thus

$$\frac{L}{d}<\frac{1+\cos n^{\frac{1}{2}}\pi}{n^{\frac{1}{2}}\sin n^{\frac{1}{2}}\pi}. \qquad (2)$$

For the radial motion the equations are the same, except that $n^{\frac{1}{2}}$ is replaced by $(1-n)^{\frac{1}{2}}$.

According to Dennison and Berlin, the allowable range of n values in the racetrack is between $n=0.56$ and $n=0.75$. The corresponding limits given by (2) are $L/d<0.56$ and $L/d<0.25$. These are not unduly restrictive conditions. However, the defocusing effect which leads to this instability will manifest itself, even when the limits are not exceeded, by an increased amplitude of the oscillations. For orbits crossing the equilibrium orbit at the same angle, the amplitude of oscillation in the racetrack will be larger than in a circular synchrotron by a factor $\sin n^{\frac{1}{2}}\pi/\sin \pi\mu$. For $n=\frac{2}{3}$, $L/d=0.3$, this is a factor 2.3. One thus pays a price for the convenience of having the straight legs: insofar as the yield of the machine is concerned, the gap width and all vertical clearances are effectively reduced in just this ratio.

This work was carried out under the auspices of the Manhattan District.

[1] H. R. Crane, Phys. Rev. **69**, 542 (1946).
[2] D. M. Dennison and T. H. Berlin, Phys. Rev. **69**, 542 (1946).
[3] For the method of calculating μ see Whittaker and Watson, *Modern Analysis*, Sec. 19.4. A very similar problem has been treated by B. van der Pol and M. J. O. Strutt, Phil. Mag. **5**, 18 (1928).

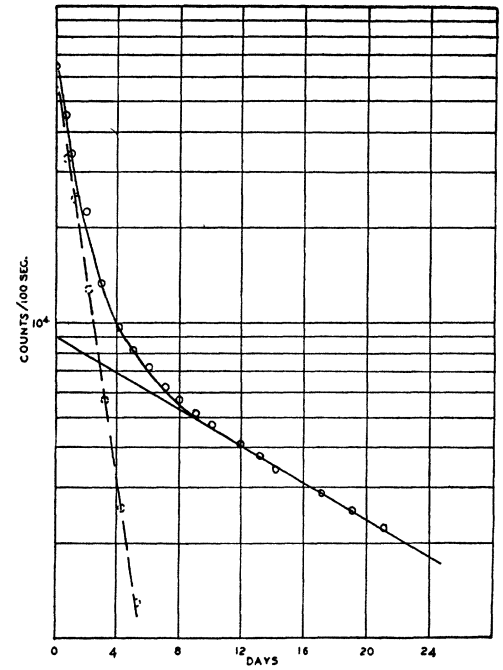

FIG. 1. Decay of long-period activities in columbium showing 21.6-hour and 11-day activities.

Radioactive Isotopes in the Columbium Region

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IN addition to the well-known activities in columbium (i.e., Cb^{93*} 40 days, Cb^{92} 11 days, Cb^{94} 6.6 minutes, Cb^{95} 75 minutes), a series of isotopes has been reported of half-lives 4 minutes, 12 minutes, 38 minutes, 21 hours, and 96 hours. These have been found by the Rochester group[1] and were produced from zirconium by the p-n reaction.

Short bombardments of columbium metal foils with 10-Mev deuterons produced the 6.6-minute β^--activity in Cb^{94} as well as 18-minute and 6.5-hour[2] positron activities. The latter periods can be assigned to isomeric states of Mo^{93} produced in the Cb^{93} $(d, 2n)$ process. Deuteron bombardment of molybdenum also yielded the 18-minute and 6.5-hour β^+-activities along with the 15-minute and 68-hour β^--decay periods.

Prolonged irradiation of a stack of columbium metal foils by 10-Mev deuterons produced intense activities in the front layers but essentially none (less than 2 percent of that in first foil) in the foils which were not penetrated by the beam of deuterons. After the short-lived activities (including the intense 6.5-hour Mo^{93}) had decreased to a negligible value, the decay followed the curve shown in Fig. 1. It is seen that two long periods remain, Cb^{92} 11 days and one of 21.6 hours. The latter activity is presumably identical with that of 21 hours formed by Zr $(p$-$n)$.

Cloud-chamber observations indicated that negative beta-particles were emitted by the latter isotope. Absorption in aluminum foils gave a value of 1.2 Mev for the upper limit of the β-spectrum. Gamma-rays of energy 0.6 Mev (as determined by absorption in lead) were also emitted by this isotope.

In studying the activities as a function of the average deuteron energy, it was found that the 11-day and 21.6-hour activities had similar excitation functions, the threshold for each being $\sim$5 to 6 Mev. The low value of the threshold energy indicated that Cb^{92} (11 days) is formed in the process Cb^{93} (d, H^3).

Slow neutron bombardment of columbium yielded the 6.6-minute activity but not the longer periods. The 21.6-hour period is therefore assigned to an isomeric state of Cb^{92} produced in the Cb^{93} (d, H^3) reaction.

[1] See G. T. Seaborg, Rev. Mod. Phys. **16**, 13 (1944).
[2] D. N. Kundu and M. L. Pool, Phys. Rev. **70**, 111 (1946).

Production of Heavily Ionizing Particles by X-Rays Generated by a 100-Mev Betatron[1,2]

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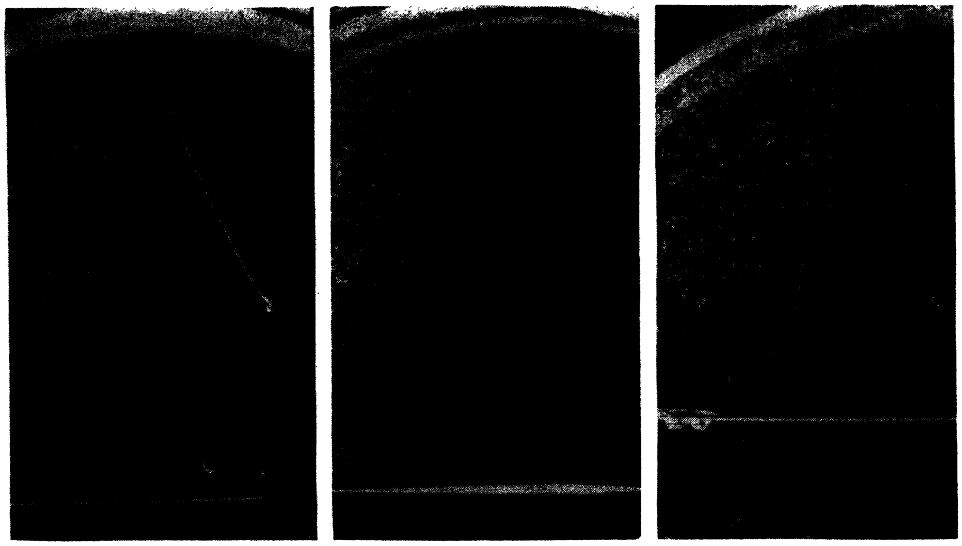
CLOUD-CHAMBER photographs of ionizing particles generated by x-rays of 100-Mev peak energy were taken in a magnetic field. It was found that in addition to numerous tracks due to electrons and positrons, tracks of heavily ionizing particles also occurred in the chamber. An attempt was made to obtain the masses of these particles from measurements of the range and curvature of their



a b c

FIG. 1. Tracks of heavily ionizing particles generated by x-rays of 100-Mev peak energy. a, track showing measurable curvature of negatively charged particle stopping in the gas. b, track showing curvature of negatively charged particle stopped in brass plate. c, track showing no measurable curvature stopped in brass plate.

tracks and from estimates of their specific ionization. Some additional evidence as to the nature of these particles was obtained from their stopping in thin brass plates.

A cloud chamber equipped with a stereoscopic camera arrangement was used for these experiments. This chamber of 20-cm diameter was filled with argon and placed between the poles of a permanent magnet giving a field of 900 gauss. The expansion of the chamber was synchronized with the betatron to receive a single pulse of high energy x-rays at the optimum time in the expansion cycle. The direction of the primary x-ray beam is indicated by the arrow in each figure.

Figure 1a shows a picture in which a heavily ionizing particle exhibiting measurable curvature stopped in the gas of the chamber (argon at 85 cm of Hg pressure). The track has a length of 6 cm in the gas of the chamber and exhibits a radius of curvature of 23 cm near its midpoint. This curvature and the measured range of the track correspond to a singly charged negative particle of mass $75m_e$ (m_e = mass of electron). For this determination, however, the probable curvature of the track owing to multiple scattering in the gas has not been taken into account. If one assumes that the measured curvature is the resultant of the magnetic deflection and that owing to the most probable value of the multiple scattering as given by Williams[3] and Bethe,[4] one obtains as an upper limit for the mass a value of $450m_e$. If, however, the actual scattering in the gas was considerably greater than the most probable scattering, the particle could have been a proton curved entirely by multiple scattering. The probability of this happening can be calculated to be approximately 0.012 which is small since very few heavily ionizing tracks of comparable range were obtained so far.

The radius of curvature of the track shown in Fig. 1b is 75 cm in a direction corresponding to a negative particle coming from above and stopping in a 0.025-cm brass plate placed in the middle of the chamber. (The stopping power of this plate is equivalent to that of 135 cm of standard air and hence any proton which stopped in the plate should have a maximum energy of 11×10^6 ev.) If this particle were a proton, its ionization could not have been smaller than 22 times that of a fast electron. If it were a meson of mass $200m_e$, its ionization could have been as low as 8 which seems to fit the appearance much better. A proton having the maximum range of 135 cm in the brass plate would, however, exhibit a negligibly small curvature due to both multiple scattering in the gas and the magnetic deflection. On the other hand a proton just reaching the plate should have a curvature due to multiple scattering less than one-half of its observed value. In this case, however, the ionization of the particle should be 80 times that of a fast electron which seems most improbable.

In Fig. 1c a particle is shown which stopped in the brass plate but does not exhibit a measurable curvature. If it were a proton, the minimum value of its ionization should have been 22 times that of a fast electron. On the other hand, for a meson of mass $200m_e$ the corresponding value of the ionization should be 8. The appearance of the track compared with the numerous electronic tracks in the immediate neighborhood definitely favors the latter possibility.

In view of the fact that a relatively small number of tracks of similar nature have only been found in the chamber so far, it seems necessary to carry out further investigations before definite conclusions can be reached as to the real nature of the above described ionizing particles.

[1] Reported at 270th meeting of the American Physical Society at Columbia University, New York, New York, January 26, 1946.
[2] W. F. Westendorp and E. E. Charlton, J. App. Phys. 16, 581 (1945).
[3] E. J. Williams, Phys. Rev. 58, 292 (1940).
[4] H. A. Bethe, Phys. Rev. 69, 689 (1946).

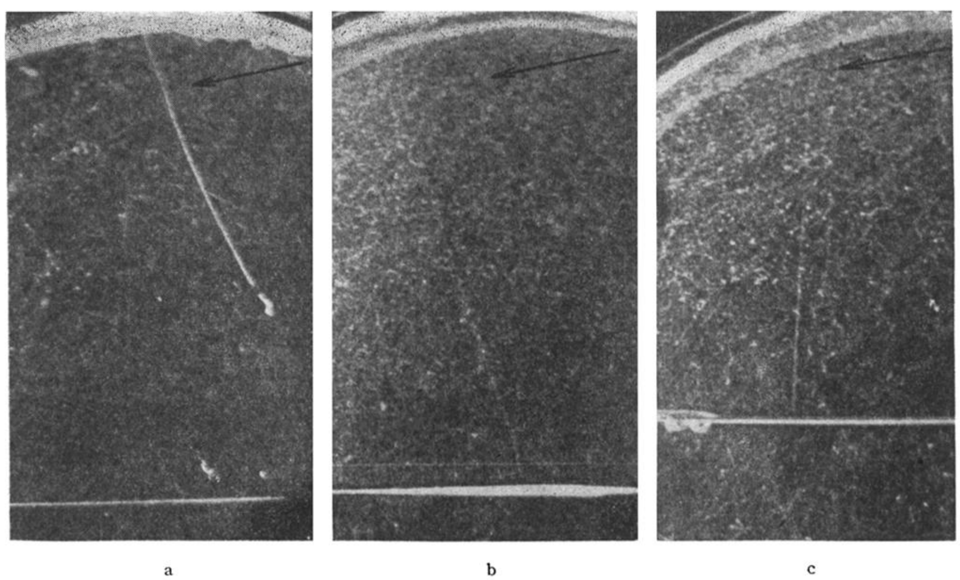


FIG. 1. Tracks of heavily ionizing particles generated by x-rays of 100-Mev peak energy. a, track showing measurable curvature of negatively charged particle stopping in the gas. b, track showing curvature of negatively charged particle stopped in brass plate. c, track showing no measurable curvature stopped in brass plate.