It is interesting to combine (3) and (4) as follows: (1) Put for F_P the dielectric strength of air and calculate the corresponding value of Q. (2) Substitute this value in (4) and calculate F_S. This would give the maximum gradient at the earth's surface for this special case. If this is done, we obtain as the corresponding gradient F_S the value 6410 volts/cm., which checks approximately with the gradient which Norinder surmises exists at the point where the lightning stroke occurs just previous to the stroke.

From the values given above it seems very probable that the quantity of electricity discharged in a lightning flash is of the order of magnitude of 10 coulombs. Very likely the value 2.3 coulombs is somewhat low while all the remaining values are much too high.

With regard, however, to equation (1) it is to be noted that if the gradient F were everywhere known over a given area, A, of the earth's surface, the corresponding quantity Q stored on the area would be given directly by

$$Q = \int F dA/4\pi \qquad (5)$$

so that if it be true that the maximum gradient at the earth's surface cannot exceed 3300 volts/cm. and that the area discharged is one circular kilometer, then it follows that the order of magnitude of the quantity discharged in a stroke is less than 10 coulombs, rather of the order of 1 coulomb.

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[1] *Electrical World*, **83**, 223 (1924).

[2] *Jrl. Frank. Inst.*, **199**, 142 (1925).

SECONDARY ELECTRONS FROM COBALT

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Numerous investigators have studied the emission of electrons from metal surfaces under bombardment by slow electrons. When this emission is studied as a function of the energy of the primary electrons, results characteristic of the metals under investigation have been found.

Farnsworth[1,2,3] and Petry,[4] working with iron, nickel and copper, have found particularly characteristic results for those metals. With this fact in mind, it was decided to study the secondary emission from cobalt for low velocity primary electrons. The sequence of iron, cobalt, nickel and copper in the atomic series, and the ferro-magnetic character of the first three of the above-named metals gave rise to the hope that some interpretable variation from metal to metal, or some characteristic similarity might be discovered.

Apparatus and Procedure.—Two different vacuum tubes have been employed in this investigation. The first was one used by Farnsworth in a portion of his work on iron, nickel and copper. A careful description of this tube is included in his reports.[2,3] A beam of primary electrons was secured by accelerating thermions from an oxide-coated plate through a series of diaphragms. The primary current was measured by means of a Faraday cylinder. The target, which could be moved by a magnetic control, was then interposed in the path of the beam and the current to it was measured, the secondary electrons going to a cylinder located directly in front of the target. The difference between the currents to the Faraday cylinder and to the target gave the secondary current. When not in the beam of primary electrons, the target was withdrawn into a side tube. In this position it could be heated by high frequency induction for outgassing.

The second tube, which will be referred to as tube II in the remainder of the report, differed essentially from the tube just described only in the elimination of the Faraday cylinder for measuring the primary current. The target was fixed in position in the beam of primary electrons. The secondaries were again received in a cylinder in front of the target, the current to this cylinder giving the secondary current. The sum of the currents to the target and to the cylinder in front of the target gave the primary current. In this tube the primary electrons were accelerated from the middle portion of a single loop tungsten filament. The target was heated for outgassing by electronic bombardment, a second filament acting as a source for these electrons.

The targets used in this work were ground from a sample of cobalt secured through Professor L. R. Ingersoll from the Deloro Smelting and Refining Co., Deloro, Ont. Chemical analysis showed the composition to be Co 98.67; Ni 0.44; Fe 0.60; Al 0.05; S 0.06 and Si 0.00 per cent.

After a vacuum has been obtained, the tube was always baked until the pressures were about 10^{-6} mm. Hg with the furnaces hot. The targets were then heated to a bright yellow until further heating caused no change in the characteristics. At the end of this outgassing process, the pressures were about 5×10^{-6} mm. Hg with the target hot. The pumps were left running continuously while the data were being taken, the pressures being so low that the mercury stuck to the top of the capillary in the McLeod gauge when the pressure was being measured.

Results.—The data obtained with either tube were reduced by taking the ratio of secondary to primary current for each accelerating potential impressed on the primary beam. This gave the number of secondaries per primary electron and made it unnecessary to keep the primary current constant throughout a run. The ratios obtained were then plotted against the corresponding accelerating potentials.

The curves in figure 1 will serve as a basis for discussion of the results of the investigation. Curve I is typical of all the data obtained with tube I after the target had been outgassed, and of results with tube II after certain heat treatments, while Curve II was only obtained with tube II after a different heat treatment. Curves like II were obtained after the target had been heated for a total of fifty-four hours at temperatures ranging up to a bright yellow. The latter temperatures had been maintained for about ten hours. Six hours further heating at the same temperature failed to change the shape of the curve, which was obtained repeatedly. In assuming this shape, the curves passed through the shape of curve I. A few minutes heating near the melting point, however, sufficed to change conditions in such a way that curves of type I were again obtained. During this heating, evaporation of the target took place very rapidly. Further heating at a yellow heat failed to cause a reversion of the curves obtained to the shape of II.

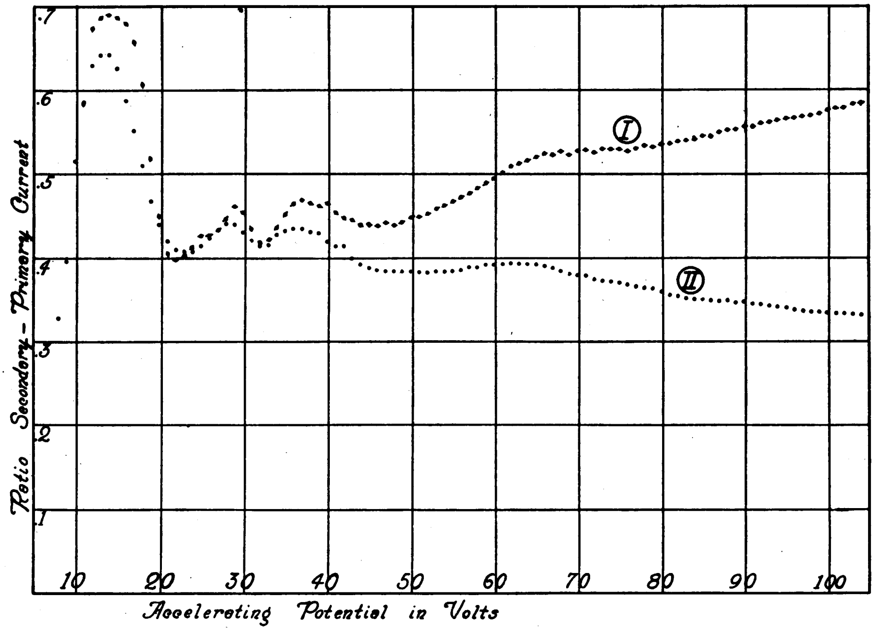

FIGURE 1

Secondary electron curves for outgassed cobalt. Curve I after heating the target near the melting point. Curve II after special heat treatment.

The values of the abscissas in the curves have been corrected by the addition of 4.9 volts, the work function of the tungsten filament, to the observed values for the accelerating potential. As plotted, the abscissas give the energy of the electrons after being accelerated by the work function of the target. No correction is necessary for the potential drop in the filament used as source of electrons, since this was negligibly small over the part of the filament used, and since the accelerating potentials were applied through a potentiometer arrangement.

Before the target had been heated for outgassing, the secondary emission curve was always low and without marked maxima and minima. As the process of outgassing proceeded, the various maxima and minima began to develop, and the values of the secondary emission began to increase in magnitude. Only as the outgassing appeared to near completion did the first maximum attain its greatest height and the minimum at 45 volts make a definite appearance. After the maxima and minima had once appeared there was no change in their position. Only their magnitudes changed thereafter. When the tube was allowed to stand for some hours without heating of the target, the height of the curve usually changed only slightly. A few seconds heating was always sufficient to bring back the previously observed values.

Discussion.—The secondary emission from cobalt is much greater than that from any other metal as yet investigated. Not only are the maxima much more pronounced, but even at the minima the height of the curve is decidedly above the corresponding values for other metals. Plotted to a scale in which the ordinates are large, iron and nickel show something of the same form of curve, but for them the breaks are not so pronounced, being at lower values of the primary energy, and do not extend to as high values of the primary energy. If one assumes that the first maxima of the curves for these three metals "correspond," it then turns out that these maxima shift toward higher primary energies with (and in the order of) increasing atomic weight, rather than, as might be expected, atomic number. Curves given by Farnsworth[3] show first maxima at 1.5 and 3 volts for iron and nickel, respectively. These values have been corrected for contact potential, but require a further correction for the work function of the target before comparison with the value 14 volts which was found for cobalt, but this correction cannot be expected to invert the order of these two metals.

The crystal lattice of cobalt is known to change from hexagonal close-packed to face centered cubic at 470°C., to maintain this form throughout the range of temperatures to 1120°C., and to change to hexagonal close-packed once more at the latter temperature. Both hexagonal close-packed and face centered cubic forms of lattice have been observed at room temperature. Previous to the time during which curves of type II were obtained, the target had been subjected to a long period of heating in the range of temperatures in which the hot target should have had the face centered cubic structure, and this type of curve continued to be observed as long as heating at this temperature was continued. It may be that conditions were correct for the target to carry down some of the cubic form to low temperatures, and that the difference between curves I and II is due to a difference in crystal structure of the target. The exact conditions necessary to bring about this result have not yet been determined.

Krefft, in a paper which has recently appeared,[5] describes an investigation of the secondary emission from tungsten. He was able to observe with the target hot as well as with it cold. He finds that his data with a cold target must be taken within a few minutes after the target has been heated in order to obtain the same results for a cold target as for a hot. Standing cold for half an hour was sufficient to cause a decided change in the form of the curve, particularly that of the first maximum. This change he ascribes to the adsorption of gas by the surface of the target. As has already been remarked, no such rapid change was observable in this work after a sufficient heat treatment. Even if the target were allowed to stand without heating for more than thirty hours, the only change observable was a slight lowering in height of the whole curve. We may conclude, therefore, that either (*a*) the cobalt surfaces were more thoroughly outgassed and picked up gas more slowly than the tungsten, or (*b*) the cobalt was *never* free from gas, and on this account changed less rapidly upon standing. The latter conclusion seems hardly consistent with the general trend during outgassing, and especially with the fact that the results were unaffected by heating very nearly to the melting point. We are, therefore, inclined to accept alternative (*a*) and to argue that the cobalt maxima and all of Krefft's maxima except perhaps the one which developed on standing cold are characteristic of the metals themselves. The effect of observing with a hot target will be studied in the near future. Krefft suggests that the maximum which appears at 15.5 volts may be due to the ionization of a layer of oxygen molecules on the surface of the target. This maximum may be compared with maxima for cobalt appearing at 9.1 and 24 volts (the uncorrected values should here be used). These values are too low and too high, respectively, to be attributable to ionization of the common gases.

Krefft gives some evidence of coincidence between values of breaks in the secondary emission curves for carefully outgassed tungsten with critical potential values for that metal. It was thought at the conclusion of the work with tube I in this investigation that similar evidence was offered by the many small breaks in the cobalt curves. Further work with tube II does not seem to support this idea, although some further study of this point will be made. A single run, covering the range from 3 to 40 volts at $^1/_{10}$ volt intervals was made. Conditions throughout the run were very steady, and no evidence of the existence of breaks corresponding to critical potentials was obtained. Unhappily, the target was melted by excessive heating before further observations of this character could be performed.

In conclusion, the author wishes to extend his thanks to Prof. C. E. Mendenhall, whose suggestions and coöperation made this work possible.

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[1] H. E. Farnsworth, *Phys. Rev.*, **25,** 41 (1925).

[2] H. E. Farnsworth, *Ibid.*, **27,** 413 (1926).

[3] H. E. Farnsworth, *Ibid.*, **31,** 405 (1928).

[4] R. L. Petry, *Ibid.*, **26,** 346 (1925).

[5] Hermann E. Krefft, *Ibid.*, **31,** 199 (1928).

SPARKS OF THE INDUCTION COIL BETWEEN MUCRONATE ELECTRODES

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1. *Spark Gap $x = 2$ Cm.*—The coil of the usual pattern with platinum spring break. From a single storage cell it produced sparks a little over 3 cm. between points under best conditions. The pitch of the break could be varied by tension from *G* to *c* judging by the ear. The secondary was connected with the mucronate electrodes, figure 1, having a spark gap from $x = 1$ to over 4 cm. and the needles y,y', both of the positive and negative plates E,E' of the gap, were actuated for protrusion y, with micrometer screws, S,S'. The hard rubber base B supports the brass posts P,P'.

The sparks were all white as a rule with exceptions to be noted. There were no purple cones. As it is convenient to introduce a terminology here, I shall call the promiscuous spark discharge from edge to edge of the electrodes EE', a spark rain. This does not depend on incidental conditions of the surface of the disc electrodes; for if the sparks are between the top edges, they remain so when either disc is rotated on its axis. They show a marked tendency to remain near the top even when the plates are slightly oblique or when the spark gap is inverted. A wind blown across the spark gap is usually ineffective.

Darts designate the nearly linear sparks which pass from the point of the needle to the opposite plate. Sometimes they contain purple strands and they may be purpled by special interference. All such darts terminate in the darkish space already described, and this was here usually nearer the negative plate.