Further work is in progress to investigate the energy of the γ-rays and a more detailed account of these experiments will be given after this work has been completed.

W. E. Bennett
T. W. Bonner

The Rice Institute,
Houston, Texas,
June 27, 1940.

[1] C. C. Lauritsen and H. R. Crane, Phys. Rev. **45**, 345 (1934).

[2] M. A. Tuve and L. R. Hafstad, Phys. Rev. **48**, 106 (1935).

[3] T. W. Bonner, E. Hudspeth and W. E. Bennett, Phys. Rev., following letter.

[4] M. M. Rogers, W. E. Bennett, T. W. Bonner and E. Hudspeth, Phys. Rev., following letter.

[5] C. C. Lauritsen and W. A. Fowler, this issue, p. 193A.

Resonances in the Emission of Neutrons from the Reaction $C^{12}+H^2$

We have investigated the excitation curve for the reaction

$$C^{12}+H^2\rightarrow(N^{14*})\rightarrow N^{14}+n^1-0.25\text{ Mev.} \qquad (1)$$

The excitation curve for the neutrons had previously been obtained by Amaldi, Hafstad and Tuve[1] using a thick carbon target. Their measurements showed no resonances because they extended to only 950 kev.

We have found that the excitation curve from a thin carbon target is not a smooth one, but shows resonances at 920, 1160, 1300, and 1825 kev. To detect the neutrons we have used a Wulf electroscope filled with hydrogen at a pressure of 7 atmospheres and we have studied the radioactivity of the N^{13} which is formed whenever a neutron is emitted according to reaction (1). The ionization measurements are much quicker, and so most of the data are of this kind. The measurements of the radioactivity of N^{13} were taken as a check on the ionization chamber data.

The hydrogen-filled electroscope would also detect neutrons from the reaction

$$C^{13}+H^2\rightarrow(N^{15*})\rightarrow N^{14}+n^1+5.2\text{ Mev.} \qquad (2)$$

However, the yield from this reaction is only 1 percent that from reaction (1) at 800 kev.[2]

The amount of radioactive N^{13} formed in a thin paraffin target was measured by means of a thin-walled Geiger counter placed outside a thin window on the target tube. The procedure was to bombard the target for ten minutes, then shut off the high voltage and follow the activity of the target.

Figure 1 shows the excitation curves obtained from the ionization currents in hydrogen and from the radioactivity of the N^{13}. Since some of the ionization in hydrogen is due to γ-rays, corrections had to be made to compensate for this effect. By using radium filtered by 1.0 cm of lead, we found that the γ-ray sensitivity of the electroscope filled with hydrogen was only 4.75 percent that of the argon-filled chamber which was used in the γ-ray measurements. We used the same target in both experiments, so we were able to calculate that the contribution of the γ rays to the total ionization in hydrogen was 19 percent at 1525 kev. A corresponding correction was made at all other voltages. Curve (3) gives this corrected ionization due to the neutrons alone. Both curves (1) and (3) show resonances at 920, 1160, and 1300 kev. These are the same resonances as those found for the emission of γ-rays.[3] However, the γ-ray resonance at 1430 kev does not show as a resonance for neutron emission.

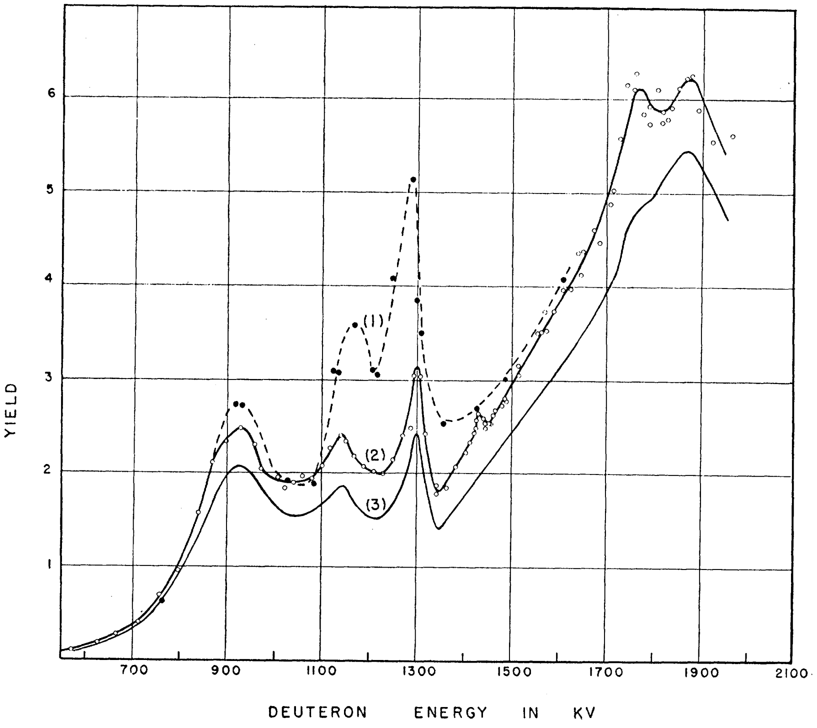

FIG. 1. Excitation curves for the emission of neutrons from a thin target of carbon bombarded by deuterons. Curve (1) gives the yield of N^{13} produced in the reaction. Curve (2) shows the ionization in a hydrogen-filled ionization chamber. Curve (3) is obtained from curve (2) by subtracting the effect produced by the γ-rays from carbon. Hence curve (3) represents the neutron yield.

Above 1430 kev the hydrogen ionization data shows a level at 1740 kev and 1825 kev. The resonance at 1740 kev disappears after the γ-ray correction is made (curve 3). The neutron resonance at 1825 kev is definitely at a higher energy than the γ-ray level at 1740 kev.

The neutron resonances at 920, 1160, 1300 and 1825 kev correspond to excited states in the intermediate N^{14} nucleus at 11.19, 11.39, 11.51, and 11.96 Mev. These excited states of N^{14} might also be expected to break up into $C^{13}+H^1$, giving resonances in the yield of protons. This prediction has been tested and the results are given in the following letter.[4]

T. W. Bonner
Emmett Hudspeth
W. E. Bennett

The Rice Institute,
Houston, Texas,
June 27, 1940.

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[1] E. Amaldi, L. R. Hafstad and M. A. Tuve, Phys. Rev. **51**, 896 (1937).

[2] T. W. Bonner and W. M. Brubaker, Phys. Rev. **50**, 308 (1936).

[3] W. E. Bennett and T. W. Bonner, preceding letter.

[4] M. M. Rogers, W. E. Bennett, T. W. Bonner and E. Hudspeth, following letter.

Resonances in the Emission of Protons from the Reaction $C^{12}+H^2$

Since the γ-rays[1] and neutrons[2] from the bombardment of carbon by deuterons show many of the same resonances, we might expect the protons from the reaction

$$C^{12}+H^2\rightarrow(N^{14*})\rightarrow C^{13}+H^1+2.7\text{ Mev} \qquad (1)$$

also to show the same resonances. These resonances correspond to excited states in the intermediate N^{14} nucleus, and we might expect the emission of a neutron, a proton or a γ-ray to be competing processes. We have studied the excitation curve of the 15-cm protons to see if resonances occur.

The protons were detected by a 2.5-cm deep ionization chamber connected to a linear amplifier. Such a deep chamber was used so that protons could be counted far from the end of their range. This was useful because the range of the protons from reaction (1) changes with bombarding energy.

Figure 1 gives our experimental excitation curve for protons. The curve shows the same resonance at 920 kev that was exhibited for the emission of γ-rays and neutrons. The next resonance occurs at 1220 kev; this is 60 kev greater than the second resonance for the emission of γ-rays. In order to make certain whether the resonances come at different positions, we have checked the γ-ray curve immediately after obtaining the proton resonance. The γ-ray resonance came at 1160 kev. It seems possible that the resonances at 1160 and 1220 kev really are the same level in N^{14} but that the exact position of the peak depends upon the particle that is emitted. Breit[3] has predicted that the peak on such a resonance curve may be displaced as much as the width of the level, depending upon the mode of disintegration. It seems possible that the neutron resonance at 1825 kev may likewise be the same level in the intermediate N^{14} as the 1740-level for γ-ray emission.

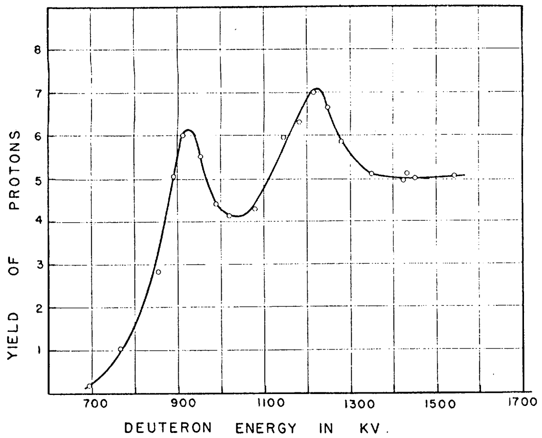

FIG. 1. The excitation curve for the emission of 15-cm protons from a thin target of carbon bombarded by deuterons.

The protons do not show a resonance at 1300 kev, in contrast to the neutrons and γ-rays. A careful search was made to see if the protons showed a resonance at 1430 kev. The high voltage was adjusted to be on the peak of the 1430-kev level for γ-rays and then the yield of protons observed. No increased yield was found at this voltage. The proton curve, unlike the curves for γ-rays and neutrons, does not show a rise in the region of 1350–1600 kev, indicating that the level at 1740 or 1825 kev may be missing.

The relative yield of protons and neutrons has been obtained at 920 kev, by counting the number of N^{13} atoms formed in comparison to the number of protons from the same thin target. At 90° to the bombarding direction the ratio of protons to neutrons is 1.9. This indicates that the excited intermediate N^{14} nucleus is about equally likely to break up into a proton or a neutron. The relative number of γ-rays is more difficult to obtain, but there seem to be more quanta of γ-rays than protons or neutrons.

There appear to be selection rules which prohibit the emission of protons from the 1300, 1430, and 1740-kev levels. Also there appears to be a selection rule which prohibits the emission of neutrons from the 1430-kev level. The 1430-kev level might be expected to be narrower than the other levels because it can decay only by emission of γ-rays and therefore has a longer lifetime.

M. M. Rogers
W. E. Bennett
T. W. Bonner
Emmett Hudspeth

The Rice Institute,
Houston, Texas,
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[1] W. E. Bennett and T. W. Bonner, preceding letter.

[2] T. W. Bonner, E. Hudspeth and W. E. Bennett, preceding letter.

[3] G. Breit, Science **91**, 419 (1940).