THE DISINTEGRATION OF NITROGEN BY SLOW NEUTRONS

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1. Introduction

The disintegration of nuclei by slow neutrons with the emission of heavy particles has been established in three cases, namely for lithium, boron and nitrogen. The transformation of nitrogen was first detected in an ionization chamber connected to a linear amplifier and oscillograph, and the energy released in the disintegration was estimated from the size of the oscillograph deflections to be about $0{\cdot}5 \times 10^6$ e.v.* The disintegration process was assumed to be

$$^{14}N + {}^{1}n \rightarrow {}^{11}B + {}^{4}He. \tag{1}$$

Bonner and Brubaker† investigated the transmutation of nitrogen by slow neutrons in an expansion chamber, and observed a group of tracks of range 1·06 cm. of air. Assuming reaction (1) they calculated that the energy release was $2{\cdot}33 \times 10^6$ e.v., which is in disagreement with the ionization measurements by much more than the experimental error. If, however, we assume that the disintegration process is represented by the reaction

$$^{14}N + {}^{1}n \rightarrow {}^{14}C + {}^{1}H \tag{2}$$

instead of by reaction (1), the energy release calculated from the range given by Bonner and Brubaker is $0{\cdot}58 \times 10^6$ e.v., which is in good agreement with the ionization measurements. Bonner and Brubaker‡ advanced further indirect evidence that reaction (1) cannot take place with slow neutrons, by calculating the energy release from the data of two related reactions; they found it to be $-0{\cdot}28 \times 10^6$ e.v., which agrees well with the estimate from the masses recently given by Aston§ and Oliphant‖. The mass of the nucleus ^{14}C is not known from any other reaction, so that it is not possible to calculate the energy release in

* Chadwick and Goldhaber, *Nature*, 135 (1935), 65; *Proc. Camb. Phil. Soc.* 31 (1935), 612.
† Bonner and Brubaker, *Phys. Rev.* 48 (1935), 469; 49 (1936), 223.
‡ Bonner and Brubaker, *Phys. Rev.* 49 (1936), 778.
§ Aston, *Nature*, 137 (1936), 357.
‖ Oliphant, *Nature*, 137 (1936), 397.

reaction (2) from the mass scale. It was, furthermore, not possible in either of the above-mentioned experiments to decide whether a proton or an α-particle was emitted in the transmutation, and it therefore seemed desirable to establish by a direct method that a proton is emitted.

2. Experimental method

A direct decision between the emission of singly or of doubly charged particles can be obtained by observing the tracks of the particles in photographic emulsions of different sensitivity. The photographic method has already been applied to a study of the disintegration of lithium and of boron by slow neutrons by impregnating the emulsion with compounds containing these elements*. The impregnation process is not necessary for an investigation of nitrogen, since the gelatine of the emulsion contains about 18 % of this element, which is a large amount compared with the concentrations that can be attained by impregnation. In our experiments we have used the Ilford R emulsions†, whose response to the passage of charged particles has been studied carefully by Taylor‡. He finds that the R_1 emulsion records α-particles but not protons, which have a smaller specific ionization, whereas the more sensitive R_2 emulsion records protons as well as α-particles. A study of the nitrogen disintegration in the two emulsions should therefore enable the charge of the disintegration particle to be ascertained.

Plates coated with the R_1 and R_2 emulsions were exposed to slow neutrons together with a plate containing a known amount of boron for comparison purposes. The neutron source was 100 milligrams of radium mixed with beryllium powder, and the plates were shielded from direct γ radiation by 20 cm. of lead. The effect of scattered γ radiation was reduced by surrounding the source by 5 cm. of lead and the plates themselves by 1 cm. This arrangement was surrounded by about 10 cm. of paraffin wax to slow down the neutrons. Two sets of R_1 and R_2 plates were exposed, one transversely to the primary neutrons and the other in a plane containing the source. The latter plates were intended to record recoil protons, produced by collisions of fast neutrons with hydrogen atoms in the gelatine, as well as the nitrogen disintegration; in the former set of plates the number of measurable recoil proton tracks was small. In order to distinguish clearly between effects due to slow and to fast neutrons, a set of plates exactly similar to the others, but surrounded by 1 mm. of cadmium, was also exposed. The plates were left for about 3 weeks and were then developed and examined under the microscope.

* Taylor and Goldhaber, *Nature*, 135 (1935), 341; Taylor, *Proc. Phys. Soc.* 47 (1935), 873; Taylor and Dabholkar, *ibid.* 48 (1936), 285.

† See *Photography as an Aid to Scientific Work* (Messrs Ilford, Ltd.).

‡ Taylor, *Proc. Roy. Soc.* 150 (1935), 382.

3. Results

Counts were made of the number of tracks per unit area on the plates which had been exposed in the transverse position, and on unexposed control plates. The relative numbers are given in Table I; the statistical fluctuation is about 10 % in each case. The actual number of tracks per square centimetre of plate was about fifty times the number given in the table. The tracks on the unexposed control plates are due to radioactive contamination present in all photographic emulsions. The large number of tracks on the exposed R_2 plate compared with the much smaller number on the similarly exposed R_1 plate indicates the production

Table I

Type of plate	Exposed	Unexposed
R_2	100	10·3
R_1	7·1	6·3

of protons in the emulsion during the exposure. In order to show that these protons were due to the disintegration of nitrogen by slow neutrons, measurements of track lengths in the plane of the emulsion were made on both the R_1 and the R_2 plate; the distribution is shown in Fig. 1. It is seen that whereas the

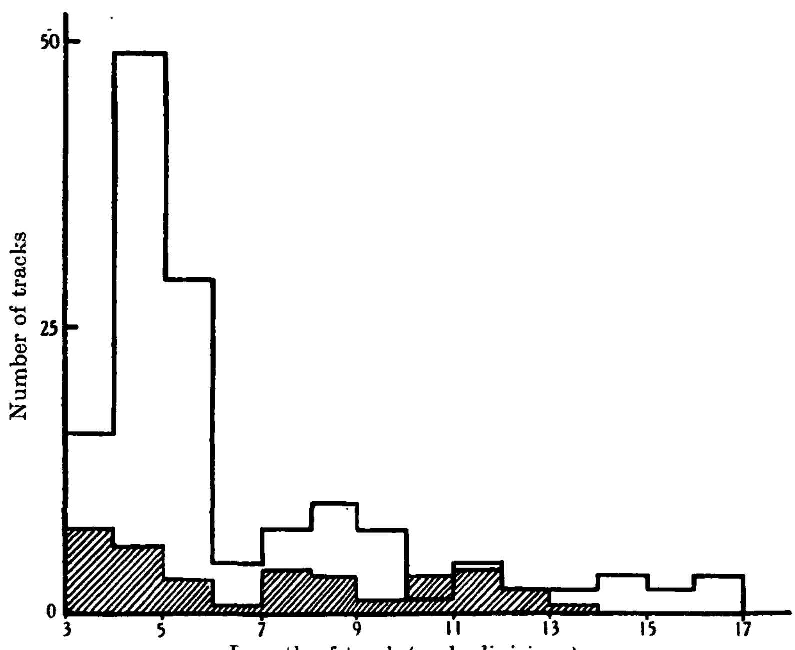

Figure 1. Distribution of track lengths on R_1 plate (shaded) and R_2 plate (unshaded).

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tracks on the R_1 plate, which are presumably due to radioactive contamination, show a nearly uniform distribution, the majority of those on the R_2 plate fall into a short range group. The equivalent range in air of this group was calculated from the known stopping power of the emulsion for α-particles, and was found to be just over 1 cm., in agreement with Bonner and Brubaker's value for the combined range of the disintegration particles in the nitrogen reaction. We made no attempt to fix the range more accurately.

The number of tracks in the 1 cm. group on the cadmium screened R_2 plate was about 10 % of the number on the unscreened R_2 plate. In a similar experiment with boron impregnated plates, cadmium shielding was also found to reduce the number of disintegrations to about 10 %. The strong absorption by cadmium proves that the disintegration of nitrogen is mainly due to neutrons of thermal energy.

4. Discussion

The conclusion from these results, that protons are emitted in the disintegration of nitrogen by slow neutrons, rests on two assumptions; first that the R_1 and R_2 plates are equally sensitive to α-particles, and secondly that the R_1 plate is insensitive to protons. The first assumption was tested by exposing a corner of each plate to α-particles from a uranium source for equal times before development; subsequent examination revealed the same number of α-particle tracks per unit exposed area of both plates. The proton response was tested in two ways: (i) by an examination of the plates placed to record recoil protons, which showed that actually only the R_2 plate had recorded these particles, and (ii) by exposing R_1 and R_2 plates impregnated with lithium sulphate to slow neutrons and comparing the tracks subsequently found in them. The disintegration of lithium by slow neutrons gives rise to both singly and doubly charged particles in accordance with the reaction

$$^{6}\mathrm{Li} + {}^{1}n \rightarrow {}^{4}\mathrm{He} + {}^{3}\mathrm{H},$$

and an R_1 plate should consequently show only the 1 cm. ^{4}He tracks, whereas under the same conditions an R_2 plate should record about the same number of the combined $^{4}\mathrm{He} + {}^{3}\mathrm{H}$ tracks of equivalent range 6·6 cm. This was found to be so.

The possibility that the short tracks observed in the R_2 plate were due not to nitrogen but to some other abundant constituent of the emulsion (H, C, O, Br or Ag) seems rather remote. It is known that the elements H, C and O are not disintegrated by slow neutrons*, and it is very unlikely on theoretical grounds that Br and Ag, of nuclear charge as high as 35 and 47 respectively, should emit protons under the action of slow neutrons. The possibility that the effect in the R_2 emulsion was due to a boron contamination which was not present in the R_1 emulsion was excluded by a colorimetric determination of the boron content of

* Chadwick and Goldhaber, *loc. cit.*

the R_2 emulsion made by Messrs Ilford, Ltd.; it was found to be certainly less than 1 part in 10^6 of the emulsion. A comparison of the number of tracks on the exposed R_2 plate with the number on similarly exposed plates containing a known amount of boron* showed that a boron contamination of at least 1 part in 10^3 of the emulsion would be necessary to explain our results.

It therefore seems certain that the disintegration of nitrogen by slow neutrons takes place according to the reaction

$$^{14}N + {}^{1}n \rightarrow {}^{14}C + {}^{1}H.$$

The emission of a hydrogen isotope of mass number 2 or 3 cannot be excluded by our results alone, but such a process seems energetically impossible on the current mass scale. It may be noted that Macmillan† assumes the existence of a radioactive ^{14}C in order to explain some of his observations on deuteron induced radioactivity.

We have estimated the cross-section for the disintegration of nitrogen by slow neutrons by comparing the number of tracks on the R_2 plate with the number of tracks obtained on the similarly exposed plates containing a known amount of boron*. The boron disintegration tracks are also of equivalent length of about 1 cm., which facilitates the comparison. We find that the cross-section for the nitrogen disintegration is about 1/300 of that for the disintegration of boron by slow neutrons‡, and is therefore about 10^{-24} cm.^{2}

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SUMMARY

The disintegration of nitrogen by slow neutrons has been studied in photographic emulsions of different sensitivity, which enable an unambiguous distinction to be made between the emission of α-particles and protons. Evidence has been obtained that the disintegration takes place according to the reaction

$$^{14}N + {}^{1}n \rightarrow {}^{14}C + {}^{1}H$$

with a cross-section of about 10^{-24} cm.^{2}

* Ilford emulsions L 3339 B and C containing 0·047 and 0·094 mg. B/cm.^{2} respectively.
† Macmillan, *Phys. Rev.* 49 (1936), 875.
‡ Mitchell, Dunning, Segré and Pegram, *Phys. Rev.* 48 (1935), 774.