Direct Reactions at Stable Beam Facilities

Nicholas Keeley

NARODOWE CENTRUM BADAŃ JĄDROWYCH ŚWIERK

The absolute magnitude of the α clustering in heavier nuclei remains an open question. The *absolute* α spectroscopic factors extracted from the traditionally employed (^{6}Li,d) and (^{7}Li,t) transfer reactions are notoriously variable between the two reactions and over different incident energies.

This suggests that the reaction mechanism is not properly understood (need to go beyond the usual DWBA approach). Alternative α-transfer reactions, e.g. (^{12}C,^{8}Be), (^{16}O,^{12}C) and (^{20}Ne,^{16}O), have to date been little explored.

(^{12}C,^{8}Be) has experimental complications, although these are by no means insuperable, but the other two reactions make good subjects for an experimental programme at a heavy ion cyclotron.

There is a need for systematic data probing the α clustering across isotopic chains. This is of particular current interest for nuclei in the fp shell for comparison with large-scale shell model calculations.

Existing analyses suffer from *ad-hoc* adjustments of exit channel optical potentials as well as reliance on DWBA (direct transfer mechanism) making reliable trends in spectroscopic factors difficult to establish.

Example of possible complications: in (^{6}Li,d) and (^{7}Li,t) most of the mass of the projectile is transferred. This could explain the problems with these reactions and may require the re-examination of the underlying assumptions of standard DWBA.

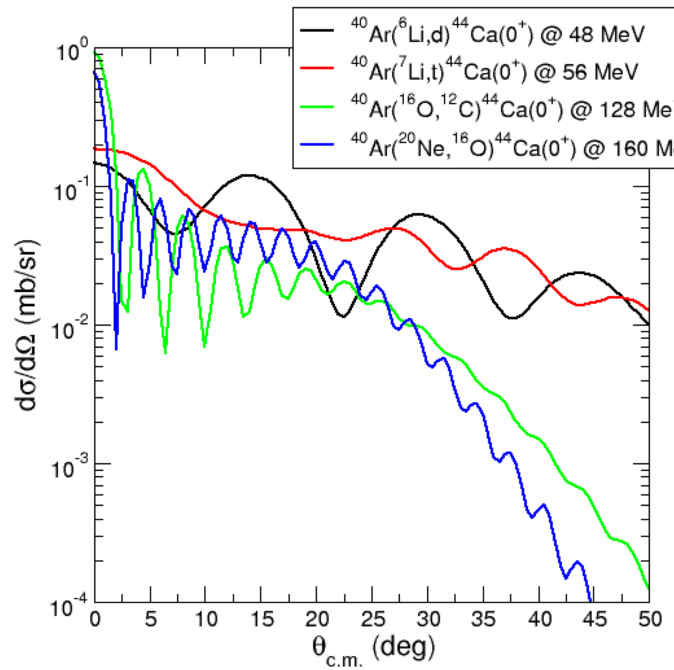
Comparative studies required to decide on the “cleanest” α transfer reaction, i.e. which has a mechanism truly dominated by direct transfer of an α cluster?

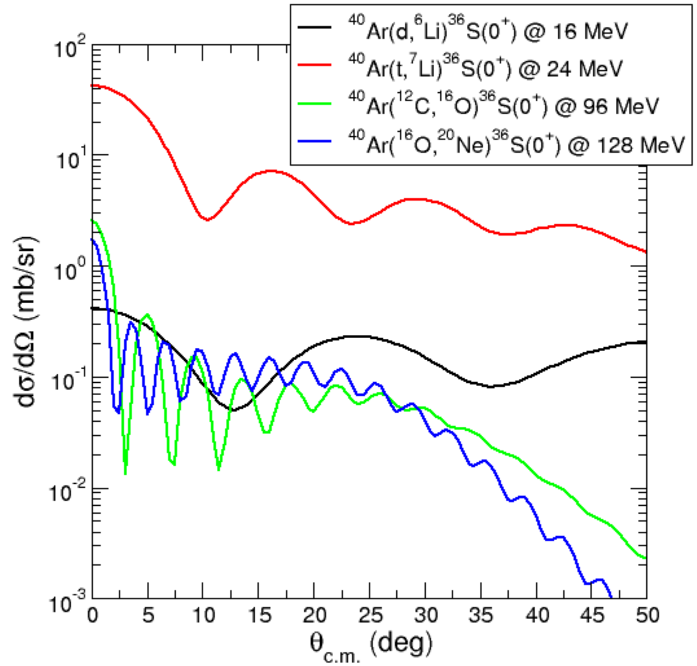
A programme that could be carried out with a heavy ion cyclotron would be a comparative study of absolute α spectroscopic factors across the Ar and Ca isotope chains.

Emphasis on as complete as possible data sets (elastic and inelastic scattering as well as the transfer angular distributions, plus exit channel elastic scattering at appropriate energy where possible).

Estimate cross section magnitudes with DWBA and spectroscopic factors set to 1.0 – should be good to within an order of magnitude. Also give a guide to the shape of the angular distributions.

We look at α-stripping and α-pickup for an ^{40}Ar target (probes α clustering in ^{44}Ca and ^{40}Ar respectively). Incident energies 8 Mev/nucleon ("typical" HI cyclotron beam energy).





Note cross sections are *small* – high beam current and/or thick targets. Also, comparable for (almost) all reactions; (t,^{7}Li) pickup much larger than other pickup reactions.

Confirmation of highly structured ADs for (^{20}Ne,^{16}O) and its inverse can be done with a magnetic spectrometer.

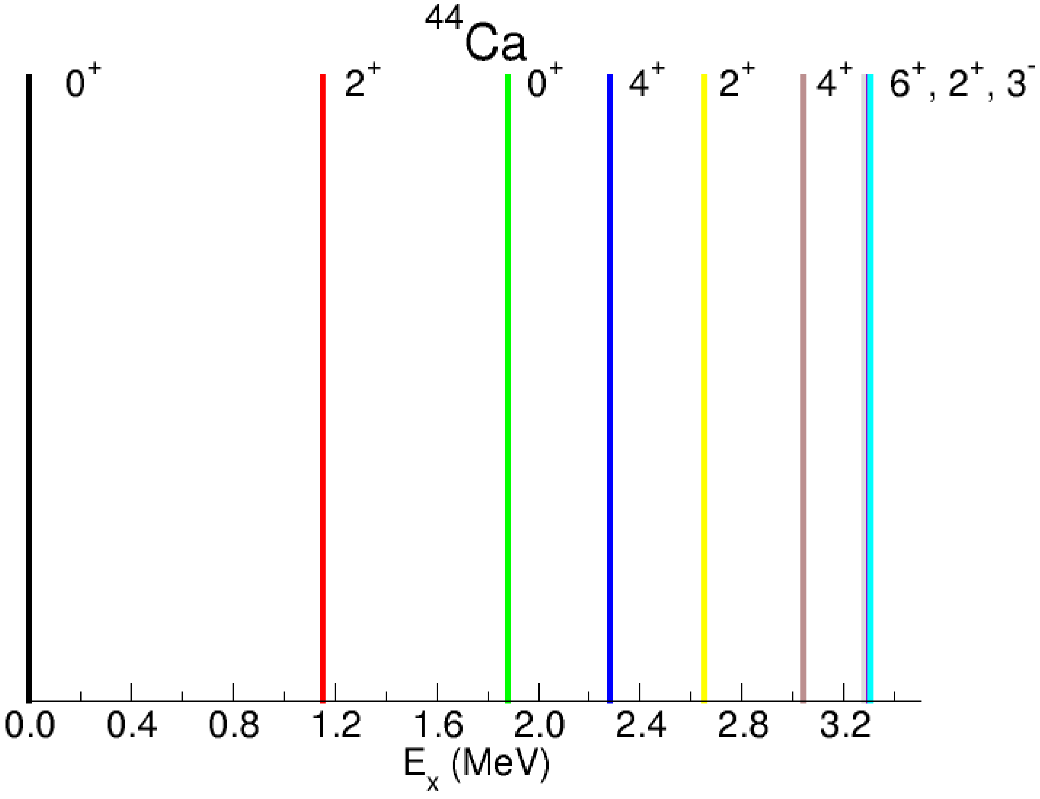
What are the requirements for such experiments?

A modern HI cyclotron with good beam energy resolution and beam spot size on target.

Targets: gas cell or implanted (e.g. Ar targets). Possibly vacuum target lock (for Li targets for inverse kinematics, metallic Ca targets).

A magnetic spectrometer. If implanted targets are used this would be essential to remove scattering from the metal foil with ^{16}O and ^{20}Ne beams. Spectrometers also allow closer approach to 0° than silicon arrays. Finally, if we want to access excited states in fp shell nuclei we will need the resolution of a spectrometer …

As a typical example, the levels of ^{44}Ca up to 3.5 MeV in excitation energy:



In summary, we now have the theoretical tools – modern shell model approaches to clustering, e.g. Volya and Tchuvil'sky, Phys. Rev. C **91**, 044319 (2015) and the ability routinely to perform rather complete coupled reaction channels calculations to model the reaction mechanism – to tackle the problem of the extent of α clustering in fp shell nuclei.

The goal is to extract reliable *absolute* α spectroscopic factors from transfer reactions to compare with the structure model results. To do this we need to establish the "best" α transfer reaction and obtain systematic, complete data sets.

Such a study would form a natural part of a direct reaction research programme at a future stable beam facility in Poland, although it could be begun with existing facilities at HIL.

Work done in collaboration with:

Kirby Kemper, Department of Physics, Florida State University

Krzysztof Rusek, Heavy Ion Laboratory, University of Warsaw