Search for three-body force effects in the alpha-induced break-up of deuterons at low energies

A. De[1*], Debakinandan Majee[1], Sushovan Paul[1], S. R. Banerjee[2], Surajit Pal[2], S. Mukhopadhyay[2], Deepak Pandit[2], Debasish Mondal[2], Srijit Bhattacharya[3] and Balaram Dey[4]

[1]*Department of Physics, Raniganj Girls' College, Raniganj, Burdwan 713358, W. B., India*
[2]*Variable Energy Cyclotron centre,* 1/AF Bidhan Nagar, Kolkata – 700064, W. B., India
[3]Department of Physics, Barasat Govt.College, Barasat, N-24 Pgs, Kolkata– 700124,WB, India
[4]*Tata Institute of Fundamental research Centre, Colaba, Navy Nagar, Mumbai-400005, India*
** email:akd.panua@gmail.com*

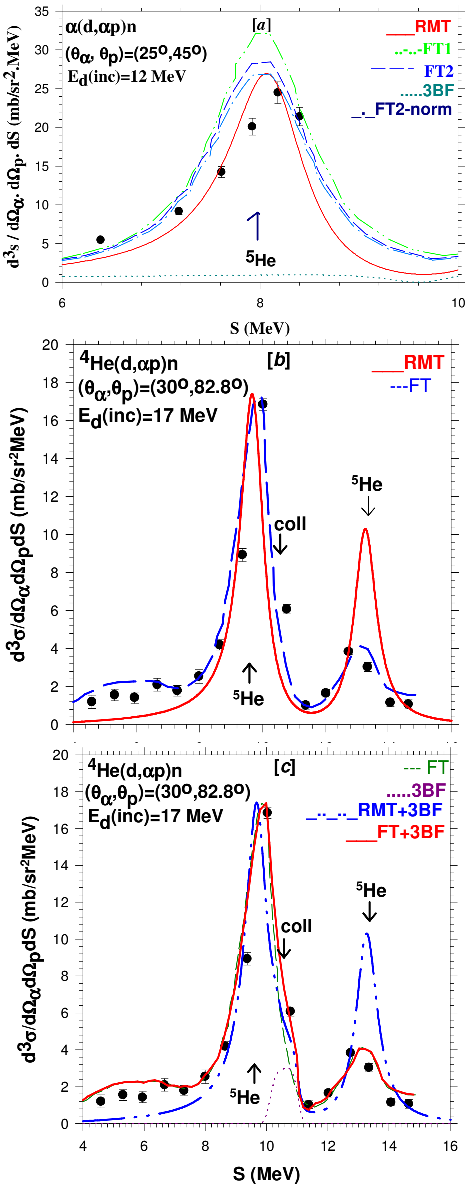
Introduction and Aim

Renewed interests are being paid [1-6], on the existence and manifestation of three-body force (3BF) effects in nuclear scattering as well as bound state studies, both experimentally and theoretically. Although 'unambiguous evidence for the missing' 3BF effects has been established [2] with the three-nucleon systems, such an evidence involving alpha-deuteron system is yet to be proven, especially in the break-up of deuterons by α-particles in kinematically complete configuration [3-6]. At low energies, α-particle, to a good approximation, may be treated as a structureless boson and thus the α-d system, next to N-d system, has been an obvious testing ground to explore the few-body aspects of nuclear forces, including the 3BF effects. From theoretical point of view, Faddeev type rigorous theoretical calculations (FT) are best suited for examining and explaining the experimental kinematically complete three-body correlation cross sections. However, there are cases of spectacular agreement as well as strong disagreement [3, 7] and thus calls for further investigation. Present article is an attempt to better understand an existing set of kinematically complete experimental data on the break-up of deuterons by alpha particles at E_d(inc)=17 MeV, at judiciously chosen correlated pair of angles $(\theta_\alpha,\theta_p)=((30^o,82.8^o)$, satisfying the condition of collinearity, the latter being prescribed as a sensible kinematic region of the probable 3BF effects. The existing fit due to FT in this specific region is reported [6] to be not as good as in the other region. For comparison, we have also looked into experimental data for another correlated pair of angles, $(\theta_\alpha,\theta_p)=((25.0^o,45.0^o)$, at E_d(inc)=12 MeV, for which the collinearity region is absent in the kinematically allowed phase space.

Data Analysis and Discussions

As the data sets under investigation are strongly dominated by the kinematically predicted α–n final state interaction (FSI) region, we first computed the three-body correlation cross sections in the light of single level R-matrix theory (RMT), assuming dominant multiple processes following the procedure of Sagara et al [8]. The R-matrix parameters used are a=2.9 fm, γ^2= 6.9 MeV and E_0=-4.3 MeV corresponding to $P_{3/2}$ channel of α-n system. 3BF effect is then incorporated, based on a simple form [3] of three-body interaction, taking into consideration that three-body forces (3BF) are, in general, strongly angle dependent and that three-body interactions are likely to be favoured at low relative energies due to long time of escape from the nuclear interaction volume. The results of our calculations are displayed in the following figures (Figs 1a,b & c). We summarize our findings as follows.

(i) So far as the line shape of the α-n FSI spectrum is concerned, the fit due to RMT (represented by solid line) at (θ_α,θ_p) = $(25.0^o,45.0^o)$ (Fig. 1a) is reasonably satisfactory, and, at least, comparable to the existing [9(a)] Faddeev theoreotical fits FT1 (with Coulomb interaction; dashed-double dotted line) and FT2 (without Coulomb interaction; dashed line). This is also viewed through the normalized FT2 (FT2-norm) as shown by dashed-dotted line in the



Figs. 1a, b, c. Three-body correlation cross-sections as a function of arc length (s) for the reaction α(d, αp)n for incident energies and correlated pairs of angles as mentioned in the figures. RM: R-matrix theoretical calculation; 3BF: three-body force contribution; FT1 & FT2, FT: existing Faddeev type calculations [9(a),6]. Experimental data are from ref [6].

figure (Fig. 1a).

(ii) The fit due to RMT (represented by solid line in Fig. 1b) at (θ_α,θ_p) = (30.0°, 82.8°) deviates significantly from the experimental distribution as well as from the Faaddeev theoretical one [6] (FT, the dashed line).

(iii) 3BF contribution, as shown by dotted curve in fig. 1a, is found to be insignificant for the distribution at (θ_α,θ_p) = (25.0°,45.0°), where the collinearity region is absent in the allowed phase space.

(iv) A prominent bump due to 3BF is observed in the collinear region at (θ_α,θ_p) = (30.0°, 82.8°), as shown by dotted curve in fig. 1c. Inclusion of the same with RMT improves the fit significantly (RMT+3BF, dashed-double dotted curve, in the fig.). Notable improvement in the reproduction of the experimental distribution is observed when 3BF contribution is incoherently added with the existing Faddeev theoretical fit (FT+3BF; shown by solid line in the figure).

Conclusion

3BF effect appears to be manifested in the collinear region, involving the α-d system, however, it seems to be most important to analyse the data in the light of the recent state-of-the-art Faddeev type calculation [9], including Coulomb interaction as well as 3BF effects, for precise understanding of the problem.

References

[1] K Minomo et al, Phys. Rev. **C 96** (2017) 024609.
[2] S. Binder et al, Phys. Rev. **C 93** (2016) 044002.
[3] A. De et al, Few Body Systems, **19** (1995) 195; Proc. DAE Symp. Nucl. Phys. **51** (2006) 369; Int. Nucleus-nucleus Conf., Aug 28 – Sep. 31, 2006, Rio-Brazil.
[4] S. S. Dasgupta et al, Phys. Rev. **C 22** (1980) 1815.
[5] M. Bruno et al, Phys. Rev. **C 24** (1981) 2751.
[6] I. Slaus et al, Nucl. Phys. **A** 397 (1983) 205.
[7] Y. Koike, Nucl. Phys. **A 301** (1978) 411.
[8] K. Sagara et al, J. Phys. Soc. Japan, **42**(1977) 732.
[9] (a) A. Deltuva et al, Phys Rev. **C 74** (2006) 064001, (b) Phys. Rev. **C93** (2016) 044001.