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ON A CERTAIN EXPERIMENTAL POSSIBILITY OF STUDYING THE MECHANISM OF THE (t, d) *REACTION*

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Excitation of $5/2^-$ levels (at 7.47 MeV and in the region of 5—6 MeV) in the $Li^6(t,d)Li^{7*}$ reaction is considered. It is shown that, owing to the strong structure selection rules established in the paper for neutron and triton reduced widths, the relative probability for excitation of these levels depends on the ratio of the contributions from the stripping and "knock-on" mechanisms. By studying the excitation spectrum of the Li^7 nucleus in the $Li^6(t,d)Li^7$ reaction one can thus derive information on the relative contributions of these mechanisms.

DIRECT nuclear reactions in which H^3 and He^3 nuclei participate are continuously gaining in interest. Unlike the well investigated reactions of the (d, p) or (p, d) type, which proceed principally via transfer of one nucleon (stripping, pick-up), the important processes in the reactions of the type (t, d), (He^3, d) etc. are apparently the more complicated "knock-on" and "heavy stripping."

This raises the question of the relative role of different mechanisms in these reactions. In the presently developing dispersion theory of direct nuclear reactions[1], the main criterion is the location (energywise) of the singularities corresponding to the individual diagrams (mechanisms) of the reaction under consideration. Unfortunately, such a criterion is insufficient. In order to select the diagrams that are the most important in each individual case, it is necessary to know not only the position but also the "power" of the corresponding singularities. In particular, it is necessary to know the absolute values of the different vertex parts of the diagrams. Calculations of this type no longer belong in dispersion theory. Different model representations concerning the nuclei, to the contrary, may turn out to be quite useful here.

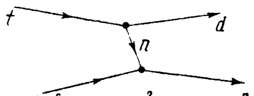
Holmgren and Wolicki[2] called attention to the fact that whereas the single-particle (shell) aspect of the nuclear wave function comes into play in single-nucleon stripping or pick-up, it is the cluster aspect of the wave function which appears in "knock-on" or "heavy stripping," i.e., the processes connected with exchange of entire groups of nucleons. These ideas offer much promise, if we consider the influence of the cluster-exchange mechanism on the variation of the total reaction cross sections on going from nucleus to nucleus. However, the question of the relative role of processes of such exchange and stripping (pick-up) is left aside. Apparently, the cluster model is little suited in its present form for the solution of similar problems, since it obscures the single-particle shell aspects of the nuclear structure.

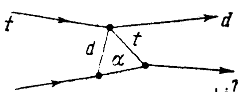
At the same time it is well known that the main features, of nucleon clustering in the nucleus are successfully represented by the shell model. A few years ago a method was developed for calculating within the framework of the shell model the reduced widths of light nuclei relative to α particles, tritons, and other complex particles[3]. Applying this method to a description of reactions of the type (t, d), (t, α) etc, we can cover in a single manner both the cluster and the single-particle aspects of these reactions. In other words, with the aid of identical shell wave functions we can calculate both the single-particle and the many-particle aspects of the corresponding diagrams.

In this connection it is interesting to compare two or several reactions of some definite type, which are close to each other in their kinematic symptoms (spins, positions of singularities of the diagrams) but differ greatly in the internal structure of the participating states.

Such a possibility, which is almost unique, occurs in the study of the $Li^6(t,d)Li^7$ reaction. It is well known that in Li^7 the theory predicts the presence of a level $\frac{5}{2}^-$ with excitation energy in the region 5—6 MeV[4] in addition to the 7.47-MeV $\frac{5}{2}^-$ level. The close energy values of these two states make all the kinematic conditions of the reaction $Li^6(t,d)Li^{7*}$ with production of these states, including the position of the singularities, practically the same even at triton energies of 10 MeV. By the same token, the relative contribution of the different reaction mechanisms is determined in this case only by the internal structure of the considered states.

If we illustrate the single-nucleon stripping and "knock-on" processes with the aid of the simplest diagrams (pole and triangle):





then the problem reduces to a calculation of the neutron and triton reduced widths of the $\frac{5}{2}^-$ states of Li^7 (ϑ^2 and θ^2, respectively). A calculation performed within the framework of the intermediate coupling of the shell model (for optimal values of the parameters) yields

$$(\theta_2/\theta_1)^2 \approx 0.05$$

(this ratio holds true also for the "heavy stripping"), and

$$(\vartheta_2/\vartheta_1)^2 \approx 60$$

(the subscripts 2 and 1 refer to the upper and lower $\frac{5}{2}^-$ levels). Thus, in the stripping process the excitation of the lower $\frac{5}{2}^-$ level is highly suppressed compared with the excitation of the $\frac{5}{2}^-$ level at 7.47 MeV. To the contrary, the "knock-on" process leads to a preferred excitation of the lower level compared with the upper one.

It is known that much hope is placed at present in the optical model of the nucleus when it comes to calculating the reduced vertices. It is easy to see, however, that in such an approach two levels that have identical spins, parities, isospins, and practically the same excitation energy are equivalent in all respects. By extending this approach to the reaction under consideration, we can expect the two $\frac{5}{2}^-$ levels to be excited with equal probability regardless of the relative roles of the stripping and "knock-on" mechanisms.

Actually, as can be seen from the results presented above, the relative probability of the excitation of $\frac{5}{2}^-$ levels depends on which of the mechanisms predominates. This indeed determines the value of the proposed experiments. Were it to happen, for example, that the excitation of the upper level is suppressed compared with the excitation of the lower one then this would offer evidence of the major role of the "knock-on" process. To the contrary, predominant excitation of the $\frac{5}{2}^-$ level at 7.47 MeV would indicate that the stripping mechanism prevails.

The approximate structural selection rules established above for neutron and triton reduced widths are the consequence of the closeness of the real picture of the intermediate coupling in the Li^7 to the extreme case of LS-coupling (and are therefore very insensitive to the assumptions made with respect to strengths used in the calculations). In the case of LS-coupling the upper $\frac{5}{2}^-$ state is characterized by a Young tableau [421], which is incompatible with the [4] × [3] symmetry of the α particle + triton system; as to the lower state $[43]^{22}F_{5/2}$, its coupling with the ground state $[42]^{13}S_1$ of Li^6 is forbidden in the orbital angular momentum of the nucleon.

In conclusion we note that the fact that the $\frac{5}{2}^-$ level drops out in the 5—6 MeV region from the Li^7 level scheme established in various experiments[5] is not surprising. The experiments on the scattering of tritium by helium, where this level manifests itself with high probability, have been carried out at too low an energy[5]. On the other hand, in the $Li^6(d,p)$ reaction, this level is practically not excited, owing to the smallness of the nucleon reduced width. To the contrary, the level $\frac{5}{2}^-$ at 7.47 MeV appears in this reaction with a reduced width which is close to the single-particle one; this excludes, in particular, the possibility of assigning it to the doublet $[43]^{22}F$. The correctness of comparing the $\frac{5}{2}^-$ level in the 5—6 MeV region with the theoretical level $[43]^{22}F_{5/2}$ is confirmed by its intense excitation in the $Li^7(\gamma,t)He^4$ reaction[6].

Strong excitation of this level is also expected in inelastic scattering of α particles (at the same time, the excitation of the $\frac{5}{2}^-$ level at 7.47 MeV is here highly suppressed). Thus, a study of the $Li^6(t,d)Li^7$ reaction is of interest not only for a clarification of the mechanism of the (t, d) reaction [or the analogous (He^3, d) reaction], but also from the point of view of the spectroscopy of the Li^7 nucleus.

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[1] I. S. Shapiro, JETP **41**, 1616 (1961), Soviet Phys. JETP **14**, 1148 (1962).

[2] H. D. Holmgren and E. A. Wolicki, Proc. Rutherford Jubilee Int. Conf. 1961, London, p. 541.

[3] Balashov, Neudachin, Smirnov, and Yudin, JETP **37**, 1383 (1959), Soviet Phys. JETP **10**, 983

(1960); Ju. F. Smirnov and D. Chlebovska, Nucl. Phys. **26**, 306 (1961).

[4] S. Meshkov and C. W. Ufford, Phys. Rev. **101**, 734 (1956).

[5] F. Ajzenberg-Selove and T. Lauritsen, Nucl. Phys. **11**, 1 (1959).

[6] V. G. Shevchenko and B. A. Yur'ev, Izv. AN SSSR, ser. fiz. **25**, 1269 (1961), Columbia Tech. Transl. p. 1280.

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