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A Cloud-Chamber Study of the Disintegration of Lithium by Slow Neutrons

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The ranges of tritons and alpha-particles formed in the slow neutron reaction $^6Li(n,\alpha)\,^3H$ have been measured in a cloud chamber and found to be $R_\alpha=10.4\pm0.2$ mm and $R_{^3H}=60.0\pm0.6$ mm in air at N.T.P.; the corresponding Q values, derived from the blue-printed Cornell energy *vs.* range curves, disagree, and the Q derived by the proton relation is also in disaccordance with other data. The discrepancies suggest the establishment of a new point on the proton energy *vs.* range curve, *viz.*, $R_p=20.0$ mm, $E_p=0.88$ Mev, which means a reduction of the energy by about 6 percent.

INTRODUCTION

THE energy released when lithium reacts with slow neutrons

$${}_3{}^6Li+{}_0{}^1n\rightarrow{}_2{}^4He+{}_1{}^3H+Q$$

can be determined from the mean range of either one of the released particles by means of the energy range relations for alpha-particles or protons, considering the law of conservation of momentum. The Q values reported in earlier investigations are somewhat higher than the value calculated from the isotopic weights of the nuclei involved in the reaction and do not seem to be consistent with other transmutation data. Consequently, the ranges of the two particles have now been carefully remeasured, and the results were used for a discussion of the reliability of the energy range relations.

By proper choice of the experimental conditions it was possible to select the paired tracks of the $^6Li(n,\alpha)^3H$ reaction and, therefore, a moderate number of tracks should be expected to give good values of the mean ranges. It may be added that conditions should also be favorable for finding weak groups provided that the groups are not too close to each other. We have found, however, only one group and, thus, no evidence of the existence of a ^6Li reaction by which the ^3H nucleus is left in an excited state.

EXPERIMENTAL ARRANGEMENTS

Foils carrying thin evaporated layers of lithium fluoride were suspended in the middle of a 25-cm cloud chamber, and the lithium was exposed to neutrons produced by deuteron bombardment of lithium or beryllium and slowed down by means of paraffin.

In the first part of the investigation, when studying the range of the short alpha-tracks, the support was a mica foil having a stopping power equivalent to 12 mm of air, supplied on each side with a lithium fluoride layer with a stopping power of 0.65 mm of air. The tritons could penetrate the mica foil, but the alpha-particles were stopped. Thus, only those alpha-particles gave tracks which were ejected from one of the lithium layers directly into the chamber gas. The tracks could be recognized as formed in the lithium reaction and selected from other tracks by means of the accompanying triton penetrating the mica foil in the opposite direction and giving a fainter track in the other half part of the chamber. A typical example of the paired tracks is given in Fig. 1A. The cloud chamber contained helium, ethyl alcohol, and a small amount of boric acid ethyl ester, the total pressure being about 32 cm of Hg. The stopping power of the gas was determined by measuring the tracks of the boron disintegrations produced by slow neutrons in the gas of the chamber, and were easily identified by their characteristic features.* This is a convenient method of controlling the stopping power when short range particles are studied.

The triton tracks were studied under the following conditions. On one side of an extremely thin gold foil a lithium fluoride layer was evapo-

* J. K. Bøggild, Kgl. Danske Vid. Sels. Math.-Fys. Medd **23**, No. 4 (1945). (The total mean range, 11.35 mm of air, given here for the main group of boron tracks is revised to 11.50 mm because of small corrections in the stopping power of the gas mixture and in the value of the polonium alpha-range used to control the stopping power.)

rated, having a stopping power of 1.4 mm of air. The chamber contained air and the vapors of a mixture of ethyl alcohol and water in equal portions, the total pressure being about 62 cm. The stopping power of the gas was determined by means of alpha-tracks from a thorium *C* source inside the chamber. The tritons could easily be recognized by means of the accompanying short, denser alpha-tracks, as it appears from Fig. 1B. Corrections were applied for the stopping power of the LiF layer and also of the gold foil for tritons penetrating it.

Figure 2 shows the range distribution of 95 alpha-tracks from the ^{6}Li reaction and of the

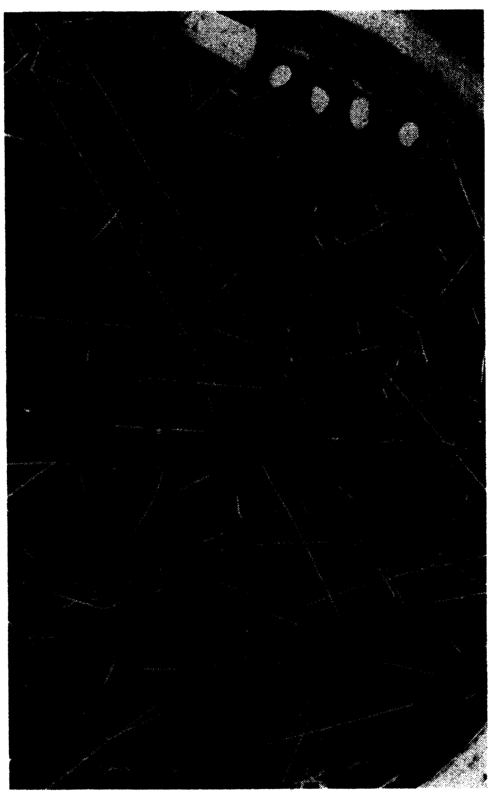

FIG. 1A. Paired tracks from a lithium disintegration. The chamber is filled with helium at low pressure in order to get alpha-tracks suitable for measurement. The dense track downward from the foil corresponds to the alpha-particle, the fainter track traversing the whole upper half part of the chamber belongs to the triton which has penetrated the mica foil carrying the lithium layers. Compare the different appearance of the track of a recoiling proton—to the right of the alpha-triton tracks and almost parallel to them—starting below the foil, penetrating it, and ending in the upper part of the chamber, the density increasing along the whole track.

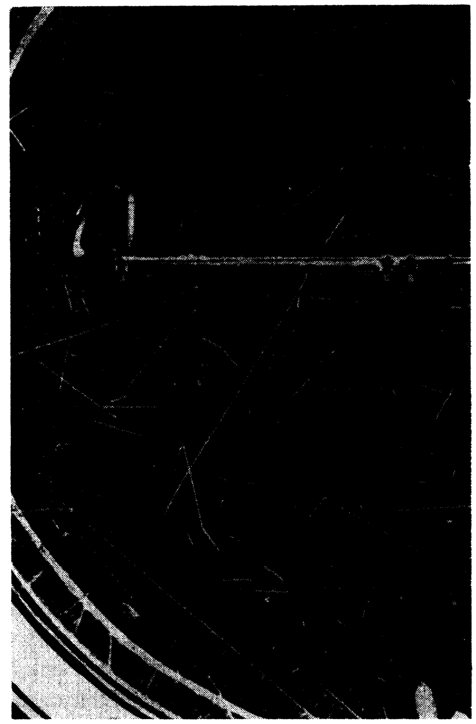

FIG. 1B. Triton track with accompanying alpha-track from a lithium disintegration. The chamber contained air with the pressure high enough to stop the triton in the gas. The obtuse-angled track intersecting the triton track near its end is to be ascribed to the fast neutron reaction $_7{}^{14}N(n,\alpha)\,_5{}^{11}B$.

tracks of boron disintegrations used as control. Figure 3 illustrates the distribution of 159 triton tracks. The mean range of the alpha-particles was found to be 10.4 ± 0.2 mm and that of the tritons 60.0 ± 0.6 mm in air at N.T.P., the maximum errors being estimated to be about 2 percent of the alpha-particle range and 1 percent of the triton range. The very few tracks shorter than the characteristic groups are supposed to be spurious—either originating in the lithium reaction, the length being reduced by some local defects, e.g., droplets on the foil, or in events in the gas accidentally resembling the tracks from the lithium reaction.

Using the energy range relations for alpha-particles (Cornell 1938[1]) and for protons (Cornell 1937 revised[2]), the following energy values are

[1] M. G. Holloway and M. S. Livingston, Phys. Rev. **54**, 18 (1938).

[2] H. A. Bethe, Phys. Rev. **53**, 313 (1938).

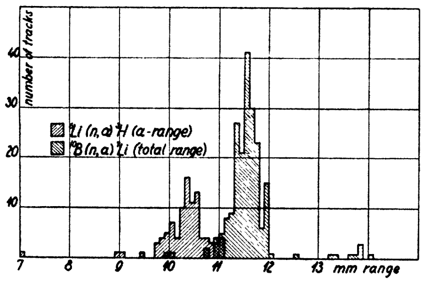

FIG. 2. Distribution of alpha-tracks from the $_3^6$Li(n,α) $_1^3$H reaction and of tracks from the $_5^{10}$B(n,α) $_3^7$Li* reaction used to determine the stopping power of the gas in the cloud chamber. The mean range of the alpha-particles is found to be 10.4 mm; the value used for the total mean range of the main group of the boron disintegration is 11.5 mm.

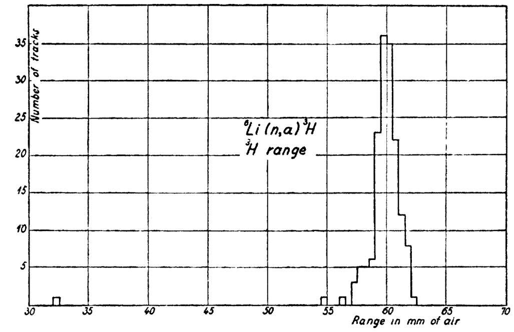

FIG. 3. Distribution of triton tracks from the $_3^6$Li(n,α) $_1^3$H reaction. The mean range is found to be 60.0 mm.

obtained:

$$E_\alpha=1.955 \text{ Mev},\quad Q'=7/3\cdot E_\alpha=4.56\pm0.08 \text{ Mev},$$
$$E_p=0.937 \text{ Mev},\quad Q''=7/4\cdot 3E_p=4.92\pm0.03 \text{ Mev},$$

where E_α is the energy of an alpha-particle with a mean range amounting to 10.4 mm, and E_p is that of a proton having a range of 20.0 mm, which is one-third of the triton range 60.0 mm. The fact that the difference between the two values of Q obtained is larger than the estimated maximum errors, indicates that at least one of the energy range relations is somewhat incorrect.

DISCUSSION

The energy range relation for alpha-particles is considered reliable at the present time, but recent investigations on reaction cycles[3] indicate that the revised proton relation gives too high energy values, in the case of 10-mm protons by about 10 percent. It thus seems reasonable to consider our Q' value, determined from the alpha-particle range, as fairly reliable and to establish a new point on the proton relation by combining our triton range with the triton energy as calculated from Q' and by converting the values in the usual way into range and energy of a proton. The energy of a 20.0-mm proton should thus be

$$4/7\cdot\tfrac{1}{3}\cdot(4.56\pm0.08)=0.870\pm0.015 \text{ Mev}.$$

By substituting for Q' the Q value calculated from the isotopic weights ($Q=4.65\pm0.06$ Mev, using Mattauch's[4] values and $Q=4.64$, using those of Segrè[5]), the proton energy 0.885 ± 0.011 Mev is obtained.

Another way of determining the Q value is to combine the ^{6}Li(n,α) ^{3}H reaction with the ^{6}Li(p,α) ^{3}He reaction:

$$\left.\begin{array}{l} ^6\text{Li}+n\rightarrow{}^4\text{He}+{}^3\text{H}+Q \\ ^6\text{Li}+{}^1\text{H}\rightarrow{}^4\text{He}+{}^3\text{He}+Q_p \end{array}\right\}$$
$$Q=Q_p+(n-\text{H})-(^3\text{H}-{}^3\text{He});$$

here, $(n-\text{H})=0.755\pm0.016$ Mev,[6] and

$$(^3\text{H}-{}^3\text{He})=0.011\pm0.002 \text{ Mev}.^7$$

Thus,

$$Q=Q_p+(0.744\pm0.016) \text{ Mev}.$$

With Perlow's[8] $Q_p=3.945\pm0.06$ Mev, as determined from the alpha-range by a method which is fairly insensitive to the alpha-relation, $Q=4.69\pm0.06$ is obtained, the corresponding proton energy being 0.895 ± 0.011 Mev.

The three proton energy values given above are in reasonable agreement, and the accuracy of the mean value, 0.883 Mev, corresponding to 20.0-mm proton range, is probably better than 2 percent. This proton energy is about 6 percent smaller than that given by the revised Cornell relation, *viz.*, 0.937 Mev, and even somewhat smaller than that given by the Livingston and Bethe[9] relation from 1937, *viz.*, 0.91 Mev.

[3] I. Cornog, W. Franzen, and W. E. Stephens, Phys. Rev. **74**, 1 (1948).

[4] J. Mattauch, *Kernphysikalische Tabellen* (Berlin, 1942).

[5] E. Segrè, Atomic Energy Commission Report MDDC (1945).

[6] W. E. Stephens, Rev. Mod. Phys. **19**, 19 (1947).

[7] R. J. Watts and D. Williams, Phys. Rev. **70**, 640 (1946).

[8] G. J. Perlow, Phys. Rev. **58**, 218 (1940).

[9] M. S. Livingston and H. A. Bethe, Rev. Mod. Phys. **9**, 268 (1937).

As to previous range measurements, it appears that our triton range, 60.0±0.6 mm, is in agreement with that found by Livingston and Hoffman,[10] *viz.* 59.0±0.6 mm, and also with that found by Rumbaugh, Roberts, and Hafstad,[11] *viz.*, 61 mm (which is, however, not claimed to be very accurate). The latter authors have determined the alpha-range, too, but their value, 11.8 mm, exceeds ours by more than 10 percent and leads to $Q=4.97$ Mev, which is in serious disagreement with the data given above.

In conclusion, the authors wish to express their gratitude to Professor Niels Bohr, who placed at their disposal the facilities of the institute, for his kind interest and valuable advice regarding this investigation. Our thanks are also due Mr. O. B. Nielsen, civil engineer, and Mr. S. Holm for valuable assistance during the experiments.

[10] M. S. Livingston and J. G. Hoffman, Phys. Rev. **53**, 227 (1938).
[11] L. R. Rumbaugh, R. B. Roberts, and L. H. Hafstad, Phys. Rev. **54**, 657 (1938).

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Thresholds for Fast Neutron Fission in Thorium and Uranium*

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The threshold energy for fast neutron fission of thorium and uranium has been measured by using the neutrons from thin lithium films through the $Li^7(p,n)$ reaction. Neutron energy fission thresholds were found to be 1.0±0.1 Mev for U^{238} and 1.10±0.05 Mev for Th^{232}.

INTRODUCTION

The reaction $Li^7(p,n)Be^7$ provides a convenient source of fast neutrons, the maximum energy of which is determined by the energy of the bombarding protons. These neutrons may be used to investigate the threshold of any fast neutron reaction which occurs with an observable cross section within the range of neutron energies available. Preliminary reports[1] were published for the thresholds of fast neutron fission in uranium and thorium obtained by this method. This paper gives a more complete description of these experiments, together with the results of experiments on the threshold of fast neutron fission in uranium, in which the neutrons were obtained from thin foils of lithium bombarded with protons. As a part of this problem, the yield of neutrons from thin foils of lithium was measured as a function of the energy of the bombarding protons.[2]

THICK TARGET EXPERIMENTS

In these experiments the uranium and thorium targets were bombarded with neutrons obtained from thick targets of lithium metal or lithium

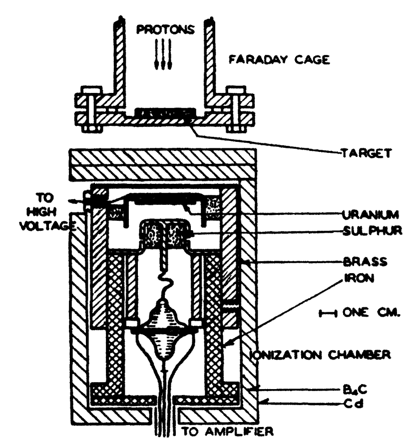


Fig. 1. Arrangement for measuring neutron fission.

* This work was completed in 1941 and has been recently declassified. Even though more accurate values may have been made since then, these results are of value due to their historical importance and may serve some use until more accurate values are made available.
[1] R. O. Haxby, W. E. Shoupp, W. E. Stephens, and W. H. Wells, Phys. Rev. **57**, 1088A (1940).
[2] J. E. Hill and W. E. Shoupp, Phys. Rev. **73**, 931 (1948).

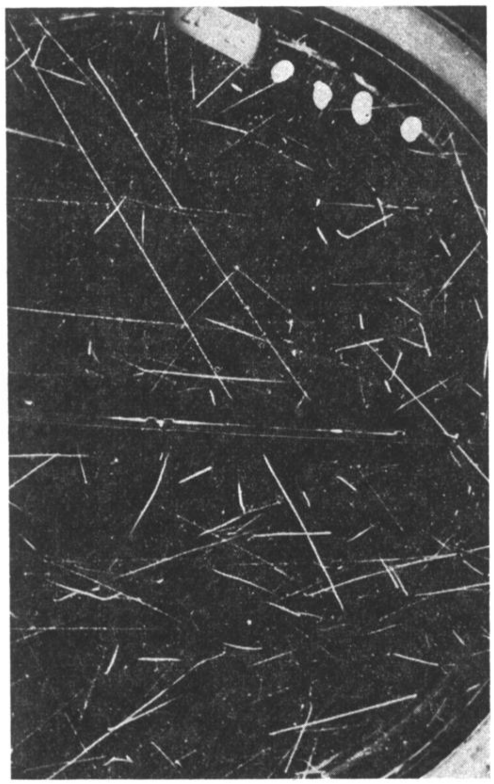
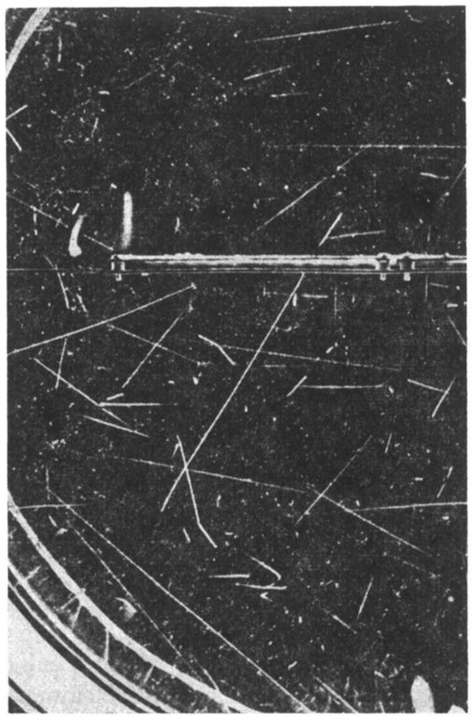


FIG. 1A. Paired tracks from a lithium disintegration. The chamber is filled with helium at low pressure in order to get alpha-tracks suitable for measurement. The dense track downward from the foil corresponds to the alpha-particle, the fainter track traversing the whole upper half part of the chamber belongs to the triton which has penetrated the mica foil carrying the lithium layers. Compare the different appearance of the track of a recoiling proton—to the right of the alpha-triton tracks and almost parallel to them—starting below the foil, penetrating it, and ending in the upper part of the chamber, the density increasing along the whole track.



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