DESIGN, CONSTRUCTION AND CALIBRATION OF A PHOTOELECTRIC PYROMETER

by

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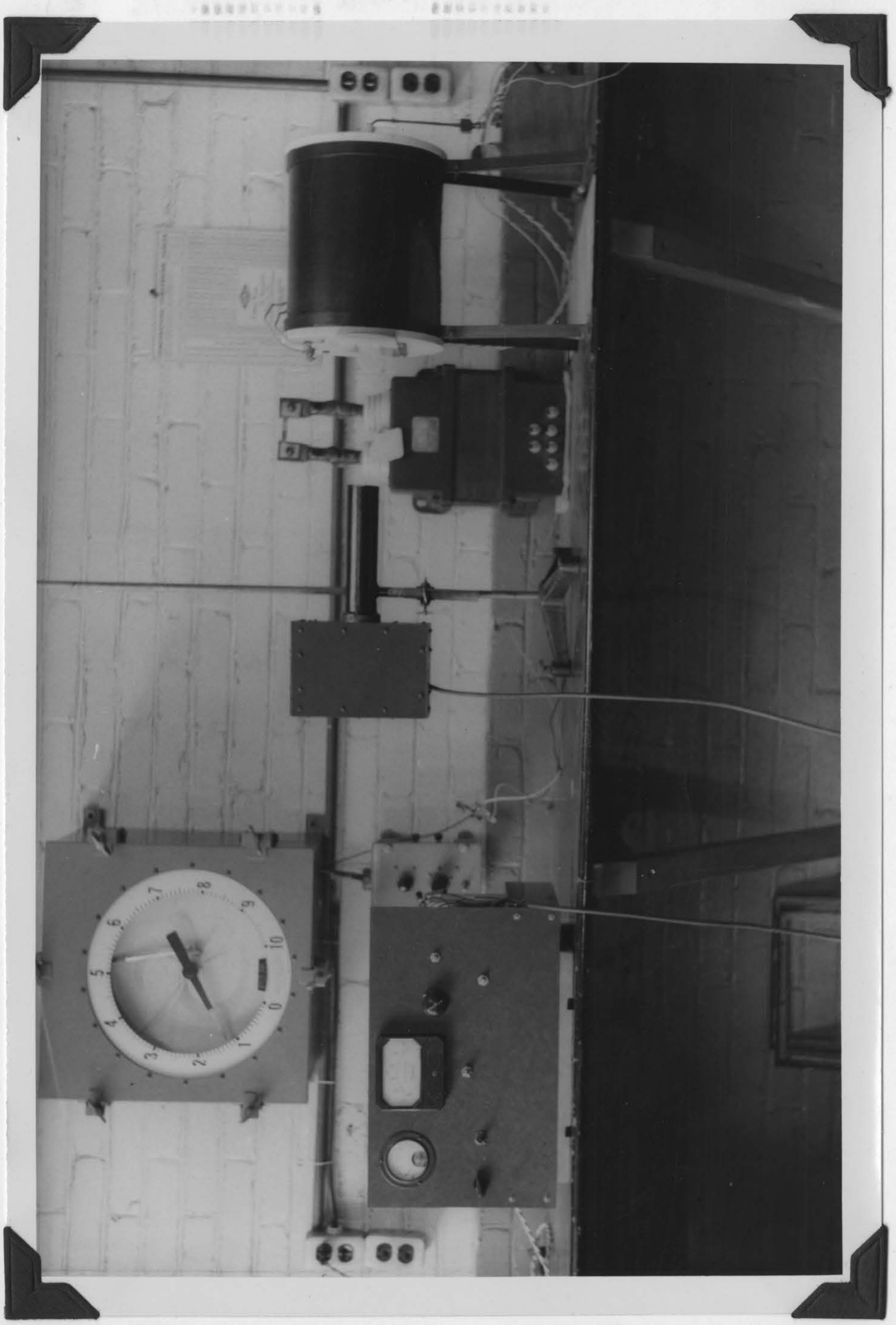

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INTRODUCTION

On account of the growing necessity for accurate and fast methods of measuring temperature, this investigation was undertaken at the Pyrometry Laboratory of the Department of Physics at the Virginia Polytechnic Institute. The objectives to be reached were the design, construction, and calibration of an instrument for fast and accurate measurements of high temperatures using a photoelectric tube as the receiver of the radiation from the body whose temperature was to be determined.

Because of the nature of the furnaces to be used in the calibration of the instrument, it was necessary to place the high temperature limit of the instrument at about 1650° F.

The results of the investigation indicate that this method of temperature measurement has advantages over the other systems in common usage. Under laboratory conditions, using a number 8 chromel-alumel thermocouple as a standard, temperature measurements were reproducible within 1% of each other over the range 1200° F to 1600° F.

The apparatus consists of three main parts: (1) the radiation receiver, (2) the amplifier, and (3) the power supply. The current to the meters is controlled by the output of the amplifier which is responsive to the minute signal from the photoelectric tube.

The instrument is built up entirely around electronic tubes of various types.

IV

Review of Literature

Scope of Problem

The temperature of a body has been measured by various methods. Among these are included:[1]

1. Increase in dimensions
2. Increase in pressure, if confined
3. Change in e. m. f. developed during contact with some other substance
4. Change in electrical resistance
5. Increase in the amount of radiation from the surface of the body
6. Change in color of the body
7. Change in state

This thesis is concerned only with the measurement by means of a photoelectric tube of the increase in the amount of radiation from the surface of the body.

In order to measure accurately the radiation from the surface of a body, it is important that the radiation be measured under blackbody conditions, or that the emissivity of the surface of the body be known at the temperature measured. If the emissivity is known, then the true temperature can be found by the relationship:[2]

$$\frac{1}{T(\text{true})} - \frac{1}{T(\text{apparent})} = \frac{\log_{10} E}{9880}$$

A blackbody electric furnace was used as the source of radiation in calibrating the instrument herein described.

The problem of this thesis was to design and construct a self-contained, portable instrument for fast and accurate temperature measurements using a photoelectric tube as the radiation sensing device and the usual 110 volt a. c. line as the source of power.

Temperature Measuring Instruments

The temperature measuring instruments used in this research were: the base metal thermocouple, the optical pyrometer and the photoelectric pyrometer. The thermocouple used consists of one chromel*wire and one alumel*wire welded together at one end. The heating of this junction generates an emf in the wire which is a function of the temperature of the junction. A calibration of a base metal thermocouple may be represented by Holman's equation:[3]

$$e = mt^n$$

where:

e = thermal emf as measured by a millivoltmeter with high resistance or by a potentiometer

m and n = constants dependent upon the kinds of metals used and the choice of units

t = temperature of the hot junction

The chromel-alumel thermocouple has a calibration

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* chromel: 90% Ni & 10% Cr.
alumel: 95% Ni & 2% Al & 1% Si

curve which is very nearly a straight line, and it has a thermoelectric power of 0.043 mv/°C. This means that a chromel-alumel couple at 1000°C gives an emf of 43 mv. The thermoelectric power of base metal thermocouples have a tendency to change with age. For accurate temperature measurements, a thermocouple should be recalibrated after an extended period of use.

The optical pyrometer used in this research was of the disappearing filament type. This type of pyrometer is used to measure the intensity of radiation of a body for a particular wave length. The absolute temperature of the body is determined by substituting these values in Wien's equation:[4]

$$J_\lambda = C_1 \lambda^{-5} e^{-\frac{C_2}{\lambda T}}$$

where:

J_λ = intensity of radiation at wavelength λ

c_1 = constant dependent upon the arrangement of apparatus

λ = wave length of radiation

e = base of Naperian logarithm system

c_2 = 14,330 when λ is expressed in microns

T = temperature of the body in degrees Kelvin

In the disappearing filament type of optical pyrometer a filter is used to allow only a narrow band of wave lengths to enter (usually red, λ = 0.63 micron).

In operation, the ocular is first focused upon the lamp filament, and the telescope is then pointed at and focused upon the high-temperature source. The filament is connected in series with a battery, milliammeter, and variable resistor. As R is varied the filament temperature and hence its brightness is varied. The setting of the pyrometer then consists in adjusting R until the center of the filament just merges in brightness with the bright background of the image of the high-temperature source. The reading of the milliammeter, I, for this condition of intensity match is then used as an indication of the temperature of the source. The temperature of the source can be determined by the equation:[5]

$$I = A + BT + CT^2$$

where:

A, B, and C = constants to be determined

I = Milliammeter reading

T = Absolute temperature

Or the milliammeter may be calibrated directly in degrees.

Photoelectric tubes have been used as heat sensing devices in several types of photoelectric pyrometers. The two-color photoelectric optical pyrometer[6] makes use of two photoelectric tubes, (one with a red filter and the other with a green filter) connected in a Wheatstone network. By balancing the network when both tubes are exposed to the same source, the true temperature of the radiating body may be determined by the value of the resistances used to balance the network. In using two photoelectric tubes, each exposed to a different range of wave lengths, the effect of the emissivity of the source may be eliminated and the true temperature of the body determined.

Another pyrometer employing two photoelectric tubes is the Brown Automatic Photoelectric Pyrometer.[7] In this pyrometer one of the photoelectric tubes is focused on the high temperature source and the other tube is focused on a carbon filament lamp. The lamp is connected in a network controlled by the first photoelectric tube. The measuring circuit is connected in a network with the second photoelectric tube. This arrangement gives automatic compensation for any fluctuations in line voltage.

The Foster Photoelectric Pyrometer[8] employs only one photoelectric tube with an amplifying circuit fed from a rectifier with stabilizing equipment.

All three photoelectric pyrometers mentioned are usually inaccurate below 1000° C.. Also smoke, steam, flame, and scale on the surface of the heated metal in all cases must be absent if errors in temperature reading are to be avoided.

Photoelectric Tube Characteristics

Photoelectric tubes are made in two types. They may be gas filled or vacuum type tubes. In both cases the tube must have a cathode with a coating of some substance which will emit electrons when exposed to light and an anode. The cathode films are usually made of some metalic oxide, such as cesium oxide, sodium oxide, or potassium oxide, which is deposited on the metalic cathode as a monatomic layer. Photoelectric tubes have a transparent window or else are made entirely of a transparent material (usually glass) in order for the light to reach the cathode.

If a potential difference is maintained between the cathode and anode, there will result a flow of electrons from cathode to anode when light is allowed to fall on the cathode. The electron emission of the cathode, though directly proportioned to the intensity of the radiation reaching the cathode, is most sensitive in certain wave length regions, depending upon the oxide coating on the cathode. Photoelectric tubes are made with several different cathode coatings so that a tube may be selected for maxium sensitivity in almost any spectral region from 4,000 A to 9,000 A.[9]

Gas filled and vacuum type photoelectric tubes are constructed alike. The characteristic curve of the gas filled tube shows that a larger electric current will pass through it than a vacuum type tube for the same intensity of radiation. Also the gas tube shows fatigue (decrease in sensitivity) after exposure to high intensity radiation or after long periods of exposure while the vacuum type tube does not.[10]

The ambient temperature of both types of tubes must be kept below 75° C or 100° C, depending upon the spectral response.

Since the current yield of a photoelectric tube is very small, there must be some method of amplifying the current so that the tube may be of practical use as a measuring instrument.

Electronic Methods of Amplification

Electronic amplifying tubes consist of an anode or plate, a cathode, and one or more grids. Also for most amplifying tubes there is a cathode heater so that electrons can be emitted from the surface of the cathode thermionically. These amplifying tubes are vacuum tubes and are usually made of glass. Although an amplifier may have more than one grid, the one nearest the cathode controls the amplifier output; the others being used to refine the characteristics of the tube. If the output signal is the exact duplicate of the input signal except for magnitude, the amplifier is said to be ideal. For all practical purposes this can be achieved.[11]

A potential difference is maintained between the plate and cathode, and the input signal is imparted to the control grid. As the input signal becomes more negative the output grows larger. For great amplification, tubes may be connected in cascade. The output of the first tube is used as the input signal for the second, etc.

For satisfactory operation, a source of direct current of constant voltage must be maintained. Any variation in the voltage across plate and cathode of the amplifyer will result in distortion of the output.

Electronic Methods of Voltage Regulation and Rectification

Gas filled diodes employing a heater for the cathode may be used as regulators if very low voltage is to be used. The voltage drop across an ordinary gas filled diode rarely exceeds 20 volts. Where larger voltages are to be regulated, the glow-discharge gas diode is used extensively.

The glow-discharge tube is very accurate as a voltage regulator if the current, which should be direct, does not exceed 30 ma.[12]

For the rectification of large alternating currents, mercury arc rectifiers are often used. Where only low values of direct current are needed, as in most electronic circuits, vacuum type electronic tubes are often used. This type of tube may be a half-wave or a full-wave rectifier. In both cases the electrons are emitted from the cathode thermionically, either directly from a thoriated tungsten filament cathode or from a cathode with a separate heater circuit.

In operation these tubes are connected across an alternating current line. Since the cathode emits electrons there can exist an electric current only when the plate is positive and the cathode negative. Since the plate does not emit electrons, however, there can be no electric current when the cathode is positive and the plate negative. This would result in a half-wave rectified direct current. For a full wave rectified current, two half wave rectifier tubes may be used or a tube employing two plates may be used. In the latter, one plate or the other is always positive with respect to the cathode, thus allowing direct current to pass on each half cycle of the alternating current. This direct current is pulsating, but it can be smoothed by an arrangement of capacitors and inductance coils in the circuit[13].

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THE PYROMETER DEVELOPED IN THIS RESEARCH

Theoretical Discussion

For the great majority of pyrometers in general use, it is not possible to know the exact temperature of a body at a given time except at certain transition temperatures. Because of the thermal capacity of pyrometers which must be immersed in the source, the temperature of the body is not determined until some later time after immersion. For optical pyrometers there must be a color or brightness match when the scale is read. Very seldom will two people match the brightness the same, and seldom will the same person reproduce a match exactly. With all types of pyrometers there is an ageing effect, so that frequent calibration is necessary.

Because a photoelectric tube is used as the radiation receiver, the pyrometer designed and built in this research is thought to provide a portable instrument for instantaneous temperature measurement with no thermal capacity and no chance for errors because of the characteristics of the eye and the judgment of the operator.

The Radiation Receiver

A phantom view of the radiation receiver used is shown in Fig. 1. This receiver was designed so that the baffles in the brass tube (T) would allow the radiation from the source just to cover the cathode of the photoelectric tube. This was done to protect the accuracy and life of the instrument. If radiation were focused on a certain area of the cathode, there would be a chance that the small area covered with intense radiation might be destroyed sooner than would be expected with the method employed. Also for ease of operation and the possibility of excluding some radiation there was no focusing apparatus included. As long as the source of radiation completely fills the field of view through the brass tube there should be no need for adjustments or recalibration.

Taking into consideration the properties of gas filled and vacuum type photoelectric tubes, it was decided that a vacuum type tube should be used. In selecting the spectral range of maximum sensitivity that would be best suited in this pyrometer, the temperature range under which it would be operated was first decided. Because of the nature of the electric furnaces that were available a temperature in

KEY TO FIG. 1

O - peep hole for aiming

M - mirror

P - glass plate

A - photoelectric tube 919

D - housing

C - two-wire shielded cable

T - brass tube

B - baffles

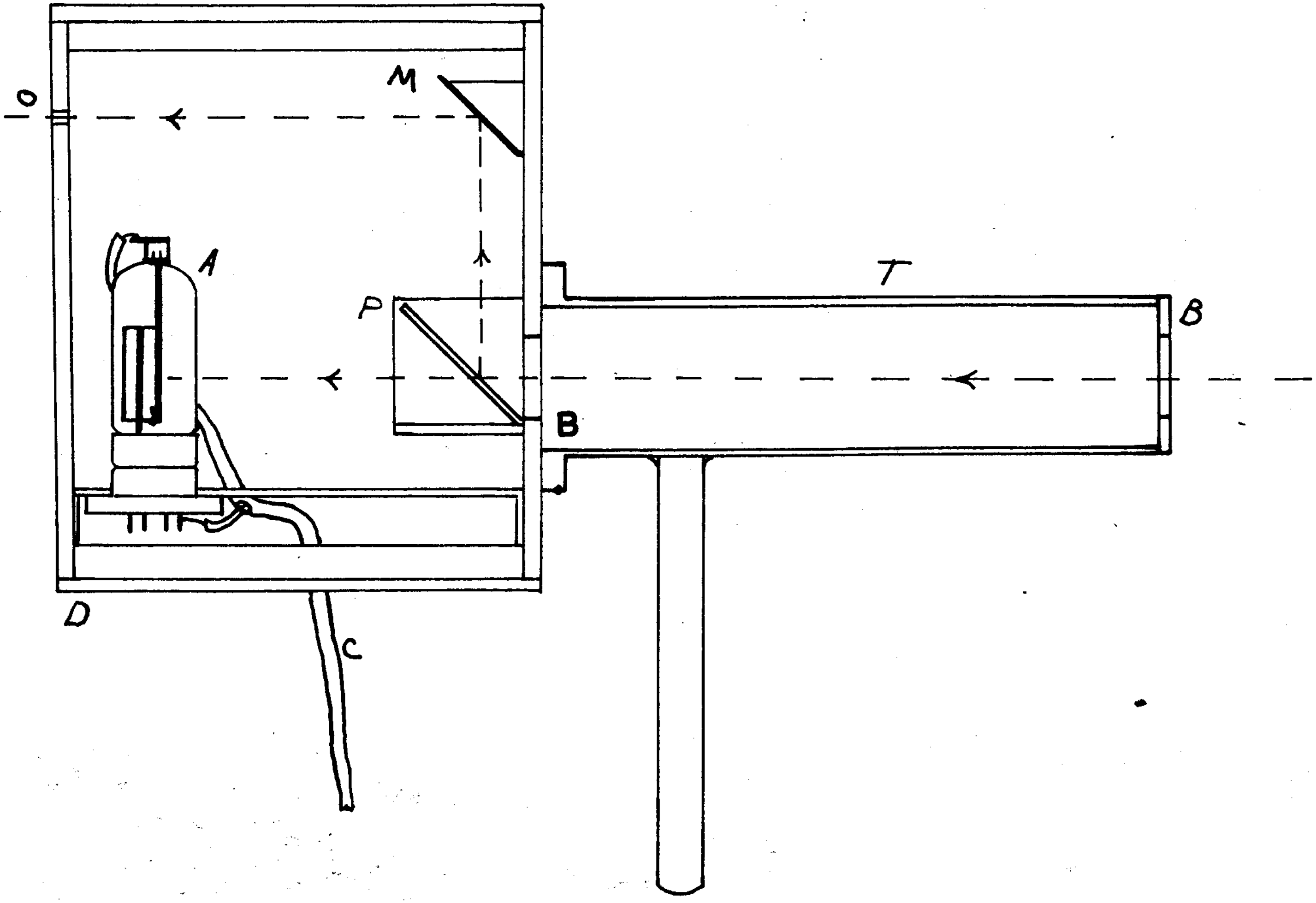


FIG. 1 Radiation Receiver

excess of about 1650° F could not be maintained without damage to the furnace. A temperature range from 1650° F down as low as could be determined was, therefore, decided upon. Bodies in this temperature range emit radiation of maximum intensity in the red and infra-red regions of the spectrum.[14] A vacuum photoelectric tube was chosen with a S-1 response curve,[15] which has high sensitivity in this region.

An optical arrangement was used to allow for aligning the receiver properly with the source whose temperature was to be measured. The glass plate, (P), was set at an angle of 45° with the incoming radiation so that a small portion (about 4%) of the radiation would be reflected to the mirror (M) and thence through the peep hole (O).

The baffle (B) in the end of the brass tube (T) and the opening in front of the glass plate (P) were made the same size as the cathode of the photoelectric tube(A). These were used in order to reduce any radiation except that coming directly from the temperature source. Except for the openings mentioned the box (D) which surrounds the photoelectric tube was made light-tight so that room lights would not cause false temperature readings.

In order to reduce the error from external electrical influences, the photoelectric tube was placed on a metal base and the two wires from the tube to the amplifier were shielded with a flexible metal covering which was grounded to the tube base as well as to the power supply-amplifier base.

The Amplifier

The amplifier, a circuit diagram of which is shown in Fig. 2, was designed and constructed especially to be used with the radiation receiver described above. For the temperature region already mentioned, it was found that it was necessary to have two amplifying tubes in order to get any appreciable meter deflection at the lower temperatures.

This amplifying circuit was built into a resistance network so that it could be balanced in such ways as to get full scale meter deflections for practically any intensity of radiation reaching the photoelectric tube, above a certain minimum.

Two meters were used so that the circuit could be balanced to give a large meter deflection for a relatively small change in source temperature. This should help reduce some errors that might affect the accuracy of the instrument. Meter No. 1 has a 200 microampere full scale deflection, and meter No. 2 has a one milliampere full scale deflection. A third range is obtained by using R_5 as a shunt across meter No. 2 by throwing switch S_2.

The cathode heaters are operated from transformers T_1 and T_2. To minimize the grid current, the heater of pentode 38 is operated at only about two-thirds its normal voltage rating.

Probably one of the main advantages of this amplifying circuit is that rectified alternating current may be used as the power supply.

The Power Supply

A decided advantage of the pyrometer developed in this thesis is the ability to use any 110-120 volt outlet as a source of power. This enables the instrument to be used wherever there is an electric outlet of this voltage. By eliminating batteries as a source of power, the weight of the instrument is decreased considerably.

The power supply for the amplifier discussed above is assembled compactly on the same chassis as the amplifier. A circuit diagram of the power supply is shown in Fig. 3. Since electric power of two accurately controlled voltages are necessary to balance the bridge network of the amplifier, the electronic voltage regulator tubes of the glow-discharge type were employed. By using two 150 volt regulator tubes in series the 300 volt source was established, and by connecting between the two tubes, the 150 volt source was secured.

As a source of power to these two voltage regulator tubes it was necessary to supply at least 300 volts. This was accomplished by rectifying alternating current from a 435 volt center-tapped transformer.

KEY TO FIG. 2

R_1 = 1 megohm

R_2 = 101 megohms

R_3 = R_4 = 0.1 megohm

R_5 = 25 ohms

R_6 = 0.5 megohm

T_1 = 5 volt transformer

T_2 = 6.3 volt transformer

S_1 = 3 pole switch

S_2 = shunt switch

KEY TO FIG. 3

C_1 = C_2 = 15 microfarads

R_1 = 3500 ohms

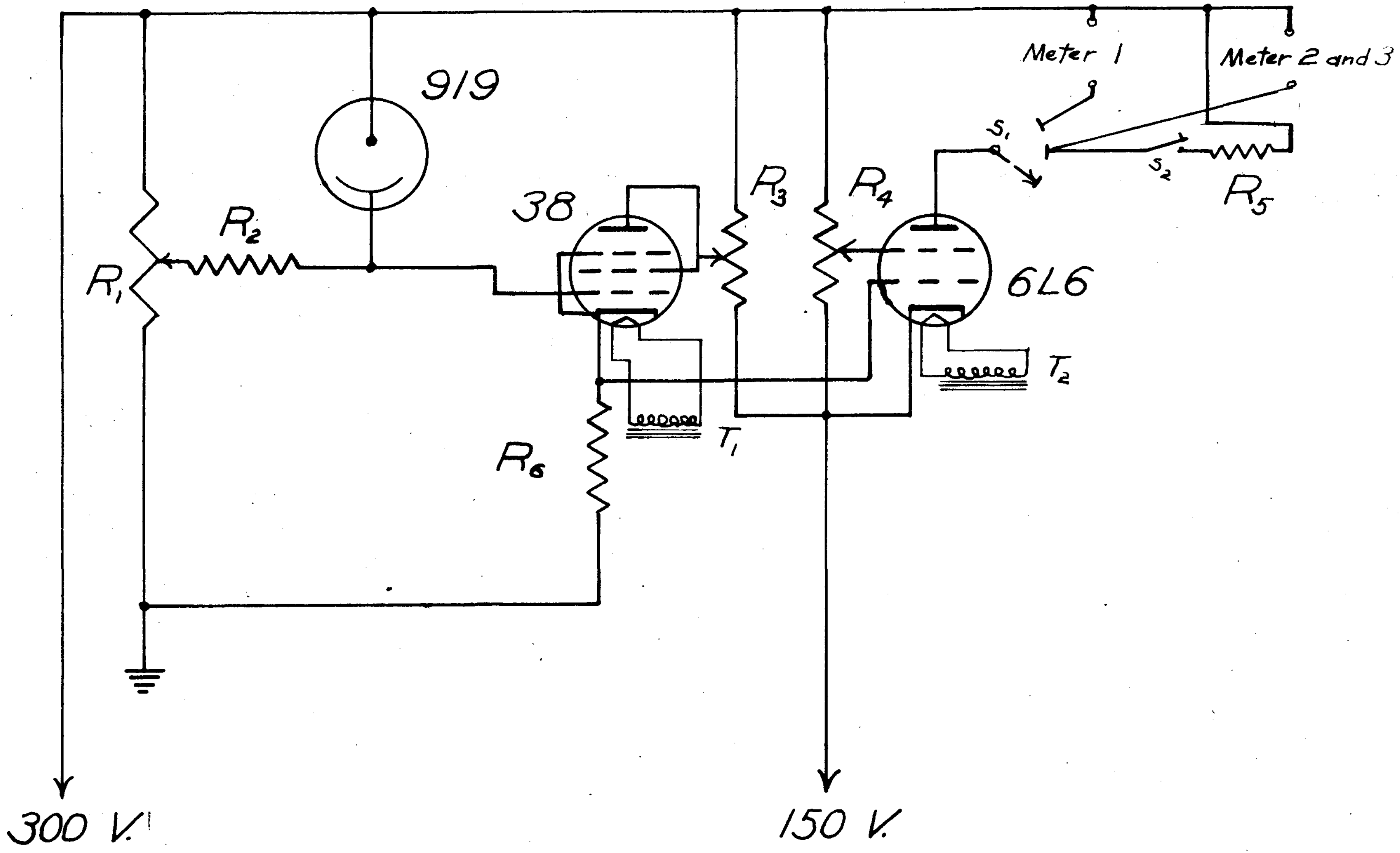


FIG. 2 Amplifying Circuit

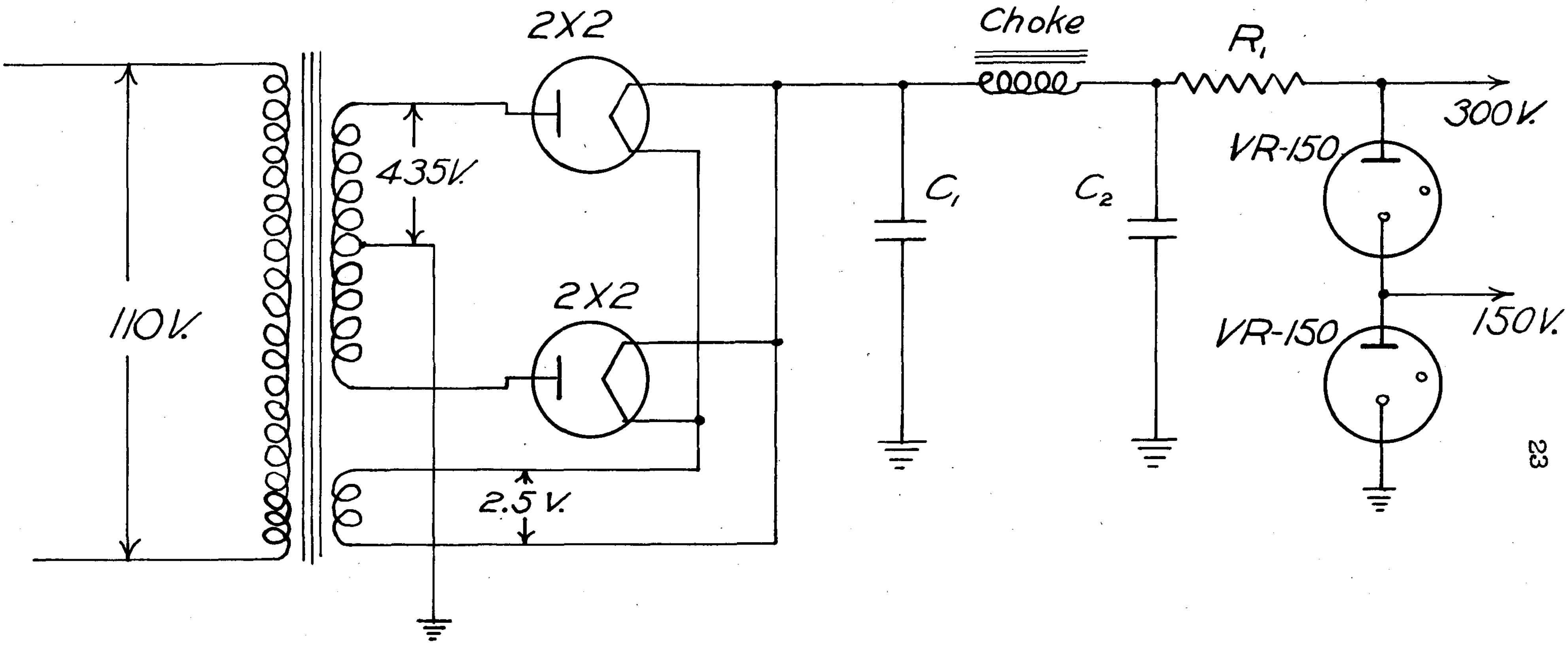


FIG. 3 Rectifier and Voltage Regulater Circuit

As rectifying electronic tubes, two 2 X 2 vaccuum type tubes were used. The full-wave, rectified, pulsating direct current from these tubes was smoothed out to constant voltage by the two 15 microfarad capacitors and the 20 millihenry choke coil. Since only a small amount of power was required to operate the instrument, a small, relatively light transformer was used. For the various heater circuits, one small filament transformer was used. It was connected in parallel with the main transformer, and provides the correct voltage and current required by each tube in the entire instrument. The compactness of the amplifier and power supply, and the relatively light weight ofthe pyrometer make it conveniently portable.

Principles of Operation

The spectrum of a blackbody radiator is continuous. From the short-wave end, the spectral intensity curve rises rather sharply to a maximum and then declines more gradually toward longer wave lengths. The position of the maximum depends on the temperature of the radiator, in accordance with Wien's displacement law:[16]

$$\lambda_m T = b$$

where:

λ_m = wavelength of maximum intensity in A

T = temperature of radiator in degrees Kelvin

b = a constant, 2.884×10^7

From this relationship it may be seen that the temperature of a blackbody radiator may be determined with the use of a spectrograph to determine the wave length of maximum intensity. However, this would be a rather slow and cumbersome method. Although it may be possible to use several photoelectric tubes in connection with a spectroscope to determine temperatures in this manner, it was not the intent of this research to develope such a method.

As the temperature of a blackbody radiator is increaseed the total radiation emitted from it increases in accordance with the Stefan-Boltzmann law:[17]

$$W = \sigma T^4$$

where:

W = total radiant power in watts/cm^2 of source area

σ = a constant, 5.735×10^{-12}

T = temperature in degrees Kelvin

Since photoelectric tubes are not sensitive in all regions of the spectra, and since they are not equally sensitive to all wave lengths to which they respond, photoelectric tubes can not be used to measure tatal radiant power. Photoelectric tubes may be used as radiation receivers, however, and the amount of radiation recorded by an amplifier can be calibrated against a standard temperature measuring instrument. This is what was done in this research.

A blackbody electric furnace was used as the source of heat so that the emissivities of a body would not have to be considered. Blackbody radiators are useful as standards in the visible and infrared regions because their radiation distribution is completely determined by their temperature.

VI

EXPERIMENTAL PROCEDURES

The first problem to be considered was that of selecting a photoelectric tube with maximum sensitivity in the range of the spectrum most abundant at the temperature to be measured. After considering the characteristics mentioned in a preceding section, a RCA-919 tube was selected as the sensing element. To facilitate handling and for the sake of weight, the only tube placed in the radiation receiver was the photoelectric tube. The response curve for the RCA-919 tube is shown in Fig. 15 of the appendix. Also the spectral emittance of a blackbody at certain indicated temperatures is shown in the same figure.

The rest of the instrument was built so that the radiation received by the sensing element could be detected and its effect amplified enough to give a fairly large meter deflection for a small change in temperature in the range from 1100° F. to 1600° F. Accuracy and portability were considered most important in the construction of the amplifier and power supply.

It was found (even for a very sensitive meter) that the meter deflections were relatively small for considerable changes in temperature at the lower end of the proposed temperature range. But at the upper end of the temperature range there were very large deflections for small changes in temperature. In order to cover the entire range accurately with tuning the instrument only once, it was decided to use more than one meter. Meter No. 1 (200 microampere range) was used in the low end of the tmperature range; meter No. 2 (one milliampere range) was used in the middle temperature range; and a shunt resistance across meter No. 2 was used in the high temperature range. Instead of tuning the instrument for large meter deflections in each range, a switch was provided to change from one meter to another.

The completed instrument arranged to observe temperatures in a furnace is shown in the photograph used as the frontispiece.

VII

DISCUSSION OF RESULTS

After the photoelectric pyrometer described above was assembled, the problem arose of adjusting the resistors in the circuit of the amplifier so that maximum sensitivity in the temperature range desired could be obtained. Of course, there were several procedures that could be followed in each temperature range that would give approximately the same meter deflection for the same temperatures, but it was decided that the instrument could be more easily adjusted by a person not familiar with its internal circuit if a definite prodedure were followed for tuning. Two methods for tuning were worked out (one for low temperature and one for higher temperatures), and are included in the appendix.

The photoelectric pyrometer was calibrated using a No. 8 chromel-alumel thermocouple as the standard temperature measuring instrument. For the low temperature settings four sets of data for each meter were recorded while the furnace was heating. These runs were made under as nearly the same conditions as possible. The average of these four runs representing the calibration curves for the three meters are plotted in Figs. 4, 6, and 8.

To determine the accuracy with which temperatures could be determined in the low range, the extreme meter readings for each meter were plotted against the thermocouple temperature. These curves are represented in Figs. 5, 7, and 9. From these graphs it may be seen that the maximum temperature fluctuations for each meter is within ± 1%.

For the high temperature readings four sets of data were taken for Meter No. 1 and the averages of these two runs gave the calibration curve plotted in Fig. 10. Fig. 11 shows curves representing the extreme meter deflections. From this graph it is seen that the accuracy of the instrument for this temperature range is also within ± 1%.

Table No. 1

LOW TEMPERATURE SETTING FOR METER NO. 1

Result of Four Runs heating

Furnace Temp. °F	meter readings heating				
	1 st	2 nd	3 rd	4 th	av.
1000	10	10	10	10	10.00
1050	10.5	11	11	11	10.87
1100	12	13	13	13	12.75
1150	14	17	16	16	15.75
1200	20	22	22	22	21.50
1250	31	36	36	33	34.00
1300	55	58	57	58	57.00
1350	115	119	120	117	117.75
1400		off	scale		

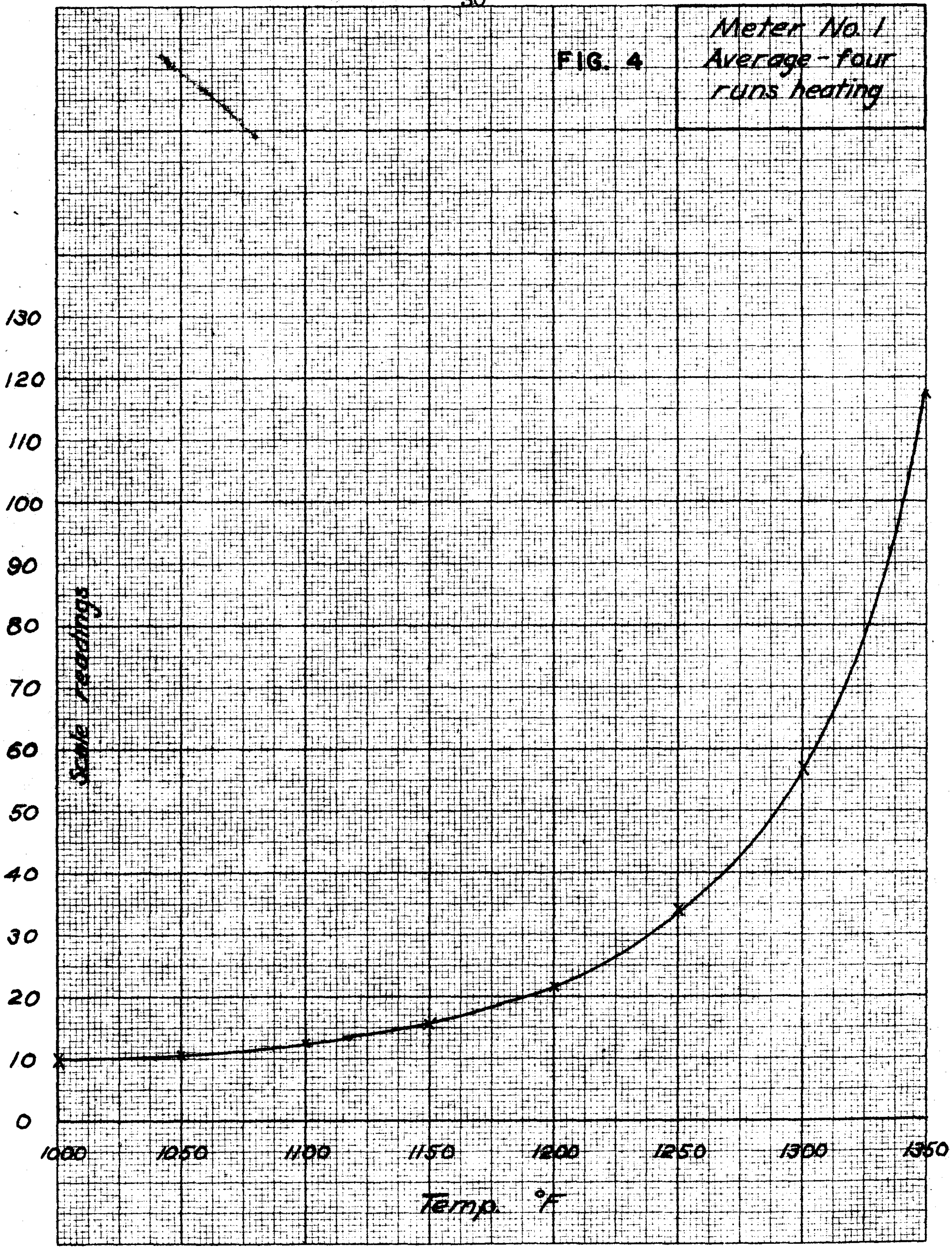


FIG. 4

Meter No. 1
Average - four runs heating
Scale readings
0
10
20
30
40
50
60
70
80
90
100
110
120
130
1000
1050
1100
1150
1200
1250
1300
1350
Temp. °F

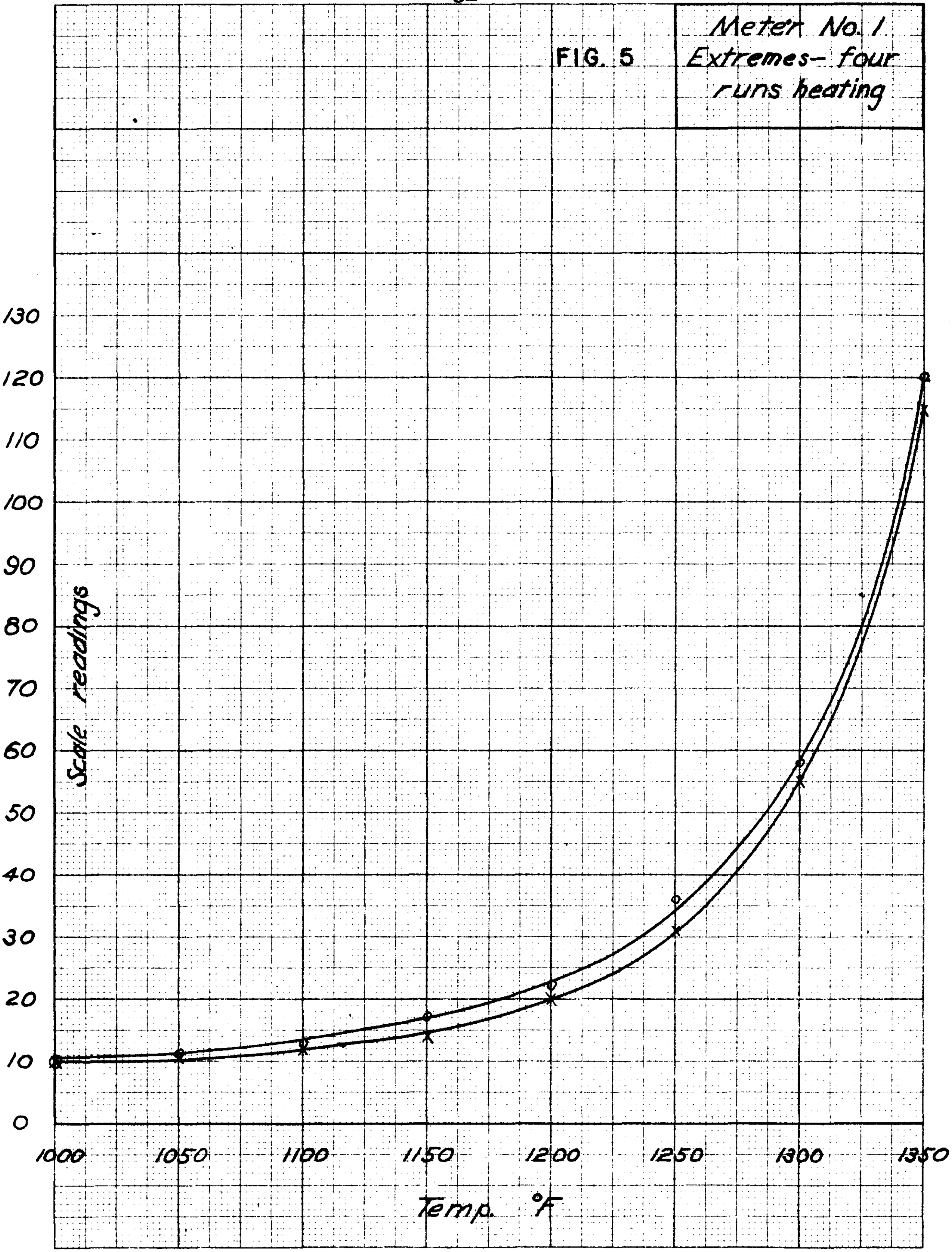


FIG. 5

Meter No. 1
Extremes- four
runs heating

Table No. 2

LOW TEMPERATURE SETTING FOR METER NO. 2

Result of Four Runs Heating

Furnace Temp. °F	meter readings heating				
	1 st	2 nd	3 rd	4 th	av.
1200	2.1	2	2	2	2.03
1250	5	4	4	3	4.00
1300	9	9.5	8	7	8.38
1350	15	16	13	15	14.75
1400	28	28	32	28	29.00
1450	63	63	58	61	61.25
1500		off scale			

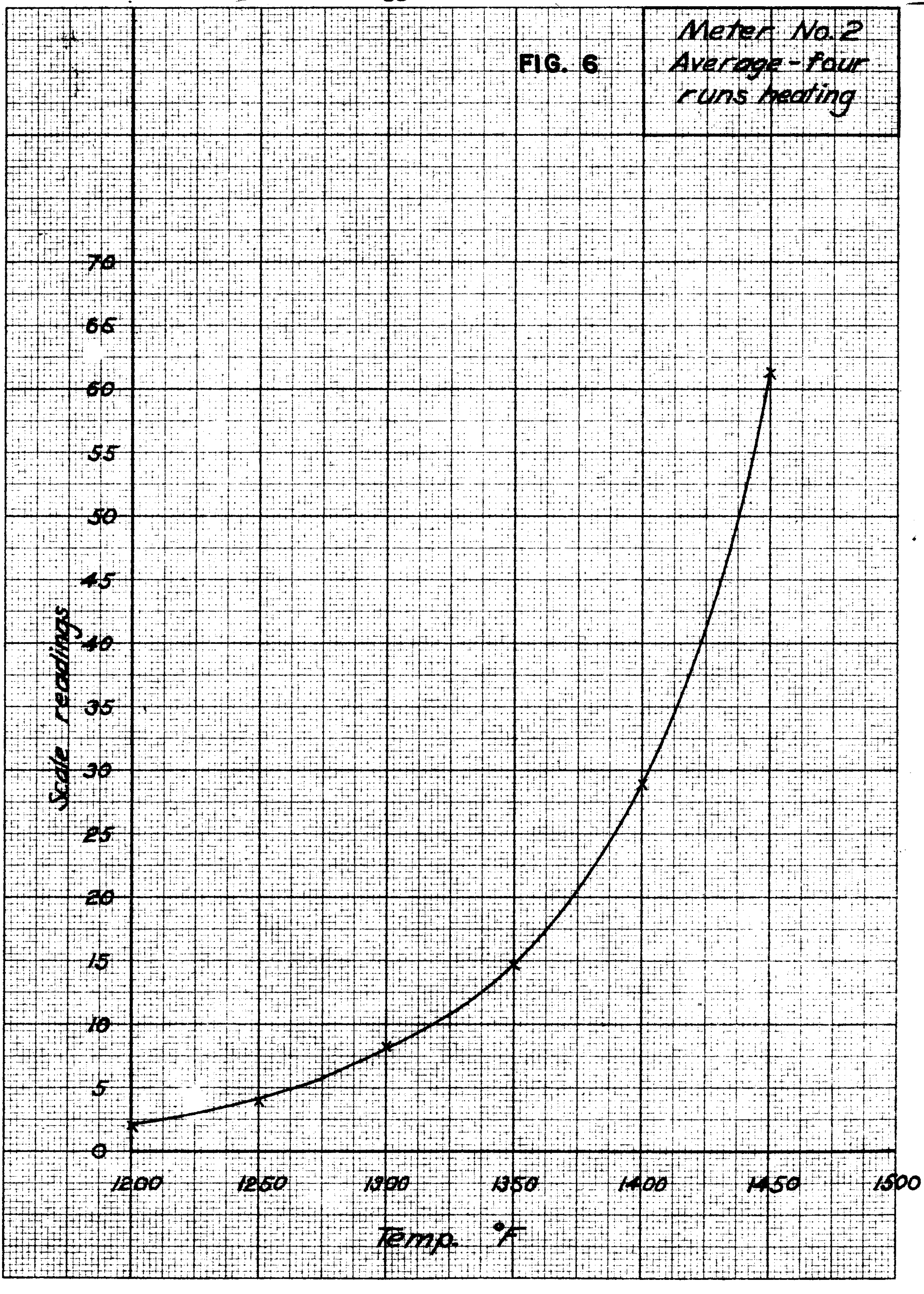


FIG. 6

Meter No. 2
Average - four
runs heating

FIG. 7

Meter No. 2
Extremes - four
runs heating

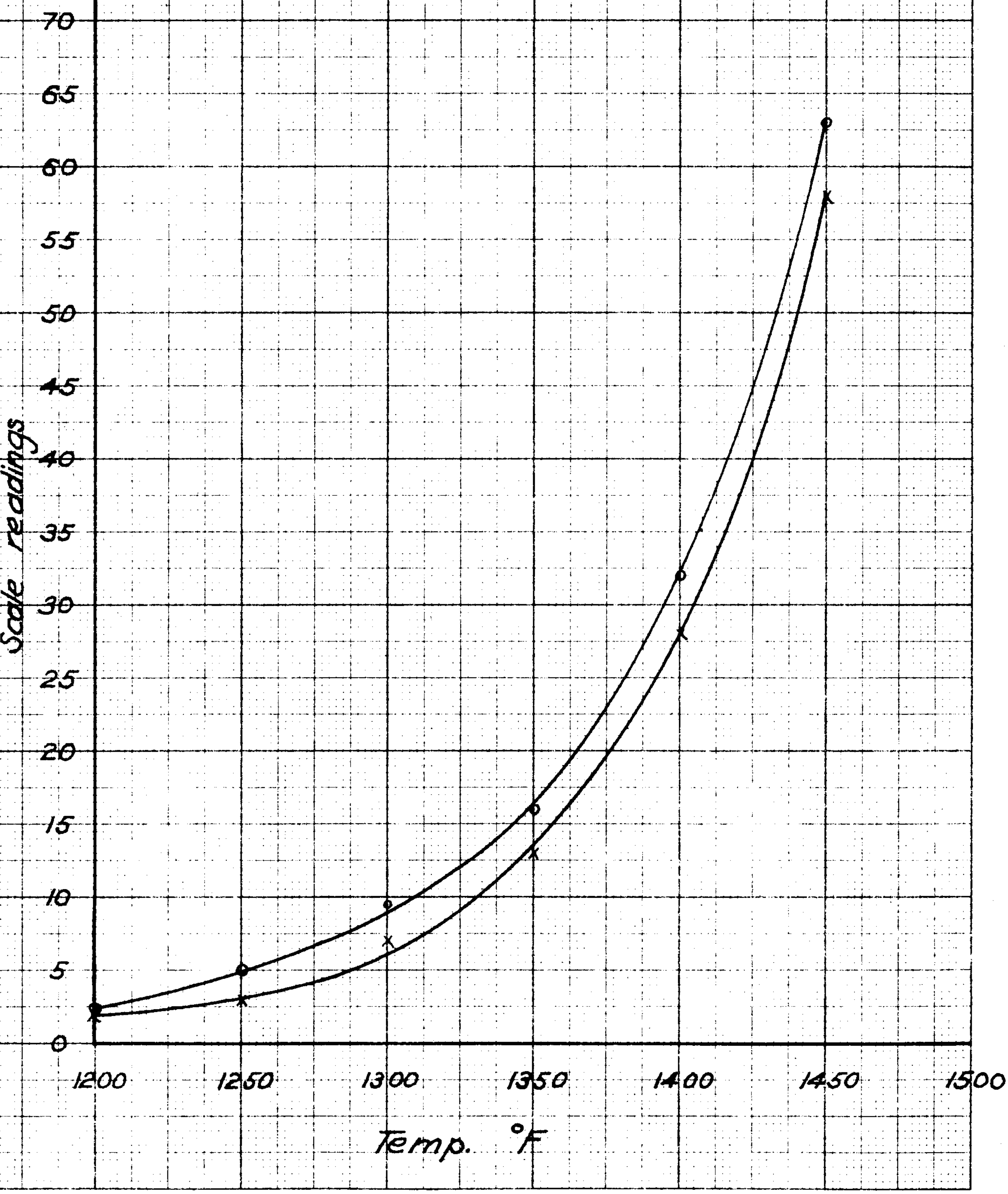


Table No. 3

LOW TEMPERATURE SETTING FOR METER NO. 3

Result of Four Runs Heating

Furnace Temp. °F	meter readings heating				
	1 st	2 nd	4 rd	4 th	av.
1200	4	4	4	4	4.00
1250	6	6	7	7	6.50
1300	14	12	13	13	13.00
1350	25	26	26	27	26.00
1400	57	57	60	60	58.50
1450	119	125	130	130	126.00
1500	266	270	265	270	267.75
1550	351	351	350	355	351.75
1600	380	379	376	375	377.50

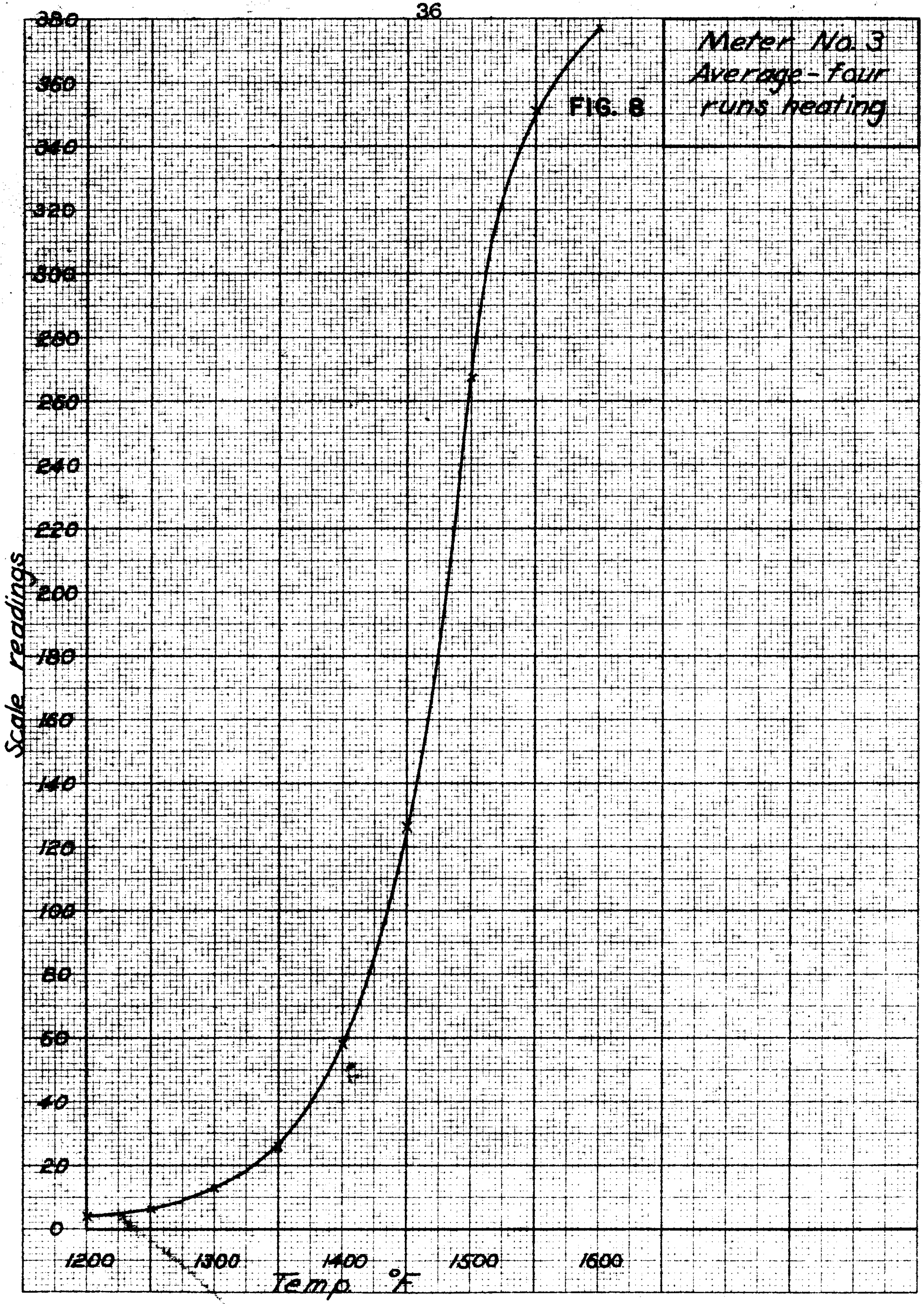
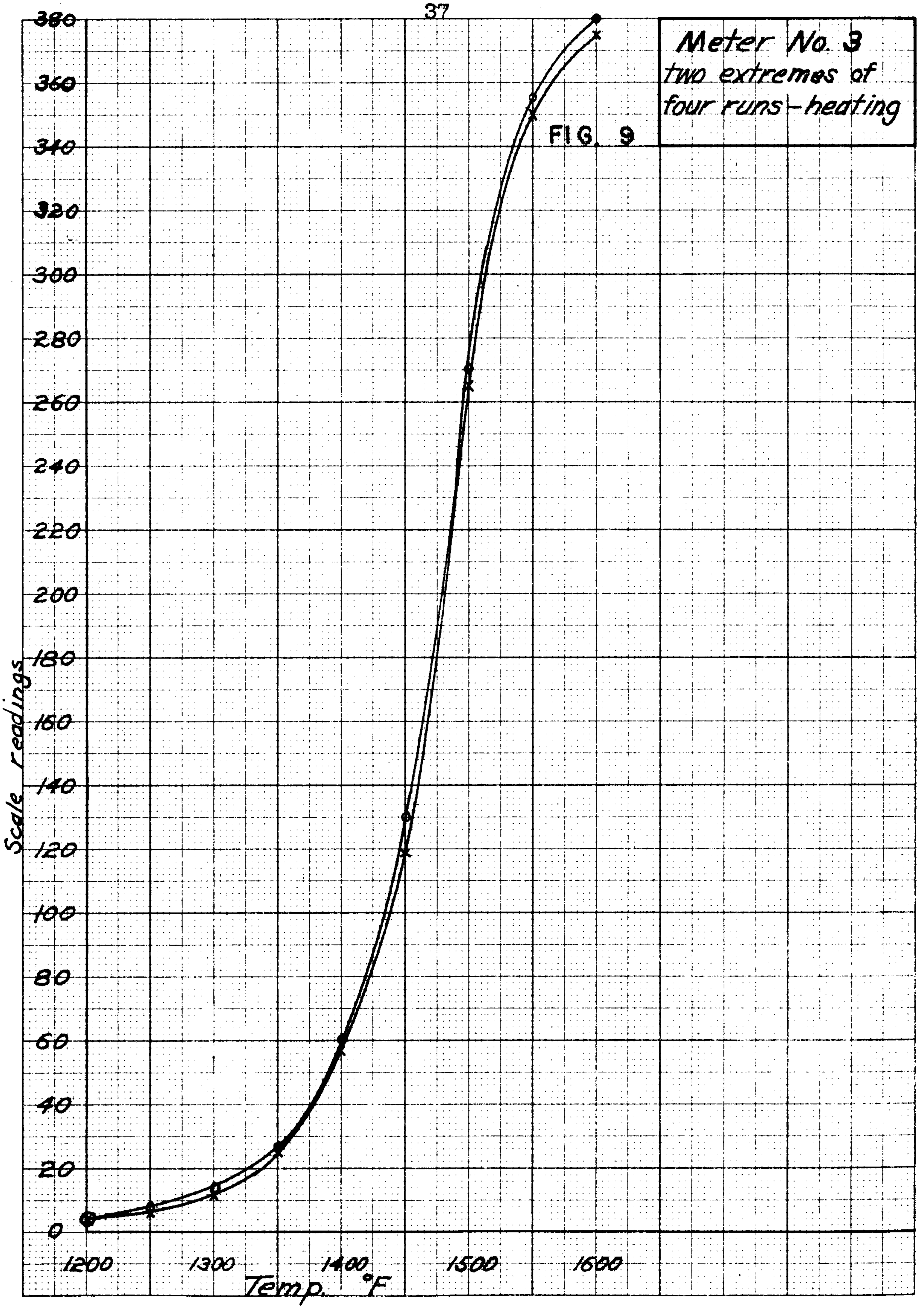


FIG. 8

Meter No. 3
Average - four runs heating
Scale readings
Temp °F
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
1200
1300
1400
1500
1600



Meter No. 3
two extremes of
four runs - heating
Scale readings
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
1200
1300
1400
1500
1600
Temp. °F

FIG. 9

All the above data were recorded with the radiation receiver eight inches from the furnace so that the cathode of the photoelectric tube was completely covered with radiation from the furnace.

Without taking into consideration the emissivites of an incandescent tungsten filament lamp, temperatures were taken with an optical pyrometer and the photoelectric pyrometer. Characteristic curves were plotted using voltage across the lamp as the independent variable in Fig. 12.

To determine the relationship between thermocouple, optical pyrometer and photoelectric pyrometer, all three were set up to indicate the temperatures simultaneously of a blackbody electric furnace. Using the temperatures indicated by the thermocouple as abscissas, curves were plotted for the optical pyrometer and the photoelectric pyrometer. The results are shown in Fig. 13.

In order to determine the relative speed with which temperatures can be determined with the photoelectric pyrometer as compared with a No. 8 chromel-alumel thermocouple, the blackbody electric furnace was heated up and held at a constant temperature. The photoelectric pyrometer with a cover over the baffle tube was set 8 inches from and aligned with the furnace. The thermocouple was placed in the furnace and the cover was removed from the pyrometer simultaneously. Readings of both instruments were taken

Table No. 4

HIGH TEMPERATURE SETTING FOR METER NO. 1

Results of four Runs Heating

Furnace Temp. °F	meter readings				
	1 st	2 nd	3 rd	4 th	av.
1000	15	14	15	14	14.50
1050	19	17	19	19	18.50
1100	27	23	26	27	25.75
1150	35	33	34	36	34.50
1200	47	45	47	46	46.25
1250	59	57	60	59	58.75
1300	71	68	72	72	70.75
1350	85	78	90	85	84.50
1400	99	95	101	101	100.00
1450	114	110	120	116	116.00
1500	130	125	134	132	131.25

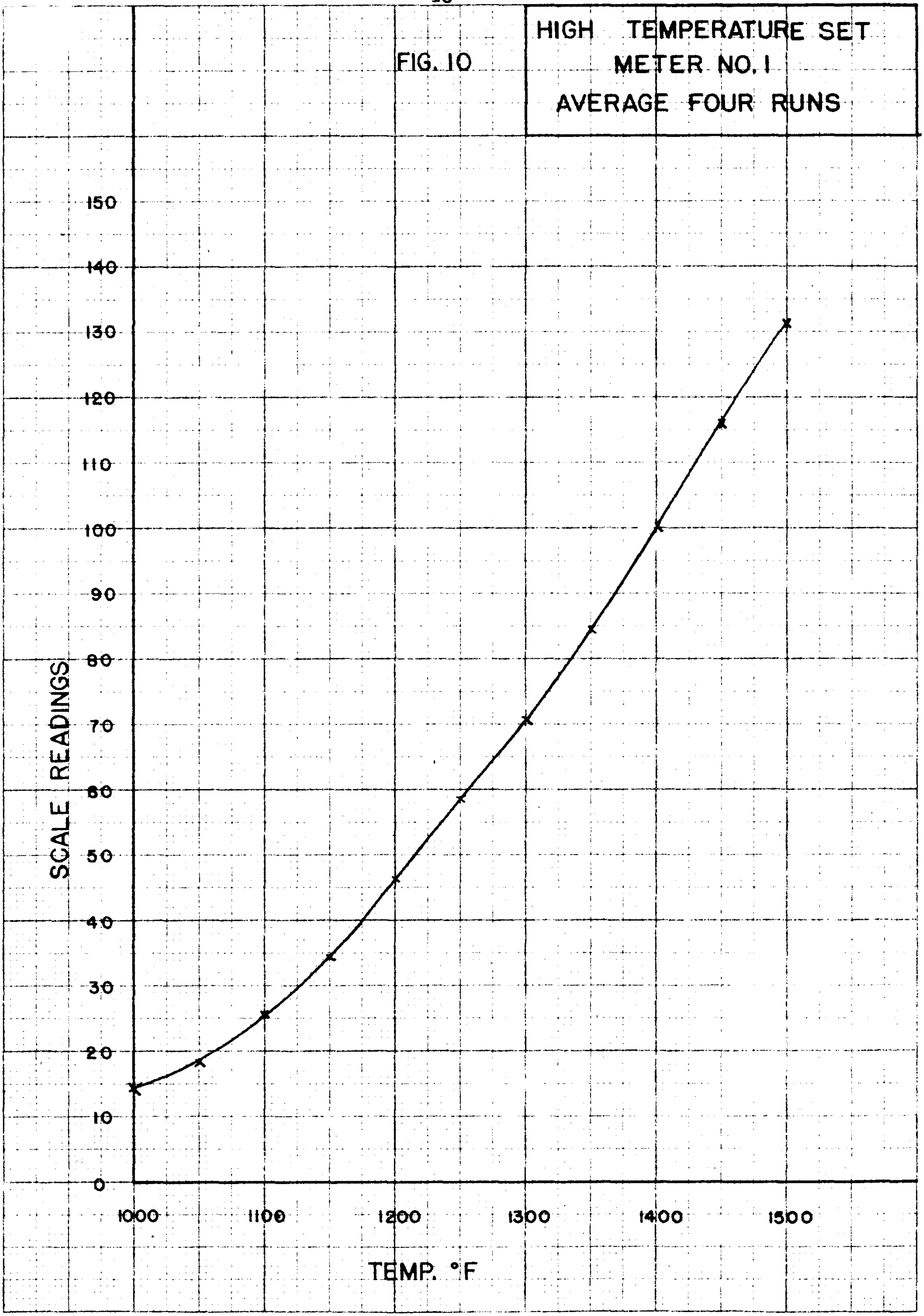


FIG. 10

HIGH TEMPERATURE SET
METER NO. 1
AVERAGE FOUR RUNS

FIG. 11

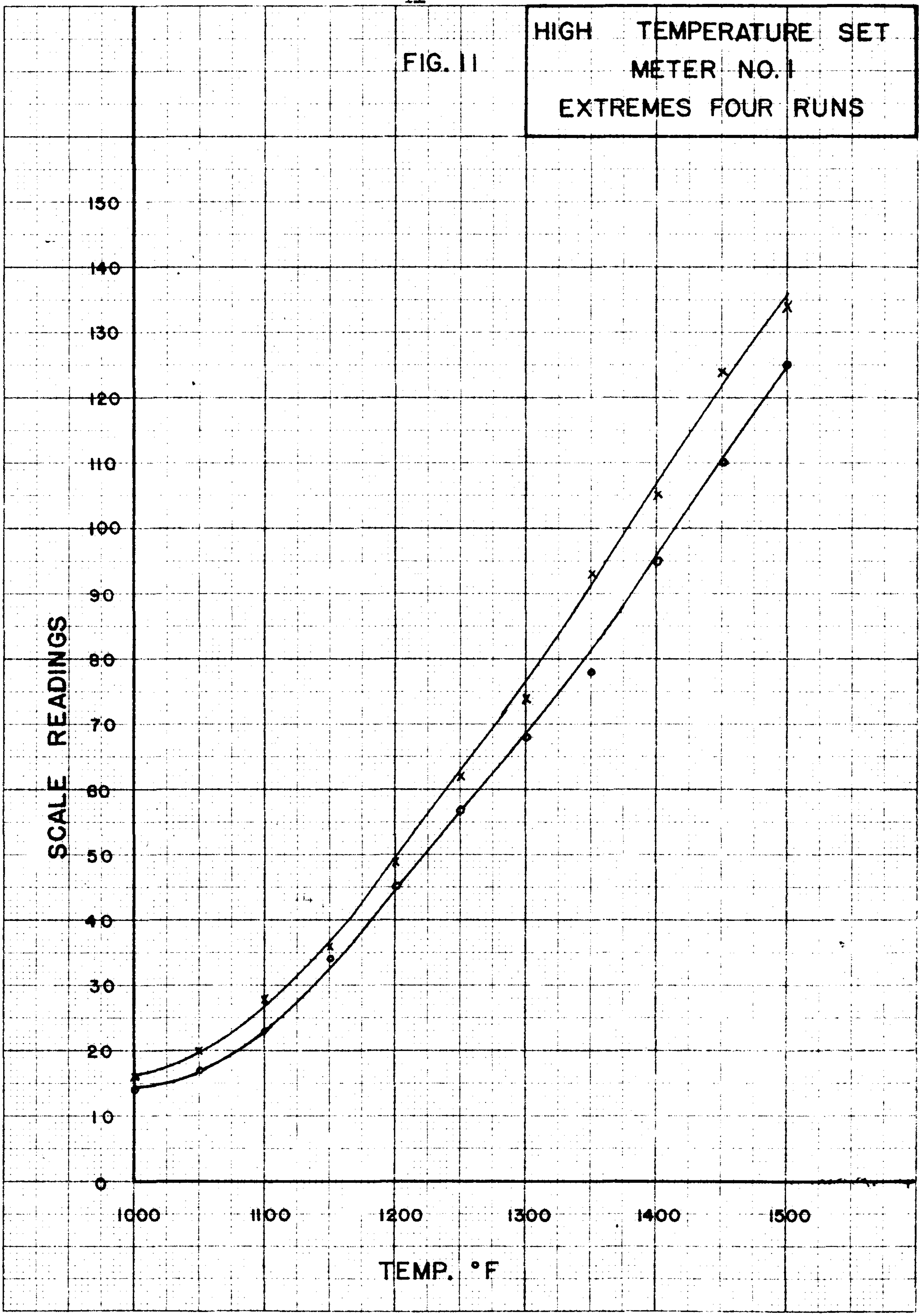

HIGH TEMPERATURE SET
METER NO. 1
EXTREMES FOUR RUNS
SCALE READINGS
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
1000
1100
1200
1300
1400
1500
TEMP. °F

Table No. 5

CALIBRATION WITH OPTICAL PYROMETER AGAINST VARIABLE VOLTAGE INCANDESCENT LAMP

Voltage to lamp	Optical Pyro. temp. °F	Photoelectric Pyro. scale readings meter No. 1
0	-	10
10	1820	10
15	2020	10
20	2150	11
25	2535	13
30	2660	17
35	2860	40
40	3100	70
45	3200	150

This data was collected with the photoelectric pyrometer tuned for low temperature measurements and the radiation receiver set 62 in. from the lamp.

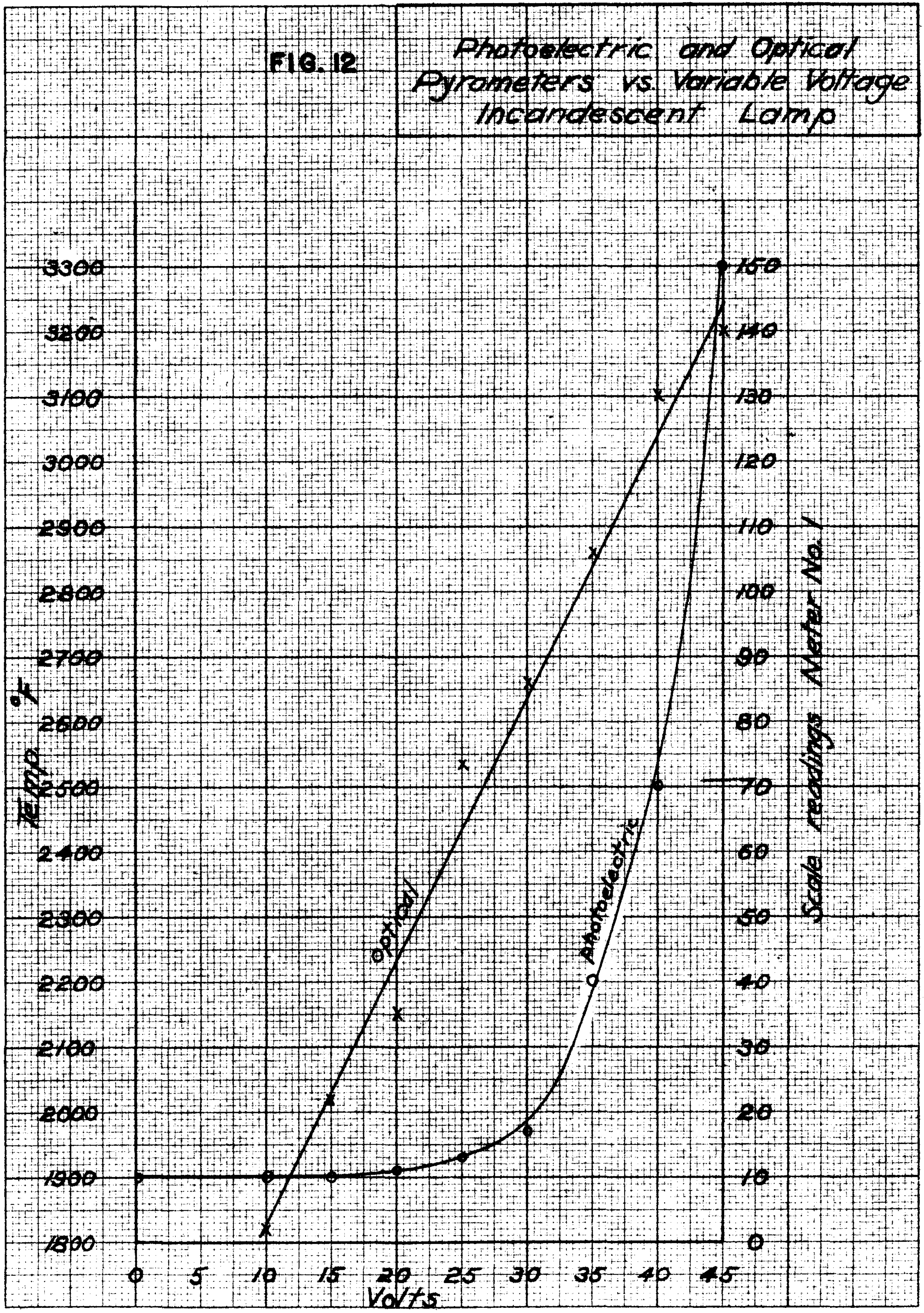


FIG. 12

Photoelectric and Optical Pyrometers vs. Variable Voltage Incandescent Lamp every 15 seconds. The readings of both instruments were plotted against time in Fig. 14. These curves show that the photoelectric pyrometer indicated the true temperature of the furnace practically instantaneously. The thermocouple, on the other hand, required 4½ minutes to come up to 1442° F while the true temperature of the furnace as indicated by the photoelectric pyrometer was about 1460° F or 1465° F.

VIII

CONCLUSIONS

It is believed that the photoelectric pyrometer offers temperature measuring characteristics superior to the other instruments described here. There are, however, certain disadvantages. The most serious is the fact that a time period of from 20 to 30 minutes is required for the instrument to become stable after first tuning it on. Perhaps this time period could be reduced considerably if the resistors in the circuit were replaced with resistors less sensitive to small changes in temperature.

Another characteristic that might be considered a disadvantage is the fact that if the instrument is adjusted sensistive enough to show readable meter deflections at a temperature lower than 1100° F, the instrument is very unstable.

An extension of this project to include a high temperature furnace controller might prove advantageous.

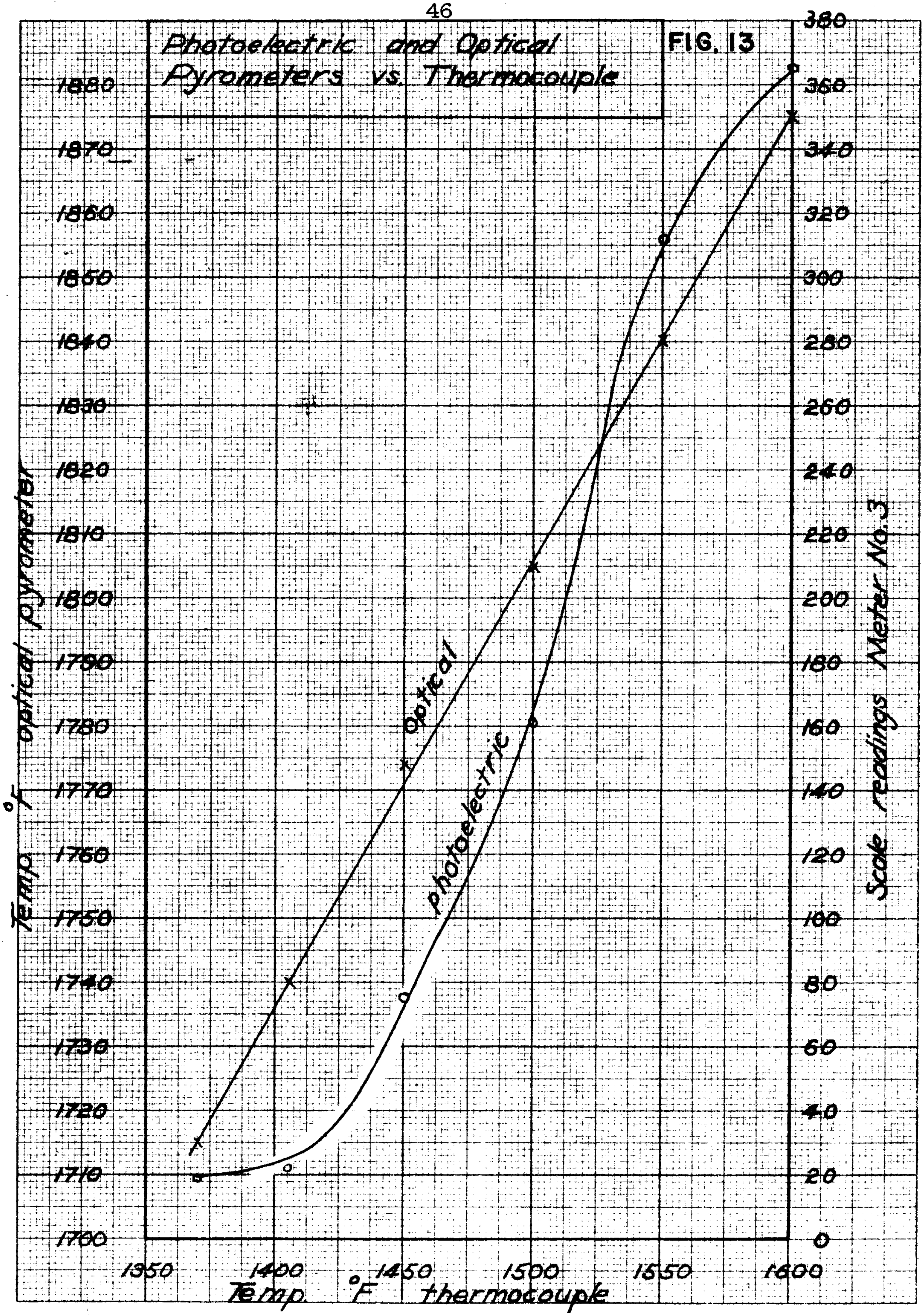
Table No. 6

CALIBRATION WITH OPTICAL PYROMETER AGAINST THERMOCOUPLE

Thermocouple temp. °F	Optical Pyro. temp. °F	Photoelectric Pyro. scale readings meter No. 3
1370	1715	19
1405	1740	22
1450	1774	75
1500	1805	161
1550	1840	312
1600	1875	365

These data were collected with the photoelectric pyrometer tuned for low temperature measurements and the radiation receiver set 10 in. from the furnace.

FIG. 13



Photoelectric and Optical Pyrometers vs. Thermocouple

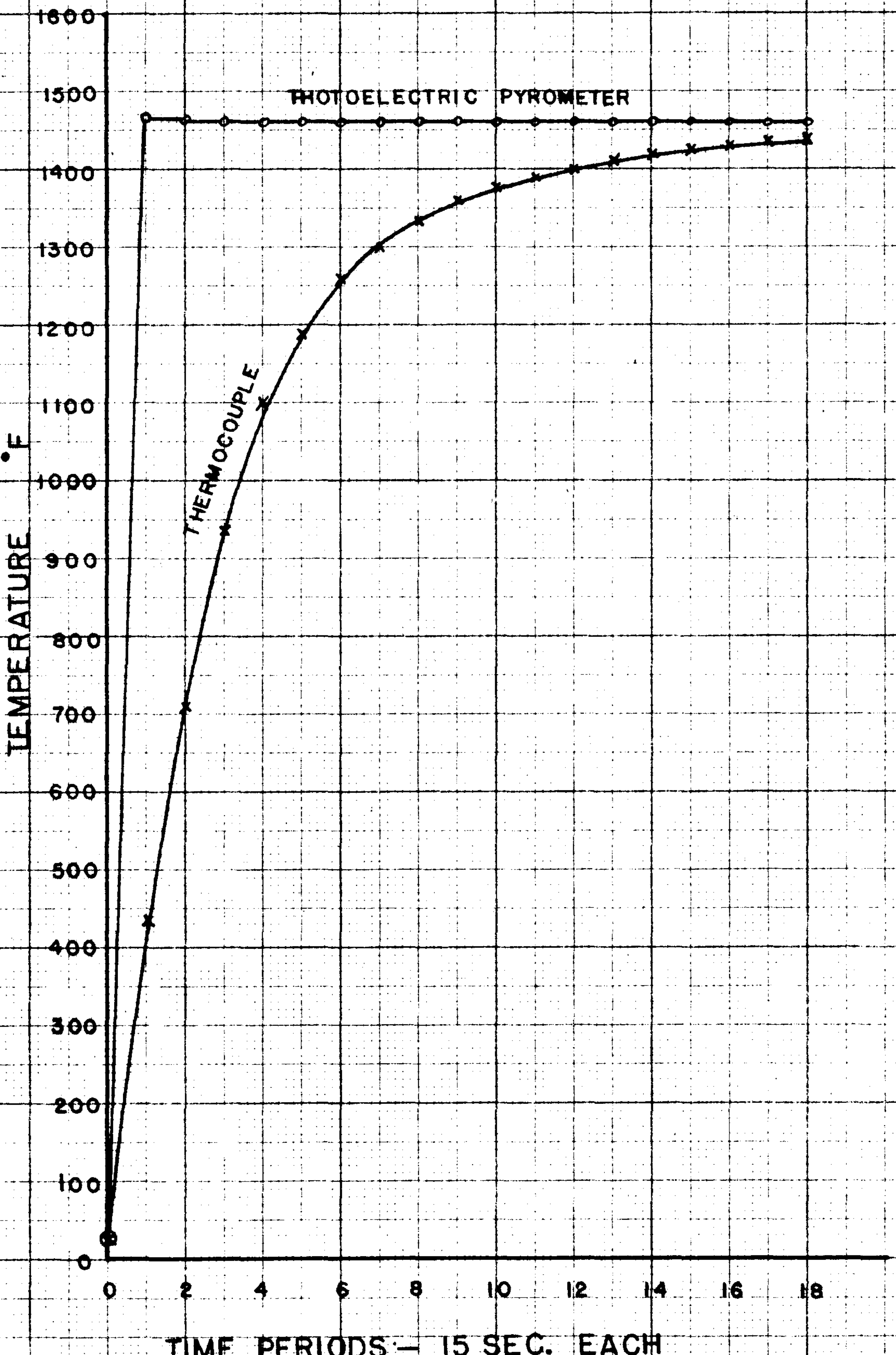
Table No. 7

TEMPERATURE vs. TIME FOR PHOTOELECTRIC PYROMETER AND THERMOCOUPLE

Thermocouple temp. °F	Photoelectric Pyro. scale readings meter No. 2	Photoelectric Pyrometer temp. °F	Time 15 sec. intervals
80	5	-	0
440	175	1465	1
710	150	1463	2
940	130	1460	3
1100	125	1459	4
1190	130	1460	5
1260	120	1458	6
1300	125	1459	7
1335	130	1460	8
1360	130	1460	9
1380	130	1460	10
1390	125	1459	11
1400	120	1458	12
1410	122	1458	13
1420	125	1459	14
1430	125	1459	15
1435	125	1459	16
1440	120	1458	17
1442	120	1458	18

TEMPERATURE vs. TIME CURVES

FIG. 14



IX

SUMMARY

The pyrometer described herein is a portable temperature measuring instrument that has no thermal capacity and which does not rely on the eye and judgment of the operator for brightness or color matches. This instrument can indicate the temperature of a body practically instantaneously over a wide range of temperatures. For blackbody radiators the temperature indicated by the photoelectric pyrometer is within ± 1 % of its true temperature.

X

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The author wishes to acknowledge his indebtedness to the members of the staff in the Department of Physics at the Virginia Polytechnic Institute who willingly gave their time and interest in the progress of this research. Also, the direct assistance of Professor Ryman, Dr. Robeson, and Mr. Bishop was greatly appreciated.

XI

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XIII

APPENDIX

Method of Tuning For Low Temperatures

On the panel of the instrument:

1. Turn upper right resistor (R_3 in Fig. 2) to extreme counterclockwise position.
2. Turn upper left (R_4 in Fig. 2) and lower resistors (R_1 in Fig. 2) to extreme clockwise positions.
3. Then turn lower resistor slowly in a counterclockwise direction until meter No. 1 shows a full scale deflection (200 microamperes).
4. Then turn upper right resistor clockwise until meter No. 1 shows a half scale deflection (100 microamperes).
5. Finally turn upper left resistor counterclockwise until meter No. 1 shows a 10 microampere deflection. The circuit is then adjusted to take temperature readings.

Method of Tuning For High Temperatures

On the panel of the instrument:

1. Turn upper right and lower resistors to their extreme clockwise positions.
2. Adjust upper left resistor exactly half way between its extreme limits.
3. Turn lower resistor counterclockwise until meter No. 1 shows a deflection of 100 microamperes.
4. Turn upper left resistor counterclockwise until meter No. 1 shows a 10 microampere deflection.

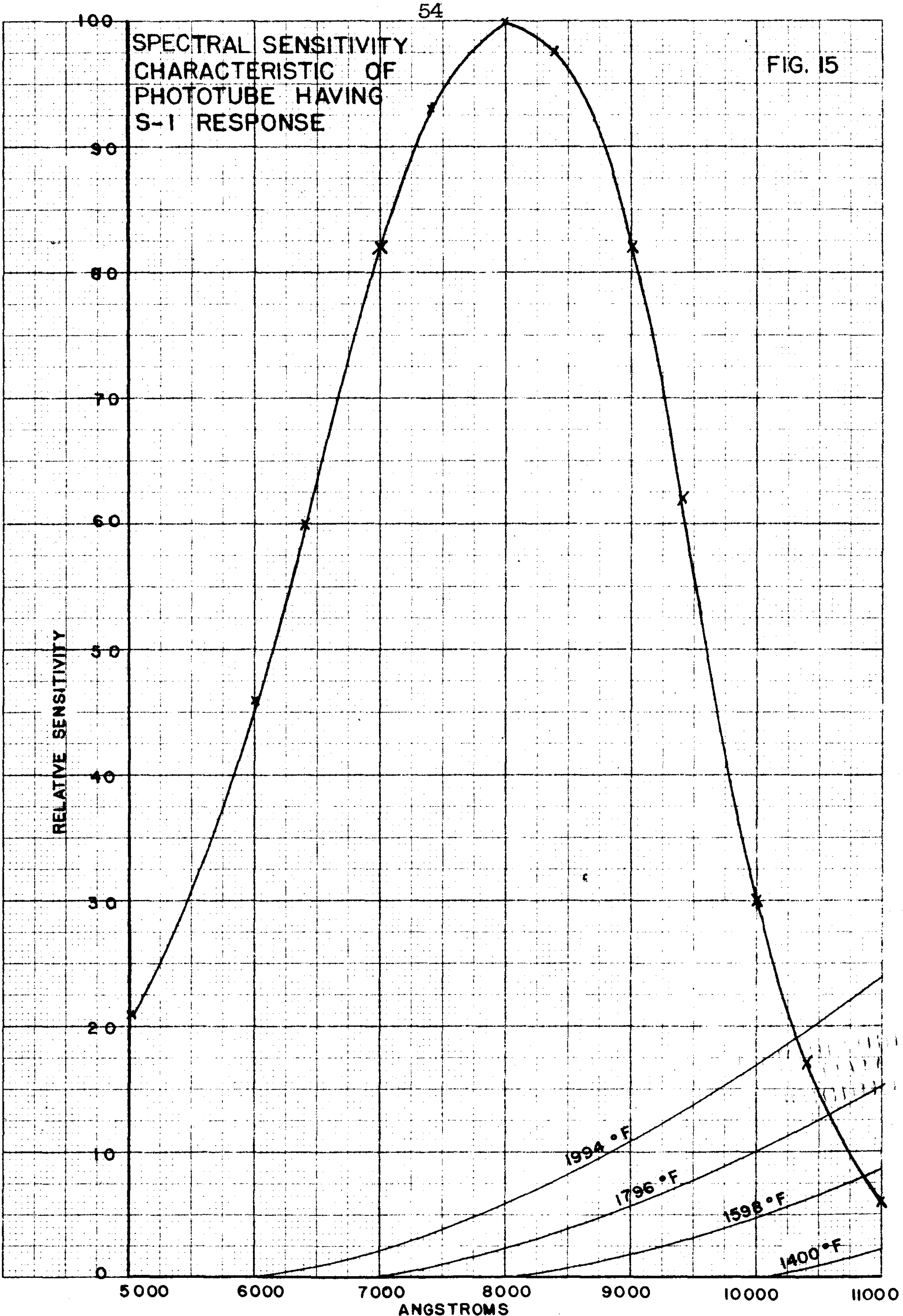

FIG. 15

SPECTRAL SENSITIVITY CHARACTERISTIC OF PHOTOTUBE HAVING S-1 RESPONSE