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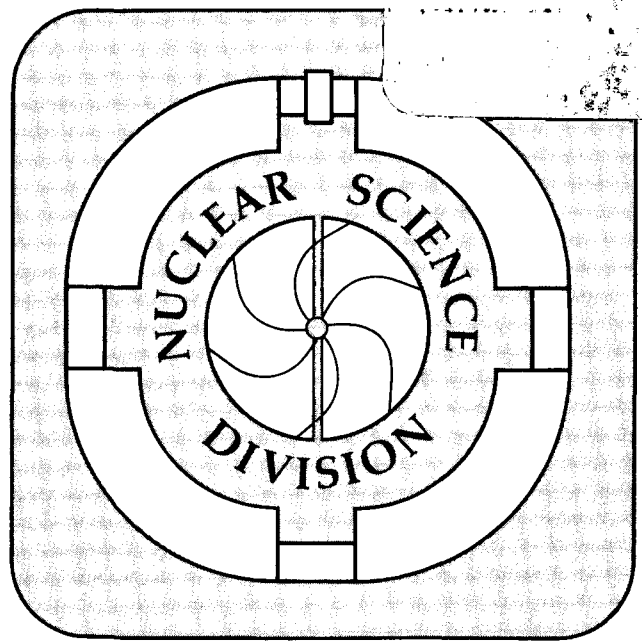
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^{12}C DECAY OF ^{24}Mg FOLLOWING NUCLEAR INELASTIC SCATTERING*

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Abstract:

The decay of ^{24}Mg into two ground-state ^{12}C nuclei following inelastic scattering of 15 MeV/nucleon ^{24}Mg by a ^{12}C target was studied. Three resonances at excitation energies in ^{24}Mg of 21.9, 23.6 and 24.8 MeV were observed. Their spins, $J^\pi = 2^+$, 0^+ (2^+) and 0^+ , respectively, have been deduced from the ^{12}C - ^{12}C angular correlations.

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The possible existence of excited states in ^{24}Mg having pronounced $^{12}\text{C} + ^{12}\text{C}$ structure is a question that continually attracts interest. The so-called "molecular" resonances observed in the $^{12}\text{C} + ^{12}\text{C}$ excitation functions^{1,2} are usually interpreted as entrance-channel phenomena, and it is not clear to what extent they might be related to the ground-state structure of ^{24}Mg .

A few strong, nonstatistical resonances have been observed in the radiative-capture reaction $^{12}\text{C}(^{12}\text{C}, \gamma_0)^{24}\text{Mg}_{g.s.}$ (Refs.3,4), as well as in its inverse process, the electrofission of ^{24}Mg (Ref.5). These resonances are very likely linked to the ground-state structure of ^{24}Mg .

Since both the electromagnetic and the inelastic hadronic interactions preferentially excite collective states, the latter processes are a promising alternative way to study the intriguing resonances that have been observed in the radiative-capture reaction. Moreover, since nuclear inelastic scattering is not restricted to the lowest multipolarities, as is the case in the electromagnetic reactions, one might expect to populate a greater number of resonances related to the ground-state structure of ^{24}Mg .

In the present work, we used the inelastic scattering reaction $^{12}\text{C}(^{24}\text{Mg}, ^{24}\text{Mg}^*)$ to induce disintegration of $^{24}\text{Mg}^*$ into $^{12}\text{C} + ^{12}\text{C}$. The main disadvantages of the "normal kinematics" reactions in which ^{24}Mg is the target (low detection efficiency, low kinetic energies of the decay products) such as in the $^{24}\text{Mg}(\alpha, \alpha')^{24}\text{Mg}^* \rightarrow ^{12}\text{C} + ^{12}\text{C}$ reaction reported in Ref.6, do not exist when the ^{24}Mg nucleus is used as the projectile. In the present experiment, we observed the sequential decay of ^{24}Mg into

$^{12}\text{C} + ^{12}\text{C}$ with high efficiency and sufficient angular resolution for a precise determination of the relative kinetic energy of the two ^{12}C fragments. Along with a strong resonance at the same excitation energy (21.9 MeV) observed in the radiative-capture work^{3,4}, we observed two new resonances at higher excitation energies in ^{24}Mg .

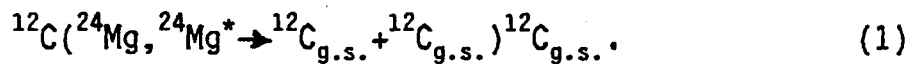
The experiment was performed with the use of a 357-MeV ^{24}Mg beam produced by the new Electron Cyclotron Resonance ion source and the 88-Inch Cyclotron of the Lawrence Berkeley Laboratory. A $475\text{-}\mu\text{g}/\text{cm}^2$ ^{12}C foil was used as a target. In such a reverse-kinematics reaction, the inelastically scattered ^{24}Mg nuclei emerge close to the beam direction. Therefore, the ^{12}C - ^{12}C coincidences from ^{24}Mg decay are detected with the highest efficiency if both ^{12}C detectors are placed at forward angles on opposite sides of the beam.

Two large-solid-angle telescopes (~ 5 msr, each) were used to determine the charge, mass and kinetic energy of each reaction product. The telescopes consisted of $40\text{-}\mu\text{m}$ ΔE detectors and large-area position-sensitive E detectors. Their centers were placed at $+10^\circ$ and -10° with respect to the beam direction. The telescopes were collimated to accept coincidences with opening angles ranging from 15° to 25° and out-of-plane angles in the range of $\pm 1.5^\circ$ (Only one-dimensional position information was supplied by the telescopes.)

From the precisely measured kinetic energies (E_1 and E_2) of the two detected particles ($\delta E = \pm 0.25$ MeV at $E(^{12}\text{C}) = 178$ MeV) and their emission angles ($\delta\theta = \pm 0.15^\circ$), each event was reconstructed by using three-body kinematics. The spectrum of the total kinetic energy,

$E_{\text{tot}}=E_1+E_2+E_3$, is shown Fig. 1. (E_3 is the kinetic energy of the unobserved particle.) The spectrum of E_{tot} shows a well resolved peak, which corresponds to three ^{12}C nuclei in their ground states ($Q_{\text{ggg}}=-13.93$ MeV). The next peak at lower E_{tot} corresponds to one of the three ^{12}C nuclei being in the first excited state (4.44 MeV). The remaining peak corresponds to either two of the three ^{12}C nuclei in their 2^+ , 4.44 MeV state or the ^{12}C -target nucleus in the 3^- , 9.64 MeV state.

Events in the ground-state peak at Q_{ggg} may be interpreted as resulting from sequential breakup of ^{24}Mg following inelastic scattering:



Information on the excited states in ^{24}Mg that decay into $^{12}\text{C} + ^{12}\text{C}$ can be obtained from the spectrum of the relative energy, E_{rel} , of the two detected ^{12}C nuclei. The spectrum of the excitation energy in ^{24}Mg , $E^*=E_{\text{rel}}+13.93$ MeV, is presented in Fig. 2a. The experimental energy resolution in this spectrum was about 400 keV. This was due mostly to our limited accuracy in the determination of the angle between the momentum vectors of the two ^{12}C nuclei.

The efficiency for detecting $^{12}\text{C} + ^{12}\text{C}$ coincidence events was determined by a Monte Carlo simulation of the sequential-decay reaction (1). Fig. 2b shows the efficiency curve obtained with the assumptions that (i) the angular distribution of the primary $^{24}\text{Mg}^*$ nuclei is the same as for the bound ^{24}Mg ions observed inclusively in the equivalent

range of Q-values, and (ii) that the decay in the c.m. frame of ^{24}Mg is isotropic. As seen from Fig. 2b, there was a detection threshold at $E^* \approx 20$ MeV, caused by the finite minimum opening angle. The excitation energy spectrum of Fig. 2a, corrected for the detection efficiency, is shown in Fig. 2c. The spectrum shows pronounced structure with peaks at $E^* = 21.9, 23.6$ and 24.8 MeV. The first peak coincides with the 2^+ resonance at $E^* = 21.95$ MeV observed^{3,4} in the radiative-capture reaction $^{12}\text{C}(^{12}\text{C}, \gamma_0)^{24}\text{Mg}_{g.s.}$. (Fig. 2d shows the results of Ref.4, for comparison.) Two other peaks at $E^* = 23.6$ and 24.8 MeV were not seen in either the radiative-capture or electrofission reactions.

In order to determine the spins of the observed resonances, we have analyzed the angular distributions of the respective $^{12}\text{C} + ^{12}\text{C}$ events in the c.m. frame of the moving $^{24}\text{Mg}^*$ nucleus. These angular distributions are shown in Fig. 3. Since all the nuclei in the initial and final state of the reaction (1) have $J^\pi = 0^+$, the angular distributions are expected to be proportional to $[P_J(\cos\psi)]^2$, where J is the spin of the decaying $^{24}\text{Mg}^*$ nucleus, and ψ is the decay angle in the c.m. frame of $^{24}\text{Mg}^*$ (measured with respect to the momentum vector of the $^{24}\text{Mg}^*$ nucleus).

Experimental angular distributions for the three peaks of interest (at $E^* = 21.9, 23.6$ and 24.8 MeV) are shown in the left-hand side of Fig. 3. These distributions have been corrected for the ψ -dependence of the detection efficiency as deduced from the Monte Carlo calculations. The efficiency-corrected distributions are shown

on the right-hand side of Fig. 3.

The angular distribution for the peak at $E^*=21.9$ MeV exhibits a clear $[P_2(\cos\psi)]^2$ dependence. Therefore this peak can be identified with the strong, nonstatistical resonance observed in the radiative-capture reaction⁴ at $E^*=21.95$ MeV, also assigned as $J^\pi=2^+$.

A least-squares analysis of the distributions for the $E^*=23.6$ and 24.8 MeV peaks suggests a $J^\pi=0^+$ assignment for both these resonances, although a $J^\pi=2^+$ assignment for the former peak cannot be ruled out. The confidence levels of the $J=0$ fits are 0.7 and 0.2, respectively, while the corresponding values for $J=2$ fits are considerably smaller, 0.09 and 0.0001, respectively. Attempts to assume still higher spins (up to $J=10$) lead to much worse agreement with the data.

An important question is to what extent the observed resonances might be related to purely statistical decay from the continuum of excited states in ^{24}Mg . An answer on the basis of absolute cross sections cannot be given because the cross section of the primary inelastic scattering leading to these high excitations in ^{24}Mg is not known. There are, however, several arguments suggesting a non-statistical nature of the resonances: (i) One of the resonances that was also observed in the radiative-capture reaction (2^+ , $E^*=21.95$ MeV) was proved⁴ to be populated well above statistical expectation. See also Ref.7; (ii) The reaction (1) is observed only in a very limited range of excitation energies ($E^* < 26$ MeV). At somewhat higher energies ($E^* \approx 30$ MeV) the reaction cross section drops down by at

least two orders of magnitude. It is unlikely that the primary cross section for inelastic scattering drops so dramatically. (Hauser-Feshbach calculations⁸ show that the probability for statistical decay of ^{24}Mg to $^{12}\text{C}_{\text{g.s.}} + ^{12}\text{C}_{\text{g.s.}}$ is almost constant in the whole region of excitation energy from 22 to 30 MeV); (iii) Levels of higher spins ($J=4$ and $J=6$) should be excited together with $J=0$ and $J=2$ in the primary inelastic scattering leading to the excitation of ^{24}Mg of about 25 MeV. Subsequently they would decay statistically, but only $J=0$ and $J=2$ spins are observed; (iv) The relatively small "background" between the observed resonances can be viewed as an upper limit on the statistical-decay yield. Actually, the same can be stated about the region of higher excitation energies, $E^* \approx 30$ MeV, as discussed above.

In summary, we have observed three resonances in the spectrum of ^{24}Mg that decay into two ground-state ^{12}C nuclei following the inelastic-scattering reaction $^{12}\text{C}(^{24}\text{Mg}, ^{24}\text{Mg}^*)^{12}\text{C}_{\text{g.s.}}$. There are strong indications for a non-statistical nature of these resonances. From a study of angular correlations of ^{12}C - ^{12}C coincidences, the spins of the resonances have been determined. In contrast to the molecular resonances in the $^{12}\text{C} + ^{12}\text{C}$ excitation functions (which are predominantly $J^\pi = 4^+, 6^+$ and 8^+ in the region of excitation energy from 21 to 25 MeV⁹), we observed only 0^+ and 2^+ resonances.

This is remarkable because higher spins could have been as easily excited in the primary inelastic-scattering reaction. It seems that in both inelastic hadron scattering and electromagnetic reactions³⁻⁵, a specific group of low-spin states in ^{24}Mg of

considerable $^{12}\text{C} + ^{12}\text{C}$ parentage is excited. There has been speculation¹⁰ that excitations of the giant quadrupole resonance (GQR) may be related to the observed $^{12}\text{C} + ^{12}\text{C}$ decay of the 2^+ resonances. However, the GQR strength in ^{24}Mg is fragmented into a number of states at rather low excitation energies in the range from about 10 to 20 MeV.¹¹ Consequently, only states belonging to the high-energy tail of GQR in ^{24}Mg may decay into $^{12}\text{C} + ^{12}\text{C}$. A coupling of the 0^+ resonance(s) observed in this work to the giant monopole resonance seems unlikely. An interesting open question is whether these 0^+ resonance(s) might be interpreted as a kind of β -vibration.

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References

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Mexico 01000, D.F. Mexico.
- 1) D.A. Bromley, J.A. Kuehner and E. Almqvist, Phys. Rev. Lett.
4, 365 (1960)

- 2) E. Almqvist, D.A. Bromley and J.A. Kuehner, Phys. Rev. Lett. 4, 515 (1960)
- 3) A.M. Sandorfi and A.M. Nathan, Phys. Rev. Lett. 40, 1252 (1978)
- 4) A.M. Nathan, A.M. Sandorfi and T.J. Bowles, Phys. Rev. C24, 932 (1981)
- 5) A.M. Sandorfi, L.R. Kilius, H.W. Lee and A.E. Litherland, Phys. Rev. Lett. 40, 1248 (1978)
- 6) J. Wilczynski, K. van der Borg, H.T. Fortune, J. van Popta, R.H. Siemssen, K. Siwek-Wilczynska, S.Y. van der Werf and A. van der Woude, Nucl. Phys. 334, 317 (1980)
- 7) An additional indication of the nonstatistical behavior is the observation of the 21.9 MeV state in a similar experiment at 7.5 MeV/nucleon performed at Daresbury by B.R. Fulton et al., Proc. Symposium at Argonne National Lab., March 1986, and private communication.
- 8) R.G. Stokstad, WNSL Report No. 52 , Yale University, 1972 (unpublished)
- 9) K.A. Erb and D.A. Bromley, Treatise on Heavy-Ion Science, ed. D.A. Bromley, Plenum Press, New York, 1985, Vol.3, p.3
- 10) R.H. Lemmer and C. Toepffer, Phys. Rev. Lett. 44, 26 (1980)
- 11) F.E. Bertrand, K. van der Borg, A.G. Drentje, M.N. Harakeh, J. van der Plicht and A. van der Woude, Phys. Rev. Lett. 40, 635 (1978)

Figure captions

Fig. 1

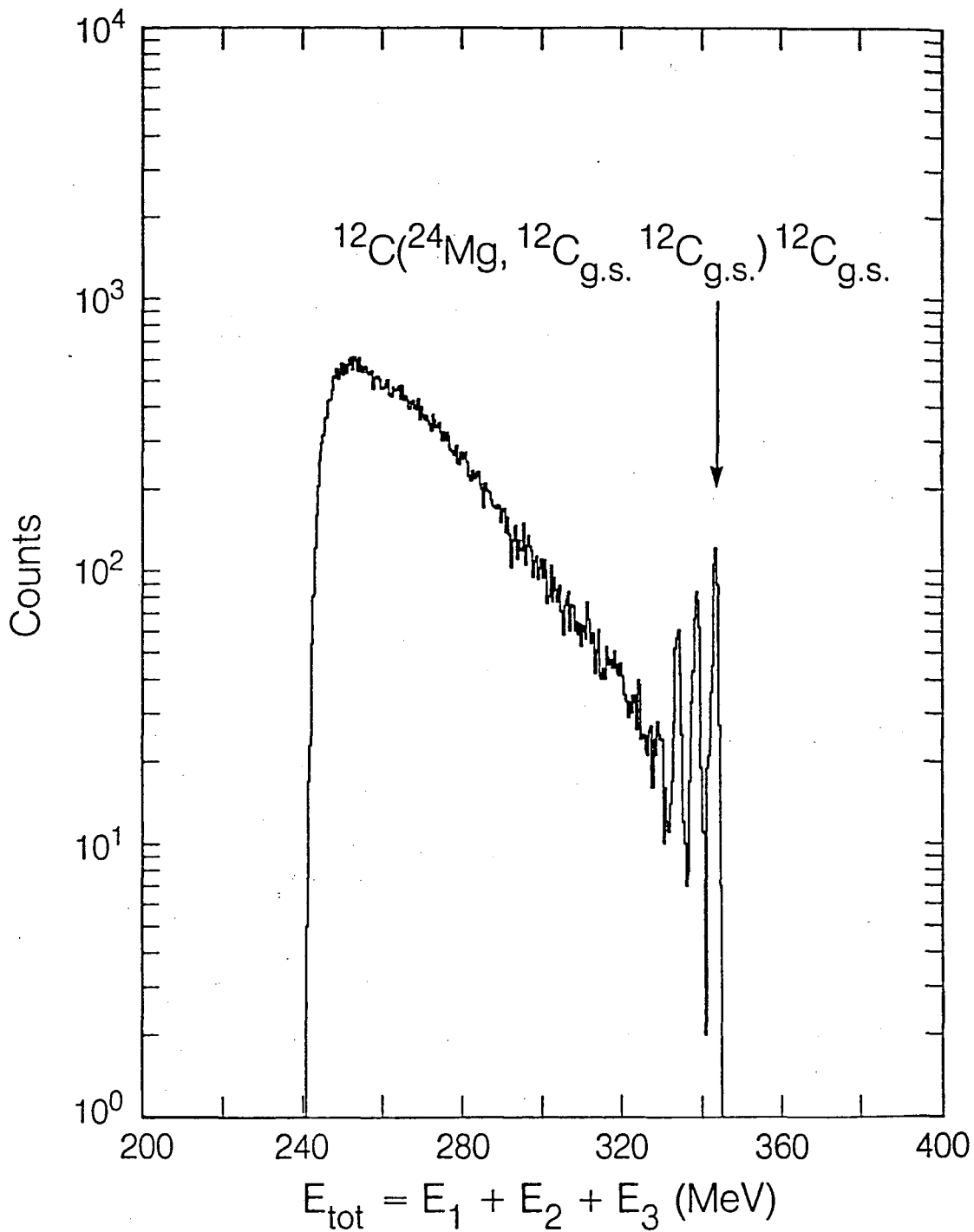
Total-energy spectrum of the $^{12}\text{C}(^{24}\text{Mg}, ^{12}\text{C}^{12}\text{C})^{12}\text{C}$ reaction at $E(^{24}\text{Mg}) = 357$ MeV.

Fig. 2

(a) Spectrum of the $^{12}\text{C}(^{24}\text{Mg}, ^{12}\text{C}_{\text{g.s.}})^{12}\text{C}_{\text{g.s.}}$ reaction as a function of the excitation energy of ^{24}Mg ; (b) Detection efficiency, ϵ , calculated with the Monte Carlo method; (c) Spectrum of Fig. 2a corrected for the energy dependence of the efficiency, ϵ ; (d) Spectrum of the radiative-capture reaction $^{12}\text{C}(^{12}\text{C}, \gamma_0)^{24}\text{Mg}_{\text{g.s.}}$, redrawn from Fig. 7a of Ref.4.

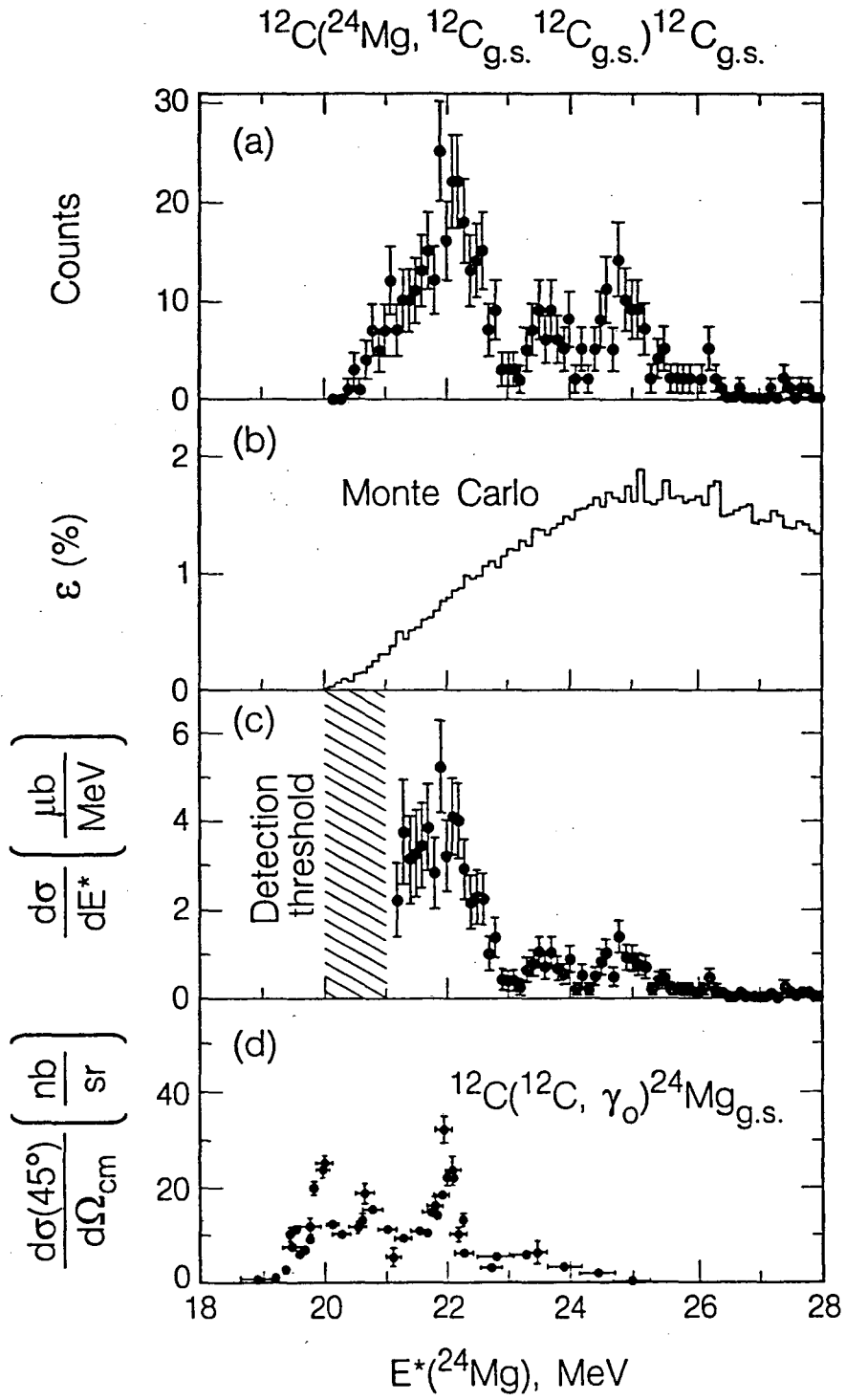
Fig. 3

Angular distributions of the $^{12}\text{C} + ^{12}\text{C}$ decay in the rest frame of $^{24}\text{Mg}^*$ for the resonances at $E^* = 21.9, 23.6$ and 24.8 MeV (left). On the right-hand side, the angular distributions are corrected for the dependence of the detection efficiency (calculated with the Monte Carlo method) on the decay angle ψ . The least-squares fits for a $[P_J(\cos\psi)]^2$ dependence are shown.



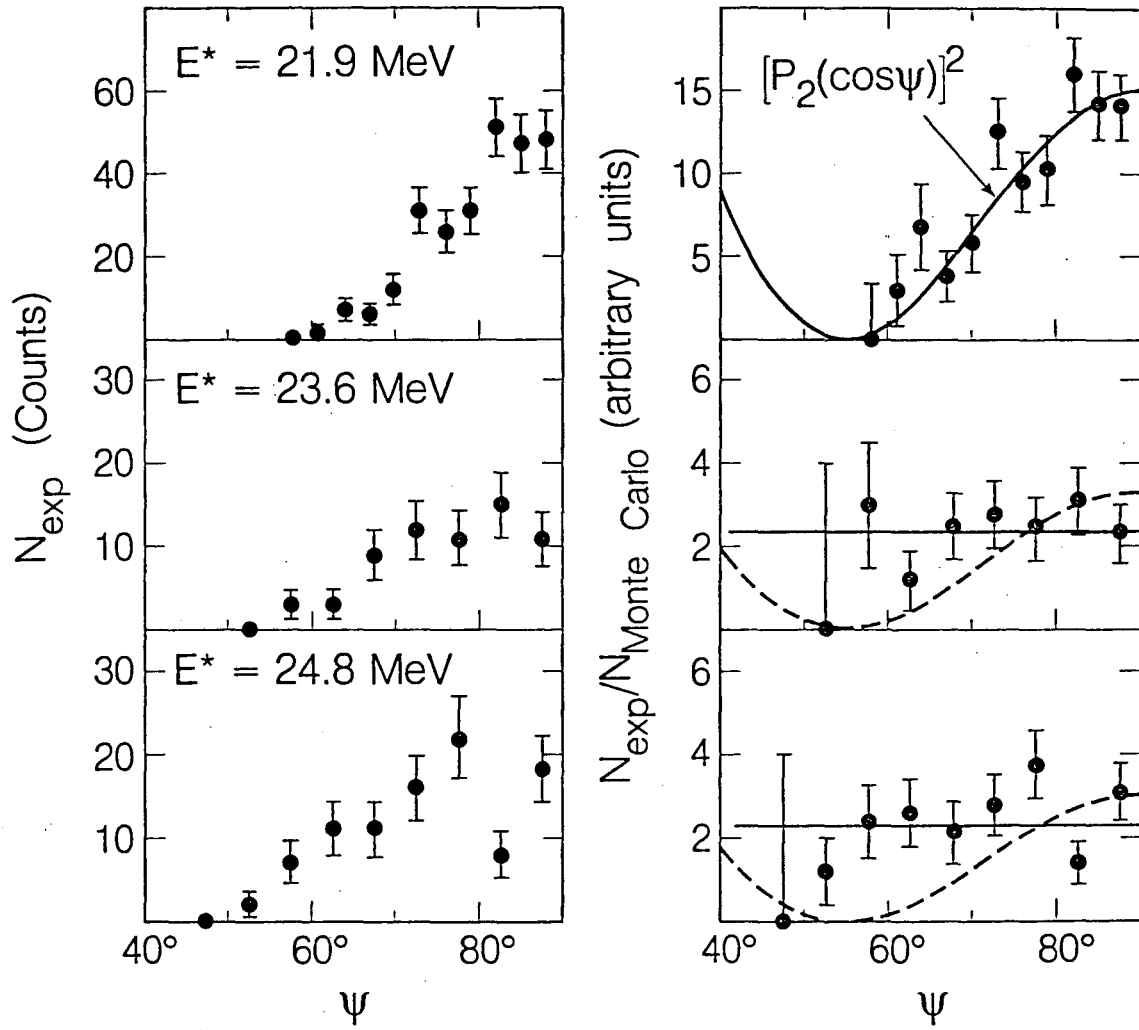
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Fig. 1



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Fig. 2



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Fig. 3

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