ENERGY DISTRIBUTION OF SECONDARY ELECTRONS FROM COPPER, IRON, NICKEL AND SILVER.

By H. E. Farnsworth

Abstract

This is an extension of previous experiments. An improved form of tube was used from which certain former disturbing factors were eliminated. The energy distribution curves show no evidence of the existence of inelastic collisions, but are found to vary with the metal and to be different for the metal before heating at red heat than after. When the primary voltage is less than about 35 or 40 volts, which varies somewhat with the metal, there are practically no electrons escaping from the metal which have just sufficient energy to do so, but all have an energy of 0.5 equivalent volt or more in excess of that required to escape. A possible interpretation of this result is given.

Introduction

THE experiments here described are a continuation of an attempt to obtain an accurate measure of the energy distribution of secondary electrons from metal surfaces.[1] The especial interest in these experiments developed as a consequence of the results obtained on the magnitude of the secondary electron current from copper and iron as a function of primary or bombarding potential. The curves expressing this relation for these metals were found to have unusual maxima and minima in the low voltage region. As previously pointed out,[1] if these changes in slope have their origin in atomic inelastic collisions similar to those which occur in the vapor state of a metal, one might expect that such inelastic collisions would also result in a characteristic energy distribution of the secondary electrons. Hence, an accurate knowledge of the energy distribution of secondary electrons for low primary voltages should be of value in determining the cause of the unusual secondary electron characteristics mentioned above.

The writer's previous experiments were not decisive for experimental reasons. The results here described were obtained with an improved apparatus from which the disturbing factors of the former apparatus were eliminated. Because of the nature of the results obtained for copper and iron, it seemed advisable to repeat former observations on nickel[2] with the present apparatus. In addition, results on a silver target were obtained.

Apparatus and Procedure

A diagramatic cross-section of the tube is shown in Fig. 1. The advantages of this tube over those previously used are: (1) a new method of obtaining a more intense beam of low velocity electrons with no scattering;

[1] H. E. Farnsworth, Phys. Rev. **25**, 41 (1925); **27**, 413 (1926).
[2] H. E. Farnsworth, Phys. Rev. **20**, 358 (1922).

(2) the use of a larger sphere and a smaller target so that a more nearly radial electric field may be established between them.

A description of the cathode and focusing arrangement, together with measurements on energy distribution of primary electrons, is given elsewhere.[3] C is an insulated diaphragm which forms a part of the sphere D. The Faraday cylinder F and shield E, indicated by the dotted lines, were inserted at first so that measurements could be made on the primary electron beam and were than replaced by the target T. As in former tubes, the target was mounted on quartz rods (not shown in the diagram) and could be removed into the side tube by a magnetic control and there separately heated by high-frequency induction. Evaporated metal was prevented from entering the sphere by a metal diaphragm which was automatically raised in the tube between the sphere and target when the target was pulled back.

The energy distribution of secondary electrons, for a given primary voltage between the cathode and target, was obtained by measuring the

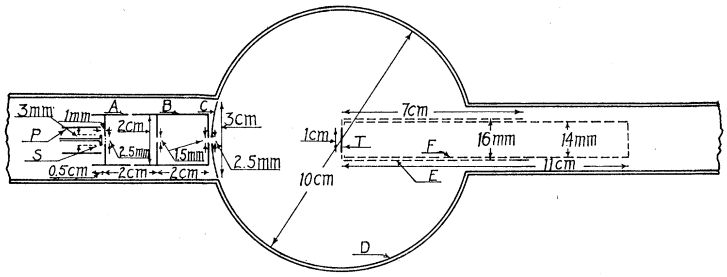

Fig. 1. Apparatus.

ratio of the secondary current (to C and D) to the primary current (to C, D, and T,) as a function of a variable retarding potential on B, C, and D. B and C were kept at the same potential to eliminate scattering in the space between them. Measurements obtained when A was kept at a constant potential with respect to B and C were the same as those obtained when A was kept at a constant potential with respect to the target and ground. The latter method gave the larger primary currents. While obtaining the results given here, A was kept at $+7.5$ volts with respect to the target.

The usual secondary electron curve could be obtained by measuring the above ratio as a function of a variable accelerating potential difference between S and T with B, C, D, and T at zero potential. Multiple reflection between the sphere and target was neglected, but that this must have been small is shown by the sharpness of the breaks in the secondary electron curves. The diaphragm C was covered with sputtered platinum, as was also the inner surface of D, so that their reflection characteristics should have been the same.

Liquid oxygen was used to prevent mercury vapor from entering the tube. A mercury vapor pump, backed by an oil pump, kept the pressure

[3] H. E. Farnsworth, J.O.S.A. & R.S.I. **15**, 290 (1927).

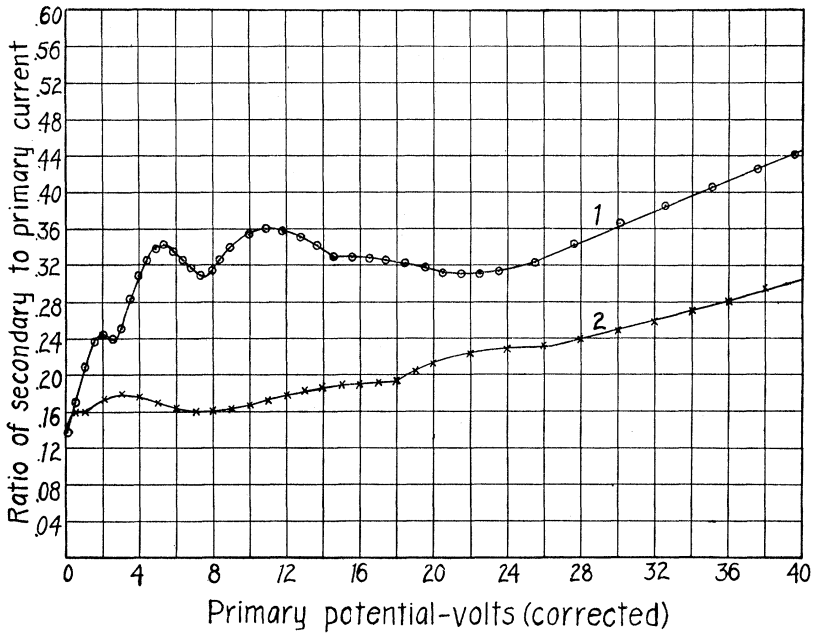

Fig. 2. Secondary electron curves. Curve 1 is for a copper target after red-heat treatment. Curve 2 is for a nickel target after red-heat treatment.

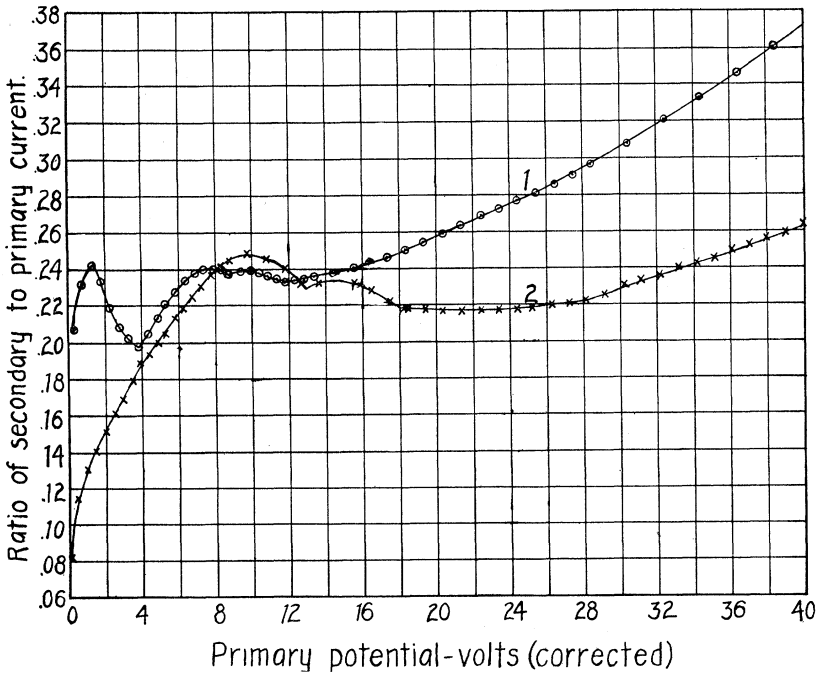

Fig. 3. Secondary electron curves. Curve 1 is for an iron target after red-heat treatment. Curve 2 is for a silver target after red-heat treatment.

less than 10^{-7} mm Hg during observations. During some of the early measurements a ground glass joint was attached at one end of the tube which was sealed on the outside with Khotinsky wax. The joint was later removed and the former measurements checked. While the joint was attached, the tube was exhausted at both ends. Helmholtz coils were used to compensate the earth's magnetic field.

Results and Discussion

Results on the ratio of secondary to primary current, as a function of primary voltage, for Cu, Fe, Ni and Ag are shown in Figs. 2 and 3 for reference. Values of the primary voltage have been corrected. The curves for Cu and

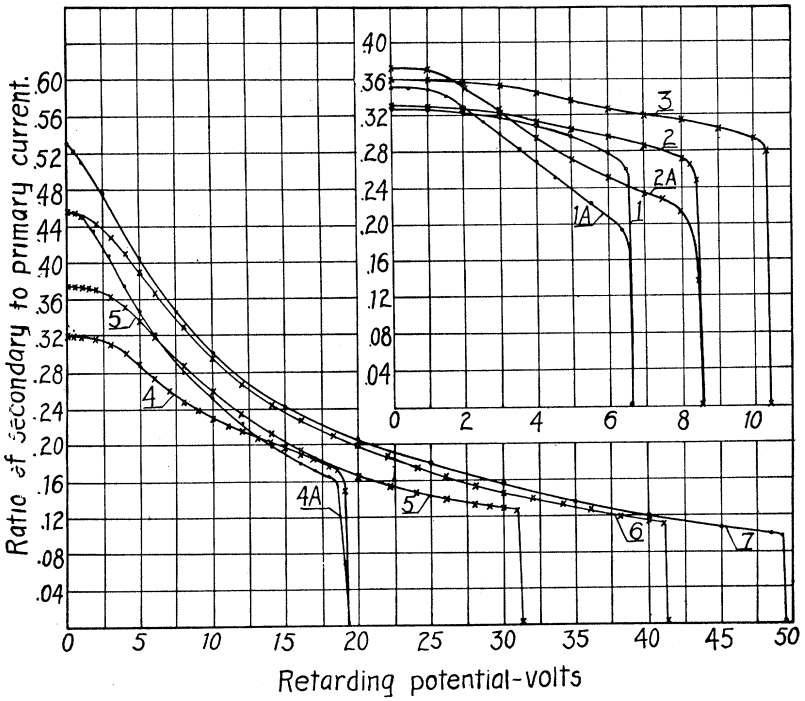

Fig. 4. Energy distribution of secondary electrons from copper. Curve 1, 1A for 6.6 volt (corrected) primary electrons, curve 2, 2A for 8.5 volt electrons, curve 3 for 10.4 volt electrons, curve 4, 4A for 19.0 volt electrons, curve 5 for 31.2 volt electrons, curve 6 for 41.2 volt electrons, curve 7 for 49.2 volt electrons. Curves 1A, 2A, and 4A are for targets subsequent to baking at 350°C, but previous to red-heat treatment. The other curves were obtained subsequent to red-heat treatment of the target.

Fe are similar to those previously obtained,[1] while those for Ni and Ag show more breaks than were obtained with a tube used several years ago.[2]

Energy distribution of secondary electrons from Cu, Fe, Ni, and Ag are shown in Figs. 4, 5, 6 and 7, respectively. Measurements on energy distribution were made for each metal after it had been heated at red heat until the characteristic secondary electron curves shown in Figs. 2 and 3 were obtained.

The above measurements were also made for Cu, Ni and Ag before heating the metals at red heat, but subsequent to baking them at 350°C for several hours. The actual distribution curves, obtained by plotting slopes of the curves shown as ordinates, are not given but their general shapes are apparent. The results on energy distribution of secondary electrons may be summarized as follows:

(1) *No evidence was obtained of critical potentials such as was formerly thought to exist.* The former evidence, because of the inferior tube used,

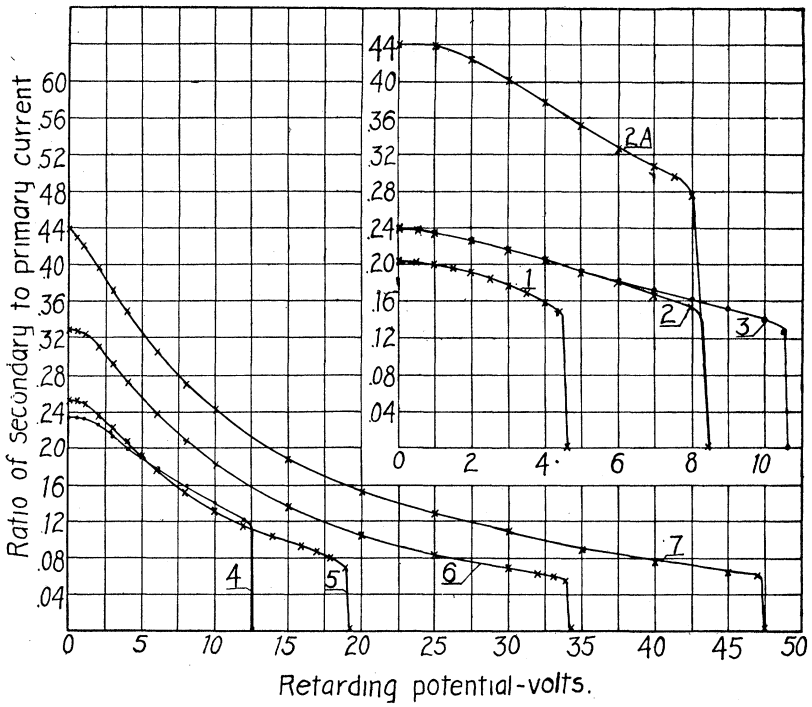

Fig. 5. Energy distribution of secondary electrons from iron. Curve 1 for 4.6 volt (corrected) primary electrons, curve 2, 2A for 8.4 volt electrons, curve 3 for 10.6 volt electrons, curve 4 for 12.5 volt electrons, curve 5 for 19.0 volt electrons, curve 6 for 34.0 volt electrons, curve 7 for 47.4 volt electrons. Curve 2A is for a target subsequent to baking at 350°C, but previous to red-heat treatment. The other curves were obtained subsequent to red-heat treatment of the target.

must then be considered as spurious. One may be led to either of two conclusions: (A) Inelastic collisions occur at the potentials corresponding to the maxima of the secondary electron curve even though no evidence of them is obtained by a measure of energy distribution. This would mean that those electrons which make inelastic collisions lose all of their energy on collision, or are unable to leave the metal even though they retain some energy after collision. (B) The results are not due to atomic inelastic collisions, but to an apparent selective reflection which depends on the structure

of the metal and the energy of the incident electrons. An apparent selective reflection might result from a diffraction phenomenon indicated by results of Davisson and Germer.[4] Brinsmade[5] has also observed a reflection maximum for those electrons leaving an aluminum target in a direction at right angles with the primary beam. Conclusion (B) appears to be much more probable since other results [1,6] indicate that the structure is the determining factor in the appearance of the secondary electron curve.

(2) *For primary voltages below a certain limiting value, which varies with the metal, most of the secondary electrons have energies approximately equal*

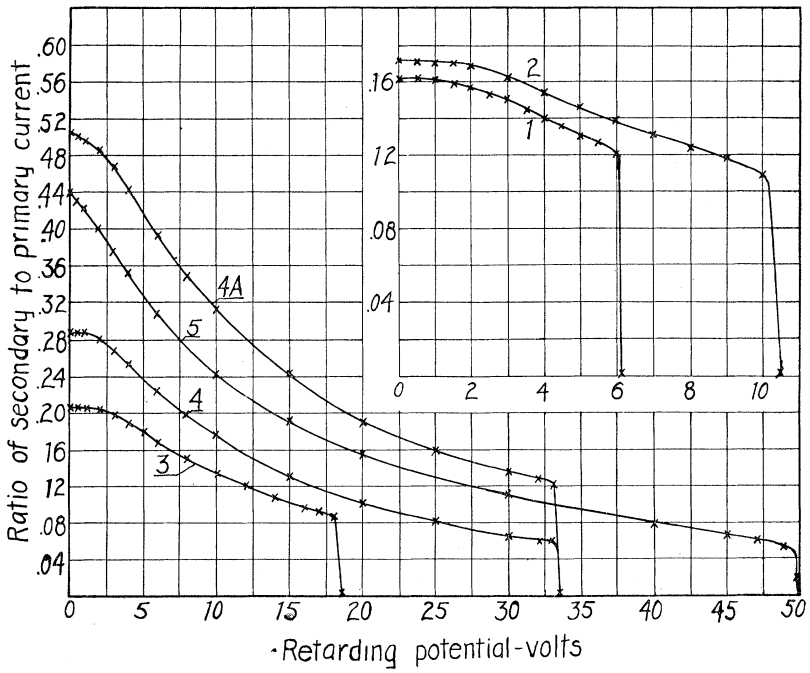

Fig. 6. Energy distribution of secondary electrons from nickel. Curve 1 for 6.2 volt (corrected) primary electrons, curve 2 for 10.4 volt electrons, curve 3 for 18.6 volt electrons, curve 4, 4A for 33.5 volt electrons, curve 5 for 50.0 volt electrons. Curve 4A is for a target subsequent to baking at 350°C, but previous to red-heat treatment. The other curves were obtained subsequent to red-heat treatment of the target.

to the average primary energy. The limiting value is higher for silver than for the other three metals tried.

(3) *As the primary voltage is increased beyond this limiting value, there appear, in addition to the general distribution, two groups of secondary electrons;* the first occurs at a retarding potential of a few volts and the second at a retarding potential nearly, if not quite, equal to the primary potential. The

[4] Davisson and Germer, Nature **119**, 558 (1927); Phys Rev. **30**, 705 (1927).
[5] Brinsmade, Phys. Rev. **30**, 494 (1927).
[6] H. E. Farnsworth, Phys. Rev. **31**, 419 (1928).

relative number of electrons in the first group increases while that in the second group decreases as the primary voltage is increased. The present results for Cu and Ni differ from those previously obtained for these metals in regard to the position of the first group mentioned above. In the results formerly obtained [1,2], the maximum of the first group occurs at very nearly a zero value of the retarding potential. In the present results for these metals, as well as for Fe and Ag, the maximum occurs at a higher value which varies with the metal and primary voltage. As the primary voltage is increased from

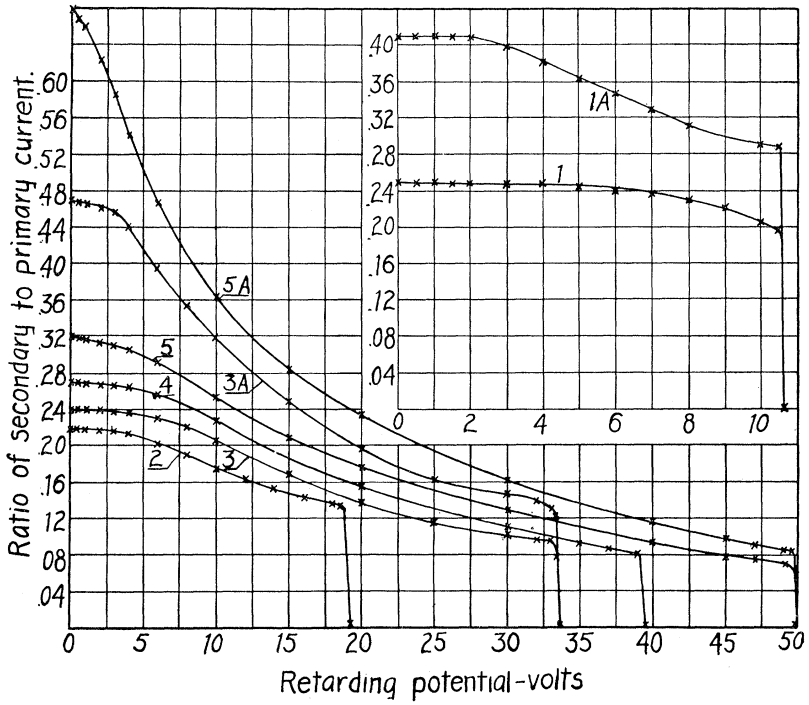

Fig. 7. Energy distribution of secondary electrons from silver. Curve 1, 1A for 10.6 volt (corrected) primary electrons, curve 2 for 18.7 volt electrons, curve 3, 3A for 33.5 volt electrons, curve 4, for 39.0 volt electrons, curve 5, 5A for 50.0 volt electrons. Curves 1A, 3A, and 5A are for targets subsequent to baking at 350°C, but previous to red-heat treatment. The other curves were obtained subsequent to red-heat treatment of the target.

the limiting value to 50 volts, this maximum moves first slightly toward higher and then toward lower retarding potentials, and becomes much broader. In general, it occurs between about 3 and 12 volts for the region investigated. It seems likely that the initial shift toward higher retarding potentials is due to the fact that, for the lower primary voltages, this group consists chiefly of scattered primary electrons which have lost some energy and that the average energy which they retain increases with the primary voltage. The subsequent shift toward lower retarding potentials is then due to an increasing number of emitted electrons whose average energy ap-

parently decreases with increasing primary voltage. For the same primary voltage, the retarding potential corresponding to the maximum of the first group is higher for silver than for any of the other metals tried. The relative number of electrons in the second group is also greatest for silver. The reason for the difference between the present results and those previously obtained is due to the fact that the former tubes did not permit a radial retarding field. This condition causes the indicated value of the average electron energy to be less than the true value.

Brinsmade[5] and Sharman[7], both using the magnetic deflection method, have observed the two groups of secondary electrons. Since the position of the first group varies with the metal, the previous heat treatment of the metal, the primary voltage and probably the angle of emission, a quantitative comparison of their results with the present ones cannot be made, but they appear to be in at least qualitative agreement.

(4) *There are practically no secondary electrons having energies very nearly zero for primary voltages less than about 35 or 40 volts (this varies somewhat with the metal), for any of the four metals.* This seems especially significant, for it denotes that for primary voltages below the above value there are practically no electrons escaping from the metal which have just sufficient energy to do so, but each of those escaping has an energy which exceeds that required to escape by 0.5 or more equivalent volts. This result cannot be a spurious effect caused by the target assuming a negative potential with respect to its surroundings. Although the target was found to be at a negative potential after it had been heated at red heat, this potential was compensated by an applied positive potential while observations were made. As mentioned above, the electrons in the first group probably consist of both scattered primaries, which have lost some energy, and emitted electrons. Taking the final upward rise of the secondary electron curves in Figs. 2 and 3 as being due to an increasing emission, it is apparent that the emission is appreciable for primary voltages considerably below 35 or 40 volts. The results then indicate that all electrons which are emitted from the metal possess energy, immediately after collision, in excess of the equivalent work function of the metal by a certain minimum value, but that, as the primary voltage is increased, electrons are emitted from greater depths and consequently lose more energy before escaping from the metal. This latter condition accounts for the decrease in the average energy of electrons emitted at the surface with increasing primary voltage.

Brinsmade[5] and Sharman[7] both attribute the small number of very low speed secondary electrons in their results to the action of surface forces. It is difficult to see how surface forces might account for the absence of low speed electrons at primary voltages below about 35 or 40 volts and the presence of such electrons about this voltage, as was found in the present experiments.

[7] Sharman, Proc. Camb. Phil. Soc. **23,** 523 (1927).

From measurements on a blackened platinum surface, A. Becker[8] has concluded that the electrons emitted from such a surface have a distribution in energy which is independent of the average energy of the incident electrons, the most probable value being that corresponding to about 2 volts. The present results show that this is not the case for a pure metal which has been thoroughly outgassed.

(5) *The energy distribution of secondary electrons before and after heating the target at red heat is not the same, the percent of low energy electrons being greater before heating than after.* This means that the increased secondary current due to gas on the surface before heating consists chiefly of low energy electrons. Since this is true for all primary voltages tried (0–50 volts), both above and below the ionizing potential of the gas, it follows that the relative number of emitted electrons, as well as the fraction of scattered primary electrons which have lost some energy, is greater for a gas covered surface than for a gas free surface. This is true for the metals Cu, Ni, and Ag. No observations for Fe were obtained previous to heating the target at red heat. It is interesting to note that Jackson[9] has found the electron emission due to positive ion bombardment to be greater from a gas covered surface than from a degassed metal.

It is a pleasure to record here my thanks to Professor A. deF. Palmer and especially to Professor F. G. Keyes, for their interest and assistance in procuring necessary apparatus and material for continuing my investigations in this laboratory.

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[8] A. Becker, Ann.d. Physik, **78,** 228 (1925).
[9] W. J. Jackson, Phys. Rev. **30,** 473 (1927).