Energy distribution of deuterons from the breakup of ^3He nuclei by an α beam

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The energy distribution of deuterons from the reaction $^3He + \alpha \to d + p + \alpha$ at $E_\alpha = 26.3$ MeV has two broad peaks, which correspond to the ground and first excited states of the ^5Li nucleus. The following parameters were found for these states: $E_0 = 1.93 \pm 0.21$ MeV, $\Gamma_0 = 1.9 \pm 0.25$ MeV, and $E_1 = 4.74 \pm 0.11$ MeV, $\Gamma_1 = 1.64 \pm 0.25$ MeV (the positions and widths of the levels are given in the c.m. frame of the $^4He + p$ pair).

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Soon after the discovery of the ground and first excited states of the ^5Li nucleus as resonances in proton scattering by ^4He, indications of the existence of these unbound (nearly stationary) states of ^5Li, which are unstable with respect to decay accompanied by the emission of a proton and an α particle, were found in several nuclear reactions in which the nucleus ^5Li is produced in the final state (see the bibliography in Ref. 1). In contrast with the ground state, $^5Li_0$, for which the data on the positions and widths found from the different reactions are in approximate agreement, the excitation energies reported for the first excited state range from 2.3 ± 0.5 to 10.2 ± 0.28 MeV, and the half-widths range from 1.49 ± 0.61 to 9.0 ± 1.5 MeV.

In the experiments which we are reporting here we have observed the ^5Li nucleus for the first time in the energy distribution of deuterons from the reaction $^3He(\alpha,d)\,^5Li$. The experiments were carried out with an α beam from the U-120 cyclotron of the Institute of Nuclear Physics, Kiev. The beam was colliminated by a system of circular diaphragms to an angular spread no greater than 5×10^{-3} rad. A cylindrical gaseous target 50 mm in diameter, with an entrance section 100 mm long, was placed in a vacuum chamber. Entrance and exit windows for the beam and for the reaction products were fabricated from 2-μm nickel foil or 8-μm aluminum foil. The target was filled with gaseous ^3He (98% enrichment) to a pressure of 200 Torr. Where necessary, the gas could be purified further in a cold trap of activated charcoal cooled with liquid nitrogen.

The products of the nuclear reactions were detected and identified with silicon semiconductor telescopes (the thickness of the ΔE spectrometer was 50 μm, and that of the E spectrometer could be varied to 4 mm). Collimation for the telescopes was provided by a system of rectangular slits, which set the aperture angle at $\pm 0.4°$. The energy resolution of the telescope for the deuterons was ~ 140 keV. This value was found with a gaseous working target (which was filled with atmospheric air to a

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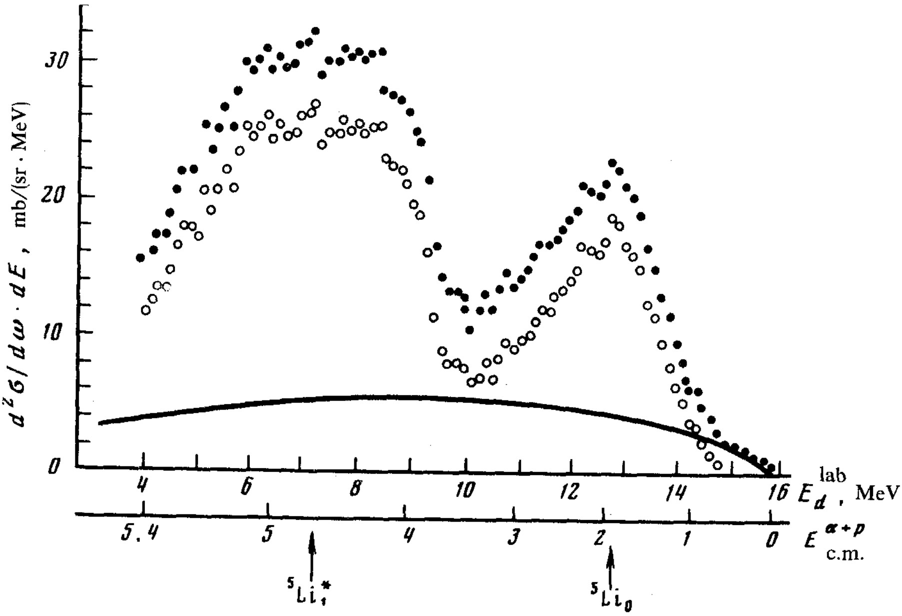

FIG. 1. Energy distribution of deuterons from the reaction $^3He(\alpha,d)\,^5Li$ at $\theta_{lab} = 15°$. Filled circles—Experimental; curve—distribution for direct breakup (under the assumption that the matrix element is a constant), normalized on the basis of a high-energy tail of the distribution at 15–15.6 MeV; open circles—results of a subtraction. The error of the absolute calibration is 10%.

pressure of 50 Torr and bombarded by a beam of 13.6-MeV deuterons). This value includes the spread in the beam, the intrinsic resolution of the spectrometer, and the spread due to the finite aperture angle of the telescope. The events from each telescope were recorded in the memory of an M6000 computer in a (32×128)-channel $\Delta E \times(\Delta E+E)$ matrix. The other experimental details are described in Ref. 2.

In the deuteron energy distribution (Fig. 1) we see two broad groups, which correspond to the ground and first excited states of the ^5Li nucleus. For an energy calibration of the deuteron distribution over the energy range from 4.8 to 12.5 MeV, and in order to monitor the efficiency at which the low-energy part of the distribution was detected, we used the elastic scattering $^3He(d,d)\,^3He$ at $E_d = 13.47$ MeV (this is the energy of the deuterons at the center of the gaseous target). The differential cross section for d-^3He scattering found for the angular interval $\theta_{lab} = 14$–$70°$ was compared with the results of other investigators[3] at similar energies. Because of the calibration used here, it was not necessary to make corrections for the ionization loss and for straggling in the gas, in the output foil, and in the ΔE detector in order to determine the actual distribution, especially its low-energy part.

The positions of the nearly steady states of the ^5Li nucleus along the $E_{c.m.}^{\alpha+p}$ scale in Fig. 1 were determined from the expression[4]

$$E^{\alpha+p}_{\rm c.m.} = Q + \frac{M_{^3\rm He}E_\alpha}{M_{^3\rm He}+M_\alpha} - \frac{M_p+M_d+M_\alpha}{M_p+M_\alpha}$$

$$\times\left\{E_d^{\rm lab}(\theta) - 2\frac{[M_dM_\alpha E_\alpha E_d^{\rm lab}(\theta)]^{1/2}}{M_{^3\rm He}+M_\alpha}\cos\theta_{\rm lab} + \frac{M_dM_\alpha E_\alpha}{(M_{^3\rm He}+M_\alpha)^2}\right\},$$

where M_i are the masses of the corresponding nuclei, $\theta_{\rm lab}$ is the laboratory angle, $Q = M_{^3\rm He} - M_p - M_d$, and E_α is the laboratory energy of the beam particles.

Since the energy of the beam particles at the center of the gaseous target (E_α) which appears in this expression is important for determining the positions of the ^{5}Li levels, we found E_α experimentally within 1% by comparing the kinematic curves $E_p(\theta)$ for the reactions ^{3}He($\alpha,p_{0,1}$) ^{6}Li and ^{1}H(α,p), which were detected simultaneously with deuterons in the experiment. The laboratory angles $\theta^*_{0,1}$ at which these curves intersect depend quite sharply on the energy of the α particles.

According to these results, when the deuteron energy distribution is approximated by two groups with Gaussian distributions, the ^{5}Li ground state lies at $(E^{\alpha+p}_{\rm c.m.})_0 = 1.93 \pm 0.21$ MeV and has a half-width $\Gamma_0 = 1.9 \pm 0.25$ MeV in the c.m. frame of the ^{4}He + p pair. If the broad group in the low-energy part of the deuteron distribution, which runs from 4 to 9.5 MeV in the laboratory frame, is identified as the first excited state of the nucleus, ^{5}Li$_1$, it should be put at $(E^{\alpha+p}_{\rm c.m.})_1 = 4.74 \pm 0.22$ MeV. This position corresponds to an excitation energy $E_1 = 2.82 \pm 0.35$ MeV in the ^{5}Li nucleus with a half-width $\Gamma_1 = 1.64 \pm 0.25$ MeV. The parameters found here for the first excited state of ^{5}Li are quite different from the results of a phase-shift analysis of free $p\alpha$ scattering. The differences may be due to the effect of the field of a third particle,[5] in this case the deuteron, as has been discussed in recent years.

[1]F. Ajzenberg-Selove, Nucl. Phys. **A320**, 1 (1979).

[2]V. S. Belyavenko, A. V. Lashko, O. F. Nemets, *et al.*, Preprint KIYaI-79-16, Institute of Nuclear Research, Kiev, 1979.

[3]T. R. King and R. Smythe, Nucl. Phys. **A183**, 657 (1972).

[4]G. G. Ohlsen, Nucl. Instrum. Methods **37**, 240 (1965).

[5]E. G. Bercowitz, Nucl. Phys. **60**, 555 (1964); W. Bretfeld, W. Bermer, H. Eichner, *et al.*, Z. Phys. **A282**, 365 (1977).

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