The role of the deuteron d-state and nonlocal effects in (d,p) reactions

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Introduction - Deuteron d-state

- Single bound state at 2.2245(1) MeV
- Superposition of s and d-states. Typically ~94% s-state, ~6% d-state
- (d,p) reactions still critical to nuclear astrophysics studies.
- d-state often ignored in reaction calculations
- d-state shown to have most impact on polarisation and spin observables.
Introduction - Nonlocality

- Theoretically all optical model potentials, used in (d,p) reaction calculations, should be energy dependent and nonlocal

- Nonlocality arises because the elastic channel, included in the calculation, is coupled to other channels

- Adiabatic models for deuteron stripping also include deuteron break-up channel via an approximate solution of the n+p+target three-body problem

- Nonlocality can be treated in an equivalent local model in which deuteron distorting potentials are modified
Previous work - Nonlocal Adiabatic (d,p) reactions

Work by Timofeyuk and Johnson (2013) into adiabatic nonlocal models revealed high relative n-p momenta influences the deuteron-target potential.

Energy at which equivalent local potentials need to be calculated is shifted ~40 MeV.
d-state can dominate the wavefunction at these high momenta, so may have a large effect within adiabatic non locality

Example: Hulthén s- and d-state deuteron wavefunctions in momentum-space
Break-up and Nonlocality (1)

\[ U_{JT}(\mathbf{R}) = \frac{\langle \phi_d^{M_d}(\mathbf{r}) | V_{np} [V_n + V_p] | \phi_d^{M_d}(\mathbf{r}) \rangle}{\langle \phi_d^{M_d} | V_{np} | \phi_d^{M_d} \rangle} \]

Johnson-Tandy potential which accounts for deuteron break-up.

\[ \phi_d^{M_d}(\mathbf{r}) = \sum_{l_d \lambda_d s_d \sigma_d} (l_d \lambda_d s_d \sigma_d | J_d M_d) \chi_{s_d \sigma_d} \frac{u_{l_d}(\mathbf{r})}{r} Y_{l_d}^{\lambda_d}(\hat{\mathbf{r}}) \]

\( \phi_d^{M_d} \) is the deuteron wavefunction
Break-up and Nonlocality (2)

To introduce energy independent nonlocality to the system the nucleon-target potentials can be replaced with potentials of the Perey-Buck form.

\[ V_N(\mathbf{R}, \mathbf{R}') = H(\mathbf{R} - \mathbf{R}') U_{NA} \left( \frac{\mathbf{R} + \mathbf{R}'}{2} \right) \]

\( H \) is a Gaussian, where \( \beta \) is the nonlocality range. Typically \( 0.85 \)fm for nucleons

\[ H(\mathbf{R} - \mathbf{R}') = \frac{1}{\pi^{3/2} \beta^3} \exp \left[ - \left( \frac{\mathbf{R} - \mathbf{R}'}{\beta} \right)^2 \right] \]

\( U_{NA} \) is a potential form factor, which can be taken as a Woods-Saxon
Example - $^{40}\text{Ca} + d\ (E_d = 10\ \text{MeV})$

The d-state has influence on potential terms calculated within energy independent adiabatic non-locality. (Giannini-Ricco parameters)

When including non-locality and break-up, the d-state reduces the potentials.
Example – Cross-section $^{40}\text{Ca}(d,p)^{41}\text{Ca}$ at 10MeV

Including d-state alters the cross-section and reduce the spectroscopic factor, $S$ deduced from data

$$S = \frac{\sigma_{exp}(E)}{\sigma_{th}(E)}$$

Calculations did not include tensor terms which could have a large effect on cross-sections.
Conclusion

- The deuteron d-state changes the deuteron-target potential terms when both break-up and nonlocality are included.
- This will also change calculated cross-sections and other observables.

Future work

- Work to include the tensor effects within reaction calculations is on going.
- Once completed changes in observables will be investigated.
- Include energy dependent nonlocality into the model
Thank you for listening

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References


