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OBSERVATION OF THE NEW ISOTOPE ^{17}C USING A COMBINED TIME-OF-FLIGHT, PARTICLE-IDENTIFICATION TECHNIQUE*

A. M. Poskanzer, Gilbert W. Butler, Earl K. Hyde, Joseph Cerny, D. A. Landis, and F. S. Goulding

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May 1968

A telescope of silicon semiconductor detectors has been used to study light nuclei ejected from a uranium target bombarded with 5.5-GeV protons. Addition of time-of-flight to the previously used particle-identification technique has established the existence of ^{17}C and the particle instability of ^{13}Be.

The interaction of GeV protons with a high-Z target leads to the copious production of isotopes of the light elements with energy distributions peaking near or somewhat below the nominal Coulomb barrier for the target element but extending to much higher energies. We are engaged in a systematic study of the energy and angular distribution characteristics of these fragments with a particle identifier system which is based on the measurement of energy losses in thin semiconductor detectors. Studies of fragment production have made it clear that all isotopes of the light elements are made in such reactions and, consequently, that a systematic search for previously unreported particle-stable isotopes can be carried out. In a previous publication[1] we demonstrated the utility of the technique by proving the existence of ^{11}Li, ^{14}B, and ^{15}B, the particle instability of ^{10}Li, and the probable particle instability of ^{13}Be. In the present note we report new results which depend

upon an extension of the earlier technique to include mass identification by a time-of-flight measurement in addition to particle identification by energy-loss measurements.

The experiment was performed by using the Bevatron's 5.5-GeV external proton beam to bombard a uranium metal target of 27 mg/cm^2 thickness placed in the center of an evacuated 36-in. diameter scattering chamber. Beam pulses 0.6 sec long and containing about 3×10^{11} protons occurred every six seconds. In a preliminary experiment not involving time-of-flight a telescope of phosphorus-diffused silicon counters was located 22 cm from the target at an angle of 30 degrees to the beam; it consisted of two ΔE detectors (61 and 46 μ thick), an E detector (195 μ), and a rejection detector. A small magnet (to deflect electrons) and a 1.2-mg/cm^2 nickel foil (to stop spallation recoils) were placed in front of the telescope. The first and third detectors were collimated to 4 × 6 mm. Details of the circuitry employed with the detectors to effect the particle identification can be found elsewhere.[2] Figure 1 shows the particle spectrum covering the region of the Be, B, C, and N isotopes which resulted from 35 hr of data collection. The improved resolution in the carbon region over our previous work is due to a decrease in the power-law exponent of the particle identifier from 1.7 to 1.6 and an increase in the minimum energy required from the E detector from 20 to 30 MeV. The isotopes ^{14}B and ^{15}B are nicely reproduced in Fig. 1 and it is now quite clear that ^{13}Be does not exist.[3] However, in an attempt to determine the existence of other isotopes a difficulty arose in that the particle-identifier signals corresponding to the heaviest isotopes of one element overlapped those for the lightest isotopes of the next element. Hence it is clear that measurement of energy losses in thin

detectors is not sufficient for an unambiguous identification. For example, in Fig. 1 the expected position of ^{14}Be is under the low side of the ^{8}B peak and that expected for ^{18}C lies very near the known isotope ^{12}N. There appears to be evidence for a ^{17}C peak in this figure but in order to verify this and to resolve some of the other ambiguities we decided to change our apparatus to permit measurement of an additional parameter, the time-of-flight of the fragments, and from this and their energy to obtain an independent determination of fragment mass.

The telescope used for the combined time-of-flight, particle-identification measurements consisted of five detectors at an angle of 45° to the beam. The first, at a distance of 18 cm from the target, was 31 μ thick and was used only to obtain a start time signal. The second detector, at a distance of 38 cm from the target, was 60 μ thick and was used both to obtain a stop time signal and a ΔE signal for the particle identifier. The next counter was a 46 μ thick ΔE detector, followed by a 195 μ E detector, and finally by a rejection detector. The preamplifiers used for the detectors from which timing signals were derived were integrally mounted with the detectors in the vacuum chamber. The signals were sent to fast amplifiers with 30 ns double delay-line shaping and then to tunnel-diode discriminators operating on the zero-crossing signal. The discriminator outputs then went to a time-to-amplitude converter. In a preliminary experiment a flight path of only three cm was used in order to determine the zero time and the time resolution. The net walk of time with pulse height was found to be less than 0.05 ns for the energies deposited by all fragments from ^{7}Be to ^{15}N. The time resolution varied from 1/3 ns for ^{15}N up to 1/2 ns for ^{7}Be. The time-of-flight signal t, and E_T, the total energy deposited in the E

detector and the two ΔE detectors, were sent to a circuit which performed the analogue calculation $E_T \times t^2$ and thus produced a signal proportional to the mass of the fragment. The mass signal and the particle signal were then stored in a 4096-channel two-parameter analyzer. The data obtained in 2 days of data collection are presented as a particle spectrum in Fig. 2 and show clear evidence for a ^{17}C peak. Mass spectra were then summed for the ten indicated regions in the particle spectrum and these are plotted in Fig. 3. Actually, because of radiation damage to the detectors which caused a slight degradation of the particle spectrum but not the mass spectrum, the data in Fig. 3 correspond to a running time 2 1/2 times longer than the data in Fig. 2. Almost all the events which fell in the ^{17}C region of the particle spectrum also fell in the mass 17 region of the mass spectrum, thus clearly proving the existence of ^{17}C.

By looking at Fig. 1, one might have been tempted to ascribe a peak to ^{18}C but the time-of-flight data indicate fewer events and most of them do not fall in the mass 18 region. Assuming a yield ratio of $^{18}C/^{17}C$ similar to the $^{16}C/^{15}C$ or $^{15}B/^{14}B$ ratios one would have expected about ten ^{18}C events. In fact only three events are consistent with ^{18}C so that we are presently unable to determine experimentally whether ^{18}C is particle stable. It is likely that most of the other events are ^{12}N fragments even though for some unknown reason their masses appear slightly high.

In a separate experiment with a different version of the equipment which gave somewhat worse mass resolution a search was made for ^{14}Be. A limit could be set only a factor of four lower than the number expected assuming the $^{14}Be/^{12}Be$ yield ratio was the same as the observed $^{12}Be/^{10}Be$ ratio. Thus our

results are inconclusive concerning the particle stability of ^{14}Be. However, this same experiment easily exhibited mass peaks for ^{11}Li and ^{15}B as expected.

Garvey and Kelson[4] predicted the instability of ^{13}Be but were unable to make a clear prediction for ^{17}C. Of course the existence of ^{17}C makes it certain that ^{18}C, an even-even isotope, also is particle stable.

We wish to thank R. P. Lothrop and M. D. Roach for making the detectors.

FOOTNOTES AND REFERENCES

*This work performed under the auspices of the U. S. Atomic Energy Commission.

1. A. M. Poskanzer, S. W. Cosper, E. K. Hyde, and J. Cerny, Phys. Rev. Letters 17, 1271 (1966).

2. G. W. Butler, J. Cerny, S. W. Cosper, and R. L. McGrath, Phys. Rev. 166, 1096 (1968), and references therein.

3. We also have another spectrum where the yield ratio $^{12}Be/^{13}Be$ is greater than 100 whereas if ^{13}Be exists this ratio should be similar to the $^{10}Be/^{11}Be$ or $^{13}B/^{14}B$ ratios which are about 10.

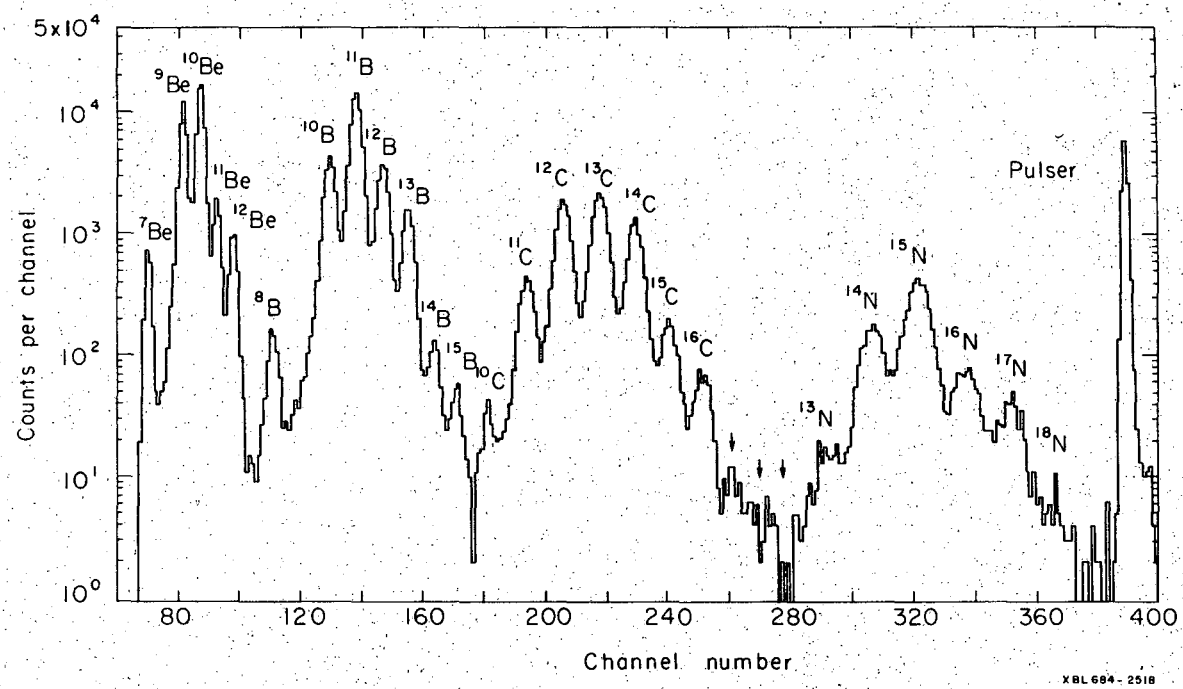
4. G. T. Garvey and I. Kelson, Phys. Rev. Letters 16, 197 (1966).

Figure Captions

Fig. 1. Particle spectrum derived from energy loss measurements in semiconductor detectors. The fragments were produced by the bombardment of uranium by 5.5 GeV protons. The three arrows indicate in order the positions that would be expected for ^{17}C, ^{18}C, and ^{12}N. (Peak areas do not accurately reflect relative yields because of the narrow and different ranges of total energy accepted for each isotope.)

Fig. 2. Particle spectrum obtained during the combined time-of-flight, particle-identification experiment. The double-headed arrows indicate the regions for which the mass spectra are summed and presented in Fig. 3.

Fig. 3. Mass spectra derived from time-of-flight and energy measurements. Each mass spectrum corresponds to a region in the particle spectrum indicated in Fig. 2.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10^4
10^3
10^2
10^1
10^0
Counts per channel
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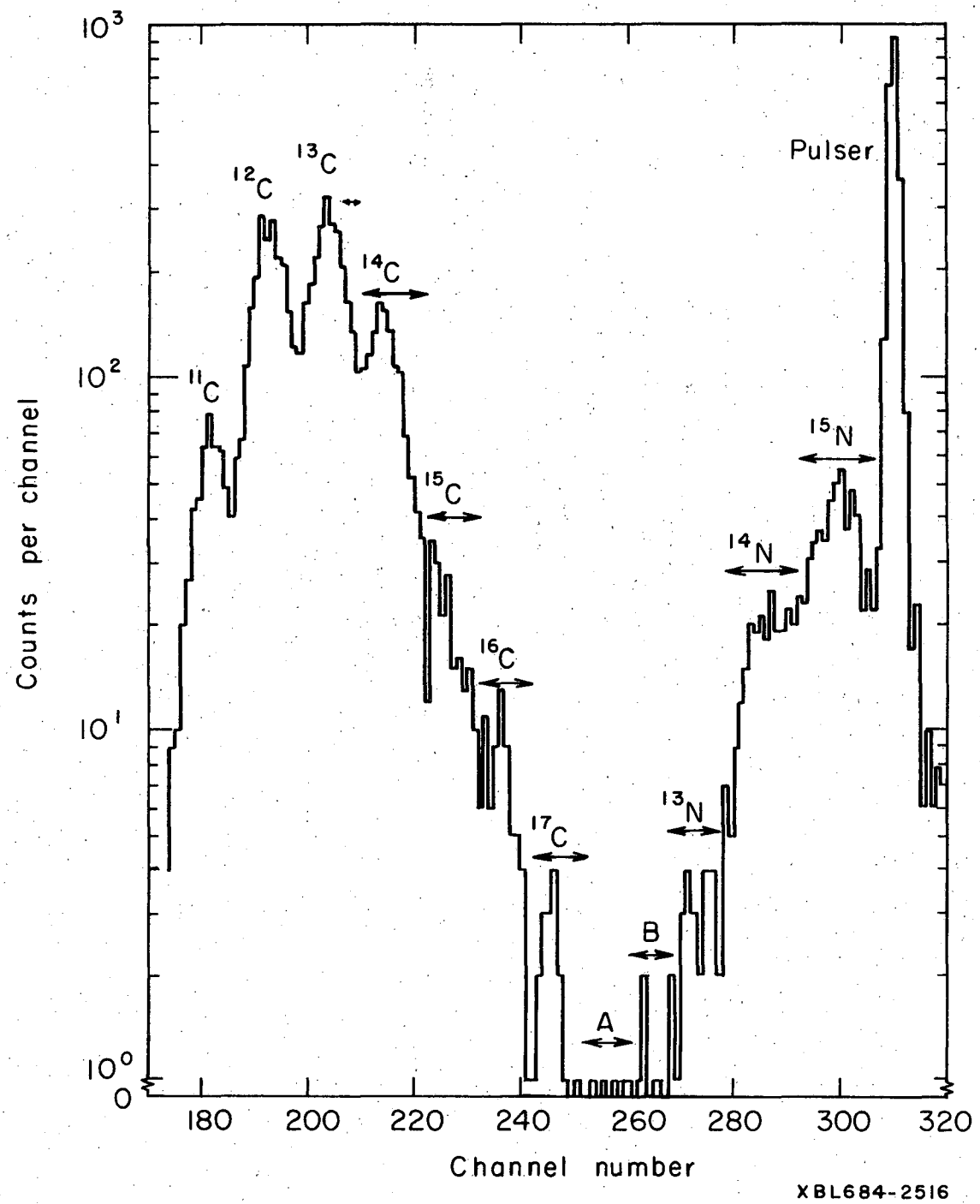
120
160
200
240
280
320
360
400
Channel number
7Be
9Be
10Be
11Be
12Be
8B
10B
11B
12B
13B
14B
15B
10C
11C
12C
13C
14C
15C
16C
13N
14N
15N
16N
17N
18N
Pulser
XBL 684-2518

Fig. 1


Counts per channel
Channel number
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10^2
10^1
10^0
0
180
200
220
240
260
280
300
320
^{11}C
^{12}C
^{13}C
^{14}C
^{15}C
^{16}C
^{17}C
A
B
^{13}N
^{14}N
^{15}N
Pulser
XBL684-2516

Fig. 2

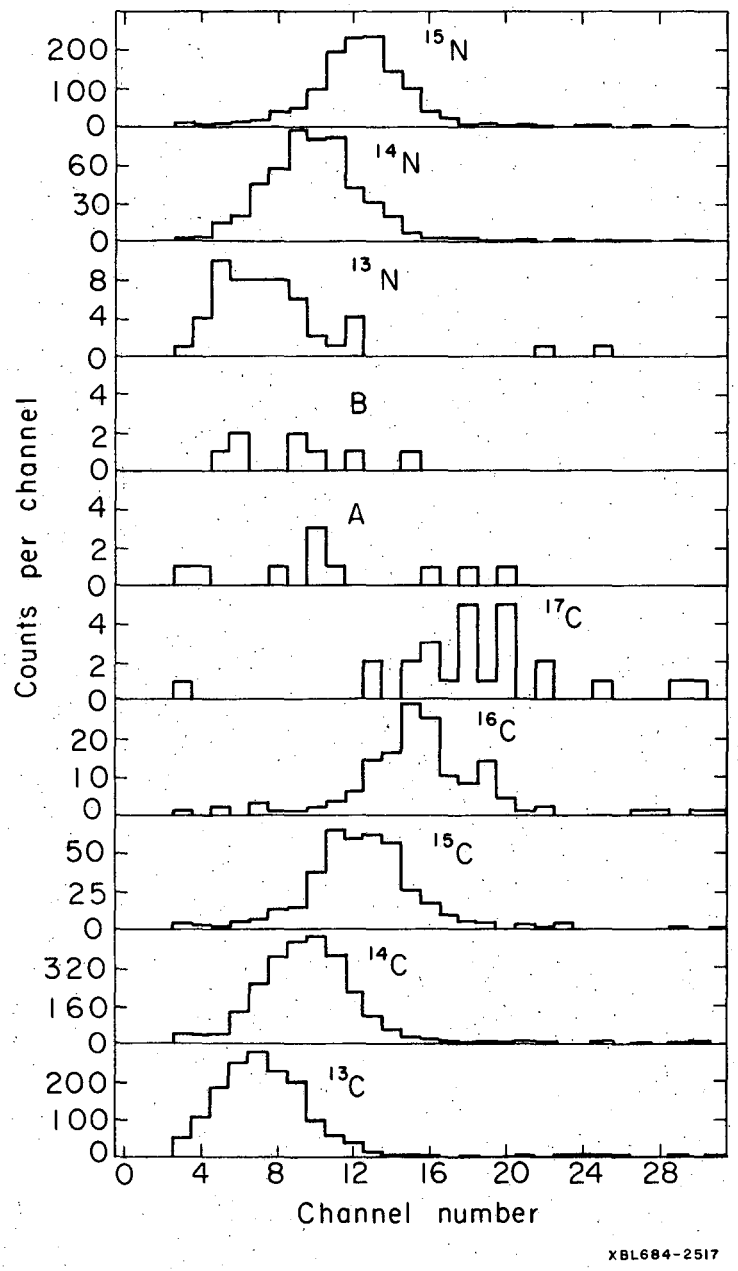
^{15}N
^{14}N
^{13}N
B
A
^{17}C
^{16}C
^{15}C
^{14}C
^{13}C
Counts per channel
Channel number
XBL684-2517

Fig. 3

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