INVESTIGATION OF THE ANGULAR DISTRIBUTIONS OF α PARTICLES FROM THE $Li^7(p, \alpha)He^4$ *REACTION*

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Submitted to JETP editor June 18, 1961

J. Exptl. Theoret. Phys. (U.S.S.R.) **42**, 353-357 (February, 1962)

The angular distributions of α particles emitted in the $Li^7(p, \alpha)He^4$ reaction at angles between 20 and 160° were measured for incident proton energies of 5.78, 6.15, and 6.55 MeV. The excitation curve for proton energies between 3.3 and 6.6 MeV was found to have a distinct resonance structure. The results are analyzed.

THE angular distributions of α particles produced in the $Li^7(p, \alpha)He^4$ reaction have been studied[1] only for proton energies $E_p < 3.75$ MeV. These measurements indicate the existence of an excitation resonance on the excitation curve at $E_p \sim 3.0$ MeV. An analysis of the angular distributions in this energy region has been made by Inglis.[2]

In the present experiment, the $Li^7(p, \alpha)He^4$ reaction has been investigated for proton energies in the interval 3.3 — 6.55 MeV. The α particles produced in the reaction were recorded by a "telescope" consisting of three proportional counters.[3] Targets of Li_2CO_3 deposited on gold tinsel by evaporation in vacuo were used in the measurements. The target thicknesses were 0.16, 0.52, and 0.92 mg/cm^2, which corresponded to losses of 13, 41, and 70 keV for 6-MeV protons.

Figure 1 shows the range distribution of the α particles and He^3 nuclei emitted at 30° from the target in the case of 6.5-MeV incident protons. The expected positions of the He^4 and He^3 groups formed in the $Li^7(p, \alpha)He^4$ and $Li^6(p, \alpha)He^3$ reactions are indicated by arrows.

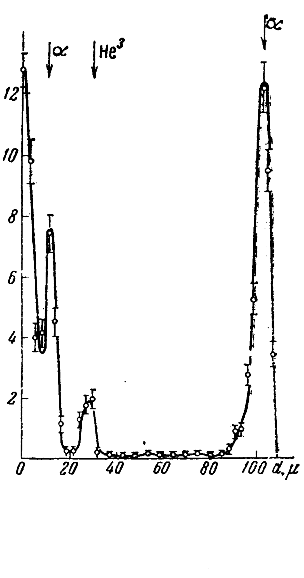


FIG. 1. Range distribution of α particles and He³ nuclei emitted at an angle of 30° in the Li(p, α) reaction (E_p = 6.5 MeV). The abscissa axis gives the thickness d of an aluminum absorber in front of the first counter.

The angular distributions of the α particles produced in the $Li^7(p, \alpha)He^4$ reaction (Q = 17.35 MeV) were measured for three incident proton energies: E_p = 5.78, 6.15, and 6.55 MeV. The results were recalculated for the c.m.s. and are shown in Figs. 2a, b, c. Since two identical particles are produced in this reaction, the angular distributions in this reaction can be represented in the form of a series of even powers of $\cos\vartheta$ (where ϑ is the c.m.s. angle) or in the form of an expansion in even Legendre polynomials $P_n(x)$. From the experimental distributions we calculated, by the method of least squares, the coefficients in expressions of the form

$$d\sigma / d\Omega = (\sigma / 4\pi) [1 + a_2 P_2(x)],$$

$$d\sigma / d\Omega = (\sigma / 4\pi) [1 + A_2 P_2(x) + A_4 P_4(x)]$$

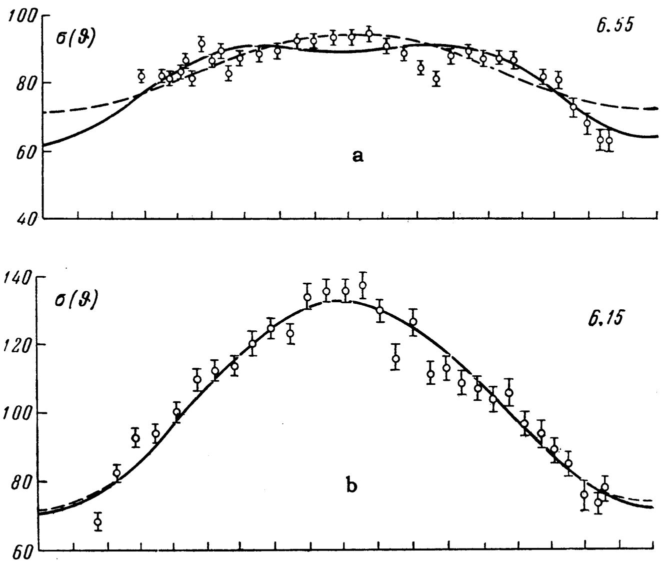
where σ is the total cross section.

We use the following values for the coefficients

E_p, MeV	a_2	A_2	A_4
6.55	—0.169	—0.167	—0.102
6.15	—0.357	—0.356	—0.010
5.78	—0.717	—0.693	+0.085

The results of the calculation of the angular distributions from the foregoing formulas are shown in Figs. 2a, b, c [the dashed curves correspond to the formula with two terms and the solid curves to the formula with $P_4(x)$]. It is seen from the figures that even the simple formula of the form $1 + a_2P_2(x)$ satisfactorily describes the experimental results.

The excitation curves were measured in the proton energy regions 5.25 — 6.55 MeV at 30° (35° in the c.m.s.) and 3.3 — 6.55 MeV at 80° (90° in the c.m.s.). The results of the measurements are shown in Fig. 3. Also shown in the same figure are the data for 90° obtained by other authors (see [1]) (E_p = 1.0 — 3.75 MeV). Since in our and in other experiments[1] only the relative cross sec-



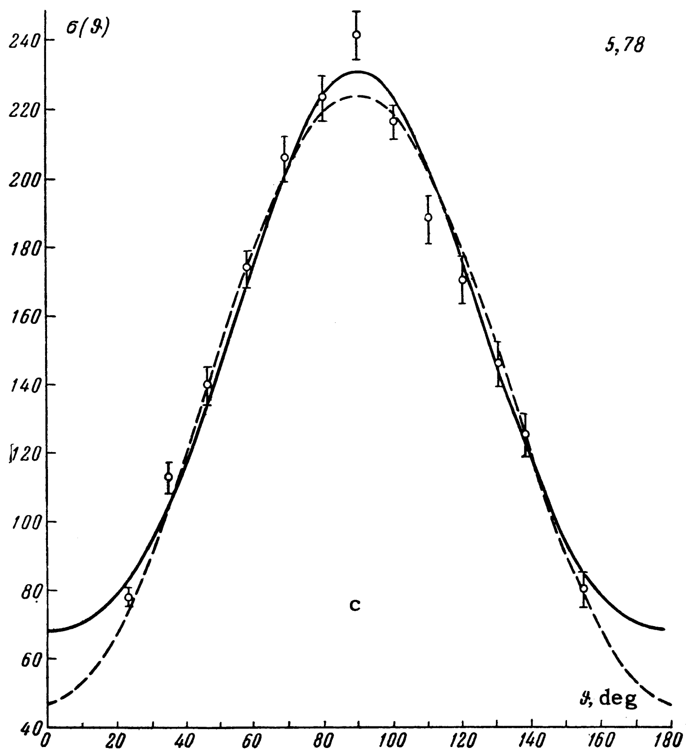


FIG. 2. C.m.s. angular distributions for α particles from the Li^7 (p, α) He^4 reaction. The mean values of the proton energy in the target are: a – 6.55 MeV, b – 6.15 MeV, and c— 5.78 MeV.

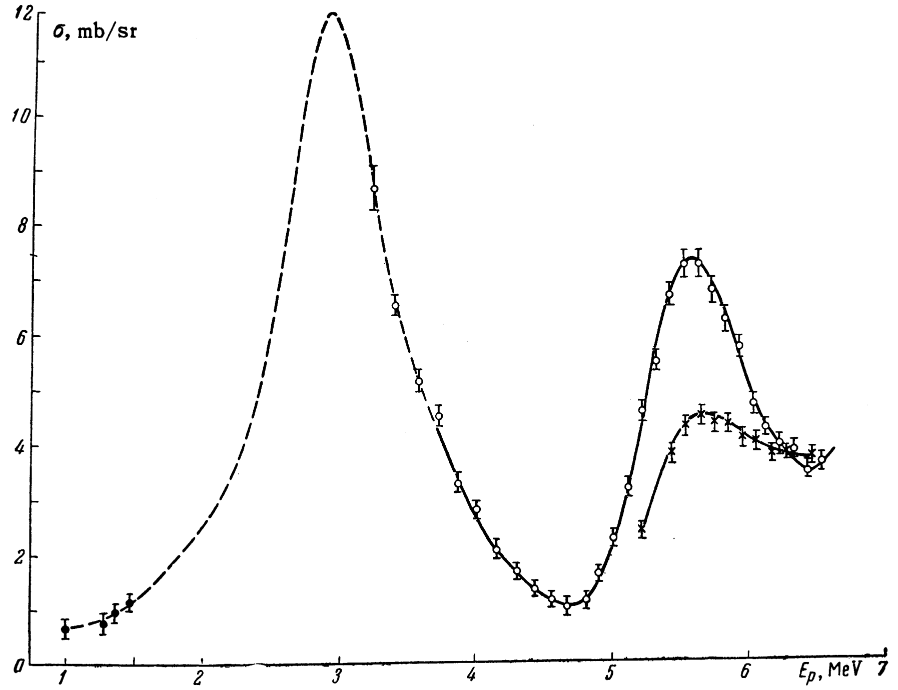


FIG. 3. Excitation energy as a function of the proton energy: × – for α particles emitted at 30° l.s.; o – at 80° l.s; ● – data of Freeman et al.[4] The results obtained by Heydenburg et al[1] are shown dashed.

tions were measured, the excitation curves for 80 and 90° were fitted together in the overlapping region (3.3 – 3.75 MeV). It is seen from Fig. 3 that the curves fit together well; here, the effect due to the difference in the angles of measurement (80° in our experiment and 90° in the others) is at most 3%. In order to determine the absolute differential cross sections given on the ordinate axis, we used the results of Freeman, Hanna, and Montague[4] at 90° for several values of E_p.

From the data for 30° and 80° we calculated the values of the coefficient a_2 for proton energies between 5.25 and 6.5 MeV. The obtained values (black circles in Fig. 4) indicate that $a_2 < 0$ and that $|a_2|$ increases as the resonance value of E_p is approached. Shown in the same figure (empty

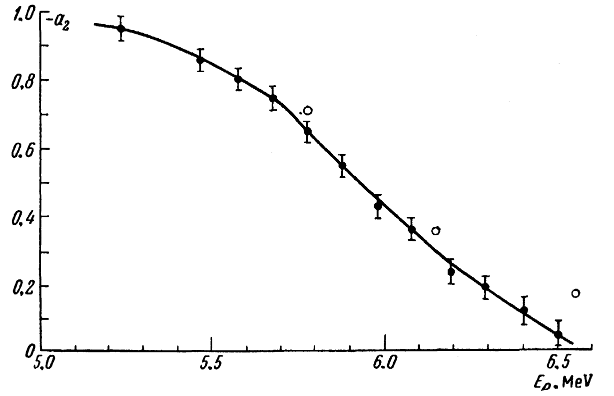


FIG. 4. The coefficient a_2 as a function of the proton energy.

circles) are the values of the coefficient a_2 calculated by the method of least squares from the angular distributions (see the data given above).

The quite distinct resonance structure of the excitation curve for the $Li^7(p, \alpha)He^4$ reaction for incident proton energies up to 6.6 MeV (Fig. 3) indicates that the basic mechanism for the reaction is a mechanism associated with the formation of a Be^8 compound nucleus. This is also confirmed by the application of the expressions $1 + a_2P_2(x)$ and $1 + A_2P_2(x) + A_4P_4(x)$ to describe the angular distributions.

The excitation curve (Fig. 3) contains two resonances: one in the region 3.0 MeV and the other in the region 5.6 MeV. The resonance at 3 MeV was analyzed by Inglis,[2] who concluded that the angular distributions of the α particles in the region of this resonance can be explained if it is assumed that the Be^8 compound nucleus has a 2^+ state with excitation energy 19.9 MeV and a width $\Gamma = 1$ MeV and a 0^+ state with a width of several MeV lying above the resonance region.

The existence of the resonance at 5.6 MeV is most simply explained by the occurrence of a state with excitation energy 22.3 MeV and width $\Gamma = 1$ MeV in the Be^8 nucleus. In a review article, Ajzenberg-Selove and Lauritsen[5] listed a level with excitation energy 22.6 MeV observed by Whaling and Bonner.[6] These latter authors, who investigated the excitation curves for the $Li^6(d, \alpha)He^4$ and $Li^6(d, p)Li^7$ reactions found that the function $\alpha(E_d) = \sigma(90°)/\lambda\!\!\!^{-2}P_0(E_d)$ (where P_0 is the penetrability for s deuterons) has a resonance at $E_d = 0.4$ MeV. However, Hirst, Johnstone, and Poole[7] did not observe this level in their study of the $Li^6(d, \alpha)He^4$ and $Li^6(d, n)Be^7$ reactions. Comparison of these two experiments indicates that the results of Hirst et al[7] are apparently more reliable. First, in the latter work, the authors used tables of Coulomb functions in the calculation of the penetrability P_0, while Whaling and Bonner[6] calculated P_0 with the aid of approximation formulas. Second, Hirst et al[7] used a thin target (0.005 mg/cm^2), while Whaling and Bonner[6] employed a comparatively thick target (0.15 mg/cm^2), which could have affected the results of the cross section measurements for low-energy deuterons. Hence the existence of a 22.6-MeV excited state in Be^8 cannot be regarded as established.

Thus, it is most natural to assume that the resonance at $E_p = 5.6$ MeV is connected with a single level of the compound nucleus having an excitation energy of 22.3 MeV and width $\Gamma = 1$ MeV. In determining the characteristics of this level we should keep in mind the fact that only states of Be^8 having even spins (0^+, 2^+, 4^+, etc.) can decay into two α particles. From the law of conservation of angular momentum it follows that the $Li^7(p, \alpha)He^4$ reaction involves only protons with orbital angular momenta $l = J \pm 1$. Since, for $E_p = 6$ Mev, the ratio of the penetrabilities $P_1 : P_3 : P_5$ is $1 : 0.11 : 0.0006$,[8] only protons with l equal to 1 and 3 need to be taken into account.

It thus follows that the possible states are 0^+, 2^+, and 4^+. The value 0^+ drops out since a 0^+ state would lead to isotropic angular distributions. The results of the calculation by the method of Inglis[2] show that for the 4^+ state, with only the f protons taken into account, the coefficient a_2 should be positive. This result also holds if, in addition to the 4^+ state, the 0^+ state is present (for example, a broad state whose existence was suggested by Inglis to explain the angular distributions in the region $E_p = 3$ MeV). Since $a_2 < 0$ in the region of the 5.6 MeV resonance (see the values of the coefficients and Fig. 4), the value 4^+ also drops out. Hence, if the 5.6-MeV resonance is associated only with one state of the compound nucleus with an excitation energy of 22.3 MeV, the spin and parity of this state are 2^+.

It should be mentioned that Gibbons and Macklin,[9] who studied the $Li^7(p, n)Be^7$ reaction, observed a resonance in the yield curve of this reaction at $E_p = 5.0$ MeV. Since we did not find this resonance in the excitation curve measured by us, it is evidently associated with a Be^8 state which does not decay into two α particles.

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Translated by E. Marquit
55