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DISINTEGRATION OF BORON BY SLOW NEUTRONS

BY

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§ 1. Introduction.

The disintegration of boron by slow neutrons has been investigated by numerous authors using quite different techniques. Since the reaction is exotherm and sensitive to slow neutrons, it is rather appropriate to investigation, the energy release being well defined and the cross section being very large. That the reaction resulted in the formation of ^{7}Li and ^{4}He

$$^{10}_{5}\mathrm{B} + ^{1}_{0}\mathrm{n} \rightarrow ^{4}_{2}\mathrm{He} + ^{7}_{3}\mathrm{Li}$$

was shown by Chadwick and Goldhaber (1), Taylor and Goldhaber (2), and by Amaldi, d'Agostino, Fermi, Pontecorvo, Rasetti and Segrè (3). However, a determination of the ranges of the ^{4}He and ^{7}Li particles is rather difficult in view of the shortness of the ranges. The determination of the total energy released in the reaction depends furthermore on the knowledge of the energy range relation for α-particles; unfortunately, this relation is not very reliable for α-particles of short range. Therefore it is not surprising that the various results do not agree too well.

The investigations of the reaction can be arranged in 3 groups, *viz*, A: Methods by which the ranges of the He and Li particles are investigated. Walen (4), Rotblat (5), Fünfer (6), Haxel (7), Livingstone and Hoffmann (8), and O'Ceallaigh and Davies (9). It is a weak point in these investigations that the boron film is applied as a "thick" layer, which complicates the resolving of probably closely situated groups.

B: Determination of the total length of pared tracks of He and Li particles. Taylor and Dabholkar (10) (using boron impregnated photographic emulsion), Roaf (11), Bower, Bretscher and Gilbert (12), Kurtschatov, Morozov, Schep-

KIN and KOROTKEVICH (13) (using cloud chambers filled with a gas rich in boron).

C: Determination of the reaction energy. FÜNFER (6) (measuring the size of kicks in a boron coated ionization chamber). MAURER and FISK (14) and WILSON (15) (measuring the size of kicks in a ionization chamber filled with a gas rich in boron).

The results of these investigations are shown in Table I, where the first part gives the range values and the second part the reaction energy.

Table I.

Authors	Range in mm. of air			Reaction energy			
	He-range		Total range	calculated by He-range*		measured by kick size	
	normal level	excited level		normal level	excited level	normal level	excited level
WALEN	8.5	..	..	2.87	..	..	..
ROTBLAT	8.2	..	..	2.78	..	..	..
FÜNFER	8.6	..	..	2.90	..	2.52	..
HAXEL	9.4	6.4	..	3.11	2.19	..	..
LIVINGSTONE, HOFFMANN	8.0	6.6	..	2.72	2.26	..	..
O'CEILLAIGH, DAVIES	8.9	7.15	..	3.00	2.45	..	..
TAYLOR	..	..	11.4	..	..	..	..
ROAF	..	..	11.5	..	..	..	..
BOWER, BRETSCHER, GILBERT	..	7.0	11.3	..	2.40	..	..
KURTSCHATOV, MOROZOV, SCHEPKIN, KOROTKEVICH	(8.8)	(7.4)	11.3 9.4	(2.96)	(2.53)	..	..
MAURER, FISK	..	..	..	..	..	2.80	2.70 2.40 2.26
WILSON	..	..	..	..	..	2.88**	2.46

* The energy values are recalculated, using the energy-range relation of BLEWETT and BLEWETT. Proc. Roy. Soc. A. The publication is not at the author's disposal, and the partly extrapolated data are taken from the work of O'CEALLAIGH and DAVIES.
** Relative measurement, arbitrarily identified with the reaction energy to be expected from the masses (MATTAUCH and FLÜGGE).

It seems rather reasonable for the present to place the He ranges in two groups, *viz.* a main group corresponding to a reaction where the ^{7}Li atom is left in an excited level, and a weaker long range group leaving the ^{7}Li nucleus in the normal state.

The energy release to be expected from the masses is 2.99 MeV., according to the nuclear masses reported by LIVINGSTONE and BETHE (16), and 2.88 MeV., according to MATTAUCH and FLÜGGE's (17) statements.

The second part of Table I gives the values of the reaction energy calculated from the He ranges and from the size of kicks. When taking into consideration the energy release to be expected, the energy values of Table I seem to indicate that the main group corresponds to a reaction leaving the Li nucleus in an excited level with an energy of 0.4—0.7 MeV. The energy values given for the long range group appear to be fairly consistent with the expected energy; but, after all, the data of Table I concerning the long range group are rather conflicting. The three workers stating to have found both groups give a relative intensity quotient of the long range group to the main group of 1:3 or 1:4. On the other hand, the authors who investigated the total range, using cloud chambers, did not find any long range group, and BOWER, BRETSCHER and GILBERT estimated the intensity of the long range group, if existing, to be less than 1:10. The four groups given by MAURER and FISK agree neither with the cloud chamber reports nor with a similar investigation by WILSON, leading to a main group and a much weaker high energy group (relative intensity 1:15). KURTSCHATOV, MOROZOV, SCHEPKIN and KOROTKEVICH, using a not too convincing estimation of the partition ratio, attribute the main group (total range 11.3 mm.) to the normal state reaction and report in addition the finding of a short range group (total range 9.4 mm.) which corresponds to a reaction leaving the Li nucleus in an excited level.

Evidence of disintegration of boron by slow neutrons following the equation

$$^{10}_{5}\mathrm{B} + ^{1}_{0}\mathrm{n} \rightarrow ^{1}_{1}\mathrm{H} + ^{10}_{4}\mathrm{Be}$$

is given by MAURER and FISK and by KURTSCHATOV, MOROZOV, SCHEPKIN and KOROTKEVICH.

§ 2. Experimental Method.

In preliminary investigations, a 24 cm. cloud chamber was filled with helium and equal parts of liquid $B(O\,CH_3)_3$ and methyl alcohol, the total pressure being about 30 cm. Hg. The high stopping power of the boron ester, however, caused the length of the tracks to be smaller than planned. Better conditions were obtained by using the ethyl ester of boron, $B(O\,C_2H_5)_3$, mixed with equal parts of methyl alcohol. When adding helium to a total pressure of about 30 cm. Hg, the tracks of boron disintegration appeared with a length of about 50 mm. in the chamber. The diaphragm made from commercial rubber was slightly attacked by the boron gas, and frequent refilling with boron ester was necessary.

The neutrons were produced by the high tension apparatus in this institute by bombarding beryllium with deuterons. The target and the chamber were surrounded by paraffin. The emission of neutrons was synchronized to the expansion by a switch in the high tension power supply of the ion source. Stereoscopic photographs were taken with an optical system containing a Contax camera and a mirror placed vertically on one side of the cloud chamber and giving complete direct and mirror images of the chamber. The film plane of the camera was corrected in order to match the oblique projection.

Measurements of the films were carried out by means of the same arrangement, using the same camera and mirror as in the original photograph. The natural size images of the tracks were examined in space, employing the method described by Nuttal and Williams (18) which, with some modification, has been used in this institute (19). The method was found to be both convenient and accurate and to yield the additional advantage that the observer, simultaneously with the measurement, is able to control the shape and the position of the tracks. In view of the appreciable change in stopping power of the gas with changing room temperature, the stopping power of the gas was frequently controlled (at about every 40 picture) with Po-α particles. The α-source was placed inside the chamber in a small brass holder which was kept on a slightly higher temperature in order to prevent vapour condensation. The α-particles were synchronized to the expansion by an electromagnetic shutter. The range r_n of the tracks in standard air was calculated according to the equation

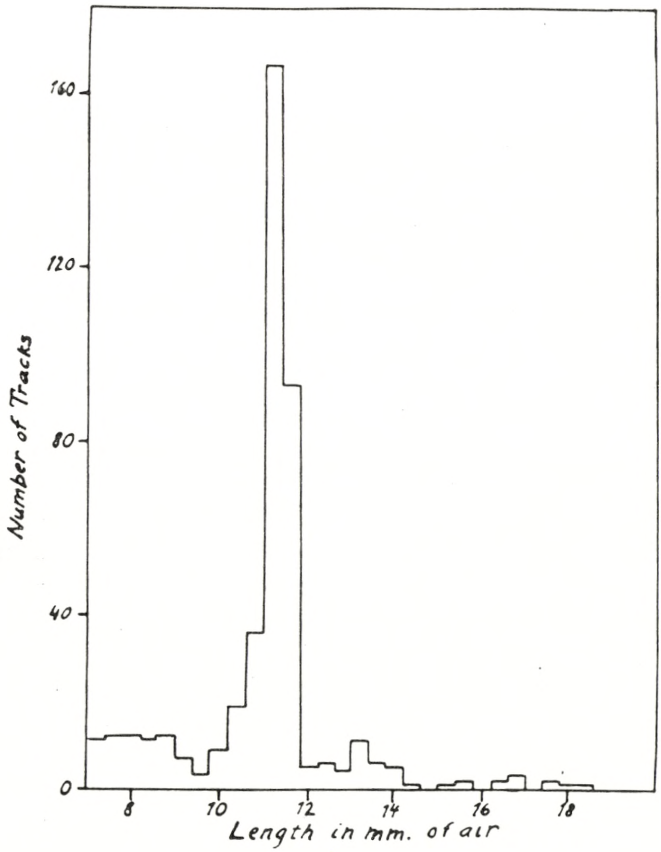

Fig. 1. Statistics of tracks produced by boron disintegrations and recoiling atoms.

$$r_n = 39.0 \frac{r}{r_\alpha} \text{ mm.},$$

where r is the measured length of the tracks and r_α the length of the α-tracks, the range of Po-α particles being 39.0 mm. at 760 mm. Hg. and 15° C.

A histogram of about 450 tracks is shown in Fig. 1. In agreement with most previous investigations performed with the same method, only a single group with a range of 11.2—11.4 mm.

appears above the background of recoil tracks. In accordance with BOWER, BRETSCHER and GILBERT it was found reasonable to estimate a possible long range group to be at least 10 times weaker. A faint trace of a group is visible in the neighbourhood of $13^1/_2$ mm. A definite conclusion, however, is impossible for statistical reasons.

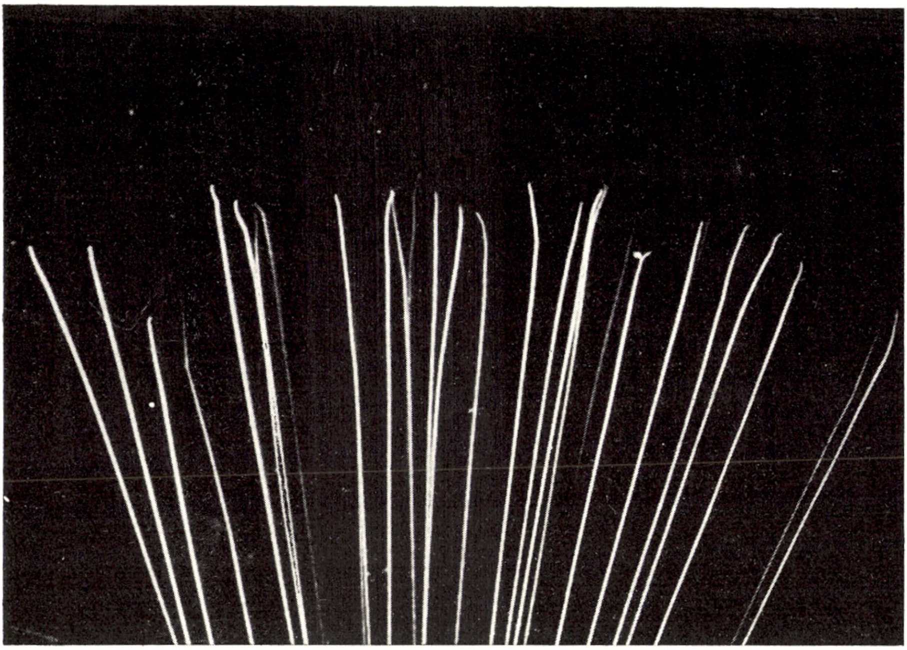

Fig. 2. Later part of the tracks of a beam of α-particles. Demonstrates the tendency to fortuitous bending and curvature close to the very end of the tracks.

A closer examination of the tracks yielded a new method which makes it possible among all tracks in the chamber to pick out those of the boron disintegration. The method is based on the fact that the very ends of the tracks of nuclear particles tend both to fortuitous bending and curvature and to a more frequent branching due to nuclear collisions. Hence, it follows that the tracks of the boron disintegration may be expected to show these characteristic features of low velocity in both ends of the tracks, while the recoil tracks, having high velocities in the first traversed part of the track, will only appear with bending in one end.

Fig. 2 is a reproduction of the later part of a beam of α tracks from the control study, and Fig. 3 reproduces the tracks of a boron disintegration showing fortuitous bending in both ends[1].

A selection embracing only those tracks which show for-

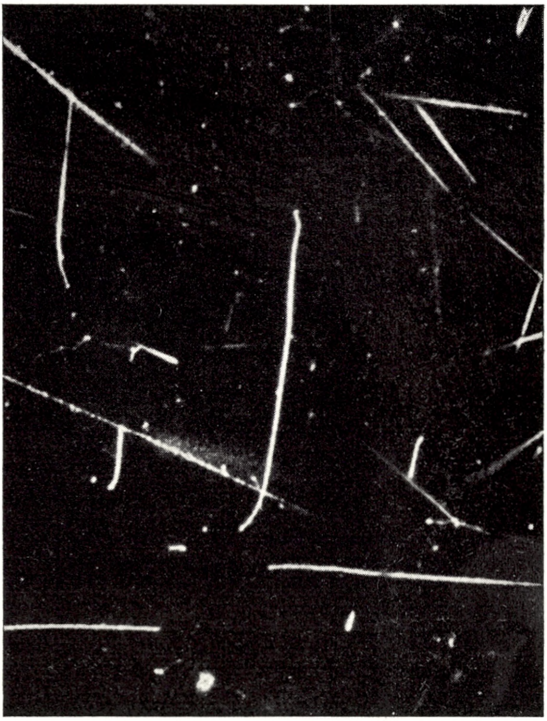

Fig. 3. Track of boron disintegration. The type of track is established by means of the characteristic feature, i. e., the fortuitous bending of both ends of the track demonstrates that the velocity is small in both ends. The track is thus produced by two ionizing particles originating somewhere in the track and moving in opposite directions.

tuitous bending or branching in both ends will rather certainly include a great deal of the boron disintegration. The excluded part without traceable bending in both ends must comprise all the tracks of recoil atoms and some of the boron disintegrations.

[1]) The optical examination makes it possible to detect deformities of the end parts of the tracks considerably less pronounced than by the obvious specimen reproduced here in order to illustrate the method. Fig. 2 demonstrates further the fact that fortuitous bending and curvature are more useful indications of low velocity than branching due to nuclear collision.

The examination of the tracks is facilitated when the neutron source is relatively weak and hence the chamber less occupied of tracks.

A histogram including about 400 selected tracks of a length

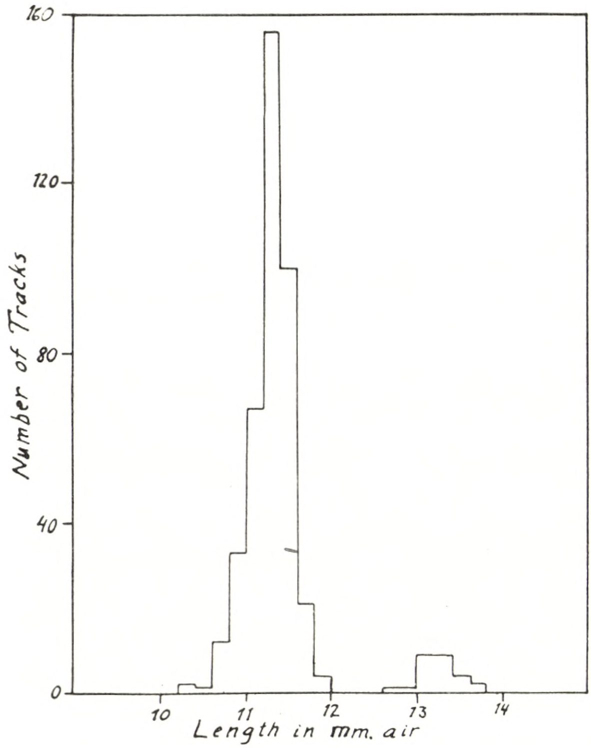

Fig. 4. Statistics of selected tracks. The selection includes only the type of tracks showing fortuitous bending in both ends and involves a complete removing of the background of recoil tracks. In addition to the main group a 15 times weaker long range group is found, the mean range of the two groups being 11.3 and 13.2 mm., respectively.

between 7 and 19 mm. is reproduced in Fig. 4. It demonstrates that the method succeeded in a complete removal of the background. The histogram further shows clearly a very weak group of long range. The total mean ranges of the two groups are found to be 11.3 and 13.2 mm., and the relative intensity 1 : 15. The long range tracks of the weak group appear to be very similar to the tracks of the main group, indicating that the reaction is of the same type—$^{10}B(n,\alpha)^7Li$—only leaving the ^7Li-nucleus in the normal state or in a level of lower excitation. Fig. 5 is a reproduction of a long range track of the weak group. That an identification of the long range group with the boron disinte-

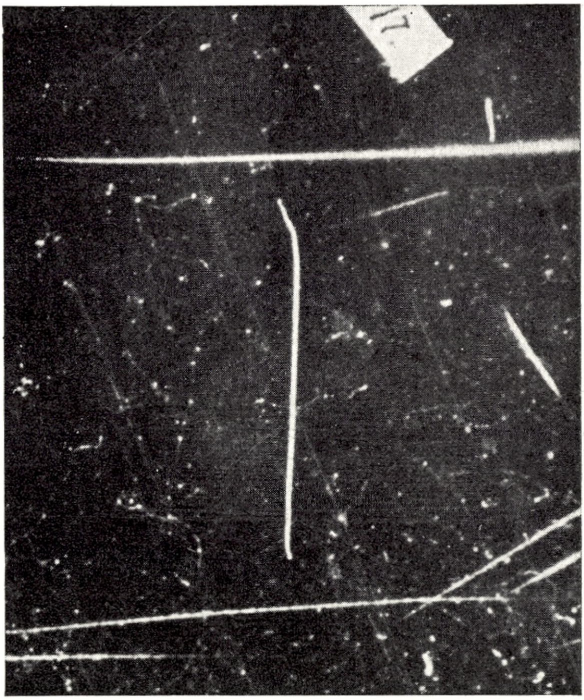

Fig. 5. Track of the long range group. Shows the characteristic bending in both ends.

gration—$^{10}B(n,p)^{10}Be$— is excluded is established in the following part of this work.

§ 3. Examination of Track Types.

It has been demonstrated that the selection of tracks showing fortuitous bending in both ends makes it possible to remove completely the background of recoil atoms. The selected part of the tracks is found to include a great deal of the boron disintegration, but any disintegration in two heavy particles of atoms in the gas by slow neutrons might show tracks of similar features.

The gas in the cloud chamber is known to contain H, He, B, C, N, and O (nitrogen as an impurity in the helium gas). Taking this into account, it might be possible that the weak long range group is produced not by the reaction—$^{10}B(n,\alpha)^{7}Li$—, but by one of the following reactions—$^{10}B(n,p)^{10}Be$—or—$^{14}N(n,p)^{14}C$—. The

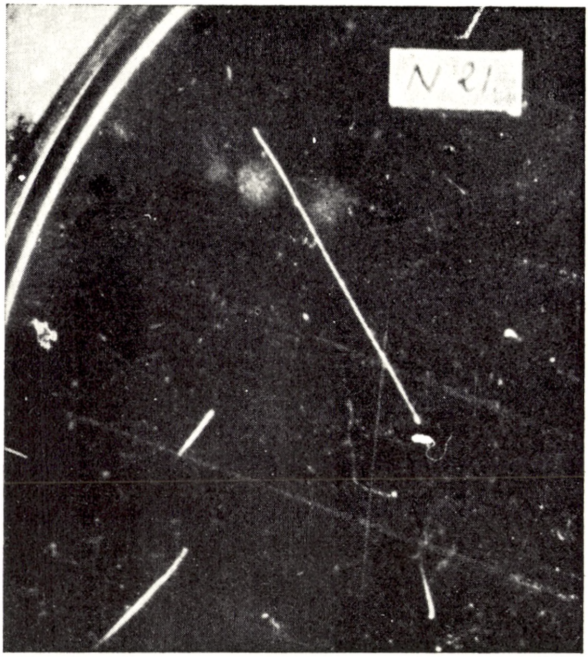

Fig. 6. Track of a nitrogen disintegration. The small lump in the lower end of the track is produced by the recoiling ^{14}C-nucleus.

disintegration of nitrogen by slow neutrons has been studied by Chadwick and Goldhaber (20), Bonner and Brubaker (21), and Burcham and Goldhaber (22) who have finally identified it with the reaction—$^{14}N(n,p)^{14}C$—. Bonner and Brubaker, using cloud chambers, observed a total range of 10.6 mm. This range is so much smaller than the observed range of 13.2 mm. of the long range group of Fig. 4 that it is difficult to attribute this group to nitrogen disintegration. In order to settle the question it was decided to study selected tracks in a gaseous mixture fairly rich in nitrogen and poor in boron ester. The cloud chamber was filled with air and methyl alcohol to a total pressure of about 18 cm. Hg. Though the piston and the rubber diaphragm were exchanged with new parts never exposed to boron ester, many boron disintegrations were found to occur (due to boron ester dissolved in the rubber gaskets), and both the main group and

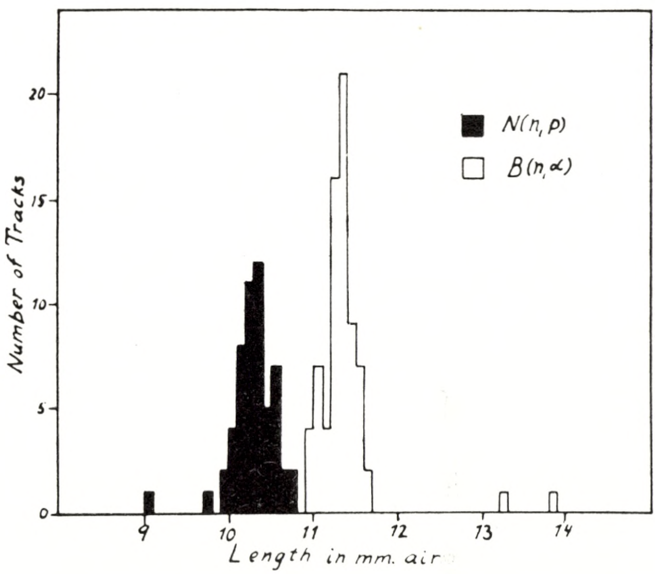

Fig. 7. Statistics of selected tracks of boron and nitrogen disintegration. The mean range of the tracks of nitrogen disintegration is found to be 10.3 mm. and for the main group of boron disintegrations 11.3 mm. The long range group is weakened following the main group and unaffected by the presence of nitrogen.

a few tracks of the long range group appeared, while the nitrogen disintegrations failed to appear. Rather close to the range value given by BONNER and BRUBAKER for the tracks of the nitrogen disintegration, a group of tracks appeared in the excluded part of the tracks, and many of these tracks stood out with a small lump in one end. The feature of the tracks makes it possible to select those of nitrogen disintegration by picking out the tracks showing fortuitous bending in one end and equipped with a small lump in the other end, the part of the track close to the lump being rather straight due to the corresponding high velocity of the proton[1]. The length of the lump is usually about 1—1$^1/_2$ mm. in the chamber. Fig. 6 is a reproduction of the tracks of a nitrogen disintegration showing the small lump in the lower end of the track. A histogram of about 70 selected boron disintegrations and 55 selected nitrogen disintegrations is shown in Fig. 7. The mean range of the nitrogen disintegration is found to be 10.3 mm., and for the main group of boron disintegration 11.3 mm., in accordance with the value obtained from Fig. 4. The long range group is weakened following the main group, and is unaffected by the presence of nitrogen. Besides, the features of the tracks state that the long range group belongs to the same type of disintegration as the main group and can neither be ascribed to the reaction—$^{14}N(n,p)^{14}C$—nor to the reaction—$^{10}B(n,p)^{10}Be$—, since the features of the tracks of the latter reaction are expected to be similar to the features of the tracks of nitrogen disintegration.

§ 4. Search for Tracks of the Reaction $^{10}B(n, p)^{10}Be$.

A study of the features of the tracks in a gaseous mixture containing nitrogen and boron ester has demonstrated the possibility of distinguishing between tracks produced by the two types of disintegration (n,α) and (n,p), and the weak long range group of Fig. 4 is established as produced by the reaction—$^{10}B(n,\alpha)^7Li$—. More extensive experiments were carried out in order to examine possible tracks produced by the boron disintegration—$^{10}B(n,p)^{10}Be$—by slow neutrons. The chamber was filled with helium and equal parts of liquid $B(O\ C_2\ H_5)_3$ and ethyl alcohol to a pressure of about 50 cm. Hg. Two types of tracks were selected separately, one of them being the boron disintegration—$^{10}B(n,\alpha)^7Li$—showing fortuitous bending in both ends, and the other one the tracks only bended in one end and lumpy in the other.

A histogram of about 1000 selected tracks is given in Fig. 8, showing the main group and the long range group of ranges 11.4 and 13.4 mm., respectively. The relative intensity of the two groups is 1:15 in agreement with the ratio given in § 2 (Fig. 4).

[1] The selection of tracks of this type is less certain than the selection of the tracks of the boron disintegration. Difficulties in recognizing the lump cause a somewhat larger part of the tracks to escape the selection.

Tracks of the type (n,p) were found as a very weak group with a range of about 10 mm. This is so close to the range (10.3 mm.) of the nitrogen disintegration given in Fig. 7 that it is most reason-

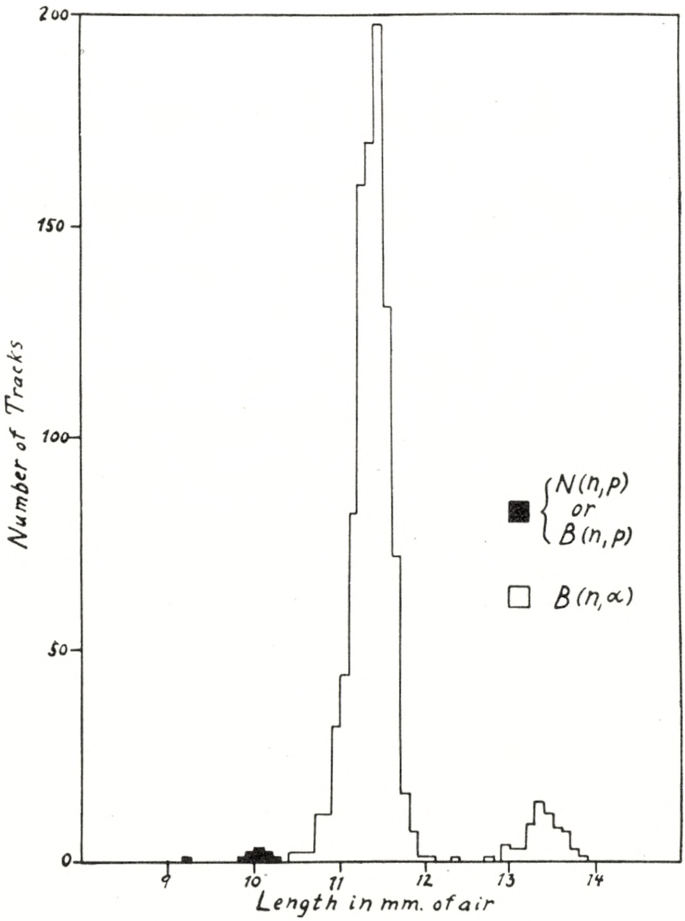

Fig. 8. Statistics of selected tracks of the two types of disintegration (n, α) and (n, p). The mean range of the two groups of boron disintegration is found to be 11.4 and 13.4 mm., respectively. The small group of tracks of the type (n, p) having a range of about 10.0 mm. is attributed to the reaction ^{14}N (n, p) ^{14}C. No trace of the disintegration ^{10}B (n, p) ^{10}Be appears in the figure.

able to assume the nitrogen disintegration—$^{14}N(n,p)^{14}C$—to be responsible for the group. No trace of the enquired boron disintegration—$^{10}B(n,p)^{10}Be$—has been found, though the selection method stands a good chance of finding the group even if the range happens to be rather close to the range of the main group or the long range group. Evidently, the boron disintegration—$^{10}B(n,p)^{10}Be$—by slow neutrons is pretty rare (somewhat less than 1 % of all disintegrations) or the total range is so small that it is impossible to detect the lump.

§ 5. Preliminary Discussion.

The disintegration of boron (and nitrogen) by slow neutrons has been studied in the following gaseous mixtures: (1) helium and the vapours of equal parts of CH_3OH and $B(OC_2H_5)_3$, total pressure about 30 cm. Hg. (2) air and the vapours of CH_3OH and an unknown small amount of $B(OC_2H_5)_3$, total pressure about 18 cm. Hg, and (3) helium and the vapours of equal parts of C_2H_5OH and $B(OC_2H_5)_3$, total pressure about 50 cm. Hg. The values of the mean total ranges of the tracks are given in Table II.

Table II. Total range in mm. of air.

Gas mixture	$^{14}N(n, p)^{14}C$	$^{10}B(n, \alpha)^{7}Li$	
(1)	..	11.3	13.2
(2)	10.3	11.3	..
(3)	(10.0)	11.4	13.4
Average mean range..	10.3	11.35	13.3

The stopping power of the gaseous mixtures was controlled with Po-α particles (range 39 mm. of air) instead of α-particles of the same short range as the disintegration particles. This might lead to a systematic error in the performed reduction of the ranges to normal air conditions. On the other hand, it has been demonstrated by Gurney (23) that the stopping power of helium for α-particles is rather independent of the particle range. Since a considerable amount of helium does not influence the reduction, and since, moreover, the measured range of the main group using the gaseous mixtures rich in He (1) and (3) lead to nearly the same value as the gas mixture (2) containing air, it was found reasonable to use the average of the range values given in Table II as mean total range reduced to normal air conditions.

The results of our experiments are given in Table III together with corresponding information from other workers using similar techniques.

Table III. Total range in mm. of air.

Author	$^{10}B(n,\alpha)^7Li$ Long range group	Main group	Short range group	$^{10}B(n,p)^{10}Be$
TAYLOR, DABHOLKAR	..	11.4	..	..
ROAF	..	11.5	..	..
BOWER, BRETSCHER, GILBERT	no or < 1:10*	11.3	..	..
KURTSCHETOV, MOROZOV, SCHEPKIN, KOROTKEVICH	..	11.3	9.4	5.7
This work	13.3 (1:15)*	11.35	no or < 1:100*	no or < 1:100* or very short

* Intensity estimation relative to the main group.

It will be seen that the range determinations of the main group agree surprisingly well and that only the method of track selection has been able to state the existence of the long range group and to point out the absence or weakness of other groups.

§ 6. Examination of the Partition Ratio.

The total range of the tracks is inappropriate for the determination of the reaction energy. For this purpose, the range of the He-particle must be known either from direct measurements or from determinations of the partition ratio of the two particle ranges together with the total range. BOWER, BRETSCHER and GILBERT succeeded in detecting the common point of origin of the He- and Li-particles by a special technique for measuring the track density along the photographic image of a cloud track; they report that on many tracks the discontinuity in density could easily be seen by eye. The latter technique has not been useful in this work. A discontinuity in density was never observed by eye, not even in the tracks of a short run with a still smaller stopping power, giving a total range in the chamber of about

100 mm. No photometrical measurements were carried out. An examination of the partition ratio was performed by studying the boron disintegrations from a very thin layer of boron evapo-

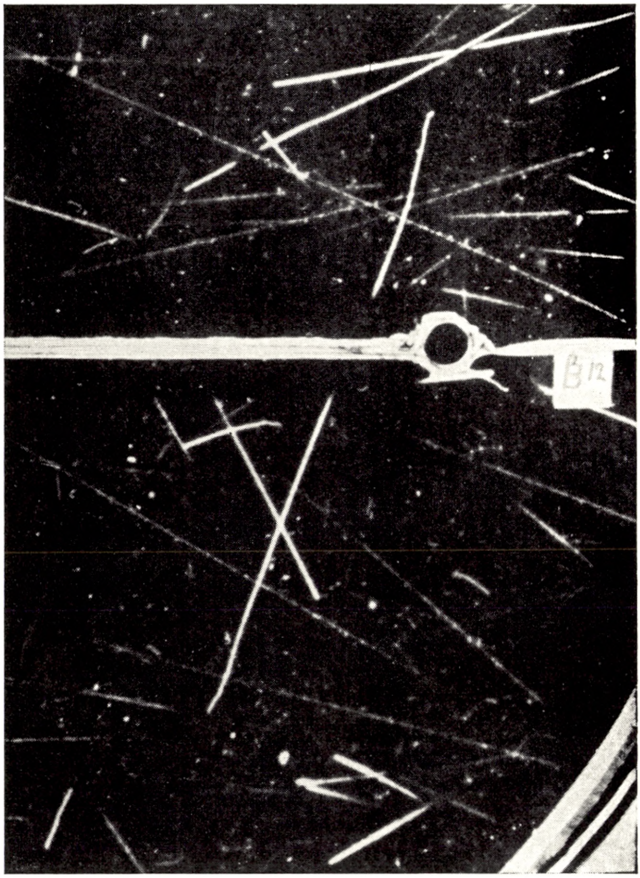

Fig. 9. Pared tracks of a boron disintegration. The boron is evaporated as a very thin layer (0.04 mg/cm^2) on a gold leaf. The white band in the middle of the photo is the frame supporting the gold and boron foils. The short range Li-atom goes upwards and the He-atom downwards through the gold foil. It will be noticed that the tracks are not visible right up to their common point of origin, but that the foil on both sides is surrounded by a condensation-free space.

rated on a gold leaf and supported by a frame in the middle of the chamber. The thickness of the boron film was 0.04 mg/cm^2 and that of the gold leaf 0.16 mg/cm^2, corresponding to about

0.4 and 0.2 mm. of air, respectively. The chamber was filled with helium and ethyl alcohol to a pressure of about 15 cm. Hg.

The number of boron disintegrations from the thin foil is extremely small compared with the number of recoil tracks in the chamber, but it is still possible to recognize the tracks of boron disintegration and to remove to a large extent the background of recoil tracks. The selection has to contain pared tracks starting from the boron foil in opposite directions and showing the characteristic features of low velocity in the ends. Fig. 9 is a reproduction of the pared tracks of a boron disintegration showing fortuitous bending in the ends. The white band in the middle of the photo is the frame supporting the gold and boron foils. The short range Li-atom goes upwards and the He-atom goes downwards through the gold foil.

The result of the measurements is given in Table IV[1]. The Table contains 6 pared tracks, the first 5 of which are estimated to be reliable. The total length of track No. 6 points to a boron disintegration, but the partition ratio diverges so much that the track is supposed to be due to a sporadic contamination with boron ester. The point of origin is then not in the foil, but somewhere in the track.

Table IV.

Track No.	Partition ratio
1	1.64
2	1.52
3	1.68
4	1.64
5	1.50
6	(1.18)

Mean partition ratio 1.60.

This supposition is supported by the fact that a few boron disintegrations originating in the gas of the chamber are found in this part of the investigation despite all possible care, such as

[1] More extensive experiments were planned, but restrictions in the power supply have prevented their performance.

application of new rubber parts, new velvet and daily renovation of the gas and alcohol filling in the chamber.

The mean partition ratio was found to be 1.60 in reasonable accordance with the value 1.62 given by BOWER, BRETSCHER and GILBERT. Combining the average 1.61 of these determinations and the value 11.35 mm. for the total range, the mean range in standard air was found to be 7.0 mm. for the He-atom and 4.35 mm. for the Li-atom.

§ 7. Discussion.

The final problem of the investigation is the determination of the energy released by a reaction leaving the Li-nucleus in the normal state; unfortunately, the examination of the partition ratio of the long range groups has failed, and even a considerably more extensive examination, using the method described in § 6, is hardly able to give an exact measurement of the ratio due to the weakness of the group.

The partition ratio could be determined by means of velocity-range relations for He- and Li-particles combined with the known total range. Though this relation is somewhat questionable for α-particles of short range and unknown for Li-atoms, it was found worth examining a semi-theoretical solution. The velocity range relation for α-particles to be used is based on the Cornell University energy range curves. The velocity range relation for Li-particles is produced from the He-relation by means of BLACKETT's (24) semi-empirical formula

$$R = \text{const} \cdot m \cdot z^{-\frac{1}{2}} \cdot f(v),$$

where R is the range, m the mass, z the atomic number, and v the velocity; the function f(v) is independent of the kind of nucleus. Using these relations, two sets of ranges and velocities R_{He}, v_{He} and R_{Li}, v_{Li} are chosen, satisfying the two conditions: $R_{He} + R_{Li} = R_T$ ($R_T = 11.35$ mm. and 13.3 mm. for the main group and the long range group, respectively) and $\frac{v_{He}}{v_{Li}} = \frac{7}{4}$. Table V shows the semi-empirical range values and the experimental results given in § 6 of this work and by BOWER, BRETSCHER and GILBERT. A comparison between the semi-empirical and the experimental range values of the main group indicates the usefulness of the method, especially by extrapolation to the rather closely situated long range group. The calculated partition ratios are therefore supposed to be about 3—4 % too high in both groups and the value to be used for the long range group turns out to be 1.68, giving a He range of 8.35 mm. of air.

According to the Cornell University curves, the energy of a 7.0 mm. and a 8.35 mm. α-particle is 1.32 MeV. and 1.59 MeV., respectively. The energy of the He-particle being $\frac{7}{11}$ of the energy released by the disintegration of boron, the main group and the long range group correspond to reaction energies of $\frac{11}{7}\cdot 1.32 = 2.07$ MeV. and $\frac{11}{7}\cdot 1.59 = 2.50$ MeV., respectively. The measurements of BLEWETT and BLEWETT indicate an energy some 15 % higher for a given α-range, and lead to a reaction energy of

Table V.

	Semi-empirical			BOWER, BRETSCHER, GILBERT			Our work		
	R_{He}	R_{Li}	$R_{He}:R_{Li}$	R_{He}	R_{Li}	$R_{He}:R_{Li}$	R_{He}	R_{Li}	$R_{He}:R_{Li}$
Main group..	7.1	4.25	1.67	7.0	4.3	1.62	7.0	4.35	1.60
Long range group.....	8.45	4.85	1.74	..	..	..	8.35*	4.95*	1.68*

* Corrected semi-empirical values.

2.40 MeV. for the main group and 2.82 MeV. for the long range group. Considering a reaction energy of 2.88 MeV. to be expected from the masses given by MATTAUCH and FLÜGGE, the experiments tend to confirm the measurements of BLEWETT and BLEWETT, and it was found reasonable to conclude that the long range group corresponds to a reaction leaving the Li-nucleus in the normal state, and that the Li-nucleus has an excited level at 2.82 — 2.40 = 0.42 MeV. The relative intensity of the two groups indicates that about 93 $^0/_0$ of all boron disintegrations by slow neutrons lead to the excited level.

Further evidence about excited states in the ^{7}Li-nucleus obtained from the results of other workers studying the same or other reactions are given in Table VI, and will be seen to

Table VI.

Author	Reaction	Measured object	Excitation energy in MeV.
Maurer, Fisk	$^{10}B(n,\alpha)\,^7Li$	α-groups	0.2 0.41 0.64 0.84?
Wilson	$^{10}B(n,\alpha)\,^7Li$	α-groups	0.42
This work	$^{10}B(n,\alpha)\,^7Li$	α-groups	0.42
Bothe (25)	$^7Li(\alpha,\alpha)\,^7Li$	γ-rays	0.2 0.39 0.59 0.85
Fowler, Lauritsen (26)	$^7Li(p,p)\,^7Li$	γ-ray	0.495
Several workers (27)	$^6Li(d,p)\,^7Li$	p-groups	0.445
Williams, Shepherd, Haxby (28)	$^6Li(d,p)\,^7Li$	γ-rays	0.40
Graves (29)	$^9Be(d,\alpha)\,^7Li$	α-groups	0.494
Roberts, Heydenburg, Locker (30)	$^7Be + e^-\ ^7Li + K$	γ-rays	0.425
Maier-Leibnitz (31), Rubin (32)	$^7Be + e^-\ ^7Li + K$	γ-rays	0.465

confirm the existence of a single excited level with an excitation energy of 0.4—0.5 MeV. Bothe's results indicating the existence of more than a single excited level is, though doubtful, not out of question, but the results of Maurer and Fisk are inconsistent with the work of Williams and the results of this work, and are most likely due to some uncertainty in the physical conditions of the experiments. Similar circumstances are probably responsible for the registration reported by the same authors of the boron disintegration $^{10}B(n,p)^{10}Be$, since this reaction according to § 5 Table III is rather infrequent or the tracks are very short.

§ 8. Disintegration of Nitrogen by Slow Neutrons.

Tracks of the nitrogen disintegration have been studied in § 3 and the tracks are found to consist of a pròton track and a small lump corresponding to the recoiling ^{14}C-nucleus. The length of the lump is usually about 1—1 $^1/_2$ mm. in the chamber, corresponding to 0.3 mm. of air. The total track length being 10.3 mm., the track of the proton was found to be 10.0 mm. of air. According to the range velocity relation for protons given by Livingstone and Bethe, a 10.0 mm. proton corresponds to an energy of 0.56 MeV. and gives a reaction energy of $\frac{15}{14} \cdot 0.56 =$ 0.60 MeV., which is slightly lower than the value of 0.62 MeV. used for determinations of the mass of the ^{14}C-nucleus.

Summary.

The disintegration of boron by slow neutrons has been studied in a cloud chamber filled with boron ester.

A selection method based on the difference in feature of the tracks of boron disintegration and the tracks of recoiling atoms has made a complete removal of the background possible. A main group and a 15 times weaker long range group have been found, the total length being 11.35 and 13.3 mm. of air, respectively, the former in agreement with several authors. The long range group has been demonstrated to belong to the same type of disintegration as the main group—$^{10}B(n,\alpha)^7Li$—. The absence or weakness of the boron disintegration—$^{10}B(n,p)^{10}Be$—has been demonstrated by a search for tracks similar to those of the nitrogen disintegration—$^{14}N(n,p)^{14}C$—also studied by a selection method. An examination of the tracks going out from a very thin boron foil placed in the chamber has enabled a rough determination of the partition ratio (1.60) of the main group in reasonable agreement with Bowers, Bretscher and Gilbert. A semi-empirical extrapolation leads to a determination of the partition ratio (1.68) of the long range group. Hence, the He-particles have ranges of 7.0 mm. for the main group, and 8.35 mm. for the long range group, and the reaction energies deduced by means of the energy-range relation of Blewett and Blewett were found to be 2.40 and 2.82 MeV. Consequently, about 93 $^0/_0$ of all boron disintegrations by slow neutrons lead to an excited state with an energy of 0.42 MeV. and, in agreement with

several workers, no other excited level in the ^{7}Li-nucleus is found to appear in this or other reactions leading to the same nucleus.

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