High-Speed Protons

We have recently succeeded in obtaining and photographing the tracks produced in a Wilson cloud-chamber by high-speed protons from a high-voltage tube used with a Tesla coil,[1] and have made a preliminary measurement of the range in air of 1000-kilovolt protons.

Measurements on the high-speed protons from a "flashing" tube were reported at the June meeting in Pasadena. Visual observations of the Thomson parabolas produced by electric and magnetic deflection of a narrow pencil of rays identified without ambiguity the H^+, H_2^+, and heavier high-speed ions accelerated by voltages of the order of one million volts, and thus verified the production of high-speed protons by a "flashing" tube as observed using magnetic deflection alone throughout the previous year. Photographic recording of these parabolas was not seriously attempted due to the fogging of the plates by scattered electrons and light. The protons presumably arise from occluded hydrogen on the electrodes, and from residual gas in the tube.

A Wilson chamber[2] separated from such a "flashing" tube by a thin mica window was operated last spring without definite results. Even when the electrons were deflected away from the window, any proton-tracks which were present were masked by the ultraviolet light and x-rays which entered the chamber through the window and produced very dense fogging. The rather strict requirements for proper synchronization of the high-voltage impulse and the "sensitive time" of the chamber (0.012 to 0.035 second after the piston drop) were also emphasized by these preliminary experiments.

Accordingly during the past summer and early fall efforts were made to obtain proton-tracks using a Dempster-Ramsauer proton-source (lithium bombarded by 50-volt electrons) in conjunction with a dark tube (flashing prevented by the equalization of voltage-distribution among the tube-sections by their capacity to a "ring-shield" connected to the high-voltage corona-cap). This experiment failed by reason of too low a proton-intensity. The proton-current was of the order 10^{-10} ampere, and the on-time of the peak-voltage of the order 10^{-6} second. With these factors and the small fraction of the initial proton-current which goes through all sections of the tube (solid angle and probable de-focussing effects), apparently from electron-measurements of the order of 10^{-4} or less when focussing is not attempted, there were too few full-speed protons reaching the mica window to detect reliably even with the Wilson chamber. The sensitivity of the latter to single high-speed protons from the tube has since been demonstrated very clearly.

We consequently returned to the use of the flashing tube, utilizing magnetic analysis and obtaining x-ray shielding by means of thick slits which are considerably out of line with the window. Unambiguous results were obtained as soon as this set-up was operated. For the first observations a wide band of proton-velocities was admitted to the chamber and tracks of a great variety of lengths (ranges up to 4 cm) were obtained. Heavier and hence slower ions deflected to the same point by the magnetic analysis (electric deflection omitted) cannot pass through the mica window, which has a stopping power of 1.8 cm of air for α-particles. The number of proton-tracks observed varied from one to more than 200 (unresolvable). The tube was operated to moderate voltages only, spark-gap measurements indicating somewhat above one million volts.

Although we have had ample experience of the fact that the Tesla coil and particularly the flashing tube are far from ideal for quantitative work, we have used this set-up with increased magnetic resolution to obtain at least a rough measurement of the range of 1000-kilovolt protons. Since protons of any speed down to zero can arise from intermediate electrodes, it is necessary to compare the maximum range observed with the maximum $H\rho$ which any proton can have and still enter the mica window of the Wilson chamber. The result of the measurements was a maximum total range of 2.8 cm in air reduced to stand-

[1] G. Breit and M. A. Tuve, Nature **121,** 535 (1928); G. Breit, M. A. Tuve, and O. Dahl, Phys. Rev. **35,** 51 (1930); M. A. Tuve, G. Breit, and L. R. Hafstad, Phys. Rev. **35,** 66 (1930); M. A. Tuve, L. R. Hafstad, and O. Dahl, Phys. Rev. **35,** 1406 (1930) and **36,** 1261 (1930).

[2] We are indebted to Dr. L. F. Curtiss, of the Bureau of Standards, for the loan of parts and for assistance with the design and technique of the automatic Wilson-chamber apparatus.

ard conditions (1.0 cm in chamber), for a given setting of the magnetic field and a fixed position of the window. This figure was obtained from three separate runs, each involving approximately 50 pictures of proton-tracks (from 10 to several hundred protons per picture) with major changes of voltage-distribution, with and without carbon point-flasher, and with greatly altered vacuum-conditions and electrode-contamination at the high-voltage end of the tube between the different runs. The separate films gave results for the maximum range agreeing within about 6 percent.

The assignment of the proper maximum value of $H\rho$ to be associated with this maximum measured range requires an assumption as to the precise direction of motion of these protons in the tube. If the proton-beam is parallel to the axis of the tube, the magnetic field measurements yield the result that 1035-kilovolt protons will be deflected 6.2 cm to the center of the 3 mm window, and 1100-kilovolt protons can just enter the window on the side of least deflection. The assumption that the protons move very nearly parallel to the axis of the tube appears to us the most reasonable one to make in view of the tendency of the electric fields between successive electrodes to make parallel to the axis the motion of particles which are moving near the axis and at a small angle to it, and to remove from the beam particles which move at a considerable angle with the axis. This effect has been shown in the work of Sloan and Lawrence.[3] However, if the proton-beam is assumed to have the solid angle (0.02 radian) determined by the entire area of the high-voltage end of the tube which is visible from the slit-system through the holes in the electrodes (3 mm slits, 25 cm apart), the spread in values of $H\rho$ is considerably increased, and the maximum value then corresponds to nearly 1300 kilovolts. This possibility appears to us as highly improbable on the basis of our previous experience, particularly with the Thomson parabolas.

Assuming from the literature that the range of a proton struck head-on by a Ra-C α-particle, and therefore given a velocity of 3.08×10^9 cm per second, is 32 cm in air at 15°C and 760 mm, the range of a 1000-kilovolt proton is 2.92 cm on the assumption of the α-particle law of range proportional to the cube of the velocity. Assuming the β-particle law of range proportional to the fourth power of the velocity, this figure becomes 1.32 cm. The corresponding figures for 1100 kilovolts are 3.32 cm and 1.60 cm. The voltages corresponding to a 2.8-cm range are respectively 960 and 1460 kilovolts on the two laws. It appears to us that our measurements exclude the β-particle law and suggest that the law governing the range of protons is nearer to the velocity-cubed law which holds for α-particle ranges.[4]

The difficulties of doing quantitative work with a Tesla coil, due to the short on-time and fluctuating value of the peak-voltage, are obvious, and we hope in the near future to undertake a program of quantitative measurements using the newly developed Van de Graaff electrostatic generator[5] as the source of high voltage for the tubes.

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Carnegie Institution of Washington,
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[3] D H. Sloan and E. O. Lawrence, Phys. Rev. **38,** 2021 (1932).

[4] See Chadwick, Constable, and Pollard, Proc. Roy. Soc. **A130,** 477 (1931) and Blackett, Proc. Roy. Soc. **A103,** 65 (1923).

[5] R. J. Van de Graaff, Phys. Rev. **38,** 1919-A (1931).

On the Classification of Certain Lines of Radium

The radium spark lines of wave-length 6446.1, 5823.7, 2836.5, 2813.7, and 2708.9A can be accounted for by assuming a set of doublet levels at 73,820; 72,162 cm^{-1} and at 36,917; 36,632 cm^{-1}. The lower levels are analogous to the $^2D_{5/2,3/2}$ levels of Ba II at 75,781; 74,980 cm^{-1}, while the upper levels are analogous to the $^2F_{7/2,5/2}$ Ba II levels at 32,397; 32,172 cm^{-1}.

The positions of the levels are fixed by the combination of the two lower levels with the known $7^2P_{3/2}$ level. The $7^2P_{1/2}$ combination should give a line at 8121A, which is beyond the region investigated by various workers (6642–2709A).[1] The estimated intensities are in the correct order for each line of the multiplet.

[1] Kayser, Handbuch der Spectroscopie, B6.