was measured by putting layers of graphite above the counters.

It was consistently found that the mass absorption in air was considerably larger than that in carbon. One set of measurements, for instance, gave the following results: Mt. Evans (4300 m, atmospheric pressure 618 g/cm²) without graphite: 11.9 ± 0.07 coinc./min. *Ibid.*, under 84 g/cm² graphite: 11.0 ± 0.057 coinc./min. Echo Lake (3240 m, atmospheric pressure 700 g/cm²) without graphite: 9.7 ± 0.046 coinc./min.

Thus the additional air layer of 82 g/cm² between Mt. Evans and Echo Lake reduced the intensity of the mesotrons by more than twice as much as did the graphite screen of 84 g/cm². It is obvious that this large difference cannot be ascribed to the difference in stopping power of air and carbon. We see, therefore, definite evidence for the disintegration of the mesotrons.

The above results show that 1.3 mesotrons out of 11 disintegrate while traveling a distance of $4.30\times10^5-3.24\times10^5=1.06\times10^5$ cm. Their mean-free-path for the distintegration is, therefore, $L=1.06\times10^5/\log(11/9.7)=8.5\times10^5$ cm.

L is connected with the lifetime τ_0 by the formula: $c\tau_0=\mu cL/p$ where μ is the mass and p the momentum of the mesotrons. At sea level the average value of $\mu c/p$ was estimated to be about 0.07.[1] Assuming tentatively the same value in our case, one finds $\tau_0=2\times10^{-6}$ sec.

A fuller account of these experiments will be published later. The writers acknowledge with thanks the helpful discussions and support given to this work by Professor A. H. Compton. They also wish to express their appreciation for the facilities made available in Colorado by Dr. Joyce Stearns, as well as for the assistance of Mr. O. E. Polk and Mr. W. Bostick.

BRUNO ROSSI
H. VAN NORMAN HILBERRY
J. BARTON HOAG

Ryerson Physical Laboratory,
University of Chicago,
Chicago, Illinois,
September 30, 1939.

[1] B. Rossi, Cosmic Ray Symposium, Chicago, June, 1939; Rev. Mod. Phys. July–October (1939).

Magnetic Spectrograph Investigation of N^{13} Gamma-Radiation

Richardson[1] has reported that the decay of N^{13} is accompanied by a gamma-ray of 280 ± 30 kev in addition to the well-known positron annihilation radiation. This gamma-ray is estimated to occur in 40 percent of all N^{13} disintegrations which take place.

The same radiation has been reported by Lyman[2] who estimates it to occur in 20 ± 15 percent of all disintegrations; and by Watase and Itoh[3] who estimate it to occur in 20 percent of all disintegrations. The estimates of Richardson and of Watase and Itoh are uncertain by a factor of two. In view of the general interest in N^{13}, it has seemed desirable to make further observations on this radiation, using a method which is free from statistical errors.

The N^{13} gamma-ray spectrum was explored by measuring the energy and intensity of the secondary electrons ejected from lead and aluminum foils of equivalent thickness. The magnetic spectrograph used was of the usual semi-circular focusing type, constructed largely of lead. The slit jaws and other parts nearest the radioactive source were faced with graphite in order to minimize the background. The radioactive sources were produced by bombarding 0.5 mm thick graphite plates with 4.3-Mev deuterons. Eastman "No Screen" x-ray film was used, and was developed for eight minutes in D19 developer at 66°F.

The Pb and Al foils were placed in contact with the radioactive sources. A particular gamma-ray will eject both photoelectrons and recoil electrons from lead, but only recoil electrons from aluminum because of the different Z dependence of the two effects. The photoelectrons from a particular gamma-ray, having an initially homogeneous velocity, will appear on the spectrogram as a group with a sharp upper energy limit followed by a gradual decrease in intensity toward lower energies because of a straggling in the emitting foil. The recoil electrons ejected by the same gamma-ray under these conditions will have a much less homogeneous energy distribution because their energies depend greatly upon their directions of emission with respect to those of the quanta.

In this experiment the photoelectron spectrum of lead irradiated by N^{13} gamma-radiation was isolated from the recoil spectrum as well as from the instrumental background. This was done by successive exposures with lead and aluminum secondary emitters, the latter distribution being subtracted from the former. The relative photoelectron intensities due to any gamma-rays present may thus be directly compared without making any estimates of the contribution of recoil electrons as was necessary in the experiments of Watase and Itoh.

The data are shown in Fig. 1, which gives the film opacity as a function of $H\rho$. Because of differences in source intensities it was necessary to multiply the aluminum ordi-

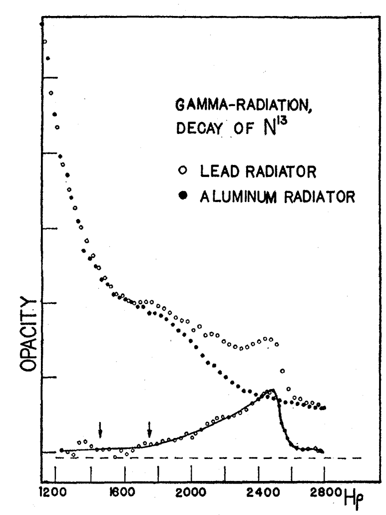

FIG. 1. Photometric measurements of films exposed to secondary electron spectra from lead and aluminum irradiated by N^{13} gamma-radiation. The lowermost curve is the difference between the Pb and Al data. The vertical arrows indicate the $H\rho$ region corresponding to lead K photoelectrons from a gamma-ray of 280 ± 30 kev.

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.

The author wishes to thank Professor L. A. DuBridge and Dr. S. N. Van Voorhis for their interest in this problem.

G. E. VALLEY*

Department of Physics,
University of Rochester,
Rochester, New York,
September 29, 1939.

* Now at Harvard University, Cambridge, Massachusetts.

[1] J. R. Richardson, Phys. Rev. **53**, 610 (1938); **55**, 609 (1939).
[2] E. M. Lyman, Phys. Rev. **55**, 1123(A) (1939).
[3] Y. Watase and J. Itoh, Proc. Phys. Math. Soc., Japan **21**, 289 (1939).
[4] L. H. Gray, Proc. Camb. Phil. Soc. **27**, 103 (1931).
[5] C. D. Ellis and G. H. Aston, Proc. Roy. Soc. **A119**, 645 (1928).
[6] K. T. Li, Proc. Camb. Phil. Soc. **33**, 164 (1937).

Search for β- and Delayed γ-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 γ-radiation from the *d-d* reaction have failed to show its presence in amount greater than one γ-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

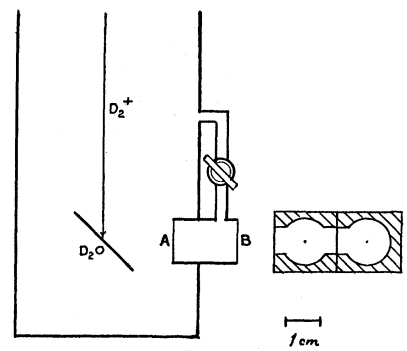

FIG. 1.

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 2×10^{-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 $20\mu a$ 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 2×10^6 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.

In order to investigate the possibility that the He^{3*} might be a long-lived positron or γ-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 $20\mu a$ 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 γ-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 γ-ray counter we obtained about 10 counts/min. over the counter background (75/min.) after bombardment