track can be observed and the angle of penetration measured by visually focussing the microscope on one grain after another.

We are at present improving our technique and testing the method by application to other problems of current interest. The work has been made possible through the generosity of the Department of Physics at Princeton University which provided all the equipment and supplies required. We are also greatly indebted to Professor R. Ladenburg and others of the staff for their advice and suggestions as well as to Professor T. R. Wilkins and Mr. W. T. Rayton of the University of Rochester who gave us valuable information about the emulsion technique.

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The Emission of Disintegration-Particles from Targets Bombarded by Protons and by Deuterium Ions at 1200 Kilovolts

In view of the hypothesis of the instability of the deuton with a resulting neutron-mass of nearly unity advanced[1] and supported[6, 7, 8] by Professor Lawrence and his colleagues at Berkeley, it appeared essential to us on beginning our own program of disintegration-observations in the region above 1000 kilovolts to check first their published results. Avoiding the introduction of lithium or boron into our new tube,[2] we selected the following as representative of the targets which they used: Be, C, SiO_2, CaF_2, Al and Ag (Pt was displaced by an Ag-target previously tested for contamination[2]). Observations have been made at 1200 kilovolts since last November on these six targets by using magnetically resolved mass-1 and mass-2 beams giving proton-currents of 1 to 2 microamperes and deuton-currents of 0.2 to 0.5 microampere. Voltage-measurements were made by range-measurements on the proton- and deutron-beams, checked at first by magnetic deflection-measurements. (A generating voltmeter was found to indicate too high a voltage by more than 50 percent, probably because of corona and space-charge, and was discarded as unreliable for use with the corona-limited electrostatic generator.) The ionization-chamber of the linear amplifier used in these experiments subtended a solid angle 1/200 to 1/700 of 4π, and the residual count (with the tube operating) was usually 1 to 3 counts per minute. Within the limits by which our targets overlap the published Berkeley data, we have obtained the following results.

(A) With 2 microamperes of protons on these targets no alpha-particle emission in significant numbers of range exceeding that of the primary protons was observed[3, 4, 5] except from CaF_2, which emits only one group[3] of range 60 mm, with no trace of any longer range alpha-particles. An unsuccessful search down to 2.2 cm was made for the 3.3-cm group reported for Be,[4] reducing the voltage in successive observations to eliminate possible spurious counts due to unresolved multiples of scattered primary protons giving deflections the same size as alpha-particles. With deutons, a strong alpha-particle group was found from CaF_2 ending near 71 mm.[3] Bombarding Be no evidence of the 3.3-cm group[5, 8] was found, although with deutons on Be the presence of neutron-recoils and disintegration-protons gives a rather high residual count. No other definite alpha-particle emission from these targets was observed by using deutons. Multiple-proton counts are indistinguishable from alpha-particles with an amplifier having fixed constants, and at short ranges spurious counts of this type were present with most of these targets under deuton-bombardment, thus preventing the identification of small numbers of alpha-particles if such were present.

(B) We have been unable to confirm the Berkeley reports[5, 6, 7] of an 18-cm group of protons from all targets, with similar reported yields[6] for targets as different in atomic number as "brass-wax" and platinum, using 1200-kilovolt deutons. A proton-group was found which showed the typical characteristics of a contamination-effect and which probably corresponds to their 18-cm group. Instead of the homogeneous group indicated by their hypothesis (but not by their observations[7]), this group showed an apparently continuous range-distribution, tapering out and disappearing between 15 and 17 cm, the end-point (as few as 1/10,000 of the maximum number of counts) being a function of the intensity of the group, whether changed by altering the current to one target or by shifting between targets. The quantitative yields from our targets differed by large factors from their yields, and varied greatly from target to target. The group was not observable from the Be-target (which did emit a group of longer range). The yield from the Ag-target was at most a small fraction of 1 percent of that from C, and the yield-ratios between various targets fluctuated from time to time, indicating at least some degree of transient contamination. Several other proton-groups were evidently characteristic of particular targets, but these have not been confirmed as yet by the necessary tests on several duplicate targets. The degree of caution necessary for such conclusions was sufficiently illustrated by our work with protons reported a year ago.[2] As described below, we have recently demon-

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[1] E. O. Lawrence, M. S. Livingston and G. N. Lewis, Phys. Rev. **44**, 56 (1933).

[2] M. A. Tuve, L. R. Hafstad and O. Dahl, Phys. Rev. **43**, 942 (1933).

[3] E. O. Lawrence and M. S. Livingston, Phys. Rev. **44**, 316–317 (1933).

[4] M. S. Livingston, M. C. Henderson and E. O. Lawrence, Phys. Rev. **44**, 316 (1933).

[5] G. N. Lewis, M. S. Livingston and E. O. Lawrence, Phys. Rev. **44**, 55–56 (1933); **44**, 317 (1933).

[6] M. S. Livingston, M. C. Henderson and E. O. Lawrence, Phys. Rev. **44**, 781–782 (1933).

[7] G. N. Lewis, M. S. Livingston, M. C. Henderson and E. O. Lawrence, Phys. Rev. **45**, 242–244 (1934); **45**, 497 (1934).

[8] E. O. Lawrence and M. S. Livingston, Phys. Rev. **45**, 220 (1934).

strated that deuterium is the contamination responsible for the proton-group ending between 15 and 17 cm.

(C) With the use of deuton-currents exceeding 0.5 microampere, a search for the neutrons reported[6, 7, 8] to accompany the 18-cm proton-group showed no observable neutron-emission except from Be and a probable trace from CaF_2. Carbon gave an increased residual count which was immediately recognized as a typical beta-ray "noise" in the linear amplifier, and was shown by Wilson cloud-chamber tests to be due to a strong gamma-ray emission[9] from this target. The residual counts then set as our limits of detection approximately one neutron-recoil from paraffin per 100,000 observed disintegration-protons from C and SiO_2 (through the ionization-chamber), or about 1/30 of the number to be expected on the basis of the Berkeley reports, by using our own proton-yields. This failure to observe neutrons cannot be ascribed to a weak deuton-beam or to imperfect detection, since our measured yield of neutrons from Be per microampere of deutons was approximately ten times that reported by the Berkeley investigators. It is possible that beta-ray "noise" would be more troublesome and misleading with their apparatus because of the strong magnetic field impressed on the ionization-chamber of their linear amplifier, curling the paths of secondary electrons perhaps sufficiently to give rise to more frequent spurious impulses large enough to be mistaken for neutron-recoils. If neutrons are emitted in some preferred direction other than 90°, the absence of any heavy materials near our targets may prevent their being scattered into our ionization-chamber; in the Berkeley experiments ample scattering could take place.

(D) No evidence has yet been found for any "voltage-threshold" effects.[1, 3, 4, 5] The alpha- and neutron-emissions we have failed to find cannot be explained by an erroneously low voltage, as we have continuously checked the latter by the (primary) proton- and deuton-ranges. The alpha- and proton-emissions we have observed showed no indication of thresholds. In fact, carbon bombarded with 600-kilovolt deutons (mass-4 spot at 1200 kilovolts; by previous tests pure He gave no effect using the mass-4 spot) gave more than 1/10 the number of protons in the 15-cm to 17-cm group which were observed using 1200-kilovolt deutons, the range-distribution curve was similar, and the range-limit was reduced from 17 to roughly 13.5 cm. With 800-kilovolt deutons (mass-3 spot) the range-limit was approximately 15 cm.

There is thus no evidence in these observations to support the Berkeley suggestion of a neutron-mass lower than that given by Chadwick.

Having established that the 15-cm to 17-cm proton-group was strictly identifiable with the group of shorter range but similar range-distribution which is observed at lower voltages, we turned to the identification of the contamination responsible for this effect by bombarding gases with lower-voltage deutons projected from the high-voltage tube through a Cu-foil window of 1-cm stopping power into a gas chamber (a mica window does not withstand the bombardment more than a few seconds). Since January we had been suspicious that the erratic behavior of our targets was at least in part due to some contamination arising from the bombardment itself, although the high yields obtained from the beginning with C and SiO_2 were disturbing. The Cu-foil window was arranged at an angle and the walls offset to prevent any disintegration-protons from the window or walls reaching the ionization-chamber through the side-window on the gas chamber, which could be filled with a gas at reduced pressure to give the deutons a range extending well beyond the column of gas "visible" to the ionization-chamber. Successive bombardment of air, CO_2, and tank hydrogen gave no detectable disintegration-protons beyond 3.5-cm range (the stopping power used in the tests), showing that the effect was not due to either H^1, C, N, or O. Introducing 15-cm pressure of 98 percent deuterium gas, very large numbers of protons were instantly recorded. (The tank hydrogen at low pressure would not be predicted to give a detectable effect from its H^2-content.) The range and the range-distribution curve for these protons were the same as for those observed from C, SiO_2, and the other targets at the corresponding deuton-speed, and the disintegration-yield per 10^6 deutons was very much greater. Reduced to full voltage by the factor ($\times 5$) shown for this group on the C-target, the very large yield of one disintegration-proton per several thousand primary deutons was obtained. This yield value is preliminary and may be in error by a considerable factor, but it indicates the magnitude of the effect and the reason why the deuterium occluded on and in the target by the beam is able to give rise to such a large contamination-effect. Difficulties in interpretation introduced by the evidently continuous distribution of proton-ranges even from the gas will be discussed later. A modest number of neutrons appears to be emitted by the deuterium gas under bombardment; gamma-rays are not produced in any great intensity. Oliphant, Harteck and Rutherford have also recently demonstrated the emission of large numbers of protons by various deuterium compounds under bombardment by deutons[10] at speeds as low as 20,000 volts. During the past two weeks we have been attempting to extend these gas-observations to the identification of the element (elements?) responsible for the delayed radioactivity shown by all targets so far tested after bombardment by deutons. The results as yet are not definitive, being made difficult by the smallness of the effect even at full voltage. The intense (non-delayed) gamma-ray emission[9] produced by deuton-bombardment of various targets may have origin in a similar contamination, but efforts to test for this by gas bombardment gave negative and hence inconclusive results, at least partly because of the gamma-rays from the Cu-foil window and its support. These gas-bombardment experiments, with both protons and deutons, are being continued.

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[9] L. R. Hafstad, M. A. Tuve and C. F. Brown, abstracts for Washington meeting, American Physical Society, April, 1934.

[10] M. L. Oliphant, P. Harteck and Lord Rutherford, Nature **133**, 413 (1934).

We take pleasure in recording our indebtedness to Professor Urey and his colleagues, Professors Zanetti and La Mer, for the deuterium gas used in most of these experiments. Our first observations were made with a sample of heavy water presented to us more than a year ago by the late Dr. Washburn. To our colleagues O. Dahl and C. F. Brown, and Dr. J. A. Fleming, Acting Director of this Department, we record our grateful thanks for their assistance and support.

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The Relation of the Positron Energy Spectrum to the Decay Constant and to the Energy of the Bombarding Protons

We have reported[1] approximate energy distributions of the positrons emitted by various substances activated by proton or deuton bombardment. A typical photograph is reproduced in Fig. 1. To find whether a relation exists between the maximum energy of the bombarding particles and the energies of the disintegration positrons we have studied numerous samples of carbon bombarded by protons at peak voltages of 900,000 and 700,000, supplied us by Dr. Lauritsen and Mr. Crane. The results of cloud chamber measurements on these samples are shown in Figs. 2 and 3, in which the number of tracks in two overlapping sets of 200,000 volt intervals is plotted against energy in electron-volts. The existence of a definite energy limit to the positron spectrum is not established, but we may infer something as to the relative limits in the above two cases by ignoring the small tail and extrapolating to

Fig. 1. Magnetic field 800 gauss. Disintegration positrons from carbon target after bombardment by 900,000 electron-volt deutons.

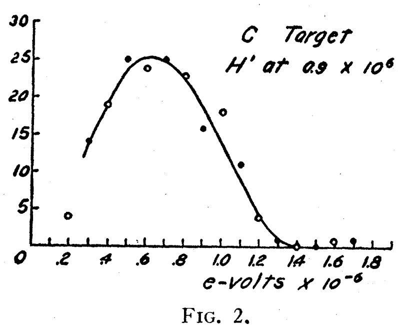

Fig. 2.

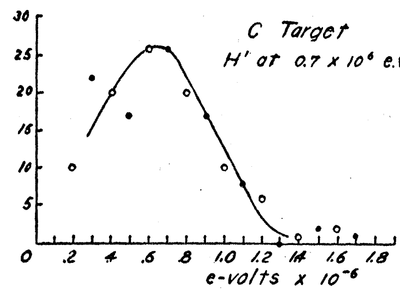

Fig. 3.

the energy axis the declining portions, and comparing intercepts. We find in this way about 1.3×10^6 e.v. for both curves and conclude that the disintegration energy within experimental uncertainties is not a function of the energy of the bombarding particles. As a further check on this conclusion we compared the mean energy of the disintegration positrons from the above targets activated at the two different voltages, with results as shown in Table I, which gives the data obtained from two independent measurements on the same sets of photographs,

Table I.

Maximum energy of bombarding proton	Mean positron energy	Number of tracks	
0.7×10^6 e.v.	0.64×10^6 e.v.	157	First meas.
.9	.69	103	
.7	.67	95	Second meas.
.9	.70	93	

the second measurement representing a more critical choice of only the sharpest tracks. Whereas the difference in energy of the protons was 200,000 e.v., the difference in mean positron energy was, for the two sets of measurements, only 50,000 and 30,000 e.v., respectively.

As we have previously stated[1] there exists a rough connection between the energies of the disintegration positrons and the disintegration probability. That the upper limits of the β-ray spectra of natural radioactive bodies and the disintegration probabilities are related by a quite definite law, which in its general character is similar to the Geiger-Nuttall law for the α-disintegrations, has been pointed out by Sargent.[2] For convenience we

[1] Neddermeyer and Anderson, Phys. Rev. **45**, 498 (1934).