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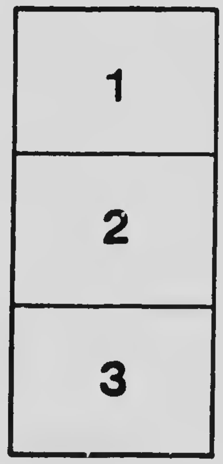
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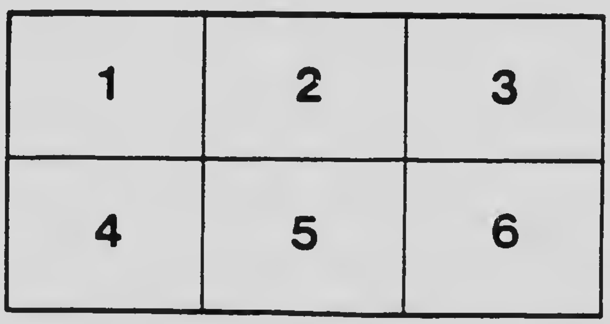
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UNIVERSITY OF TORONTO STUDIES

PAPERS FROM THE PHYSICAL LABORATORIES

No. 76: ON THE ELECTRICAL CONDUCTIVITY OF COPPER FUSED WITH MICA, BY A. L. WILLIAMS

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From the PHILOSOPHICAL MAGAZINE, vol. xl. September 1920.

On the Electrical Conductivity of Copper fused with Mica. By Sub-Lieut. A. L. WILLIAMS, R.N., *with Introduction by* Prof. J. C. McLENNAN, *F.R.S.**

[Plates V.–VII.]

INTRODUCTION.

WHILE acting as Scientific Adviser to the Admiralty, I had my attention drawn by Sub-Lieut. A. L. Williams, R.N., to some experiments made by him in the early part of 1919 at Cambridge, in which he found that samples of copper when fused with mica exhibited a remarkably large fall in resistance when gradually subjected to rising temperatures.

During a short furlough he was given an opportunity at the Admiralty Physical Laboratory, South Kensington, to develop this discovery and, on going back to duty, he left with me some notes embodying the results of his work. I have not had an opportunity of communicating with him again, but as the results are interesting it is thought they should be duly recorded. His experiments are described below, and accompanying them are some additional notes of results obtained at the University of Toronto by Miss Isabel Mackey and Miss I. Giles, who have followed up the subject still further. J. C. McL.

A.

EXPERIMENTS BY SUB-LIEUT. A. L. WILLIAMS, R.N.

I. *Preparation.*

The samples for test were all prepared in the open on a piece of iron or copper plate—used as an anode—and a carbon rod as the cathode, the arc being struck at first between the plate and carbon, and then, when hot, to the mixture. The mica was first melted, then the copper added. In making up the samples studied, about equal proportions of copper and mica were used.

II. *Effect of Temperature.*

Resistance temperature measurements for two samples were made for a range of temperatures from 27° to 850° C. For sample A, the curves of which are attached, Graphs 1 and 2 (Pl. V.), the resistance fell from 16,000 ohms at 27° C., to 0·5 ohm at 850° C.

* Communicated by Prof. J. C. McLennan.

ZUMSTEIN 0.25

III. *Notes.*

(1) It was noted that the material was malleabl
2000 C.

(2) A specimen piece was rolled at this temper
a small rod 2·5 mm. in diameter for the purpose
taining the specific resistance of the mixture.
found to be as follows:—

25° C., Specific Resistance, 10,400 ohms
30° C., " " 8,000 ohms

(3) An attempt was made to obtain a sample of
ture in the form of a very thin film for delicate te
measurements, etc., and it was found possible to
out to about 1/1000 of an inch between platinum foi
not possible, however, to separate the film from the
two pieces of foil cemented together by this fine
found to be extremely sensitive to heat. The
responded to the action of infra-red rays from an
one yard away, notwithstanding the comparativ
volume of platinum to be heated first.

It is thought that with suitable films of the co
mixtures enclosed in hydrogen it may be possib
them for signalling purposes. It is also suggested
films may be used instead of wires in microphones f
ranging, as the changes of resistance, due to c
temperature, are quite considerable, being some tho
ohms per degree centigrade with some samples.

(4) Attempts were made to make thin sheets b
the copper-mica material, finely powdered, with fi
in the form of cane-sugar, and driving off the
heating. The resistance of the resulting mat
extremely high, but very regular thin sheets
obtained in this way. It is possible, when the c
this mixture is increased by compression in an
press, that it may be obtained in sheets, rods, or ot
having a moderate resistance and yet possessin
resistance-temperature coefficient.

5. Attempts to cast the material in various form
successful, partly owing to the difficulty in workin
requisite high temperatures. The material, when
absorbed by such porous substances as porcelai
glazed porcelain is used the glazing melts and mixe
material. It is possible that castings could be ob
using fused quartz as a moulding material.

6. Attempts were made to make up similar compounds with the following metals and mica:—

Tin. The metal vaporized at too low a temperature.
Silver. Did not combine.
Platinum. Did not combine.
Iron. Combined, but no resistance temperature measurements were made.

B.

EXPERIMENTS BY MISS MACKAY

I. *Experimental Arrangements.*

(a) The samples to be tested were all made in the open on a piece of iron plate used as an anode and a carbon rod as a cathode. The current was controlled by a large rheostat giving up to 30 amperes on the 110 D.C. circuit. An arc was struck between the plate and carbon and, when hot, the mica was melted and the other material added.

(b) A quartz tube closed at one end and covered with nichrome wire was used as a receptacle in which to melt the material and form it into a regular cylindrical shape for experimental work.

(c) A small electrical furnace was used to heat the material. It consisted of a circular porcelain foundation covered with wire and all was covered with asbestos except the two binding posts.

II. *Results.*

(a) *Mica and Copper.*—Mica and copper were fused on the iron plate into small lumps, and some of these were then finely ground into powder. No traces of mica or copper could be detected, only a uniform dull black powder. The powder was put into a quartz tube and heated, but this did not prove a satisfactory method of obtaining the mixture in the form of solid rods, as part of the mixture fused to the quartz, and it was found impossible to separate the two substances. When the quartz was broken, the copper-mica was found to be very brittle and not at all suitable for resistance measurements. Platinum wires were then fused into the ends of the copper-mica lumps which had not been powdered, and the variations in the resistances of these lumps were observed when they were raised to various temperatures.

Two different samples of copper and mica were
the furnace for variation in resistance with temperat
only up to about 400° C.). In Case No. 1 (Grap
the resistance was found to vary from 1400 ohms to 3
while the temperature varied from 25 C. to 400
specific gravity of the specimen was found to be 5·
copper is given by 8·9, it will be seen that the
contained considerable mica.

Graph No. 3.

Temperature, C.	Resistance (Ohms).	Temperature, ° C.	Resis (Oh
22	4,400	148	1,2
46	3,600	154	1 1
54	3,200	164	1,1
58·5	2,940	206	7
61	2,900	250	6
65·5	2,800	275	4
70	2,460	315	4
72	2,400	344	3
93	1,950	364	2
127	1,570		

In Case No. 2 (Graph No. 4) the variation in r
was from 95,000 ohms to 3000 ohms, while the ten
changed from 100 C. to 400 C. The specific gra
found to be 4·3.

Graph No. 4.

Temperature, ° C.	Resistance (Ohms).	Temperature, C.	Resist (Ohm
139	45,550	228	11,3
178	23,330	211	13,5
236	11,615	208	14,5
262	9,120	200	16,7
311	6,000	192	19,0
345	4,590	172	23,4
361	3,790	165	26,2
378	3,605	155	29,6
395	3,280	147	34,0
333	4,200	139	40,5
323	4,740	130	44,3
313	5,490	122	51,3
290	6,530	118	57,1
278	7,036	113	64,0
267	7,790	108	74,0
256	8,610	103	81,7
245	9,110	99	91,0
232	10,790		

From these results it would appear that an increa
mica-content of the mixture raises the resistance at

temperature and causes the fall in resistance with temperature to be much more rapid.

While more brittle than copper, the copper-mica is not as brittle as iron-mica compounds described below. The hardness is almost the same as that of glass. X-ray photographs showed the composition to be quite homogeneous. The mixture was black with a dull metallic lustre.

(b) *Iron and Mica.*—Two mixtures were made as in the case of the copper and mica, and the temperatures and resistances were measured as before. In Case No. 1 (Graph No. 5) the resistance fell from 1300 ohms to 100 ohms on being heated from 25° C. to nearly 300° C.

GRAPH No. 5.

Temperature, °C.	Resistance (Ohms).	Temperature, °C.	Resistance (Ohms).
26	1,350	303	91
42	980	308	90
47·5	890	165	235
52·5	825	138	310
54	790	116	380
101	410	97	490
131	350	75	650
138	340	83	590
178	219	64	765
195	180	55	860
209	160	51	905
218	150	45	1,010
165	280	40	1,070
214	170	38	1,110
263	115	33·5	1,203
282	103	31	1,240
294	95		

In Case No. 2 (Graph No. 6) the resistance fell from 32,000 ohms on being heated from 160° C. to 380° C.

GRAPH No. 6.

Temperature, °C.	Resistance (Ohms).	Temperature, °C.	Resistance (Ohms).
250	6,100	294	3,380
228	9,050	282	3,900
280	3,870	255	5,970
318	2,410	242	7,350
335	1,980	231	8,440
344	1,780	222	10,380
360	1,550	214	11,720
377	1,280	204	15,750
360	1,550	197	15,900
336	1,980	187	19,550
322	2,360	175	25,210
309	2,750	164	32,100

The hardness was above that of glass, and the mat much more brittle than copper-mica and had more lustre. X-ray examinations showed the mixtur homogeneous. The specific gravity in Case No. 1 and in Case No. 2 was 4. The specimens studied w irregular in shape, but from a rough examination of of the samples, it appeared that the sample which higher mica-content was the one which had th specific resistance.

(c) *Aluminium and Mica.*—No fusion was between aluminium and mica. The two seemed t entirely separate.

(d) *Antimony and Mica.*—The antimony when hea off dense clouds of vapour, leaving nothing to f the mica.

(e) *Bismuth and Mica.*—The same results were as with antimony.

(f) *Cobalt and Mica.*—Cobalt and mica were fus iron plate in the same manner as the copper and mi cobalt-mica had a very dull black colour and brittle, but hard enough to scratch glass. Platin were fused in the ends with difficulty, and the resi ordinary temperatures was very great. When he hot with a bunsen flame, a current of about ·02 was obtained, using the 110 circuit.

(g) *Nickel and Mica.*—When nickel and mica w the substance produced was very similar to col When it was heated red hot, a current of about ·00 was obtained, using the 110 circuit.

(h) *Manganese and Mica.*—Mica and manganes seem to mix at all. In one test, the manganese w to form a complete shell around the mica, and in ot an X-ray photograph showed the two to be quite se

(i) *Silicon and Copper.*—It did not seem at al indeed possible, to fuse copper and silicon. The stances appeared to be quite separate after fusion.

(j) *Selenium and Copper.*—These fused quite re formed a dull black substance with very little or The resistance was found at various temperatur graph, No. 8, drawn. The specific gravity was 6·(hardness less than that of glass. With this mixt be seen that a discontinuity occurred in the resista perature measurements at about 150 C. The expla this result does not appear evident at present.

GRAPH NO. 8.

Temperature °C.	Resistance (Ohms).	Temperature, °C.	Resistance (Ohms).
370	·219	124	·261
335	·207	115	·200
315	·200	108	·176
298	·188	104	·172
260	·173	101	·169
247	·161	98	·169
240	·164	95	·168
230	·162	92	·163
221	·157	90	·164
204	·152	87	·161
190	·147	84	·163
180	·139	80	·165
173	·136	78	·167
167	·136	65	·176
160	·135	61	·176
154	·130	59	·177
136	·333	58	·176
130	·317	44	·185
127	·300		

(k) *Ferro-Silicon.*—A sample of commercial ferro-silicon was also investigated. It was found to be very brittle and difficult to grind up into regular form for examination. In studying a sample, leading wires of iron were used, as platinum fused readily at the junction when the ferro-silicon was raised to a high temperature. When a graph was drawn between temperatures as abscissæ and resistance as ordinates, the result was a straight line showing that the resistance varied directly as the temperature, just as in the case of ordinary pure metals. (See Graph No. 7.)

GRAPH NO. 7.

Temperature, °C.	Resistance (Ohms relative).	Temperature, °C.	Resistance (Ohms relative).
280	·092	148	·078
259	·089	139	·077
246	·088	126	·076
226	·085	118	·075
214	·084	109	·074
202	·083	96	·073
185	·082	84	·071
176	·081	79	·070
165	·079	71	·070

C.

EXPERIMENTS BY MISS GILES.

In these experiments a micrographic study was made of the plane polished surfaces of the fused copper-mica mixtures referred to above. These were made both when the mixtures

were at room temperatures and when their temper
gradually raised by means of an electric furnace.
in view was to see whether the fused mixtures pos
crystalline structure, and if they did whether the
conductivity observed with them on raising their
ture could be connected in any way with observab
cations in their crystal structure.

I. *Preparation of Specimens.*

In preparing these specimens they were first
off to an approximately flat surface. The surfaces
ground on a carborundum wheel, and after that
successive grades of aloxite of increasing fine
grades used were those commercially known as No
220, and 3F respectively. The polishing was th
with optical alundum and finished with jewelle
The two coarsest grades of aloxite were used on a
plate, while the finer grades and the optical alu
used on fine even linen fabric stretched over a sm
plate. The rouge was used on a piece of soft, smo
cloth stretched over a glass plate. The plates
fastened on a horizontal revolving table rotated
electric motor. In some cases the surfaces were e
nitric acid of various concentrations ranging from
of 10 per cent. to 25 per cent. and even to 50
Better results, however, were obtained by the use o
in solution, with a specific gravity of about 0·93.
solution the specimens were found to be unifor
by an attack of about one hour.

II. *Optical Equipment.*

The microscope used was one of the instrument
designed by Bausch and Lomb for micrographic
normal illumination the type of illuminator us
usual reflecting disk of thin cover glass. In t
the light was projected at right angles to the op
the microscope, reflected from the cover glass
optical axis of the system to the specimen, and
through the microscope. For visual examination
of light was a frosted electric light bulb, while fo
graphic work a small carbon arc was used. The p
plates used were rapid panchromatic, and the sh
lengths in the illuminating beam were cut out wit
and Wainwright filter. Oblique, in place of norm
tion, was used in some cases.

III. *Results.*

When examined under the microscope different specimens were found to exhibit different appearances. Most samples appeared to be quite uniform in structure, while in some many little globules could be seen, which from their lustre appeared to be pure copper.

Specimens which possessed a high temperature coefficient were found both under high and low power magnification to show no change in structure, either by normal or oblique illumination, when heated to temperatures as high as 400° C.

Pl. VII. fig. 1 shows the appearance of a specimen at room temperatures with a magnification of 46. The resistance of this sample, which was 3200 ohms at 21° C., fell to 1600 when at 95 C. The structure of the specimen appeared very uniform, and no copper could be discerned in it judging by metallic lustre.

Pl. VII. fig. 2 shows the appearance of this specimen when etched with ammonia solution for an hour. As pure copper was found to require approximately about seven hours' exposure to ammonia to bring out its crystalline structure, the markings on the plate may be taken to indicate the boundaries between copper and mica or the constituents of the latter. The regularity of the markings would indicate that the copper and mica fused into an intimate and homogeneous mass.

A specimen, whose resistance at 100° C. was found to be 95,000 ohms and only 3000 ohms at 400° C., was polished and examined previous to etching it with ammonia, both with high-power and low-power magnification, and with oblique and direct illumination.

Pl. VII. fig. 3 shows its appearance when illuminated obliquely under a magnification of 46.

Pl. VII. figs. 4 & 5 show the same region when illuminated by normally reflected light under magnifications 46 and 205 respectively. The structure in this case, as will be seen, is quite different from that shown in Pl. VII. fig. 1.

With the sample illustrated by figs. 3, 4, and 5 there appeared to be a great many streaks of light and dark, bounded by straight lines running in all directions, while in other specimens there appeared to be nothing uniform in the shapes of the patches. The portions of the surface which are dark in Pl. VII. fig. 3 it will be seen are light in Pl. VII. fig. 4. In this specimen much detail was brought out with the low-power objective. It was therefore used among others with low magnification to study the effect of any increase in temperatures. A water-cell provided with

running water was placed between the specime
microscope objective, in order to cut off the he
objective, and the specimen was heated up to 40
change could be discerned in the appearance of th

Pl. VII. fig. 6 shows the appearance of a por
surface at a temperature of 350° C.

The specimen was then etched with the ammon
Here, again, the surface was found to be marked b
after an attack of about an hour, but no coppe
detected. It was heated again to 400° C. after e
no change in structure could be observed due to
temperature.

IV. *Resistance-temperature coefficient of Glass.*

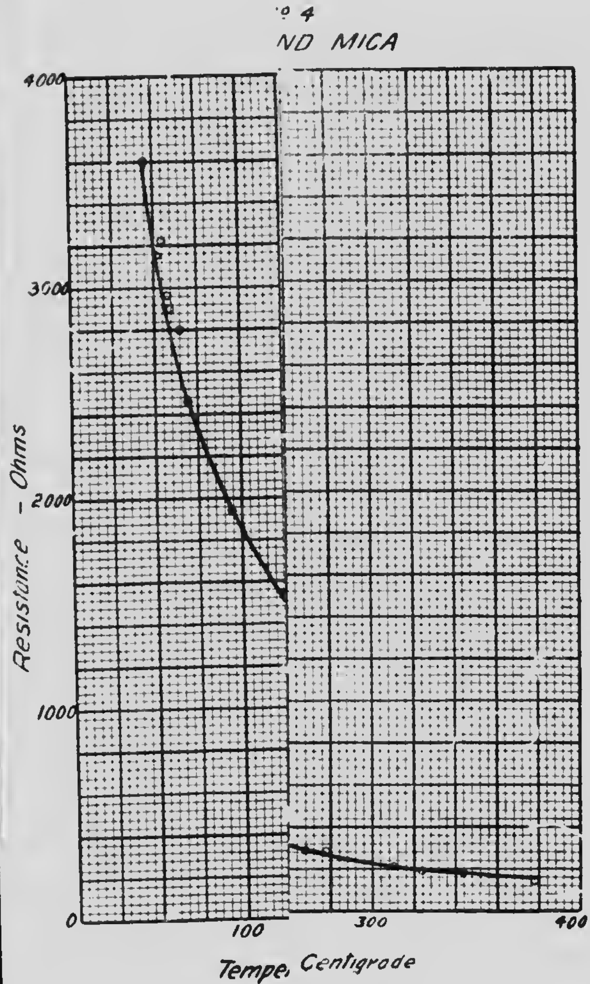
In studying these specimens one gained the
that they possessed a number of the characterist
In most cases the specimens were very hard, an
easily produce scratches on a glass plate with ma
It is known, too, that many glasses when stro
become electrically conducting, and with a view
comparison between the behaviour of these spe
that of a sample of glass, some measurements w
the resistance of a rod of glass when its temp
gradually raised.

In these experiments a rod of "Schmeltzg
8·0 cm. long and 5·0 mm. in diameter was u
platinum wires were attached. These were th
circuit with the mains of the 110 volt D.C. circ
glass portion was placed within an electric furna
temperature rose observations were made on
which passed and on the fall of potential betw
of the glass rod, contact being made with the e
platinum junctions.

In these observations practically no current
pass through the glass until a temperature of abou
reached. Even then the current was only of
10^{-7} ampere, which showed that the resistance of
at this temperature was very high, practically ab

From this result it would appear that the hi
temperature coefficient possessed by the fused
mixtures is something specific, and it does not ap
remarkable property they exhibit finds a direc
the behaviour of glass.

The Physical Laboratory,
University of Toronto,
May 15th, 1920.



fused with Mica.

e specimen and the
off the heat from the
l up to 400 C. No
rance the etching.
of a portion of the

he ammonia solution.
e marked by fine lines
t no copper could be
C. after etching, but
ed due to the in

f Glass.

gained the impression
haracteristics of glass.
hard, and one could
to with many of them.
when strongly heated
th a view of making a
these specimens and
rements were made on
n its temperature was

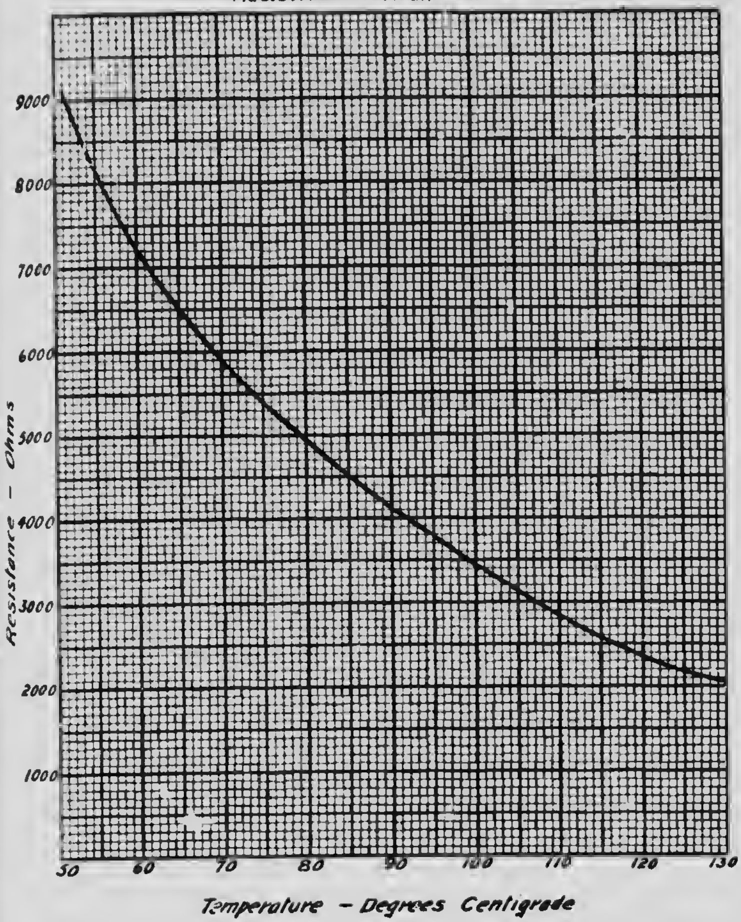
Schmeltzglas " about
ter was used. Short
e were then joined in
D.C. circuit, and the
ctric furnace. As the
made on the current
ntial between the ends
with the circuit at the

current was found to
ure of about 300 C. was
only of the order of
esistance of the glass rod
actically about 10^9 ohms.
hat the high resistance
the fused copper-mica
does not appear that the
nds a direct parallel in

Graph No 1

COPPER - MICA

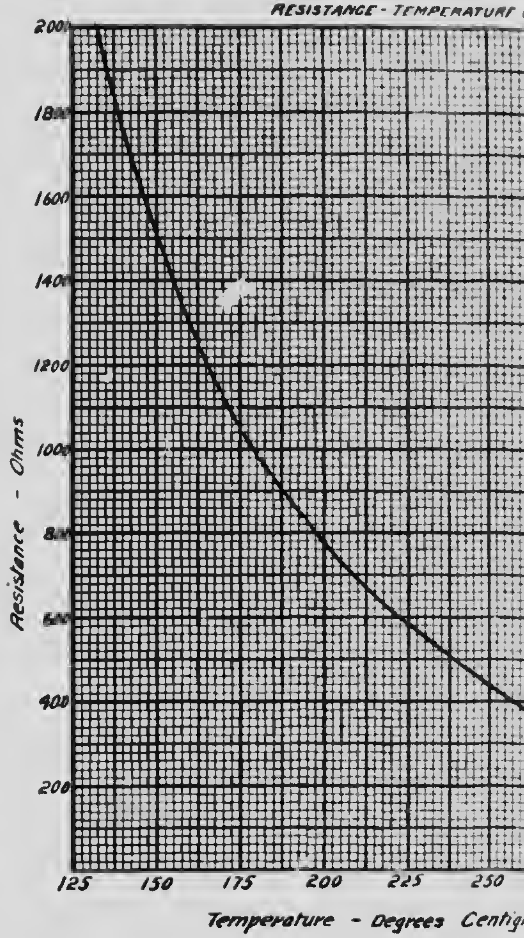
RESISTANCE-TEMPERATURE CURVE



Graph No 2

COPPER - MICA

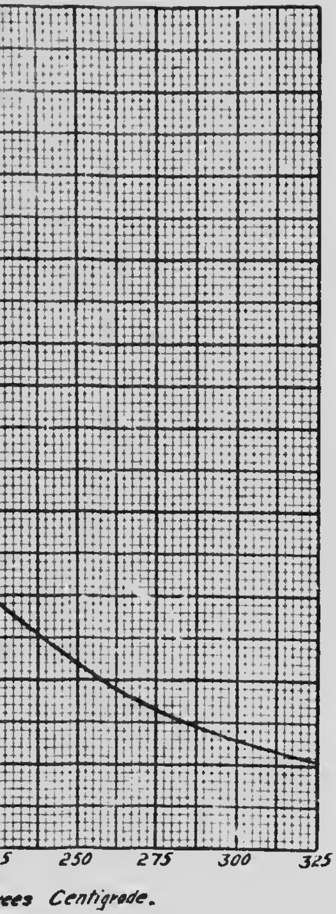
RESISTANCE - TEMPERATURE



N° 2

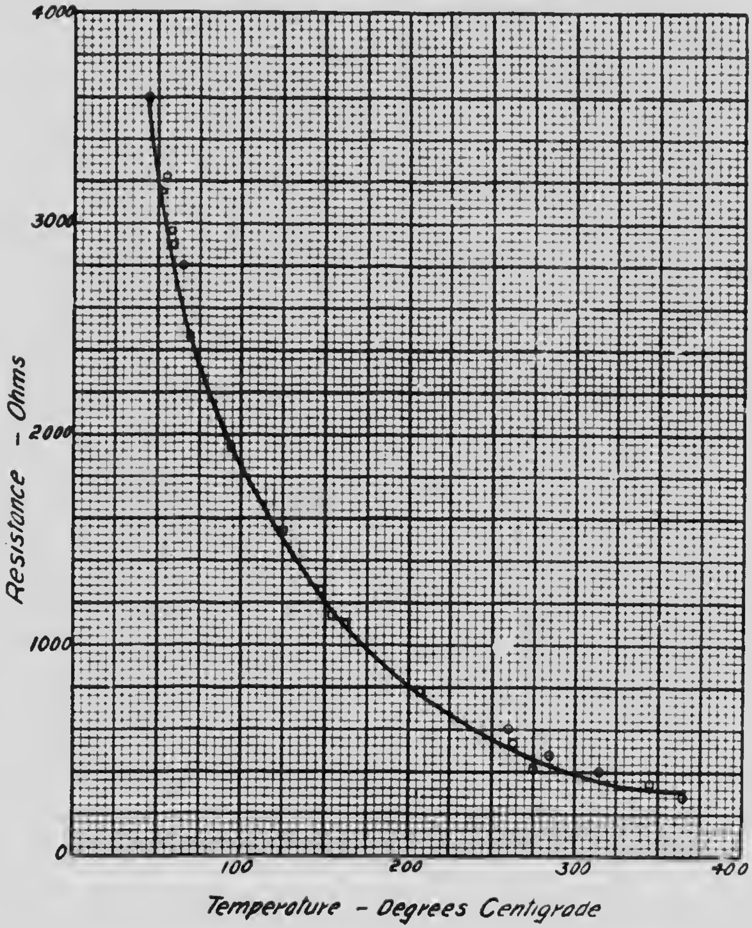
- MICA

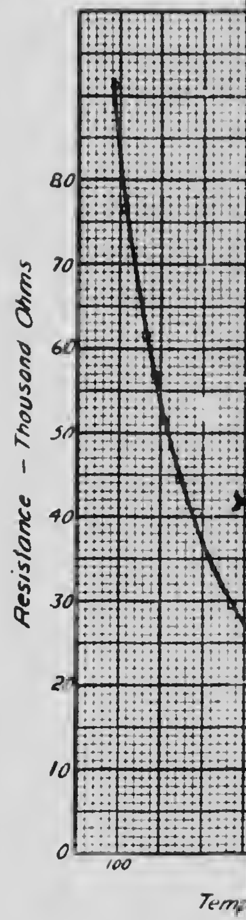
EMPERATURE CURVE



Graph N° 3

COPPER AND MICA

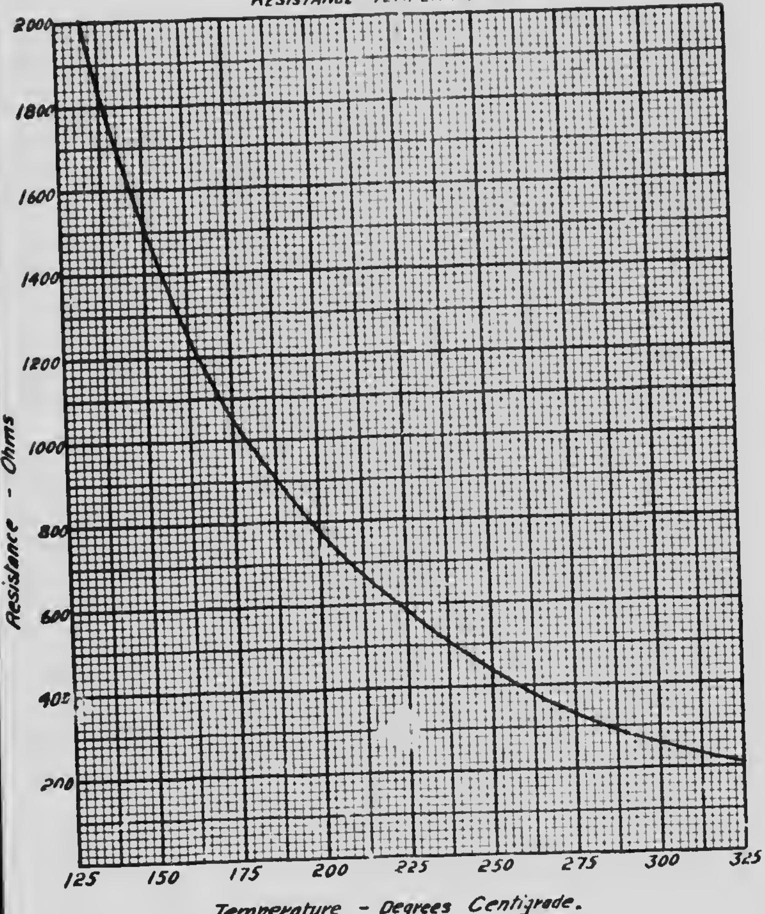




Graph N° 2

COPPER - MICA

RESISTANCE - TEMPERATURE CURVE



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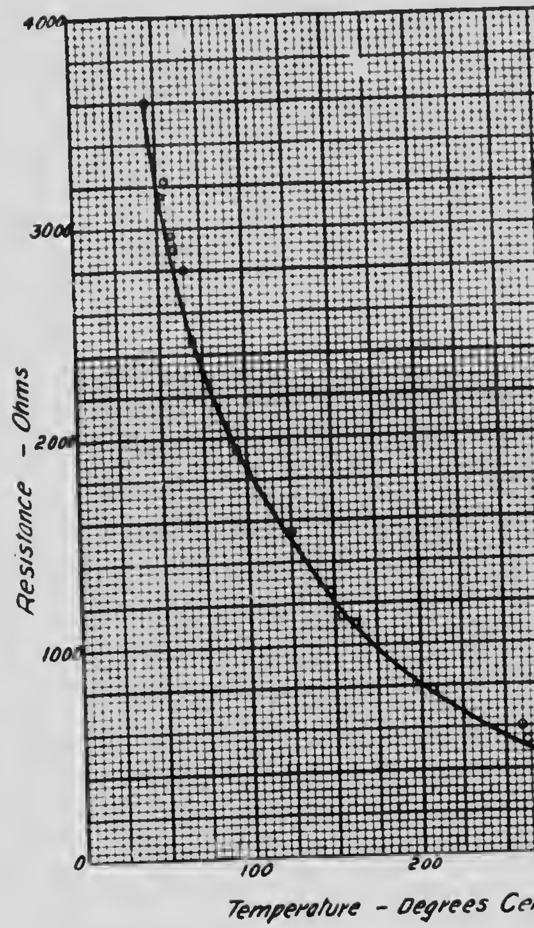
COPPER AND MIC



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N° 3
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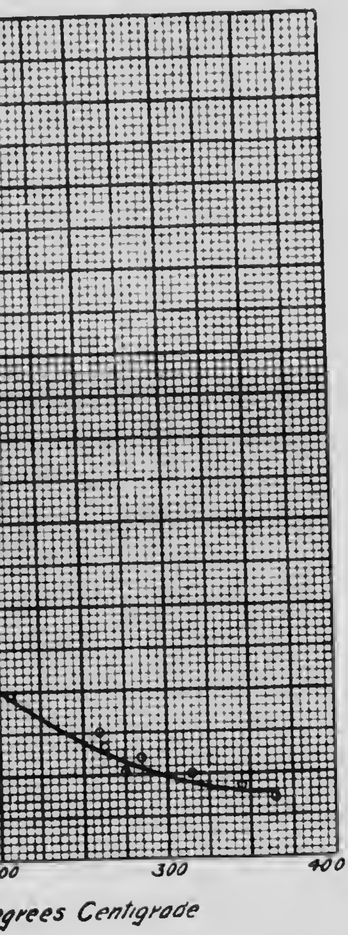

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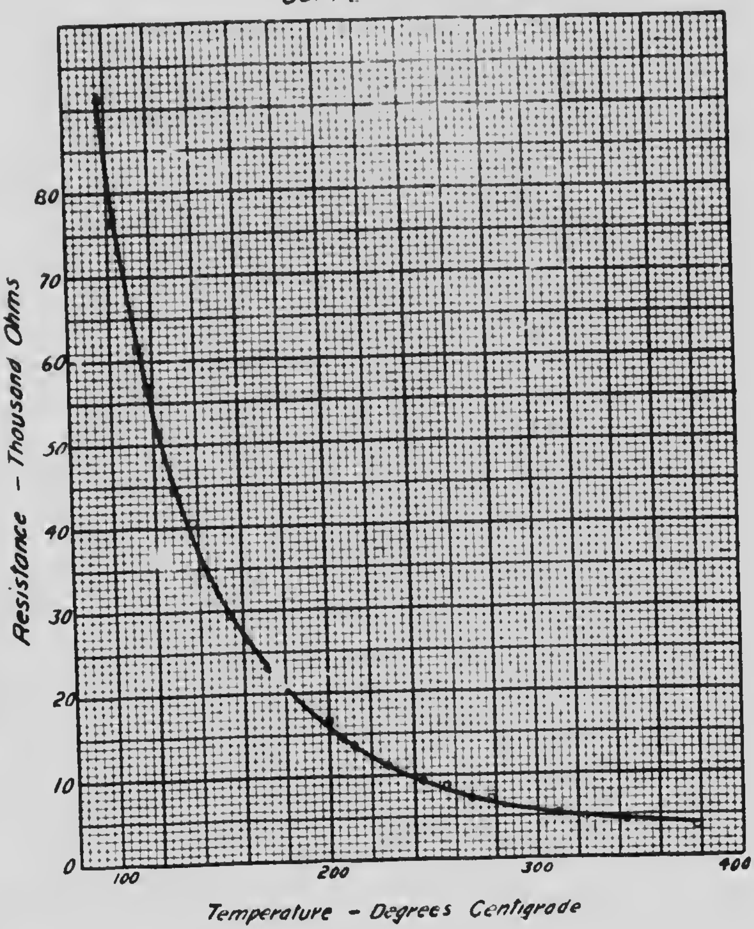
COPPER AND MICA



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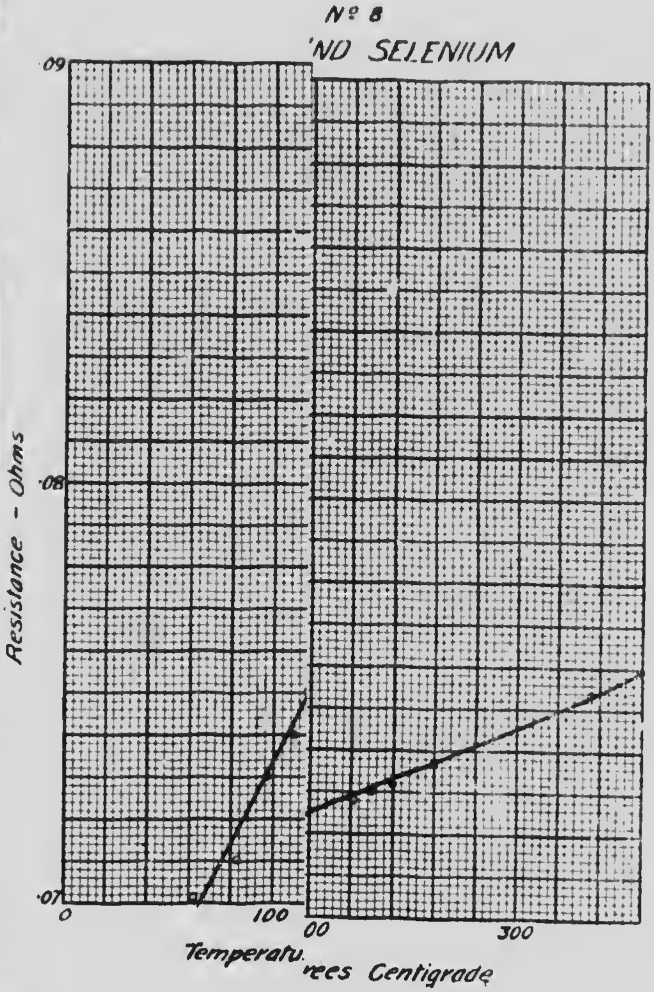
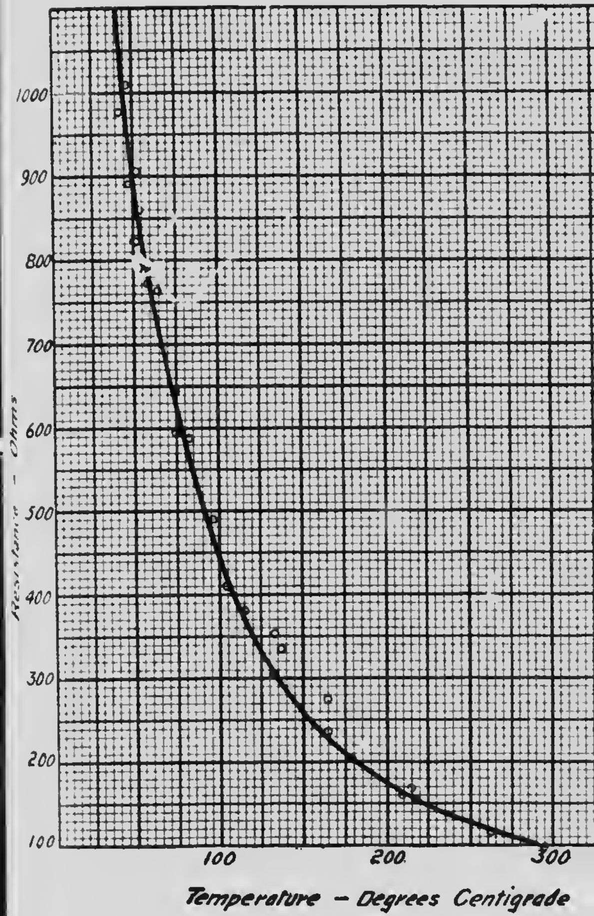
Resistance - Ohms

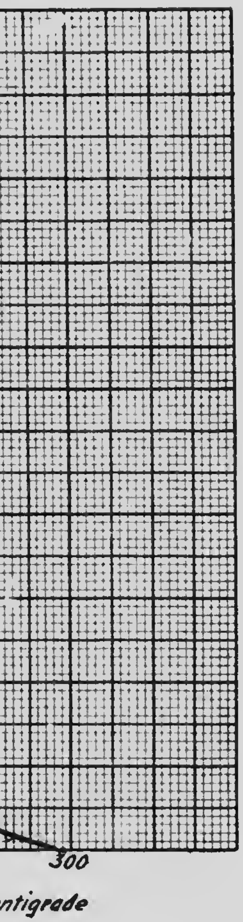


ZUMSTEIN 0.25

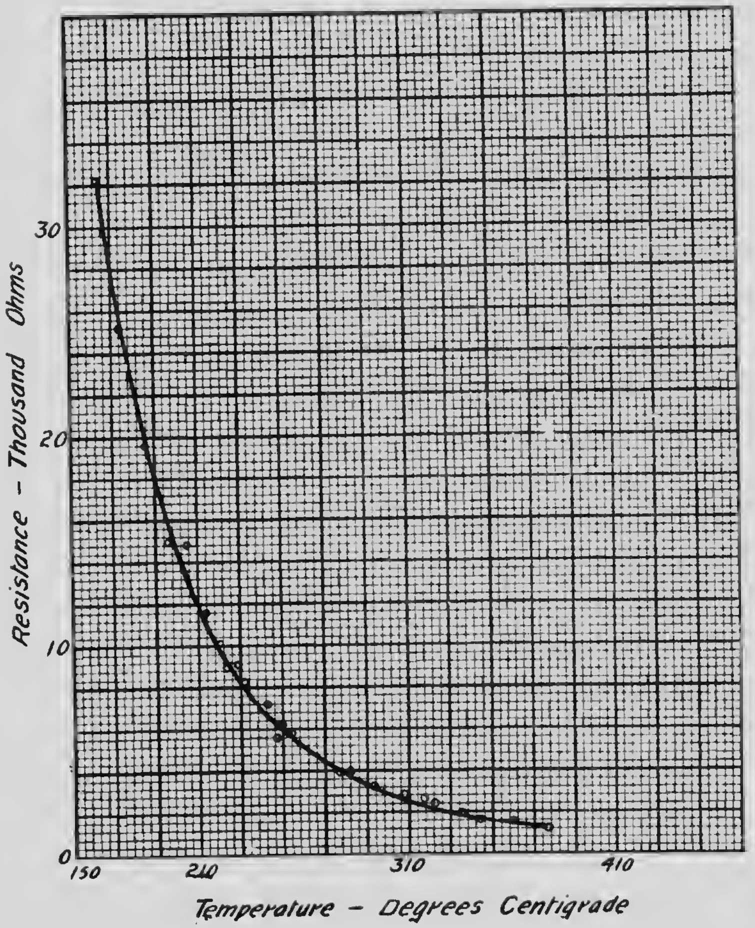
Graph No 5

IRON AND MICA

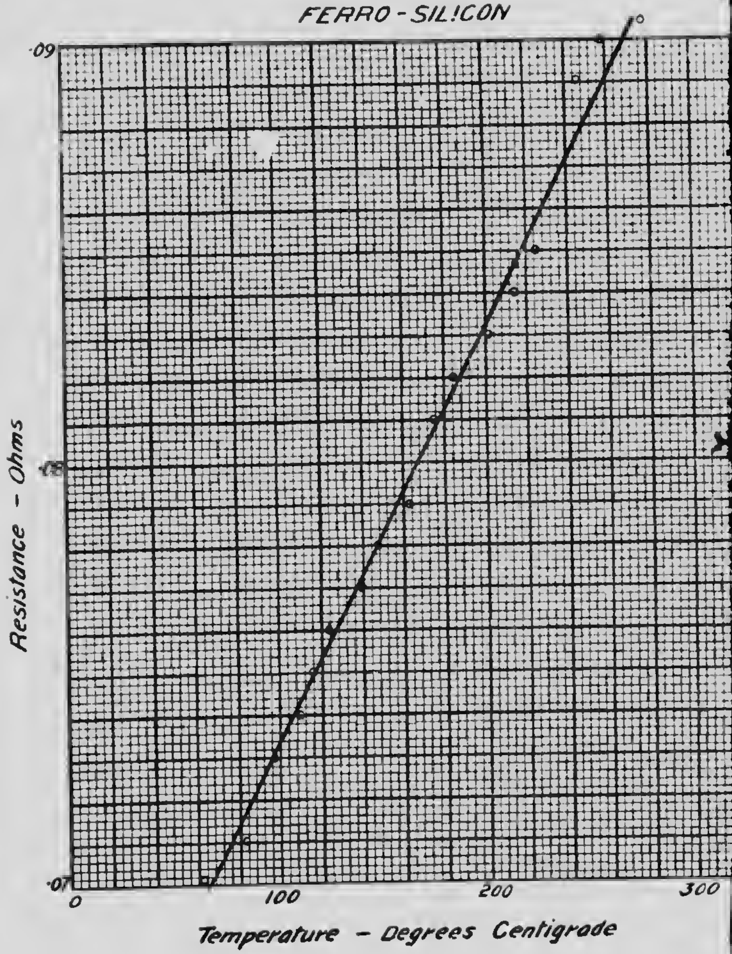




Graph Nº 6
IRON AND MICA

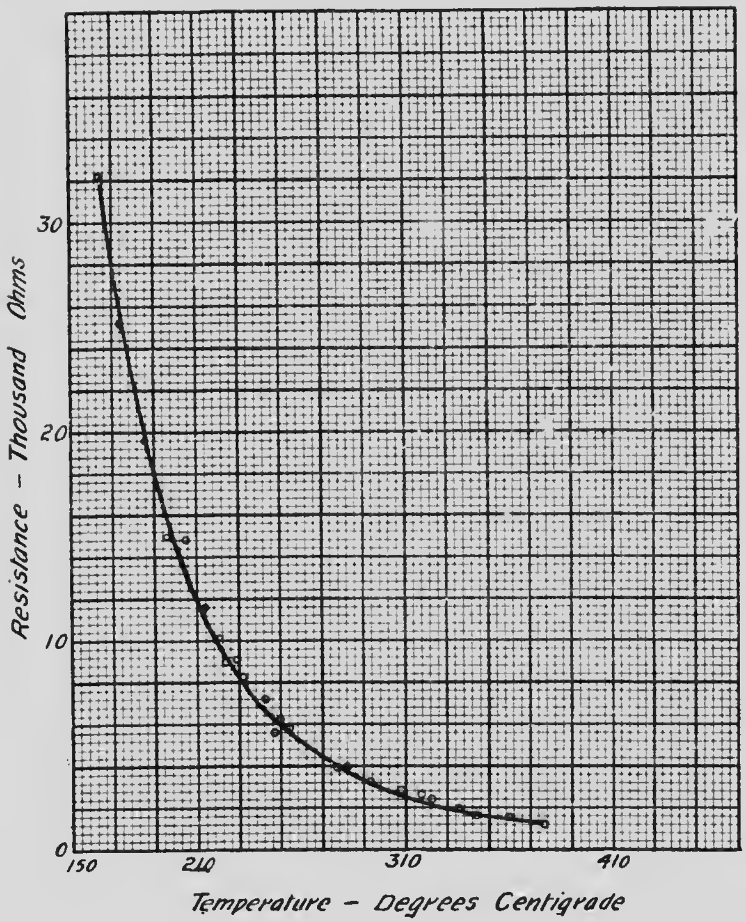


Graph Nº 7
FERRO-SILICON

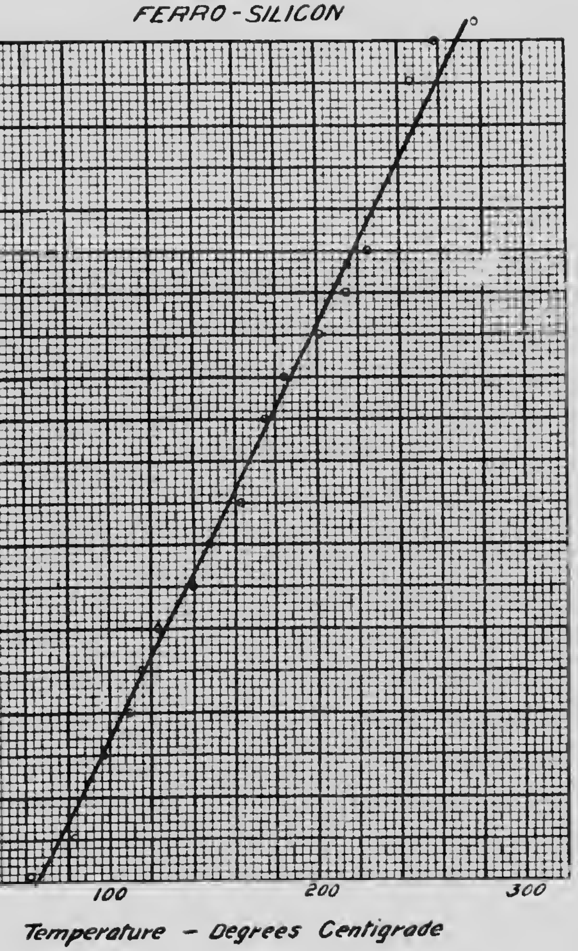


Graph Nº 6

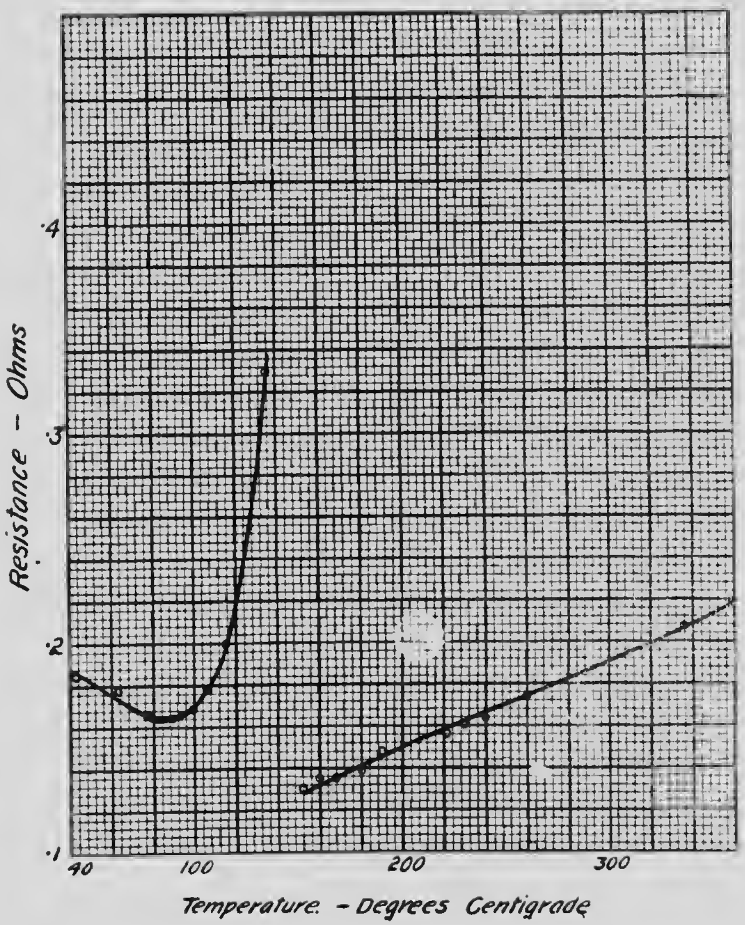
IRON AND MICA

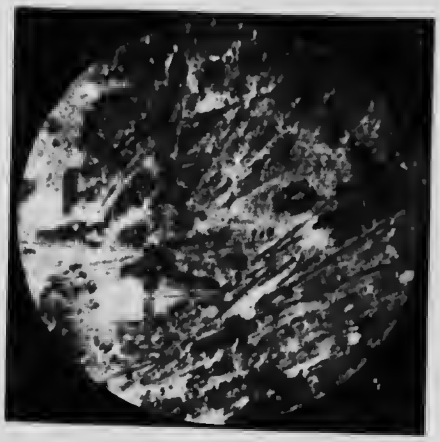


Graph Nº 7
FERRO-SILICON



Graph Nº 8
COPPER AND SELENIUM





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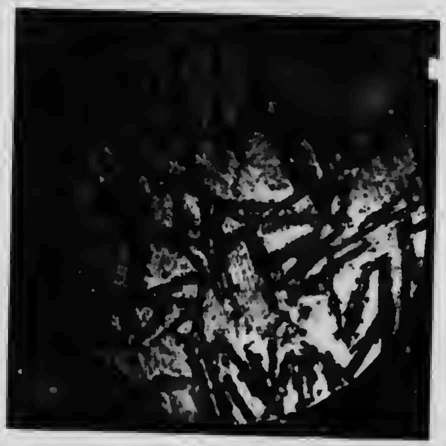

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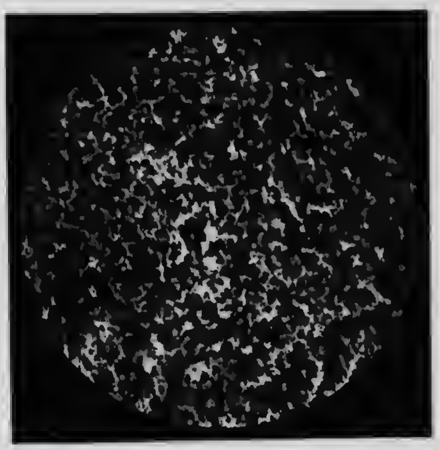

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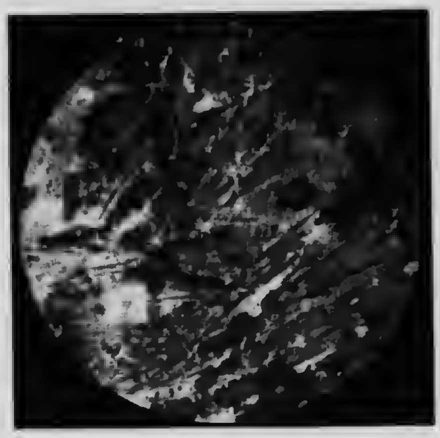

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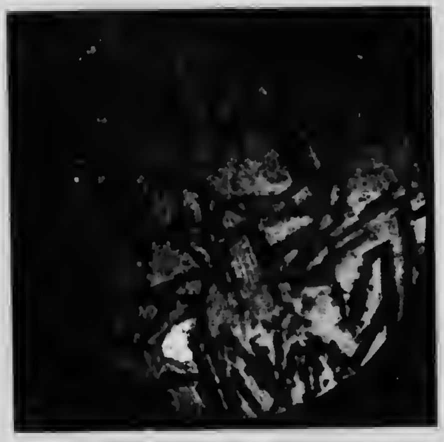

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UNIVERSITY OF TORONTO STUDIES

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