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DIRECTION OF PHOTO-ELECTRON EMISSION

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Abstract

Direction of emission of photoelectrons from hydrogen, air and argon irradiated by Mo Kα x-rays.—Photographs of the photo-electron tracks in a Wilson expansion chamber through which a narrow beam of monochromatic Mo Kα x-rays were passed were taken with a stereoscopic camera. The direction of the paths with respect to the x-ray beam was determined from measurements made with a *specially designed stereoscopic comparator*. 445 tracks were studied of which 231 were in argon, 123 in air and 91 in hydrogen. Curves showing the frequency of occurrence of different angles of ejection have a fairly sharp maximum for angles of about 70° with the forward direction of the x-ray beam. The curves are similar for the three gases studied except that the maximum in the case of hydrogen is somewhat sharper than for the other two gases.

NUMEROUS workers have observed an asymmetry in the photo-electric current arising from a radiator placed in the path of ultra-violet light, x-rays, or gamma rays. The ratio of the current in the forward direction to that in the backward direction has been found to vary from 1.17 in the case of ultra-violet light[1] using platinum films as radiators, to 20 for carbon plates and gamma rays.[2] De Foe[3] has recently obtained a ratio of 2.89 for the asymmetry of photo-electron paths in air, photographed by the cloud method, using the $K\alpha$ radiation of molybdenum. More specifically, the most probable direction of photo-electrons in gases, produced by means of x-radiation has been investigated by Bothe[4] and the author.[5] Using a method involving the counting of electrons by a Geiger counter set at various angles with respect to the x-ray beam, Bothe found a slight variaiton with the hardness of the radiation and also with the gases used. His values vary from 73° to 81° for the most probable direction of emission, depending upon the above factors and upon the gas pressure. The present author found, by photographing the tracks in air, and measuring their directions by means of a stereo-comparator (to be described in this paper) using $K\alpha$ radiations from a Mo-target Coolidge tube, the most probable angle of ejection was about 70°.

Since this work was published an entirely new expansion chamber has been constructed and much new data on the direction of ejection of photo-electrons in hydrogen, air, and argon, by the $K\alpha$ radiation of molybdenum has been obtained. The details of the expansion chamber and a discussion of the technic involved in obtaining distinct photographs is published

[1] Stuhlman, Phil. Mag. **22,** 854 (1911).
[2] Mackensie, Phil. Mag. **14,** 176 (1907).
[3] DeFoe, Phil. Mag. **49,** 817 (1925).
[4] Bothe, Zeits. f. Physik **26,** 59 (1924).
[5] Loughridge, Phys. Rev. **26,** 697 (1925).

elsewhere.[6] It will be sufficient to state here that the chamber is 10 inches (25.5 cm) in diameter by 1 5/8 inches (4.2 cm) deep. The timing of all necessary processes is done by a heavy pendulum rigidly swung from a cross rod: the latter carries the necessary commutators to provide electrical contacts for the removal of the field across the chamber, the production of the expansion, the x-ray beam, and the exposure with the camera. The photographs are taken with a box-type stereoscopic camera mounted 16 inches (40.5 cm) above the top of the chamber. The two separate plates are exposed simultaneously by a large Graflex focal plane shutter, released by an electromagnet. In all the present work the whole chamber is photographed on the $2\frac{1}{4}\times 3\frac{1}{4}$ inch plates, thus giving a reduction in size of 3.52 fold. The lenses used are Tessar f 4.5 specially matched by Bausch and Lomb Company. Eastman Speedway plates were found to be quite satisfactory when used in connection with a Sperry arc as a source of illumination.

Measurement of the Plates

Measurement of the plates was carried out on the original negatives. The stereocomparator is shown in Fig. 1. It was machined from brass cast-

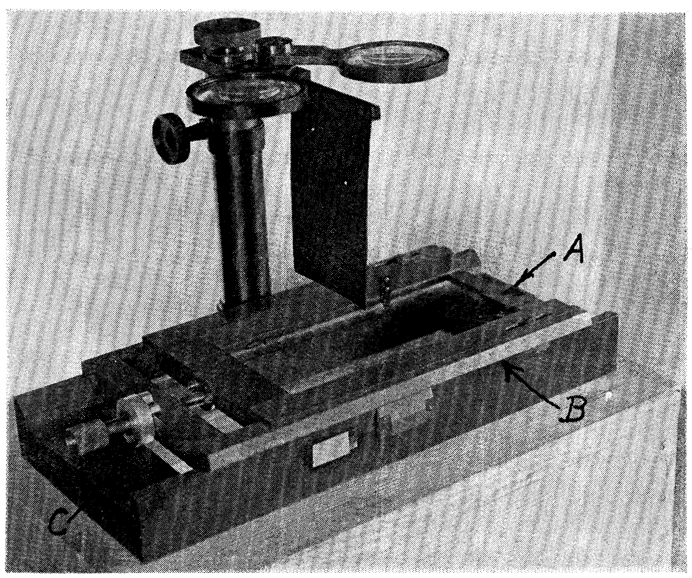

Fig. 1. Photograph of the stereoscopic comparator.

ings and consists of a heavy bed plate upon which the first carriage slides; the latter in turn carries the second carriage, and the two are moved relative to one another by the micrometer screw. Each carriage supports a cross hair which is stretched across horizontally, at such a height as to just clear the plates, which lie in a suitable support on the bed plate. It was found

[6] Simon and Loughridge, J. Opt. Soc. Amer. **13**, 679 (1926).

practicable to have the cross hair clear the plates by about 0.5 mm, although this would fluctuate some because of the differences in the thickness of the plates. The purpose in having the cross hairs as close to the plates as possible was to eliminate parallax.

The arrangement of the apparatus is such that the direction of the x-ray beam is in the vertical plane containing the center of the two camera lenses. Consequently components of tracks at right angles to this plane will be of the same length in each plate of the pair; this dimension is measured by the slider A which runs over a cross bar graduated in mm, with vernier reading to 0.1 mm, and this measurement, called the height is made upon the right hand plate. Components parallel to the incident beam, called the width components, are measured by the scale B which is engraved upon the bottom carriage and is provided with a vernier on the bed plate reading to 0.1 mm, components perpendicular to the plane of the photographic plate, called depth components, are measured by the drum C, mounted on the micrometer screw. Turning of this screw alters the distance between the two cross hairs but, in stereoscopic relief, appears to move the single cross hair, seen in the image space, perpendicular to the plane of the plates.

In the actual measurement of a track, the plates were placed in the bed plate, touching each other, and scale B read when the left hand cross hair was just over the junction point of the two plates. This was to allow the plates to be put back at any future time and the measurements on any particular part of the plate repeated at will. Thus no marking or scratching of the plates was required to reset them at their original positions. The arc light, used for the illumination, produced a caustic by reflection from the opposite side of the chamber from which it entered and this automatically insured the placing of the right side up. Only those tracks which were entirely separate from all others throughout their entire length and in which there was no doubt as to what was their head (or origin) were used in the measurements. There was two general means of distinguishing the origin from the end of a track, and usually they could both be used on a given track. The first, and more obvious method was to locate the geometric path of the x-ray beam by the large concentration of tracks which started on this line and then the end of the track which lay in this path was the origin.[7] In nearly all of the 174 stereoscopic pairs taken, the lead slits limited the x-ray beam to a cross section of about 1.5 by 0.5 mm, so that this gave a very sharp line containing most of the origins. Further, although most photo-electron paths show a small sphere, or dot, at both ends, of practically the same appearance, the section of track adjacent to the dot at the origin is nearly always less dense (showing less ionization) than the corresponding section near the end. This fact often aided in distinguishing the origins. After locating the origin of a given track the carriages were slid over the bed plate, and with respect to one another by the screw, until the cross-hair appeared to cut through the

[7] In a number of cases two photo-electron tracks started at the same point, as near as could be told, and if they were otherwise free from other tracks, both were used for measurement.

origin. This setting, as all others, could be checked for accuracy by alternately closing each eye and ascertaining if the respective cross-hair under the open eye was set above the corresponding point on each plate. However, it was found that after some practice and adjustment of one's eyes, the setting could be made as accurately with the stereoscopic vision as the slower "eye by eye" method. Scales A and B and drum C were read for the origin, and similar readings for a second point chosen on the path at the first bend. Obviously the difference between the corresponding readings were proportional to the three components of the path at right angles to each other. In order to obtain the actual components the instrument was calibrated by photographing two foot rulers, with sharpened metallic edges, clamped one in back of the other so that the edges, as measured by a traveling microscope, were separated 0.542 cm. These were placed at a distance in front of the camera equal to the distance of the x-ray beam. By measuring, on scale B, the distance between each inch mark on the rulers, the demagnification of the photographs was obtained directly and was found to be 3.52 and furthermore was constant in value across the entire 10 inches of the chamber's diameter. Likewise by setting, by stereoscopic vision, on corresponding division points on each ruler the divisions on the drum were evaluated at each inch point across the diameter of the chamber. Each drum division was equivalent to 0.226 mm in depth and was constant across the diameter of the chamber; after practice, the settings could always be repeated to within 1.5 divisions. Thus the depth readings were made to 0.34 mm, and the width and height to 0.1 mm. Having now obtained the components of the initial part of the track it is a perfectly straightforward calculation to obtain the angle with respect to the x-ray beam.

Before experiments were begun the lead collimating slits on the box enclosing the x-ray tube, were carefully lined up with a diameter of the chamber. The line connecting the two camera lenses was in the same vertical line as this diameter. This caused the x-ray beam to pass parallel to the plates and perpendicular to their long side so that the direction of the incident x-ray beam was parallel to the motion of the carriages in the stereocomparator.

The best photographs to measure were those containing about eight to ten tracks. More than this number overlapped so much that the photograph was almost useless, as far as accurate measurements were concerned. On the 174 pairs of photographs there were measured 434 separate photo-electron tracks. Of this total 231 were in argon, 123 in air, and 91 in hydrogen. The initial pressure in the chamber varied slightly from day to day, but was always between 60 and 65 mm of mercury. The expansion ratio was not determined exactly, as it was chosen so as to give the most distinct tracks, but was about 1.3.

Results

The results of measurements of tracks produced in hydrogen, air, and argon under similar conditions, by the $K\alpha$ line of Mo are shown in Fig. 2. The homogenity of the radiation was obtained by filtering that produced by a Mo-target Coolidge tube through a zirconium oxide filter especially prepared for this purpose by the General Electric Company. The cross section of the beam was about 0.25 sq. mm.

The abscissa of these curves is the angle between the initial portion of the x-ray track and the forward direction of the x-ray beam. The ordinate gives the number of tracks found to start out within the chosen angular interval. (i.e. from Fig. 2 it is seen that 24 tracks in hydrogen started out making angles of between 60 and 72° with the forward direction of the x-ray beam.)

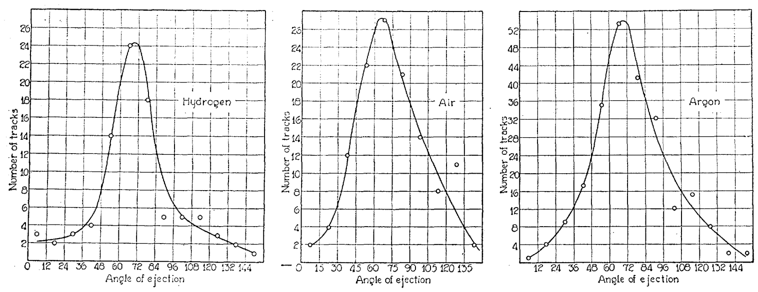

Fig. 2. Numbers of tracks of photo-electrons ejected at various angles by Mo $K\alpha$ x-rays from hydrogen, air and argon.

Practically the same maximum is obtained if the angular intervals chosen are 10°, 12°, 15°, 30°, or 45°, but the smaller intervals give points whose values are too much affected by the statistical fluctuations and the larger intervals give too few points to insure a clear curve. The 12° and the 15° intervals chosen show the effect fairly and clearly.

The curves show clearly that the most probable direction of emission is in a direction at about 70° with respect to the x-ray beam for all three of the gases studied. However, it is to be remembered that since the absorption coefficient is proportional to the fourth power of the atomic number, very probably all of the tracks dealt with in the case of hydrogen actually arise from heavier gases which are present as impurities.

These results yield a value for the most probable direction of emission somewhat smaller than that found by Bothe and Auger. This difference is larger than the probable experimental errors in the various pieces of work. Since the present work is the only one of the three in which monochromatic x-rays were used, this difference in angle may be due to the presence in previous work of soft radiation. The asymmetry of each curve is significant, being steeper on the side of the maximum toward smaller angles than on the other.

From the present work, in which the measurements on a given track can be re-checked to within about 4°, the work of using a Geiger counter by Bothe,[4] and the recent careful work of Auger,[8] there is no doubt but that there is a very appreciable forward component in the majority of the tracks.

[8] P. Auger, Jour. d. physique et le radium **8,** 85 (1927).

Discussion

The tendency toward ejection at right angles to the direction of the incident radiation is in accord with the classical theory which would demand that all of the tracks start initially in the plane of the electric vector for unpolarized rays, and in the direction of the electric vector for polarized rays. Since this last phenomenon has been observed by Bubb the classical theory would seem to be satisfactory were it not for the presence of the forward component. By allowing the momentum of the incident radiation in the forward direction to be passed on to the electron absorbing the energy, a shift of the peak forward to about 82° becomes theoretically possible. This, however, does not appear to be quite enough. Further the distribution of directions on either side of the most probable direction is not accounted for by these conceptions.

This distribution may be qualitatively accounted for by vectorially adding the random momentum of the electron in its orbit, as has been shown by Bothe, but a more satisfactory explanation would appear to be that recently put forward by Watson[9] which accounts for the spread of directions upon the basis of scattering and leads to a distribution function which fits the facts better than do any of the more elaborate theories. The asymmetry noted above is also beautifully explained by Watson's theory.

In conclusion I desire to express my warm appreciation for the inspiration and guidance given me during the progress of this work by Professor R. A. Millikan, and Dr. A. W. Simon for the help he has given in the design of the expansion chamber.

Norman Bridge Laboratory of Physics,
California Institute of Technology,
July 1, 1927.

[9] Watson, Phys. Rev. **29**, 752 (1927).

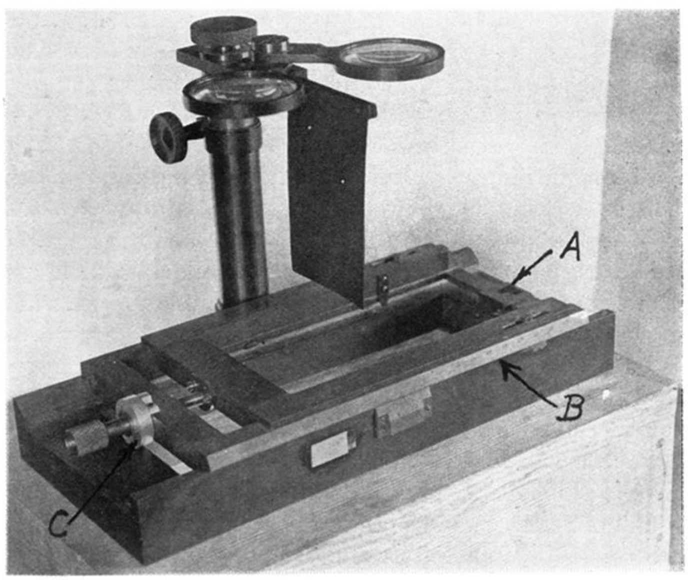

Fig. 1. Photograph of the stereoscopic comparator.