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Study of states in ^{14}C via the ^{10}Be(^{4}He,^{4}He)^{10}Be reaction

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Abstract. A study of the ^{10}Be(^{4}He,^{4}He)^{10}Be reaction has been performed at ^{10}Be beam energies of 25.0, 27.0, 29.0, 32.0, 34.0, 38.0, 40.0, 42.0, 44.0 and 46.0 MeV. The measurements were to explore possible molecular rotational bands in ^{14}C. Three states at excitation energies of E_x = 18.8, 19.76 and 20.66 MeV have been measured and their spins have been determined to be 5^-, 5^- and 6^+, respectively.

1. Introduction

From previous work [1, 2] it is well known that ^{8}Be has a well defined α-α cluster structure. The ground state of ^{8}Be is, however, unbound as the α-α interaction is weak and the Pauli principle causes a repulsive core. The introduction of one more neutron into the system, to produce ^{9}Be, has the effect of adding enough binding energy to stabilise the system. In this case the neutron orbits the α cores in a delocalised region. Extending this system to add another neutron to create ^{10}Be produces a system where there are π and σ molecular bonds binding the core [3]. There is now strong evidence supporting the molecular α cluster structure in these isotopes [4, 5].

The same principles can be applied to carbon where the nucleus can be thought of as a three α particle configuration. In neutron-rich carbon nuclei, such as ^{13}C and ^{14}C, the valence neutrons reside in delocalised molecular orbits around the core. The extra neutrons again have the effect of increasing the binding energy and creating a more stable system. It is expected that there are three possible configurations of the nucleus in ^{14}C: a triangular configuration with the valence neutrons forming σ bonds between two of the α particles, a symmetrical linear configuration where the neutrons are spaced between the α particles (α-n-α-n-α) and an asymmetric configuration where both neutrons are between two α particles (α-$2n$-α-α). The final configuration should give rise to two rotational bands with opposite parity.

In an attempt to study the potential prolate and oblate molecular band nature of ^{14}C the spins and partial decay widths of resonances in ^{14}C were measured.

2. Experimental Details

The resonant scattering reaction ^{10}Be(^{4}He,^{4}He)^{10}Be was studied at beam energies of 25.0, 27.0, 29.0, 32.0, 34.0, 38.0, 40.0, 42.0, 44.0 and 46.0 MeV. This was performed at the Holyfield Radioactive Ion Beam Facility (HRIBF) at the Oak Ridge National Laboratory (ORNL), USA. In the experiment the ^{10}Be beam was incident on gaseous ^{4}He, which filled the reaction chamber at a pressure of 720 torr, providing a range of interaction energies as the beam was slowed by the gas. The gas was contained in the chamber by a 5 micron Havar window. The Q-value for the break-up of ^{14}C into the constituent isotopes, ^{10}Be and ^{4}He, is -12.011 MeV.

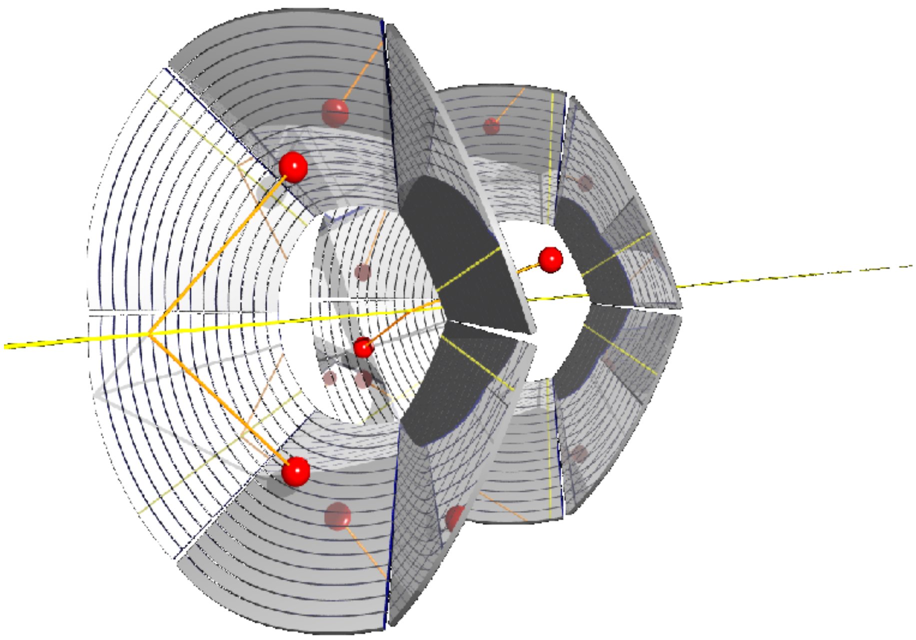

Figure 1. Schematic of the two 'lampshade' detectors.

Three sets of detectors were utilised in the experiment, two 'lampshade' detectors (shown in Fig. 1), each made from six silicon strip detectors, and a zero degree monitor. The lampshades were positioned 175 and 434 mm (to the back of the detectors) from the window with the silicon strips tilted at an angle of 46° to the beam axis. The twelve silicon strip detectors were 500 microns thick and segmented into 16 strips each, creating 96 channels per lampshade. For beam energies below 38 MeV the zero degree monitor consisted of two silicon surface barrier detectors (160 microns each) behind a 46 micron Mylar foil absorber. At 38 MeV and above the zero degree monitor was made from three surface barrier detectors (160 microns each) behind a 144 micron Mylar absorber. These were positioned 336 mm from the window.

The detectors were calibrated using α particles from ^{241}Am and ^{244}Cm, and the elastic scattering of the ^{10}Be beam from a gold target.

3. Analysis and Results

Calculations were made to correct for energy loss in the Havar window and energy loss of the beam as it traversed through the helium gas. The zero degree monitor was used for particle identification using E-ΔE. The energy deposited in the front detector is compared to that in the back detector, shown in Fig. 2, allowing the recoil ^{4}He to be identified.

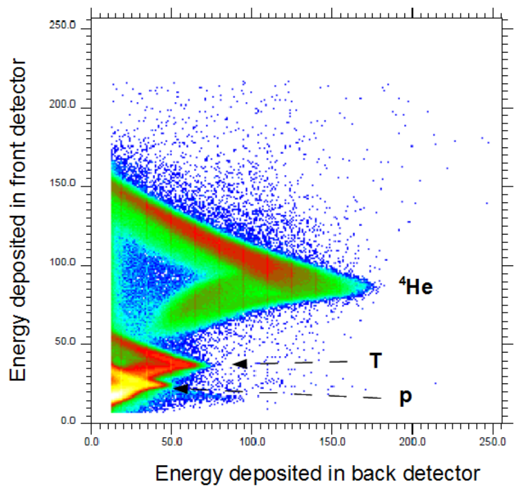

Figure 2. Particle identification plot for the zero degree monitors. Units are arbitrary

Using the monitor and correlating the data from the multiple beam energies a spectrum (Fig. 3) showing the states in ^{14}C can be constructed. The lampshade detectors were used to determine the spins of the states identified by the zero degree monitors. Both the ^{4}He and the ^{10}Be particles were detected by the lampshades in opposite silicon detectors.

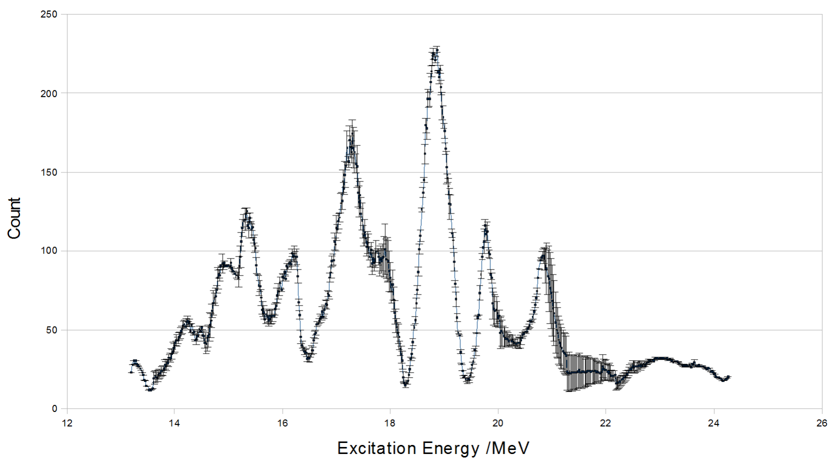

Figure 3. Normalised excitation energy spectrum of ^{14}C from the zero degree monitors.

The energy deposited in a detector was plotted against the angle to produce a two dimensional plot shown in Fig. 4. Resonances appear on the plot periodically along a line as shown in the figure. Once the resonance had been identified its spin was determined by comparing the periodicity of the data with simulated data. A range of spins were compared with the resonances shown in the two dimensional plots until a match was acquired.

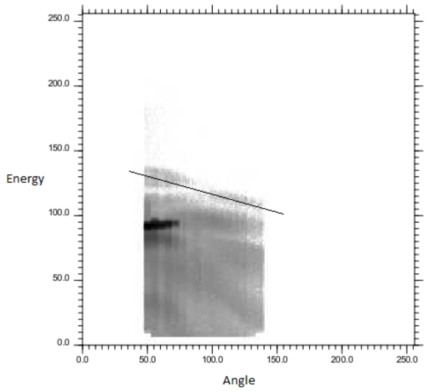

Figure 4. Real data from the lampshade detectors. Units are arbitrary

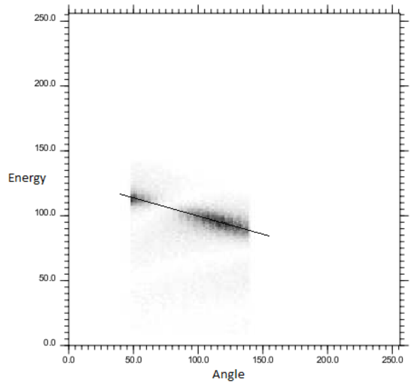

Figure 5. Simulated data for the lampshades. Units are arbitrary.

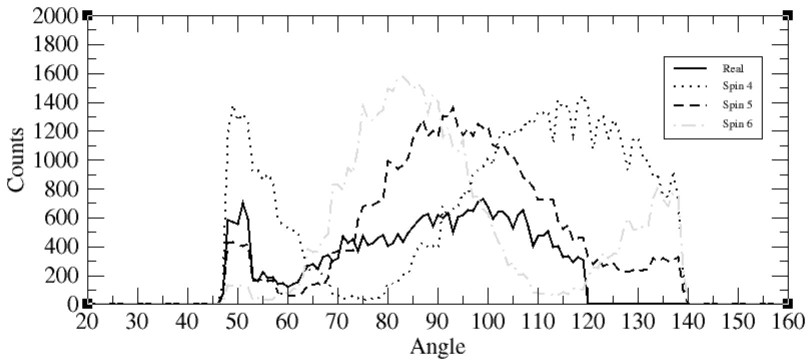

Figure 6. Comparison of real data with simulated data of different spins.

Fig. 6 is an example of the comparison process that each of the resonances underwent. As spin is increased the periodicity of the angular distribution is also increased. By matching the periodicity of the real data to that of the simulated data allowed for identification of the spin of the states. Via this method three of the resonances determined in the spectrum of ^{14}C could have their spins identified. These are the resonances at excitation energies, E = 18.8, 19.76 and 20.66 MeV which have spins of 5^-, 5^- and 6^+ respectively.

4. Summary and Future Work

The ^{10}Be(^{4}He,^{4}He)^{10}Be reaction has been studied at various ^{10}Be beam energies ranging from 25 to 46 MeV. A spectrum showing clear energy states in ^{14}C has been created and the spins of some of those states has been determined. The unknown spins of the other resonances shown in Fig. 3 will be calculated using R-Matrix analysis. Once the spins of the states have been deduced possible rotational bands may become evident.

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