THE DIRECTION OF EJECTION OF PHOTO-ELECTRONS PRODUCED BY X-RAYS

By D. H. Loughridge

Abstract

Stereoscopic photographs of photo-electrons produced by 40 kv Mo Kα x-rays, were examined by a stereoscopic comparator which gave a quantitative measure of the initial direction of ejection in space. The measurement of twenty-four distinct tracks in a series of twenty-nine pairs of photographs showed that the most probable angle of ejection was about 70° with the primary beam. This supports the view that the electric vector of the radiation plays a very important part in the production of photo-electrons. The small forward or backward component, noticed in many tracks, must come from the random momentum of the electron in its orbit before ejection.

IT has been shown by Bothe[1] that the most probable direction of ejection of photo-electrons produced in various gases by x-rays of varying hardness, makes an angle between 80 and 85° with the primary beam. This varies slightly with the gas and with the hardness of the rays. P. Auger[2] has also reported similar results. However, C. T. R. Wilson observed three characteristic angles of ejection of photo-electrons in air, namely 45, 90, and 135° with the primary beam. The present experiment was performed in order to measure accurately the initial angles of ejection of photo-electrons in air produced by radiation of a definite frequency.

Experimental Procedure

Stereoscopic photographs were taken of the photo-electron tracks produced in moist air at atmospheric pressure by the Kα radiation from molybdenum. The beam of x-rays (Fig. 1) from the molybdenum target of a water-cooled Coolidge tube, operated at about 40 kv and 35 m-amp., was sent horizontally through lead collimating slits and a zirconium oxide filter which gave practically homogeneous radiation. This beam passed through a Wilson cloud expansion chamber about 11 cm in diameter. An electric field of about 100 volts per cm was maintained, except when the picture was taken, between the top of the piston and the lower surface of the chamber top. The construction and assembly of the expansion chamber was similar to that described by C. T. R. Wilson.[3] An arc with

[1] Bothe, Zeits. f. Phys. **26,** 59-73 (1924).
[2] P. Auger, Comptes Rendus **178,** 929 (1924).
[3] C. T. R. Wilson, Proc. Roy. Soc. **104,** p. 1 (1923).

Sperry searchlight carbons, was used as a source of illumination. During adjustment of the apparatus it was operated at about 15 amp. but just before a picture was taken the current was increased to 100 amp. by short circuiting a series resistance. A shutter kept the light out of the chamber except when needed. This precaution was found necessary as even very slight heating effects within the chamber produced vortex motion of the gas which distorted the tracks. The illumination was sent in horizontally, by suitable condensing lenses, at right angles to the x-ray beam. The matched lenses were Tessar $f/4.5$, 5.5 cm focus and were mounted in a box camera with their centers 6.5 cm apart. A Graflex focal plane shutter which exposed the two plates simultaneously and was released by a plunger type solenoid, regulated the exposure. Eastman Speedway $3\frac{1}{4}\times4\frac{1}{4}''$ plates were used.

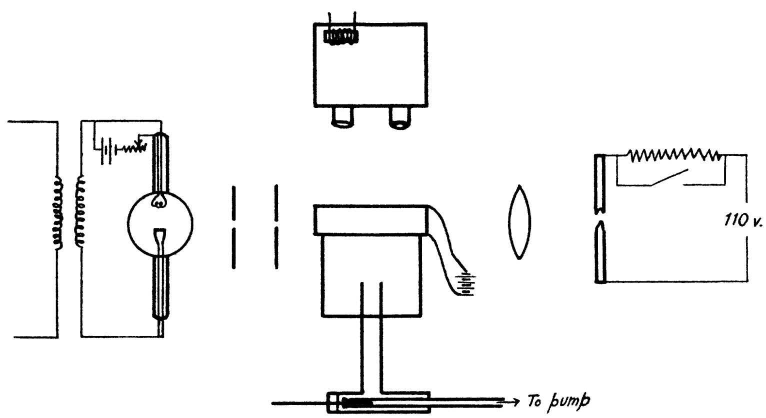

Fig. 1. Diagram of apparatus.

The timing was performed by two falling balls, released simultaneously by two solenoids in series; the first ball caused the expansion by opening the valve underneath the piston and the second ball, immediately afterward, closed the primary switch of the transformer operating the x-ray tube and then closed the circuit which operated the camera shutter. The adjustments on all these devices were regulated until sharp photographs were obtained. The switch, which controlled the solenoids holding the falling balls, also cut off the electrostatic field in the chamber.

Results

A series of 26 pairs of photographs were obtained using expansion ratios between 1.29 and 1.34. Some of these contained too many tracks for accurate measurement but, by cutting down the size of the x-ray beam, photographs were obtained where distinct photo-electron tracks could be found which did not overlie any others and were sharply in focus. The depth in the photograph was obtained by using a stereocomparator and the height and breadth were measured directly on the plate by dividers. By thus obtaining the difference between the coordinates of the initial point of the track and point where the first bend occurred, the initial direction of ejection in space could be calculated. For the calculation of the depth in the picture the angle between the optic axes of the two lenses was needed, which was 13°.

Twenty-five distinct tracks were found in the series of photographs. In all of these there was no ambiguity as to which was the head of the track. Arranged in order of increasing angle between the primary beam and the initial part of the track, the values found are 21, 45, 48, 49, 52, 53, 59, 59, 67, 69, 70, 73, 74, 80, 84, 88, 90, 96, 99, 100, 104, 107, 119 and 123°. These values are plotted in Fig. 2, with angles as abscissas, and the number

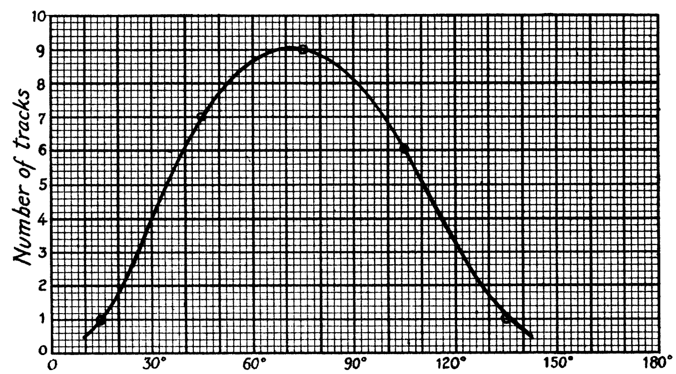

Fig. 2. Distribution of the directions of the 24 photo-electron tracks with respect to the x-ray beam.

of tracks starting within each 30° interval as ordinates. The curve clearly shows a marked angle of most probable emission around 70°. Practically the same maximum is obtained if the angular intervals chosen for plotting are 10°, 15°, 45°, or 60°; but the number of data hardly justifies the smaller intervals while the larger intervals give too few points to insure a clear curve. It is felt that the 30° interval chosen shows the effect fairly and clearly. It should also be pointed out that tracks lying close to 0° or 180° with the primary beam, would be the easiest to measure as they would all lie more nearly in the plane of the plate, while the ones bunched around 90° would contain some lying perpendicular to the plane of the plates and would therefore be more difficult to see. Thus it is obvious that if there existed a random distribution of the directions of ejection one would probably find more around 0° and 180° than around 90°.

This tendency for the emission at nearly right angles to the primary beam is in agreement with the view that the electric vector of the rays plays a very important part in the process. In fact, Bubb has shown[4] that when polarized x-rays are used the most probable direction of emission lies in the plane containing the electric vector.

The small forward component noticed in most of the tracks supports the view that the energy of the primary quanta is imparted to the photo-electron by a forward impulse along with the sidewise impulse of the electric vector.[5] Because of these two effects alone, on the basis of conservation of momentum, no tracks with backward components would be expected, but by combining with them the random momentum of the electron in its orbit, a backward momentum becomes possible.

I am grateful to Professor R. A. Millikan for his advice and inspiration during the progress of this work.

Norman Bridge Laboratory,
California Institute of Technology,
Pasadena, California.
September 18, 1925.

[4] Bubb, Phys. Rev. **23**, p. 137 (1924).
[5] Bubb, Phil. Mag. **49**, p. 824 (1925).