nates by 1.26 in order to bring them into coincidence with those for the lead at the point of lowest $H\rho$ shown. The zero line of the difference curve was drawn through its lowermost points. The large maximum in the difference curve is due to $K$ photoelectrons from annihilation radiation; the $L$ photoelectron edge does not fall on the film for the field intensity used. There is no evidence for a photoelectron line in the region of 280±30 kev (indicated by arrows).

In order to obtain the relative gamma-ray sensitivity of the spectrograph for annihilation and 280-kev radiation, it is necessary to correct, for the variation of the photoelectric effect with gamma-ray energy,[4] the variation of film sensitivity with electron energy[5] and the instrumental effect due to the different radii of curvature of the two distributions.[6] Taking all these into account the spectrograph is estimated to be *at least* four times as sensitive to 280-kev radiation as to 512-kev radiation. From Fig. 1 it is necessary to conclude that in the region corresponding to 280±30 kev there is not more than 0.05 gamma-rays per disintegration. At no point in the range from 1200 to 1800 gauss cm (gamma-ray energy 200 to 325 kev) could there be more than 0.11 gamma-ray per disintegration.

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## Search for $\beta$- and Delayed $\gamma$-Radiation from the Deuteron-Deuteron Reaction

The evidence[1–3] for the existence of a group of low energy neutrons resulting from the reaction $H^2(d, n)He^3$ has been strengthened by recent experiments of Bonner.[4] The low energy group is found to have an energy of 1.1 Mev ($Q=1.48$ Mev) and to comprise 10 percent of the total neutron yield. Since the well-known 2.4-Mev group of neutrons corresponds to a $Q$ of 3.32 Mev it follows that there should exist an excited state of $He^3$ having excitation energy of 1.84 Mev, and that the decay of this excited nucleus should give rise to observable radiation. There are several possible decay processes

(1) $He^{3*} \rightarrow He^3 + \gamma$,
(2) $He^{3*} \rightarrow He^3 + \gamma$ (largely internally converted),
(3) $He^{3*} \rightarrow H^3 + e^+$ (upper limit of spectrum 0.8 Mev).

Attempts[5–7] to observe instantaneous $\gamma$-radiation from the $d$-$d$ reaction have failed to show its presence in amount greater than one $\gamma$-ray per hundred neutrons, a value too small by a factor of ten to account for the low energy neutron group.

We have attempted to observe radiation from other possible processes indicated above. The apparatus used is shown in Fig. 1. The heavy ice target was bombarded by a beam of deuterons from the 400-kv transformer-rectifier set in this laboratory. In the first set of experiments, designed to detect internal-conversion electrons, or positrons from the decay of a short-lived $He^{3*}$, only the foil $B$, of 0.02 mm Al, was used. Observations were made with a double counter of the Trost type which was used in a coincidence circuit[8] having a resolving time of $2\times10^{-6}$ sec. The total thickness of window $B$ and both counter windows was such that electrons having energy greater than 0.23 Mev would have been counted. Numbers of counts were recorded with and without a 6-mm Al absorber between the window $B$ and the counter. With 20μa of 135-kev deuterons incident on the target a count of 900/min. was recorded. This was due to the neutrons, as it was unchanged within the limits of error (75/min.) by the interposition of the Al absorber and also of a Pb absorber. We calculate from the known yield of the $d$-$d$ reaction[9] and the geometry of the apparatus that an electron-emitting process in equilibrium with the deuteron beam should give about $2\times10^6$ counts/min., assuming that the reaction leading to $He^{3*}$ is 10 percent of the whole. This seems definitely to eliminate any possibility of internal conversion or short-lived positron radioactivity.

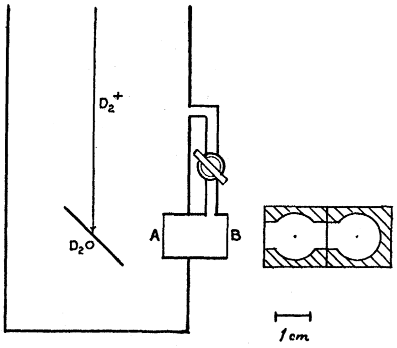

FIG. 1.

In order to investigate the possibility that the $He^{3*}$ might be a long-lived positron or $\gamma$-ray emitter the foil $A$, which consisted of a collodion film of 0.5 mm air equivalent covered with an Al foil of 0.7 mm air equivalent, was introduced. The introduction of this foil made it possible, by closing the stopcock shown in the figure, to collect in a separate vacuum-tight chamber the $He^{3*}$ recoils (range 4 mm) from the target, and to investigate their activity. Experiments were made by bombarding the target for ten minutes with 20μa of 135-kev deuterons and then making measurements with the beam shut off. Check measurements were made after identical bombardments with the stopcock open, in order to take into account the effect of induced radioactivity in the metal of the target chamber. We used the coincidence arrangement for observing electrons and a sensitive copper-walled counter for the detection of $\gamma$-radiation. The results were as follows: With the coincidence counter we obtained 4 counts/min. after bombardment with the stopcock in either position. With the $\gamma$-ray counter we obtained about 10 counts/min. over the counter background (75/min.) after bombardment with the stopcock in either position. We should have been able to detect very unambiguously a difference of 3 electron counts/min. due to the changed position of the stopcock, and similarly a difference of 20 counts per min. in the $\gamma$-ray case. No such differences were observed. We calculate that with the stopcock closed there would be $2\times10^7$ He$^{3*}$ caught in the side chamber after a ten-minute bombardment. From the geometry used and from the counter sensitivities we find that if there exists an excited He$^3$, its lifetime for positron emission is greater than 10 days and its lifetime for $\gamma$-ray emission is greater than 45 min. The high voltage apparatus used was built with the aid of a grant to Professor Ladenburg from the Rockefeller foundation.

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## Pair Emission from Fluorine Bombarded with Protons

When fluorine is bombarded by protons of suitable energies gamma-rays with $6.3\pm0.1$ Mev quantum energy are emitted. Measurements of the gamma-ray yield as function of proton energy were first made by Hafstad and Tube[1] and later with higher resolution and over a greater range by Bernet, Herb and Parkinson.[2]

These measurements were made with ionization chambers and the radiation was filtered through $\frac{1}{8}$ in. or more of lead. They show that the penetrating gamma-radiation is produced at several sharply defined energies. Dee, Curran and Strothers[3] have shown that the resonance levels at 330, 670 and 860 kev all give rise to the same gamma-radiation. We[4] have confirmed this and in addition have found that the same is true for the prominent resonances at 0.920 and 1.36 Mev. It has also been shown in this laboratory[5] that at the 330-kev resonance the gamma-rays are accompanied by alpha-particles, with a range of 8 mm in air. It seemed safe, therefore, to conclude that the 6.3-Mev gamma-radiation originates from the reaction

$$F^{19}+H^1\rightarrow(Ne^{20})\rightarrow{}^*O^{16}+He^4$$

and represents a transition in oxygen from an excited state to the ground state. The alpha-particle group at 330 kev has also been found by Burcham and Smith[6] and we have recently been informed that Burcham and his collaborators have found the corresponding alpha-particles at the 860- and 920-kev resonances.[7]

In order to investigate the possible existence of radiation of low penetrating power from fluorine bombarded by protons we have made yield measurements by simultaneous observations with two ionization chambers, to which we shall refer as No. I and No. II. The two chambers were as similar as practicable but No. II was arranged so that suitable filters could be interposed between target and chamber. To reach the chambers the radiation passed through the 0.13-mm German silver wall of the target tube and the 0.40-mm aluminum ionization chamber wall. This filtration was desirable in order to exclude the x-rays produced by protons in the target, which consisted of a copper disk on which a thin layer of CaF$_2$ was deposited.

The filter chosen for the yield measurements with chamber No. II was 3.3 mm of lead. This is sufficient to absorb gamma-radiation up to several hundred kv or electrons up to 10 Mev.

Curves 1 and 2 (Fig. 1) represent the readings obtained with chambers I and II, respectively, as function of bombarding voltage, and curve 3 represents the difference between 1 and 2.

On the assumption that curve 2 is a measure of 6.3-Mev radiation only, and that chamber No. I is equally affected by this radiation, we can conclude that curve 3 represents a kind of radiation which is completely absorbed in 3 mm of lead. These assumptions are not entirely correct and for this reason we cannot exclude the existence of a few percent of absorbable radiation, even where curves 1 and 2 coincide, but this does not in any way invalidate the conclusions to be drawn from the difference between them.

Measurements of the absorption in lead and in aluminum made at 820 and 1130 kv proved that the radiation represented by curve 3 did not consist of soft gamma-radiation and that it probably consisted of fast electrons with a maximum range of approximately 1.5 mm in lead and 7.5 mm in aluminum. From 500 cloud-chamber photographs, taken at 820 kv, we obtained 166 positive and 173 negative electrons and 29 pairs could be identified with some certainty.

We conclude from this that curve 3 represents the ionization produced by pairs. The observed energy is $5.9\pm0.5$

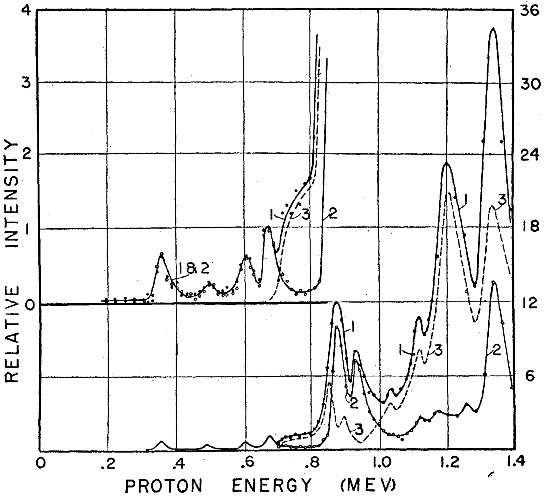

FIG. 1. Relative intensity of ionization *vs*. bombarding proton energy. Curve 1—radiation filtered by 0.5 mm aluminum. Curve 2—radiation filtered by an additional 3.3 mm lead. Curve 3—difference between 1 and 2.