

PROGRESS REPORT

Recoil properties of ^{11}C and ^{18}F produced in the interaction of 1- to 11.5-GeV protons with ^{27}Al

This work is a continuation of the recoil study of radioactive products from the proton bombardment of aluminum.¹ In the previous study the recoil properties of ^{22}Na and ^{24}Na were measured with proton energies from 3 Gev to 300 Gev. Similar measurements are reported here for the products ^{11}C and ^{18}F at 1, 3, 6, and 11.5 Gev.

EXPERIMENTAL PROCEDURE

It was necessary to modify the usual recoil techniques, because no satisfactory catcher foil was available for ^{11}C and ^{18}F . Beryllium foils were found to contain heavy-element contamination. Organic foils could not be used for ^{11}C , because this nuclide is produced directly in the catcher foil. Organic foils also gave erratic results for ^{18}F .¹ This was probably due to the escape of gaseous compounds of fluorine from this type of foil.

In order to circumvent these difficulties, no catcher foils were used, other than the target foils themselves. A stack of 5 aluminum foils was exposed to the circulating beam of the Zero Gradient Synchrotron at the Argonne National Laboratory, see Fig. 1. Foils 1 and 5 were a single foil wrapped around the three inner foils.

After irradiation, a 1 cm x 2 cm area was cut from the exposed portion of the target, as shown in Fig. 1. The various foils were then separated and mounted for counting. The total β activity of each foil was measured by means of two gas-flow proportional counters. In addition, the positron annihilation radiation was measured by two coincidence systems, each consisting of two 7.6 x 7.6 cm NaI detectors. The latter method suppressed the ^{24}Na activity by a factor of 10, thereby improving the resolution of the positron components.

The 5 foils were repeatedly rotated among the 4 detectors. After several days to a week, the counting data were analyzed by the method of least squares into 20.4m ^{11}C , 11.0m ^{18}F , and 15h Na^{24} components.

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Foils 2, 3, and 4 contained the full radioactivity (A_2 , A_3 , and A_4) of the various components, because nuclei lost by recoil out of each foil were replaced by recoiling nuclei from neighboring foils. However, foil 1 suffered a net loss of forward-recoiling nuclei, and foil 5 suffered a net loss of backward-recoiling nuclei.

As a result, the total activity that was formed in foil 1 (or foil 5) is given by

$$A = \frac{W}{W_2 + W_3 + W_4} (A_2 + A_3 + A_4) \quad (1)$$

where W is the thickness of foil 1 (or foil 5), and W_2 , W_3 , and W_4 are the thicknesses of the other foils.

The activity recoiling out of foil 5 in the backward direction is

$$A_B = A - A_5 \quad (2)$$

The activity recoiling from foil 1 in the forward direction is

$$A_F = A - A_1 \quad (3)$$

The activity remaining in foil 1 (or foil 5), if the nuclei lost by recoil had not been replaced, is then

$$A_T = A_1 + A_5 - A \quad (4)$$

The fraction of the activity recoiling into the backward direction is

$$B = \frac{A_B}{A} \quad (5)$$

and into the forward direction is

$$F = \frac{A_F}{A} \quad (6)$$

The fraction of activity remaining in an isolated target foil is

$$T = \frac{A_T}{A} \quad (7)$$

In order for this "difference method" to succeed, it is necessary that the target assembly be located in a fairly large evacuated region during the proton irradiation. Otherwise, the outer foils can be contaminated by extraneous activity. For this reason it was not possible to do this experiment at 300 Gev, where the previous measurements were also made.¹

RESULTS

The values of B , T , and F are given in Table I for ^{11}C , in Table II for ^{18}F , and in Table III for ^{24}Na . The values given in these tables are the average of all of the results at each proton energy.

The values of F/B and $2W(F+B)$ are also given. The ratio F/B is a measure of the average momentum that is transferred to the nucleus in the forward direction. A large value indicates a relatively large momentum transfer. The value $2W(F+B)$ is related to the recoil range of the final nucleus from the decay of some postulated intermediate excited nucleus. A more complete discussion of the significance of these recoil parameters is given in Refs. 2-4.

The errors given for F/B and $2W(F+B)$ are the average deviations from the mean. Most of this error was due to the fact that A_B and A_F were obtained by difference. This source of error was largest for ^{24}Na , where $B = .04$, and smallest for ^{11}C , where $B = .11$. The total error from other sources was less than 1 percent.

The values of F/B and $2W(F+B)$ for ^{24}Na from earlier work are given in the last two columns of Table III. These values agree with those reported here within experimental error. The earlier more accurate values for ^{24}Na will be compared with the values for ^{11}C , ^{18}F , and ^{22}Na in the following discussion.

DISCUSSION

The previously measured values of $2W(F+B)$ for ^{22}Na and ^{24}Na were found to be essentially constant over the energy range from 3 to 300 Gev.¹ Similar results were obtained here for ^{11}C and ^{18}F in the region from 3 to 11.5 Gev, see Tables I and II. The values at 1 Gev, measured for ^{11}C , ^{18}F , and ^{24}Na ,⁵ may be slightly larger than at the higher energies. However, the experimental uncertainty and the effect are almost equal.

The values of F/B for ^{22}Na and ^{24}Na drop slightly from 3 to 11.5 Gev. A similar trend for ^{11}C and ^{18}F could not be observed here, because of the larger experimental errors.

A comparison of the values of F/B and $2W(F + B)$ for the four nuclides in this energy region is given in Table IV and Fig. 2. The values of F/B are seen to be the same within the uncertainties of the measurements. On the other hand, the values of $2W(F + B)$ vary with mass number A of the product nuclide.

These results point to several conclusions:

1. At proton energies above 3 Gev, the $2W(F + B)$ ranges of the four nuclides studied are essentially constant. Thus, there appears to be no significant change in reaction mechanism as a function of energy.

2. The $2W(F + B)$ ranges in this energy region increase linearly with the difference in mass number between the target and product nuclides.

3. There is a small trend downward in the values of F/B for ^{22}Na and ^{24}Na in this energy region. The larger errors for ^{11}C and ^{18}F mask this trend, if present.

A similar study of the product nucleus ^7Be is now under way. These results, when obtained, will be compared with those reported here in order to determine the mechanism of the interaction of high-energy protons with a typical light nucleus, ^{27}Al .

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No. of measurements

Table I

THE DISTRIBUTION OF ^{11}C NUCLEI RECOILING FROM AN ALUMINUM TARGET

PROTON ENERGY (GeV)	THICKNESS OF AL TARGET (W) (mg/cm ²)	FRACTION OF NUCLEI IN FOLDS			F/B	2W(F+B) (mg/cm ²)
		B	T	F		
1	1.887	.111	.575	.314	2.8	1.60
3	1.804	.116	.582	.302	2.6 ±.2	1.51 ±.06
6	1.825	.121	.569	.310	2.6 ±.2	1.57 ±.05
11.54	1.818	.107	.601	.292	2.7 ±.4	1.45 ±.08
AVERAGE =					2.7±.1	1.53±.05

TABLE II

PROTON ENERGY (GeV)	THICKNESS OF AL TARGET (W) (mg/cm ²)	FRACTION OF NUCLEI IN FOLDS			F/B	2W(F+B) (mg/cm ²)
		B	T	F		
1	1.887	.067	.726	.207	3.1	1.03
3	1.804	.067	.739	.194	2.9 ±.4	.94 ±.07
6	1.825	.078	.726	.196	2.5 ±.1	1.00 ±.05
11.54	1.818	.066	.742	.192	2.9 ±.2	.94 ±.05
AVERAGE =					2.8±.2	.98±.04

Table III. THE DISTRIBUTION OF ^{24}Na NUCLEI RECOILING FROM AN ALUMINUM TARGET EARLIER WORK

PROTON ENERGY (GeV)	THICKNESS OF AL TARGET (w) (mg/cm ²)	FRACTION OF NUCLEI IN FOILS			EARLIER WORK				
		B	T	F	F/B	2W(F/B) (mg/cm ²)	F/B	2W(F/B) (mg/cm ²)	REFERENCE
1	1.887	.042	.840	.118	2.8	.60	3.4	.52	4
3	1.804	.039	.861	.100	2.6 ± .8	.50 ± .10	2.7	.46	1
6	1.825	.048	.837	.115	2.4 ± .3	.59 ± .06	2.6	.48	1
11.5	1.80 ₂	.030	.864	.106	3.5 ± .5	.49 ± .06	2.5	.48	1
AVERAGE =					2.8 ± .3	.54 ± .05	2.8 ± .3	.48 ± .02	

TABLE IV
 AVERAGE VALUES OF F/B AND 2W(F+B)
 FOR 3-TO 11.5-MeV PROTONS

	F/B	2W(F+B) (mg Al/cm ²)	REFERENCE
¹¹ C	2.6 ± .1	1.51 ± .04	THIS WORK
¹⁸ F	2.8 ± .2	.96 ± .03	THIS WORK
²² Na	2.70 ± .07	.644 ± .003	1
²⁴ Na	0.7 ± .1	.48 ± .01	1

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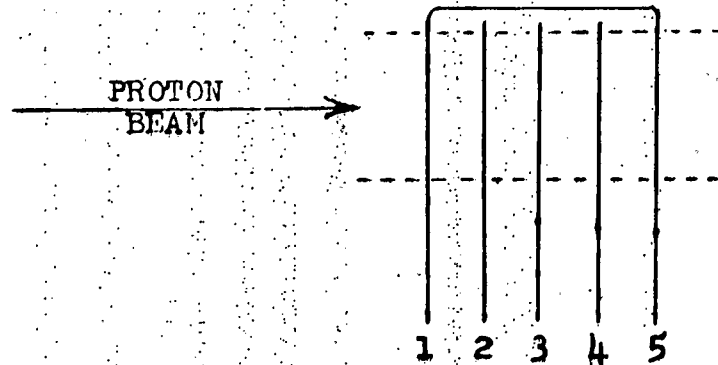


Fig. 1. Arrangement of Al foils in target assembly. The dotted lines indicates how the foils were cut for mounting after the proton irradiation.

Figure 2. The values of the $2W(E + B)$ range for the products of the bombardment of ^{27}Al by 1- to 11.5-Gev protons.

