Protons from Deuteron Bombardment of C^{13}

R. F. HUMPHREYS AND W. W. WATSON
Sloane Physics Laboratory, Yale University, New Haven, Connecticut
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Comparison of the proton groups emitted under deuteron bombardment by a target of ordinary carbon and by one enriched 25 times in C^{13} shows the existence of an excited state of C^{14} at 5.24 ± 0.29 Mev. This state serves as a possible source for the known 5.5-Mev γ-rays. There is no evidence of any lower-lying excited level in the C^{14} nucleus.

A CONSIDERABLE amount of research has been done on the nuclear reactions involving carbon. Much of this has been reviewed by Bennett, Bonner, Hudspeth, Richards and Watt in a paper[1] which describes additional work employing samples of carbon both enriched and depleted in C^{13}. A summary of the results obtained up to the present time of deuteron bombardment of carbon is given in Table I. In each case the assignment of a reaction to the particular isotope was made by Bennett *et al.* with the aid of targets of altered isotope ratios. A search was made by these authors for proton groups of energy less than 6.6 Mev which might represent an excited state of C^{14}, and thus account for the 5.5-Mev γ-ray. Since none was found the γ-ray was ascribed to an excited state of N^{14} formed in the reaction $C^{13}(dn)N^{14*}$. In the present work which likewise uses targets enriched in one isotope an excited state of C^{14} of energy 5.24 Mev above ground has been found. This offers an alternative explanation for the source of the 5.5-Mev γ-rays.

TABLE I. *Summary of previous results of deuteron bombardment of* C.

Initial Nucleus	Emitted Particle	Energy	Reaction	Energy Released (Q)
C^{12}	γ-ray	3.0 ± 0.2 Mev	$C^{12}(dp)C^{13*}$ $C^{13*}(\gamma)C^{13}$	
	n	0.9 Mev	$C^{12}(dn)N^{13}$	-0.19 ± 0.05 Mev
	P	2.9 Mev	$C^{12}(dp)C^{13}$	2.71 ± 0.05 Mev
		0.8 Mev	$C^{12}(dp)C^{13*}$	-0.52 ± 0.07 Mev
C^{13}	γ-ray	5.5 ± 0.2 Mev	$C^{13}(dp)N^{14*}$ $N^{14*}(\gamma)N^{14}$	
	n	1.49 ± 0.03 Mev	$C^{13}(dn)N^{14*}$	0.40 ± 0.05 Mev
	P	6.6 Mev	$C^{13}(dp)C^{14}$	6.09 ± 0.2 Mev

EXPERIMENTAL PROCEDURE

The carbon targets were prepared from methane gas in which the C^{13} content had been raised to about 27 percent in a multistage thermal diffusion apparatus.[2] A Nier-type 60° mass spectrometer was used to determine the $C^{13}:C^{12}$ abundance ratio. Some 1500 cm³ of this CH_4 enriched in C^{13} to this or a greater extent were passed through a silent discharge under conditions found to give a maximum yield of acetylene. This "heavy" acetylene was desired for spectroscopic experiments. The considerable

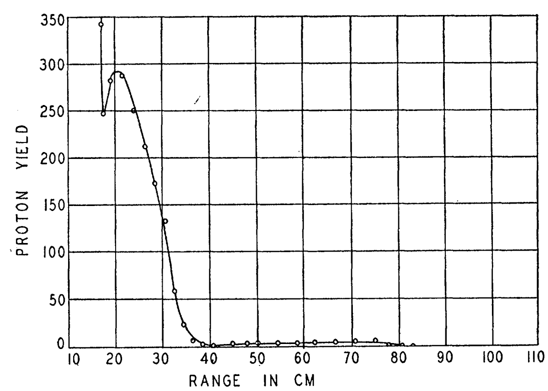

FIG. 1. Proton yield from ordinary carbon, $C^{12}:C^{13}$ ratio 93.3 : 1, bombarded by deuterons.

residue of tar and carbon occurring in this discharge tube was carefully removed and deposited as a mixture in ethyl ether onto gold foil. The result was a somewhat non-uniform, sufficiently durable, "thick" layer of carbon. As judged by the proton groups resulting from deuteron bombardment, this target contained no appreciable amount of N, O or any other light element as

[1] W. E. Bennett, T. W. Bonner, E. Hudspeth, H. T. Richards and B. E. Watt, Phys. Rev. **59**, 781 (1941). This paper contains references to previous work on carbon.

[2] W. W. Watson, Science **93**, 473 (1941).

impurity. For control experiments other targets were prepared in identical fashion with pure ordinary methane. As an additional check a similar appearing deposit on gold foil was made from some "extra-pure" spectroscopic carbon.

These targets were placed at 45° to a beam of deuterons of 3.82 ± 0.07-Mev energy from the cyclotron. The emitted protons were counted at 90° to the incident deuterons with three proportional counters used in coincidence.[3] With 1.5 microamperes of deuterons the proton yield was enough to necessitate use of diaphragms reducing the count by factors of 200–1000. To increase the resolving power considerable effort was expended to "peak-up" the groups—i.e., to employ the counters more as differential rather than integral counters.

Results

Figure 1 indicates the protons from the bombardment of ordinary carbon; Fig. 2 resulted when the $C^{12}:C^{13}$ ratio was changed from 100 : 1 to 3 : 1; Fig. 3 is an enlargement of the

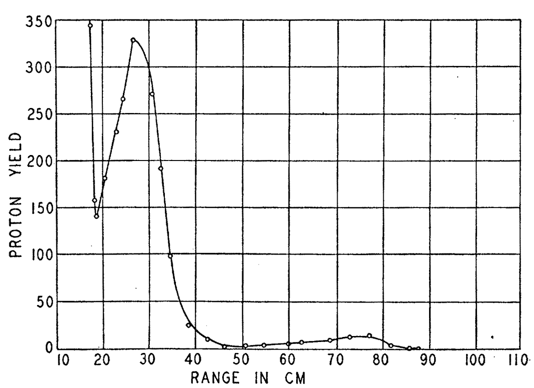

Fig. 2. Proton yield from enriched carbon, $C^{12}:C^{13}$ ratio $\sim 3:1$, bombarded by deuterons.

$C^{13}(dp)C^{14}$ proton group in Fig. 2. Comparison of Figs. 1 and 2 indicates strongly that the 19 cm and 85 cm groups arise from C^{13}. Likewise, Fig. 3 shows only a single group between 35 cm and 85 cm range. The three groups found, when reduced to their mean ranges,[4] correspond to energies of 3.60 ± 0.10 Mev, 5.21 ± 0.08 Mev and 8.55 ± 0.05 Mev. This gives the following Q values:

$$C^{12}(dp)C^{13} \qquad Q=2.38\pm0.15 \text{ Mev}$$
$$C^{13}(dp)C^{14*} \qquad Q^*=0.58\pm0.17 \text{ Mev}$$
$$C^{13}(dp)C^{14} \qquad Q=5.82\pm0.12 \text{ Mev}$$

and indicates an excited state in C^{14} of 5.24 ± 0.29 Mev. This is thus a possible source for the 5.5 ± 0.2-Mev γ-rays.

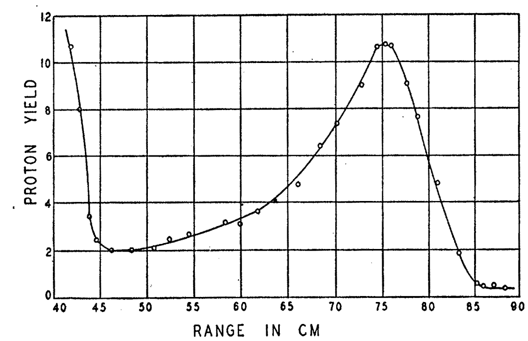

Fig. 3. The long range protons from $C^{13}(dp)C^{14}$ of Fig. 2 magnified by a factor of 25.

Discussion

It is difficult to estimate proton yields from overlapping groups. However, a rough estimate indicates that protons leaving C^{14} in an excited state must be some 50 to 100 times more abundant than those leaving C^{14} in the ground state. In substantiation of this it should be noted that Bennett *et al.*[1] found the 5.5-Mev γ-rays approximately 70 times as numerous as the long range protons. Failure of these authors to find the group resulting in the excited state of C^{14} may lie in the appreciably smaller dispersion offered by a deuteron beam of 1.5 Mev as compared with one of 3.8 Mev.

It is not possible to say unambiguously that 5.24 Mev is the first excited level of C^{14}, since a group coinciding with the C^{12} protons cannot be ruled out. Such a group would lead to a state of 3.44 ± 0.27 Mev above ground. Feenberg and Phillips[5] have predicted with the aid of the Hartree model an excited ^1D state some 1.7 Mev above the ^1S ground state. This corresponds to a proton range of 60 cm. Figure 3 indicates no possibility of such a group of appreciable intensity. A calculation using the single particle

[3] The details of this technique will be published shortly by E. Pollard and one of us (RFH).

[4] M. S. Livingston and H. A. Bethe, Rev. Mod. Phys. **9**, 245 (1937).

[5] E. Feenberg and M. Phillips, Phys. Rev. **51**, 597 (1937).

model puts an upper limit for the ^1D state of 9 Mev.[6] This would lend some support to assuming the first excited level reasonably high. The lack of a γ-ray corresponding to the transition $5.2 \rightarrow 3.4$ Mev likewise discourages the existence of this 3.4 level.

[6] We are grateful to Professor Henry Margenau for this calculation.

Whether the $C^{13}(dp)C^{14*}$ is the sole source of the 5.5-Mev γ-rays or simply competes with the $C^{13}(dn)N^{14*}$ reaction it is not possible to say. Gamma-ray-proton coincidence measurements would be helpful in this respect.

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A Study of the Radiations from the Disintegration of Br^{82}

A. Roberts, J. R. Downing and M. Deutsch
Massachusetts Institute of Technology, Cambridge, Massachusetts

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The radiations from the 36-hour activity ascribed to Br^{82} have been studied by coincidence methods, absorption, and spectrometer techniques. The beta-ray spectrum is simple, and its endpoint is at 0.465 ± 0.01 Mev. Each beta-ray is accompanied by three cascade gamma-rays of energies 0.547 ± 0.01, 0.787 ± 0.015, and 1.35 ± 0.03 Mev. Neither orbital electron capture to Se^{82} nor internal conversion of the gamma-rays is observed. Coincidence measurements made on the beta-ray spectrometer yield independent confirmatory evidence of the simplicity of the beta-ray spectrum. Some considerations concerning the excited states of Kr^{82} obtained in this disintegration are presented.

Introduction

The 36-hour slow neutron-induced activity of bromine has been assigned to Br^{82}, and emits a large number of gamma-rays in addition to moderately soft beta-rays. The purpose of the experiments to be described was a study of the radiations from Br^{82}, with the object of determining the modes of disintegration, the energy of the radiations, and, if possible, the resulting energy levels in the product nucleus Kr^{82}.

Apparatus

Two essentially similar coincidence amplifiers were used in the course of this work. Each of these was of the conventional resistance-coupled pentode type, basically similar to the amplifier described by Langer and Whitaker.[1] In place of cathode biasing, the grid bias on each amplifier stage was separately adjustable. The output of the Rossi coincidence stage was fed into an 885 thyratron mixer, and also into a pulse equalizing amplifier. Grid circuit constants were adjusted to give the sharpest pulses consistent with full saturation of the grids of the Rossi stage. Grid, screen, and plate voltages were obtained from stabilized voltage supplies. Preamplifier stages of Neher-Harper, Neher-Pickering, and modified Neher-Pickering[2] types were used. Separate stabilized high voltage supplies were used for the counters. To obtain individual rates, the pulse equalizing amplifier was used to feed a scale-of-32. Coincidences were counted with the 885 thyratron mixer, which was connected as a self-quenching scale-of-1. The coincidence resolving time was continuously variable by means of the grid bias on the 885. The individual amplifiers of each coincidence amplifier were checked under operating conditions for relative phase shifts by connecting their outputs respectively

[1] L. M. Langer and M. D. Whitaker, Phys. Rev. **51**, 713 (1937).

[2] In this modification, due to Dr. A. F. Kip, the screen battery is replaced by a 5-megohm resistor connected between plate and screen and a 0.5 mf condenser connected between screen and cathode. This is the most satisfactory preamplifier we have used.