Analysis of The ^{197}Au(p,d) ^{196}Au Reaction at 68 MeV with Direct Reaction Model

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Abstract

Double differential cross section for the ^{197}Au(p,d) ^{196}Au reaction has been studied here with 68 MeV protons for the 30^0, 35^0, 45^0 and 60^0 angles. Calculations of the spectra have been carried out here using the distorted wave Born approximation (DWBA) -based cross-sections and the asymmetric Lorentzian form strength response function having energy dependent spreading widths. The results of comparisons between the experimental and calculated spectra are described. Numerical values of the double differential cross sections are lower than experiment by approximately 10% or so.

***Keywords*:** double differential cross section, (p,d), nuclear reactions, direct reaction model, DWBA analysis

1. Introduction

Generally, the spectrum of the emitted particles from one nucleon transfer reaction can be divided into three parts, because the mechanisms of this type of reaction are classified to three types, i.e, direct, pre-equilibrium and evaporation processes.

The evaporation and pre-equilibrium processes are analyzed with statistical models and present days some computer codes (GNASH, CASCADE, QMD) are available to calculate double differential cross sections [1-6]. However, the continuum spectrum in the direct reaction region is not possible to analyze easily.

From the above points of view, it is indispensible to develop a theoretical model which reproduces 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], therefore, is employed in the present analyses, based on the distorted wave born approximation (DWBA) and an asymmetric Lorentzian form strength function. Matoba et al. [10, 11] in agreement with Lewis [8] have advanced an analysis using an asymmetric Lorentzian shaped strength function having energy-dependent spreading widths and distorted wave born approximation (DWBA) cross sections. This model has been successfully applied for the (p,d) reactions [12-17], then applied for the (n,d) reaction [18-20] with a slight modification and demonstrate its reasonable ability.

In the present work, the continuum spectra for the ^{197}Au(p,d) ^{196}Au reaction have been analyzed by the same method of calculation. Here, the laboratory angles are 30^0, 35^0, 45^0 and 60^0 and the incident energy is 68 MeV. The experiments in the present work were carried out in the same way with exactly identical arrangements of the experiment given in section 2 and in details in ref. [21]. Earlier, another work [17] also was done at the same energy and for the same reaction but at different laboratory angles 75^0, 90^0 and 120^0 to make this method of calculation as a global one over a wide range of scattering angles. With the same method of calculation, the application of seniority scheme to the present model for odd target nucleus [i.e, ^{197}Au(p,d) ^{196}Au] makes this model more feasible. The calculated results are compared here with the experimental ones.

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2. Materials and Methods

2.1 Experimental Calculations

The experiments were performed at the "Takasaki Ion Accelerators for Advanced Radiation Application (TIARA)" facility of Japan Atomic Energy Research Institute (JAERI). A proton beam of 68 MeV from the AVF cylotron was led to the HB-1 beam line.

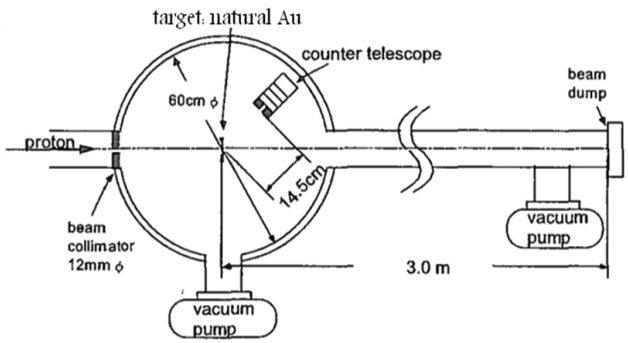

Fig. 1: Experimental setup of the HB-1 beam line

As illustrated in Fig. 1, the accelerated proton beam bombarded a thin target foil placed in the center of a 60 cm ϕ scattering chamber installed in the HB 1 beam line. Energy distributions of light ions emitted from the target were measured using a ΔE-E counter at 25^0, 30^0, 35^0, 45^0, 60^0, 75^0, 90^0, 12^0, and 150^0 in the laboratory system. The counter telescope consisted of two thin silicon E-detectors (30 μm and 500 μm in thickness, respectively) and a CsI(Tl) E-detector (18 mm¢ x 30 mm long) with photo-diode readout [21]. Energy distribution of light ions emitted from the target were measured using a ΔE-E counter

telescope, which consisted of two thin silicon ΔE-detetors and a CsI(T1) E-detector with photo-diode readout. Details of the experimental procedure and the results have been reported in ref. [22].

2.2. 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 distorted wave born approximation (DWBA) predictions and expressed as below:

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

where $d\sigma/d\Omega\big|_{l,j}^{DW}(E)$ is the cross-section calculated by a distorted wave born approximation (DWBA) code, DWUCK-4 (distorted wave born approximation, Zero range code) [23] and $C^2S_{l,j}(E)$, the spectroscopic factor expressed as

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

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 [11, 12, 24, 25]

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

and

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

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 ref. [26]. The sums of spectroscopic factors and the centroid energies ($E_{l,j}$) for $J = l \pm \frac{1}{2}$ shell orbits have been estimated by using Bardeen-Cooper-Schrieffer (BCS theory) calculations. In these calculations, single particle energies required to calculate the centroid energy are calculated by the prescription of Bohr and Mottelson [27]. Spreading width (Γ) is expressed by a function proposed by Brown and Rho [28] and by Mahaux and Sartor [24-25] as,

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

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

$$\varepsilon_0 = 19.4 \text{ (MeV)}, \quad E_0 = 18.4 \text{ (MeV)}$$
$$\varepsilon_1 = 1.40 \text{ (MeV)}, \quad E_1 = 1.60 \text{ (MeV)}. \quad (6)$$

It should be mentioned here that the effects of the nuclear damping are felt in the continuum spectra of the double differential cross section much more in the lower energy regions than at higher energy. There is a close similarity between theory and experiment except that in the direct nuclear reactions the effects show dominance at lower energies. This is not unexpected.

The sum rule of the spectroscopic factors of nucleon orbits for $T \pm \frac{1}{2}$ isospin states are estimated with a simple shell model prescription [29]

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

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.

3. Results and Discussion

Double differential cross-sections (DDXs) are calculated here for the ^{197}Au(p,d)^{196}Au reaction at 68 MeV for the laboratory angles of 30^0, 35^0, 45^0 and 60^0 as shown in figs. 2-3. Experimental and theoretical results are given by the circles and lines respectively in Figs. 2 and 3. Theoretical results are in general agreement with experimental results and the discrepancies are not more than 10% for all optical model potentials.

Three global potentials were used here for protons, while for deuteron an adiabatic potential [29-31] based on the proton and neutron potentials were constructed for the DWUCK-4 calculations as shown in Table 1. The solid, dotted and short-long-dashed lines represent the DDX for Beccheti and Greenlees [29], Koning and Delaroche [30] and Menet et al. [31] potentials respectively.

Figs. 2 - 3 show that for 30^0, 35^0 and 60^0 laboratory angles, the theoretical values are fairly in good agreement with experimental ones with approximately 10% lower for all potentials [29-31]. For 45^0 laboratory angles, the theoretical result is in good agreement with the experimental one for the Koning and Delaroche [30] and Menet et al. [31] potentials.

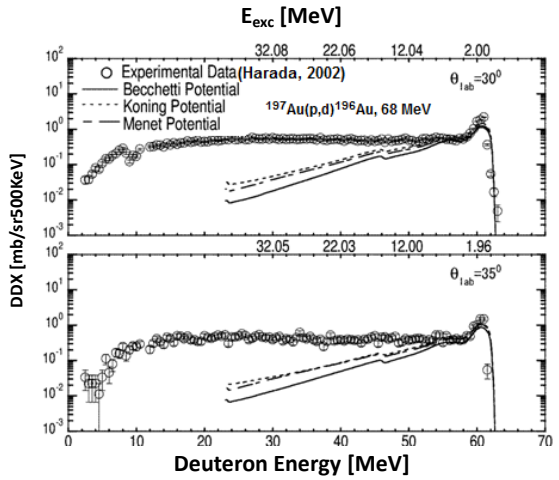

Fig. 2: Double differential cross sections for the ^{197}Au(p,d)^{196}Au reaction at 68 MeV for $30^0$and 35^0 laboratory angles

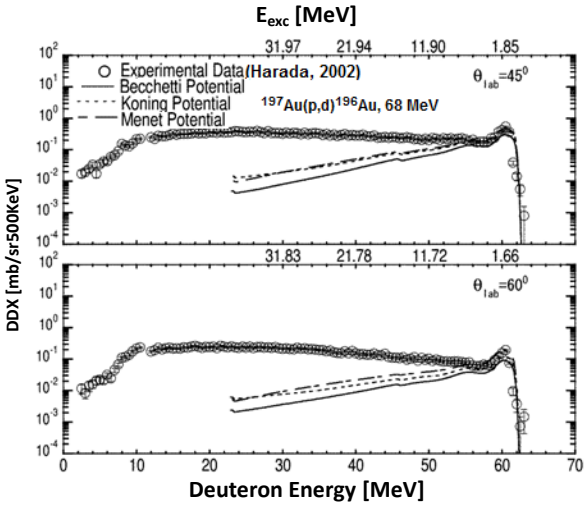

Fig. 3: Double differential cross sections for the ^{197}Au (p,d)^{196}Au reaction at 68 MeV for 45^0 and 60^0 laboratory angles for Beccheti and Greenlees [29] potential.

Table 1: Optical model parameters used in the DWBA calculations for the ^{127}Au(p,d)^{126}Au reaction at 68 MeV

Becchetti and Greenlees potential [28]

Particle	V (MeV)	r (fm)	a (fm)	r_c (fm)	W_v (MeV)	W_s (MeV)	r′ (fm)	a′ (fm)	V_{so} (MeV)	r_{so} (fm)	a_{so} (fm)
Proton	42.42	1.17	0.75	1.25	12.26	0.00	1.32	0.65	6.20	1.01	0.75
Deuteron	a	1.17	0.78	1.25	b	b	1.29	0.65	6.20	1.06	0.75
Neutron	c	1.25	0.65								

[a]V = [110.3 – 0.64(E_d/2) + 0.4Z/$A^{1/3}$] MeV

[b]W_v = [0.44(E_d/2) – 4.26] MeV, Ws = [24.8 – 0.50(E_d/2)] MeV, E_d is the deteron kinetic energy and [c]Well depth adjusted to fit the separation energy

Koning and Delaroche potential [29]

Particle	V (MeV)	R (fm)	a (fm)	r_c (fm)	W_v (MeV)	W_s (MeV)	r′ (fm)	a′ (fm)	V_{so} (MeV)	r_{so} (fm)	a_{so} (fm)
Proton	30.63	1.23	0.65	1.22	6.72	4.96	1.25	0.51	4.85	1.07	0.59
Deuteron	a	1.23	0.65	1.22	a	a	1.25	0.57	a	1.07	0.59
Neutron	b	1.25	0.65								

[a]Adiabatic potentials with those of [29]

[b]Well depth adjusted to fit the separation energy

Menet potential [30]

Particle	V (MeV)	R (fm)	A (fm)	r_c (fm)	W_v (MeV)	W_s (MeV)	r′ (fm)	a′ (fm)	V_{so} (MeV)	r_{so} (fm)	a_{so} (fm)
Proton	45.60	1.16	0.75	1.25	7.32	3.87	1.37	0.40	6.04	1.06	0.75
Deuteron	a	1.16	0.75	1.25	b	b	1.37	c	6.04	1.06	0.75
Neutron	d	1.25	0.65								

[a]V = [99.8 – 0.44(E_d/2) + 0.4Z/$A^{1/3}$] MeV

[b]W_v = [2.4 + 0.18(E_d/2)] MeV, Ws = [8.40 - 0.10(E_d/2)] MeV, E_d is the deteron kinetic energy, [c]a′ = 0.74 0.008(E_d/2) + 1.0(N-Z)/2A and [d]Well depth adjusted to fit the separation energy

For all potentials nonlocality parameters and finite-range parameters are shown below:

	Nonlocality parameters	Finite-range parameter	λ= 25
proton	0.85fm	0.621	
neutron	0.85fm	0.621	
deuteron	0.54fm		

From the above discussion, we can find that the theoretical results are generally in good agreement with the experimental ones. The use of other optical model potentials may improve the theoretical results to fit the experimental ones.

Here, it should be noted that the calculated double differential cross sections agree with experimental data only above tens of MeV energy region, because our calculated energy spectrum regions are treated in the direct reaction scheme.

4. Conclusion

The present work based on direct reaction model was carried out in the same line by Crawley [8] and Gales et al. [9]. Proton induced reaction on ^{197}Au has been analyzed here with direct reaction model. Here, the incident energy is 68 MeV. The calculated DDXs show a good agreement with the experimental data both in magnitude and shape. Three global potentials are used for proton and deuteron in this theoretical model for the DWUCK-4 calculation for being confident about the theoretical method of DDX. We suggest here that using different optical model potentials may improve the result at forward angles.

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