

**Purification and Spectroscopic Evidence for He<sup>3</sup>**

Following the procedure outlined in a previous letter<sup>1</sup> deuterium was circulated through a large canal-ray discharge tube. The discharge ran at an average of 75 kv and 10 m.a. exhibiting an intense canal-ray beam which was, however, of a slightly green color due to a trace of mercury vapor which had entered the system. The discharge tube was filled twice and each time a run of 4 hours was made. After this treatment the two samples, which amounted to 5 cc at N.T.P. of deuterium and its disintegration products, were combined together and sealed off in a bulb having a magnetic break seal.

After transportation to the Massachusetts Institute of Technology it was sealed by means of the magnetic break-off to a purifying apparatus designed by one of us (W.D.U.) for the isolation of small quantities of helium. After flushing the entire apparatus with air-free oxygen the gas mixture was introduced and purified. The complete process used is described by Paneth and Peters.<sup>2</sup> Owing to the inaccuracy of McLeod gauge measurements with such small quantities of gas a modified Pirani-Stern manometer system developed by Paneth and Urry<sup>3</sup> was used to measure the quantity of helium contained in the sample.

It was found after purification that  $1.1 \times 10^{-5}$  cc at N.T.P. of gas remained. From the nature of the purifying process this could be only helium and neon, and the lines due to these gases were the only ones which could be observed spectroscopically. The spectroscopic examination was made with a calibrated D-77 Hilger spectrograph. The gas was compressed into a capillary tube 0.000132 sq. cm in internal cross section and the discharge was excited by means of a leak-tester in contact with an external electrode of thin copper wire wound around the gas-filled space. An estimate of the intensities of the helium and neon lines showed that the neon was present to at most ten percent of the mixture (see Paneth and Peters). The neon present was presumably of atmospheric origin and had diffused through the hot glass during sealing off from the canal-ray tube or had been driven out of the walls or metal parts of the apparatus during the bombardment process. A certain amount of ordinary atmospheric helium would be expected to be associated with this neon. As the neon-to-helium ratio in air is 18 : 5 an amount of helium equal to  $0.28 \times 0.1 \times 1.1 \times 10^{-5}$  cc or about  $3 \times 10^{-7}$  cc was probably present as an impurity. No appreciable amount of helium can have been introduced during the purifying process for a control run the previous day agreed with weekly controls over a period of two years in giving only about  $10^{-8}$  cc of neon and helium in atmospheric proportions. Atmospheric helium is therefore expected to be present to the extent of at most three percent, and neon to a maximum of ten percent; hence at least  $9.6 \times 10^{-6}$  cc at N.T.P. was the helium disintegration product from the deuterium reaction. Previously reported<sup>4</sup> results obtained with the mass-spectrograph from samples which have been subjected to the same canal-ray bombardment have shown this helium to be of mass three. None of the helium isotope of mass four has ever been found by the mass-

spectrograph in these samples except when it has been deliberately admitted to the analyzing apparatus for comparison purposes. The three percent attributed to atmospheric helium in this sample is too small an amount to have been detected and identified as of mass four by the mass-spectrograph.

The quantitative agreement between the amount of helium isolated from this sample and the He<sup>3</sup> peak obtained with the mass-spectrograph is also satisfactory. The estimate by the latter method of the He<sup>3</sup> content of comparable samples varies from about  $10^{-4}$  to  $10^{-5}$  cc at N.T.P. depending on the discharge conditions. Because of the trace of mercury vapor present in the discharge from which this helium was isolated there is reason to believe that the discharge conditions were not the optimum ones. As it has not as yet been possible to measure the number of D-D collisions during a run no quantitative estimate of the yield can be given, though it is certainly very large.

In an attempt to remove the helium from the purifying system the specimen was lost. It is hoped that with future samples the mass may be further verified by a thermal-conductivity method and the spectroscopic characteristics such as fine structure and isotopic shift studied. We are indebted to the Princeton Department of Chemistry for supplying us with the deuterium used.

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<sup>1</sup> Harnwell, Smyth, Van Voorhis and Kuper, *Phys. Rev.* **45**, 655 (1934).

<sup>2</sup> Paneth and Peters, *Zeits. f. physik. Chemie* **134**, 353 (1928).

<sup>3</sup> Paneth and Urry, *Zeits. f. physik. Chemie* **152**, 110 (1931).

<sup>4</sup> Bleakney, Harnwell, Lozier, Smith and Smyth, *Phys. Rev.* **46**, 81 (1934).

**The Production of Radioactive Oxygen**

Since the preliminary report<sup>1</sup> from this laboratory on the radioactivity induced in certain substances by deuteron bombardment, the apparatus has been changed so as to bring the ion beam outside the apparatus through a thin aluminum window. Both solid and gaseous targets can be exposed to the beam, and then removed to a quartz-fiber electroscopes for measurement of the induced activity. For these experiments 1 microampere of 2 million-volt deuterons was used.

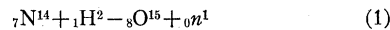
With this arrangement, carbon and aluminum targets were bombarded and found to give the activities already reported.<sup>1</sup> When a carefully cleaned platinum target was bombarded in air, a much smaller but accurately measurable positron activity with a half-life of  $126 \pm 5$  sec. was observed. Both clean and oxidized copper targets gave the same effect. When the target was bombarded in N<sub>2</sub> gas the same activity was found, but it was not present when O<sub>2</sub>, H<sub>2</sub> or A were used. In CO<sub>2</sub> an activity of the same

magnitude was observed, decaying with the characteristic 10 minute half-life of deuteron activated carbon.

It is apparent that these effects are due to atoms of the gas, activated in the space between the window and the target and driven onto the target by recoil. This interpretation is supported by the observation of an activity with a period characteristic of the aluminum in the window when the space was evacuated. To show more conclusively that nitrogen is responsible for this 126 second activity, nitrogen gas was bombarded, transferred to a bulb, and its gamma-ray (positron annihilation) activity measured. From an empirical calibration of the chamber for gamma-rays, this experiment showed that approximately 1 nitrogen atom is activated per million incident deuterons.

A solid  $\text{KNO}_3$  target did not show the expected large effect, probably because the active oxygen is not tightly held in the nitrate lattice, as it is in platinum.

A chemical separation showed that the active constituent is oxygen. The  $\text{N}_2$  gas was activated, mixed with some  $\text{O}_2$  and an excess of  $\text{H}_2$  and passed over heated platinized asbestos. The oxygen, present as  $\text{NO}_2$ ,  $\text{N}_2\text{O}$  or  $\text{O}_2$ , was reduced to  $\text{H}_2\text{O}$  and collected in a  $\text{CaCl}_2$  drying tube, the residual gases being collected in a previously evacuated bulb. The active constituent was found to go entirely into the drying tube. In a check run with the platinized asbestos cold the activity went into the collecting bulb. The probable nuclear reactions are:



The neutrons given by reaction (1) were found to be produced in the activating process in about the expected numbers. The maximum energy of the positrons from the radioactive process (2) estimated from their absorption in aluminum, is about 1.7 million volts.

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<sup>1</sup> Henderson, Livingston and Lawrence, Phys. Rev. 45, 428 (1934).

#### The Annihilation of the Proton

The experiments of Anderson, Millikan, Neddermeyer and Pickering<sup>1</sup> and Gilbert<sup>2</sup> on the production of showers indicates that the immediate cause of the spray of negative and positive electrons observed in cloud photographs of the showers are gamma-rays. The high energy gamma-rays on striking a nuclear field lose their energy by generating a number of high energy pairs, negative and positive electrons. The origin of these hard gamma-rays is obscure. Experiments indicate that these high energy photons are probably not produced by electrons impinging on the nucleus. There then remains the possibility that their formation arises from the annihilation of matter, in a somewhat similar way to that suggested by Jeans<sup>3</sup> in

his paper on the origin of cosmic rays. We shall give in this note an approximate expression for the probability  $P(\eta)$  of the following process. A high energy proton strikes a nuclear Coulomb field of atomic number  $Z$  and is converted into a gamma-ray and a positive electron of energy  $\eta c$ .

In treating this problem we have followed the method suggested by Fermi for the analysis of the beta-ray problem. We shall suppose that the wave function  $\mu$  of the proton is changed into the wave function  $\phi$  of a neutral particle and at the same time a positron and a photon of energy  $h\nu$  appear in the field. According to Heisenberg we should consider the proton and the neutral particle as two separate states of the particle described through an inner coordinate  $\rho$ :

$$\begin{aligned} \rho &= +1 && \text{for the neutral particle,} \\ \rho &= -1 && \text{for the proton.} \end{aligned}$$

The passage from the proton to the neutral particle is determined through the operators  $Q = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix}$  and  $Q^* = \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix}$  which operate on the coordinate  $\rho$  appearing in the Hamiltonian of the proton and the neutral particle. The Hamiltonian function for the problem is composed of three terms, the energy  $H_1$  of the proton and neutral particle, the energy  $H_2$  of the photon and positron and finally the coupling energy between the two sets of particles,  $H_3$ .

$$H_1 = (1 + \rho)N/2 + (1 - \rho)P/2,$$

where  $N$  and  $P$  are the energy operators for the neutral particle and proton, respectively. The wave functions for the positron in the central field  $Ze$  are designated by the symbol  $\psi_s$ . In carrying out the calculations, the vector potential  $a$  of the radiation field is analyzed into a system of plane waves  $a = \sum_i g^i a_i$ . We shall assume, following Fermi, that the coupling term is effective only at small distances and can be represented by the expression

$$H_3 = g \{ Q\psi(x)\phi(x) + Q^*\psi(x)\phi(x) \} - e(\alpha a),$$

where the coordinates of the proton and neutral particle are taken at the position of the proton. If the proton changes into a neutron and positron the neutron represents one of the neutral particles but if the mass of the proton is annihilated we shall assume the neutral particle is a neutrino. We have attempted in this way to give a mathematical description of a process which we recognize may be only crudely represented by such a mechanism. In the annihilation problem the failure of the conservation laws will be taken care of by the energy given to the neutrino.

On the basis of calculations performed with this Hamiltonian, we have arrived at the following results. The positrons are distributed in energy near their maximum energy  $\eta_0 c$  according to a law very similar to that with which we are familiar in beta-particle emission from radioactive nuclei in the same region. The total probability of annihilation per nucleus  $P = \int_0^{\eta_0} P(\eta) d\eta$ , where  $\eta_0 c$  is the maximum energy possible for the positron, varies as  $(\eta_0)^5$  and is practically independent of the atomic number of the nucleus with which it collides.