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# Secondary Emission from Composite Surfaces

HAROLD JACOBS, JACK MARTIN, AND FRANK BRAND
*Signal Corps Engineering Laboratories, Fort Monmouth, New Jersey*

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A method was utilized of determining the secondary emission threshold energy for various composite surfaces. It was found that each compound had its own threshold energy value below which primaries would not yield true secondaries and above which primary electrons would cause the emission of secondary electrons. The experimental results were checked by means of two very different experimental structures.

Comparisons were made of the electron energy necessary to remove an electron and these represent almost the same values as the energy necessary to remove an electron from the filled band to the vacuum when compared with optical experiments and with calculations.

It was concluded that true secondaries originate from the filled band of the compound rather than from electron traps, as several authors previously supposed. In addition, it was found that the addition of silver to caesium oxide did cause an increase in secondary emission yield, not due to traps, but because of the formation of a new filled band level, less deep than that of caesium oxide without the silver additive. It was inferred that the action of the silver was to form a new compound, more active as a secondary emitter than caesium oxide.

## I. INTRODUCTION

THE theory of the mechanism of secondary emission from composite surfaces is a subject which is not in a very satisfactory state, even though considerable application has been made of secondary emission in electronic devices. Some of the more commonly used surfaces are caesium oxygen silver, magnesium oxide, barium oxide, and magnesium oxygen silver. Of these, the caesium oxygen silver surfaces have received the greatest utilization, and in addition, the greatest amount of study.

Of the various theories proposed, these are the two major schools of thought concerning the mechanism of secondary emission. Bruining and DeBoer[1] have proposed that high secondary emission yields occur in insulators where the lowest conduction band lies above or near the surface barrier. They claimed that, secondary electrons arise from the filled band, from there emerge into the conduction band and from the conduction band are readily emitted into the vacuum since for the class of materials studied, the electron affinity is negligible. Much of their work was done with surface films of alkali halides. Their work indicates furthermore, that electron traps such as those formed by a stochiometric excess of metal in the insulator, do not enhance the release of secondary electrons from the surface. Another school of thought has been represented by Timofeev,[2] Khlebnikov,[3] Pomerantz[4] and others. This group has proposed that secondary emission electrons are released from electron traps in insulators. Timofeev and Khlebnikov, working with caesium oxygen silver surfaces, found that by adding free caesium or free silver to a caesium oxide surface, an enhanced secondary emission would result. Upon further increasing the metallic content, the secondary emission reached a maximum and then started to decline with increasing metallic additive. They concluded from their experiments that silver or caesium atoms, dispersed through the caesium oxygen structure, formed electron traps and that these traps were the source of secondary electrons.

Timofeev later claimed that field enhanced secondary emission could occur when surface atoms were ionized. The surface charges were believed to set up intense fields in the insulator removing electrons from the traps of the vacuum. This concept is similar to the "Malter effect."

Pomerantz, bombarding barium strontium oxide, such as used in oxide cathodes, claimed, from the temperature dependence of secondary emission, that electrons originated from traps due to alkaline earth atoms in the oxide coating.

Thus, we have at least two schools of thought concerning the source of secondary electrons, both conflicting in experimental results and in theory. One group looks upon traps as the source of secondaries, the other group looks to the filled band as the source.

By means of the experiments to be described it was

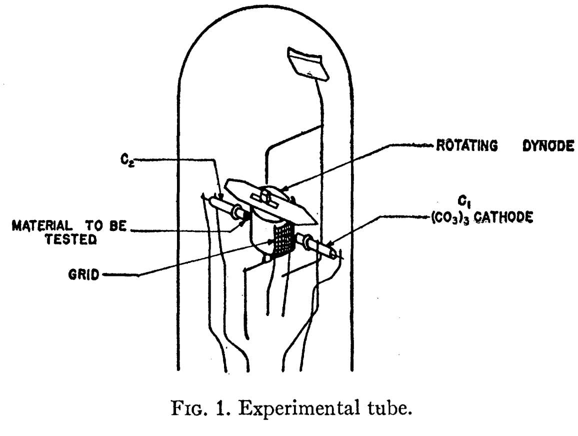

FIG. 1. Experimental tube.

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[1] H. Bruining and J. H. DeBoer, Physica **6**, 823 (1939).

[2] P. W. Timofeev and A. I. Pyatnitzky, Physik Z. Sowjetunion **10**, 518 (1936).

[3] N. Khlebnikov and A. Korshunova, J. Tech. Phys. U.S.S.R. **V**, 363 (1938).

[4] M. A. Pomerantz, Phys. Rev. **70**, 33 (1946).

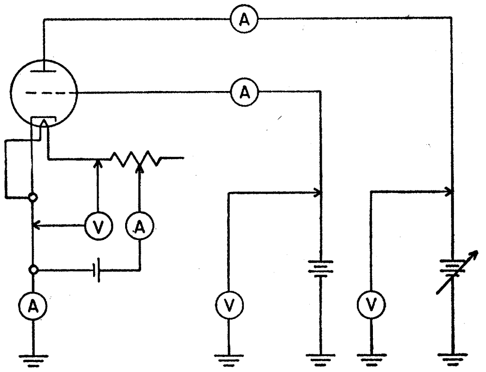

FIG. 2. Test circuit for triode.

hoped that a more general theory of secondary emission processes would be developed.

In order to determine whether the source of secondary electrons were the traps or the filled band, measurements were made to determine a threshold energy of secondary emission. If a critical energy of primary electrons could be determined, below which no secondaries appeared and above which secondary electrons could be detected, then we might have a tool for determining the source of secondary electrons. If the threshold energy to start secondary emission were about 7 to 15 electron volts, it would make possible a theory that secondary electrons originate from the filled band in composite materials. If the threshold energy were only two or three electron volts it might be thought that secondary electrons emanated from traps in the material, as postulated by Timofeev.

The problem in this investigation was to determine the threshold energies of secondary emission from several composite surfaces. From the energies required to liberate secondary electrons, a theory was developed regarding the source of the secondaries.

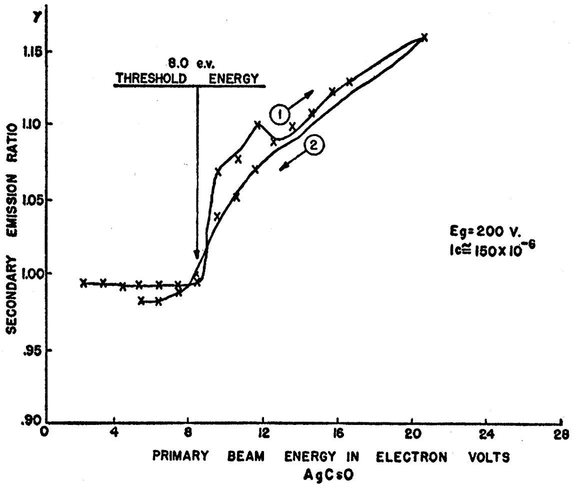

FIG. 3. Secondary emission *vs* primary beam energy for AgCsO.

## II. EXPERIMENTAL METHOD-DESIGN OF FIRST EXPERIMENTAL TUBE

Test tubes were constructed as shown in Fig. 1. A standard, cathode-ray type of oxide coated cathode was used as a source of primary electrons ($C_1$). The grid in front of the cathode was made a high purity nickel mesh. On test, the grid was to be used as both collector and accelerator. The grid contained large spacing between wires to prevent grid interception of the primary current. A rotating anode was provided in order to allow controlled evaporation of contaminants from the materials source $C_2$. For instance, the (BaSrCa)CO$_3$ cathode could be heat treated and activated without contaminating the side of the dynode facing $C_2$. $C_2$, which contained the material to be studied, could then be heated and a layer of contaminant deposited on the dynode surface. The dynode was then rotated by a magnet external to the tube and placed in front of the oxide coated cathode. Following this, the surface was then bombarded by the primary beam of 10 to 100 microamps by applying dynode and grid voltages and maintaining the cathode at a low temperature, i.e. 400°C. There was a twofold purpose in maintaining the cathode well below color temperatures. First, the reduced temperatures provided low current density electron beams, which in turn prevented space charge effects. Second, the operation of the cathode at low temperatures could prevent barium evaporation from the cathode. The problem of barium evaporation could be further checked by bombarding various parts of the anode and observing the secondary emission characteristic. It was found that a freshly deposited KCl layer had a characteristic secondary emission response, while the part of the anode coated with barium and barium oxide during cathode activation had a markedly different response.

At test, the circuit was used as shown in Fig. 2. The cathode was practically at ground potential, the grid set at 200 volts and the dynode run from 0 to 40 volts. The secondary emission could be calculated in this range by either the dynode characteristic or by measuring the grid and cathode currents.

In evaporating the material to be tested, by heating $C_2$ and allowing the material to deposit on the dynode, it was sometimes found that the material was too thick. The material seemed to have a high resistance and results were not reproducible. To circumvent this difficulty, either of two techniques were used. First, the heavy deposit could be electron bombarded for long periods of time on exhaust. This would result in a liberation of gas and an increase of conductivity of the coating. Following the sealing of the tube from the vacuum system, further electron bombardment could be used. After this treatment, a characteristic result could be obtained reproducibly. Second, the anode could be so rotated that upon further heating $C_2$, the material to be treated, would deposit on a relatively clean spot, starting with thin layers and gradually building up consecutively thicker layers. This was the technique most often used. In the actual test, with a given layer of material, the dynode was run from 0 to 18 volts in one volt steps with a waiting period of 30 seconds at each step. The secondary emission was recorded at the beginning of each 30-second interval and at the end of the period.

It was found that at most bombarding voltages, for a specific material, the secondary emission was constant with respect to time. However, at certain critical and characteristic voltages the secondary emission might shift slowly in the 30-second waiting period. This sliding in secondary emission at characteristic electron energies was to prove valuable as a hint concerning the processes involved in the tubes studied.

In all cases the applied voltages on the dynode were corrected to true potentials in order to calculate electron energies. The method of correction used, while admittedly subject to error, was considered accurate to ±0.5 volt. Corrections were necessary because the electrons reaching the dynode were subject to the sum of contact potentials and thermal energies. The technique used was as follows. The dynode voltage was increased from zero to higher values, with the grid set at test voltage (200 volts). The point at which the dynode collected 1 $\mu$a was taken as the zero voltage. At higher dynode voltages the current would increase rapidly and then start to decrease with voltage as a result of temperature limited cathode emission and the start of electron emission. The temperature limited cathode emission ran at about 10 to 30 microamperes. A correction in the order of one volt was used with this technique of measurement.

## III. DATA RELATING TO FIRST EXPERIMENTAL TUBE DESIGN

In Fig. 3 we see the results of bombarding a film of caesium oxygen silver. This tube had a thick deposit, and in order to obtain reproducibility the surface was bombarded for 30 minutes at 40 volts and 20 microamperes after sealing the tube from the vacuum system. The surface was prepared in the following manner. A physical mixture of $Cs_2CO_3$ and AgO was made and inserted in the container $C_2$. At exhaust, after processing the cathode, grid, and dynode parts, the container $C_2$ was heated to roughly 775° Centigrade brightness temperature, for two to three minutes, and a deposit was evaporated to the dynode, which was a mixture of caesium oxide and silver. The deposit was found to be an active secondary emitter and to be a good insulator. In curve (1) of Fig. 3, the dynode voltage was raised in one-volt steps of 30 seconds each. At the primary electron energies below 7.5 volts we see that the ratio was less than one. In the region from one to 7.5 volts a characteristic wavelike form was noted in the ratio. It was found that with thinner films, rather discrete changes and a decrease in the number of reflected electrons could be more readily observed. With thicker layers the number of reflected electrons was very high, and the smoothness of the curve was increased. At 7.5 electron volts, a large rise in electrons emitted was observed. In addition, a rather erratic drifting in secondary emission was noticed at this critical energy, which did not appear at the other dynode voltages. As the dynode potential was still further raised the ratio again appeared constant and well over one. At 7.5 volts the instability and slow shift of secondary emission to a greater value may indicate a charging of the surface. This charging could occur due to electrons being released from the surface in suddenly greater numbers, making the secondary emission surface more and more positive. Another factor to consider is the sudden change in slope. Up until the critical energy, there was a tendency for the emitted electrons to either remain fairly constant or decrease in number. However, at 7.5 volts and above, the ratio of secondaries increased markedly with dynode potential. Curve (2) in Fig. 3 shows an immediate

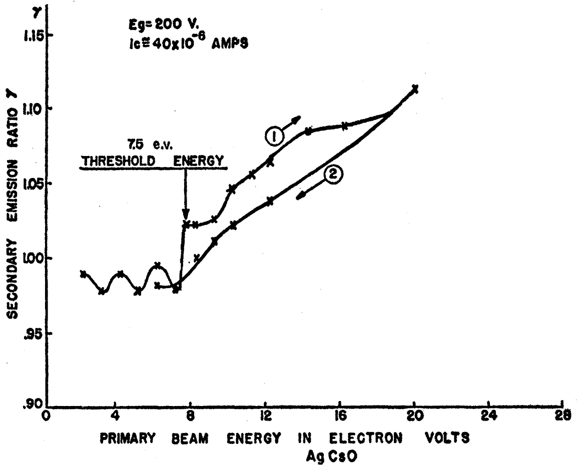

FIG. 4. Secondary emission *vs* primary beam energy for AgCsO.

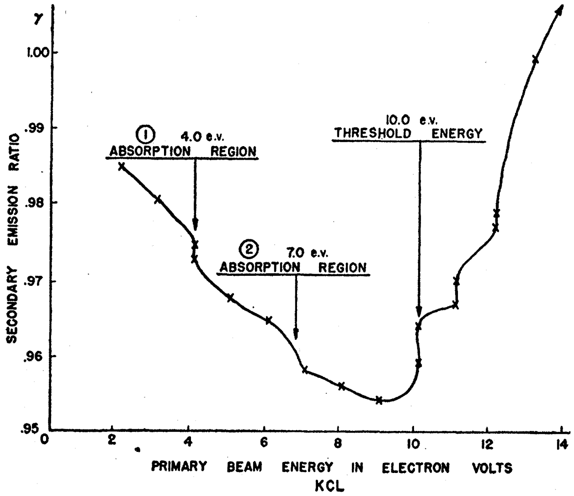

FIG. 5. Secondary emission *vs* primary beam energy for KCl.

TABLE I. Threshold energies of secondary emission from various surfaces.

| Tube No. | Trial No. | Threshold energy (ev) | Material tested | Description of film deposit |
|---|---|---|---|---|
| *Q* | 1 | 10.0 | KCl | First layer of thin film of KCl deposit on clear dynode spot |
| *Q* | 2 | 10.0 | KCl | Additional deposit added to surface repeated measurements. |
| *Q* | 3 | 10.0 | KCl | Still further deposition of KCl, measurements repeated |
| *Q* | 4 | 10.0 | KCl | First deposit on another clear portion of dynode |
| *Q* | 5 | 12.0 | KCl | Very heavy deposit strong interference colors |
| *Q* | 6 | 11.0 | KCl | Repeat run (60 $\mu$a) |
| *Q* | 7 | 11.0 | KCl | Repeat run, primary current reduced by factor of $\frac{1}{2}$ (30 $\mu$a) |
| *R* | 1 | 11.0 | KCl | 1st heavy deposit of KCl strong colors noted |
| *R* | 2 | 11.0 | KCl | 1st thin deposit of KCl on clear part of dynode surface |
| *R* | 3 | 10.0 | KCl | Additional deposit |

decrease in anode potential after running through curve (1). The charging seems to have disappeared.

Figure 4 illustrates the bombardment of another thick deposit of caesium oxygen silver film. Here, again, the yield was flat and reflected electrons high in number, in the region below approximately 8.0 electron volts. In the region from 8 to 9 volts, the instability again appeared and above this a steep rise in secondary emission with dynode potential was observed. Curve (1) shows the results of rising dynode potentials and curve (2) the results of lowering the dynode voltages.

In Fig. 5, we see the results of bombarding a thin film of potassium chloride. In this case the film was of such thinness that interference colors were just at the point of being formed. Here we see characteristic energies at which reflected electrons are decreased in number or in other terms, the electrons are absorbed at critical energies 5 volts at point (1) and about 7 volts at point (2). This process of absorption of electrons at about 7.0 volts has also been discussed by Bruining.[5] He points out that 7.0 electron volts correspond to the first optical absorption peak for pure KCl and that there may be an equivalence in the optical absorption and electron absorption, with respect to energy. We might add that this electron absorption at 7 to 8 volts has appeared consistently with all samples of thin KCl films. At 10 electron volts a sliding or apparent charging occurred and instability was noticed again at 11 electron volts. On further increasing the dynode potential a stable condition resulted, and the secondary emission rose very rapidly with increased anode potential.

In Table I there is listed a sample of some of the surfaces tested and the values taken to represent the characteristic energies of enhanced secondary emission for these materials.

To summarize the data, the following values were found for energy of the threshold of secondary emission for the materials listed. For KCl, 10.7 volts primary electrons were required to produce secondary electrons; for RbCl, 9.1 volts; for CsCl, 10.0 volts; for $Cs_2O$, 8.0 volts; and for CsOAg, 7.0 volts.

In addition, it was noted that these energies were independent of current and thickness of material over a considerable range. The increased thickness, however, did tend to flatten out variations in absorption of electrons at low energies below the threshold values. Also, a higher yield of reflected electrons was noted. For thin layers, an absorption of reflected electrons was observed from KCl which corresponds in energy to the first optical absorption peak determined by Schneider and O'Bryan,[6] and Hilsch and Pohl.[7]

## IV. INTERPRETATION

In comparing the values obtained for the second optical absorption band with the characteristic energies required to provide the enhanced secondary emission, one finds very good agreement. The values involved are listed in Table II.

TABLE II. Comparison of second optical absorption band and secondary emission.

| | Threshold energies | |
|---|---|---|
| Material | Optical energy of absorption (ev) | Electrical energy required to release secondary electrons (ev) |
| KCl | 9.4 | 10.7 |
| RbCl | 9.9 | 9.1 |
| CsCl | 10.3 | 10.0 |
| $Cs_2O$ | ... | 8.0 |
| CsOAg | ... | 7.0 |

In the case of KCl, CsCl, and RbCl, the secondary emission experiments showed a correspondence in the electronic energies of absorption and the photon energies of absorption. This must mean that the electron affinity for these materials is negligibly small, which checks with theoretical considerations.[8]

The experiments just described also provide us with an opportunity to determine where the source of secondary emission lies in CsOAg and $Cs_2O$ surfaces. Since the threshold of secondary emission occurred at 7.0 volts for CsOAg and at 8.0 volts for $Cs_2O$, it seems likely that here, too, the secondary electrons come from the filled band. It was found to be experimentally true that the addition of silver to the caesium oxide enhanced thermionic emission, but not because electron traps are formed. What actually happens is that the silver is added and a new compound is formed with its own system of energy bands. The raising of the filled band in the CsOAg structure from 8.0 volts to 7.0 volts may be one

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[5] R. Hilsch, Z. Phys. **77**, 427 (1932).

[6] E. G. Schneider and H. M. O'Bryan, Phys. Rev. **51**, 293 (1937).

[7] R. Hilsch and R. W. Pohl, Z. Physik **59**, 812 (1930).

[8] F. Seitz, *Modern Theory of Solids* (McGraw-Hill Book Company, Inc., New York, 1940), p. 401.

factor in the increased secondary emission yields, since the electrons then require less energy to escape from the material.[9] In any case, the traps are not the sources of secondaries, since if they were, the threshold of secondary emission would occur at much lower energies.

The following conclusions were drawn from the experiments described above:

(a) For a given thin film of secondary emitting material, such as the ionic crystalline materials described, a characteristic threshold energy of secondary emission can be determined. This threshold is characterized by: (1) a large rise in secondary emission with increasing primary electron energies, (2) a sliding effect, or charging effect causing increasing secondary emission, and (3) in some cases, a ratio of greater than one to one.

(b) The threshold energies for secondary emission check well with the calculated and the optical energies to remove an electron from the filled band into the vacuum. This indicates that secondary emission electrons originate from the filled band rather than from traps. An enhanced secondary emission, such as caused by silver added to caesium oxide, is the result of the formation of a new band scheme such as would be expected as a result of the formation of a new compound.

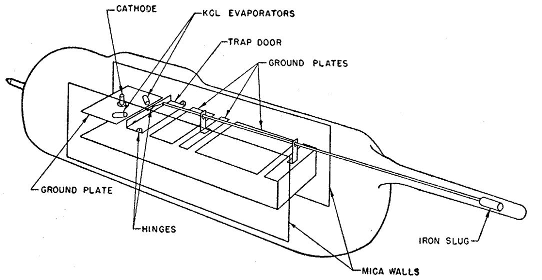

FIG. 6. Experimental tube structure for cycloidal electron beam.

## V. EXPERIMENTAL METHOD-DESIGN OF SECOND EXPERIMENTAL TUBE

In the work described thus far, all of the experiments were done in a triode design with a rotating anode to insure the cleanliness of the surface. This design, however, showed certain possibilities for error which needed checking in an experimental tube of a radically different design. In the following description we shall describe the second experimental approach and show how this approach verified the conclusions previously obtained.

Some of the problems, or possibilities for error in the triode design were concerned with contaminations and electron scattering. For instance, even though a rotating anode was used together with low cathode temperatures, a small quantity of barium might still contaminate the cathode. Calculations on this effect are difficult, and the new design (Fig. 6 and Fig. 7) was developed to check the fact that there was little or no evaporated barium on the surface. The second problem was that the grid (set at 200 volts) could scatter a small number of electrons. The new design eliminated the grid and the possibility of electron scattering by the grid wires.

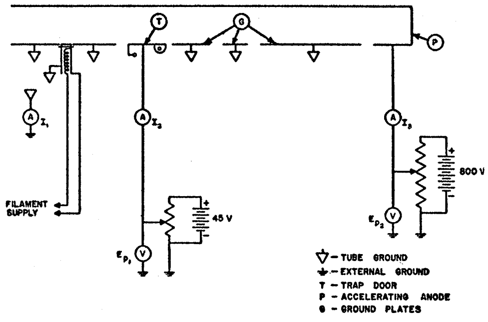

FIG. 7. Test circuit for experimental tube.

In Fig. 6, the general scheme is illustrated for the experimental tube. A similar tube was used by Nelson[10] in his studies of secondary emission from MgO targets. The circuit arrangement is illustrated in Fig. 7. Electrons liberated from the cathode (set at a low temperature, such that the only 10–20 $\mu$a represented the temperature limited emission) were accelerated toward the anode labeled *P*. A tranverse magnetic field was then applied such that the electrons would bombard the dynode target, *T*. This target could be varied in potential from 0–45 volts. The secondary emission electrons or reflected electrons could then leave the target and start toward *P*. The same magnetic field could again deflect the electrons and by means of a cycloid path, the electrons could be collected at the upper end of *P*. All metal parts of the tube except the cathode were made of tantalum to prevent the magnetization of the structure. The focusing of the electrons, and their trajectories was checked by making of several tubes with commercial willemite dusted throughout the tube and observing the position of the fluorescence upon electron bombardment. The material to be studied, such as KCl, was placed in a small container (not shown in Fig. 7). The target surface, *T*, could be lowered by means of moving the iron slug with an external magnet. With the target lowered, KCl could be evaporated to the surface without contaminating the inner part of the tube structure. In this tube design electron focusing could be quite accurate and contaminations deposited on the KCl target from the cathode could be made very unlikely. Contact potential and initial velocity corrections were made as in the first experimental tube and the secondary emission from the surface was studied in the region from 0–20 electron volts, bombarding energy. Layers of KCl were evaporated with runs made after

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[9] It was thought, at first, that the rise in secondary emission due to the presence of silver might be due to the work function. However, in rather extensive testing no correlation was found between work function and secondary emission. Work function measurements were made by contact potential determinations using an additional cathode in the experimental tube.

[10] H. Nelson, Phys. Rev. 57, 560 (1940).

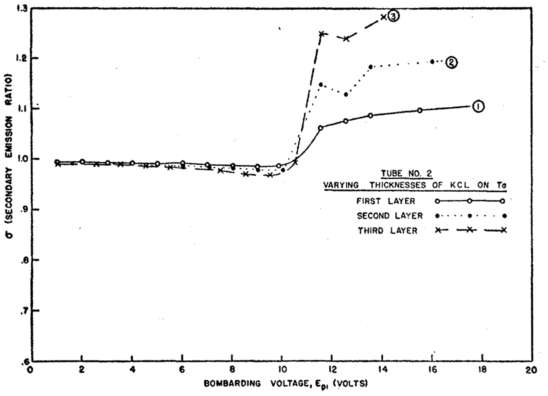

FIG. 8. Secondary emission *vs* primary beam energy for KCl.

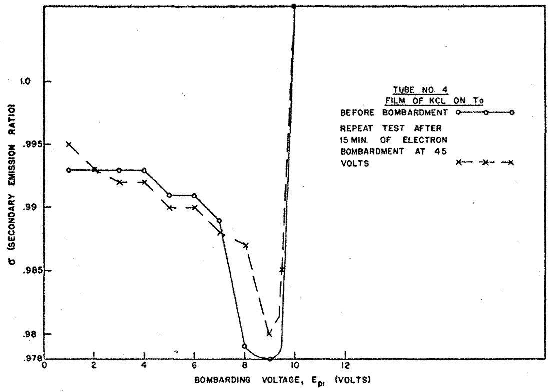

FIG. 9. Secondary emission *vs* primary beam energy for KCl.

each additional evaporation and sometimes after continuous bombardment.

In Fig. 8 we see results for KCl which are very similar to the data obtained in the triode design (see Fig. 5). The curves show that at about 10 volts, over different thicknesses (in the order of $10^{-5}$ cm) there was a sudden rise in the secondary emission yield.

In Fig. 9, we see that the results of another run with the scale greatly amplified. We again see the absorption peak at 7–8 electron volts. These are the peaks that Hilsch and Bruining looked upon as representing the absorption of reflected electrons by the excitation of an electron from the filled band to an exciton level.

At 9 to 10 volts the sudden rise in yield occurs to a region over a ratio of one, thus indicating true secondary electrons have been emitted.

## VI. FURTHER DISCUSSION

The fact that at about 10-volts bombardment there appears to be a sudden rise in the secondary yield and at the same time there is considerable sliding, or what appears to be a charging of the surface, provides an opportunity to discuss the mechanism of this abrupt enhanced electron emission.

Several years ago, Nelson[10] reported experiments in which he studied secondary emission from magnesium oxide surfaces. He found that at about 16 volts primary electron energy a marked enhancement of secondary emission occurred. In addition, he found that at this particular energy a drifting of secondary emission took place, which he attributed to the charging of the secondary emission surface. He postulated that the charging of the surface produced a field enhanced secondary emission, which accounted for the rising secondary emission yield.

In our data such as in Fig. 5, as an example, it was observed that there was a sudden increase in secondary emission at about 10 volts. This might be looked upon as a threshold of secondary emission, because, first, the secondary emission increases rapidly as the energy is raised above this point. Secondly, there is evidence of charging or ionization of the surface by electrons at about 10 volts. And thirdly, the energy at this point equals the calculated and optical energies necessary to remove an electron from the filled band. If 10 volts is the threshold energy of secondary emission, then it would appear that secondary electrons originate from the filled band, as postulated by Bruining.[1]

Using this hypothesis, the theories of H. Nelson concerning field enhanced secondary emission would appear consistent with the above experiments. If the resistance of the film is increased by some method such as increasing the thickness, positive charges could reside on the surface for considerable lengths of time. A positive charge on the surface would produce an intense field in the material allowing a greater probability for secondaries to escape.

For KCl, one can calculate the maximum voltage which could be developed across the material. Assume the surface to be $10^{-6}$–$10^{-5}$ cm in thickness. The maximum field is about $10^6$ volts/cm before breakdown. Thus a difference of potential could exist across the coating of from 1 volt to 10 volts. For a field of $10^6$ volts/cm, the charges on the surface would be in the order of $10^{12}$. This is a reasonable number since on the surface there would be about $10^{15}$ atoms/cm$^2$. Hence only one out of a thousand surface atoms need be ionized to develop the maximum field across the film. The description of field enhanced secondary emission would then be that as the film is increased in resistance (due to thickness) a field of $10^6$ could be developed by ionization produced in the liberation of electrons from the filled band. This high field might well enhance secondary electron emission and produce results which are consistent with the experimental evidence.

## VII. CONCLUSIONS

The following conclusions were drawn from the experiments described:

(a) For the case of thin films of the composite secondary emission surfaces described, a characteristic energy of bombarding electrons was observed for each material, at which there was a sudden increase of secondary electron emission.

(b) The energy for enhanced secondary emission corresponds to the energy required to liberate an electron from the filled band to the vacuum. This indicates secondary electrons originate from the filled band and that the energy required is the threshold energy of secondary emission.

(c) The drifting in secondary emission yields noticed with thicker surfaces may be due to field enhanced secondary emission produced by positive charges at the surface of the material.

## VIII. ACKNOWLEDGMENTS

We wish to thank Mr. Herbert Nelson of the Radio Corporation of America for his suggestions pertaining to the design of the second experimental tube and for his discussions during the course of this work. We should also like to acknowledge suggestions from Dr. J. B. Johnson of the Bell Telephone Laboratories, Professor A. van der Ziel of the University of Minnesota, Dr. J. E. Gorham, and Mr. G. Ross Kilgore of the Signal Corps Engineering Laboratories.

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# Nuclear Disintegration by Positron-*K* Electron Annihilation

R. D. Present and S. C. Chen
*University of Tennessee, Knoxville, Tennessee*

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A new process for the annihilation of fast positrons is discussed, in which a positron with insufficient energy to excite or disintegrate a nucleus by collision, annihilates a $K$ electron of an atom with subsequent excitation or disintegration of its nucleus. If the positron energy is close to threshold for the process, competition from two-quanta annihilation does not occur. The process is of first order and, apart from the occurrence of negative energy states, is the reverse of internal conversion. The cross section can be factored into a cross section for annihilation with emission of a photon converging on the nucleus times a probability for nuclear disintegration. In the electric dipole case, the latter is just the ratio of the photodisintegration cross section to the $P$-wave blackbody absorption cross section of the nucleus. The photodisintegration cross section is taken from experiment.

The annihilation cross section in light elements has been calculated in the Born approximation using the complete retarded interaction corresponding to converging spherical waves of electric dipole radiation (the nucleus acts as a sink for these waves, in addition to conserving momentum). For large incident energy of the positron ($\gg mc^2$) the difference between positive and negative energy states can be neglected approximately, and the cross section obtained by detailed balancing from the internal conversion coefficient. Insofar as accurate values of the latter are known in the proper energy range for high atomic numbers $Z$, the annihilation cross section for very fast positrons can be obtained to a good approximation for the same values of $Z$.

Numerical estimates have been made for the disintegration of $Be^9$ with emission of a neutron and also for the disintegration of $U^{238}$ resulting in nuclear fission. The total annihilation-disintegration cross sections near the threshold in these two cases are $\sim 10^{-34}$ cm$^2$ and $\sim 10^{-31}$ cm$^2$, respectively. The total cross section for an annihilation-excitation of $In^{115}$ into an activation level for the metastable state, resulting in the formation of a nuclear isomer, is found to be $\sim 10^{-26}$ cm$^2$.

## I. INTRODUCTION

The purpose of this note is to discuss a new type of annihilation process for positrons.[1] Consider a positron incident on an atom with less kinetic energy than would be needed to disintegrate the nucleus. If the positron annihilates an orbital electron, the energy released, which is greater by $\sim 2\ mc^2$ than the initial kinetic energy, may be sufficient to produce a nuclear disintegration in the same atom. A possible competitive process is the two-quanta annihilation of the positron in which one of the quanta produces photodisintegration of a nucleus of the same kind. This competitive process will not occur, however, if the positron energy is sufficiently close to threshold, since one of the quanta in two-quanta annihilation must take away a minimum energy $\sim mc^2/2$.

The annihilation-disintegration process may be described as a transition of an electron from an orbital state into a vacant negative energy state in the continuum corresponding to the incident positron, accompanied by a nuclear transition from the ground state into an excited continuum state corresponding to disintegration. The mechanism for the process and the perturbation that induces the transitions is the complete retarded electromagnetic interaction between the electron and the nucleus. Clearly our process would be the reverse of internal conversion were it not for the negative energy states. The close relation to internal conversion will be taken advantage of in the following discussion.

In Section II we show that the annihilation-disintegration cross section ($\sigma_{ad}$) can be factored into a cross section for annihilation with emission of a spherical wave of photons converging on the nucleus ($\sigma_{aq}$) times a probability for nuclear disintegration. The latter is just the ratio of the nuclear photodisintegration cross section to the maximum (blackbody) absorption cross section of the nucleus for the photon. In the absence of an adequate nuclear theory, the cross section for the nuclear photoeffect is to be taken from experiment. In Section III we make use of a theorem that for large

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[1] A preliminary abstract appeared in Phys. Rev. **83**, 238 (1951).