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Berkeley, California

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Secondary charged particles from nuclei bombarded by 90 Mev neutrons[1] produced in the 184-inch cyclotron of the University of California Radiation Laboratory were examined in a series of preliminary experiments by Herbert F. York. He measured the range of these particles at various scattering angles from the neutron beam using a telescope of proportional counters. His preliminary results indicated that, if the particles were all protons, the energy distribution in the forward direction showed a broad maximum at about 40 to 50 Mev and the number per unit solid angle fell to half value at about 12 degrees. This result was difficult to reconcile with the ideas of semi-transparent nucleus which seemed to indicate that a forward peak of protons with energies near 80 Mev was to be expected. Further, the relatively low energy maximum of the observed protons was difficult to reconcile with the pronounced forward angular peak. It was expected theoretically that large energy loss would be associated with several collisions of the emitted particle in the nucleus and a resulting more isotropic angular distribution.

It occurred to us that some of these particles might be deuterons because in earlier cloud chamber experiments tracks had been observed with momenta too high to be accounted for by the known neutron energy distribution. Further experiments were made immediately by Herbert F. York[2], Hugh Bradner[3], and us[4] to find out what was taking place and the results obtained with a cloud chamber are reported here.

A 22-inch cloud chamber with a magnetic field of 21,700 gauss was used. The neutron beam collimated to 1/2" x 1/2" was passed along a diameter of the chamber, through a 1/8" carbon target, and through a 3/4" x 7/8" hole in a 1/8" glass absorbing plate. The glass plate was located in the center of the chamber normal to the neutron beam direction, and the carbon target was 8 inches from the glass. A fraction of the secondary particles from the carbon struck the glass absorber and could be identified by $H\rho$ before and after passing through the glass. The lighted region of the chamber limited the measurement of tracks to those which struck the glass absorber along a strip 9" x 1.1".

Protons with energies from 32 to 107 Mev, deuterons from 25 to 124 Mev, and tritons from 56 to 95 Mev could be identified with very small uncertainty in the type of particle and about a $\pm 6\%$ probable error in energy. The angular range from 0 to 36° was included, with a probable error of about $\pm 2^{\circ}$ in angle.

386 recoil particles were measured and identified as 202 protons, 162 deuterons, and 22 tritons. The energy distributions of the protons and deuterons in the angular intervals of 0-12 degrees and from 13-24 degrees are given in Figures 1a and b. The angle at which the angular distribution per unit solid angle drops to half maximum is given in Table 1. The data have been corrected for the geometry of the experiment and for the finite thickness of the carbon target. These corrections are less than 20% for the major part of the data.

Further analysis of 207 deuterons with energies above 50 Mev has confirmed the presence of the distinct group of deuterons at 70 Mev indicated in Fig. 1a.

The cross sections for these phenomena can be estimated from other cloud chamber work. It has been found that in carbon and oxygen stars produced by 90 Mev neutrons, $12 \pm 3\%$ give high energy particles which would have been included in this analysis. Theoretical and experimental work[5] indicate that the cross section for star formation, i.e., for the emission of a charged particle from the nucleus, is about 1/3 of the total carbon cross-section of $.550 \pm .011$ barns[6] and can be taken as $.20 \pm .05$ barns with sufficient accuracy for this purpose. Using these results, he cross-section for the production of the particles observed in this experiment is

$$\sigma = 24 \pm 12 \text{ millibarns}$$

Cross-sections for various phenomena calculated on the basis of this value are given in Table 2.

The authors wish to thank Dr. Evans Hayward and Walter D. Hartsough for their many contributions to this work which was done under the auspices of the Atomic Energy Commission.

TABLE 1

Protons	Angular width at half maximum
32-62 Mev	Isotropic within probable errors
62-98 Mev	18 ± 3 degrees
Deuterons	
30-58 Mev	18 ± 3 degrees
58-93 Mev	11 ± 2 degrees

TABLE 2

CROSS-SECTIONS

Protons, Energy 32-107 Mev	
0-12°	3.7 ± 1.8 millibarns
13-24°	7.6 ± 3.8 millibarns
Deuterons, Energy 25-124 Mev	
0-12°	2.9 ± 1.5 millibarns
13-24°	4.5 ± 2.2 millibarns

FIGURE CAPTIONS

Fig. 1a - Energy distribution of the deuterons leaving carbon within 12° of the neutron beam.

Fig. 1b - Energy distribution of the deuterons leaving carbon with angles between 13° and 24° from the neutron beam. The errors indicated are standard deviations based only on the number of tracks used to determine the values.

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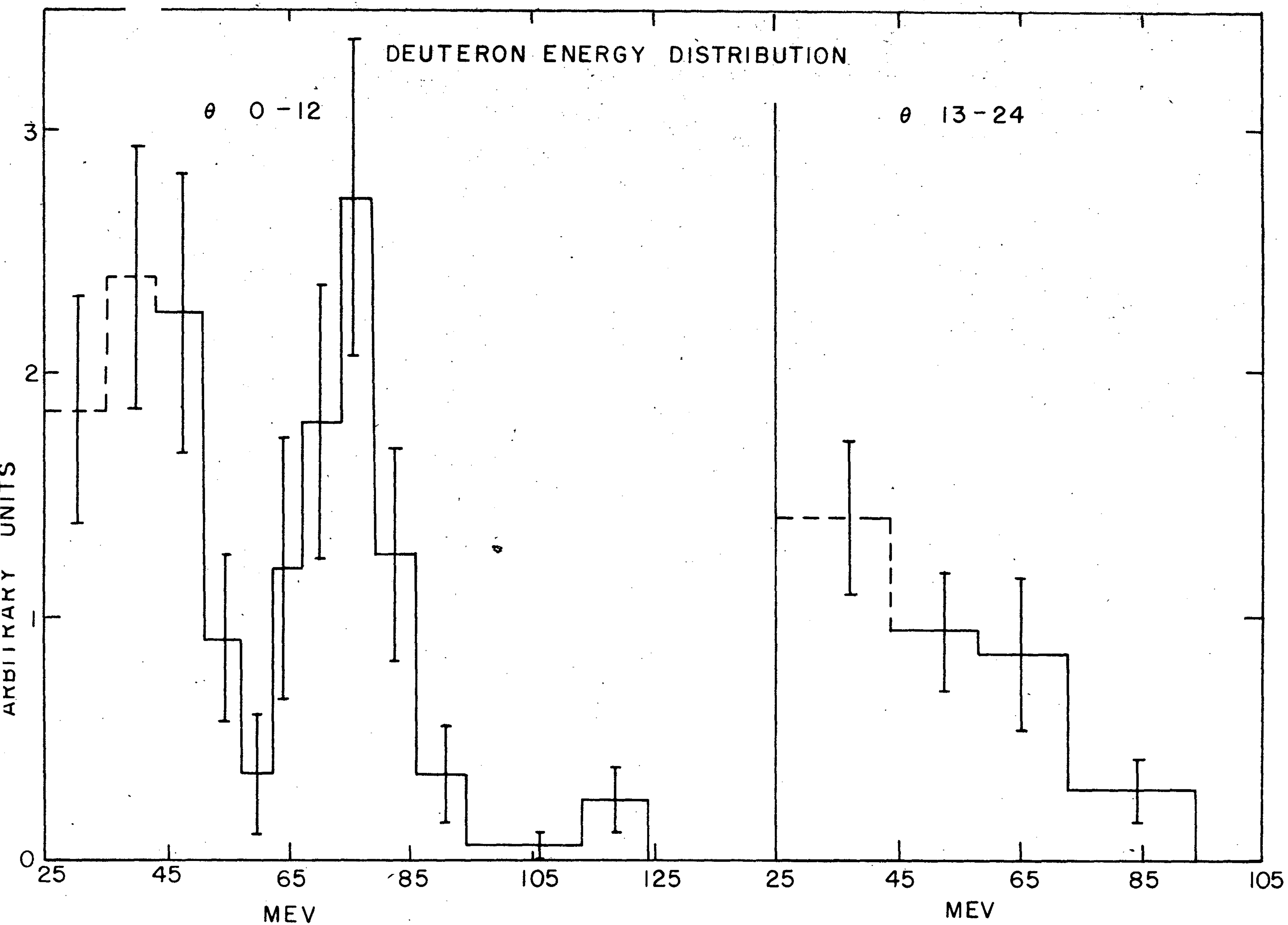
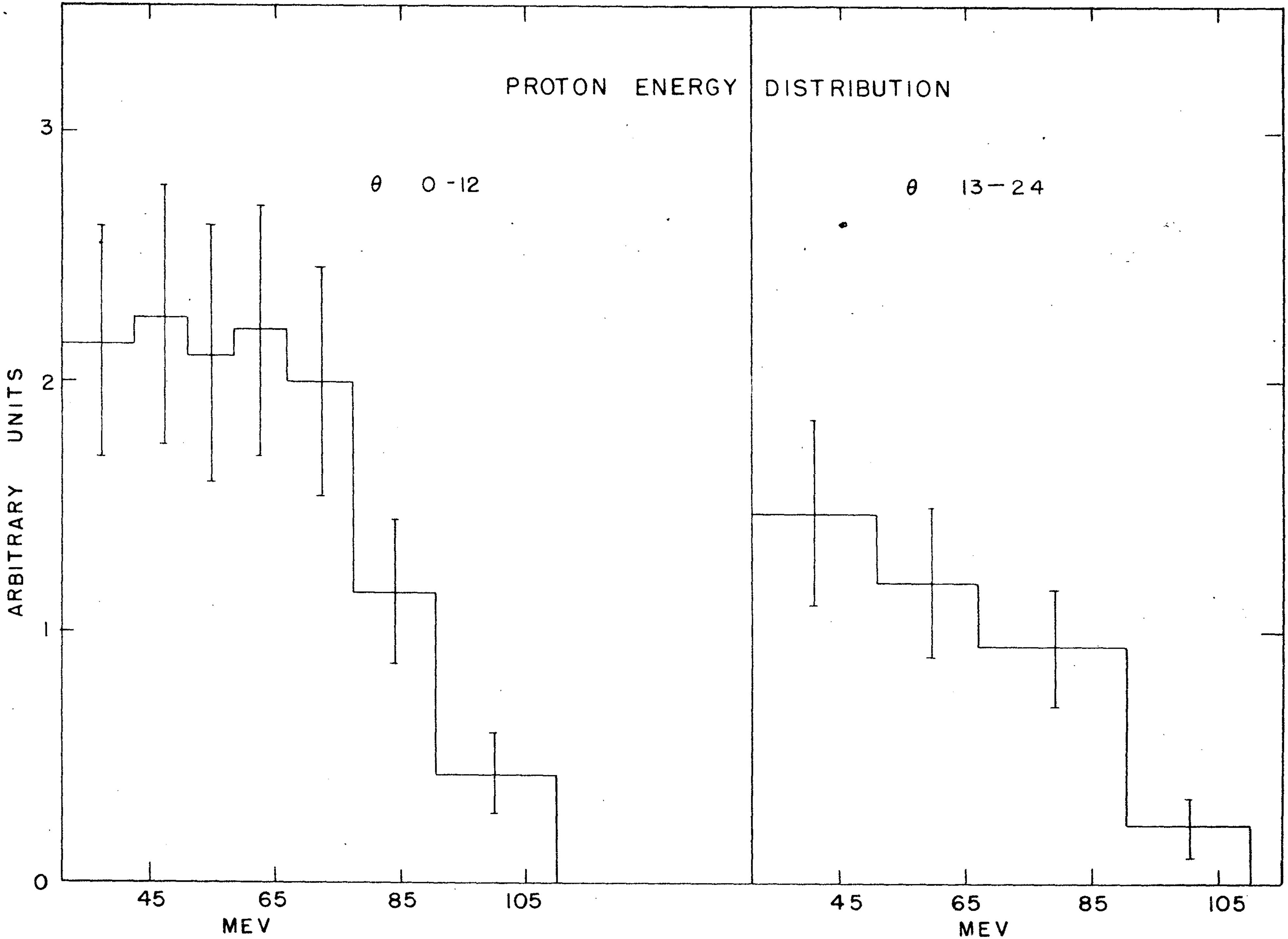


DEUTERON ENERGY DISTRIBUTION
θ 0-12
θ 13-24
ARBITRARY UNITS
0
1
2
3
25
45
65
85
105
125
25
45
65
85
105
MEV
MEV

13470-1

Figure 2a - Energy distribution of the protons leaving carbon within 12° of the neutron beam.

Figure 2b - Energy distribution of the protons leaving carbon with angles between 13° and 24° from the neutron beam. The errors indicated are standard deviations based only on the number of tracks used to determine the values.


PROTON ENERGY DISTRIBUTION
θ 0-12
θ 13-24
ARBITRARY UNITS
0
1
2
3
45
65
85
105
MEV
45
65
85
105
MEV

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