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Comment on a Possible $J^\pi = 0^+$, $T = 2$ Resonance in Be^9(He^3, $\gamma\gamma$)C^{12}†

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The reaction Be^9(He^3, $\gamma\gamma$)C^{12} has been reexamined near a previously reported resonance at $E_{\mathrm{He}^3} = 1.739 \pm 0.007$ MeV, which was ascribed to the lowest $T = 2$ state in C^{12}. No resonance was observed and an upper limit $\Gamma_{\mathrm{He}^3}\Gamma_\gamma/\Gamma < 1.5$ meV is established for the $T = 2$ resonance strength (assuming $\Gamma \le 1.5$ keV) which is $\frac{1}{5}$ of the previously reported strength.

Several unsuccessful efforts have been made in recent years to observe the lowest $T = 2$ level in C^{12} as an isospin-forbidden resonance in proton[1] and deuteron[2]-induced reactions. This level is known to have an excitation energy $E_x = 27.595 \pm 0.020$ MeV from a C^{14}(p, t)C^{12} measurement.[3,4] Recently Black, Caelli, and Watson[2] reported the observation of a strong candidate for this level as a resonance in the reaction Be^9(He^3, $\gamma\gamma$)C^{12} at an excitation energy of 27.585 ± 0.005 MeV corresponding to a bombarding energy of 1.739 ± 0.007 MeV. An upper limit of $\Gamma < 1.5$ keV for the total width and a value for the capture strength of $\Gamma_{\mathrm{He}^3}\Gamma_\gamma/\Gamma = 8 \pm 5$ meV were given. We present the results of a reinvestigation of the same reaction in the region $E_{\mathrm{He}^3} = 1.721$ to 1.764 MeV, in which no resonance was observed.

In this experiment, thin metallic Be^9 targets evaporated on polished Au backings were bombarded with the He$^{3(+)}$ beam of the Brookhaven National Laboratory 3.5-MV Van de Graaff accelerator, and high-energy γ rays were detected in a 10×10-in. NaI(Tl) detector at 0°. The accelerator beam analyzing magnet was calibrated by use of the resonance Mg^{24}(α, γ)Si^{28} at $E_\alpha = 3.1998 \pm 0.0010$ MeV,[5] the C^{13}(p, γ)N^{14} resonance at $E_p = 1.7476 \pm 0.0009$ MeV,[6] and the Be^9(p, γ)B^{10} resonance at 1.0832 ± 0.0004 MeV.[7] The internal consistency of the various calibrations was equivalent to ±1 keV at $E_{\mathrm{He}^3} = 1.74$ MeV. To prevent energy shifts from target contamination, carbon buildup on the target surface was kept to a negligible level by the use of a liquid-nitrogen cold trap with a cold finger ~2 mm from the target. The thicknesses of the thin targets were measured in two steps: First, the thickness of a 33-μg/cm^2 Be^9 target was determined from the observed width of the narrow Be^9(p, γ)B^{10} resonance at $E_p = 1.083$ MeV; secondly, the thicknesses of the 1.3- and 3.2-μg/cm^2 targets were obtained from a comparison of relative yields of the reaction Be^9(d, p)Be^{10}. The thicknesses of the latter two targets correspond to energy losses of 1.7 and 4.1 keV, respectively, for the He^3 beam at 1.74 MeV.

The $J^{\pi}=0^{+}$, $T=2$ level in C^{12} is expected to undergo γ decay strongly to the $(1^{+}, 1)$ level at 15.1 MeV, which in turn decays predominantly to the ground state. Black, Caelli, and Watson[2] searched for resonances in the coincidence yield of two high-energy γ rays detected in two large NaI crystals placed 180° apart. The present experiment was designed to detect the γ-cascade coincidences as a summed peak at $E_{\gamma}=27.6$ MeV in a single 10 × 10-in. NaI detector placed with its front face from 6 to 10 mm from the target spot at $\theta=0°$. The crystal had a plastic anticoincidence shield for cosmic-ray rejection and lineshape improvement and was operated with antipileup electronics similar to previously described arrangements.[8] The sum-coincidence technique has the advantage of producing a high-energy signal which lies above the strong background below $E_{\gamma}\sim 20$ MeV. This signal has the same energy as the (nonresonant) background from direct radiative capture, $Be^9(He^3, \gamma_0)$ to the ground state of C^{12}, which served as a useful monitor during the experiment.

The high-energy portion of a typical run taken near 1.74 MeV is shown in Fig. 1. The 27.6-MeV ground-state transition is clearly resolved, and the transition to the 4.44-MeV state is apparent as a shoulder. The area of the ground-state peak was obtained using a background subtraction indicated by the dashed lines. γ-ray spectra were recorded with both thin targets for bombarding energies ranging more than 2 standard deviations above and below the reported resonance energy of 1.739 ± 0.007 MeV. The step size was 1.9 keV for the 4.1-keV target and 1.3 keV for the 1.7-keV target and runs were typically made for an accumulated charge of about 25 000 μC with a beam current of about 4 μA. The observed strength of the 27-MeV γ peak is plotted in Fig. 2 as a function of bombarding energy. The assigned errors contain statistical errors as well as relative uncertainties in the evaluation of the area. No resonance is apparent in either curve.

A comparison of this result with the published resonance strength requires knowledge of the detector efficiency ϵ, which enters quadratically in the present measurement. The efficiency ϵ contains solid angle, absorption, and electronic-acceptance-ratio[8] factors, and was determined experimentally by observing the yields of three known reactions which produce γ rays with energies comparable to those expected in the decay of the $T=2$ state. The reaction $C^{13}(p, \gamma_0)N^{14}$ was measured at the narrow resonance[6] at $E_x=9.17$ MeV, and the reaction[9] $B^{11}(p,\gamma)C^{12}$ was measured at $E_p=1.42$ MeV. Also, the present $Be^9(He^3, \gamma_0)C^{12}$ measurements were compared at $E_{He^3}=2.5$ MeV with absolute measurements made previously.[10] Care was taken in these comparisons to account properly for cascade-summing effects in the present measurements. These three measurements, which were internally consistent within ±5%,

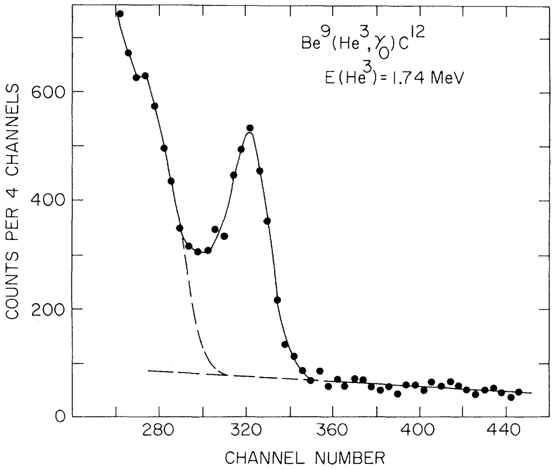

FIG. 1. High-energy portion of the γ spectrum from the reaction $Be^9(He^3, \gamma)C^{12}$ at $E_{He^3}=1.74$ MeV observed in the 10×10-in. NaI(Tl) crystal. The peak near channel 320, which has an energy of 27.6 MeV, contains the ground-state transition and possible contributions from summed cascades.

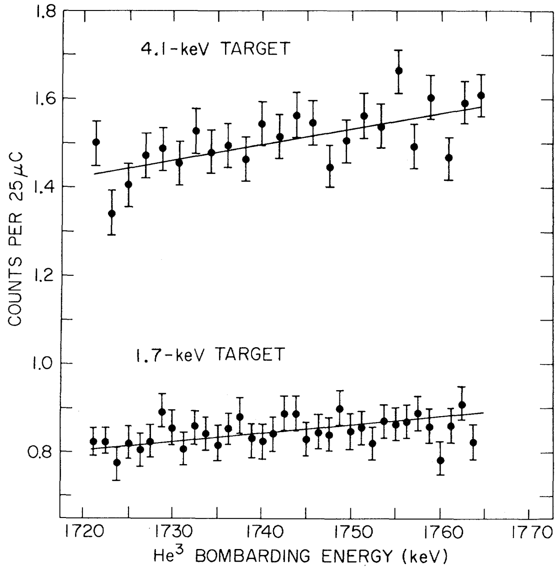

FIG. 2. Observed full-energy γ yield from the reaction $Be^9(He^3,\gamma)C^{12}$ in the vicinity of the $T=2$ state in C^{12} expected at $E_{He^3}=1739\pm 7$ keV. The upper curve was measured using a 4.1-keV target and a step size of 1.9 keV, and the lower curve with a 1.7-keV target and a step size of 1.3 keV. The yields do not scale according to the thickness, because of slightly different solid angles.

yielded a photopeak efficiency $\epsilon=0.214$ (±15%) at a detector distance of 6 mm, where the uncertainty is dominated by the absolute errors quoted for the calibration reactions. The same ϵ was used for both γ rays in the cascade, since the efficiency is only weakly energy-dependent.

The previously reported capture strength of $\Gamma_{\mathrm{He}^3}\Gamma_{\gamma}/\Gamma=8\pm5$ meV along with the $0^{+}\rightarrow1^{+}\rightarrow0^{+}$ angular correlation and the measured efficiency quoted above lead to a predicted yield of 0.95 ± 0.60 counts/25 μC for an infinitely thick target, which is an order of magnitude greater than the apparent fluctuations in the lower curve of Fig. 2. The present data for E_{He^3} between 1.721 and 1.764 MeV result in an upper limit of $\Gamma_{\mathrm{He}^3}\Gamma_{\gamma}/\Gamma<1.5$ meV corresponding to 2 standard deviations (95% confidence level), assuming $\Gamma\leq1.5$ keV as previously quoted.[2] For a less restrictive upper limit, $\Gamma\leq10$ keV, the upper limit on the capture strength becomes 13 meV. The radiative width Γ_{γ} of this level is expected to be strong, based on the shell model. If Γ_{γ} is equal to 1 Weisskopf unit (41 eV), then the present results yield $\Gamma_{\mathrm{He}^3}/\Gamma<3.6\times10^{-4}$ for $\Gamma\leq10$ keV. We note that these limits are dependent on the assumption of $J^{\pi}=0^{+}$ for the resonance, since they are dependent on the angular correlations of the two γ rays with each other and with the beam axis.

In summary, all attempts to detect the lowest $T=2$ level in C^{12} as an isospin-forbidden compound-nuclear resonance have failed. This is in contrast to the other known 0^{+}, $T=2$ states in light even-even self-conjugate nuclei, which all have an appreciable ground-state decay width in at least one of the energetically open (but isospin-forbidden) particle channels.

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