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A study of the electrical resistance of coke, gas-carbon, and kryptol under varying conditions

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T230

A STUDY

OF THE ELECTRICAL RESISTANCE OF COKE, GAS-CARBON, AND KRYPTOL UNDER VARYING CONDITIONS.

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-OBJECT-

This thesis was undertaken to make a study of the resistance of coke, gas-carbon, and kryptol when used as resistors in the electric resistance furnace, which daily is becoming of increasing industrial importance.

It would appear at first sight that the calculation and design of an electric resistance furnace would be an extremely simple problem, since the whole effect is the change of electrical energy into heat according to Joule's Law; but this is by no means the case, as the resistance of the resistor may change enormously during the run of the furnace. The great difficulty met with is the lack of data on which to base the calculations.

To find the causes and amount of change in the resistance of the material, and to add to the present available data on this line was the object sought for in this thesis.

-PREVIOUS WORK DONE-

Doctor Voelker has apparently discovered a remarkable law connecting volts with the size of carbon granules so that a thorough utilization of the electrical energy may be obtained. In short the law may be expressed in Doc. Voelker's figures, as follows: In using granular carbon as a resistor for voltages of (100N-100) to 100 N volts, the proper diameter of the carbon grains is n millimeters.

In the January issue for 1905 of the Electro Chemical and Metallurgical Industry F. A. J. Fitz Gerald discusses this law and comes to the conclusion that the law is too simple owing to the number of factors which determine the result and resistance. The effect of temperature on the resisting material is great and the voltage can not be kept within the limits of the above law and still allow for the proper regulation of the current passing through the resistor.

In the December 1904 issue of the Electro Chemical and Metallurgical Industry Fritz Gerald gives a lengthy description of an experiment with granular carbon resistors and draws the following conclusions from the experiment:

1. When the current is started there is first a rapid decrease in the resistance, followed by a slow increase. This increase is followed by a decrease, if the conditions are such that radiation of heat from the resistor is prevented and the temperature continues to rise.

2. Other things being equal preventing the radiation of heat from a carbon resistor causes a decrease in its resistance. That is the electrical resistance of carbon decreases with increasing temperature.

3. If pressure is applied to the rsistor the resistance decreases, and after removing the pressure the resistance is

lower than it was before applying the pressure.

4. Of two granular carbon resistors, each composed of grains of unifrom size, the coarser grained resistor has the lower resistivity.

5. If the same pressure is applied to coarse grained and fine grained resistors, the decrease in resistivity produced is greater in the former than in the latter.

Fitz Gerald also says that amorphous carbon when heated to high temperatures undergoes physical and chemical changes. The most important ones are increased density, increased heat conductivity and decreased electrical resistivity.

In the February 1905 issue of the Electro Chemical and Metallurgical Industry, Fitz Gerald describes an experiment using two granular carbon resistors from which the following data was obtained. The resistors were of graphitized coke, one through 5 and on 6 mesh (G1), and the other through 3 and on 4 mesh (G2).

Two readings were taken during the experiment and the resistivities calculated.

Resistance per cubic centimeter unit.

	G1	G2.
reading 1	.19 ohms	.13 ohms
reading 2	.27 ohms	.19 ohms

In the same article comparing the resistance in a run of a carborundum furnace the following data are given:

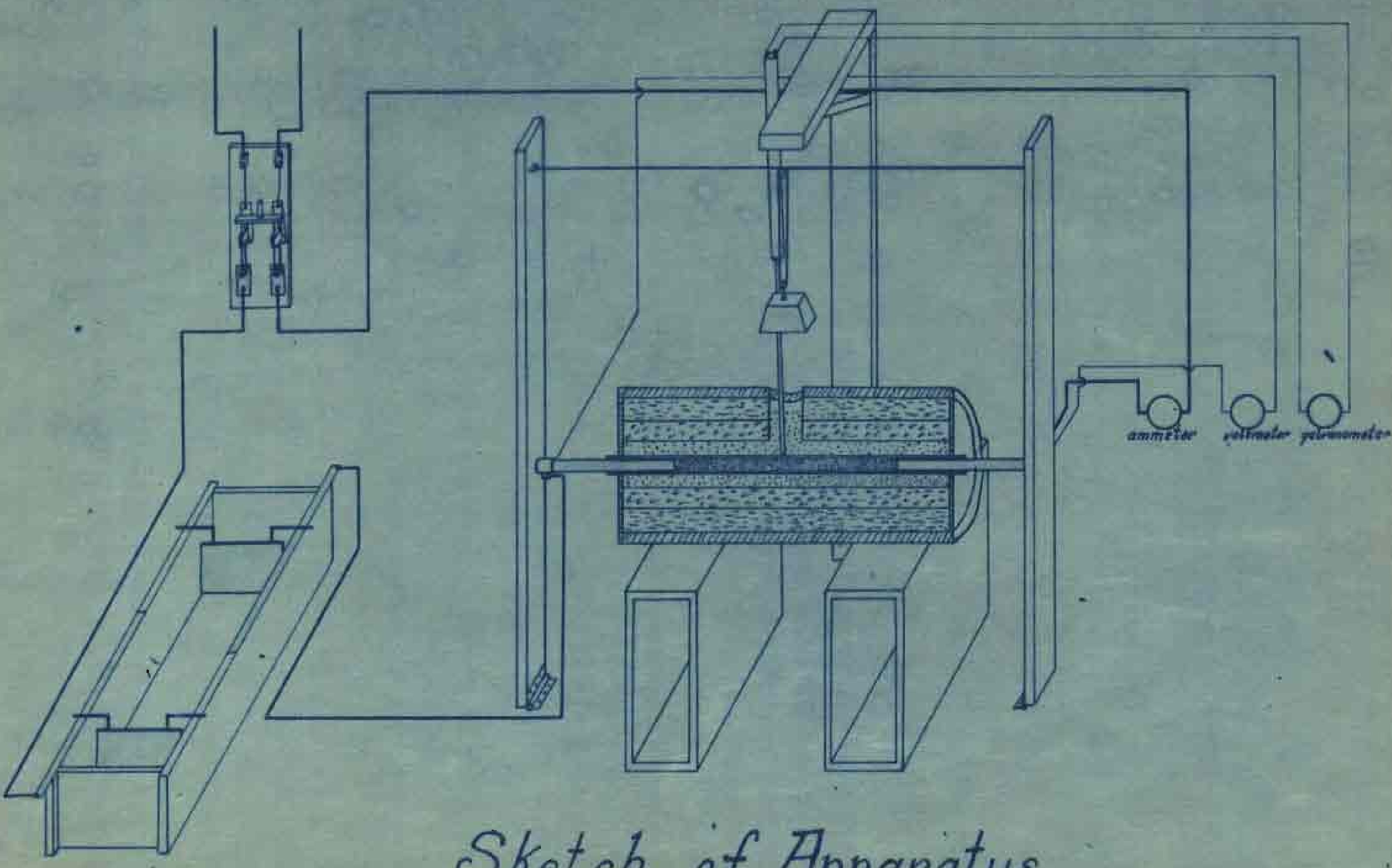
rsistance of 1 c.c.	ordinary coke	on reaching load	=	.44	ohms.
" " "	graphitized "	" " "	=	.16	"
" " "	at end of furnace run		=	.07	"

-APPARATUS-

The apparatus used in these experiments consisted of a furnace, water rheostat, pyrometer, voltmeter, and ammeter.

The furnace was made from a 12 inch vitrified pipe 3 feet in length. The pipe was first lined with 2 inches of lime mortar, then followed a 2 inch lining of kaolin. A 1 inch fused silica tube was placed in the centre of the remaining opening and surrounded by pure silica sand. The ends of the pipe were closed with circles of 1/4 inch asbestas board, allowing the silica tube to project through the abestas a few inches at both ends. A 3 inch hole was drilled through the side of the pipe and linings and into the sand filling. This hole was made to allow for the entrance of the pyrometer junction.

The water reheostat consisted of a wooden box 12 inches by 12 inches by 3 1/2 feet with copper strips placed along the tops of its sides. These copper strips were connected to a 220 volt circuit. The box was filled about 3/4 full of a 10% salt solution and two copper plates were suspended in this solution. These plates, each having a contact on one of the



Sketch of Apparatus

copper strips, completed the circuit through the solution. By shifting these plates the resistance of the rheostat could be varied.

The pyrometer consisted of a thermo-electric junction, connected to an ordinary galvanometer by copper leads. The junction was of platinum and platinum rhodium, and the wires were 60 inches long. The two wires were insulated from one another by a small fused silica tube and the entire thermo junction encased in a larger silica tube.

-METHOD-

The silica tube in the interior of the furnace was filled with the sized material used in the run. Graphite plugs 1 inch in diameter and 12 inches long were inserted, one in each end of the tube, to act as terminals. These terminals were held firmly against the resistor by means of two upright posts fastened to the floor, between the tops of which a weight was suspended. By this arrangement the pressure produced by the weight was transmitted directly against the ends of the graphite plugs pushing them firmly against the resisting material and giving a good contact between the two.

The two terminals of the furnace, the water rheostat, and an ammeter were all connected in series with the switch by number 8 copper wire.

A voltmeter was connected across the two terminals of the furnace. The thermo junction was placed in the opening in the side of the furnace and connected to the galvanometer by the copper lead wires.

The current was then switched on and readings of the ammeter, voltmeter, and galvanomter taken at intervals of two minutes. Readings were taken in this manner until the pyrometer showed a temperature of about 1200 °Centigrade, this being the maximum temperature we cared to risk in the furnace.

The plates in the rheostat were shifted whenever the voltage across the terminals became too high or to low.

At the end of every run the length of column and the area of cross section were measured.

The following readings were taken and the resistivities calculated:

-EXAMPLES OF CALCULATION-

$R = EI$ - - - - - - - Ohms Law.

Now where E = the drop in volts across terminals

and I = the current flowing in circuit

the product $EI = R$ = resistance of entire column.

Now if the length of the column in centi-meters be called A

the $\frac{R}{L}$ = resistance of a section of the column 1 centi-meter long.

And $\frac{R}{L} A$ = resistance of 1 cubic centi-meter of the resisting material.

-RUN NO. I-

Material use - Kryptol 1-2 m.m.

lenght of column of material - 79.38 cm. area cross section 5.48 sq. cm.

Room temperature 22 °C

Intervals between readings - 2 minutes.

Amperes.	Volts drop..	Galvanomter.
14.25	155	0.5
17.25	142	1.0
19.50	132	1.6
21.50	125	2.2
22.75	120	2.7
25.25	118	3.2
27.25	116	3.7
28.75	113	4.2
30.00	112	4.7
31.75	110	5.1
32.50	104	5.6
32.75	1045	6.0
34.25	106	6.2
36.00	112	6.6
34.75	120	7.0
35.25	126	7.2
33.75	130	7.5
33.00	136	7.8
31.50	138	8.2
29.75	141	8.4
28.25	144	8.7
27.50	148	8.9
27.25	150	9.1
26.60	152	9.2
26.00	154	9.5
25.00	156	9.6
24.50	160	9.6
24.00	160	10.0

-RUN NO.I- (CONTinued)

Temperature °C.	Total Resistance.	Resistance per.c.c.
122	11.89	0.804
202	8.23	0.558
302	6.78	0.469
402	5.81	0.394
492	5.27	0.348
552	4.67	0.315
622	4.25	0.288
682	3.98	0.270
742	3.73	0.253
792	3.47	0.236
852	3.20	0.245
902	3.18	0.245
922	3.07	0.208
972	3.11	0.210
1022	3.45	0.234
1042	3.53	0.239
1072	3.56	0.240
1102	4.12	0.279
1142	4.37	0.296
1162	4.74	0.321
1202	5.09	0.345
1212	5.38	0.365
1232	5.52	0.374
1242	5.73	0.388
1282	5.92	0.401
1292	6.08	0.412
1300	6.29	0.426
1322	6.66	0.451

-RUN NO 2-

Material use - Kryptol 1-2 m.m.

length of column of material - 71.75 cm. - area cross section 5.05 sq. cm.

Room temperature 25 °C.

Intervals between readings 2 minutes.

Amperes.	Volts drop.	Galvanometer.
11.50	200	0.2
19.50	187	0.6
37.50	170	1.2
17.50	137	2.0
14.00	167	2.8
18.50	171	3.3
27.00	140	3.9
31.00	132	4.3
34.00	125	4.9
36.00	124	5.4
37.00	128	6.2
36.50	132	7.0
34.50	139	7.5
32.25	143	8.3
32.00	146	8.9
31.00	150	9.3
29.50	152	10.1
28.25	162	10.4
26.00	159	10.6
25.00	162	10.8
24.25	161	10.9
22.00	157	11.0

-RUN NO 2- (Continued)

Temperature °C.	Total Resistance.	Resistance per c.c.
65	17.39	1.165
125	9,59	0.642
235	4.53	0.303
375	7.82	0.524
505	11.93	0.799
565	9.24	0.619
645	5.18	0.347
695	4.25	0.282
765	3.68	0.246
835	3.43	0.253
925	3.46	0.279
1025	3.61	0.240
1075	4.03	0.275
1155	4.43	0.295
1212	4.56	0.305
1265	4.84	0.324
1345	5.17	0.344
1365	5.73	0.384
1395	6.11	0.410
1455	6.41	0.434
1425	6.63	0.438
1435	7.13	0.467

-RUN NO. 3-

Material use - Gas-carbon (2-4 m.m)

length of column of material 54.61 area cross section-5.48 sq.cm.

Room Temperature 25 °C.

Intervals between readings- 2 minutes.

Amperes.	Volts drop.	Galvanometer.
14.50	150	0.05
14.25	152	0.20
15.00	180	0.40
9.50	195	0.70
7.75	198	0.90
10.50	204	1.00
10.00	204	1.20
10.75	205	1.40
10.25	206	1.50
3.75	204	1.70
8.75	205	1.90
7.50	206	2.00
7.00	206	2.20
10.00	203	2.4
10.00	206	2.5
10.00	204	2.7
10.50	204	2.9
10.25	203	3.1
10.00	205	3.4
8.75	204	3.6
11.00	202	3.8
7.50	206	4.0
9.00	203	4.3
8.00	206	4.6
7.50	204	4.8
7.00	206	5.0

-RUN NO 3- (Continued)

Temperature °C.	Total Resistance.	Resistance per c.c.
40	10.34	1.019
65	10.66	1.051
105	12.00	1.183
165	20.52	2.023
195	25.54	2.539
205	19.43	1.916
235	20.40	2.007
265	19.07	1.881
285	20.09	1.981
325	23.31	2.298
355	24.24	2.390
375	27.46	2.709
405	29.43	2.902
445	20.30	2.001
465	20.60	2.031
485	20.40	2.007
515	19.43	1.916
545	19.80	1.953
585	20.50	2.022
605	23.31	2.298
625	18.27	1.800
655	27.46	2.709
695	22.55	2.233
735	25.75	2.538
755	27.20	2.682
785	29.93	2.901

-RUN NO 4-

Material used- Gas Carbon (1-2 m.m.)

length of column - 53.41 cm. area cross section 5.48

Room temperature 22 °C.

Intervals between readings - 2 minutes.

Amperes.	Volts drop.	Galvanometer.
27.50	180	2.7
26.50	140	2.5
15.75	172	4.2
19.50	194	5.2
19.00	198	6.0
16.00	192	6.9
14.50	200	7.1
16.75	206	7.3
15.25	204	7.7
15.25	202	8.1
13.50	206	8.3
14.50	204	8.5
16.00	208	8.9
12.75	205	9.0
12.50	203	9.1
16.25	206	9.3
13.00	204	9.6
13.00	206	9.7
13.75	211	9.7
11.25	208	9.8
11.50	212	10.1

-RUN NO 4- (Continued)

Temperature °C.	Total Resistance.	Resistance per c.c.
382	4.73	0.477
462	5.28	0.531
647	10.99	1.104
802	9.98	1.005
902	10.42	1.050
1012	12.00	1.209
1032	13.79	1.389
1072	12.32	1.239
1047	13.38	1.347
1132	13.32	1.341
1152	15.26	1.536
1182	14.07	1.426
1202	13.00	1.310
1232	15.68	1.580
2232	16.24	1.635
1252	12.36	1.347
1296	15.85	1.596
1302	15.34	1.545
1308	18.42	1.856
1332	18.43	1.856

-RUN NO 5-

Material used - Coke (1-2 m.m)

length of column 55.24 cm. area cross section 5.05 sq. cm.

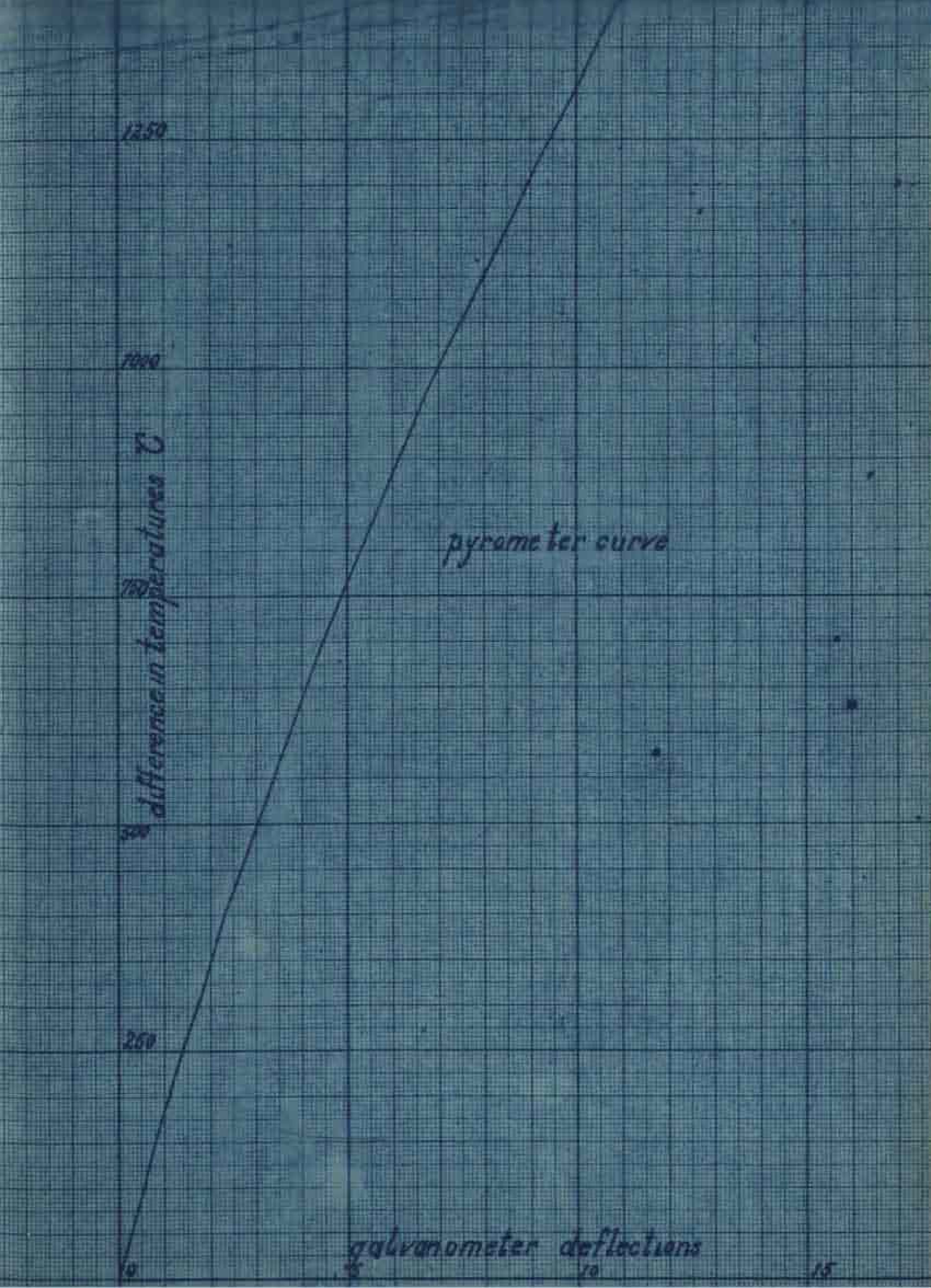
Room temperature 23 °C.

Intervals between readings - 2 minutes.

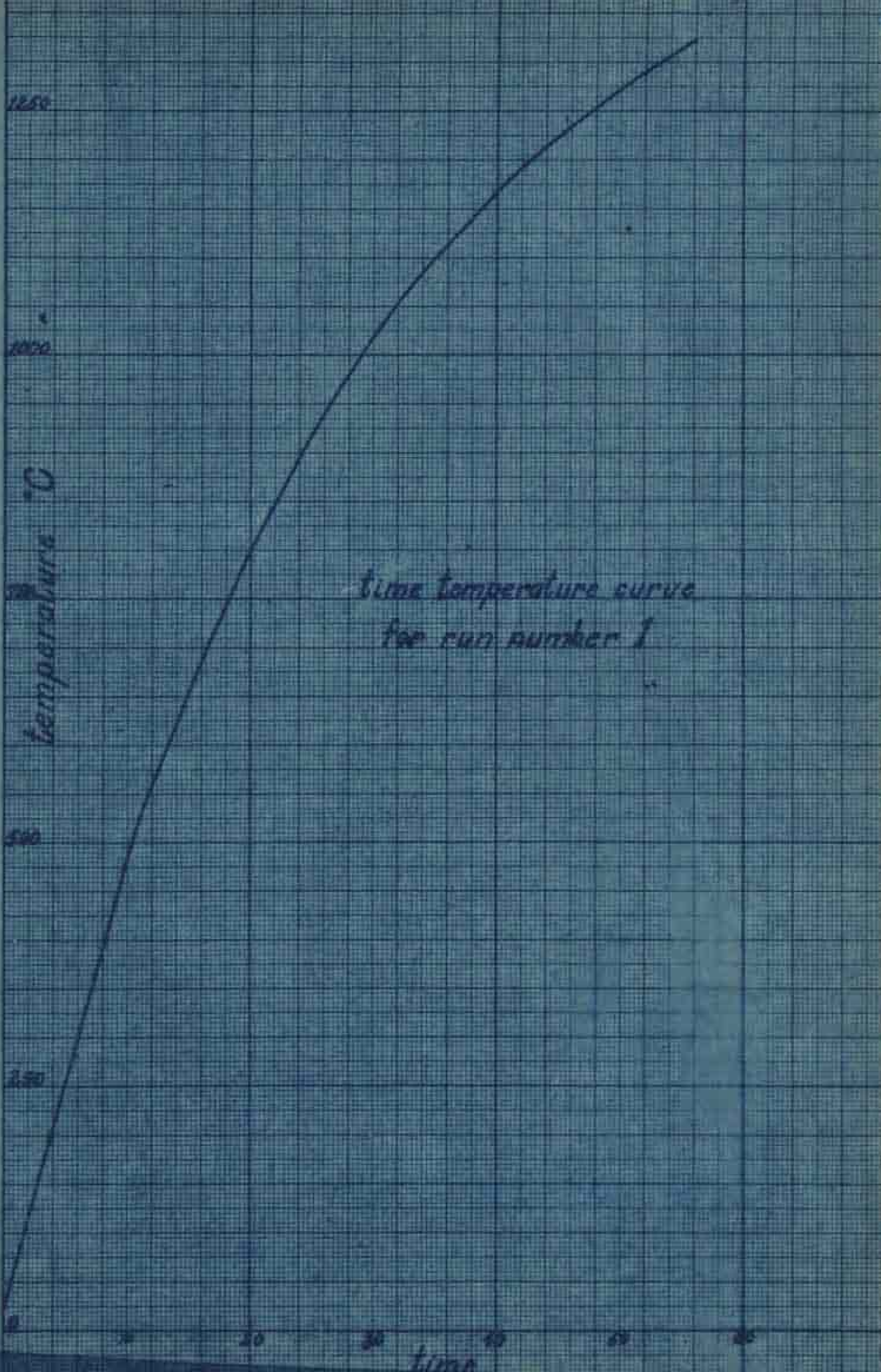
Amperes.	Volt drop.	Galvanometer.
14.00	767	3.4
17.00	157	3,8
21.00	142	4.4
23.50	135	4.9
25.75	128	5.4
26.25	127	5.9
24.75	135	6.5
22.00	145	6.8
13.50	174	7.1
8.75	190	7.2

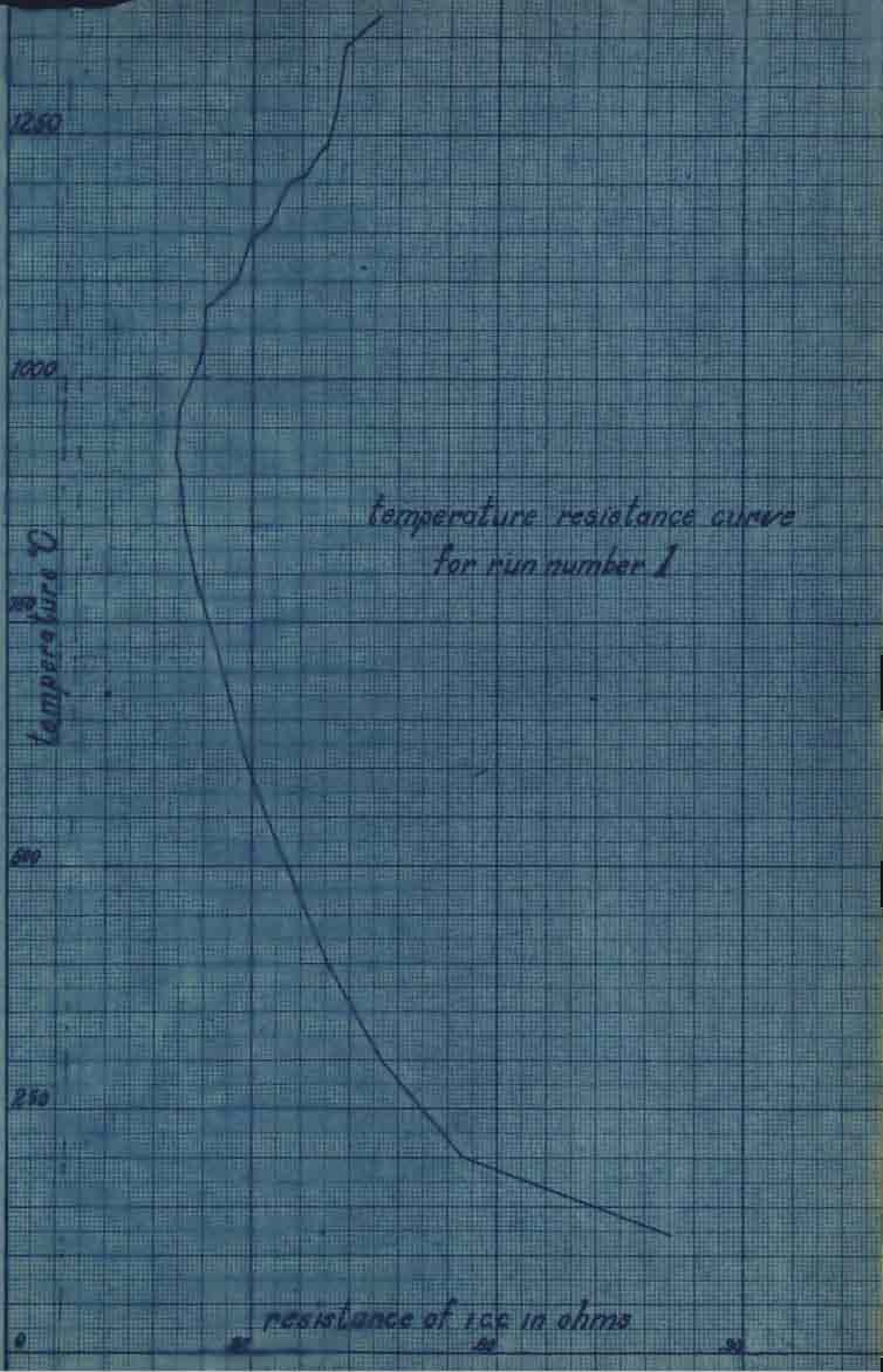
-RUN NO 5- (continued)

Temperature °C.	Total Resistance.	Resistance per c.c.
573	11.96	1.041
623	9.23	0.803
703	6.78	0.590
773	5.74	0.499
823	4.98	0.434
893	4.87	0.424
963	5.45	0.474
993	6.59	0.576
1033	12.96	1.103
1043	21.71	1.889

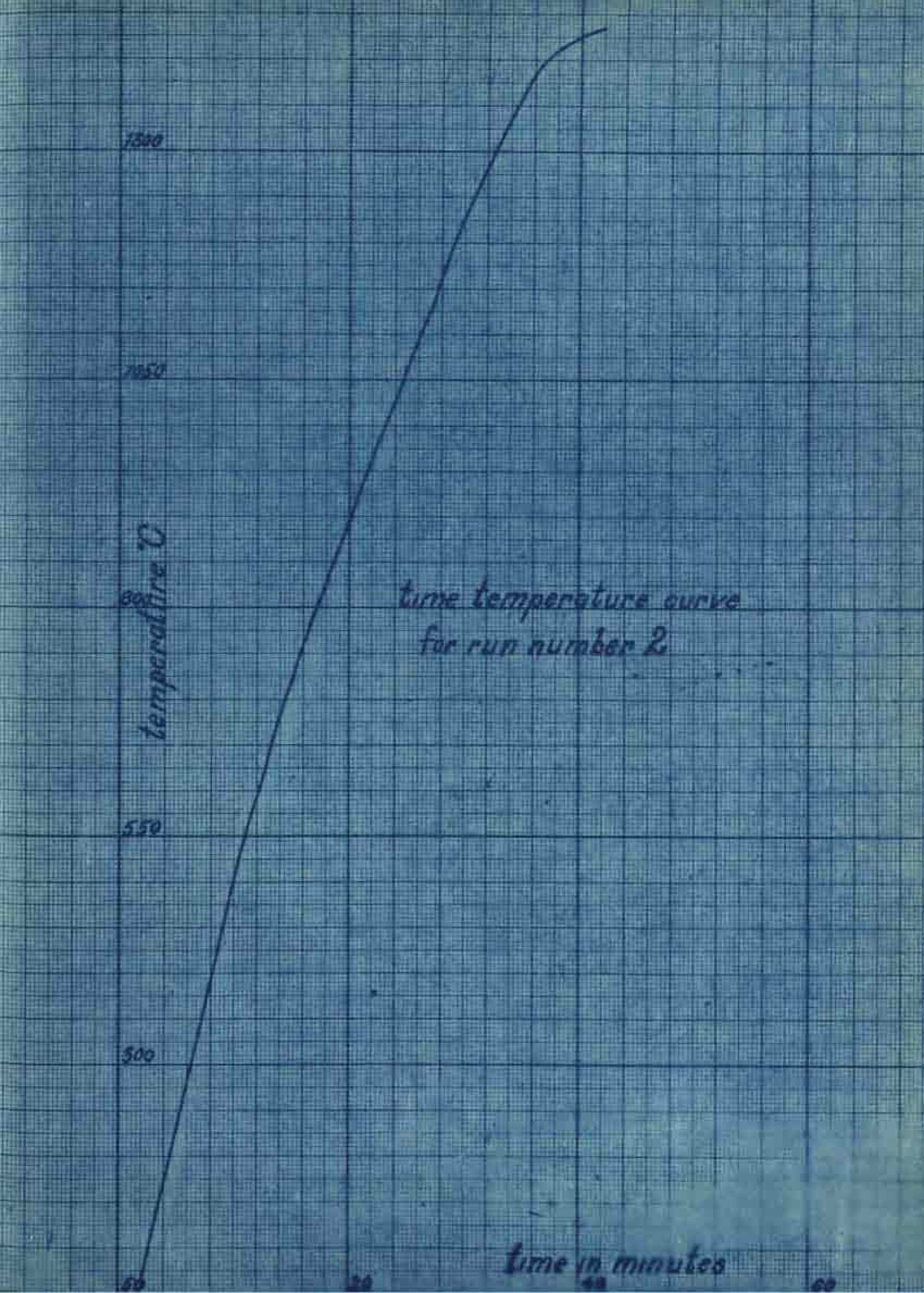


pyrometer curve
difference in temperatures C
galvanometer deflections
1250
1000
750
500
250
0
5
10
15

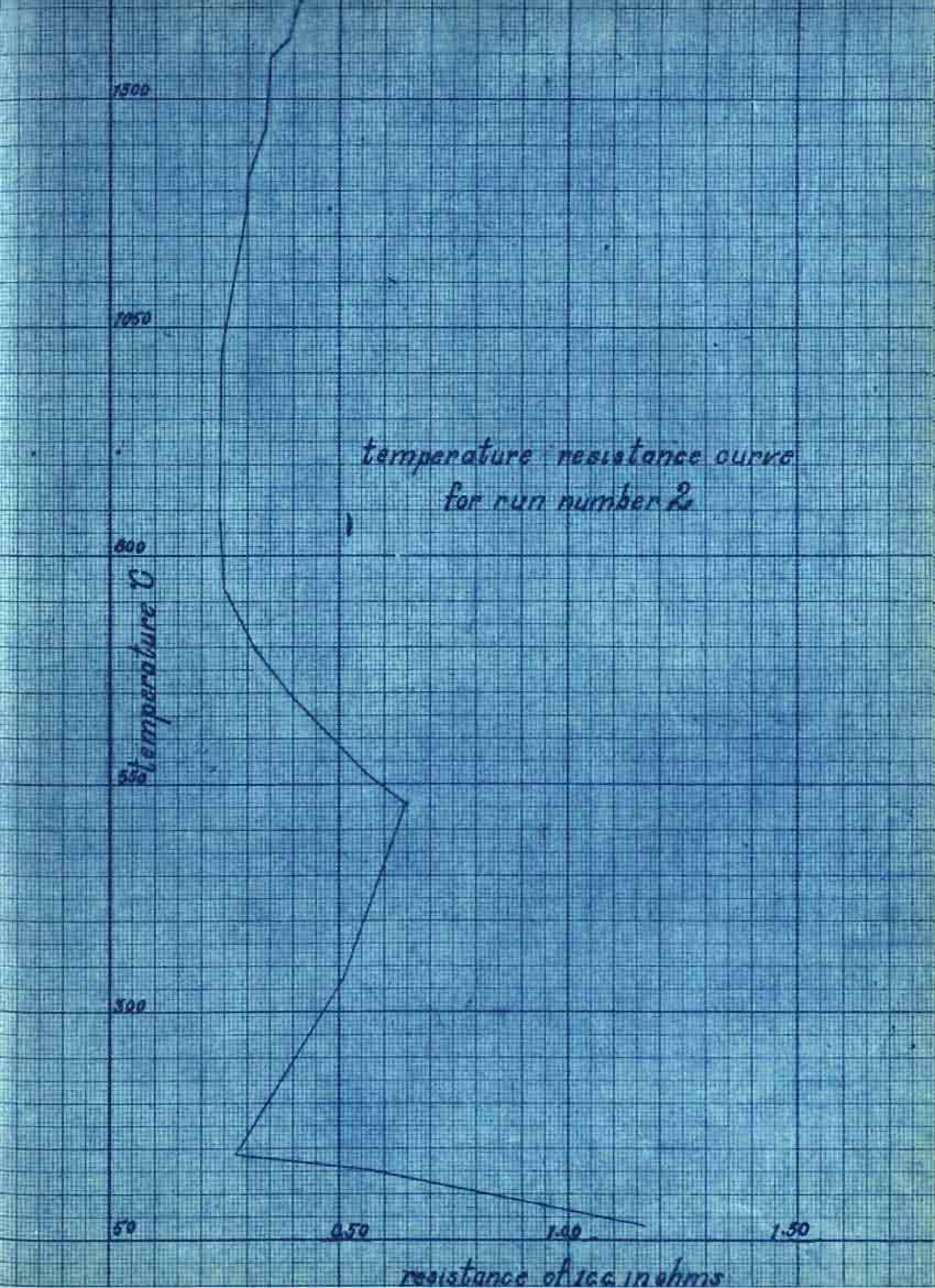

time temperature curve
for run number 1
temperature °C
time
1250
1000
500
250
0
20
30

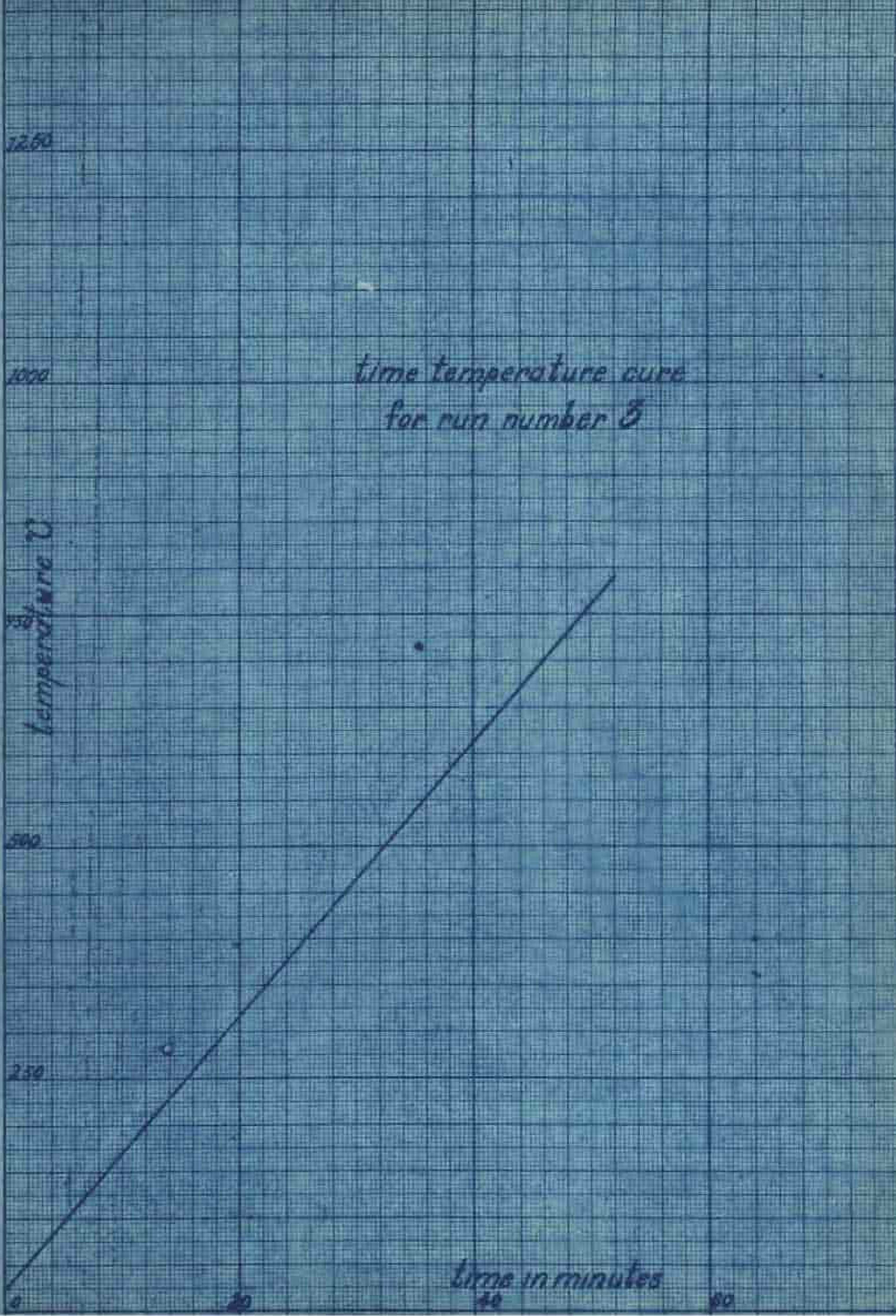


temperature resistance curve
for run number 1
temperature °C
1250
1000
250
0
resistance of i.c.c. in ohms

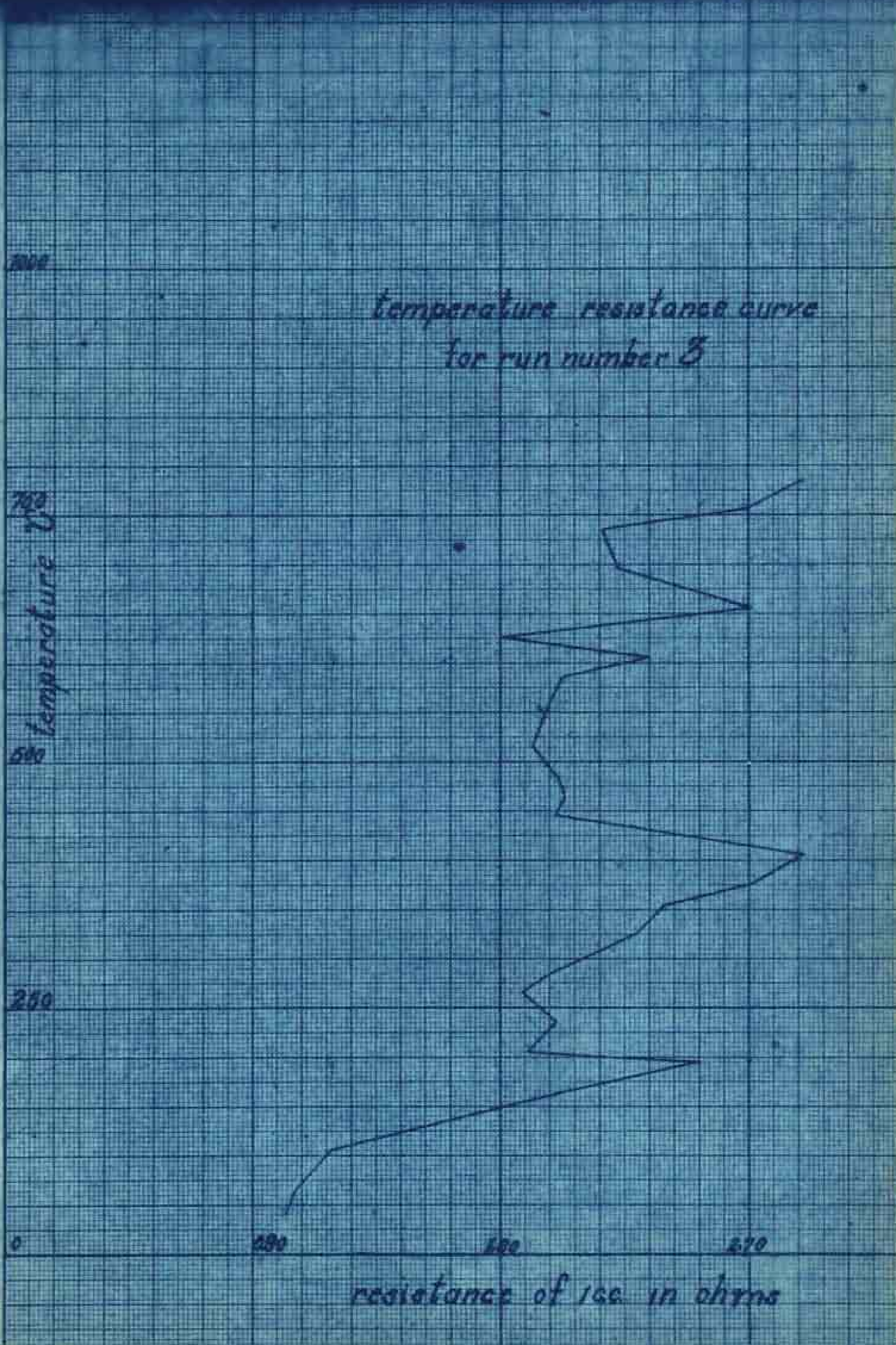


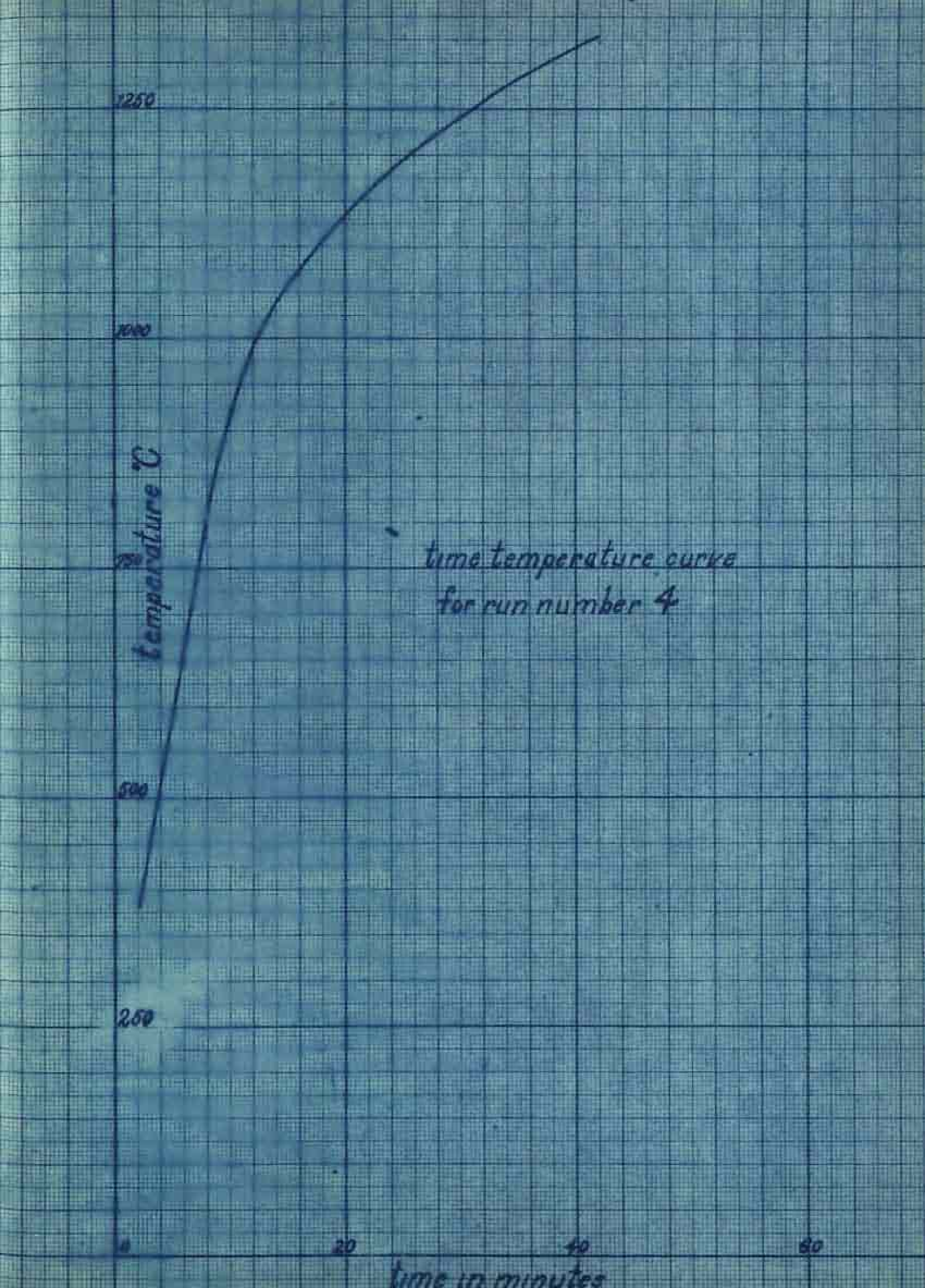
time temperature curve
for run number 2
temperature °C
time in minutes
1300
1050
800
550
300


temperature resistance curve
for run number 2
temperature C
1500
1050
800
550
300
50
0.50
1.00
1.50
resistance of 1 c.c. in ohms

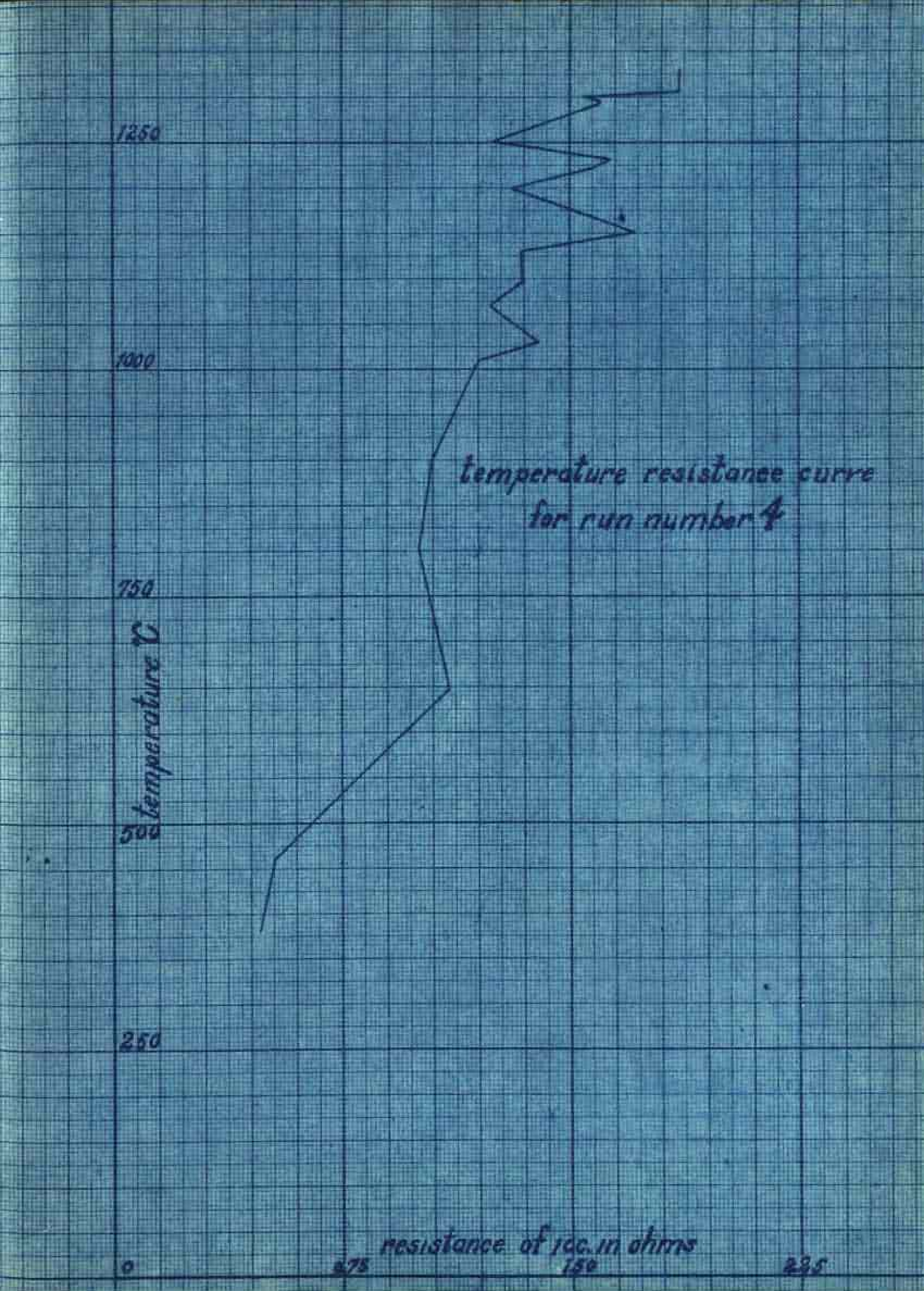


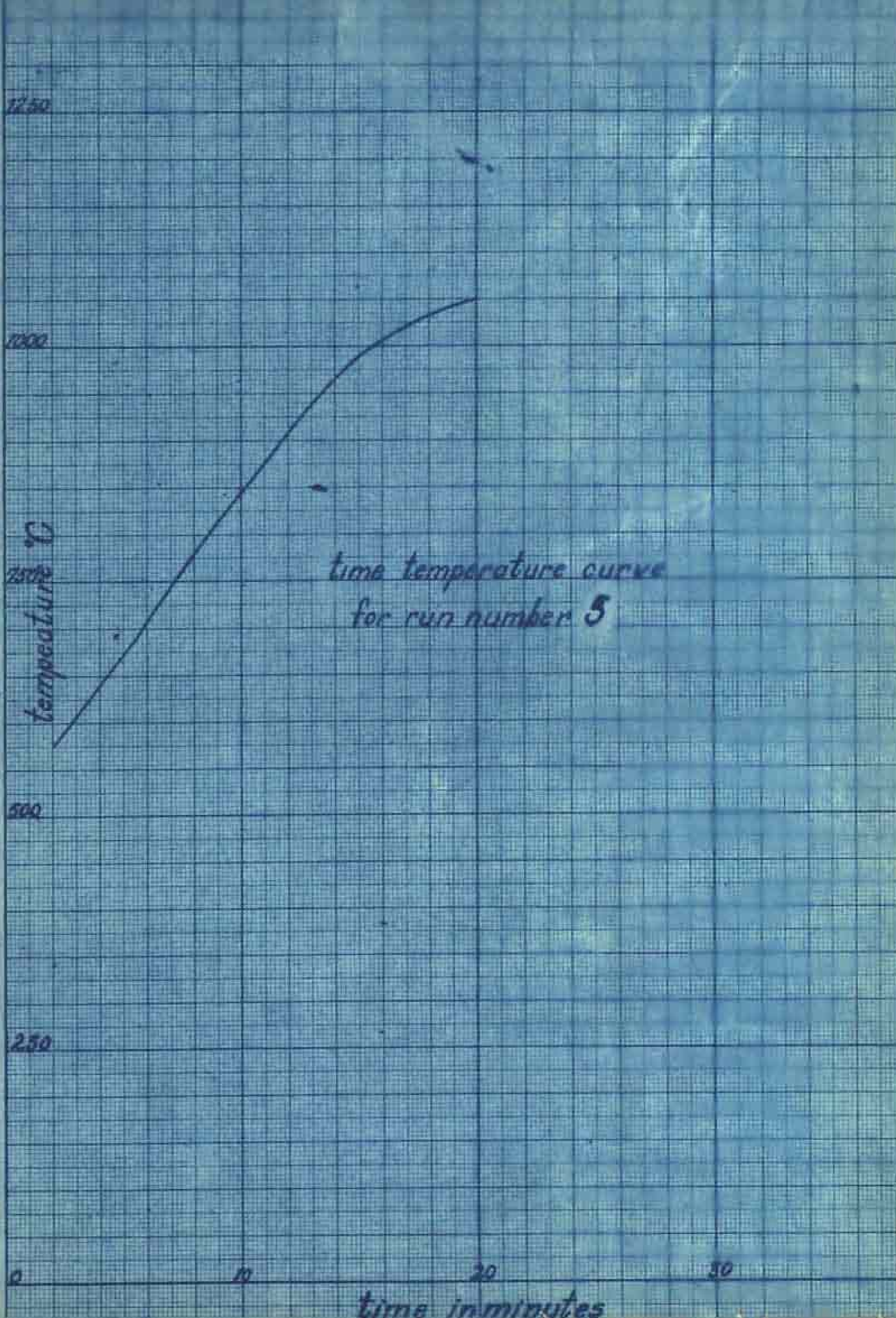
time temperature cure
for run number 3
temperature C
1250
1000
750
500
250
time in minutes
0
20
40
60

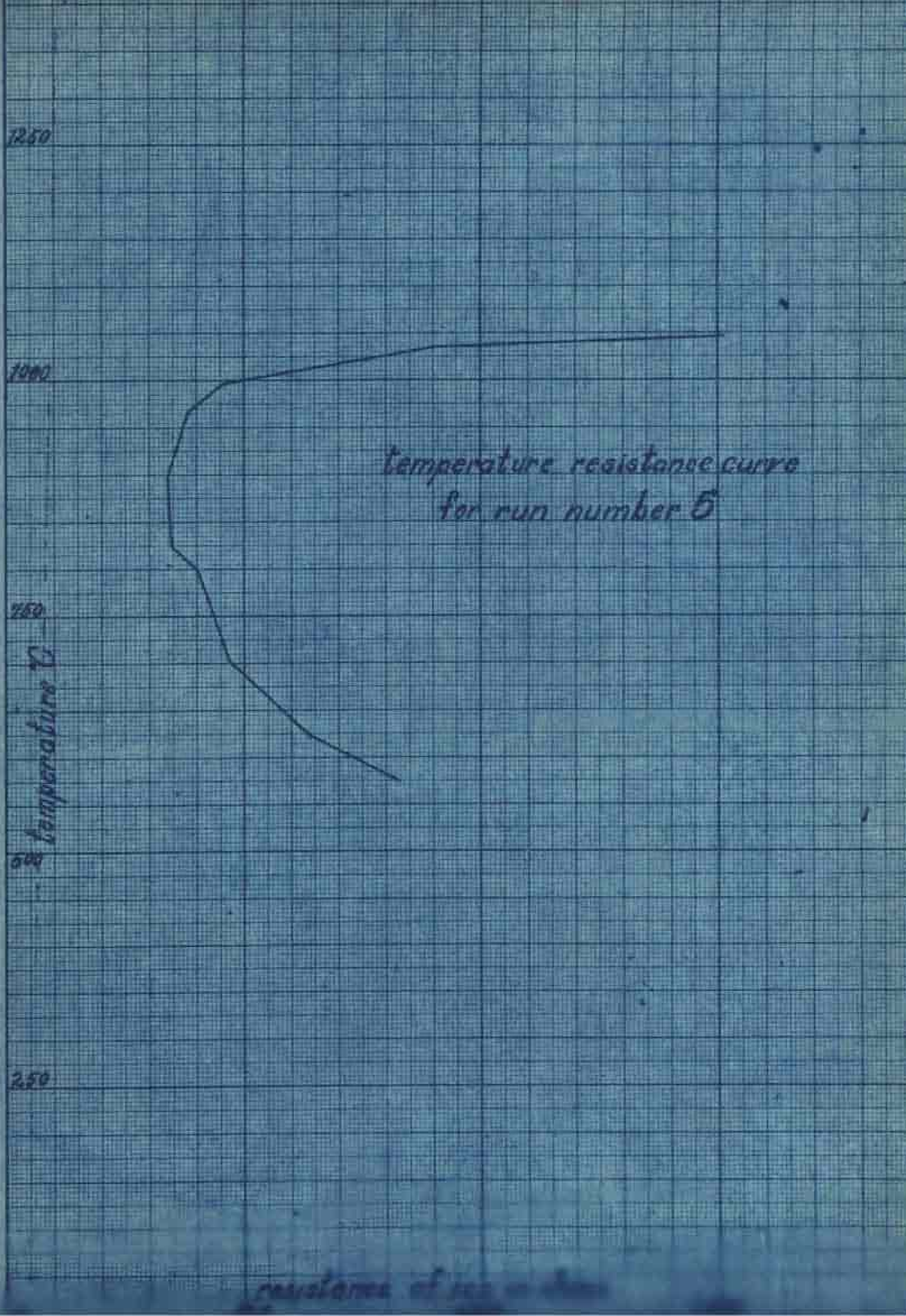

temperature resistance curve
for run number 3
temperature C
500
250
0
270
resistance of 1cc. in ohms



1250
1000
750
500
250
0
20
40
60
temperature °C
time in minutes
time temperature curve
for run number 4


temperature resistance curve
for run number 4
temperature °C
1250
1000
750
500
250
0
075
150
225
resistance of 1cc. in ohms


1250
1000
750
500
250
0
10
20
30
tempeature C
time temperature curve
for run number 5
time in minutes


1250
1000
750
500
250
temperature °C
temperature resistance curve
for run number 5

-DISCUSSION OF RESULTS-

The first two runs were made on kryptol (1-2 m.m) and the data obtained and the curves plotted are very much alike. The curves are quite regular and show in both cases a gradual decrease in resistance as the temperature was raised. When a temperature of 1000 °Centigrade was reached this decrease stopped and from 1000 °C up to the end of the run the resistance increased.

The third and fourth runs were on gas carbon, number 3 on material sized from 2 to 4 m.m., and number 4 on 1 to 2 m.m material. Although the same characteristics were observed in both cases, in the run on the larger sized material the resistance was greater at all temperatures than the resistance of the smaller particles at the same temperatures. An explanation of this must lie in the difference in the size of the particles used in the two runs, because all other conditions were the same.

The resistance temperature curves for these two runs show directly from the start a very irregular increase in the resistance with the rise in temperature. These irregularities are due without a doubt to the arcing of the current from one particle to another. This arcing continued through out the entire runs on both trials with gas carbon, and was the cause of the uneven increase in resistance.

The fifth run was on crushed coke sized between 1 and 2 m.m. The behavior of this material was similar to that of kryptol, the resistance decreasing with the rise in temperature until 1000 °C was reached, and then increasing. The resistance of the coke, however, increased very rapidly and at about 1050 °C, the resistance was so great that the amount of current flowing was practically nothing. When the coke was allowed to cool and another run made on the same coke particles the resistance was found to be the same as it was at the end of the preceding run. The coke evidently went through some chemical or physical change which increased its resistance very much.

Other runs were tried on larger sized particles of the same materials, but no results of any value were obtained. As the size of the particles was increased the tendency to sparking or forming of minute arcs in the resistor became very great. The prevention of sparking is one of the hardest things to contend with, and is important, as when this arcing occurs the true resistance is not shown, but rather the resistance of the air gaps between the particles.

-SUMMARY-

1. The resistance of kryptol decreases with increasing temperature up to about 1000 °C, from which point there is an increase in resistance.

2. The resistance of gas carbon increases steadily with rising temperatures.

3. The resistance of coke decreases with increasing temperature up to 1000 °C, from which point there is a rapid increase in resistance.