Search for analogs of isovector resonances excited by the (^{3}He, t) reaction

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For the previously reported Gamow-Teller transition centered in ^{90}Nb at 8.4 MeV, two components are observed in the ^{90}Zr (^{3}He, t) ^{90}Nb reaction at 80 MeV. The first one of $M1$ type is centered at 7.2 MeV, the other one of unknown multipolarity at 9.7 MeV.

[NUCLEAR REACTIONS ^{90}Zr(^{3}He, t), E = 80 MeV; measured $\sigma(\theta)$ IAS and Gamow-Teller states.]

Recently a Gamow-Teller transition in the ^{90}Zr – (p, n)^{90}Nb reaction performed at 35 and 45 MeV, leading to the 8.4 MeV level in ^{90}Nb, has been reported by Doering *et al.*[1] The same transition has also been seen, in a preliminary experiment, using the (^{3}He, t) reaction[2] at 80 MeV, and at Julich in (^{3}He, t) at 130 MeV.[3] Similar broad peaks were observed by Doering for the (p, n) reaction on ^{48}Ca, ^{120}Sn, and ^{208}Pb.[1]

We have studied the (^{3}He, t) reaction on a target of ^{90}Zr using the 80 MeV beam of the ISN cyclotron at Grenoble. The tritons were analyzed using a magnetic spectrometer and detected with a multiwire proportional chamber (MWPC), triggered by two plastic scintillators. The angular range studied was from 3° to 20°. At small angles the ^{3}He$^+$ were eliminated by dE/dx discrimination using conventional electronics. The isotopically separated target was 6 mg cm^{-2} thick. The energy spread of the incident beam was 350 keV, which added to the contribution due to the target thickness leads to a total resolution [full width at half maximum (FWHM)] of about 450 keV. The energy scale for the tritons was calibrated using known levels observed in the ^{12}C(^{3}He, t) ^{12}N and ^{13}C(^{3}He, t)-^{13}N reactions. At triton energies below 55 MeV, the MWPC was saturated by deuterons from the (^{3}He, d) reaction, so no results are given for excitation energies higher than 20 MeV.

Two typical spectra are given in Fig. 1. Besides some clusters of peaks due to low energy levels at 0.35 and 0.85 MeV, the peaks for the 2.12 MeV (1^+) and the isobaric analog state (IAS) at 5.18 MeV are clearly seen. In the 8 MeV region, we observe the broad structure previously reported, but now it appears to be split into two components centered at 7.2 and 9.7 MeV, with FWHM of 2.5 and 2 MeV, respectively.

As it can be seen in Fig. 2, the ratio of the differential cross sections of the 7.2 MeV bump to the 2.12 MeV level is constant (total $\chi^2 = 0.42$). As the 2.12 MeV level is well known to be a 1^+ state, this strongly suggests a 1^+ nature for the 7.2 MeV resonance. A similar result has already been given in Ref. 1 for the total bump. However, for the 9.7 MeV bump, the same kind of ratio clearly indicates a different angular distribution ($\chi^2 = 9.2$). The χ^2 values in Fig. 2 account for the uncertainties on the background substraction under the different peaks.

The angular distribution for the IAS (see Fig. 3) was compared to distorted-wave Born approximation (DWBA) calculations using a macroscopic form factor (code DWUCK[4])

$$\Delta v = v_0 + 4v_1 \frac{\vec{t}\cdot\vec{T}}{A} .$$

A Woods-Saxon potential was used to generate the form factor. The parameters were varied to obtain a fit to the experimental angular distribution. The final values obtained are

$$\mathrm{Re}(v_1) = 14.6\ \mathrm{MeV}, \quad \mathrm{Im}(v_1) = 7.3\ \mathrm{MeV},$$

$$R_R = 1.32\ \mathrm{fm}, \quad R_i = 1.40\ \mathrm{fm},$$

$$a_R = 0.72\ \mathrm{fm}, \quad a_i = 0.88\ \mathrm{fm}.$$

These values are in agreement with the results of Ref. 5.

Microscopic DWBA calculations [code DWBA 70 (Ref. 6)] for the ($\pi g_{9/2} - \nu g_{9/2}^{-1}$) configuration coupled to 0^+ were also performed. The nucleon-^{3}He force of Ref. 7 was used. An imaginary part, half the strength of the real part, as suggested by the macroscopic calculations, has been added to the N-^{3}He potential in a second trial. In all cases,

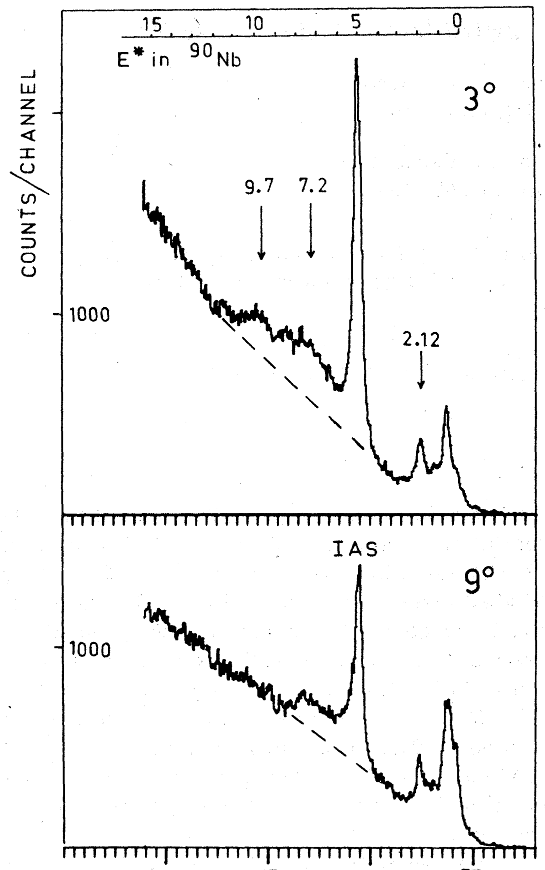

FIG. 1. Triton spectrum for ^{90}Zr(^{3}He, t)^{90}Nb at $E_{^3\mathrm{He}} = 80$ MeV for $\theta = 3°$ and 9°.

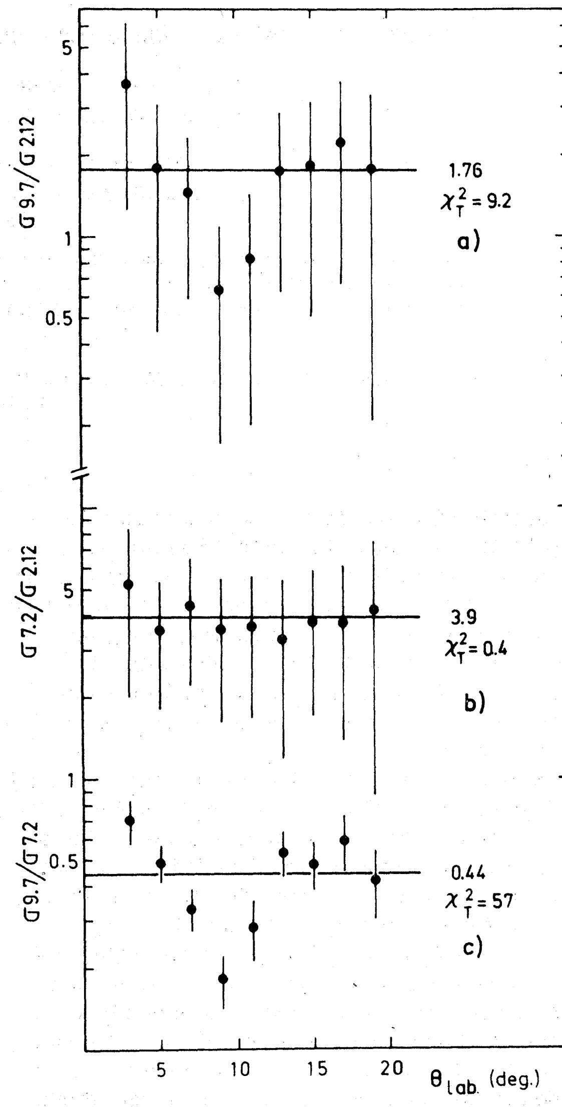

FIG. 2. Cross section ratios versus θ lab. For (a) and (b) the error bars account for the background uncertainty under the peaks. For (c) this error is omitted.

the agreement with the experiment is quite good.

The same kind of calculation was performed for the states at 2.12 and 7.2 MeV using the first derivative of Δv for the macroscopic form factor. No agreement in shape with the angular distributions was obtained, however, even after changing the ratio $\mathrm{Im}(v_1)/\mathrm{Re}(v_1)$.

In the microscopic calculations the $(\pi g_{9/2} - \nu g_{9/2}^{-1})$ configuration coupled to 1^+ $\Delta T = 1$ is used for the 2.12 MeV level, and the $(\pi g_{7/2} - \nu g_{9/2}^{-1})$ configuration coupled to 1^+ $\Delta T = 1$ for the 7.2 MeV resonance.

The shapes of the angular distributions are identical to those obtained in the macroscopic calculations. At small angles the experimental angular distribution is dominated by the $L = J + 1$ term, whereas the theoretical curve is much closer to the $L = J - 1$ distribution. This preference for the higher L value for (^{3}He, t) reactions has already been pointed out.[8]

Experimentally the 2.12 MeV cross section is lower than the 7.2 MeV one by a factor of about 4, in agreement with the (p, n) results.[1] This factor cannot be obtained by the microscopic calculations: the predicted magnitudes are nearly the same for the two levels. Changing the radial part of the configuration wave functions, from harmonic oscillator to Woods-Saxon, does not yield any difference in the cross sections.

Two step mechanisms are also important in (^{3}He, t) reactions but one would not expect them to lead to very different cross sections for the 2.12 and 7.2 MeV states. As the DWBA calculations do not fit the well-known 1^+ state at 2.12 MeV, the evidence for a 1^+ assignment for the state at 7.2

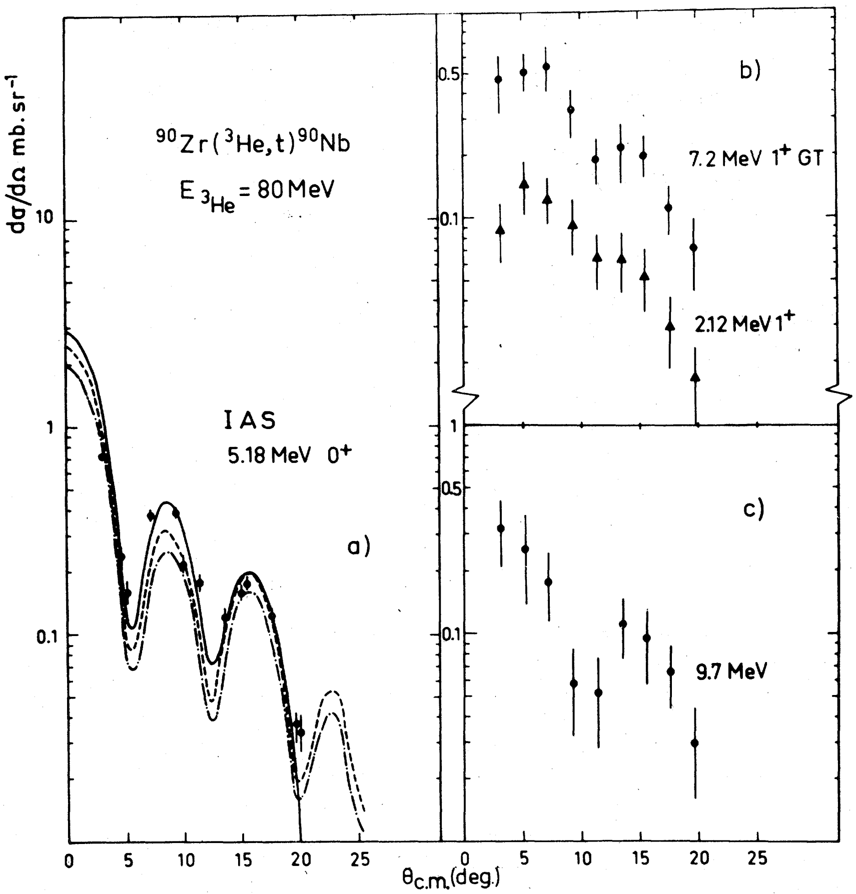

FIG. 3. (a) Experimental cross section for the IAS peak compared to DWBA calculations: —— Macroscopic complex form factor, ----- Microscopic Real form factor, -·-· Microscopic complex form factor; (b) and (c), experimental cross section for the 7.2, 2.12, and 9.7 MeV peaks. All error bars account for background uncertainty.

MeV comes only from the similarity of the two experimental angular distributions. For the 9.7 MeV peak there is no similarity with angular distributions of low-lying levels, so no assignment could be given.

The appreciable amount of *M*1 strength in the 8 MeV region obtained in charge-exchange reaction is in contradiction with electron scattering experiments on ^{90}Zr (Ref. 9) where only weakly excited *M*1 states have been reported at excitation energies of 8.24 and 9.37 MeV, whereas many *M*2 states lie in the 8 to 10 MeV region.

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