Excitation of $^{12}C+^{12}C$ "quasimolecular" resonances by inelastic scattering of 190 MeV protons from ^{24}Mg

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The symmetric fission of ^{24}Mg into $^{12}C+^{12}C$ by inelastic proton scattering at $E_p=190$ MeV and $\theta_p(\text{lab})=15.25°$ has been observed. A yield curve of events versus excitation energy in ^{24}Mg is given.

There has been great interest in the $^{12}C+^{12}C$ system since the original observation of resonances near the Coulomb barrier a number of years ago.[1] A considerable amount of work has now been done on this system and it has been observed that broad overlapping doorway states of definite J^π are present in the data.[2] At higher energies, broad resolvable states of high spin with noticeable fine structure have been observed.[3] This is usually regarded as evidence for "molecular" resonances serving as doorway states to the underlying structure in $^{24}Mg^*$.[2,4,5] To investigate how these resonances are connected to the intrinsic structure of ^{24}Mg, work on electrofission,[6–8] radiative capture,[9] and alpha inelastic scattering[10] have been published. These measurements observed states that have little apparent correlation with the states observed in heavy ion reactions. The electrofission work could only observe states of spin $J=0$ and 2. Other states, including presumably some of higher spin, were seen in the symmetric fission of ^{24}Mg by alpha particles.

This experiment has examined the $^{12}C+^{12}C$ final states by inelastic proton scattering. The medium resolution spectrometer (MRS) at TRIUMF was used to detect protons inelastically scattered at $\theta_{\text{lab}}=15.25°$ from a thin (195 $\mu g/cm^2$), enriched (99.92%) ^{24}Mg target which was rotated 60° from perpendicular to the 100 nA proton beam. Two 300 μm thick fully depleted 9 cm^2 silicon surface barrier (SSB) detectors were placed at 18.5 cm and 82° to the left (the MRS side) and 20.6 cm and 88.5° to the right of the 190 MeV proton beam. A plastic veto scintillator was placed behind each SSB detector. An event was defined by a triple-coincidence between a proton in the MRS and a fragment of the recoil nucleus in each of the SSB detectors. The energy and time of flight (TOF) (relative to the proton TOF start counter of the MRS) of each fragment was determined, as were the position in the MRS focal plane, the time of flight through the MRS, and the energy deposited in large plastic scintillators behind the MRS top wire chamber.

Knowledge of the possible breakup channels of $^{24}Mg^*$ and the above information permitted each event to be associated with a final state of the ^{24}Mg nucleus. This was done by examining the times of flight and energies of both fragments and comparing them to kinematic predictions for two carbon nuclei arising from the breakup of a recoiling $^{24}Mg^*$. Since a SSB detector had a time resolution of ~ 6 ns and a carbon ion of a few MeV energy loses about 1 MeV in fully traversing the target, the kinematic region for $^{12}C+^{12}C$ events was rather poorly resolved from other reactions, as discussed below. Thus, in addition to including events due to $^{12}C+^{12}C$ breakup of ^{24}Mg, events from other sources were included as well. However, the resolution in summed energy of the two fragments is determined mainly by the straggling through the target.

The energies of the two fragments and the proton were summed. The energy scales in the two SSB detectors were determined by an ^{241}Am α source ($E_\alpha=5.48$ MeV). The momentum of the proton in the MRS is determined from its position in the focal plane and the strength of the magnetic field. The MRS resolution, as determined from the ground state in elastic scattering, was observed to be 0.6 MeV (FWHM). The total summed energies for $^{12}C+^{12}C$ events is shown in Fig. 1. The "missing energy" then reflects the Q value for the breakup of ^{24}Mg and the energy losses of the fragments in the target (the energy loss of the proton being negligible). The prominent peak at -15 MeV is due to the $^{24}Mg(p,p')^{24}Mg^* \rightarrow {}^{12}C+{}^{12}C$ reaction (the Q value for $^{24}Mg \rightarrow {}^{12}C+{}^{12}C$ is -13.9 MeV). The peak at -19.5 MeV is due to the $^{24}Mg(p,p')^{24}Mg^* \rightarrow {}^{12}C+{}^{12}C^*(4.44\text{ MeV})$ reaction. The small peak at -8 MeV arises from the $^{16}O(p,p')^{16}O^* \rightarrow {}^{12}C+\alpha$ reaction.

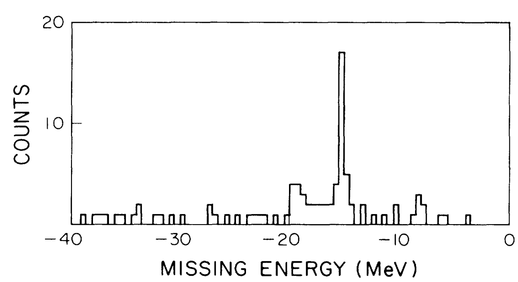

FIG. 1. Events after cuts on times of flight and ratio of energies deposited in the SSB's as a function of "missing energy," i.e., the Q value of the reaction plus energy losses. The peak at -15 MeV is the $^{12}C+^{12}C$ breakup of $^{24}Mg^*$ after excitation by inelastically scattered protons.

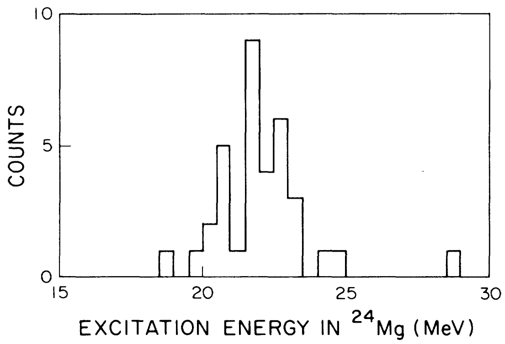

FIG. 2. The $^{24}Mg(p,p')^{24}Mg^* \rightarrow {}^{12}C + {}^{12}C$ events in the prominent peak in Fig. 1 as a function of excitation energy in ^{24}Mg.

The continuum of events from -15 to -20 MeV is due to the $^{24}Mg(p,p')^{24}Mg^* \rightarrow {}^{16}O + {}^{8}Be(\rightarrow 2\alpha)$ reaction. The $^{16}O + {}^{8}Be$ breakup of ^{24}Mg has a Q value of -14.1 MeV, but its peak is spread out because we detect only one of the alpha particles.

Figure 2 shows the $^{12}C + {}^{12}C$ events as a function of excitation energy in ^{24}Mg. Most of the events are located between 20 and 25 MeV in excitation energy (the MRS accepted momenta corresponding to excitation energies as high as about 40 MeV). At lower energies there is a cutoff at about 16—17 MeV due to the recoil of the excited nucleus $^{24}Mg^*$, leaving one of the breakup carbons with too little energy to be observed. The laboratory second differential cross section integrated over the excitation energy (and taking into account changing efficiency for seeing the $^{12}C + {}^{12}C$ breakup as a function of excitation energy) is

$$\frac{d^2\sigma}{d\Omega_p d\Omega_{CC}} = 1.3 \pm 0.3 \frac{\mu b}{(sr)^2} .$$

The events due to $^{24}Mg(p,p')^{24}Mg^* \rightarrow {}^{12}C + {}^{12}C^*(4.44$ MeV) are spread over a larger region of energy, from about $E_x = 20$ MeV to almost 40 MeV, but are otherwise too few to draw any conclusions.

The electrofission and radiative capture work[7–9] reported structure for $E_x = 20$—23 MeV of $J = 0$ and 2. The alpha-particle-induced fission work[10] reported structure for $E_x = 20$—27 MeV and concluded that most of the strength had $J \neq 0$. They also observed that for $^{24}Mg(\alpha,\alpha')^{24}Mg^* \rightarrow {}^{12}C + {}^{12}C^*(4.44$ MeV), the events were spread over a larger region in E_x, as in the present experiment. The symmetric fission of ^{24}Mg following excitation by either electromagnetic or inelastic hadron scattering may be related to the ground state of ^{24}Mg.[10] Inelastic scattering of heavier particles can excite higher multipoles than electromagnetic probes. The present work is an intermediate case between alpha-particle-induced fission and electrofission in respect of the multipoles excited.

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