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DOI:
10.1088/1742-6596/569/1/012052

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Document Version
Publisher's PDF, also known as Version of record

Citation for published version (Harvard):
Walshe, J, Freer, M, Wheldon, C, Achouri, LN, Ashwood, NI, Catford, WN, Celik, IC, Curtis, N, Delaunay, F, Fernández-Domínguez, B, Grassi, L, Kokalova Wheldon, T, Marqués, M, Orr, NA, Prepolec, L, Scuderi, V, Soić, N & Tokić, V 2014, 'The thick target inverse kinematics technique with a large acceptance silicon detector array', *Journal of Physics: Conference Series*, vol. 569, no. 1, 012052. https://doi.org/10.1088/1742-6596/569/1/012052

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2014 J. Phys.: Conf. Ser. 569 012052

(http://iopscience.iop.org/1742-6596/569/1/012052)

The thick target inverse kinematics technique with a large acceptance silicon detector array

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Abstract. An experimental technique for studying elastic scattering using a thick gas target is described, with a measurement of the $\alpha(^{24}\mathrm{Ne},\alpha)$ reaction used as an example. Advantages such as ease, detector efficiency, and the possibility of measuring the cross section at 180° in the centre-of-mass are discussed. It is shown that a resolution of tens of keV is practical at zero degrees, and that the dominant contribution to the resolution for large angles is angular straggling of the beam in the entrance window. The use of helium gas as the target allows direct measurement of α-cluster states.

1. Introduction

Traditional methods of studying elastic nuclear scattering use thin foil targets, and the elastically scattered beam-like particles are identified by energy discrimination. Counting the events in this elastic peak gives the cross section for a single centre-of-mass (c.m.) energy; in order to construct an excitation function the beam energy must be changed and the measurement repeated, often hundreds of times. While effective, this method is only practical with relatively simple accelerators – most commonly tandem Van De Graaffs – and so experiments of this type are limited by the beams available at such facilities. In particular, modern radioactive beam facilities provide access to much new physics, but as the creation and acceleration of radioactive nuclei is typically a complex process the retuning of these beams can take several hours. Studies using these beams must then use a different technique.

2. Method

The thick target inverse kinematics technique, first described in [1], allows continuous measurement of an excitation function using a single beam energy. The set-up of the target chamber is shown in figure 1. In this work the target was helium gas, which filled the chamber and is described as thick because the pressure is tuned such that the beam is stopped within the

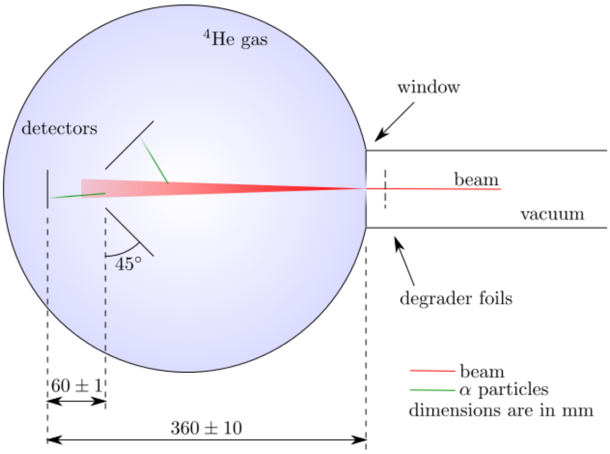

Figure 1. Schematic of the experimental chamber.

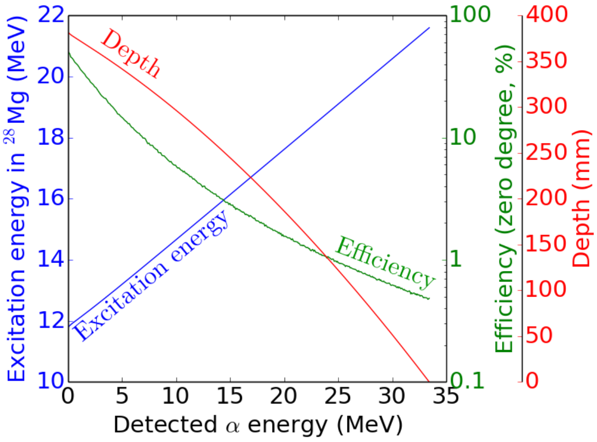

Figure 2. Calculation of the kinematics and energy loss allows reconstruction of the reaction from the detected particle energy.

gas volume. A thin window, in this case a 5 μm Havar foil, separated the gas from the beam line. A beam of ^{24}Ne with an energy of 3.8 MeV/A and intensity of 3×10^5 pps was provided by the SPIRAL facility at GANIL. As the beam is stopped in the target, nuclear reactions take place over a continuous range of energies with the maximum defined by the beam energy immediately after the window and the minimum limited only by Rutherford scattering. While reactions are produced simultaneously over this energy range, it is useful to note that each c.m. energy is localised to a point in the chamber.

In a thick target experiment, the detected particles must be lighter than the beam nuclei to escape the target gas and reach the detectors. Normally, experiments are performed in inverse kinematics where the beam nuclei are heavier than the target nuclei, and the target-like particles can be detected. An important feature of this method is that the scattered light particles are confined to forward angles in the laboratory (for elastic scattering), which means that the efficiency of appropriately positioned detectors is doubled. In addition, as the beam is absorbed, a detector can be placed at zero degrees in the laboratory, corresponding to 180° in the c.m. frame; at this point the Rutherford scattering cross-section is at a minimum and the resonance scattering cross-section is maximal.

The detector array is placed within the gas volume such that the beam does not reach the detectors but the scattered target-like particles do. In the current work the array consisted firstly of a square double-sided silicon strip detector at zero degrees with 256 pixels, each 3 mm square. In addition, a 'lampshade' array of six wedge shaped silicon detectors (Micron YY1 design[2]) captured events at large angles. These detectors were single sided, with 16 curved strips each covering an approximately constant polar angle range. The lampshade provided full azimuthal coverage, and the maximum θ measured was at least 44° in the c.m. frame, increasing to full coverage for lower energy events that take place closer to the array. Finally three additional Havar foils, each 2 μm thick, were available upstream of the window to allow the beam energy to be easily reduced in approximately 10 MeV steps.

3. Data reconstruction

In a thin target experiment the c.m. interaction energy can be straight forwardly reconstructed kinematically from the energy of the beam. For a thick target experiment, the energy of the detected particle is used but the energy loss of the beam and target through the gas must be

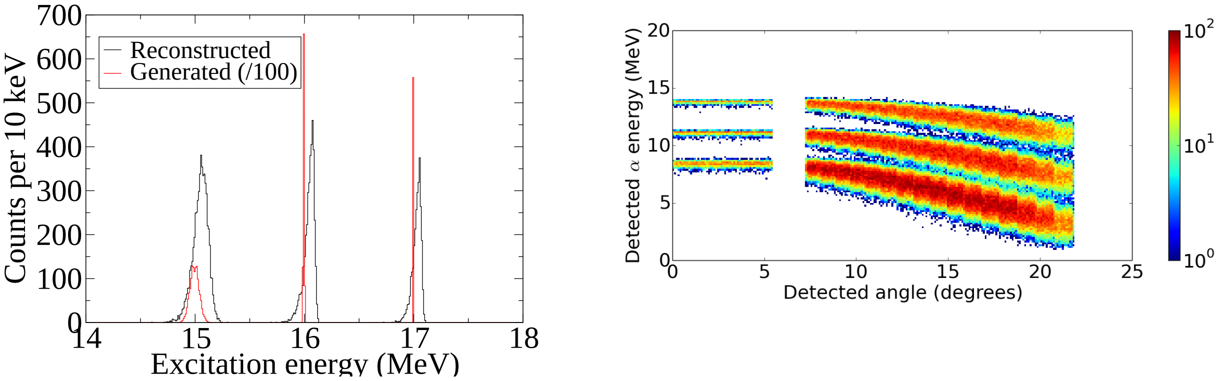

Figure 3. Simulated excitation function for ^{28}Mg using REX. (left) The zero degree detector showing (red) input data reduced by a factor of 100 and (black) reconstructed data. (right) The entire array.

taken into account. Figure 2 shows a calculation for the ^{24}Ne+α reaction, which can be used to find the properties of the interaction from only the energy of the detected α particle. However, in order to do this reconstruction, elastic scattering must be assumed – there is no way to distinguish elastic and inelastic events using only one beam energy. It is known though that the very highest energy events must be elastic; by leaving one of the reaction nuclei in an excited state a known minimum amount of energy must be removed from the available kinetic energy. In the case of ^{24}Ne+α, the first excited state of ^{24}Ne is at 1.98 MeV, so events within this energy of the maximum of the spectrum must be elastic. Then, by stepping the beam energy down (using additional Havar foils as described above) a larger 'clean' region can be produced.

4. Experimental characteristics

A new in-house Monte-Carlo code, the Resonant Excitation Function Simulation (REX), was used to simulate the experiment and identify the effects that contribute most to the resolution and efficiency of the data. This code generates events using a given excitation function and includes all of the experimental effects such as energy loss, energy and angular straggling, and the geometry of the detector array. The output is a list of detected events that can be analysed in the same way as experimental data in order to test the reconstruction method.

Figure 3 shows how well the true excitation function simulated using REX can be reconstructed using the method outlined above. The input parameters for the simulation were three states in ^{28}Mg at 15, 16 and 17 MeV, with widths of 100, 10 and 1 keV respectively; the detector set-up was identical to the experiment as described above with a ^{24}Ne beam. The reconstructed widths were 147, 70 and 68 keV. As the measured peak width does not change for the 1 and 10 keV peaks this minimum width represents the overall resolution of the method, approximately 70 keV FWHM. Importantly, this is better than the intrinsic energy resolution of the silicon detectors. The transformation of the data into the c.m. frame improves the resolution by a factor of approximately 3.5, and this effect scales with the c.m. velocity so that for heavier beams the resolution will be better.

Figure 3 also shows the data from the same simulation including the data from the lampshade array. The detected α-particle energy is plotted against the angle of the strip with respect to the entrance window (*i.e.*, these data are shown in the laboratory frame). The kinematic fall-off of the angular distributions can be seen, as well as the change in resolution with angle. Examination of the simulations reveals the reason for the latter effect. A number of factors are involved, but

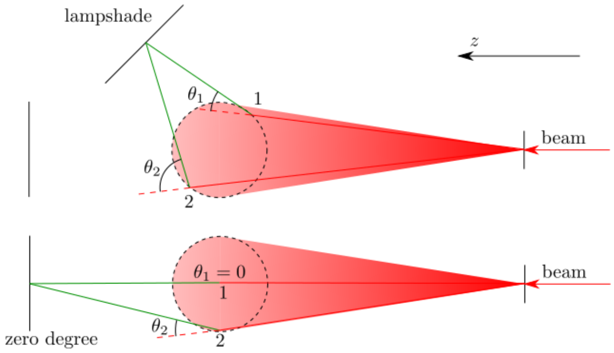

Figure 4. The effects of angular and energy straggling. See text for details.

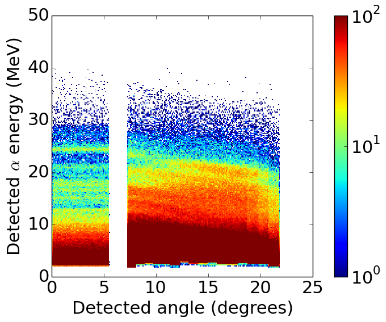

Figure 5. Experimental data for ^{28}Mg from the entire detector array.

the most important are energy and angular straggling of the beam caused by the entrance window and, to a lesser extent, the gas, as shown in figure 4. Events for a given c.m. energy, which can nominally be associated with a given depth in the gas, can in fact take place within a finite area, denoted roughly by the dashed circle. Points 1 and 2 represent two extremes. For events in the zero degree detector the scattering angle, θ, varies only a small amount, and thus the resolution is best in this detector. For the lampshade, however, the range of scattering angles available for a given c.m. energy and a given detector strip is large, and so there is significant kinematic broadening of the data.

For a ^{24}Ne beam at 90 MeV passing through 5 μm of Havar, the energy loss is approximately 20 MeV with 100 keV of straggling. This corresponds to a position straggling in the beam direction of the order of millimetres. The angular straggling after the window is approximately one degree, which produces a position straggling perpendicular to the beam direction approaching 5 mm for low energy events. Thus the angular straggling is the dominant contributor to the resolution of the array at large angles.

5. Data

Figure 5 shows experimental data taken using this technique for the $\alpha(^{24}\mathrm{Ne},\alpha)$ reaction. As in the simulated data, states are seen as lines in the zero degree detector, with angular distributions present in the lampshade array. The resolution at larger angles means that the angular distributions of states cannot always be separated, even if they can be at zero degrees. For some isolated states, however, the angular distributions are clear.

6. Conclusions

The Thick Target Inverse Kinematics technique provides an effective method of studying elastic scattering which can be used with stable or radioactive beams. It allows the cross section to be measured at 180° in the c.m. frame with a resolution of the order of 50 keV FWHM. Away from this angle the resolution is worse, primarily due to the geometrical effect of angular straggling, most of which is caused by the entrance window. The use of helium gas as a target is a powerful method of studying α-cluster states.

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