Near-symmetric breakup of ^{25}Mg

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The breakup of ^{25}Mg has been studied using a beam of 180 MeV ^{25}Mg with a ^{12}C target. The main reaction channels investigated are the near-symmetric breakup into $^{12}C+^{13}C$ and symmetric breakup into $^{12}C+^{12}C$ following neutron transfer to the target. The symmetric breakup into two ^{12}C nuclei is observed to occur from states at high excitation in ^{24}Mg. The yield is, however, about two orders of magnitude smaller than that observed in a similar experiment using a ^{24}Mg beam.

In a recent publication Fulton and Rae[1] have presented a comprehensive review of recent results on the breakup of some *sd*-shell nuclei into fragments heavier than alpha particles. Perhaps the most striking of the experimental data presented in the review are those on the symmetric breakup of ^{24}Mg into two ^{12}C nuclei. In this case, measurements using different reaction processes indicate that the breakup proceeds through discrete states of ^{24}Mg with excitation energies in the range 19 to 25 MeV.

At these high excitation energies one might expect any structure to become smeared out by the high level density (approximately 1000 states/MeV) compared to the average width of a state (20 keV). It is therefore surprising that decays involving such large clusters should occur from discrete states in this region. One interpretation of this observation of breakup is that it may be revealing an overlap between the ground-state wave function and a configuration involving two large fission fragments, and may be regarded as evidence for the existence of large-scale clustering phenomena in ^{24}Mg.

There are connections with recent calculations[2] which suggest that the resonances which have been observed in certain heavy-ion scattering experiments (e.g., $^{12}C+^{12}C$) involve the formation of superdeformed states in the composite system. These superdeformed states are predicted to have large widths for decay into two heavy-ion clusters, for example, states based on the highly deformed triaxial configuration in ^{24}Mg can decay into $^{12}C+^{12}C$ and correspond to the broad resonances observed by Cormier *et al.* in $^{12}C+^{12}C$ channel.[3] The relationship between superdeformed states and the asymptotic cluster channels can be predicted using a simple schematic model proposed by Harvey.[4] As pointed out by Fulton and Rae,[1] the Harvey model also makes predictions about the fission modes which would be allowed for nuclei in their ground-state configurations. The experimental data[1] for nuclei such as ^{24}Mg, ^{28}Si, and ^{32}S are found to be in agreement with the Harvey model: ^{24}Mg is observed to fission symmetrically following its interaction with a ^{12}C target with both fission fragments in their ground state whereas there is very little evidence for the symmetric fission of ^{32}S into two ground-state ^{16}O nuclei or the fission of inelastically excited ^{28}Si into $^{16}O_{g.s.}+^{12}C_{g.s.}$. However, these results do not conclusively test the validity of the Harvey model. There could be other reasons why the above breakup modes for ^{28}Si and ^{32}S are not observed; for example, there may be no suitable "doorway" states above the appropriate threshold energy. The study of breakup modes of nuclei such as ^{25}Mg and ^{23}Na may provide more stringent tests of the Harvey model, since the structure of these nuclei will be more similar to that of ^{24}Mg itself. In this paper we present the results of a measurement of the fission of ^{25}Mg into ^{12}C and ^{13}C nuclei following inelastic excitation of ^{25}Mg projectiles.

A beam of 180 MeV ^{25}Mg projectiles obtained from the 20 MV Tandem at the Daresbury Laboratory were used to bombard a 400-μg cm^{-2} natural carbon target. The fission fragments from the excited nuclei were detected in coincidence using the CHARISSA detector array and data-acquisition system.[5] The array consisted of six particle identification (E,dE) telescopes closely packed in diametrically opposite pairs about the beam axis with one pair of telescopes at 11.0° and the two remaining pairs at 14.8°. Each telescope comprised of a 30-μm dE and a 600-μm E position-sensitive silicon surface-barrier detectors. The detectors were oriented with their position-sensitive axes orthogonal to each other to enable both in-plane and out-of-plane angular information to be obtained. This allows full kinematic reconstruction of each event. The detectors had an active area of 10 mm$\times$10 mm and were positioned 120 mm from the target, giving a solid angle of 7 msr.

In Fig. 1 we show the total energy spectra E_{tot} for two of the near-symmetric breakup channels open for this experiment. E_{tot} is the summed energy of the two detected breakup fragments plus the energy of the unobserved recoiling nucleus calculated from the missing momentum. The E_{tot} value marked Q_{ggg} corresponds to the situation

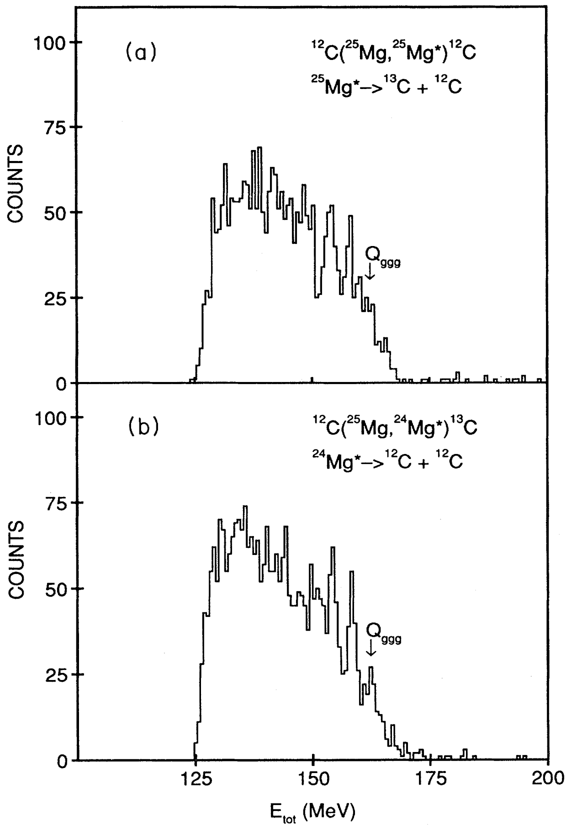

FIG. 1. Total-energy spectra for fission of (a) ^{25}Mg into ^{12}C and ^{13}C following ^{12}C+^{25}Mg inelastic scattering at 180 MeV and (b) ^{24}Mg into two ^{12}C nuclei following single neutron transfer from ^{25}Mg projectile to ^{12}C target.

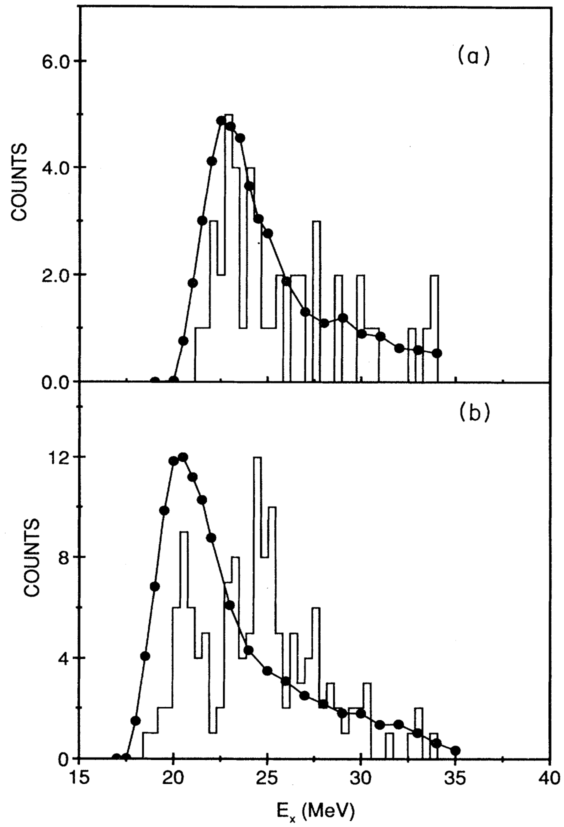

FIG. 2. Excitation energy spectra of symmetric fissioning states in (a) ^{25}Mg and (b) ^{24}Mg determined from events contributing to the Q_{ggg} peak in Figs. 1(a) and 1(b), respectively. The solid lines show the results of Monte Carlo calculations of detection efficiency.

where all three final-state nuclei occupy their ground states. The peaks at lower energy correspond to one or more of the fragments occupying excited states. Figure 1(a) shows the E_{tot} spectrum for ^{12}C+^{13}C coincidences from events corresponding to the direct breakup of inelastically excited ^{25}Mg nuclei. Contributions to the E_{tot} spectrum from events corresponding to the simultaneous detection of recoiling ^{12}C target nuclei and ^{13}C fission fragments is considered to be negligible in view of the much reduced cross section for inelastic scattering at backangles. The total-energy spectrum for the decay mode involving the fission of ^{24}Mg into ^{12}C+^{12}C is shown in Fig. 1(b). The excited ^{24}Mg is produced by neutron transfer from the projectile to the target. From these two E_{tot} spectra we conclude that although there is some evidence of symmetric breakup of ^{24}Mg into $^{12}C_{g.s.}+^{12}C_{g.s.}$, there is only weak evidence of the breakup of excited ^{25}Mg into $^{12}C_{g.s.}+^{13}C_{g.s.}$.

The excitation energy spectra determined from events contributing to the Q_{ggg} peak in Figs. 1(a) and 1(b) are shown in Figs. 2(a) and 2(b). Figure 2(a) shows that the breakup of ^{25}Mg into $^{12}C_{g.s.}+^{13}C_{g.s.}$ occurs from the excitation energy region from 21 MeV to nearly 35 MeV in ^{25}Mg. The profile of the experimental yield follows closely the solid line in the figure, which is a Monte Carlo calculation[6] of the detected efficiency. In view of the low yield, and the background under the Q_{ggg} peak, it is not possible to draw any inference from this spectrum. Figure 2(b) shows that the breakup of ^{24}Mg into $^{12}C_{g.s.}+^{12}C_{g.s.}$ is not only much stronger, but the yield also shows a structure which suggests that the breakup may be occurring from specific states in ^{24}Mg. Interestingly, a comparison with the Monte Carlo calculation of detection efficiency [solid line in Fig. 2(b)] suggests that the peaks at higher excitation may be of greater significance than that at lower energy—a feature previously commented upon in a study of the breakup of ^{24}Mg into $^{16}O_{g.s.}+^{8}Be_{g.s.}$ and $^{12}C_{g.s.}+^{12}C_{g.s.}$ following scattering of ^{12}Mg projectiles.[6] Although the peaks lie in an excitation energy region similar to that observed in a previous experiment by Fulton *et al.*[7] there is no clear overlap in the exact energies of the peaks. If it is possible to study breakup states formed via different reaction processes, this may enable information to be obtained on the structure of these states.

It is also interesting to compare the yield of the ^{12}C+^{13}C channel in the present experiment to that observed in a recent remeasurement of the symmetric breakup of ^{24}Mg following inelastic excitation by Freer *et al.*[8] The total-energy spectrum for the data of Ref. 8 is shown in Fig. 3. This may be compared with the spectrum shown in Fig. 1(a). The data shown in Figs. 1(a) and 3 correspond to integrated beam exposure of 5.1 and 3.7 mC, respectively. Other experimental parameters such as beam energy, scattering angle, target thickness, and detector geometry are similar in both experiments. Provided the only reaction mechanism populating the states in the two resonant nuclei is inelastic excitation, one might expect the reaction strengths for the breakup of ^{25}Mg into ^{12}C+^{13}C and ^{24}Mg into ^{12}C+^{12}C to be similar. The yield for each experiment will then be determined by the wave function of the resonant nuclei. We estimate that the yield for ground-state breakup for the ^{12}C+^{12}C channel in Ref. 7 is about 70 times that observed for the ground-state breakup for the ^{12}C+^{13}C channel in the present experiment. This dramatic reduction in the yield is obviously due to the presence of the extra neutron in ^{25}Mg. However, this is quite puzzling since one may consider the extra neutron as only weakly coupled to a ^{24}Mg core. The precise role of the extra neutron is not fully understood and requires further investigation. It is worth noting that the partial decay width for neutron emission can be expected to be larger for ^{25}Mg than for ^{24}Mg and this competition with the near-symmetric fission decay could account for the difference in the yield of the two systems. However, Hauser-Feshbach calculations using the code[9] STATIS suggests the effect is only about a factor of 2 to 3, which is not sufficient to account for the observed difference.

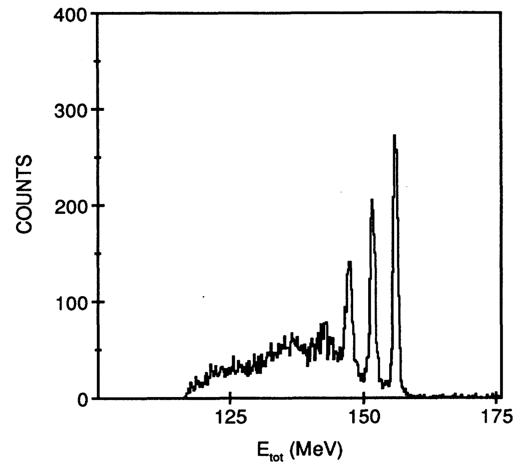

FIG. 3. Total-energy spectrum for symmetric fission of ^{24}Mg following inelastic scattering at 170 MeV (from Fig. 8).

In conclusion, although symmetric fission of ^{25}Mg is observed, it is very much weaker than that of ^{24}Mg. This may indicate that there is something special about the ^{24}Mg system as it is the only one for which a relatively strong breakup cross section is observed.

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