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1.54 Deuteron D-state Effects on the Vector Analyzing Power and Polarization in (d,p) Reactions

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The deuteron D-state has been known to have small effects on the vector analyzing power ($A_y$) and the proton polarization ($P_y$) in low-energy (d,p) reactions. However it was found recently by Cadmus and Haeberli at $E_d$ = 8.22 MeV[1] and by our group at $E_d$ = 22 and 55.4 MeV[2,3] that the D-state had substantial effects on the linear combinations of $A_y$ and $P_y$. They measured both $A_y$ and $P_y$ for the $l_n$=0 (d,p) reactions on Sn isotopes, and obtained the quantities[4] $S_p=2(P_y-A_y)$ and $S_d=3A_y-2P_y$. Their DWBA analyses clearly show the importance of the D-state effects (DSE) on $S_p$ and $S_d$. This is in contrast to the small DSE on $A_y$ and $P_y$ themselves: DSE are remarkably magnified by transforming $A_y$ and $P_y$ into $S_p$ and $S_d$. It is also shown that the large DSE observed in $S_p$ and $S_d$ arise primarily from the terms which are quadratic in the D-state component of DWBA T-matrix (DD terms[4]). We point out in this paper that similar features should be observed in more general cases.

In the absence of the spin-orbit distortions, the DWBA theory predicts that the DD terms in $A_y$ (A(DD)) and $P_y$ (P(DD)) are exactly equal in magnitude and opposite in sign regardless of $l_n$. We have found that this relation approximately holds, i.e. A(DD)$\simeq$-P(DD), even with the spin-orbit distortions. Fig. 1 shows the exact-finite-range (EFR) DWBA calculations only with the D-state for the reaction $^{116}Sn(d,p)^{117}Sn$ at 55.4 MeV leading to $1/2^+$, $3/2^+$, $5/2^+$, $7/2^+$ and $11/2^-$ states. The distorting potential parameters used are given in Table I. It is clearly seen that the relation A(DD)$\simeq$-P(DD) holds for all the transitions. It is found that the DD terms are primarily determined by the central-potential distortions and are not much affected by the spin-orbit distortions. This is the reason why this relation is not much violated by the spin-orbit distortions.

We have found that the relation A(DD)$\simeq$-P(DD) plays essential roles in the magnification of DSE observed in the $l_n$=0 (d,p) reactions. The DD terms in $A_y$ and $P_y$ are constructively added in $S_p$ and $S_d$, so that DSE are magnified. The results shown in Fig. 1 suggest that similar magnification can be observed for suitable linear combinations of $A_y$ and $P_y$ also in $l_n\neq0$ (d,p) reactions.

The magnification of DSE should also be possible in linear combinations taken between $A_y$ of a (d,p) reaction and that of a (p,d) reaction, if the latter corresponds to an approximate inverse reaction of the former. The angular distributions of $A_y$ measured in the reactions $^{116}Sn(d,p)^{117}Sn$(0.159 MeV,$3/2^+$) at 55.4 MeV ($A_y$(d,p)) and $^{118}Sn(p,d)^{117}Sn$(0.159 MeV,$3/2^+$) at 60.8 MeV ($A_y$(p,d)) are shown in Fig. 2 along with the EFR DWBA calculations with and without the D-state. Fig. 3 shows the linear combinations $A_y(p,d)-A_y(d,p)$ and $3/2A_y(d,p)-A_y(p,d)$ defined similarly to $S_p$ and $S_d$. It can be seen in Fig. 3 that DSE are remarkably magnified and the data can not be fitted by S-state alone. This result confirms the suggestion mentioned above.

It can be noted that the relation A(DD)$\simeq$-P(DD) is the general nature of DSE on $A_y$ and $P_y$ in (d,p) and (p,d) reactions. In addition, the present results predict that the relation $A_y\simeq-P_y$ holds at incident energies of several-hundred MeV, where the contributions from the DD terms become dominant.

Table I. Distorting potential parameters used in the calculations. The deuteron parameters are those of an adiabatic potential and the proton parameters are those which reproduce the elastic scattering.

| | $V_o$ | $r_o$ | $a_o$ | W | $W_D$ | $r_i$ | $a_i$ | $V_{so}$ | $r_{so}$ | $a_{so}$ | $r_c$ | ref. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| deuteron | 96.67 | 1.17 | 0.79 | 7.93 | 10.26 | 1.29 | 0.633 | 6.20 | 1.01 | 0.75 | 1.25 | 3,5 |
| proton | 41.93 | 1.197 | 0.687 | 3.80 | 5.10 | 1.24 | 0.808 | 6.11 | 1.057 | 0.80 | 1.25 | 6 |

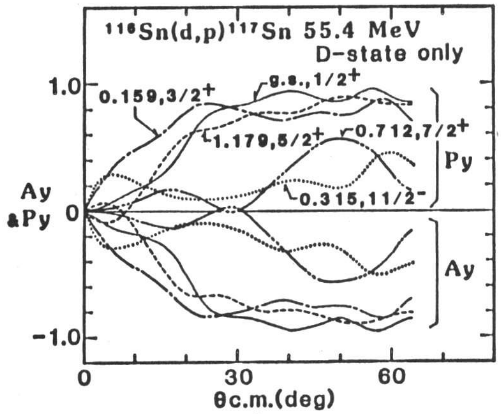


Fig. 1. EFR DWBA calculations only with the D-state for $A_y$ and $P_y$ in the reaction $^{116}Sn(d,p)^{117}Sn$ at 55.4 MeV leading to the states shown in the figure.

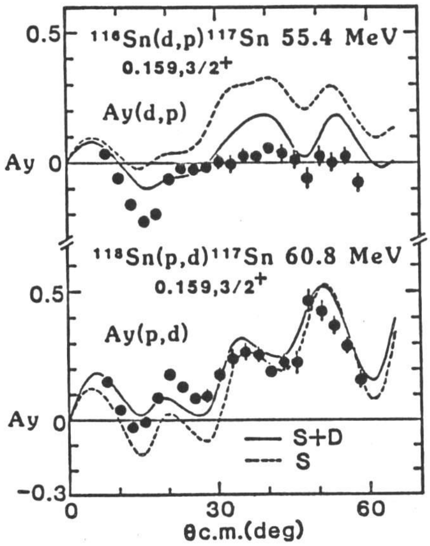


Fig. 2. Angular distributions of $A_y$ in the reactions $^{116}Sn(d,p)^{117}Sn(0.159\ MeV, 3/2^+)$ at 55.4 MeV and $^{118}Sn(p,d)^{117}Sn(0.159\ MeV, 3/2^+)$ at 60.8 MeV compared with EFR DWBA calculations with (solid lines) and without (dashed lines) the D-state.

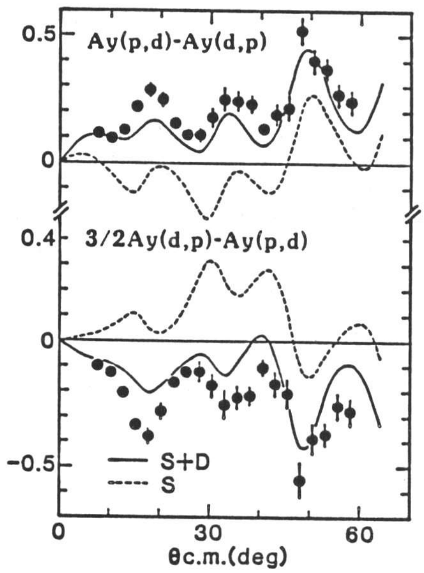


Fig. 3. Linear combinations taken between the $A_y$ of (d,p) reaction and that of (p,d) reaction shown in Fig. 2 (see text).

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