SECONDARY ELECTRONS FROM CONTAMINATED SURFACES

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Abstract

Surface fields.—Small quantities of grease, or condensed vapors, or foreign metal upon a metallic surface have in the past been the cause of many spurious electrical effects. Stuhlmann and Compton cite a spurious contact potential difference of some 60 volts. Using electron reflection and secondary emission as a tool, some of the properties of such surfaces have been investigated. The results indicate that surface fields are set up retarding the reflected electrons.

Insulating layers.—New evidence is found for a sudden breakdown of the insulation of oils in thin films which has been investigated by Brüninghaus and by Watson and Menon. The bearing of the present results on suggested interpretations of the effect is briefly discussed.

The fields in the neighborhood of incandescent filaments have been investigated[1,2] through a study of characteristics of the saturation curve. In the present investigation an attempt is made to study the fields in the neighborhood of cold metallic surfaces. The currents used are obtained by reflection and secondary emission of electrons at the surface to be studied.

Apparatus

The apparatus used is shown in Fig. 1. A filament, F, (of 7 mil tungsten wire) is placed at the center of a molybdenum cylinder, C, the diameter

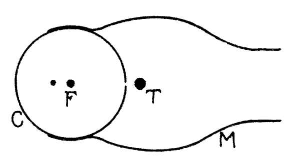

Fig. 1. Apparatus.

of which is about 1 cm. Electrons emitted by the filament are accelerated toward the cylinder by an applied potential. Some pass out through the slit (of width 0.25 mm) and strike the target, T, which is placed directly before it. The target consists of a second tungsten wire.

The potential of the cylinders, C and M, may be below that of the target, giving a field tending to prevent the escape of reflected electrons, or above it tending to accelerate them in their escape. With the cylinders at low potential, the escape may be almost entirely avoided; with C positive, the number

[1] Irving Langmuir, G. E. Rev. **23**, 503 (1920).
[2] Becker and Mueller, Phys. Rev. **31**, 431 (1928).

of electrons leaving may be greater than the primary ones which hit and the current to the target be actually positive.

The tungsten wire used for a target was in the earlier experiments a 10 mil and in the later experiments a 20 mil filament. This form of target was selected to facilitate the application of rather intense, homogeneous fields at its surface. With such a target, however, there is the danger that the full primary current will not strike it and, more serious, that the fraction which does strike it will vary as the field is changed. Fig. 2 shows the results of experiments performed to investigate this question. The current to the target was observed for different settings of the target near the slit as it was moved transverse to the slit. The numbered divisions correspond to motions of the target of approximately 1/7 cm or 0.056 in. transverse to the slit.

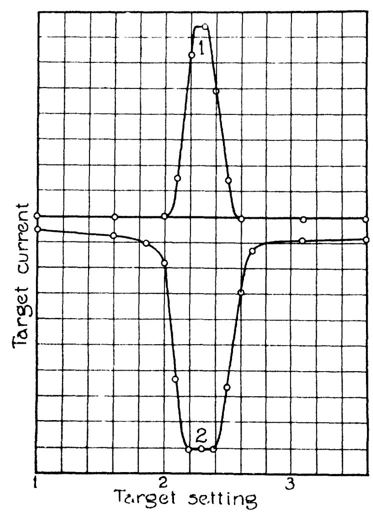

Fig. 2. Electron beam.

The curves in Fig. 2 show the results for a 20 mil target. The impacting speed was such as to produce large secondary emission in each case—in curve 1 this emission was allowed to leave; in curve 2 the field prevented secondary emission. In curve 1 the cylinders were maintained at a potential of 240 volts positive and the target 142 volts positive with respect to the source, F. Between the target and its surroundings was a potential difference of 98 volts, the field being in such a direction as to aid electrons in leaving the target. There is no current to the target until it comes into the direct electron beam from the slit. It rapidly approaches a maximum value and maintains this value while the target is moved about 1/7 mm transverse to the slit.

In the second curve, the target is 142 volts positive, but the cylinders have been lowered to 60 volts positive with respect to the source. The general shape of the curve is much the same as before except that the current is reversed in sense. The flat plateau on both of these curves indicates that the target is larger than the electron beam and hence receives the full current for a number of settings. This result would be expected from the dimensions involved. When using a 20 mil filament, the target is enough larger than the beam so that the primary current can be considered constant as the field about the target is changed. Probably also a 10 mil target receives nearly all of the current through the slit.

Influence of the Surface Electric Field on Secondary Emission

To investigate the fields present at the surface of the target, the current carried by the target was observed as a function of the applied field, all the other conditions being held as nearly constant as possible. A given potential,[3] which for any single curve was held constant, was applied between the filament and the target. The effect of variation of secondary emission with bombarding velocity was thus eliminated. In the curves which follow, the abscissas give the potential of the cylinders, C and M, relative to the target. The ordinates give the net current to the target. Electron currents to the target are plotted as negative.

In the investigation of surface fields, a tungsten wire, without any special treatment whatever, was fastened in place as a target. The current to the target was then measured for different fields determined by the potential of the cylinders relative to the target, and the resulting curve was plotted. The target was then cleaned by heating it to incandescence,[4] and after this the observations of target current against cylinder potential were repeated. The difference in the shape of the two curves thus obtained indicates the influence of the impurities eliminated by the heating.

The curve indicated as number 1 in Fig. 3 was obtained soon after the target had been cleaned through heating it by an electric current. At the left of the curve, the negative current is not increasing; very few of the electrons are reflected with sufficient velocity to overcome these high retarding fields. As the potential of the cylinders is raised, an increasing number of electrons leave the target; this decreases the net current. The increase of the return current is particularly rapid when the retarding field is removed, for this enables the slow speed electrons to leave. Finally, the net current is reversed in sign; more electrons leave the target than strike it. In addition, then, to the electrons of the original beam which have been reflected, there must be others in the return current liberated by ionization at the surface. The positive current comes to a maximum value at once. This saturation of the secondary current with low positive potentials is exactly what we should expect; all the secondary electrons are able to leave the target if no field retards their escape.

The case is different, however, for targets which have surface contamination. The second curve indicated in Fig. 3 is one obtained just before the

[3] It was found that electrons of 100 volts energy produced secondary currents of suitable value, and in the curves which follow, the source was maintained 100 volts negative with respect to the target unless some other value is given.

[4] Such high temperatures were later found to be unnecessary for the removal of the impurities causing the pronounced effects observed.

heating of the target. The most significant feature is the poor saturation of the positive current. This must be due to retarding fields in the neighborhood of the target surface; otherwise we would expect all electrons emitted to be able to leave the target. This poor saturation appears to be the analogue of that observed for composite surfaces in thermionic emission. This has been explained as an effect of the fields in the neighborhood of the filament surface. Somewhat similar fields must exist here.

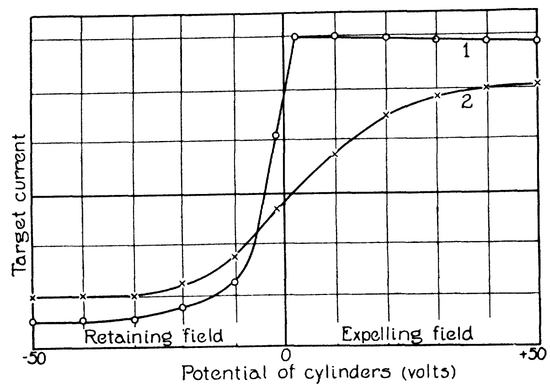

Fig. 3. Influence of electric field on secondary emission.

An attempt was made to observe by the present method fields due to thorium on a tungsten filament. That a surface field exists about an incandescent filament partly covered with thorium is known from saturation characteristics in thermionic emission. The results in the case of reflected electrons, however were not decisive. The effect of thorium on the saturation curve does not appear to be as pronounced as that due to the more easily volatilized impurities responsible for the above results.

Insulating Property of Thin Oil Films

The erratic behavior of metal surfaces contaminated by slight quantities of oil or wax have been at various times observed. Stuhlmann and Compton[5] in attempting to account for abnormally high velocities of photoelectrons showed that slight quantities of wax vapor could result in surface charges, sometimes as high as 60 volts, which acted in some respects as a contact difference of potential. A real contact potential difference of this amount is hardly plausible, and it would seem likely that the results are to be attributed to an insulating layer which was charged as high as sixty volts before the insulation broke down.

In the present experiment in the case of extreme contamination by oil particles, an interesting kind of "one way conduction" was observed which can be explained as due to an insulating layer. In the apparatus used for this experiment, the target was fastened onto wires entering the vacuum system

[5] Stuhlmann and Compton, Phys. Rev. **2**, 199 (1913).

through a stop-cock. Oil was placed around the top of the stop-cock; the stop-cock was then raised slightly from its socket, and the oil was injected into the system as a spray. The curve of Fig. 4, obtained after such treatment, follows the axis for a considerable range of potentials. The number of electrons striking the target in this range just equals the number leaving it. This rather striking result was confirmed by repeating the treatment several times.

To explain this we must suppose that the oil forms an insulating layer on the surface of the target which breaks down at some critical potential, apparently about 50 volts. The difficulty is that with retarding fields, even for small values of these fields, a negative current is indicated. To explain the entire curve on the basis of a continuous insulating layer would demand the assumption of some sort of one way conduction in the layer.

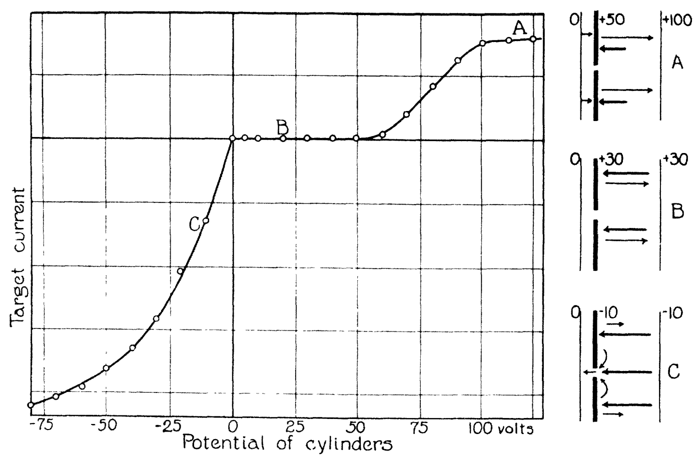

Fig. 4. Insulation due to oil film.

The curve can, however, be explained on two assumptions: first that the surface is only partially covered with minute droplets of oil, and second that these insulate only below some critical potential of about 50 volts; the insulation then breaks down. This leads to the insulation observed for small accelerating fields, which corresponds to the region B of the curve. The oil surface is raised by the more than one hundred percent reflection up to the potential of the cylinders,[6] and after this the secondary equals the primary current. The total current is zero. At higher potentials, such as in the region A, the insulation breaks down; electrons are supplied through the layer, and more than one hundred percent secondary current results. As soon as the potential of the cylinders has been reduced below that of the target, the primary and secondary currents find a way to the clean metal somewhat as

[6] See Fig. 3. The zero of current for the contaminated surface closely approaches the zero of the applied field. The zero of current does not usually fall more than five volts from the zero of applied potential. It should be noted that the argument used here does not depend upon the zero of current being exactly at the zero of the applied field.

shown in the lower sketch at the right of Fig. 4. This accounts for the negative currents indicated in the region *C*.

The apparent breakdown potential of this thin film is interesting. It has been known, of course, for some time that vaseline and other oils, which are ordinarily good insulators, may be used in thin films on electrical contacts to lower the resistance. The assumptions made above concerning this thin film and its breakdown potential appear to be in substantial agreement with the results of a number of rather detailed investigations[7,8] in which thin films (about 10μ thick) were included between two conducting planes to which a potential difference was applied. This was a simple and direct method of investigation; the results obtained could be interpreted quantitatively at once. The results obtained in the present experiment are of a more complicated nature; exact quantitative interpretations are perhaps impossible. The present verification of the effect, however, has some advantages. The results

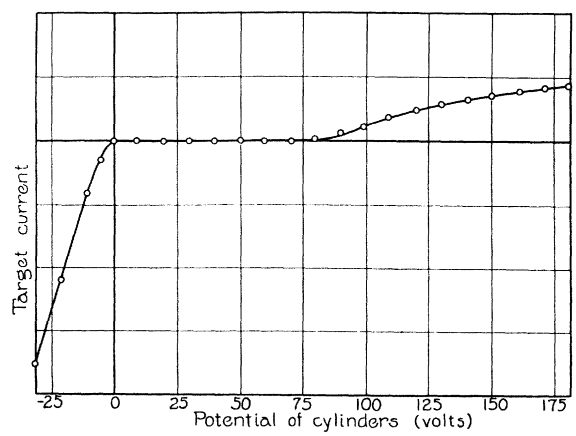

Fig. 5. Insulation at lower bombarding potentials.

of the present experiment eliminate the objection (possible in the case of the previous investigations although perhaps unfair in view of the care with which they were performed) that the breakdown obtained might be due to small projections of metal completing the circuit between the plates. In this experiment, small projecting areas are assumed to exist to explain the shape of the curves obtained. The breakdown, however, is evident; the positive current observed depends upon ionization over very considerable areas of the target surface to which the charge must be supplied through the oil. By the same argument, the experiment would seem to indicate something as to the nature of the phenomenon, because an explanation of the above results seems to demand the assumption of conductivity in the film over considerable areas. Some theories[9] have treated the conductivity as quite local.

[7] L. Brüninghaus, Comptes Rendus, **188,** 1386–88 (1929).
[8] H. E. Watson and A. S. Menon, Roy. Soc. Proc. **123,** 185–202 (1929).
[9] A. Gyemant, Phys. Zeits. **30,** 33–58 (1929).

It is probable, however, that the general electronic bombardment of the oil surface causes the disturbance to become quite general over the film. If, for instance, the theory of Güntherschulze[10] is correct and the breakdown is due to the movement of the ions in the film producing strong local heating with evaporation and the formation of gas bubbles in which the discharge takes place, it may be that the heating or the ionization produced by the impact of an electron would make such a breakdown more probable. The impact of electrons of the primary beam does in fact influence the breakdown. If the energy of the electrons striking the surface is greater than 100 volts, the breakdown occurs at a lower potential than indicated in Fig. 4. If the incident electrons are slow, the breakdown occurs at a higher potential. Fig. 5 shows the results for a bombarding velocity corresponding to 70 volts difference between the target and source. The curve follows the axis for a greater range of cylinder potentials than the curve of Fig. 4. The effect is even more pronounced at lower bombarding potentials.

In the present experiment, discharge does not occur between two metallic electrodes. The conduction appears to be from the metal to the surface of the film from which the charge may be dislodged only by electronic impact. The present results suggest that the conduction is continuous and general for the bombarded parts of the film.

Conclusions

The experiments reported here lead to the conclusions:

1. Strong fields are set up in the neighborhood of a contaminated surface retarding the escape of reflected electrons.
2. In extreme cases of oil contamination the impurities form an insulating film which breaks down at some critical value of the applied field.
3. The breakdown potential of a given film varies with the energy of the incident electrons.
4. The conductivity observed in these films appears to be rather general and continuous.

The writer wishes to thank the members of the staff of the Department of Physics of the State University of Iowa for their interest and assistance. Thanks are especially due to Professor J. A. Eldridge who suggested and directed the investigation.

[10] A. Güntherschulze, Jahrbuch d. Radioakt. u. Elektr. **19**, 92 (1922).