THE ANGULAR DISTRIBUTION OF PHOTOELECTRONS EJECTED BY POLARIZED ULTRAVIOLET LIGHT IN POTASSIUM VAPOR

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(Received April 10, 1931)

Abstract

Light of wave-lengths in the region of 2400A selected by a monochromator and polarized by a pile of quartz plates illuminated a jet of potassium vapor. The lateral directions of emission of the photoelectrons relative to the electric vector were studied. Though the electrons were ejected with energies less than one equivalent volt, the experiments were definite in establishing that the most probable direction of ejection is that of the electric vector and that the angular distribution varies as the square of the cosine of the angle between the electric vector and the direction in question. This result is in accord with predictions of the wave mechanics for a spherically symmetrical atom and incidentally therefore constitutes additional evidence that molecules do not play an appreciable part in the observed photo-ionization of potassium vapor.

Introduction

THE wave mechanics predicts that the most probable direction of emission of photoelectrons by polarized radiation is forward of the electric vector. The forward component of the ejected electrons is furnished by the momentum of the absorbed quantum and therefore is only appreciable when the momentum of the absorbed quantum is comparable with that of the photoelectron. Apart from this forward component the distribution in angle about the electric vector decreases with the square of the cosine of the angle between the direction in question and the electric vector.

A great amount of experimental work on the angular distribution of photoelectrons ejected by x-rays has verified the above predictions of theory.[1] The present work has sought to examine experimentally the phenomena in the optical region. Here the momenta of the absorbed quanta are so small that no forward component should be observed and therefore the angular distribution should follow a cosine squared law for the longitudinal as well as the lateral distribution. The experiments reported in this paper have shown that for the lateral distribution of the electrons ejected by ultraviolet light in potassium vapor such is the case.

Experimental Method

Rather troublesome difficulties were encountered in the present work because the problem was that of measuring the velocity directions of electrons

[1] C. D. Anderson, Phys. Rev. 35, 1139 (1930). This paper contains references to other work in the field.

having less than one equivalent volt of energy. Making sure that the photoelectrons observed were really from the vapor was itself an elusive and difficult task.

The main requirements of the experiment were as follows. First, light had to pass through the tube ionizing the vapor without striking the electrodes or walls of the tube which, in the presence of the vapor, were extremely photoactive. Second, the electrodes and tube had to be maintained at room temperature to avoid thermionic emission, while a sufficient and constant vapor density of potassium to obtain a measurable number of photoelectrons was necessary. Third, an intense and constant source of ultraviolet light was necessary in order to give a good photo-effect at the lowest possible vapor density. The upper limit to the allowed vapor density was set by the requirement that the mean free path of the electrons had to be comparable with the dimensions of the ionizing chamber.

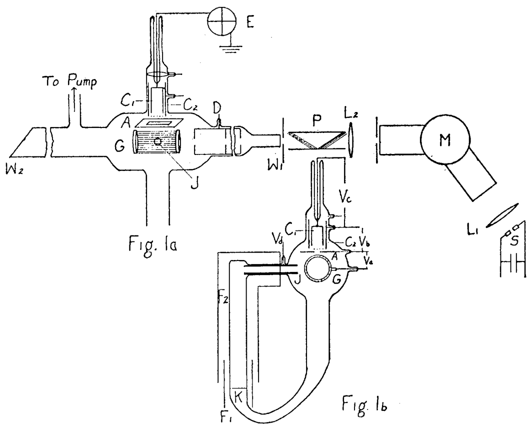

Fig. 1. Diagram of apparatus.

These requirements were satisfied by an apparatus which incorporated many features similar to that used by Lawrence[2] in his measurement of the photo-ionization probability of potassium and that of Williamson[3] who studied as well the distribution of velocities of the photoelectrons produced in potassium. A jet of vapor was ionized by plane polarized radiation inside a cylindrical grid, which was practically field free, so that electrons traveled in their original directions of ejection. Those that were ejected in the direction of a slit (a solid angle of 11.5 degrees) were accelerated into a faraday cylinder and measured by a Compton electrometer (sensitivity 10,000 mm/volt).

Figure 1a, b shows a detailed description of the apparatus. The light source consisted of a cobalt spark (which has many strong lines in the region 2300–2700A) quenched by a blast of air which served both to steady the spark at one position and to increase greatly the intensity of the ultraviolet light. The light was focused by lens L_1 into the slit of a Bausch and Lomb quartz monochromator which resolved the light into a band of about 500A

[2] E. O. Lawrence, Phil. Mag. **1**, 345 (1925).

[3] R. C. Williamson, Phys. Rev. **21**, 107 (1923).

around 2400A, thus eliminating the visible spectrum which would only produce photoelectric emission from the potassium surfaces. Lens L_2, a quartz-fluorite achromatic combination, focused the light to infinity. The light was polarized by two piles of quartz plates P set at the polarizing angle, which gave a measured polarization of 86.6 percent, the second pile of plates serving to refract the beam back to its original axis so that rotation of the polarizer did not throw the beam out of alignment with the collimating diaphragms D. The tube was constructed of Pyrex glass with the quartz window W_1 sealed on by a quartz-Pyrex graded seal. The polarized beam passed through a system of collimating diaphragms D, the last diaphragm being slightly larger than the others to avoid scattering of the main beam. It was at a small positive potential with respect to the grid and slit, so that photoelectrons ejected from the diaphragm did not enter the faraday cylinder. The light after passing through the grid passed through a long tube and out through a quartz window W_2 which was set at an angle so that the reflected beam was multiply reflected a sufficient number of times to prevent it again reaching the grid. The fluorescence of this quartz window showed the beam to be in good focus through the tube.

Figure 1b shows the arrangement of the potassium boiler and vapor jet. The heating coil around the potassium reservoir F_2 controlled the density of the vapor stream, while the furnace F_1 was kept at a slightly higher temperature to avoid condensation of the vapor. J_1 indicates the copper jet in which the vapor entered the tube, and this was at a positive potential V_d with respect to the grid in order to eliminate the emission of electrons. The potassium after passing through the grid condensed on the walls of the tube and after each run the tube was warmed enough to allow the potassium to run back into the reservoir. The tube was cooled by several air blasts, and the electrodes were kept cool by conduction through short heavy leads which were cooled on the outside of the tube by the air blast. A copper gauze cylinder concentric with the grid and at the potential of the slit was placed inside along the walls of the tube for electrostatic shielding. Denoting the potential of the grid as zero, slitA was 1.5 volts positive, denoted by V_a. V_b was 4.5 volts positive (to draw the electrons into the faraday cylinder) and V_c, the potential of the faraday cylinder, was 6 volts positive. V_d was 3 volts positive thereby preventing thermionic emission from the jet reaching the collector.

Results

Figure 2 is a plot of the relative number of electrons as ordinates ejected at angles with the electric vector given by the abscissas. The curve shows the cosine square distribution law, and the crosses represent averages of about twelve observations of each setting of the polarizer. The parallel plate polarizer was rotated over a 180° range, taking observations at 30° intervals. The abscissa 0° denotes the direction parallel to the electric vector. Assuming the validity of the cosine squared law, these observations were corrected for the lack of complete polarization of the light, due to the inefficiency of the polarizer and the depolarization of the quartz window, leading to the circles. It is seen that the corrected points fall fairly well along the cosine-squared curve.

The photoelectric currents for the 0° setting of the polarizer were of the order of magnitude of 10^{-14} amperes.

Errors

There remains after correction of the observations a small residual recorded emission of electrons at right angles to the electric vector. This is of importance for if it is real it means that the cosine-squared law does not hold. There are four paramount sources of experimental error which could be responsible for the observed effect at 90°.

First there is the possibility of a small photoelectric emission by scattered light from the electrodes. The diaphragming of the light was, however, so carefully arranged that no emission at all was observed before vapor entered the tube or after the jet of vapor was cut off. The routine preliminary procedure before each run was to make certain that there was no photo-emission before the potassium reservoir was heated, then the vapor pressure was raised

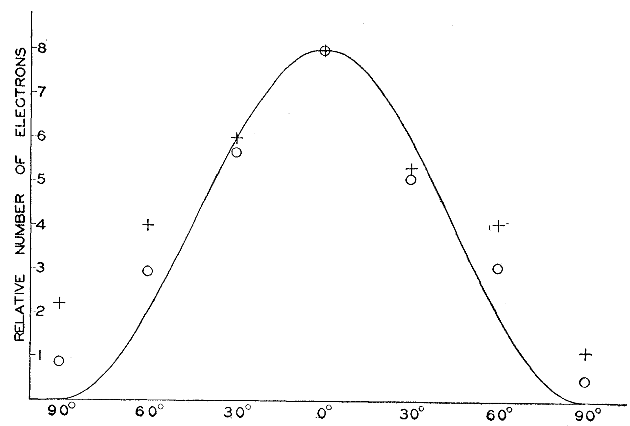

Fig. 2. The relative numbers of photoelectrons ejected at various angles relative to the electric vector. The crosses represent experimental data. The circles represent data corrected for lack of complete polarization of the light. The curve represents the cosine squared distribution.

to a point where there was a measurable photo-effect, and next it was established that the photo-effect fell to zero when the jet was cut off. These control observations practically eliminated this source of spurious effects from consideration. Secondary electrons such as photoelectrons reflected from the grid and slits, however, remain as an unknown factor which might have been great enough to contribute appreciably to the observations.

The error introduced by the finite width of the slit and the accelerating potential of 1.5 volts between the grid and slit was quite inappreciable. The earth's magnetic field was not balanced out for the curvature of the paths of the photoelectrons produced by this field was of the order of magnitude of 10 cm and therefore not a serious source of systematic error. Because of the continuous distillation of potassium on the electrodes contact electromotive force fields undoubtedly were very small.

Perhaps the greatest source of error was introduced by the scattering of the electrons in the vapor. From the temperature of the molten potassium and the geometry of the jet orifice and electrodes an estimate of the vapor pressure of the jet in the region of ionization gave the value of 0.002 mm of mercury pressure. Using Brode's[4] data on the mean free paths of 0.7 volt electrons in potassium vapor it was accordingly calculated that in the present experiments the probability of a scattering collision of a photoelectron formed in the jet on passing to the slit was of the order of magnitude of one-half. Because small angle scattering[5] is greater than scattering at large angles it therefore appears that this is a quite appreciable source of systematic error and indeed is very probably responsible for the observed emission at right angles to the electric vector.

Discussion

The wave-length dependence of the photo-ionization of potassium vapor is anomalous in the respect that it does not decrease monotonically to shorter wave-lengths beyond the series limit as is the case in caesium and rubidium.[6,7] The possibility has been suggested[1] that this anomalous behavior is ascribable to a large amount of molecular ionization, and indeed some rather good arguments have been adduced in favor of this hypothesis.[8] It appears, however, that a general consideration of all the evidence, particularly that obtained in most recent work,[9] indicates that the observed photo-ionization of potassium vapor is really that of the potassium atom.

The present experiments have a bearing on this question for it is to be expected that the cosine-squared angular distribution of the photoelectrons about the electric vector will hold only for a spherically symmetrical atomic system. Professor J. R. Oppenheimer has kindly informed the writer that he has estimated that the emission perpendicular to the electric vector would be of the order of magnitude of one-third that in direction of the electric vector if the emission were from potassium molecules. The fact that the present experiments have yielded much less than this amount therefore may be regarded as further evidence that the potassium atom is responsible for the observed effects.

The writer is indebted to the General Electric Company for a photoelectric cell used in calibrating the polarizer and to the Committee-on-Grants-in-Aid of the National Research Council for the quartz-fluorite lens used in the present work.

In conclusion the writer wishes to acknowledge a great indebtedness to Professor E. O. Lawrence who suggested the problem and gave many suggestions which made possible the success of this work.

[4] R. B. Brode, Phys. Rev. **34**, 673 (1929).
[5] F. L. Arnot, Proc. Roy. Soc. **A125**, 660 (1929).
[6] F. L. Mohler, P. D. Foote and R. L. Chenault, Phys. Rev. **34**, 233 (1929).
[7] E. O. Lawrence and N. E. Edlefsen, Phys. Rev. **34**, 233 (1929).
[8] R. W. Ditchburn and F. L. Arnot, Proc. Roy. Soc. **A123**, 516–536 (1929).
[9] E. O. Lawrence and N. E. Edlefsen, Phys. Rev. **34**, 1056 (1929).