and Fertel,[13] in which they find about 6 tracks per sq. mm per 230 days at 7 meters of water. This corresponds to a flux of 3.2×10^{-5} per sq. cm per sec. This may be compared to 6×10^{-5} observed in the present experiments at 6 meters. With an altitude dependence of two per meter of water, exact agreement is obtained, a circumstance which must be regarded as fortuitous.

The altitude dependence of the counting rate is, roughly, two per meter of water. This is the same as that of neutrons, as determined by neutron counters with boron and cadmium shields,[6,1] and also with plates.[2] The proton plates used at the Jungfraujoch were observed[13] to have ten times the number of tracks that were found at sea level in the same area and time. This corresponds to about two per meter of water. This is also the rate of increase with altitude of the soft component, a circumstance suggesting a possible connection, which has been discussed.[12]

We may also inquire whether many of the counts result from primary protons at the ends of their ranges. If we suppose the total flux of primary protons (I_{pri}) to be 0.16 per sq. cm per sec., and assume that all are stopped in the first 4 meters of water equivalent of air (4×10^5 cm), then, since they are sufficiently ionizing to be detected in these experiments only during the last 40 cm or less of their range in air, we would expect at any level to find $i=I_{\text{pri}}\times40/4\times10^5$, or 1.6×10^{-5} per sq. cm per sec., which is about one-sixtieth of the observed intensity.

Thus it appears probable that most of the discharges of the proportional counter in the stratosphere can be attributed to slow protons produced by the radiation. The majority of the slow protons (energies <10 Mev) appear to have been produced by some process connected with the soft component of the radiation, possibly nuclear photo-disintegration. Cross sections for various processes of this type have been calculated by Heitler,[14] and are found to be in sufficient agreement with experiment, considering the necessarily rough experimental data available. The neutrons, observed both by recoils and by boron disintegrations, are presumably liberated in the same process.

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[13] W. Heitler, C. F. Powell and G. E. F. Fertel, Nature **144**, 283 (1939).

[14] W. Heitler, Proc. Roy. Soc. **A166**, 529 (1938).

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Beta-Ray Energy of H^3

Sanborn C. Brown

Massachusetts Institute of Technology, Cambridge, Massachusetts

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The maximum energy of the H^3 beta-ray spectrum has been measured by its absorption in helium. The detector was a screen-wall Geiger-Müller counter with helium at atmospheric pressure flowing through it at all times. The maximum range of the H^3 beta-rays in helium was determined as 13 ± 1 mm, corresponding to a maximum energy of 9.5 ± 2.0 kev.

A NUMBER of attempts have been made to determine the energy of the H^3 beta-rays.[1] Measurements on this spectrum are made difficult by its extremely low energy, but if we use a screen-wall Geiger-Müller counter working at atmospheric pressure and filled with

[1] L. Alvarez and R. Cornog, Phys. Rev. **57**, 248A (1940); G. U. Perlow, Phys. Rev. **58**, 218 (1940); R. D. O'Neal, M. Goldhaber, Phys. Rev. **58**, 574 (1940).

helium,[2] we have a convenient method for dealing with the problem. Although the method possesses the inherent inaccuracies of absorption methods, including the lack of a good range-energy relation in this low energy range, it allows constant counter characteristics throughout the experiment, and we can evaluate and make the corrections due both to changes in solid angle and to the failure of the sensitive volume of the counter to coincide with the physical limits of the cathode screen.

The source of H^3, which was generously supplied by the Radiation Laboratory at Berkeley, was in the form of water. No simple method of preparing the source could be found to keep the counter from becoming contaminated. Therefore a more complicated method was used. P_2O_5 was sublimed onto the source plate in a vacuum. The source plate was then suspended, without coming in contact with the air, in the radioactive water vapor in an atmosphere of helium at room temperature for twenty-four hours. With sources prepared in this manner, the background of the counter remains constant over long periods of time, and the source strength remains constant as long as a dry-ice trap is provided between the counter and the helium tank. The trap eliminates moisture which would otherwise enter the counter and be absorbed by the source, whose activity would thus be decreased.

The apparatus used to measure the range of the beta-rays is shown in Fig. 1. It consists of a 14-mesh screen-cathode Geiger-Müller counter with a plunger, which holds the source, sliding in the side arm on the counter envelope. Helium from a commercial tank flows into the counter through a dry-ice trap, down over the source, and out into the air through a bubbling bottle which serves to show the rate of flow of the helium and acts as an air lock in case the helium flow is shut off. Helium at approximately atmospheric pressure, flowing through the counter in this manner, is used for three reasons. At atmospheric pressure it is not necessary to have any window between the source and counter, so that very low energy beta-rays can be measured. If the helium is kept flowing gently through the apparatus at all times the apparatus does not have to be made vacuum tight and therefore has advantages of simplicity in construction and operation. Helium is used so that at atmospheric pressure the counter will operate at voltages which are easily obtainable by ordinary Geiger-Müller counter amplifiers. The threshold of the counter used was 1200 volts.

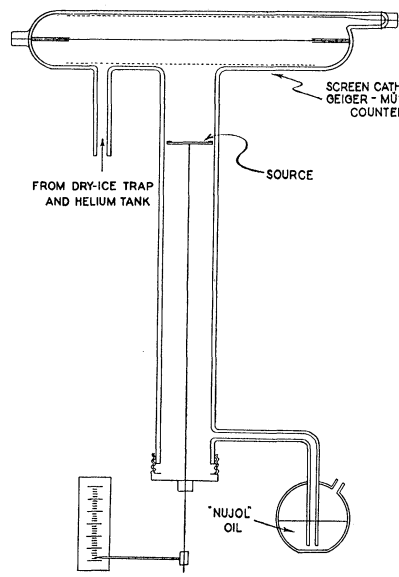

FIG. 1. Sketch of the atmospheric pressure helium flow counter used. The counter cathode is 10 centimeters long and 2 centimeters in diameter.

The counter was fed through a counting rate meter,[3] the output of which went to a galvanometer. The deflection of the galvanometer was proportional to the counting rate and was recorded photographically. The counting rate was determined as a function of the distance between the source and the outer edge of the screen. The result of this is plotted in Fig. 2.

As the source is moved away from the counter, the beta-rays are more and more strongly absorbed, and also the solid angle changes. Both these changes would affect the counting

[2] It was thought that the use of these counters was original (S. C. Brown, Phys. Rev. **58**, 1121A (1940)). It has been pointed out, however, that J. A. Bearden and C. L. Haines, Phys. Rev. **40**, 1048A (1932); and J. S. Allen and L. W. Alvarez, Rev. Sci. Inst. **6**, 329L (1935) showed that helium-filled counters could be operated at atmospheric pressure. It is unfortunate that this useful method of detecting low energy beta-rays should have been overlooked.

[3] R. D. Evans and R. L. Alder, Rev. Sci. Inst. **10**, 332 (1939).

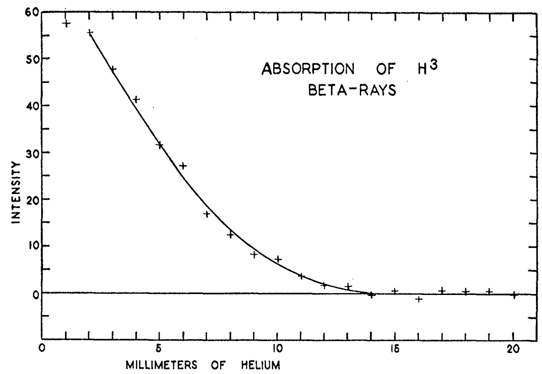

FIG. 2. Absorption curve of the H^3 beta-rays in helium at atmospheric pressure.

rate. The amount of the change due to changes in solid angle was determined by using an alpha-ray source and operating the counter as a *proportional* counter so that only alpha-rays would be recorded. When the counter is kept within the range of the alpha-particles, the counting rate as a function of distance gives the correction to be applied for changes due to solid angle. This, of course, does not change the end point, but merely the shape of the curve.

Figure 2 would give the maximum range directly if the sensitive volume of the counter coincided with the physical limits of the cathode screen. Since this is not necessarily true, the following experiment was done to determine where the electrical edge of the counter was in comparison with the physical edge. A polonium source was substituted for the H^3 source. Two sets of observations of the range were made with the counter operating in its Geiger-Müller region, one with a 0.5-mil aluminum foil wrapped around the cathode so that the field of the counter extended no farther than the edge of the screen, and another when the same aluminum foil was placed directly over the source. The measured difference in the range showed that the sensitive volume of the counter extended one millimeter beyond the physical limits of the screen, the width of the holes of which was approximately two millimeters. Applying this correction to the measured range of the H^3 beta-ray, we get for the maximum range 13 ± 1 mm of helium at atmospheric pressure.

Difficulty is encountered when one tries to convert this range into energy, because of the lack of a good range-energy relation in this low energy domain. The best that can be done at present is to compile the available data for the range of homogeneous cathode rays and put the

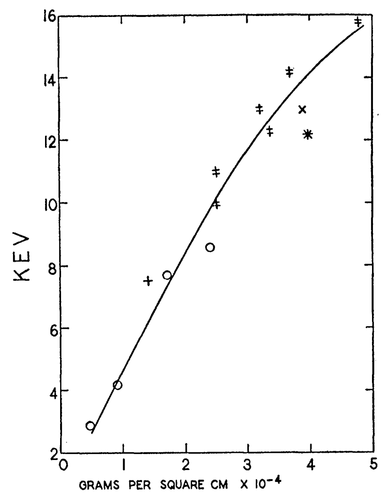

FIG. 3. Range-energy relation of homogeneous cathode rays. Data from the following authors: ○ T. Alper, Zeits. f. Physik **76**, 172 (1932); + J. M. Nuttal, E. J. Williams, Proc. Roy. Soc. **130**, 310 (1930); ‡ * B. F. J. Schonland, Proc. Roy. Soc. **108**, 187 (1925).

best curve through the values obtained by a number of different authors. This curve is shown in Fig. 3. If we use this range-energy relation and the fact that 13 mm of helium correspond to 2.3×10^{-4} grams per square centimeter, the maximum energy of the H^3 beta-ray is found to be equal to 9.5 ± 2.0 kev.

In conclusion I wish to acknowledge the help of Professor Robley D. Evans, under whose direction this work was carried out.