Examination of the adiabatic approximation for (d, p) reactions

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Deuteron-induced one-neutron transfer reactions have played a substantial role in extracting single-particle (s.p.) properties of nuclei [1], and the adiabatic (AD) approximation [2] is often used for describing the deuteron-target three-body wave functions to simply treat the deuteron breakup states. In this study, we examined the validity of the AD approximation for the (d, p) reaction systematically. For this purpose, we employed the continuum-discretized coupled-channels method (CDCC) [3], which explicitly treats the deuteron breakup channels, as a three-body reaction model and compared the resulting (d, p) cross sections with those calculated by the CDCC with the AD approximation (CDCC-AD) for 128 reaction systems.

The AD approximation affects in general the (d, p) cross section by less than 20%. We show the two typical results in which the AD approximation works well in Figure 1. The result for $^{40}\mathrm{Ca}(d, p)^{41}\mathrm{Ca}(2s_{1/2})$ at $E_d = 40$ MeV with $S_n = 8.0$ MeV is shown in Fig. 1(a), where E_d is the deuteron incident energy and S_n is the neutron separation energy. The solid and dashed lines represent the results of CDCC and CDCC-AD, respectively. The behavior of the two lines is similar except at backward angles ($\theta \geq 60°$) and the error due to the AD approximation is 13%. This is quite natural because as E_d increases the deuteron internal motion becomes slow relative to the motion of the center-of-mass of the deuteron, resulting in the validness of the AD approximation. In Fig. 1(b), we show the result for $^{100}\mathrm{Zr}(d, p)^{101}\mathrm{Zr}(2s_{1/2})$ at $E_d = 5$ MeV with $S_n = 0.1$ MeV. In this case, the error is 4% and the reaction can be regarded as adiabatic. At first look, it seems to be strange that the AD approximation works at such low incident energy. This is mainly because that the reaction is extremely peripheral, as discussed in detail in Ref. [4].

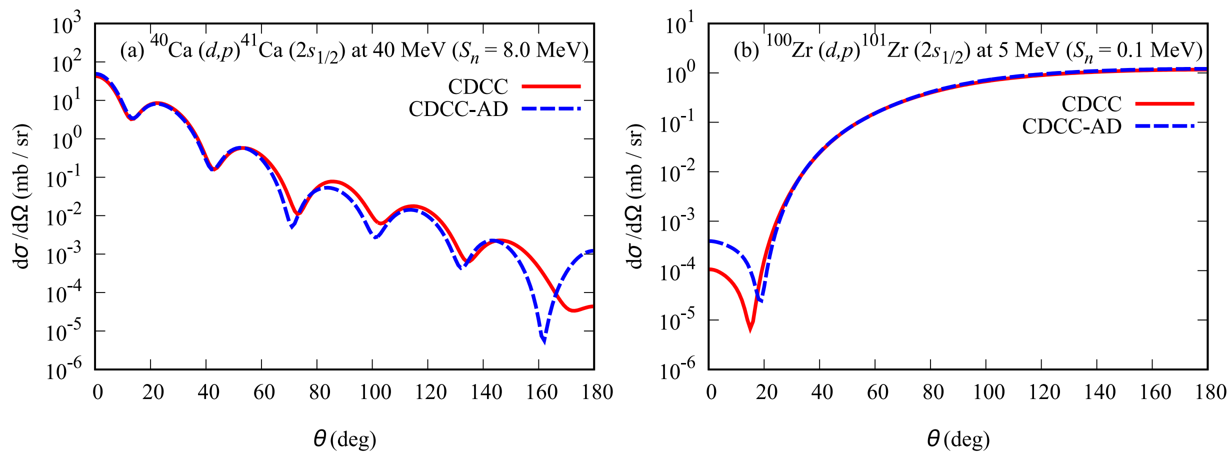

Figure 1: Angular distributions of the (d, p) cross sections calculated with CDCC (solid lines) and CDCC-AD (dashed lines) for (a) $^{40}\mathrm{Ca}(d, p)^{41}\mathrm{Ca}(2s_{1/2})$ at $E_d = 40$ MeV with $S_n = 8.0$ MeV and (b) $^{100}\mathrm{Zr}(d, p)^{101}\mathrm{Zr}(2s_{1/2})$ at $E_d = 5$ MeV with $S_n = 0.1$ MeV.

We have discussed above the cases in which the AD approximation works well. In some cases, however, the AD approximation affects seriously the angular distributions of the (d, p) cross sections. These *nonadiabatic* cases are discussed in Ref. [4] and all results are shown in its supplemental material. The role of the closed channels that often ignored in the description of breakup reactions is also discussed in the article.

References

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