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16O+8Be Cluster Structure in 24Mg

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16O+8Be cluster structure in 24Mg has been identified by observing the breakup into ground state 16O and 8Be fragments following inelastic scattering of 24Mg projectiles. The spectrum of states observed is compared to that previously measured in the 12C+12C breakup channel to obtain information on the partial decay widths.

1. Introduction

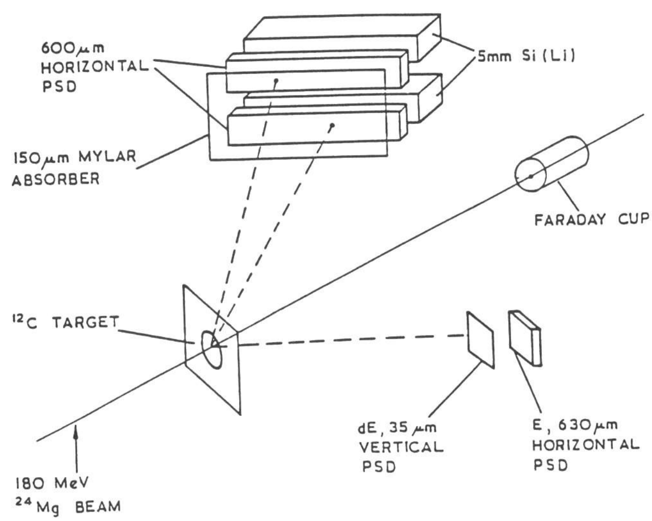
In several recent studies the fission of 24Mg following excitation by inelastic scattering has been reported (1-5). Of particular interest has been the fission into two ground-state 12C nuclei, since this may help establish a direct link between specific states in 24Mg and the well known scattering resonances observed in the 12C+12C system (6). Earlier studies of the electrofission of 24Mg (7) and the inverse process of radiative capture of 12C+12C (8) had revealed the existence of an unusual set of states at an excitation energy near 22MeV in 24Mg which are linked to the ground state and also have an appreciable overlap with a 12C+12C configuration. However, the states observed in the electrofission and radiative capture measurements did not appear to correspond directly to the resonances observed in 12C+12C scattering, or to be associated with known fragments of the giant resonance strength in 24Mg (8).

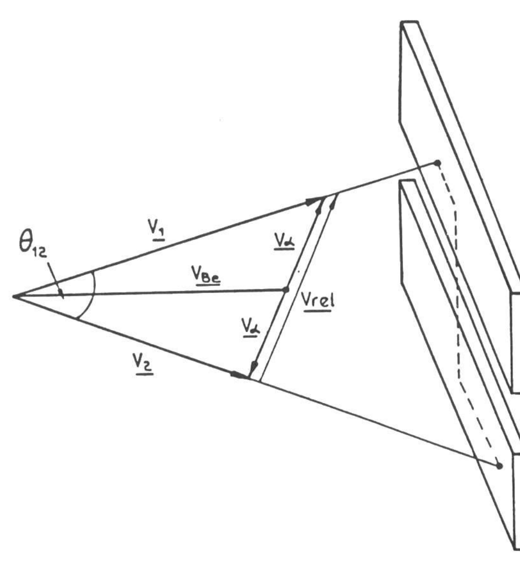
The inelastic scattering process (as opposed to electromagnetic excitation) is an alternate means of investigating these unusual states which, in principle, also removes the restriction of the latter to low multipolarities. The new experiments show fission occuring from specific states in 24Mg in the excitation energy range around 22MeV, confirming the results of the electrofission and radiative capture experiments and indicating that the occurrence of fissioning states covers a wider region of excitation than previously realised. In addition, they show evidence for fission to channels involving one or both of the 12C nuclei excited to the 2+ state at 4.44MeV.

The detailed mechanism of the fission process remains unknown at present. Clearly it involves some special states at high excitation in 24Mg which are directly related to the ground state through enhanced transition amplitudes and yet which also have an enhanced overlap with a configuration involving two 12C nuclei. However, a detailed microscopic description of these states remains to be determined. In an effort to further elucidate the nature of the fission process as described above, we have performed new measurements to search for decay to the 160+8Be channel. The breakup Q value and Coulomb barrier in this channel are similar to those in the 12C+12C channel, and this decay was also observed in the early electrofission measurements (7).

2. Experimental Method

The measurements of the 160+8Be decay channel have been performed in an identical fashion to our earlier 24Mg > 12C+12C measurements. However, the unbound nature of the 8Be ejectile imposes an additional experimental requirement in that it is necessary to record the coincident alpha particles from the 8Be decay. Figure 1 shows a schematic of the experimental arrangement. A beam of 180MeV 24Mg ions from the Daresbury Laboratory 20MV tandem was used to bombard a 400 ug/cm**2 carbon foil. 160 fragments were recorded in a conventional DE E telescope, consisting of two 10mm by 10mm position sensitive silicon surface barrier detectors mounted orthogonally to each other to provide information on both in plane and out of plane angles. 8Be fragments were recorded by detecting coincident breakup alphas in two close mounted telescopes on the opposite side of the beam. Each comprised a position sensitive silicon surface barrier detector backed by a Si(Li) detector. A mylar absorber in front of the detectors served to stop the elastically scattered beam particles and reduce the count rate in the detectors. The position measurements give the in plane angle of each alpha and (combined with an estimate of the out of plane angle) allow the relative energy of the two alphas to be determined as illustrated in figure 2. This enables us to identify alphas from the decay of the 8Be ground state (Erel = 92keV) and discriminate against alphas from other reaction processes (eg 24Mg* > + 20Ne* > + + 160).





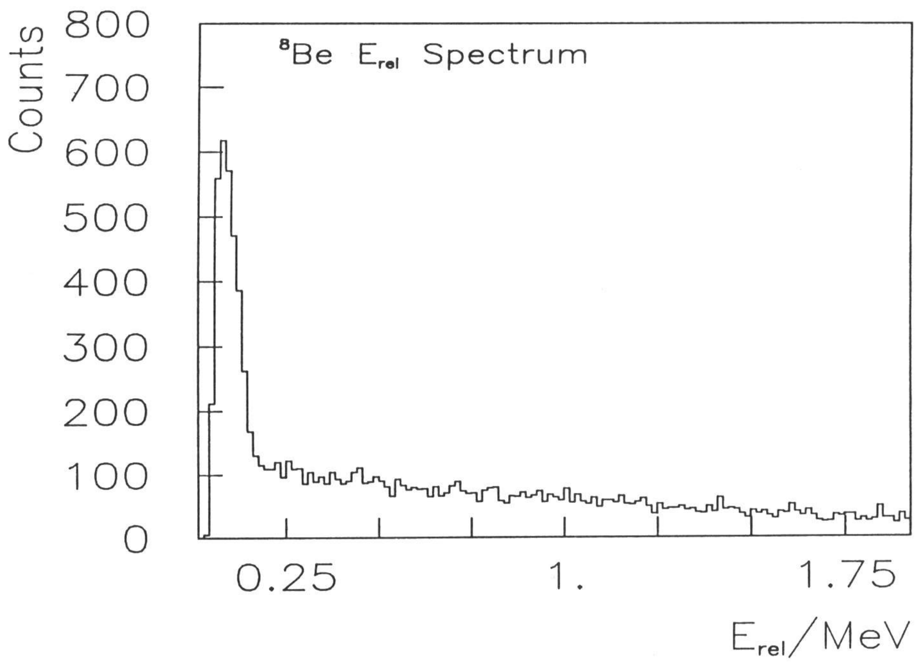


Figure 3 shows an Erel spectrum for events in this detector with a peak visible at the low energy end of the spectrum from decays of 8Be nuclei.

From the measured positions and energies of the alpha particles the momentum of the 8Be nucleus is determined. From this and the momentum of the 16O nucleus measured in the other detector we calculate the total energy spectrum (Etot) for each event. Etot is the total kinetic energy in the outgoing channel (the summed energy of the two detected nuclei plus the recoil energy of the unobserved third particle calculated from the missing momentum) and reflects the binding energy change (Q value) of the reaction.

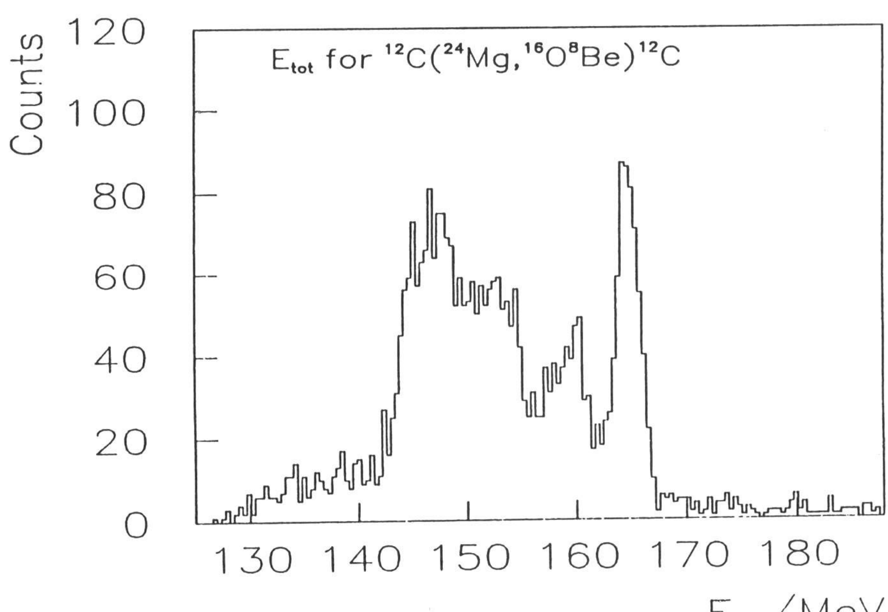
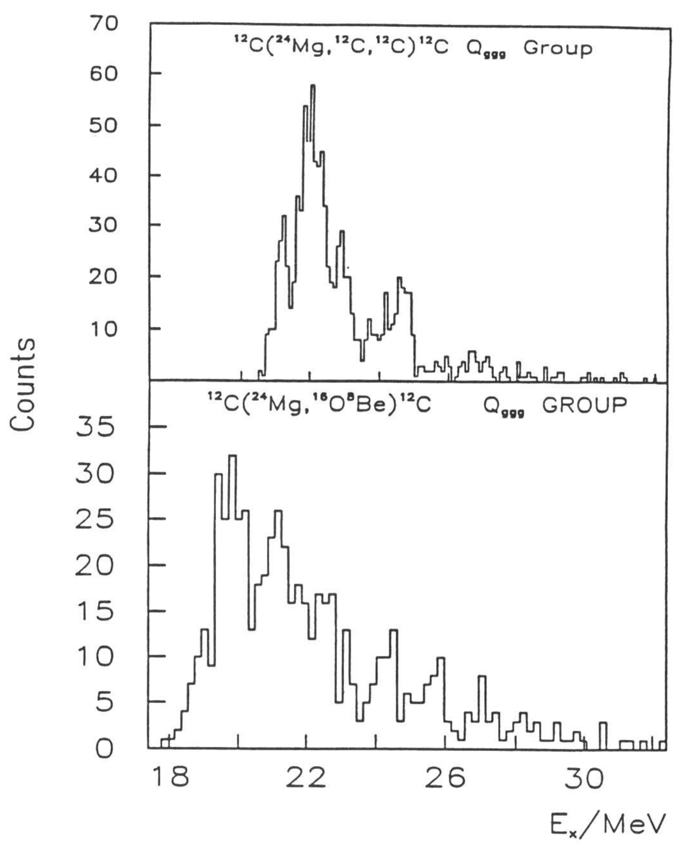


Figure 4 shows the Etot spectrum for coincident 16O and 8Be nuclei detected in the telescopes. The peaks visible in this spectrum imply a three body final state, with the highest peak corresponding to that energy expected for all three outgoing particles in their ground states. Peaks are also visible at lower energies which would correspond to one or more of the nuclei emerging in an excited state. There is evidence for a state at around 6 MeV which could be the second 0+ state in 16O, but the spectrum is too poor to make any definite assignments (a probable consequence of the large width of excited states in 8Be).

For those events corresponding to all three nuclei in their ground states we can use the measured energies and angles to determine the relative kinetic energy (Erel) of the 16O and 8Be nuclei in their center of mass frame. This is equal to the excitation energy of the state in 24Mg from which the breakup occured, minus the breakup Q value (14.1MeV). Figure 5 shows the Erel spectrum for 16O+8Be decay along with our previously measured spectrum for 12C+12C decay. It is clear that the 16O+8Be channel displays similar features to that of the 12C+12C channel, with decays arising from states in the same excitation energy region. The 16O+8Be spectrum extends to lower excitations (a consequence of the lower Coulomb barrier and the phase space covered by the detectors) and displays a poorer energy resolution (a consequence of the poorer determination of the 8Be momentum vector since there is no out of plane measurement available from the detector).



3. Interpretation

To observe such decay processes from states at high excitation requires three conditions to be met - the initial inelastic scattering process must excite the states with sufficient strength; the probability that the state decays to the symmetric fission channel must be large; the decay products must emerge within the angular region covered by the detectors. The observed yield will therefore depend on

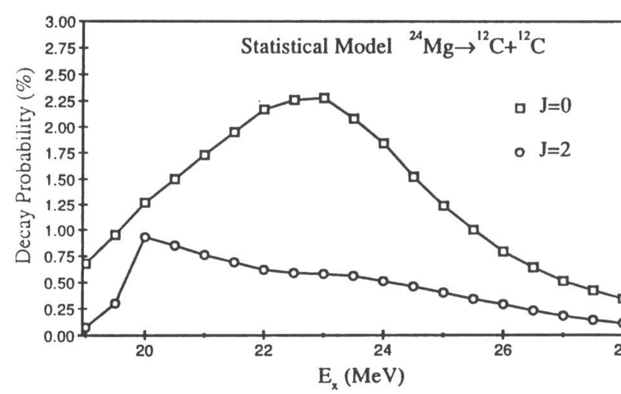
$$Y \sim P(excit) * P(decay) * P(detect) \tag{1}$$

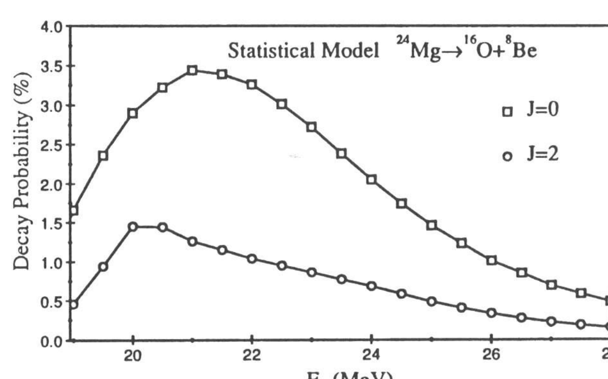
and before contrasting the yield for different channels it is important to consider the relative effect of these three factors. One of the strongest influences is the spin of the intermediate 24Mg state. This influences the excitation and decay through the effect on angular momentum barriers, and the detection probability by determining the angular distribution of the decay fragments. The similarity of the spectrum of fissioning states seen in 24Mg (4) with states in the radiative capture of 12C+12C (8) suggests the states are probably of low multipolarity, and this is confirmed by the angular correlation measurements of ref 2 and 5. For the purposes of comparison we assume a spin of J=0 or J=2.

Since we have no experimental measurement of the inelastic scattering process the absolute magnitude of this step is unknown. The strength will depend both on the kinematics of the reaction process and the structure of the states involved. An added complication is that the reaction process itself is unknown and could involve direct or multistep excitation. However, although we lack an absolute normalisation, we can of course compare the relative yields between the 12C+12C and 16O+8Be data sets since these were measured for the same reaction.

Once the nucleus has been inelastically excited it will subsequently decay, and since the excitation energy is well above the particle emission threshold these decays will dominate over gamma emission. The decay to two heavy fragments will compete with all other open decay channels, with Coulomb barrier and phase space considerations favouring the emission of light particles. In order to determine how this competition varies with energy in the 24Mg system we evaluate the probability for the decay within the Hauser Feschbach compound nucleus decay formalism.

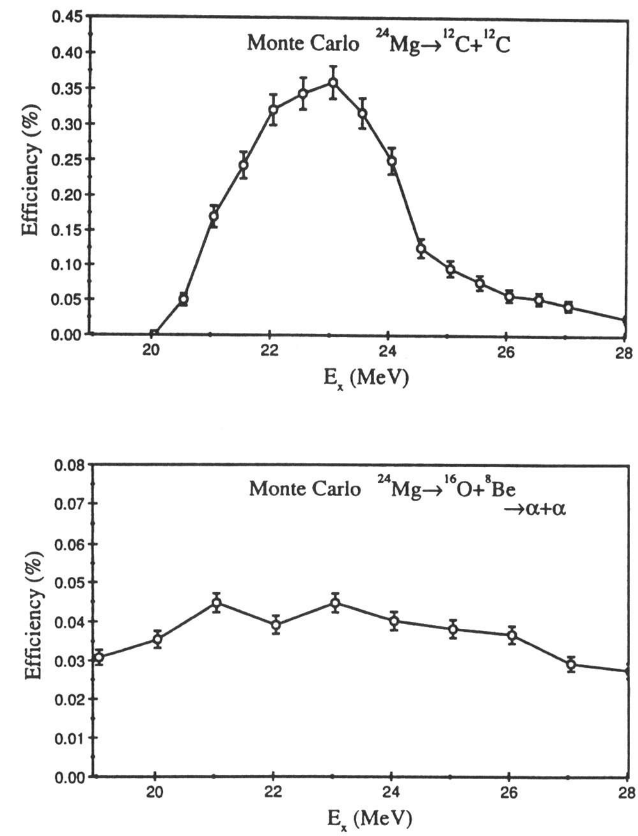
We consider a state of given spin and excitation energy and calculate the cross sections for n, p, d and alpha decay along with the 12C+12C and 16O+8Be channels. By assuming the light particles account for the bulk of the compound nucleus decay we can then evaluate the decay probability for the heavy fragment channels. The calculations have been performed using the code STATIS (9) with standard level density and optical model potential parameters. Figure 6 shows the result of these calculations and gives the probability for both 12C+12C and 16O+8Be decay as a function of excitation energy for states of spin 0 and 2.





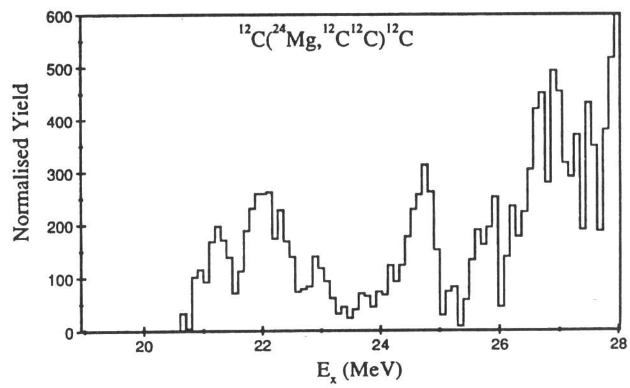
The probability of detecting the decay fragments depends on the angular settings and solid angles of the detectors. The emission angles of the decay fragments will be determined by the angular distribution of the projectile scattering and the angular correlation of the two fragments which are emitted in the decay. As noted earlier there are considerable difficulties associated with calculating what the inelastic scattering angular distribution will be. The best available data is that for the neighbouring 12C+27Al system (10) where the inelastic cross section has been measured at a similar centre of mass bombarding energy (Ecm =56.8MeV). For the excitation energy around 20MeV an exponential fall off in the angular distribution is observed. For the decay the angular correlation will be determined by the distribution of m substate populations in the excited state. For scattering at zero degrees the population is constrained by the angular momentum coupling to have m=0 with respect to the beam axis, and this results in a simple angular distribution characterised by a Legendre polynomial.

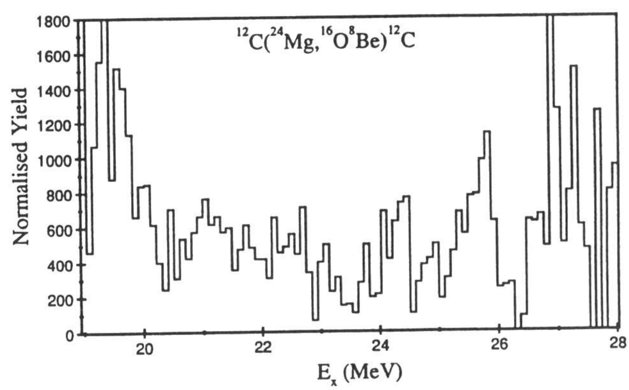
For non-zero scattering angles the sub state distribution can only be determined within some model and will in general give rise to a complex pattern. Given these uncertainties we have attempted to calculate the relative efficiencies for the two decays using a Monte Carlo approach. The input to this comprises an exponential fall off for the inelastic excitation with a characteristic half angle of 16deg., and an assumed isotropic decay for the breakup. Figure 7 shows the result of the calculation for breakup to 12C+12C and 16O+8Be fragments as a function of excitation energy of the 24Mg nucleus.



4. Conclusions

Figure 8 shows the 12C+12C and 16O+8Be spectra normalised to account for the different beam-target exposure, and modified by the decay penetrabilities and detection efficiencies as calculated above. It is difficult to compare directly peaks seen in the two spectra, partly because of the low statistics in the 16O+8Be spectrum, and also because the absolute energy scales are uncertain to +/-50keV (a result of uncertainties in the energy and position calibrations of the detectors). However it is clear that states similar to those seen in the symmetric fission of 24Mg also appear in the 16O+8Be decay channel. Interestingly, the strength is larger in this channel, indicating that the 16O+8Be cluster configuration is a more important component of the 24Mg wavefunction than 12C+12C. It is also clear that when the decay penetrabilities and detection efficiencies are folded into the experimental spectra, the occurrence of cluster states is seen to extend to much higher excitations in 24Mg than previously realised. These results suggest that it will be important to search for decays to other large-cluster channels, and to extend the measurements to wider breakup angles to determine how high in excitation energy the cluster configurations can be observed. This information, coupled with a determination of the spins from a measurement of the decay angular correlations, will be necessary before the true nature of these unusual states can be determined.





References

1) B R Fulton, S J Bennett, C A Ogilvie, J S Lilley, D W Banes, W D M Rae, S C Allcock, R R Betts and A E Smith; Symposium on The Many Facets of Heavy Ion Fusion, Argonne National Laboratory ANL-PHY-86-1, p495.
2) S Lawitzki, D Pade, B Gonsior, C D Uhlhorn, S Brandenburg, M N Harakeh and H W Wilschut; Phys. Lett. 174B (1986) 246.
3) C A Davis, G A Moss, G Roy, J Uegaki, R Abegg, L G Greeniaus, D A Hutcheon and C A Miller; Phys. Rev. C35 (1987) 336.
4) B R Fulton, S J Bennett, C A Ogilvie, J S Lilley, D W Banes, W D M Rae, S C Allcock, R R Betts and A E Smith; Phys. Lett. 181B (1986) 233.
5) J Wilczynski, K Siwek-Wilczynska, Y Chan, E Chavez, S B Gazes and R G Stokstad; Phys. Lett. 181B (1986) 229.
6) D A Bromley; Resonances in Heavy Ion Reactions, Lecture Notes in Physics 156, Springer-Verlag (1981).
7) A M Sandorfi, J R Calarco, R E Rand and H A Schwettman; Phys. Rev. Lett. 45 (1980) 1615.
8) A M Nathan, A M Sandorfi and T J Bowles; Phys. Rev. C24 (1981) 932
9) R G Stokstad, Hauser Feshbach code STATIS, Yale University, Wright Nuclear Structure Laboratory Report 52 (1972), unpublished.
10) R R Betts, S B DiCenzo, M H Mortensen and R L White, Phys. Rev. Letts. 39 (1977) 1183.