1933

Recording of low voltage cathode rays on metal films

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UMI®
RECORDING OF LOW VOLTAGE CATHODE RAYS
ON METAL FILMS

BY

J. Bion Philipson

A Thesis Submitted to the Graduate Faculty
for the Degree of
DOCTOR OF PHILOSOPHY
Major Subject Applied Physics

Approved:

In charge of Major work

Head of Major Department

Dean of Graduate College

Iowa State College
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V. CONCLUSIONS

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INTRODUCTION

Introduction

The recording of low voltage cathode rays on photographic materials has been a subject of interest for several years and has been stimulated by the investigations concerning electron diffraction by crystal surfaces. The sensitivity of photographic materials to slow electrons has been studied by several investigators.

Review of Literature

Cole found that the sensitivity of photographic plates to electrons was roughly proportional to their light sensitivity but that there was a lower limit of velocity at which electrons would affect the plates. He showed that oiling the surface of the emulsions increased their electron sensitivity many fold and that the sensitivity was as before roughly proportional to the light sensitivity. Also there was, as before, a certain velocity of incident electrons below which no effect was produced. He raised the question as to whether the developable image was due to direct impact of the electrons with the sensitive photographic crystals or
to a secondary effect, possibly fluorescence of the gelatine or other materials in the emulsion.

Burroughs, following this question, concluded from his investigations that the developability of the emulsion after exposure to slow electrons was for the most part due to radiations excited in the residual gas on or in the emulsion itself, and to a negligible extent to direct impact of the electrons on the sensitive grains of the emulsion. He concluded that the lower limit of energy for an electron to produce an image was a function of the critical potential of this gas.

Carr, following Cole's work on photographic plates, verified the fact that oiling the surface of a plate increased its sensitivity to slow electrons and showed that only in a relatively poor vacuum (0.2 to 0.3 microns) were photographic plates sensitive to electrons with energies below 25 electron volts. He, however, developed a new method for recording electron beams on metal surfaces. He found that metal surfaces which had been exposed to electron beams reacted toward vapors in a different way than did the same surfaces without exposure. Gold, silver and zinc were used for recording slow electrons accelerated in fields of less than 100 volts. Similar records of high velocity cathode rays in air were secured on copper, brass, platinum and nickel.
The exposed regions on gold plates were made evident by development in mercury vapor which apparently condensed differentially on the exposed and unexposed portions. Silver films were developed in iodine vapor which again gave markedly different colors on the exposed and unexposed regions. For zinc, hydrogen chloride vapor was used and Carr reported that in every case excepting one the unexposed region was etched leaving the exposed region bright. He was able to secure records on silver films with electrons of energy as low as 12 electron volts.

Nicholas and Malmberg have found results similar to those of Carr for high voltage cathode rays, using fields of 10 kilovolts to accelerate the electrons. They investigated the possibilities of producing an image with cathode rays which would require no development and studied not only metal surfaces but surfaces composed of salts of several metals. Their results showed that these high velocity cathode rays increased the opacity of semi-transparent films of some metals and salts. The best results were obtained with films of lead, tin and bismuth nitrate.

Wilcox carefully studied the effects of several types of developers on the "electrographic" latent image produced by 100 kilovolt cathode rays in air.

Of the possibilities so far investigated for
recording beams of slow electrons, the method developed by Carr of recording on metal films and developing in a suitable reagent seems to hold the greatest promise. This method as he points out "has the advantage of reliability, freedom from charging up, and insensitivity to light. Moreover, the metal method can be used for lower speed electrons than can the photographic method."

The Problem

Since there has for some time been an urgent need for a reliable and convenient method for recording low voltage cathode rays and since the method developed by Carr seems to be admirably adapted to this purpose, this investigation has been carried out to determine the velocity of the slowest recordable electrons and to investigate the nature of the effect which makes this recording possible.
EXPERIMENTAL

Apparatus

The electron camera.

The exposures were made in an electron camera, similar to that used by Carr and by Burroughs, which consisted of a five-liter Pyrex balloon flask with two large ground joints diametrically opposite and a third smaller outlet which connected to the pumping system. Into one of the large openings was fitted a ground glass plug carrying the recording plate and its shield. This plate holder, shown in Figure IV(a), was fitted with a long brass strip on which the sensitive plate could be secured by small metal clips. These clips made electrical contact between the brass strip and the metal film deposited on the glass plate. A small lead-in wire sealed through the back of the glass plug and connected to the brass strip allowed a direct connection to the sensitive metal surface. Around this strip carrying the plate there was placed a large brass cylinder slotted along its length to allow entrance of the electron beam. This brass cylinder served as a shield to protect the
plate and carrier strip from being struck by stray electrons. This shield was connected by a small screw to another lead-in wire through the glass plug and could be held at the same potential as the anode so that the electric field about the plate would not disturb the electron stream. The shield was supported by two glass rods which insulated it from the plate carrier. This method of support made it possible to measure the current to the plate due to the electron bombardment without including stray radiation to the shield.

It was necessary to coat the inner surface of the large bulb with a conducting surface in order to prevent charges from accumulating on the glass walls. The coating of the inside of the bulb was accomplished by sputtering it with gold in the following manner. The shield of the plate holder was wrapped with several sheets of painters' gold leaf and the secondary of a 10,000 volt, 1/3 kilowatt transformer was connected to the anode and the shield. The tube was pumped out to the proper pressure and the gold sputtered on the inside of the bulb, giving an almost opaque coating. It was necessary to repeat this process several times during the course of the experiments because such a coat had a tendency to crack and pull apart with age. A soft flexible copper lead was suspended from the plate shield and made contact with the gold surface so that the walls of the tube
could be held at anode potential. This arrangement gave the electrons a field-free space in which to move after leaving the slit in the anode.

The vacuum system.

The pumping system consisted of a large two-stage mercury diffusion pump backed by a Genco Hyvac fore-pump. A large trap was placed between the pump and the tube and was cooled with liquid air or with solid carbon dioxide in acetone to prevent mercury from diffusing from the pumping system into the bulb. A small stopcock between the pump and the trap was used to admit air at the conclusion of an exposure. The cooled trap prevented any water vapor or grease vapor from the stopcock entering the bulb. With the exception of this one small stopcock there were no grease seals in the system. The pump was sealed to the bulb and the two plugs were sealed in with Picoil wax at the back of large ground joints. The very low vapor pressure of the wax combined with the very long narrow paths through which it had to diffuse, prevented any appreciable amount of vapor entering the tube. The outer surface of the bulb was gently heated with a torch to a temperature well above 200°C. during pumping to remove adsorbed gas. No gauge was placed in the system since the exact pressure had no special significance but the pressure
was probably of the order of $10^{-6}$ cm. of mercury.

The magnetic focusing coils.

The electron focusing was accomplished by means of a pair of Helmholtz coils placed on either side of the bulb in a plane parallel to the plane of motion of the electrons. These coils were similar to those used by Cole. The mean diameter of the windings which consisted of 150 turns of No. 18 double cotton covered copper wire was 60 cm. These two coils were connected in series through a variable resistor and ammeter to a 120-volt lead storage battery which gave a very constant current throughout even the longest exposures. The axis of these coils was parallel to the earth's magnetic field, the inclination of which was secured from government surveys.

When the current was properly adjusted in the Helmholtz coils the electrons from the cathode struck the plate and were at the same time focused to a rather narrow beam according to the focusing effect described by Robinson and Rawlinson, and modified by Cole for the case of a cathode of dimensions comparable to those of the anode.
The electron gun.

The electron gun was attached to the second large ground glass plug. The anode for the gun was a thin sheet nickel cylinder 15 mm. in diameter and 2 cm. long with a narrow slit running lengthwise. The dimensions of the slit were 0.25 mm. by 7 mm. approximately. The cylinder was mounted with its axis perpendicular to that of the plug with the slit in such a position that electrons ejected through it normal to the surface of the cylinder would leave the gun along a line perpendicular to the axis of the plug and to the axis of the anode cylinder. Inside the anode cylinder was placed a cylindrical grid of fine nickel wire. This grid was taken from a commercial vacuum tube and placed with its axis coinciding with that of the anode. The purpose of the grid was to diminish the space charge between the cathode and anode, thereby allowing a greater electron current from cathode to anode. The cathode was then placed along the axis of the anode and grid. The plug carrying the electron gun was of Pyrex sealed to a large press of 702 P glass through which passed four 50 mil tungsten leads. The elements of the electron gun were then spotwelded to the tungsten leads which provided their support and electrical connections.
The cathode.

Two types of cathode were used during the experiments. The first type consisted simply of a filament made of a narrow strip of platinum rolled to a thickness of 0.05 mm. about 2 mm. wide and 2 cm. long. This filament was heated by the passage of current and coated with a thin layer of strontium and barium oxides mixed to a paste in paraffin. Increased heating caused the evaporation of the paraffin leaving the platinum oxide coated. The oxide coating greatly increased the emission from such a cathode until it had been allowed to cool in air in which case it became very inactive. It was necessary, therefore, to hold these platinum cathodes at a dull red heat continually whenever the electron camera was dismantled to replace or remove an exposed plate.

The heating current for the platinum filaments was supplied by a storage battery and the potential drop along the filament usually was about ten volts. This meant that if the accelerating potential were applied between one end of the filament and the anode there would be a variation in velocities between the electrons from one end of the filament and from the other of about ten volts. To secure a "monochromatic" beam of electrons the method used by Cole\textsuperscript{1}, Carr\textsuperscript{3} and Burroughs\textsuperscript{2} was employed. A motor driven commutator was connected to
apply the heating current and the accelerating potential alternately. With this method the accelerating potential was applied only half the time. With proper adjustment of commutator speed and heating current to suit the resistance and heat capacity of the filament, a fair electron beam was secured for accelerating potentials above 20 volts. Below this potential the current carried by the electron beam fell off so rapidly that an exposure required excessively long time.

Diagram I shows the wiring diagram of the circuit when the filament cathode and commutator were used. The commutator C was driven by a small variable speed motor. The filament was heated by a battery B of Edison storage cells. The potentiometer P allowed the variation and adjustment of the grid potential and of the accelerating field between the cathode and plate. $V_p$ and $V_g$ were Weston D.C. voltmeters which measured these potentials. The Weston milliammeter M1 measured the current from the cathode to the plate and $\mu A$ was a General Radio calibrated galvanometer which measured the electron current to the sputtered film. A part of the electrons accelerated between the cathode and the plate escaped through the narrow slit in the plate and traveled, under the influence of the magnetic field, through the field free vacuum in the bulb to the recording film F.
potential of the cathode or electrode exposed to reduce activity.

A cathode formed from the same zinc ate to two hours with a
and nickel. Heating from this point is important in the cathode
between the surface at the highest temperature of the cathode
at any time. By using heating at the highest temperature,

as read, the activity could be reduced to practice. If the
place for some time and allow for the extraction of the
through the cathode were allowed to remain cold in the same
performance with this type of cathode it was found that, given
enough to become effective as low as its volume. After some-
cathode it was possible to become extraction and hence
keep needed even in the presence of air. When this type of
heater. The performance heater was used so the cathode could be
heed.

The performance heater was used for the small platform of the
plate which served as cathode and the small platform to
charge drawn from the heat stored by a plate in both
required. The work it necessary to place a plate of heat
dimensions which were small in comparison to the volume of
a cathode or a platform at a platform current. A cathode of
the first a cathode was used which consisted of an oxide coated
at first a cathode was used which consisted of an oxide coated
long periods of time between exposures present a problem.
and allow for the oxide coated cathode to the atmosphere even for
expose the oxide coated cathode to the atmosphere even for
or process used in vacuum tubes. The fact that it was necessary
low voltages a heater type of cathode was displaced similarly.

to secure reasonable烨re extraction currents et
With this fact in mind the platinum heater was replaced by one of 0.007 mil tungsten. Previously it had not been possible to use tungsten because when heated in the atmosphere it oxidized rapidly. The increased temperature possible with the tungsten heater made it possible to make exposures with electron energies as low as 6 electron volts. The increased emission possible with the tungsten heater cathode made it the most practical notwithstanding the time required to reactivate the cathode before each exposure.

Figure III shows the component parts of an electron gun using the tungsten heater cathode. Diagram II shows the wiring diagram used with the heater cathodes giving an equipotential emitting surface and hence a "monochromatic" electron beam. The A.C. filament transformer supplied the heating current for the small heater coil and the accelerating potential was applied between the heated cathode sleeve C and the plate.

In the very long exposures and high cathode temperature necessary at low electron velocities, the nickel cathode sleeve was completely evaporated before a record was secured and it was necessary in these exposures to replace it with a sleeve of platinum. Even the platinum sleeve was destroyed in the two twelve-hour exposures which gave records at 6 volts.
RESULTS

Bismuth

Development

Opaque films of bismuth were sputtered on strips of clean glass. These films had very bright metallic mirror surfaces when removed from the sputtering jar. A bismuth film was placed in the electron camera and exposed to cathode rays of 45 electron volts velocity for an exposure of approximately 12,000 microcoulombs per square centimeter. Attempts at development of the image were tried with vapors of iodine, chlorine, hydrogen chloride and sulfur but none of these vapors gave any indication of bringing out the image except iodine, which gave a very poor image after long treatment. However a similarly exposed plate when left exposed to the atmosphere in the laboratory for twelve hours became darkened except where the electron beam had struck. This portion remained bright and after several days the darkened portion of the plate could be brushed off, leaving only the bright exposed portion. This method of development was used on all bismuth plates.
Using 30 equivalent volt velocities, exposures were made at approximately 6000, 9000 and 12,000 microcoulombs per square centimeter. The first two plates failed to show any record but the third showed a definite record of the electron impact.

Minimum velocity.

Exposures to electrons of 25 equivalent volts velocity were repeated many times with exposures running as high as 50,000 microcoulombs per square centimeter but no record was detected after development. The exposures were calculated on the basis of the area of the record secured at 30 volts. Experience with records at these velocities on silver had shown that there was very little difference in focusing between 25 and 30 volts and therefore the area struck by the electrons at 25 equivalent volts velocity was practically the same as that for 30 volts. It was concluded from these experiments that the lower limit of velocity for electrons to be recorded on bismuth by this method was between 25 and 30 equivalent volts.
Silver

Development.

The first investigations on silver were performed to determine the low velocity limit at which electrons could be recorded. For this purpose silver films sputtered on strips of clean glass were used. In earlier experiments the silver had been sputtered on thin sheets of mica but glass strips were found to be more convenient and to give smoother, more uniformly sputtered films. The thickness of the films was not measured but they were thick enough to be practically opaque.

For development a wide mouth bottle containing a few crystals of iodine was used. The plates were placed in the bottle and allowed to react with the iodine vapor until the record had been developed.

Minimum velocity.

Carry reports recording electrons as slow as 12 equivalent volts on silver films. A series of exposures was made, beginning with velocities of 45 equivalent volts to determine the approximate exposures necessary. The results of these experiments are shown in tabular form.
## Table I.

<table>
<thead>
<tr>
<th>volts</th>
<th>current to plate microamperes</th>
<th>time</th>
<th>exposure per sq.cm.</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>1.92</td>
<td>30 seconds</td>
<td>1152</td>
</tr>
<tr>
<td>30</td>
<td>0.30</td>
<td>2 minutes</td>
<td>3200</td>
</tr>
<tr>
<td>20</td>
<td>0.96</td>
<td>30 minutes</td>
<td>19600</td>
</tr>
<tr>
<td>12</td>
<td>0.32</td>
<td>3 hours</td>
<td>23300</td>
</tr>
<tr>
<td>6</td>
<td>&lt; 0.10</td>
<td>12 hours</td>
<td>&lt; 50000</td>
</tr>
</tbody>
</table>

Exposures were calculated on the basis of the area of the record after development. Although no attempt was made to determine the minimum exposure necessary for a record this table gives approximately the minimum exposures which will give a record, especially at the lower voltages. Many difficulties were encountered in securing sufficiently large exposures at low voltages and after each exposure which resulted in no record, the time of exposure was increased until finally a record was secured. The use of the tungsten heater cathode described above made it possible to secure electron currents to the plate at the low voltages although at 6 volts the current was less than 0.1 microampere. A second difficulty arising when lower voltages were used was the fact that the slower the electrons the less sharply they were focused.

The accelerating potentials given in Table I are
those measured by \( V_p \), Diagram I. The field between the cathode and anode in the electron gun was slightly different from this applied potential, being the sum of the applied potential and the contact difference of potential between the material of the cathode and that of the anode. The values for the work functions are given in the International Critical Tables. The value for nickel, of which the anode was constructed, is given as 2.77 volts and for a mixture of barium and strontium oxides, with which the cathode was coated, as 1.51 to 1.89 volts. The contact difference in potential, therefore, was very nearly 1 volt. The actual velocities of the electrons were due to accelerating potentials very nearly 1 volt higher than those shown in Table I.

Figure I shows a typical record of 7 volt electrons. It will be noticed that instead of the narrow beam as in Figure II(b), we have a wide band. This of course meant that for the same electron current to the film, the exposure per square centimeter was greatly reduced.

Although the slowest electrons recorded were of 7 equivalent volts velocity, there is no indication that this is the lower limit at which recording would take place. With this type of apparatus, however, it was impractical to attempt recording at lower voltages.
Nature of the record.

Exposed films of bismuth were allowed to develop, as described above, in the atmosphere. The unexposed portion of the plate always reacted with some component of the air, probably sulfur, to give a dark brown compound. After several days the metallic bismuth was often completely consumed and the dark compound could be easily rubbed off the glass surface leaving it clear. The exposed portion, on the other hand, always remained bright and apparently did not react at all. Such exposed bismuth plates were allowed to remain in the laboratory for several weeks and the surface of the untarnished electron record never showed any indication even of becoming dulled. During this time other bismuth films were being developed as before and always the unexposed region was darkened, leaving the exposed portion bright.

Exposed bismuth films were carefully examined immediately after removal from the camera and it was never possible to detect any difference between the exposed and the unexposed parts before the development.

Silver films exposed to cathode rays and developed slowly in iodine vapor show the reaction mentioned by Carr. The iodine reacts with the silver to give the plate a wide and beautiful variation of color in which the exposed region
may easily be seen. It is difficult at the beginning of
development to determine whether this bright coloring is due
to a condensed layer of iodine vapor or to a thin layer of
silver iodide. Quite probably it is a combination of the
two, since these partially developed plates lose much of their
brilliance when left standing for as long as twelve hours.
In the earlier experiments some of these exposed silver films
were allowed to remain in the developing bottle which con-
tained a few iodine crystals at room temperature longer than
was necessary to bring out the bright colors and the appear-
ance of the exposed region. Under these conditions the un-
exposed silver reacted with the iodine to form a transparent
film of yellow silver iodide. On some plates the record
reacted as did the silver of the background and either could
not be distinguished at all or could be seen as a slightly
different aggregation of the minute silver iodide crystals.
On other plates, however, the background changed as before
to yellow silver iodide while the exposed portion of the plate
remained as bright and apparently unaffected silver. Continued
exposure of these plates to the iodine vapors failed to alter
the appearance of the record in most cases. A few of these,
after a long time, were attacked by the iodine vapor and
either were completely converted to silver iodide or became
darker.
A survey of the exposures of these plates showed that the ones with higher quantity exposure were the ones on which the exposed silver remained after the unexposed part had been changed to iodide. Further experiments verified this fact and it was found that with sufficient exposure every plate could be developed to the point where only the bright silver record remained. Development under these conditions consisted in placing the exposed plate in the developing bottle and allowing it to remain until the unexposed background had been completely converted to silver iodide.

All further exposures on silver were made to secure this type of record. The exposures shown in Table I are those which gave such records although in some cases, possibly in all, it is possible to get the less definite colored record mentioned above with somewhat smaller exposures.

Iodine dissolved in alcohol was tried as a developer for the records on silver. About a gram of iodine crystals was dissolved in approximately 50 cc. of alcohol and an exposed plate submerged in the solution. The reaction was very similar to that of the iodine vapor. The exposed region remained unchanged while the unexposed part was rapidly converted to silver iodide. Gentle shaking of the solution removed the silver iodide from the glass, leaving the sharp silver record. When the plate had remained in the
solution for about 20 minutes the silver record itself was slowly dissolved off but the action could be stopped at any stage by removing the plate and washing it in water. There seemed to be no particular advantage in the use of the liquid developer instead of the vapor.

The glass plates on which records had been made, developed and studied were often cleaned and used again as the base for the sputtered film. These plates were washed in dilute nitric acid, then in hot water and soap and finally washed in alcohol until to the eye the glass was perfectly clean. During the washing of one of these plates in the very hot water it was noticed that there was a spot on the plate on which water vapor seemed to condense more readily than on the remainder of the plate. This spot had the size, shape and approximate position of the electron record which had previously been made on the plate.

Another plate on which a record had been made and developed was given the cleaning treatment described. This time the position and shape of the record as it appeared before cleaning the glass was kept in mind. After the plate had been thoroughly washed it was examined very carefully to see if any evidence of the previous record was visible. Apparently the surface of the glass was perfectly clean but blowing the breath across the surface made the record perfectly clear.
As the moisture evaporated from the surface, that on the spot which had been the electron record was the last to disappear. This process could be repeated any number of times and always the record became visible when the plate was covered with the film of condensed moisture.

The plate was carefully washed in carbon disulfide and in carbon tetrachloride to free the surface of any grease which might be present. Neither of these solvents had any apparent effect and the record could, as before, be made visible by condensing moisture on the surface.

When the surface of this plate was dusted with lycopodium powder the record became evident. After the plate had been gently tapped to remove any excess powder, the surface was examined. It seemed that the density of the remaining powder was a little greater on the exposed portion of the plate. Probably the differential condensation of moisture on the surface of the plate left a film of water which was a little more dense on the exposed region. The fine powder adhered more heavily on the portions where the moisture was most dense, thus making the record evident.

A strong cleaning solution of potassium dichromate and sulfuric acid was prepared and the plate washed in this solution. After a thorough washing of perhaps half a minute and subsequent rinsing in water, the record still could be
brought out by condensation of water vapor. However when the plate had been allowed to stand in a beaker of the warmed cleaning solution several minutes, the property disappeared. Another exposed and developed plate was washed in dilute nitric acid and hot soapy water. This plate as before was washed in a solution of potassium cyanide and immediately lost the ability to be redeveloped.

Metallic silver is soluble in dilute nitric acid and insoluble in potassium cyanide. Silver iodide is insoluble in dilute nitric acid but soluble in potassium cyanide. Development of the exposed plates converted the unexposed silver to silver iodide but left the exposed silver in the metallic form. Washing in dilute nitric acid removed the metallic silver but there remained a thin invisible film of silver iodide where the iodine had reacted with the silver. This film of silver iodide adhered so strongly to the glass that it resisted the washing with soap. Where the surface of the glass had been protected by the metallic silver through the iodine treatment the nitric acid and washing removed all the film so the surface partially cleaned and partially covered with the silver iodide gave the differential condensation of moisture. Subsequent washing in the potassium cyanide dissolved off the silver iodide film leaving the surface uniformly clean, and the possibility of bringing out the record by condensation of moisture disappeared.
Several exposed and developed records including one of silver and one of bismuth both of which had been exposed and developed somewhat more than three months previously were cleaned with dilute nitric acid and washed in hot water and soap until they were apparently clean. On every one of these glass plates the original record could be formed by condensing moisture from the grease on the glass surface. It was very interesting to note that on one plate two electron records were shown by the condensed vapor. Evidently, since occasionally a glass strip was cleaned and used a second time, this glass plate had been sputtered, exposed, developed and cleaned, then the process repeated a second time. The record from the first exposure had remained on the plate and had withstood the cleaning, sputtering, developing and second cleaning to make itself apparent along with the second record.

Sensitivity to light.

A sputtered silver film was exposed through a stencil to the radiation from a 500-watt Cooper Hewitt quartz mercury vapor lamp for fifteen minutes at a distance of about 45 cm. When this plate was treated with iodine vapor in the developing bottle the exposed region did not react with the iodine but remained as bright metallic silver to give a record like that produced by the cathode ray exposure.
SUMMARY

The development of a reliable and convenient method of recording slow electrons in vacuum has been the object of several recent investigations. Recording on photographic plates is reasonably satisfactory for electrons of velocities above 50 equivalent volts and is possible for electrons as slow as 25 equivalent volts. Carr has developed a method of recording electrons on the surface of metals which is adaptable for the recording of both high and low velocity cathode rays. This investigation has been concerned first with an extension of Carr's work to determine the lower limit of velocity at which cathode rays can be recorded by his method.

A study of films of bismuth sputtered on glass showed that it was possible to record cathode ray beams on such surfaces but led to the conclusion that they were incapable of recording electrons with velocities slower than 25 equivalent volts.

Carr's investigations showed that of the metals he studied, silver was the most sensitive to very slow electrons. A series of exposures was made to determine the lowest velocity
at which electrons could be recorded on silver. Films of silver sputtered on glass were used for the recording surfaces. It was found that the sensitivity of the silver decreased with the decreasing of the electron velocity. By lowering the velocity of the electron beam and at the same time increasing the exposure it was found possible to record electrons with velocities equivalent to acceleration through a field of 7 volts. Experimental limitations made it impossible to continue the increase in exposure which was necessary with a further lowering of the accelerating potential. The consistency with which records were secured down to this velocity indicates that this is not a lower limit for recordability.

Development on both bismuth and silver films depended on the fact that the developing agent which did not react with the exposed portion of the surface reacted with the remainder of the surface leaving the metallic record on a background of the compound formed of the developer and the unexposed metal. The effect of the electron bombardment is to render the metal less active chemically. Silver, which normally reacted rapidly with iodine vapor, after exposure to electrons, could remain in contact with the vapor indefinitely and remain as bright metallic silver.

When iodine dissolved in ethyl alcohol is used as
developer, the unexposed silver reacts rapidly with the
iodine leaving uncombined silver in the exposed region. In
long treatment with the iodine alcohol solution, however, the
uncombined silver of the record slowly reacts with the iodine.
The rate at which the exposed silver reacts with the iodine
under these conditions is much slower than that of the unex-
posed silver. The unexposed silver is converted to iodide
in less than one minute while the exposed silver film of the
same thickness requires from twenty to thirty minutes to
completely react.

The silver record which remains after the unexposed
silver has been converted to silver iodide may be dissolved
off in dilute nitric acid. A thin film of silver iodide is
left on the glass surface when the unexposed silver has been
changed to silver iodide, and subsequent washing in nitric
acid dissolves away the silver record leaving the silver iodide
film in place of the unexposed silver. This makes the affinity
of the surface of the glass plate for water vapor differ be-
tween the region of exposure and the remainder of the plate.
On this basis it is possible to make the original record
reappear by condensing moisture on the surface of a previously
exposed and developed plate which has been washed in dilute
nitric acid, even though the plate is apparently clean before
the condensation of the vapor.
LITERATURE CITED


6. U. S. Coast and Geodetic Survey. Magnetic Table and Charts. Special Publication No. 44, p. 120. 1915.

ACKNOWLEDGMENTS

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Fig. I. Seven volt record on silver.

Fig. II. Twelve volt record on silver. (above)
Thirty volt record on silver. (below)
Fig. III. Elements of electron gun (heater cathode).

Fig. IV. (a) Plate holder.
(b) Shield.
(c) Electron gun.
Fig. V. View of electron camera, upper Helmholtz coil removed to show assembly.

Fig. VI. The electron camera and pumping system with Helmholtz coils in place.