LARGE ANGLE SCATTERING OF LOW VELOCITY ELECTRONS FROM COPPER, IRON, NICKEL AND SILVER.

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ABSTRACT

The apparatus permitted a measure of the relative number of electrons leaving the target at angles between 163° and 179° with the primary beam. Measurements were taken at low primary voltages for which the number of emitted electrons is negligible, so that the electrons measured are primary electrons which have been scattered through large angles. For normal incidence the large angle scattering is greater than that necessary to satisfy the cosine law for the metals Cu, Fe, Ni, Ag after they have been heated at red heat in a vacuum, and is different for each metal. Subsequent to baking the tube at 350°C, but previous to heating the target at red heat, the large angle scattering is nearly the same for the four metals and approximately in accordance with the cosine law. The change in large angle scattering appears to be due to a change in the structure of the surface rather than to elimination of gas. For 45° incidence on a copper target, the scattering back in the direction opposite to that of the primary beam is less than for 90° incidence, but the direction of the surface normal is not the only determining factor in the scattering.

McCLELLAND[1] observed many years ago that, when β-rays strike a metal target at normal incidence in a vacuum, the number of electrons leaving the target in any direction is closely proportional to the cosine of the angle between that direction and the normal. This result is to be expected, since the electrons, from an element of volume at a depth in the plate, traverse a thickness inversely proportional to the cosine of the angle between its direction and the normal. Tate[2] observed that, for all angles of incidence and for primary voltages up to 50 volts, the secondary emission from a platinum target is maximum in a direction very nearly straight back on the incident beam, and decreases to zero in directions parallel to the surface of the target. Results of Davisson and Kunsman,[3] and Davisson and Germer,[4] show that reflected electrons, which have been separated from emitted electrons, have a unique angular distribution which depends on the metal and the primary voltage, especially when the latter is more than a few volts. For primary voltages at which the number of emitted electrons greatly exceeds that of the reflected electrons, any unique distribution of reflected electrons would be masked by the effect of the emitted electrons unless the two classes of electrons are separated. Hence, the cosine law would be expected to apply very closely when the relative number of emitted electrons is great. Since measurements on energy distribution,[5] however, show that the relative number of emitted electrons becomes very small for primary

[1] McClelland, Proc. Roy. Soc. **80,** 501 (1908).
[2] John T. Tate, Phys. Rev. **17,** 394 (1921).
[3] Davisson and Kunsman, Phys. Rev. **22,** 242 (1923).
[4] Davisson and Germer, Nature **119,** 558 (1927); Phys. Rev. **30,** 705 (1927).
[5] H. E. Farnsworth, Phys. Rev. **31,** 405 (1928).

voltages of the order of 10 or 15 volts and less, the extension of the cosine law to the case of these low primary voltages becomes questionable.

During the course of measurements on energy distribution of secondary electrons from metals,[5] it was possible, because of the particular construction of apparatus, to obtain a measure of the relative number of electrons which leave the target at angles between 163° and 179° with the primary beam, as a function of the primary voltage. The apparatus is shown in Fig. 1 of the previous article.[5] Referring to this figure it will be noticed that the 3 cm diaphragm *C* which forms a part of the sphere is electrically insulated from the remainder, so that it is possible to measure the fraction of the current to

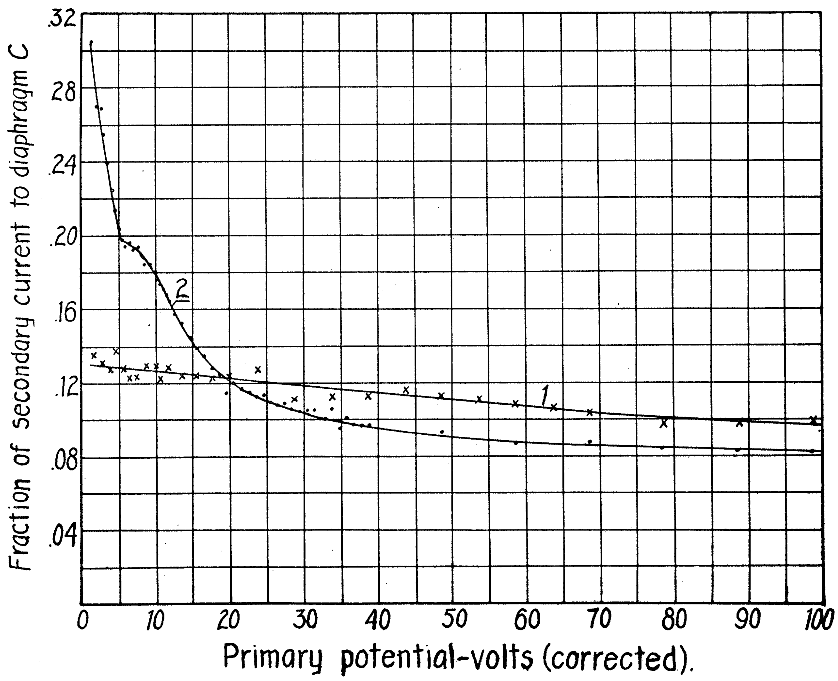

Fig. 1. Large angle scattering from iron. Curve 1 is for a target subsequent to heating at 350°C, but previous to red-heat treatment. Curve 2 is for the target subsequent to red-heat treatment.

the whole sphere which goes to *C*. This fraction is plotted as a function of the primary voltage for Fe, Cu, Ni and Ag, in Figs. 1, 2, 3, and 4, respectively. The values for the voltage have been corrected.

From Fig. 1 it is seen that, previous to heating the iron target at red-heat, the fraction of the current to *C* was nearly independent of the primary voltage, showing a slight decrease with increasing primary voltage. Assuming a consine distribution law, a computation shows that, for the dimensions of the apparatus, about 10 percent of the total secondary current should strike *C*. After heating the target at red heat the fraction of secondary current to *C* increased rapidly as the primary voltage was decreased, so that for 1 volt primary electrons about 30 percent of the secondary current went to *C*. Although the diaphragm *C* is not a perfect absorber, its reflection characteristics should be the same for the curves taken before and after heating

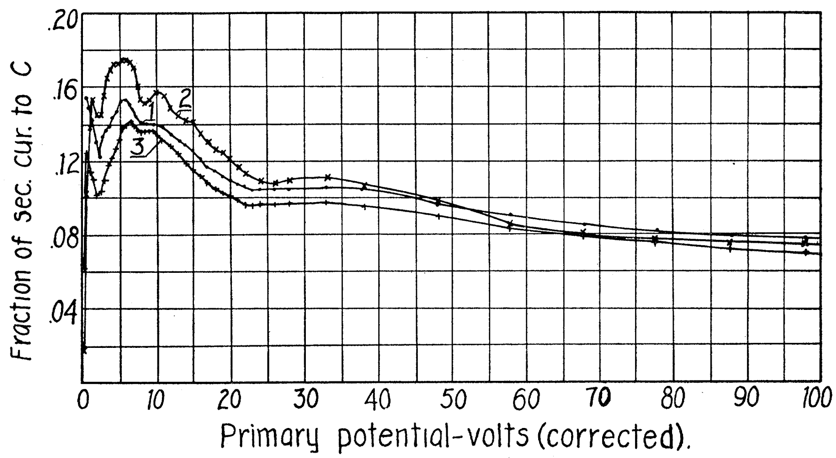

Fig. 2. Large angle scattering from copper. Curve 1 is for a target at normal incidence, subsequent to heating at red-heat for 5 min. Curve 2 is for the target at normal incidence, subsequent to heating at red-heat for more than 30 min. Curve 3 is for the target at 45° incidence, subsequent to heating at red-heat for more than 30 min.

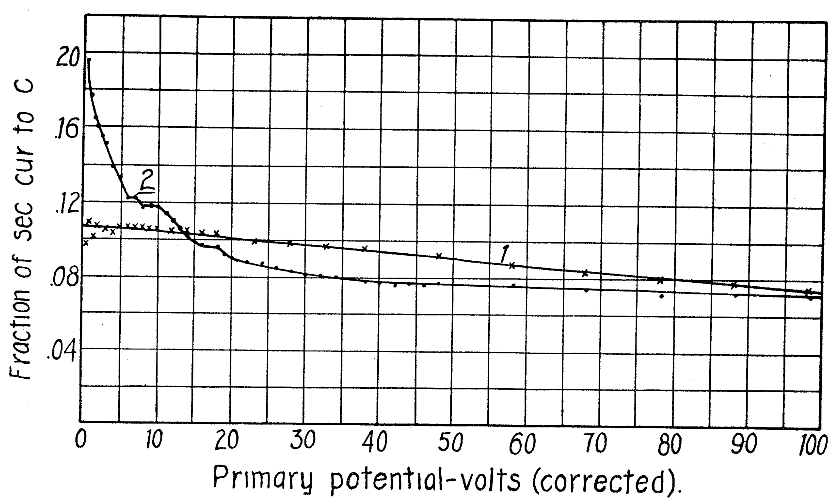

Fig. 3. Large angle scattering from nickel. Curve 1 is for a target subsequent to heating at 350°C, but previous to red-heat treatment. Curve 2 is for the target subsequent to red-heat treatment.

the target at red-heat, so that the difference between the two curves must be due to an effect of heat treatment of the target. The correction to be applied would be such as to increase the value of the current to *C* which is shown, and it would be larger for the higher primary voltages. One might expect a result similar to curve 2, Fig. 1, if the target assumed a negative potential due to the heat treatment. A negative potential was found to exist, but curve 2 was obtained with such a positive potential applied to the target as to neutralize this negative potential. In fact, a relatively large current to C was still observed when a considerably greater positive potential was applied to the target than was necessary to compensate the negative potential. Since exposing the iron target to dry air at atmospheric pressure failed to remove the effect, it appears to be due to the surface structure rather than to outgassing. Since energy distribution curves of secondary electrons show that, for low primary voltages, the secondary current consists almost entirely of reflected primary electrons, it follows that the current to C is due to a large angle scattering of primary electrons.

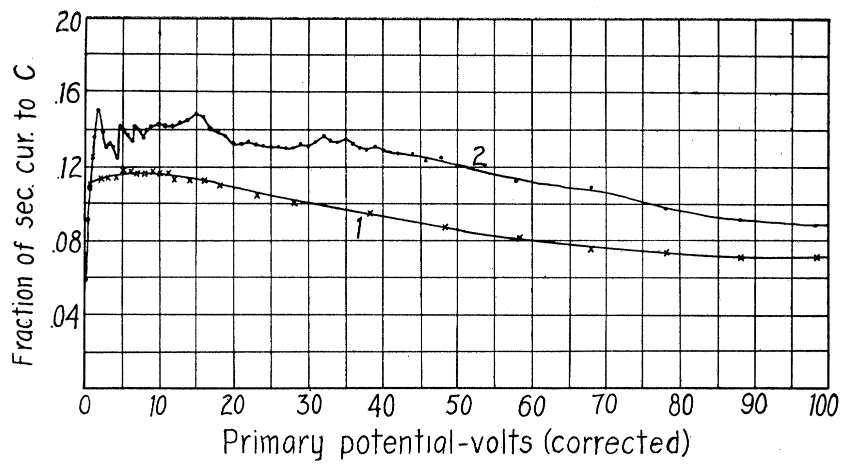

Fig. 4. Large angle scattering from silver. Curve 1 is for a target subsequent to heating at 350°C, but previous to red-heat treatment. Curve 2 is for the target subsequent to red-heat treatment.

Referring to Fig. 2, it is seen that the curve for a copper target, which has been heated at red heat, is entirely different than that for an iron target. To decide whether the plane of the target is a determining factor in the shape of the curve, observations were taken for 45° incidence. Since the tube had to be opened to effect the change of angle, the procedure was as follows: After heating the copper target at red-heat in the vacuum, curve 2 was obtained. The tube was then opened to the air and the position of the target changed for 45° incidence without touching it with the hands. After re-exhausting the tube, baking at 350°C, and separately heating the target at red-heat for 5 min., curve 3 was obtained. To make certain that this change was effected only by the change in the angle of incidence, the tube was again opened to the air and the angle of the target changed back for normal incidence. After re-exhausting and baking the tube at 350°C, and separately heating the target at red heat for 5 min., curve 2 was again obtained very accurately. Although curves 2 and 3 are widely separated for low primary voltages, there is a considerable similarity in their general form, so that the direction of the surface nornal is not the only determining factor. Curves 1 and 3 appear quite similar. Comparing curves 1 and 2, it appears that the curve continues to change with heat treatment of the metal for some time. Since the sizes of the bombarded crystals increase enormously with heat treatment, the crystal growth is probably a determining factor.

The curves in Figs. 3 and 4 for Ni and Ag, respectively, furnish further evidence that the effect in question varies with the metal. The curve for a Ni target resembles that for Fe. The fact that curve 2, Fig. 4, continues to remain above curve 1 even for the higher primary voltages is in accordance with the result that silver reflects a comparatively large fraction of the incident electrons even for these higher primary voltages[5].

Although observations on a single copper target have been checked after removing the target and again replacing it in the tube without disturbing the surface, it is not certain that the curves for two different targets of the same metal would be the same. If these results depend upon the orientation of the particular crystals and relative number of different crystal faces being bombarded, it seems probable that the results for different targets would be different. Unfortunately no observations on this point were obtained for copper. Observations on two different nickel targets show the general form of the curves to be the same, but one rises much higher for low primary voltages than the other. More observations are needed to settle this point.

Although the present results give only a part of the complete scattering picture which results when very low velocity electrons impinge on a metal surface, they do establish the fact that this scattering varies with the metal bombarded, and is far from that given by the cosine law. A further knowledge of this scattering of very low velocity electrons should be of importance in determining the exact nature of surface forces.

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November 1927.