$$E_0 = \sqrt{\mu^2 + k^2} - (M_2 - M_1) \tag{7}$$

$$= \sqrt{m^2 + p^2} + \frac{(\mathbf{p} - \mathbf{k})^2}{2(M_1 + M_2)} + \frac{M_1 + M_2}{2M_1M_2} f^2,$$

Eqs.(4) and (6) give the pion distribution near the upper limit of the spectrum. Assuming $\cot\delta_{t,s} = -\beta_{t,s/f}$ and considering mesons whose energy differs from the upper limit by an amount of the order β^2/M, we obtain

$$d\sigma = \frac{\alpha}{\pi \varkappa_m^2}\left[\frac{M_1M_2}{2(M_1 + M^2)}\right]^{1/2}\left(1 + \frac{w_m}{M_1 + M_2}\right) \tag{8}$$

$$\times\left\{\frac{|a|^2 + {}^2/_3|b|^2}{\varepsilon_t + [E_0 - w - (w^2 - m^2)/2(M_1 + M_2)]}\right.$$

$$\left. + \frac{{}^1/_3|b|^2}{\varepsilon_s + [E_0 - w - (w^2 - m^2)/2(M_1 + M_2)]}\right\}$$

$$\times\sqrt{E_0 - w - \frac{w^2 - m^2}{2(M_1 + M_2)}}\, dw.$$

Here $\epsilon_{t,s} = \beta^2_{t,s}(M_1 + M_2)/2M_1M_2$ and $\varkappa_m$ and w_m are the limiting values of $\varkappa$ and $w = \sqrt{m^2 + p^2}$ (for $f = 0$). According to (8), the pion energy distribution near the upper limit of the spectrum has two sharp peaks whose position and width is determined by ϵ_t and ϵ_s. An experimental investigation of this process in hydrogen and in deuterium would enable us to determine these important quantities as $|a|$ and $|b|$.

If bound states of the nucleons and hyperons exist there will be discrete lines in addition to the continuous portion of the pion energy spectrum. We obtain as the corresponding cross sections

$$d\sigma_t = \left(|a|^2 + \frac{2}{3}|b|^2\right) 2\frac{\sqrt{\alpha\beta_t}}{\varkappa} \operatorname{arctg}\frac{\varkappa}{\alpha + \beta}, \tag{9}$$

$$d\sigma_s = \frac{1}{3}|b|^2 2\frac{\sqrt{\alpha\beta_s}}{\varkappa} \operatorname{arctg}\frac{\varkappa}{\alpha + \beta_s}.$$

In connection with the capture of a K^-–meson from the K-shell or from the continuous spectrum, but with emission of a pion at a small angle with relation to the K-meson momentum, certain conclusions can be reached regarding the magnitudes of a and b (see the Table). Here P_K and S_K are the parity and spin of the K-meson; P_Y is the parity of the hyperon relative to the nucleon.

For the study of the interactions between Ξ-particles and nucleons we can use the reactions

$$K^- + d \rightarrow K^+ + \Xi^- + n, \quad K^- + d \rightarrow K^0 + \Xi^- + p$$

along with the corresponding reactions with protons. These reactions are impossible in connection with the capture of K^--mesons from the K-shell because of the energy threshold.

P_y \ S_k, P_k	0^+	0^-	1^+	1^-
$+1$	$a=0$	$b=0$	$a \neq 0$ $b \neq 0$	$a=0$
-1	$b=0$	$a=0$	$a=0$	$a \neq 0$ $b \neq 0$

We note in conclusion that the interaction between nucleons and hyperons could also be studied by investigating the energy spectrum of K-mesons in reactions such as[3]

$$p + p \rightarrow \begin{cases} p + \Lambda + K^+ \\ p + \Sigma^+ + K^0 \end{cases} \text{или} \quad p + n \rightarrow \begin{cases} n + \Lambda + K^+ \\ n + \Sigma^+ + K^0 \\ p + \Sigma^- + K^+ \end{cases}$$

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Spectra of Neutrons Produced by Bombarding Light Nuclei with 14 mev Deuterons

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In the previous work of our laboratory[1] it was found that the spectra of neutrons, produced by bombarding tritium and deuterium with 14 mev deuterons, are not monchromatic. Besides the neutron groups, corresponding to the production of the He^4 and He^3 nuclei in the ground state, other groups of slower neutrons were observed. The work was continued with other light-element targets in order to explain the mechanism of neutron production in these reactions. The experimental setup used analyzed the time of flight of the neutrons for the 2.85 m distance between the target and the counter. The details of the experiment are given in Ref. 2.

Two types of targets were used: gaseous H, He^3 and He^4, and solid-T (in zirconium), Li, Be, B, C and Cu. The gaseous targets were 4 cm thick and at the pressure of 2 atmospheres (in the case of He^3, 0.8 atmospheres). The entrance window of the targets, 30 mm in diameter, was covered by platinum foil 30μ thick. The back wall, upon which the beam was falling after passing through the gas, was covered by a thick layer of lead. The solid targets, about 0.5 mev thick (for 14 mev neutrons) were set up on a thick lead base. Since comparatively few neutrons are produced in the lead during the bombardment, the difference of the results obtained with the target and with the empty holder only could be could only be regarded as caused by the element under examination.

The obtained neutron spectra are shown in Figs. 1-3. The measurements were carried out at the angle of 0°. The neutron energy was in the case of solid targets equal to 14.4 mev, in the case of gases, 13.0 mev.

The curves shown are the averages obtained from several series of measurements having a spread up to ±20%. This spread is basically due to the phase instability in the cyclotron.

The resolving power of our apparatus can be characterized by the width of the γ-peak, shown in the Figures. In the case of a solid target another 0.5 mev should be added to this width in order to account for the thickness of the target. The resulting resolving power permits the observation of separate levels of the final nucleus in the case of bombardment of H and He isotopes only. In all other cases, the spectra should appear to be continuous.

If the secondary groups of slower neutrons in the T + d and D + d reactions were produced in the result of the deuteron stripping without any change in the bombarded nucleus, we could expect a similar effect in the case of other light nuclei. The neutron spectrum and the effective production cross section should, consequently, depend smoothly on the number of the nucleons in the nucleus. In reality, neither the spectrum nor the cross section change smoothly. When the reaction has a large positive value of Q, the upper limit of the spectra exceeds the maximum energy of a neutron produced by deuteron stripping, without any change in the bombarded nucleus. In consequence, the state of the final nucleus has a marked influence upon the neutron spectrum being investigated.

The comparison of the neutron spectra obtained by bombarding T and He^3 targets is of special interest (see Fig. 1). These nuclei differ only in their charge, which should not greatly influence the stripping cross section for incident deuterons, since the energy of these is much larger than the Coulomb energy. Nonetheless, the neutron production cross section is almost twice as large in the T+ d reaction as in the He^3 reaction. The mean neutron energy in the both cases differs also, by approximately 3 mev. The cross section difference is partly due to the reaction (d, $2n$) reaction nor by a possible nonuniformity of the energies of the incident deuterons. This difference is evidently due to the production of the He^4 nucleus in an excited state which was discovered previously investigating the T(p,n)He^3 reaction [3,4].

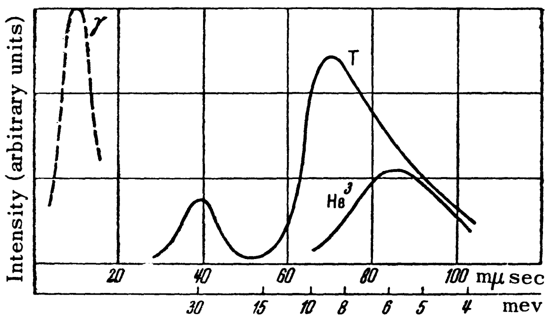

FIG. 1. Neutron spectra obtained by bombarding T and He^3 with 14.4 mev and 13.0 mev deuterons, respectively. The γ-peak is shown.

The results of Henkel, Percy and Smith[5], who studied the neutron yield bombarding the H and He isotopes with deuterons of energies close to the stripping threshold, are also in agreement with our deduction. As it can be seen from the graphs, the production cross section for neutrons emitted at the angle 0° is several times larger for the T target than for the He^3 target. This difference can be explained by taking into account the existence of an excited state of the He^4 nucleus, since the reaction (d, $2n$) has a 1.2 mev higher threshold than the deuteron stripping.

Comparison of the production cross sections and of the neutron spectra in the reactions T + d and He^3 + d confirms, therefore, the existence of the excited state of He^4 with the excitation energy equal to about 22 mev, and also indicates the absence of a similar state for the Li^4 nucleus. It should be expected that H^4, similarly to Li^4, does not exist in such a state. This confirms the assumption made by Smorodinski and Baz'[6] that the isotopic spin of the 22 mev excited state equals zero. If the isotopic spin of He^3 in this state were equal to 1, similar states would exist for Li^4 and for H^4, and the neutron spectrum of the $He^3 + d$ reaction would be analogous to the neutron spectrum of the $T + d$ reaction.

The neutron spectrum obtained by bombardment of He^4 is of equal interest. The final nucleus obtained in this case for the (d, n) reaction is Li^5. For this nucleus the existence of a 2.5 mev excited state is currently assumed[7], besides the unstable ground state. It is well known that the energy difference between the two states of Li^5 (or He^5) represents the very important spin-orbit splitting constant. It should be noted, however, that the data indicating the existence of the excited state are so far not convincing[7]. The neutron spectrum obtained by bombarding He^4 with 13.0 mev deuterons is shown in Fig. 2. The arrows indicate the position of the centers of the energy groups which should correspond to the ground state (left) and to the excited state (right) of Li^5. It can be seen that in the neutron spectrum of the $He^4 + d$ reaction the excited state of Li^5 does not show up markedly, which is in accord with works denying the existence of a similar state for the mirror nucleus He^5.

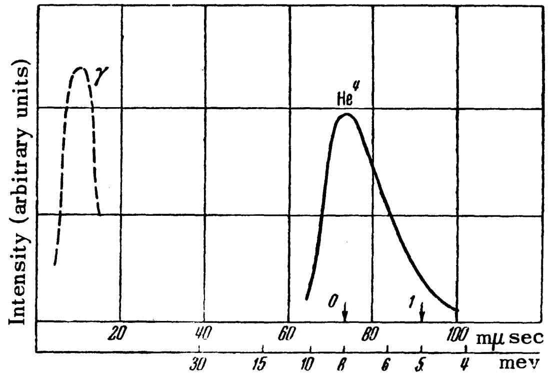

FIG. 2. Neutron spectra obtained by bombarding He^4 with 13.0 mev deuterons. Arrows indicate neutron energies corresponding to the ground state (0) and the supposed excited state (1) of Li^5. The γ-peak is shown.

We have estimated, for various elements, the effective production cross sections for neutrons emitted at the angle 0° to the direction of the incident deuteron beam. For all light elements investigated, with the exception of tritium, the cross section equals about 50 m barn/sterad per nucleon, i.e., is roughly proportional to the number of nucleons in the nucleus A. For heavier elements the cross section diminishes; for Cu it is equal to 200 m barn/sterad only.

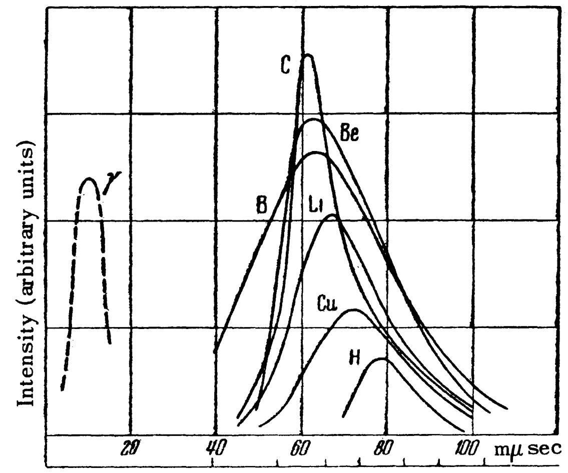

FIG. 3. Neutron spectra obtained by bombarding H and He^4 with 13.0 mev neuteron, and Li, Be, B, C and Cu with 14.4 mev deuterons. The γ-peak is shown.

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