Search for Gamma-Rays from the Deuteron-Deuteron Reaction

The discovery by Bonner[1] of a second group of neutrons from the reaction

$$H^2+H^2\rightarrow He^3+n^1 \quad (1)$$

has suggested the possibility that He^3 may be formed in an excited state about 2 Mev above the ground state. The difficulty of reconciling such a state with present nuclear theory has been emphasized by Share[2] and Schiff.[3] If such a state exists we should expect to observe gamma-rays due to the transition of He^3 to its normal state. Evidence for a gamma-ray has been given by Kallmann and Kuhn,[4] who used coincidence counters to investigate the reaction. We have made a search for this gamma-ray by means of a cloud chamber.

The cloud chamber was placed about 25 cm from a heavy phosphoric acid target bombarded by 0.5 Mev deuterons. A lead collimator was placed between the target and the cloud chamber and both were provided with thin aluminum windows. A sheet of carbon 0.15 cm thick extended across the center of the chamber as a source of Compton electrons. A magnetic field of 715 gauss was used to determine the electron energies. Many recoil electrons were observed, but most of these appeared to be due to the gamma-rays from slow neutron capture and from the inelastic scattering of fast neutrons in the material around the chamber. In order to determine whether any gamma-rays came directly from the target, the following experiment was performed. On alternate expansions the hole in the lead collimator was filled with a lead block 4 cm thick. This would have decreased the intensity of a gamma-ray from the target by a factor ten. Actually no difference in the numbers of electrons between 1 and 2 Mev energy was observed in the two cases.

In order to determine the ratio of the number of gamma-rays to the number of neutrons from the reaction, the target holder was placed directly within the cloud chamber and surrounded by a foil of Cellophane 0.1 mm thick. From the number of proton tracks coming from this foil the neutron intensity could be estimated using the known cross section for neutron-proton scattering. The gamma-ray intensity was determined simultaneously by counting the Compton electrons produced in a sheet of carbon in the center of the chamber. Since the time of sensitivity of the cloud chamber for electron tracks is smaller than the time of sensitivity for proton tracks, a correction factor was necessary. An estimate of this ratio was found by placing in the chamber a natural radioactive source which emitted a known ratio of beta-rays and alpha-particles. From the ratio of Compton electrons to protons obtained in this way it was calculated that there is not more than one gamma-ray for every 200 neutrons. This figure agrees with the estimate of Kallmann and Kuhn;[4] the intensity of Bonner's second neutron group[1] is, however, one-tenth of the 2.6 Mev group.

During the course of this investigation many protons were observed which penetrated a carbon sheet 0.15 cm thick, and consequently had an energy greater than 15 Mev. Since these were present when the chamber was separated from the target by 4 cm of lead, they must be due to neutrons, possibly from the secondary reaction

$$H^3+H^2\rightarrow He^4+n^1+17.6 \text{ Mev} \quad (2)$$

due to recoiling H^3 nuclei from the reaction

$$H^2+H^2\rightarrow H^3+H^1. \quad (3)$$

We understand that energetic protons from the analogous reaction of He^3 with H^2 have been reported by Oliphant.[5] The ratio of the number of these very energetic recoil protons to those of the 2.6 Mev group was of the order of one to one thousand; consequently reaction (2) must be an exceedingly probable one.

I wish to express my thanks to Dr. H. R. Crane for his helpful advice and encouragement.

ARTHUR J. RUHLIG

Department of Physics,
University of Michigan,
Ann Arbor, Michigan,
August 1, 1938.

[1] Bonner, Phys. Rev. **53**, 711 (1938); also Baldinger, Huber and Staub, Helv. Phys. Acta **11**, 245 (1938).
[2] Share, Phys. Rev. **53**, 875 (1938).
[3] Schiff, Phys. Rev. **54**, 92 (1938).
[4] Kallmann and Kuhn, Naturwiss. **26**, 106 (1938).
[5] Unpublished; private communication from Professor H. A. Bethe.

Observation of H^1 and H^3 Ranges from the Disintegration of Deuterium by Deuterons

Recent cloud chamber experiments[1] on the energy spectrum of recoil protons produced by neutrons from the reaction

$$H^2+H^2\rightarrow He^3+n^1$$

have shown the presence of a low energy group of neutrons, and indicate the existence of an excitation level in He^3 at 1.89 Mev. Ionization chamber studies[2] have led to this same conclusion. In view of this excitation level in He^3 it seems reasonable to expect a similar level in H^3. Consequently we have looked for a short range group of protons from the reaction

$$H^2+H^2\rightarrow H^3+H^1.$$

We used apparatus previously described.[3] The protons were observed in a cloud chamber filled with air and alcohol vapor. They were allowed to pass into the chamber through an aluminum foil which had a stopping power of approximately 0.5 cm. A slit system defined the direction

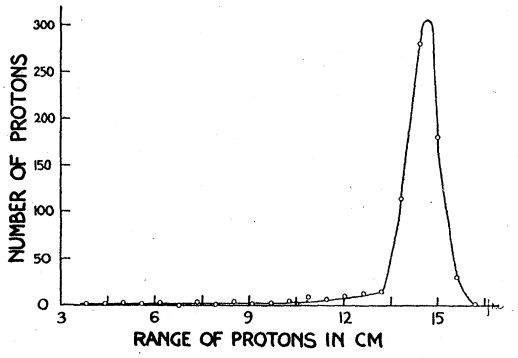

FIG. 1. Range distribution of protons from the disintegration of deuterium by deuterons.

of the disintegration particles to an angle of 99.5°±2° to the direction of the incident 100 kev deuterons, which bombarded a D_3PO_4 target. The stopping power of the gas in the chamber (1.18) was determined from the mean range (14.7 cm) of the proton group of maximum energy.

Figure 1 gives the range distribution of the protons observed, and, contrary to what one might expect, there is no indication of more than a single group. Preliminary experiments with a D_2O target frozen by liquid air gave similar results, though a higher background was present. From this experiment and that described below we conclude that H^3 is excited to a level between 0.4 and 2.9 Mev in less than 2 percent of the disintegrations, if at all.

While looking for low energy protons from the deuterium reaction we observed the range of the H^3 particles produced in the same reaction. An accurate determination of the range of these particles is useful in checking the range-energy relation for H^3 particles, and hence the range-energy curve for short range protons.

The H^3 particles were observed in a cloud chamber filled with helium and water vapor. They were allowed to pass into the cloud chamber through the slit system and an aluminum foil with a stopping power of 0.50 cm.[4] Fig. 2 gives the range distribution of the particles. The stopping power of the gas was found to be 0.30±0.01 cm for particles with a range of 3.80 cm (polonium alpha-particles).

The most probable range is 1.28±0.10 cm, which corresponds to a mean range of 1.31±0.10 cm at 99.5°. Since the

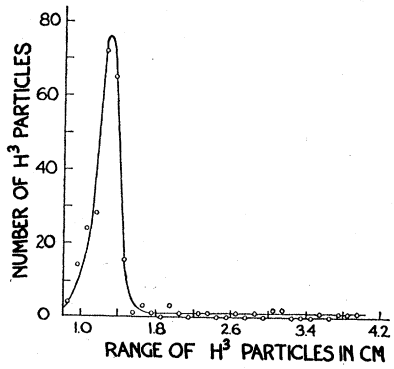

FIG. 2. Range distribution of the charged particles as observed in the helium filled chamber.

stopping power of the helium would probably be slightly higher for 1.3 cm particles than for polonium alpha-particles, this is actually a lower limit to the H^3 particle range.

The energy of the H^3 particles emitted at 99.5° was calculated from the Q value of 3.98 Mev.[5] The energy of the H^3 particles is 0.89 Mev at this angle. The range of a H^3 particle of this energy theoretically is three times the range of a proton with an energy of 0.89/3 Mev. If we use the new range-energy curve of Livingston and Bethe for protons, the mean range of the H^3 particles should be 0.95 cm. This is beyond the limits of experimental error and we conclude that their range-energy curve for protons in this region is in error. The experimental range of 1.31 cm is in much better agreement with the old curve of Livingston and Bethe[6] which predicts an H^3 range of 1.38 cm.

This suggested change in the range-energy relation for protons is important since it would necessitate raising the mass of the neutron, and lowering the mass of He^3 and C^{14}.

EMMETT HUDSPETH
T. W. BONNER

The Rice Institute,
Houston, Texas,
June 21, 1938.

[1] T. W. Bonner, Phys. Rev. **52**, 685 (1937); **53**, 711 (1938).
[2] Baldinger, Huber, and Staub, Helv. Phys. Acta **11**, 245 (1938).
[3] T. W. Bonner, Phys. Rev. **52**, 685 (1937).
[4] The stopping power of the foil was calculated by assuming 1.41 mg/cm² = 1 cm air.
[5] Oliphant, Kempton, and Rutherford, Proc. Roy. Soc. **A149**, 406 (1935).
[6] Livingston and Bethe, Rev. Mod. Phys. **9**, 245 (1937).

Ferromagnetic Colloid for Studying Magnetic Structures

The magnetic structure of a ferromagnetic material can be revealed by depositing a fine ferromagnetic powder from suspension onto the smooth surface of a specimen which is suitably magnetized. F. Bitter,[1] who first studied magnetic structures by this method, used finely ground gamma-ferric oxide suspended in ethyl acetate. Stray fields near the surface of the specimen guide such a ferromagnetic powder as it settles; the powder thereby forms a pattern recording regions where H^2 is greater than in near-by regions. A similar technique for obtaining patterns has been used by most of the other investigators[2] who have extended the work of Bitter. McKeehan and Elmore,[3] however, used a true colloid (rather than a temporary suspension) of gamma-ferric oxide. They discovered that the colloid formed patterns consisting of swarms of sol particles which under favorable conditions did not settle out or coagulate but which retained their mobility within the solution. Although this latter technique possesses many advantages over the former, no great use seems to have been made of it, a fact undoubtedly due to the difficulty of securing or of preparing a suitable colloidal suspension. This situation has prompted the writer to look for a simple means of making a ferromagnetic colloid for magnetic powder investigations.

A series of experiments have led to the preparation of a very satisfactory colloidal magnetite. The new colloid forms patterns rapidly, does not coagulate once the pattern is formed, and is superior for subjective observation and for photography since its color is a very dark reddish-black (gamma-ferric oxide is a light brick-red). Several colloidal magnetites which were prepared proved unsatisfactory. One of these, protected by dextrin, had such a fine particle size that it formed patterns only in regions possessing very intense stray fields. Another one, unprotected, produced instead of the expected pattern tree-like structures which did not disperse when the applied magnetic field was removed from the specimen. To be useful for forming patterns evidently the colloid particles must not be too small, i.e., they must lie in the upper range of colloidal size. They must also be protected by another colloid to