ANGULAR DISTRIBUTIONS OF THE $^{90}$Zr(d, p) REACTION AND THE COUPLING OF ANALOGOUS (d, p) AND (d, n) CHANNELS

U. LYNEN, Ch.V.D. MALSBURG, R. SANTO and R. STOCK*
Max-Planck-Institut für Kernphysik, Heidelberg, Germany

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The excitation functions and spectroscopic factors of several final levels in the reaction $^{90}$Zr(d, p) show an anomaly at the threshold energy for the (d, n) reaction to the $^{91}$Zr ground state analog $^{91}$Nb. This indicates a more complicated coupling of the (d, n) and (d, p) analog channels than described by the two channel approach.

In a recent paper [1] evidence has been presented for the coupling of the analogous channels in (d, p) and (d, n) reactions. The data consisted in excitation functions for the $^{90}$Zr(d, p) reaction ($E_x = 0$, $L = 2$ and $E_x = 1.21$ MeV, $L = 0$) as well as for the $^{90}$Zr(d, n) reaction to the analog states, taken at $\theta_{\text{Lab}} = 170^\circ$. The characteristic feature of these curves was a dip in the cross section for the $^{90}$Zr(d, p) transitions exactly at the energy at which the (d, n) channel to the analog state in $^{91}$Nb opens: $E_d = 7.05$ MeV for the ground state and $E_d = 8.26$ MeV for the excited state at $E_x = 1.21$ MeV. Since these excitation functions have been obtained at extreme backward angles it was interesting to look for this anomaly at forward angles and in the integrated cross sections in order to study the reaction mechanism and the effect on spectroscopic factors extracted by means of standard DWBA procedures. The experiment was performed at the Heidelberg Tandem using a multi-detector scattering chamber and a target of highly enriched $^{90}$Zr. Angular distributions have been measured in $7^\circ$ steps between $25^\circ$ and $170^\circ$ for the $\frac{1}{2}^+$ ground state, the $\frac{1}{2}^+$ level at 1.21 MeV and the $\frac{3}{2}^+$ level at 2.06 MeV using deuteron energies of 6.5, 7.05, 7.5, 8.26 and 9.11 MeV. The energies 6.5 and 7.5 MeV are intermediate, whereas the other correspond to the three thresholds. DWBA calculations have been performed using standard parameters [2] for the optical potentials. The angular distributions are shown in fig. 1 together with some typical DWBA predictions. The anomaly in the backward angles of the ground state angular distribution at $E_d = 7.05$ MeV can already be seen from this representation. The effects are more obvious if we look at the different excitation functions given in fig. 2 for $170^\circ$ as well as for the total cross section and one forward angle. The $170^\circ$ excitation functions are in agreement with ref. 1, i.e. a dip is observed for the ground state transition at $E_d = 7.05$ MeV and for the first excited state at $E_d = 8.26$ MeV. On the other hand, at forward angles and in the integrated cross sections the most pronounced anomaly in the excitation function is observed at $E_d = 7.05$ MeV for all three states considered. This anomaly at $E_d = 7.05$ MeV still remains if the experimental cross sections are compared with the DWBA calculations which reproduce the overall behaviour of the data fairly well. This implies

* Present address: Niels Bohr Institute, Copenhagen.
that the effect can by no means be explained by the moving of a stripping maximum through the angle of observation.

As may also be seen from fig. 2 the spectroscopic factors extracted by DWBA analyses are rather independent of the bombarding energy, except for $E_d = 7.05$ MeV where we obtain a deviation of about 25% from the average. The average values of the relative spectroscopic factors

\begin{align*}
(2J + 1)S_{\text{g.s.}} & = 6.0, 1.4, 2.2 \\
(2J + 1)S_{1.21 \text{ MeV}} & = 1.4, 1.4, 2.2 \\
(2J + 1)S_{2.06 \text{ MeV}} & = 1.4, 1.4, 2.2
\end{align*}

outside the anomaly are 6.0, 1.4 and 2.2 for the ground state and the 1.21 MeV and 2.06 MeV levels, respectively *. This compares with

* See footnote next page.
Fig. 2b. Relative spectroscopic factors extracted by DWBA calculations. For the ground state transition, the spectroscopic factor \((2J + 1)S\) was set equal to 6.

the relative values 6.0, 1.6 and 2.0 found by Cohen et al. [3]. The deviation of the spectroscopic factors at 7.05 MeV from the average value for all three states considered is very striking and cannot be attributed to the usual uncertainties in DWBA analyses and the experimental errors.

An explanation of the experimental results of

* In the subcoulomb experiment of ref. 2 an absolute spectroscopic factor of about 0.65 was found for the ground state transition. So the 2.06 MeV level, which according to ref. 3 should be a \(d_{5/2}\) state, may also be a \(d_{5/2}\) state.

1 Indications for this can also be found in the 40Ca(d,p) excitation function measurements of Lee and Schiffer [5]. Under several angles, the \(\frac{5}{2}^+\) ground state yield function shows an anomaly at \(E_d = 2.85\) MeV where the (d,n)-channel to the \(p_{3/2}\) level at 1.71 MeV in 41Sc opens. This level is the analog of the \(p_{3/2}\) state at 1.95 MeV in 41Ca but not of the ground state again showing a more complicated mode of coupling.

ref. 1 has been suggested by Brentano and Zaidi [4]. They describe a DWBA approach to the (d,p) reaction with inclusion of a \((l,T)\) potential acting on the outgoing proton. In this way, a coupling of each (d,p)-channel to its analog (d,n)-channel takes place and the transition amplitude splits into two parts, the second being the charge exchange amplitude. These two amplitudes may interfere and give rise to some effects on the (d,p) cross section at the threshold energy for the (d,n) reaction to the corresponding analog state.

As discussed above, the largest effect in the excitation function at forward angles and for the integrated cross sections of all three states considered is seen at \(E_d = 7.05\) MeV. Thus the coupling to the (d,n)-channel which is the analog of the (d,p) ground state transition seems to be the most important effect not only for the (d,p) ground state transition itself but also for the transitions to the excited states. (It should be noted that according to ref. 1 the (d,n) transition to the analog state of the 91Zr ground state is much stronger than to the analogs of the excited states).

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References