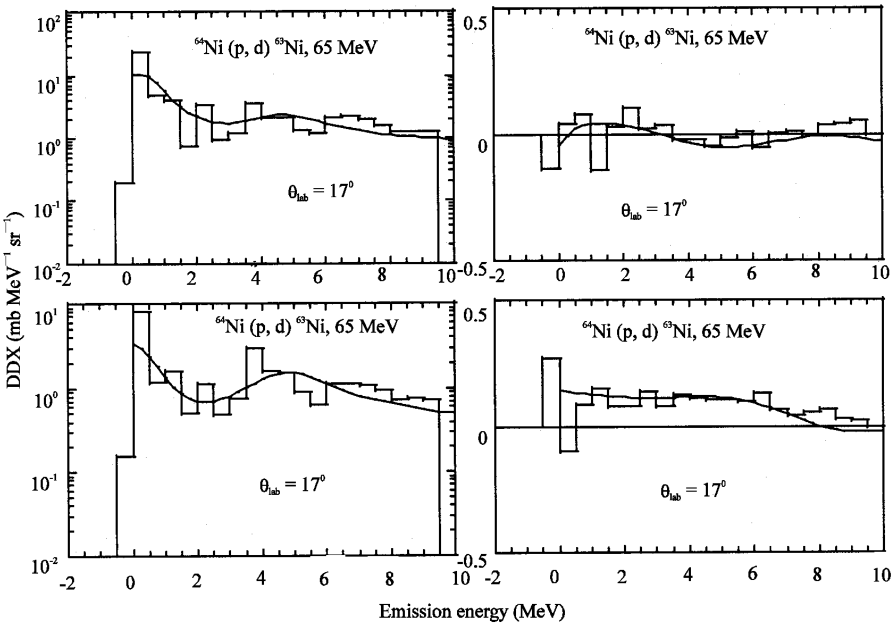

Fig. 1: Double differential cross sections (left) and analyzing powers (right) obtained for the ^{96}Mo(p,d)^{95}Mo reaction at 65 MeV. Histograms and solid lines represent the experimental and theoretical results, respectively

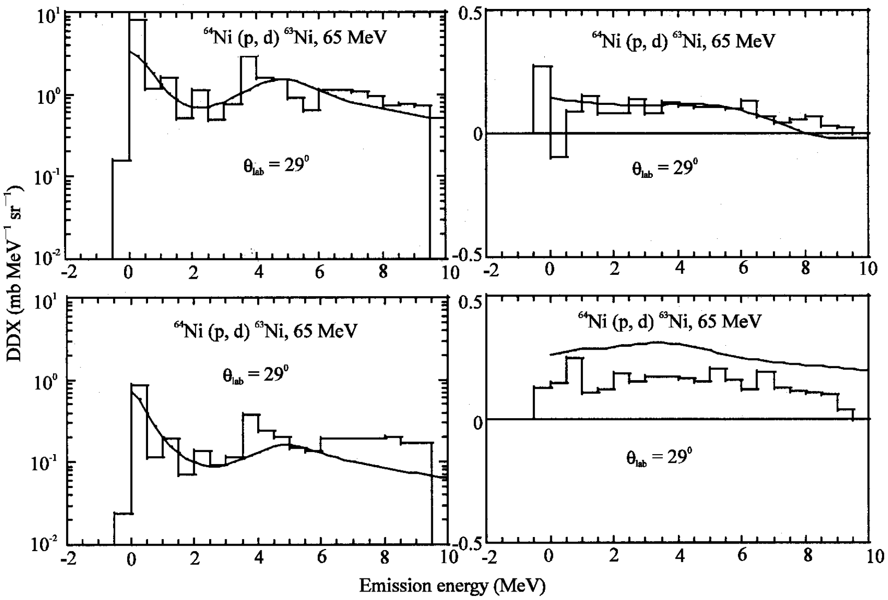

Fig. 2: Same as Fig. 1 but for different angles

and 41^0 angles. The directions of the calculated spectra are fitted well for the 29^0 and 41^0 angles but for the magnitude these are little higher than the experimental ones. It should be noted here that no renormalization is required in this method for the theoretical cross-sections calculation to make good matching with the absolute values of the experimental cross-sections.

CONCLUSION

The continuum spectra of (p,d)-one-nucleon transfer reaction have been studied here on the ^{64}Ni nucleus. The bombarding energy for proton-induced reaction is 65 MeV. One-step direct pickup reaction model is used here for analysing the continuum spectra. The theoretical distribution of the strength function over the experimental continuum spectra are reproduced well by adopting an asymmetric Lorentzian form in the DWBA-based cross sections having energy dependent spreading width. Spectral shapes are well reproduced and the absolute values of the cross sections are in good agreement with experimental ones.

ACKNOWLEDGEMENT

I am grateful to Ikeda laboratory, Department of Applied Quantum Physics and Nuclear Engineering, Kyushu University, Japan, for giving me the opportunity of using these experimental data and to the staff of the Research Center for Nuclear Physics (RCNP), Osaka University, for the support of the experiments at the Cyclotron facility.

REFERENCES

1. Aoki, S., K. Yamaguchi, Syafarudin, G. Wakabayashi, F. Aramaki, Y. Uozumi, A. Nohtomi, T. Sakae, M. Matoba, N. Koori, T. Maki and Y. Tanaka, 2002. J. Nucl. Sci. Technol., 2: 377.
2. Young, P.G., E.D. Arthur and M.B. Chadwick, 1992. Los Alamos National Laboratory, Report No. LA-MS-12343.
3. Takada, H., 1996. J. Nucl. Sci. Technol., 33: 275.
4. Niita, K., S. Chiba, T. Maruyama, T. Maruyama, H. Takada, T. Fukahori, Y. Nakahara and A. Iwamoto, 1995. Phys. Rev. C, 52, 2620.
5. Slypen, I., V. Corcalciuc and J.P. Meulders, 1995. Phys. Rev. C 51, 1303.
6. Nauchi, Y., M. Baba, T. Sanami, M. Ibaraki, T. Iwasaki, N. Hirakawa, S. Tanaka, S. Meigo, H. Nakashima, H. Takada, T. Nakamura and Y. Watanabe, 1999. J. Nucl. Sci. Technol., 36: 143.
7. Lewis, M.B., 1975. Phys. Rev., C11, 145.
8. Crawley, G.M., 1980. Proceedings of International Symposium of Highly Excited States in Nuclear Reactions, Osaka,1980 and references therein.
9. Gales, S., C.H. Stoyanov and A.I. Vdovin, 1988. Phys. Rep. 166(1988) 125 and references therein.

10. Matoba, M., O. Iwamoto, Y. Uozumi, T. Sakae, N. Koori, H. Ohgaki, H. Kugimiya, H. Ijiri, T. Maki and M. Nakano, 1995. Nucl. Phys., A581, 21.
11. Matoba, M., K. Kurohmaru, O. Iwamoto, A. Nohtomi, Y. Uozumi, T. Sakae, N. Koori, H. Ohgaki, H. Ijiri, T. Maki, M. Nakano and H.M. Sen Gupta, 1996. Phys. Rev., C53, 1792.
12. Syafarudin, F. Aramaki, G. Wakabayashi, Y. Uozumi, N. Ikeda, M. Matoba, K. Yamaguchi, T. Sakae, N. Koori and T. Maki, 2002. J. Nucl. Sci. Technol., 1: 377.
13. Sultana, S.A., D. Maki, G. Wakabayashi, Y. Uozumi, N. Ikeda, Syafarudin, F. Aramaki, T. Kawaguchi, M. Matoba and H.M. Sen Gupta, 2004. Phys. Rev. C 70, 034612.
14. Hirowatari, S. *et al*., 2003. Nucl. Phys. A 714, (2003)3.
15. Aramaki, F., Syafarudin, G. Wakabayashi, Y. Uozumi, N. Ikeda, M. Matoba, T. Sakae and N. Koori, 2002. Proceedings of the 2002 Symposium on Nuclear Data, JAERI-Conf 2002-006, pp: 178-182.
16. Ikegami, H., S. Morinobu, I. Katayama, M. Fujiwara and S. Yamabe, 1980. Nucl. Instr. Meth., 175: 335.
17. Matoba, M., K. Tsuji, K. Marubayashi, T. Shintake, H. Ikegami, T. Yamazaki, S. Morinobu, I. Katayama, M. Fujiwara and Y. Fujita, 1981. Nucl. Instr. Meth.,180: 419.
18. Kunz, P.D., DWBA code DWUCK- 4, University of Colorado (Unpublished).
19. Mahaux, C. and R. Sartor, 1991. Nucl. Phys. A, 493, 157 (1989), Adv. Nucl. Phys, 20: 1.
20. Hisamochi, K., O. Iwamoto, A. Kisanuki, S. Budihardjo, S. Widodo, A. Nohtomi, Y. Uozumi, T. Sakae, M. Matoba, M. Nakano, T. Maki, S. Matsuki and N. Koori, 1993. Nucl. Phys., A564: 227.
21. Bohr, A. and B.R. Mottelson, 1969. Nuclear Structure (W.A. Benjamin, New York, 1969), Vol. 1, Appendix 2D.
22. Brown, G.E. and M. Rho, 1981. Nucl. Phys. A, 372: 397.
23. French, J.B. and M.H. Macfarlane, 1961. Nucl. Phys., 26: 168.
24. Menet, J.J.H., E.E. Gross, J.J. Malanify and A. Zucker, 1971. Phys. Rev. C 4, 1114.
25. Becchetti, F.D., Jr. and G.W. Greenless, 1969. Phys. Rev., 182: 1190.