ELECTRICAL MEASUREMENTS ON NEW TYPES OF ENAMELLED WIRES

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Summary.—The electrical properties of two new types of enamelled wires and of one, insulated with Nylon type varnish, are given in graphs, one wire being measured for the first time at temperatures up to 400° C.

The availability of new types of materials demands a study of their properties as they may be used to make old designs more efficient or new designs possible. The production of two enamelled wires that are claimed to stand temperatures up to 200° C. and 400° C. respectively made a comparison with a Nylon insulated type desirable.

The insulating material of the new wires is essentially inorganic (ceramic) with a content of zinc, and a thin cover of Teflon.

The third was a common standard type coated with Nylon varnish. The wires were marked 200, 400 and S for reference purposes.

Thickness.—The thickness of the three wires and their insulating covering was measured with a travelling microscope and the values are shown in Table I. Each result is the average of at least six readings.

TABLE I

Wire designation	S	200	400
Diam. of wire in mm. average ..	$0{\cdot}44_3$	$0{\cdot}45_5$	$0{\cdot}46_1$
Thickness of insulating material in mm.	$0{\cdot}01_8$	$0{\cdot}00_9$	$0{\cdot}00_8$
Requirement of varnish thickness to B.S.S. 156/1943	0·023	0·023	0·023

Dielectric Constant, Power Factor and Resistivity of the Enamelled Wire

To determine the dielectric constant and resistivity, a condenser had to be made from the wire, using the copper as one electrode, the insulating material as the dielectric and a conducting coating as second electrode. From the physical dimensions, permittivity and resistivity were thus determined at room temperature.

For the measurements at higher temperatures, each wire was wound in a coil with 2 layers of wire electrically separated from each other. This arrangement allowed the application of 100 V even at temperatures upto 400° C. and was therefore suitable for investigating the variation of the electrical properties with the temperature. The same method of testing has been specified in the German V.D.E. regulations.

A Wien's series resistance bridge with a frequency source of 1,000 cycles per second was used to measure capacity and power factor. For measuring the insulation resistance an electronic D.C. Megohm bridge with measuring voltage at 100 V was used. Both bridges and the necessary leads were shielded to eliminate all stray capacitances.

RESULTS

I. *Dielectric Constant, Power Factor and Resistivity of the Enamel.*

A. *Versus Temperature.*—Figs. 1, 2 and 3 show temperature *v. dielectric constant.* The arrows on the curves show the order in which the measurements were taken. It was observed that the rate of heating influenced the value of the dielectric constant to some extent. For the 200 wire (see Fig. 2) the dielectric constant changed from the value at A of 3·9 to that at C of 5·3, if the rate of heating was kept low. If the rate increased to that of a rise of 10° C. in 10 minutes, then the dielectric constant increased to the value at B of 6·3 as shown by the dotted curve. After about five minutes

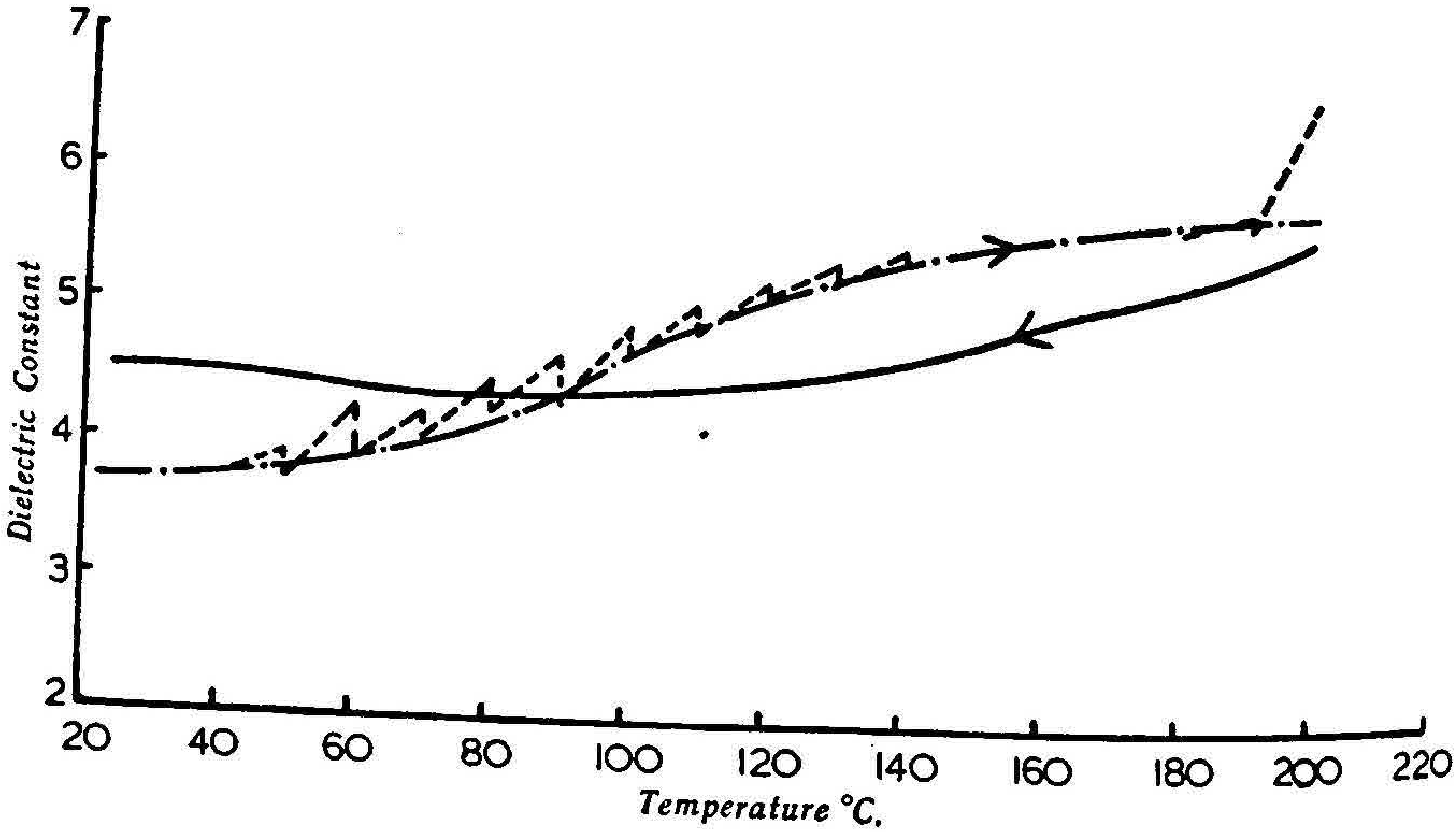

FIG. 1. S Wire.

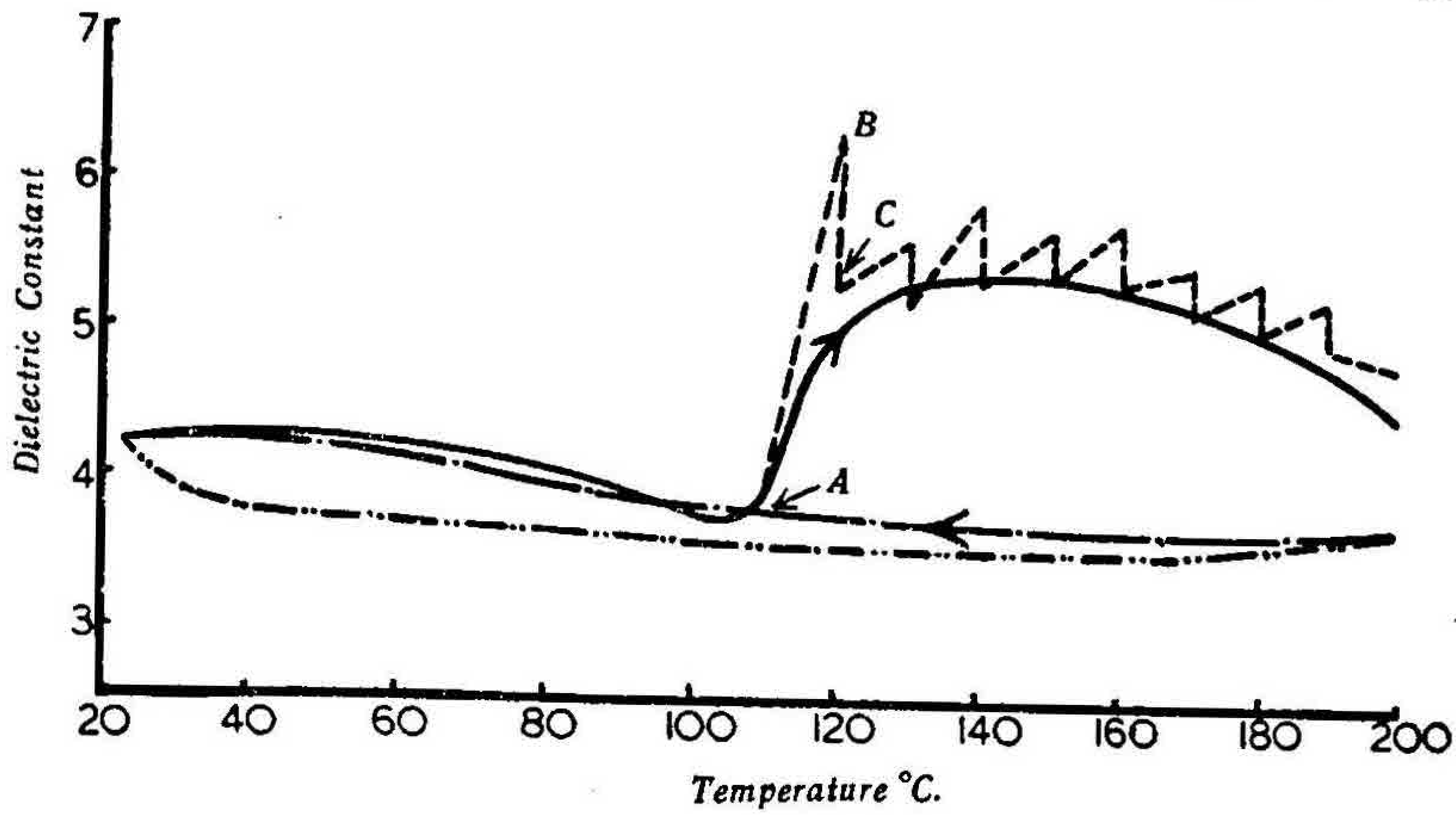

FIG. 2. "200" Wire.

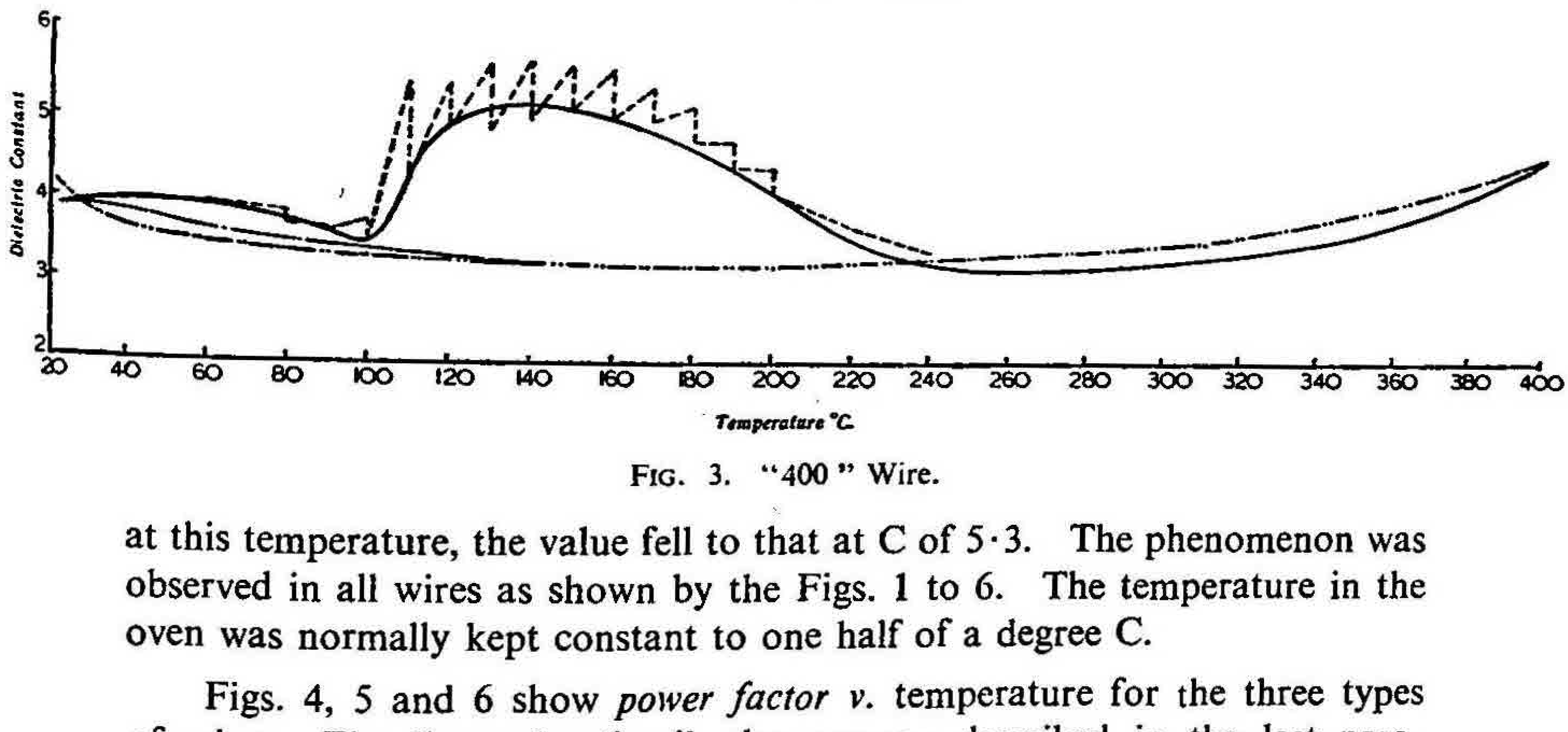

FIG. 3. "400" Wire.

at this temperature, the value fell to that at C of 5·3. The phenomenon was observed in all wires as shown by the Figs. 1 to 6. The temperature in the oven was normally kept constant to one half of a degree C.

Figs. 4, 5 and 6 show *power factor v.* temperature for the three types of wires. The "overshooting" phenomenon described in the last paragraph in regard to the dielectric constant is also present with the power factor, which is defined herein as the value of the tangent of the complement of the phase angle.

If the wires 200 and 400 are maintained at a certain temperature, the value of the power factor tends to reach the value of the "return temperature" curve. As shown, *e.g.*, in Fig. 6 the power factor of the 400 wire at point A of 195×10^{-3} will decrease in time to the value at B of $12\cdot0\times10^{-3}$, if the temperature is maintained at 130° C. for approximately an hour. The power

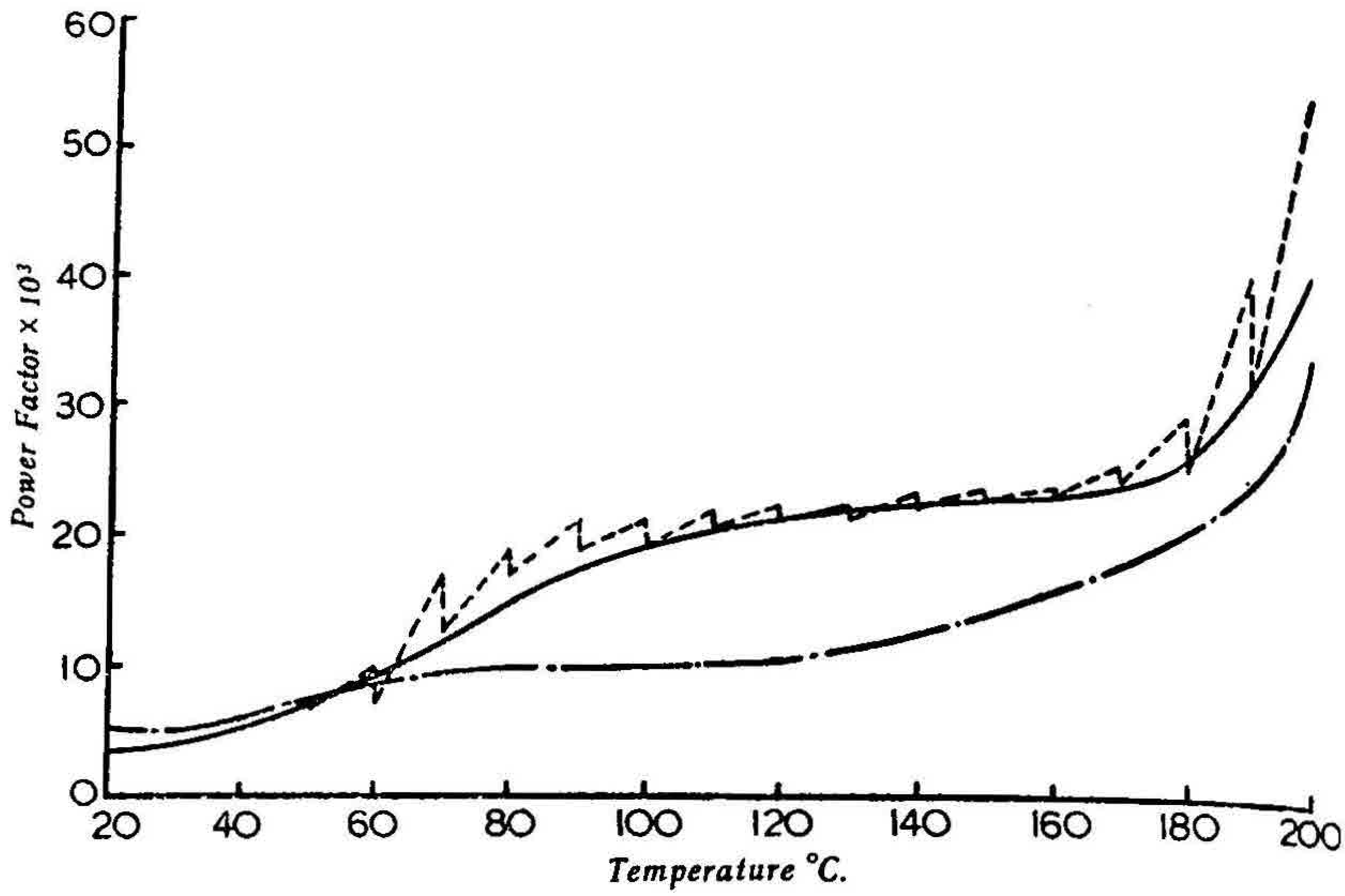

FIG. 4. "S" Wire.

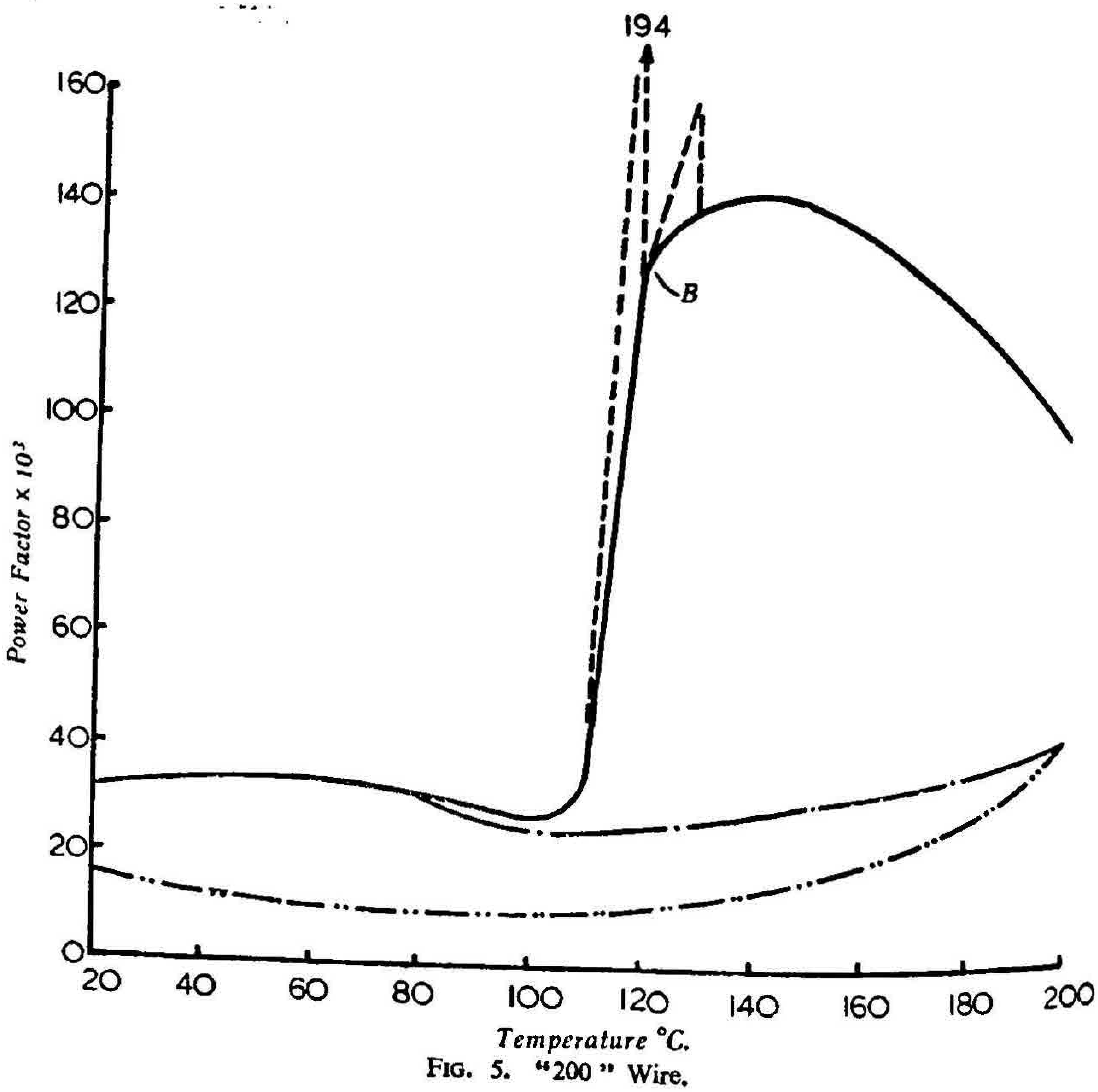

FIG. 5. "200" Wire.

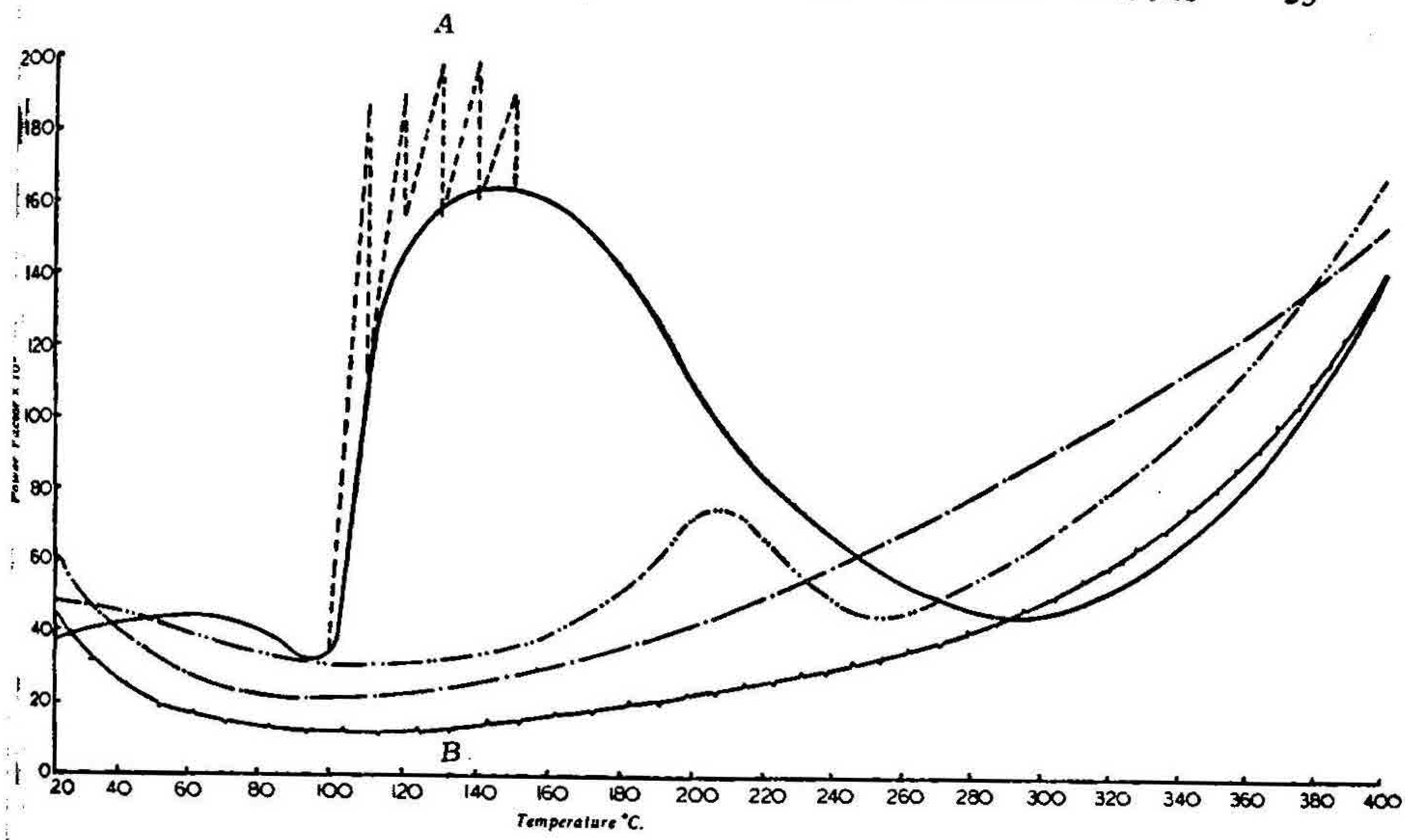

FIG. 6. "400" Wire.

factor of the S wire is low and smaller than the values of the two others up to 80° C.

Fig. 7 shows log of *resistivity* in ohm. cm. *v.* temperature. The insulation resistance of the 200 and 400 wire shows a steep decrease in the region of 100° C. to 140° C. Over this range the rate of increase of temperature has to be kept low or there may be a breakdown. The decrease of resistivity with increase of temperature is not as great with the S wire as with the 200 and 400 wires. The values of the resistivity of the three types of wire are of the same order.

It was observed for all wires that if the temperature were kept constant for any period of time, there was an increase of resistance, and a tendency to reach the point of the return curve. The return curve of the 400 wire is shown in Fig. 7. This phenomenon is common with most ceramic insulating materials.*

B. *Drying.*—A further investigation into the cause of the variation of dielectric constant with temperature was carried out using a new sample of 200 wire, similarly prepared, but dried in a desiccator over phosphorous

* Pfestorf, *Kunststoffe*, 1938, **28**, 241.
Pfestorf & Richter, *Physik. Zeitschrift*, 1939, **39**, 141.

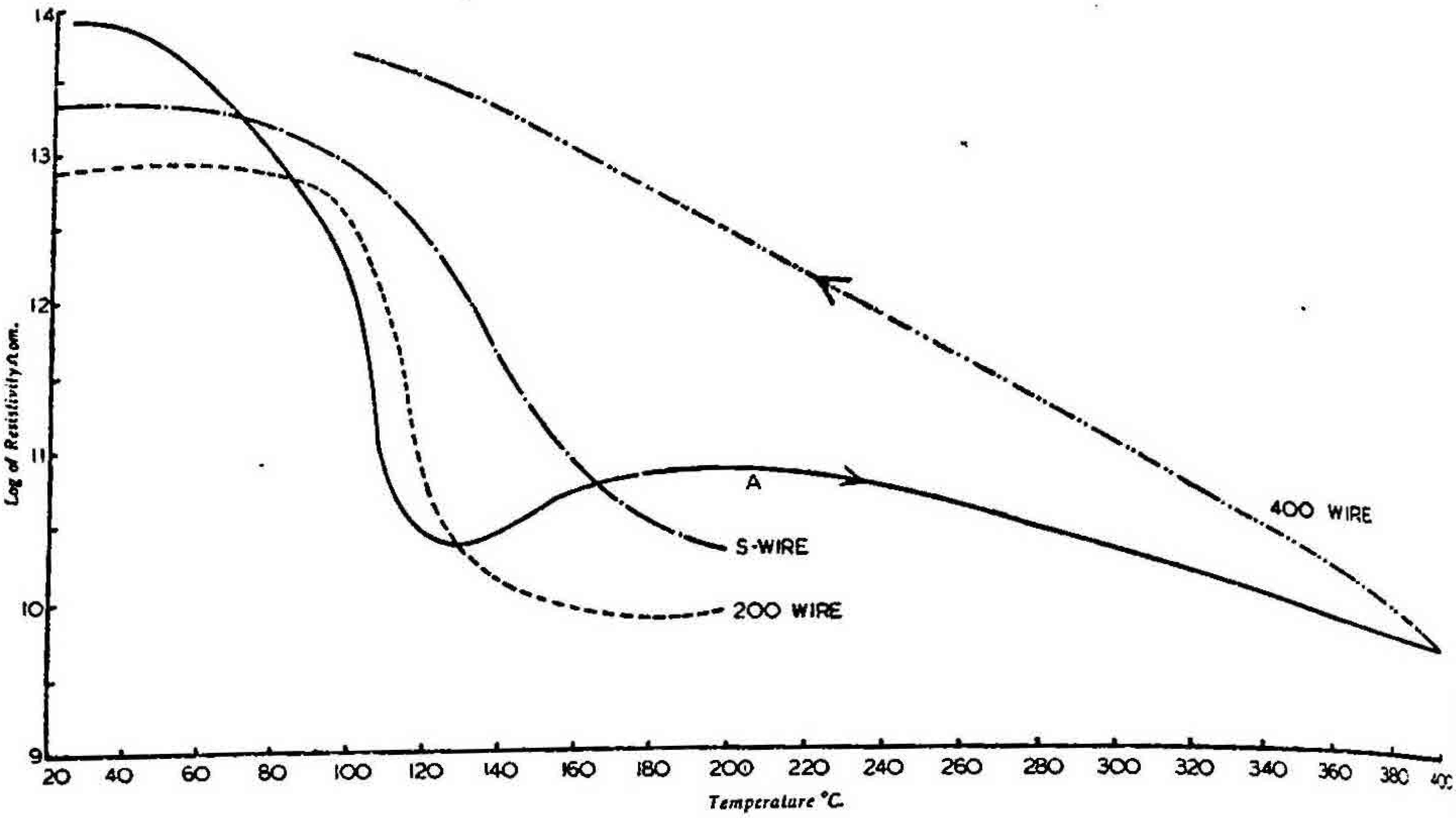

FIG. 7. "S", "200" and "400" Wire.

pentoxide for a period of 12 days before heating. A reduction in mass by ·02% was discerned. The results gave the same characteristic graph as in Fig. 2, and it therefore appears that the hump in the graph is not caused by any moisture in the insulation or aquadag coating.

C. *After Re-Heating*.—The wire samples were then re-heated and similar tests repeated. These results are shown in Figs. 2, 3, 5 and 6 by the curves marked with dash and dots.

It will be seen from Figs. 2 and 3 that the 'hump' which appeared before in the *dielectric constant* is no longer evident for the samples 200 and 400. The value of dielectric constant follows the return temperature curve from point A (Fig. 3). The dielectric constant values during the second heating are more stable.

A similar behaviour of the *power factor* of the 200 wire is shown by Fig. 5. With the 400 wire the hump is still present but not to the same extent as at the first heating (see Fig. 6). It is also displaced by about 60° C.

The overshooting of both dielectric constant and power factor is now very small.

These changes in phenomenon are similar to the changes of physical properties of polymers in a tempering process. It has been shown that a real increase in the heat stability of many polymers is induced by long heating below their decomposition point. This action of the test appears to be due only in part to the removal of volatile constituents. The exact nature of the change is not understood at present but is thought to be of a molecular nature.

II. *Breakdown Voltage*

Samples of each wire were wound once around a brass tube of external diameter of 3·2 cm. Weights of 70 g. were suspended from each end of the sample. An alternating voltage was applied between the brass tube and the exposed copper wire. This voltage was increased in about 20 sec. until breakdown occurred.

Measurements of the breakdown voltage were taken at various temperatures, see Table II, and some were done after reheating, see column 5 of Table II.

TABLE II

Breakdown Voltage and Mean Deviation (shown in brackets) in V (r.m.s.)

1	2	3	4	5
	Conditioning			
Sample	Room temper- ature	200°	400°	Cooled to 20° and raised to 200° resp. 400° C.
S	909 (137)	486 (264)	..	..
200	196 (72)	121 (74)	..	121 (104) at 200° C.
400	219 (38)	116 (34)	31 (34)	19 (14) at 400° C.

The values of the breakdown voltage of the 200 and 400 wires are rather low. However, the coating of these wires is very thin (see Table I) and does not conform with the specifications. At room temperature, the actual *breakdown strength* (V/cm) is of the same order as that of the S wire but only a tenth at 400° C.

III. *Temperature Effect and Water Absorption*

After being tested at 400° C., the 400 wire insulation left the wire easily leaving the copper very clean and bright. On measurement, the diameter of the wire had decreased by 0·003 mm. This loss of copper was due to the formation of a copper compound which had better adhering properties to the insulation than to the wire.

A new sample of each wire, 2 m. long, was weighed, heated to 100° C. for ½ hour, placed in an atmosphere of relative humidity of 100% and weighed again. The results of these tests are given in Table III.

TABLE III

Sample	Loss by heating % ½ hour at 150°	Water absorption % After 24 hours in 100% R.H. at R.T.
S	0·032	0·018
200	0·050	0·017
400	0·083	0·017

Table III shows that the water absorption of all the three types is of the same order and that the ceramic part of the new insulation of the 200 and 400 wire is well protected by the thin cover of teflon.

As the insulation of the 200 and 400 wires was mechanically weak, a protective covering seems to be necessary after winding.

CONCLUSION

Three different types of enamelled wires were investigated. The Standard Nylon type S as already known has fairly good electrical properties.

The other two Magnet wires new on the market are meant for high working temperatures; their electrical properties were measured up to 400° C. They show a behaviour similar in some respects to ceramics at high temperatures. The enamel after heating to high temperatures gets brittle and a protective covering after winding seems to be advisable.

However their electrical behaviour is amazing and outstanding, considering the extraordinary thin cover of the copper wires. The measurements on enamelled wires were for the first time extended to such high temperatures and they give a vivid indication of what can be expected of the new plastic materials in the future. Literature References are given in an Appendix.

APPENDIX

LITERATURE REFERENCES

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