ISTITUTO NAZIONALE DI FISICA NUCLEARE
Laboratori Nazionali di Frascati

LNF-84/71

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Estratto da:
Lett. Nuovo Cimento 40, 401 (1984)

Servizio Documentazione
dei Laboratori Nazionali di Frascati
Cas. Postale 13 - Frascati (Roma)

Multipole Mixture Contribution to the ^{28}Si Giant-Resonance Excitation.

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(ricevuto l'11 Aprile 1984)

PACS. 21.10. – General and average properties of nuclei; properties of nuclear energy levels.

In the last ten years a renewed interest has been devoted to studies of giant multipole resonances (GMR), pointing out their fragmentation into intermediate-width structures, with a superimposed fine structure a few tens keV wide. In order to obtain definite information both on the particle-hole structures of the GMR states and on the reaction mechanism, an accurate evaluation of the Legendre expansion coefficients for the angular distribution of the particles emitted in the GMR de-excitation is needed. In particular, an exact knowledge of their multipole contributions to the radiative strengths is required.

The new monochromatic and almost completely polarized γ-ray beam of the LADON (1) facility at the Laboratori Nazionali di Frascati allows us now to perform

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an extensive experimental study of the GMR. A particular attention will be given to processes for which the primary beam polarization can be a fundamental tool to discriminate contributions of different multipoles to the giant-resonance excitations. In this paper we present some results, obtained using this beam, on the $^{28}Si(\gamma, p)$ and $^{28}Si(\gamma, \alpha)$ reactions in a photon energy range between $50A^{-\frac{1}{3}}$ and $70A^{-\frac{1}{3}}$ MeV, *i.e.* $17.5 \leqslant E_\gamma \leqslant 22.5$ MeV, in which a large part of the giant-dipole-resonance (GDR) strength is distributed. In this energy region $E1$ contributions are expected to dominate, nevertheless possible $M1$ and $E2$ excitations may also occur.

In light nuclei (²) the $E2$ resonance falls mainly in or above the $E1$ resonance, with its strength spread downwards over a wide energy region. The $M1$ resonance has not a well-defined location, but it is expected to be on the low-energy side of the $E1$ GDR. As the latter resonances are very weak with respect to the $E1$ resonance, it is difficult to evidentiate their presence by looking only at the angular distribution of the particles emitted in the de-excitation of the intermediate system. However, additional information can be obtained using polarized projectiles or measuring the polarization of the reaction products. In the case of the ^{28}Si the behaviour of the GDR has been already studied by means of (p, γ) reactions (³) and, recently, by (γ, p) reactions based on the photon tagging technique (⁴).

The photon beam, obtained by Compton scattering of laser light against the high-energy electrons, circulating in the Adone storage ring, has an intensity between 10^4 and 10^6 γs^{-1}, linear polarization $p \approx 1$, and an energy resolution of about 3%. The beam profile, shown in fig. 1, was continuously monitored by a magnet pair spectrometer. A standard solid-state detector, 550 μm thick, was employed as a target. Moreover, because the extremely low cross-section of the photoproduction reactions and the modest intensity of the incident photon beam, a large-active-area (750 mm^2)

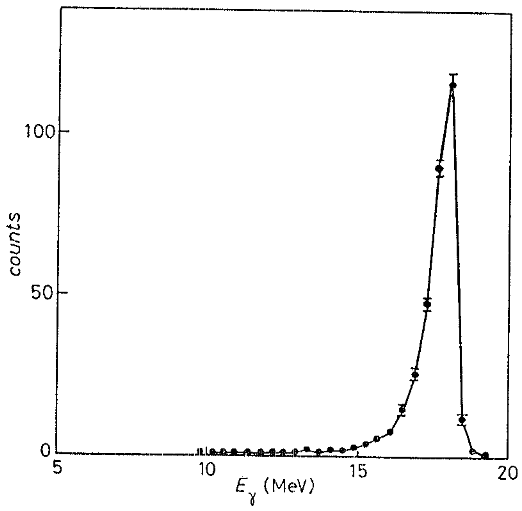

Fig. 1. – γ-beam profile corresponding to the spectrum shown in fig. 2.

(²) S. S. HANNA: in *Photonuclear Reactions I*, in *Lecture Notes in Physics*, Vol. **61** (Springer Verlag, New York, N. Y., 1977), p. 277.
(³) R. G. ALLAS, S. S. HANNA, L. MEYER-SCHÜTZMEISTER, P. P. SINGH and R. E. SEGEL: *Nucl. Phys.*, **53**, 122 (1964).
(⁴) R. L. GULBRANSON, L. S. CARDMAN, A. DORON, A. ERELL, K. R. LINDGREN and A. I. YAVIN: *Phys. Rev. C*, **27**, 470 (1983).

SiLi detector was used to improve statistics. The overall resolution on the explored energy range, mainly determined by the primary photon beam, washed out the fine structure of the GDR, of no interest in this work. By coincidence techniques between the target and the movable detector, a drastic reduction of the electron background was obtained. A typical charged-particle spectrum taken at $E_\gamma = 8.110$ MeV is shown in fig. 2*a*); in fig. 2*b*) the same experimental data are given after exponential background subtraction. The energy resolution allows a good separation of proton groups corresponding to the low-lying levels in the residual nucleus ^{27}Al. Alpha-particles from the ^{28}Si(γ, α)^{24}Mg reaction may also be seen.

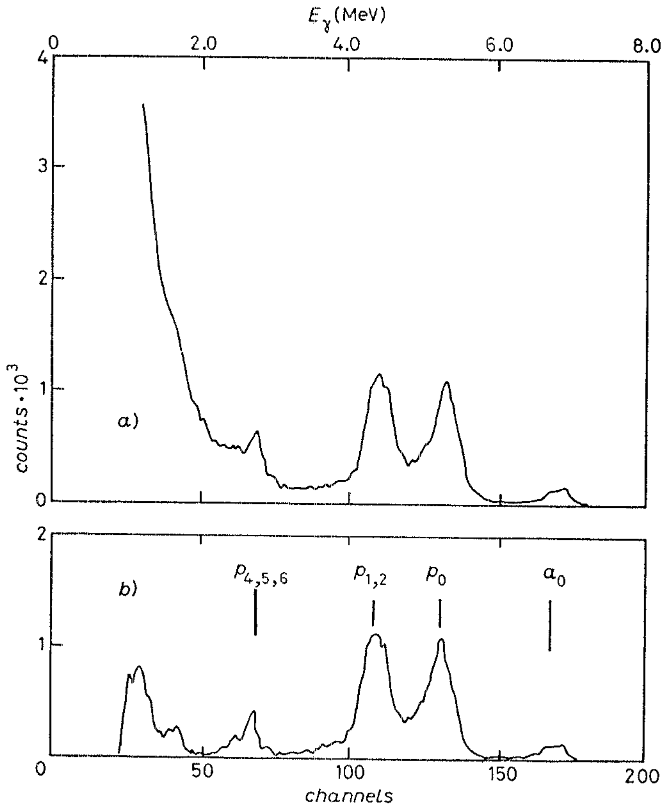

Fig. 2. – *a*) Charged-particle spectrum taken at $E_\gamma = 18.10$ MeV. *b*) The same spectrum after exponential background subtraction.

Angle-integrated proton and alpha-particles yields for the ^{28}Si(γ, p_0)^{27}Al, ^{28}Si(γ, p_{1+2})^{27}Al and ^{28}Si(γ, α_0)^{24}Mg reactions have been obtained by placing the movable detector directly on the incident beam. The experimental data, normalized to previous absolute measurements (3), are shown in fig. 3*a*), *b*), *c*). The gross structure of the giant-resonance fragmentation can be clearly seen.

Measurements of the proton angular distribution have been also performed for the ^{28}Si(γ, p)^{27}Al process to evidentiate a possible asymmetry around $\theta = 90°$, due to a mixture of different multipoles with the dominant $E1$ contribution, which is strictly symmetric around this angle. The movable detector was set at $\theta = 60°$ with the photon beam at a distance of 25 mm from the target. The solid angle subtended with respect

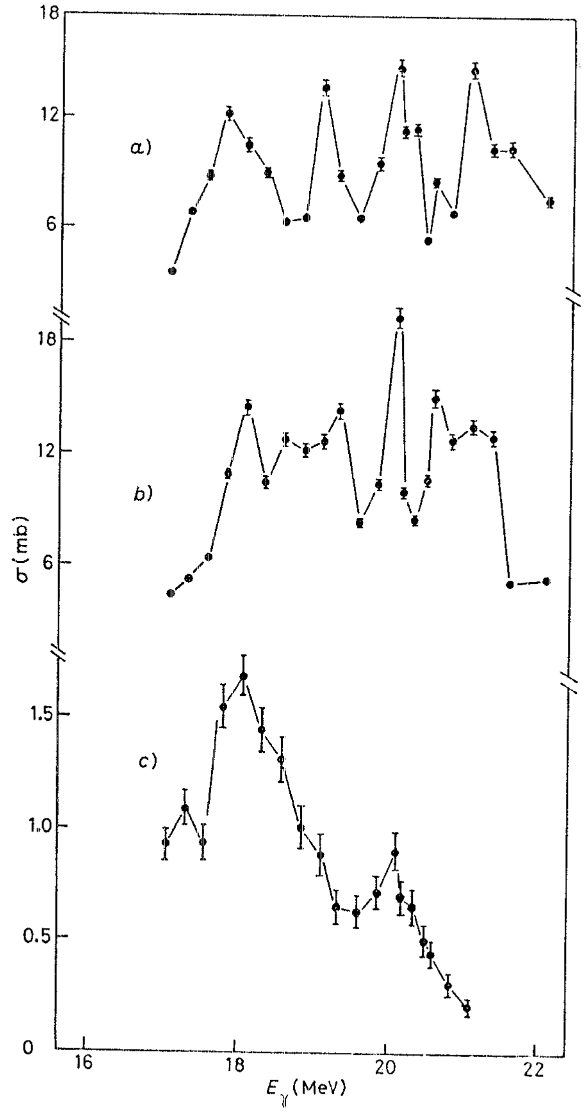

Fig. 3. – Partial cross-sections for the reactions: *a*) $^{28}Si(\gamma, p_0)^{27}Al$; *b*) $^{28}Si(\gamma, p_{1+2})^{27}Al$ and *c*) $^{28}Si(\gamma, \alpha_0)^{24}Mg$ as a function of photon energy.

to the centre of the target was $5 \cdot 10^{-2}$ sr. This set up allowed us to measure the differential cross-section integrated between $\theta = 30°$ and $90°$. Analogously, by rotating the target-detector system at $\theta = 120°$, the differential cross-section integrated between $\theta = 90°$ and $150°$ was determined. This procedure was repeated at photon energies $E_\gamma = 17.83$, 19.12, 20.12, 21.10 MeV, corresponding to the main structures shown in fig. 3*a*). Both parallel ($\varphi = 0°$) and orthogonal ($\varphi = 90°$) photon polarizations were used. Measurements were monitored by a lead-glass detector placed on the photon beam after the scattering chamber and also by means of the p_0 peak in the proton spectrum collected by the target detector during each run.

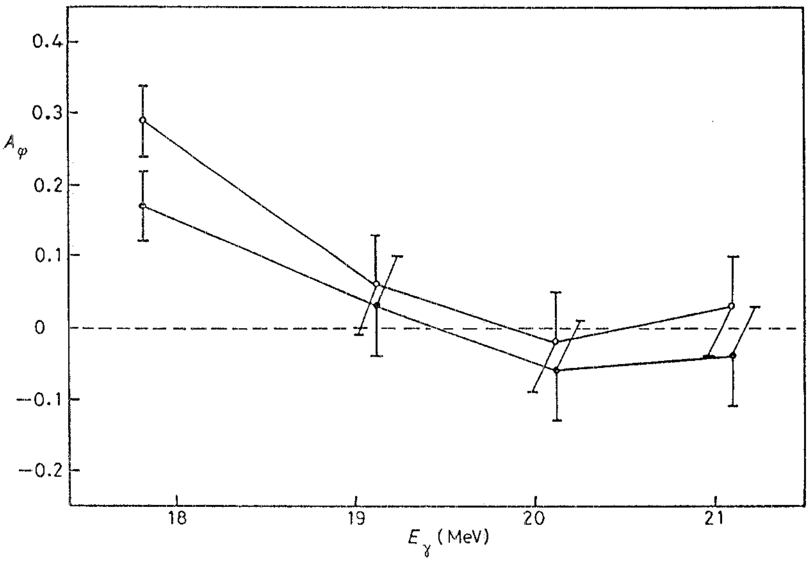

Fig. 4. – Angular asymmetry at the energies corresponding to the main structures of ^{28}Si giant resonance for parallel (full circles) and orthogonal (open circles) gamma polarization.

Figure 4 shows the angular asymmetry

$$A_\varphi = \frac{\bar{\sigma}(60°) - \bar{\sigma}(120°)}{\bar{\sigma}(60°) + \bar{\sigma}(120°)}$$

vs. E_γ. Open circles refer to orthogonal polarization and full circles to parallel polarization. The angular distribution is almost symmetric around $\theta = 90°$ for the resonances at $E_\gamma = 19.12$, 20.12, 21.10 MeV, while it is clearly asymmetric for the $E_\gamma = 17.83$ MeV resonance. This result cannot be accounted for by absorption of a pure electric dipole radiation.

Any slight asymmetry of the three highest-energy structures could be ascribed to the presence of a small $E2$ strength. The asymmetry increase in correspondence of the lowest-energy structure would not be caused by the $E2$ presence, as the $E2$ strength gets lower with decreasing excitation energy. Such a sharp variation in the angular distribution asymmetry could be due to a mixture of $E1$ and $M1$ transitions. In fact, at this energy, the $M1$ resonance can also be excited and it is possible to determine the relative contribution of the $E1$ and $M1$ multipoles by measuring the analysing power at $\theta = 90°$.

The angular distribution of protons emitted after the absorption of fully linearly polarized photons is (^{5})

$$(1) \qquad Y(\theta, \varphi) = \sum_{\nu L L'} [A_\nu(L, L') P_\nu(\cos\theta) \pm B_\nu(L, L') \cos 2\varphi P_\nu^{(2)}(\cos\theta)] \,,$$

where ν satisfies the triangle rule with L and L', the interfering multipoles. The plus sign is for electric and the minus sign for magnetic multipoles. Moreover, $B_\nu(L, L') =$

(^{5}) G. R. Satchler: *Proc. Phys. Soc. London, Ser. A*, **68**, 1041 (1955).

$= A_\nu(L, L')\,\chi_\nu(L, L')$, where $\chi_\nu(L, L')$ is a well-known geometrical factor. For $E1$ and $M1$ mixtures the analysing power at $\theta = 90°$ is

$$I\left(\theta = \frac{\pi}{2}\right) = \frac{Y(\pi/2, \pi/2) - Y(\pi/2, 0)}{Y(\pi/2, \pi/2) + Y(\pi/2, 0)} = \frac{3(A_2^{E1} - A_2^{M1})}{2A_0 - (A_2^{E1} + A_2^{M1})} \tag{2}$$

with $A_2^{E1} = A_2(E1, E1)$, $A_2^{M1} = A_2(M1, M1)$ and $A_0 = A_0(E1, E1) + A_0(M1, M1)$. Thus $I(\theta = \pi/2)$ is nonzero only if the $E1$ contribution is different from the $M1$ one.

In order to evaluate $I(\theta = \pi/2)$, we performed measurements to obtain $Y(\pi/2, 0)$ and $Y(\pi/2, \pi/2)$ in a series of alternating runs, rotating the polarization plane of the incident photons. The movable detector was placed at a distance of 50 mm from the target corresponding to a solid angle of 0.3 sr. The result was $I(\theta = \pi/2) = 0.14 \pm 0.03$.

The A_0 coefficient in expression (2) was determined by the relation $\sigma = 4\pi A_0$. A value of 0.99 ± 0.21 for the ratio A_2^{M1}/A_2^{E1} was obtained. In spite of the large error this result suggests that the asymmetry in the angular distribution of the protons emitted at $E_\gamma = 17.83$ MeV could be originated by an $E1$-$M1$ mixture in which the two parities give nearly the same contribution.

Further measurements will be performed in order to determine the absolute strength and the multipole mixtures for the main structures of the ^{28}Si giant resonance.

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The continuous co-operation and support of the ADONE technical staff is gratefully acknowledged.