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TWO NUCLEON CORRELATION IN THE (p,t) REACTION

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Abstract: We have calculated the (p,t) reaction cross section for nuclei with even Z and N. The transition matrix is expressed using a normalized form factor and a spectroscopic factor for the sake of usefulness in the DWBA computation. In the nuclear wave functions the pairing correlation is taken into account by using a BCS type function. Shown that, consequence of correlations, the fractional parentage expansion of the true wave function of the final nucleus should contain the associated states initial with a greater statistical weight than that given by the fractional parentage coefficients of the shell model wave function. The obtained results are compared with the experimental data for $^{124}Sn\ (p,t)^{122}Sn$.

Keywords: scattering, cross section, DWBA approximation, spectroscopic factor.

1. Introduction

The purpose of this paper is to present a more satisfactory analysis of the (*p*, *t*) reaction so as to get some information. Our interests are mainly in medium weight even nuclei, in which the pairing correlation and the collective motion are important.

The information obtained from (*t*, p) and (*p*, *t*) reaction experiments is concerned with the correlation of two like-nucleons. It is known that certain levels are strongly excited and the ground state of an even nucleus is most strongly excited in many cases, while, usually, higher zero spin states are not excited strongly, although there are some remarkable exceptions. The magnitude of the cross section gives us information about the detailed structure of the levels. The information obtainable from two nucleon stripping reactions is different from that obtained from single-nucleon transfer reactions; from the latter only the single particle character of the levels is obtained. The sets of data obtained from the single and two nucleon transfer reactions are both valuable, and they are mutually complementary. The analysis of the former kinds of reactions has already reached a satisfactory enough stage to furnish quantitative information about nuclear structure.

We put our focus on the role of the nuclear spectroscopy and two nucleon correlation in the reaction mechanism. The transition matrix is expressed using a normalized form factor and a spectroscopic factor for the sake of usefulness in the DWBA computation.

2. Formulation

The transfer cross section of two like nucleons may be derived in a way parallel to that used in the previous paper by taking the (*p*,*t*) reaction as [1]

$$d\sigma = \frac{E_p E_A}{\lambda^{1/2}(m_p^2 + m_A^2)(2J_p+1)} \sum (2\pi)^4 \delta^4 (P_p + P_A - P_t - P_B) M^2 dP_t \, , \tag{1}$$

where $E_p = (\mathbf{P}_p^2 + m_p^2)^{1/2}$ energy of p and $E_A = (\mathrm{P}_A^2 + m_A^2)^{1/2}$ – energy of nucleus ,

$\lambda(x, y, z) = (x\text{-}y\text{-}z)^2 - 4\,yz$ – kinematic function.

If both the initial and final shell model wave functions are assumed to be such that the center of mass motion remains in the ground state, and if, further, the interaction which causes the stripping reaction is assumed to be a spin dependent interaction with gaussian radial form

$$V = V_{pn} + V_{pn'}, \tag{2}$$

$$V_{pn} = (P_1 V_1 + P_3 V_3)\exp\left[-a^2\left(r_{p_1} - r_n\right)^2\right] \tag{3}$$

where V_1 and V_3. are the singlet and triplet potential strengths, and P_1 and $P3$ are their projection operators.

The amplitude M of the transition in the zero approximation has the following form:

$$M = \sum\langle JMI_i M_i \mid I_f M_f\rangle\langle SM_S LM_L \mid JM\rangle(-1)^L\left(\frac{A+2}{A}\right)^{(N-1+L/2)}\left\langle \chi_{1/2m_p}(p)\chi_{SM_S}(n,n') \mid P_1V_1 + P_3V_3 \mid \chi_{1/2m_t}(t)\right\rangle,$$
$$x\int \varphi^+(k_{p,}r_p)\Psi^*(r)\varphi^+(k_t,r_p)dRdrdr'$$

(4)

where $\varphi^{(+)}$ and $\varphi^{(-)}$ incident and outgoing distorted waves, respectively, $r' = R\text{-}R_A$, R_A being the center of mass coordinate of the target nucleus, S denotes the resultant internal spin, and M_S its Z component.

Using Glauber distorted waves can write [2,3]

$$\varphi_t^{(-)}(\mathbf{k}_t,\mathbf{r}) = (2\pi)^{-3/2}\exp(i\mathbf{k}_t,\mathbf{r})\prod_{j=1}^{A-2}\left[1 - \Gamma(\mathbf{b}-\mathbf{b}_j)\,\theta(\mathbf{z}-\mathbf{z}_j)\right]\chi_m^t(\mathbf{s}), \tag{5}$$

$$\varphi_p^{(+)}(\mathbf{k}_p,\mathbf{r}) = (2\pi)^{-3/2}\exp(i\mathbf{k}_p,\mathbf{r})\prod_{j=1}^{A}\left[1 - \Gamma(\mathbf{b}-\mathbf{b}_j)\,\theta(\mathbf{z}-\mathbf{z}_j)\right]\chi_m^p(\mathbf{s}), \tag{6}$$

where $\Gamma(\mathrm{b})$- profile function , $\theta(z)$- discrete Heaviside function, $\chi_m(\mathrm{s})$- spin function and b is impact parameter.

The spin wave function of the triton must be chosen so that the whole wave function may be antisymmetric with respect to exchange of two like nucleons

$$\chi_{1/2,m_t}(t) = \sum < 1/2m_p S_1 M_{S_1} \mid 1/2m_t > \chi_{1/2m_p}(p)\chi_{S_1M_{S_1}}(n,n')\delta_{S_1 0}, \tag{7}$$

from which we get

$$\left\langle \chi_{1/2m_p}(p)\chi_{SM_S}(n,n') \mid P_1V_1 + P_3V_3 \mid \chi_{1/2m_t}(t)\right\rangle = \langle 1/2m_p SM_S \mid 1/2m_t\rangle\sqrt{2S+1}(-)^s\left[\frac{1}{4}V_1 + \frac{3-2S(S+1)}{4}V_3\right], \tag{8}$$

Thus, we get

$$M = \sum\langle JMI_i M_i \mid I_f M_f\rangle\langle SM_S LM_L \mid JM\rangle(-1)^s\left(\frac{A+2}{A}\right)^{(N-1+L/2)}\sqrt{2S+1}(-)^s\left[\frac{1}{4}V_1 + \frac{3-2S(S+1)}{4}V_3\right], \tag{9}$$
$$x\sqrt{S\left(\alpha_f I_f; SLJ; \alpha_i I_i\right)}\int \varphi^+(k_{p,}r_p)\Psi^*(r)\varphi^+(k_t,r_p)dRdrdr'$$

where

$$S\left(\alpha_f I_f; SNLJ; \alpha_i I_i\right) = \sum\left| C\left(\alpha_f I_f; SNLJ; \alpha_i I\right)\right|^2 \tag{10}$$

and spectroscopy amplitude $C\left(\alpha I_i; SNLJ; \alpha_f I_f\right)$ defined as

$$C(\alpha\, I_i; SNLJ; \alpha_f I_f) = \sum (-1)^l \left(\frac{A+2}{A}\right)^{(N-1+L/2} \left\langle \frac{1}{2} l_n(j_n); J \,|\, \frac{1}{2}\frac{1}{2}(S) l_n l(L); J \right\rangle \langle n_n l_n n_{n'} l_{n'}; L \,|\, NLnL \rangle \qquad (11)$$

where *($n_n l_n j_n$)* and *($n_{n'} l_n, j_{n'}$)* are the quantum numbers of the two transferred neutrons, and J is the transferred total angular momentum with Z component M. The resultant orbital angular momentum L is composed of the orbital angular momentum of their center of the gravity $L\, M_Z$ and that of their relative motion lm_l.

We are interested in reactions where transitions take place from the ground state of an even target nucleus to the ground state of the even residual nucleus, and the spins of the initial and the final states are both zero. In such case, the most important residual interaction is the pairing interaction. We have $L = S$ when $J = 0$. On the other hand, the selection rule for the Talmi coefficients $2\,(n_n - 1) + l_n + 2\,(n_n - 1) + l_n = 2\,(N - 1) + L + 2\,(n - 1) + l$ associated with the zero-range approximation constrains the resultant internal spin S to zero. As $L = S$, the 9 - j symbol becomes simply

$$\left\langle \frac{1}{2} l_n(j_n) \frac{1}{2} l_n(j_n); 0 \,|\, \frac{1}{2}\frac{1}{2}(S) l_n l_n(S); 0 \,|\right\rangle = (-1)^{l_n + j_n + S - 1/2} \sqrt{(2j_n+1)(2S+1)}\, W\left(\frac{1}{2} l_n \frac{1}{2} l_n; j_n S\right), \qquad (12)$$

where $W\left(\frac{1}{2} l_n \frac{1}{2} l_n; j_n S\right)$ is a Racah coefficient.

Now, using these optical parameters we perform our DWBA calculations. From Eqs. (1) and (9) we get the differential cross section for *(p,t)* reactions

$$\frac{d\sigma}{d\Omega} = \frac{(2I_f+1)(m_t+m_A)(m_p+m_{A+2})}{2\hbar^4\pi(2I_i+1)m_A m_{A+2}} \sum_L \left(\frac{V_1}{4} + 3\frac{V_3}{4}\right)^2 W\left(\frac{1}{2} l_n \frac{1}{2} l_n; L0\right) \sum_{M_l} \sigma_{L,S=o,J=L} \quad . \qquad (13)$$

Fig. 1 shows the differential scattering cross section for the reaction ^{124}Sn *(p,t)* ^{122}Sn. The solid line corresponds to the cross section calculated by Eq. (10) point data from [4]. The optical potential parameters for the proton are known as a function of the incident energy and target mass, that is,

$$Vp = 53.3 - 0.55E + 0.4ZA^{-1} + 27\,(N - Z)\,A^{-1}\ \text{(Mev)},\quad Wp = 3A^{1/3}\ \text{(Mev)},$$

$$r_g = r_R = r_c = 1.25 \cdot 10^{-13}\text{cm},\quad a_p = 0.65 \cdot 10^{-13}\text{cm},\quad b = 0.98 \cdot 10^{-13}\text{cm}. \qquad (14)$$

We were limited by the fact that the internal states of the incident p, departing t, and any intermediate associations are assumed fully symmetric S-states, so that the corresponding sequential transfer interactions are diagonal in the spin states of nuclei.

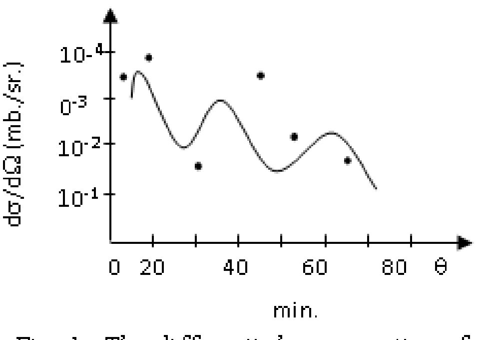

Fig. 1. The differential cross sections for the ^{124}Sn (p,t)^{122}Sn reaction

In two-nucleon transfer reactions, in contrast to the simpler one-nucleon transfer processes, we cannot extract spectroscopic amplitude from the experimental cross section due to the interference. In order to evaluate the cross section, it is therefore essential to be able to calculate the overlap integral starting from a nuclear structure model. For low-lying collective states, in general it has been possible to predict these spectroscopic amplitudes only in the limiting cases where the relevant nuclei are either spherical or well deformed; while for nuclei in the transition region no satisfactory formalism has been available.

3. Conclusions

As seen in the Fig.1, agreement with experiment sometimes is good but sometimes not so good. We have tried to improve the approximation, but it is not satisfactory in some respects yet, and some parameters are not established yet because of lack of experimental data. Therefore, it is necessary to make sure that our parameters can reproduce the elastic scattering data as well, but experimental data are not available at present. It is fortunate that the reaction cross section is insensitive to the choice of the triton optical potential. That cross section is found to be also insensitive to the cutoff radius in so far as it remains smaller than the nuclear radius. The calculated angular distribution becomes sensitive to the cutoff radius owing to the internal contributions, and we cannot obtain good results without cutting off either just at the nuclear radius or a little outside of it.

The reaction ^{124}Sn (p,t)^{122}Sn also satisfies that condition approximately. In other cases, the difference between the two wave numbers is large, the reaction is not restricted to the surface, and the angular distribution cannot be fitted without a cutoff. This might be partly because the shape of the angular distribution is very complex, but actually we do not know why we cannot get good agreement at all. Finally it may be concluded that (p, t) and (t, p) reactions may be used to obtain quantitative information about nuclear structure, although the· theory still has some defects and the approximations are not satisfactory yet, compared with the case of one-nucleon transfer reactions.

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ДВУХНУКЛОННЯ КОРРЕЛЯЦИЯ В (p, t) РЕАКЦИЯХ

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Резюме: Рассчитано сечение реакции (p, t) для ядер с четным Z и N. Для удобства применения DWBA матрица перехода выражается нормированным форм-фактором и спектроскопическим фактором. В ядерных волновых функциях корреляция спаривания учитывается с помощью функции типа БКШ. Показано, что конечное ядро, как следствие корреляций генеалогического разложения истинной волновой функции, должно содержать связанные состояния исходного ядра с большим статистическим весом, чем той, которую дают генеалогические коэффициенты волновой функции в модели оболочек. Полученные результаты сравниваются с экспериментальными данными для ^{124}Sn (p, t) ^{122}Sn.

Ключевые слова: рассеяние, эффективное сечение, приближение DWBA, спектроскопический фактор.

(p, t) REAKSİYALARINDA İKİ NUKLONLU KORRELYASİYA

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***Xülasə*:** (p,t) reaksiyasının effektiv kəsiyi cüt sayda Z və N olan nüvələr üçün hesablanmışdır. DWBA yaxınlaşmasını tətbq etməkdən ötrü keçid matrisası form-faktor və spektroskopik faktorla ifadə olunmuşdur. Nüvə funksiyalarında çütləşmə BKŞ tipli funksiyalar vasitısilə nəzərə alınmışdır. Həqiqi funksiyaların geneoloji ayrılışının korrelyasiyası nəticəsində son nüvə təbəqə modelinə nəzərən ilkin nüvənin əlaqəli hallarını daha böyük statistik çəki ilə saxlayır. Alınan nətəcələr ^{124}Sn (p, t) ^{122}Sn reaksiyası üzrə təcrübi qiymətlərlə müqayisə edilmişdir.

Açar sözlər- səpilmə, effektiv kəsik, DWBA yaxınlaşması, spektroskopik factor.