MC 0241
Box 7 Folder 42

Objectives and Methods of Cathode Testing for Electron Emission, 1953

OBJECTIVES AND METHODS OF CATHODE TESTING FOR ELECTRON EMISSION

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General

Basic to the evaluation of nickel alloys that will serve as good base metals for oxide coated cathodes is their evaluation as electron emitters. Favorable properties include:

1. high electron emission density under specified temperature and field conditions
2. uniform emission over the entire electron emitting surface
3. stability of emission

Although items 1 and 2 above are more or less self explanatory, item 3 needs further elaboration. The stability demanded of a cathode depends to some extent on the use to which it is to be put. Some applications demand tubes that are able to operate many thousands of hours under rather closely specified and constant demand conditions. Stability with respect to life under representative operating conditions is therefore an important attribute of a cathode. Tubes used in electronic computers should also have a long life and in this case stability may mean that the tube may stand by for long periods of time with no drain and then be expected to deliver a stable highly reproducible emission within a fraction of a microsecond after the demand for emission is called for. In still other cases, long operating life is not required, but long shelf life and high reliability at very high current drain may be needed.

A test program of the magnitude of the present one cannot be expected to evaluate all of the nickel alloys to be made available with respect to all of the above attributes. It will therefore be the purpose of a test program to develop methods for the evaluation of many of the desired properties of a cathode consistent with the present limitations both of time, test facilities and man power.

Preliminaries to Test

Preliminary to any emission testing, decisions must be made with regard to the vacuum tube structure and its method of processing. There is a back log of experience related to the design of diodes and their use as a medium for emission testing. Unfortunately, this experience has not led to a structure capable of giving completely reliable information concerning the true emission properties of the cathodes used in it. Arguments can be given to support the opinion that some of the faults associated with emission testing in diodes can be minimized to some extent by the use of a specially designed triode structure. With this point in mind, the remarks that follow apply equally well to the conventional diode and the triode structure which it is proposed would be used to serve the function of a test diode and would not be operated except for special tests in the conventional manner of practical triodes.

The tube should be capable of adaption to mass production although the special character of some of the tests will demand the introduction of such unusual elements as thermocouples for temperature measurement, special electrodes for resistance measurements and other features as part of the structure.

The exact method of evacuation and processing plays a very important part in the initial establishment of emission capabilities of all cathodes. In general a specific evacuation schedule will have to be adopted and applied to practically all of the nickel alloys. It is to be expected that if a particular nickel alloy seems unresponsive to the standard production schedule, then modifications of it will be introduced in order to bring out, as well as possible, the best features of each of the alloys under investigation. Attention will be given to the relative merits of the nickel alloys if they show differences in production features, such as ease of activation, uniformity and reliability of the product and early life stability.

Some Fundamentals of Electron Emission

The saturated emission current density from any thermionic emitter is extremely temperature dependent. An equation form has been used to express this relation and is known as the "Richardson Equation." Although this equation is in reality not applicable except as an empirical equation for the expression of numerical data, it is so often used that it is written here as follows:

$$i = A_R T^2 e^{-\frac{\mathcal{E}\phi_R}{kT}} \qquad (1)$$

A_R = Richardson Thermionic Constant (not the theoretical value of 120 amp/cm^{2}T^2)

ϕ_R = Richardson work-function in electrons-volts

T = Temperature K°

$\mathcal{E}$ = Electron charge 1.6×10^{-19} coulomb

k = Boltzmann's constant 1.38×10^{-23} joule per degree

In practically all applications of the Richardson form of the thermionic equation the electron emission is by no means uniformly distributed over the superficial geometrical area of the cathode. The electron reflection effect reduces the total emission and its temperature variation influences the apparent value of the work-function. These facts are generally omitted from consideration. Finally, the Richardson work-function ϕ_R cannot be identified as the "true" work-function without a knowledge of its temperature coefficient. Furthermore, the empirical value of this work-function as applied to an oxide cathode can at best be some sort of complex average for the surface as a whole. With these criticisms in mind, it is surely evident that in all practical cases the application of Eq. (1) for the expression of emission data is of very doubtful value when one considers the inconvenience of using this formula in comparison with the simplified expression given in Eq. (2).

$$i = a e^{-\frac{\varepsilon\phi}{kT}} \qquad (2)$$

a = Thermionic constant (empirical)

ϕ = Work-factor (empirical constant)

Equation (2) serves as an empirical form by which observed data representing the variation in thermionic emission with temperature can be represented with the same degree of accuracy as Eq. (1).

If suitable empirical constants are known for the Richardson form of the equation, it is a very simple matter to compute the constants for the simplified Eq. (2) by the relations given in the equations to follow. It is also evident that the reverse is equally true, that is, if the constants of Eq. (2) are known, those of Eq. (1) can be computed with the same set of relations. These relations are as follows:

$$T_o = T_1 + \frac{T_2 - T_1}{4} \qquad (3)$$

$$a = 10 A_R T^2_o \qquad (4)$$

$$\phi = \phi_R + \frac{T_1 + T_2}{11,600} \qquad (5)$$

T_1 = lowest temperature of range (600°K for oxide cathodes)

T_2 = highest temperature of range (1300°K)

T_o = Intermediate temperature (775°K)

$10T^2_o$ = 6.0×10^6 (Typical value)

A_R = 0.2 (Typical value)

a = 1.2×10^6 amp/cm^2 (Typical value)

$\dfrac{T_1 + T_2}{11,600}$ = 0.164 ev (Typical value)

Not only does the electron emission from an oxide cathode depend on the temperature, but it also depends on the applied voltage difference between the cathode and the anode. More exactly it depends on the electric field near the cathode surface. As an electron leaves a conducting surface, it is attracted to the surface by the charge which the electron itself induces in the surface. This is called the "mirror image force." There are also forces that act on the electron known as "patch-field forces" due to the non-uniformity of the surface with respect to small patches differing in their <u>true</u> work-function. Because of these two effects the electron emission even when not limited by space charge depends on the applied voltage. For a given applied voltage or more specifically a constant field at the cathode surface, the current rises according to Eq. (2) until there are sufficient electrons in transit between the cathode and the anode to be practically equal to the surface charge maintained on the anode. As this condition approaches the surface field at the cathode, it falls from its initial high value to zero, even though the anode voltage remains constant. At still higher temperatures, the number of electrons in the space between the cathode and the anode becomes so great that a potential minimum develops between the electrodes. The electron current then becomes very nearly independent of the temperature and is given with reasonable accuracy by the Langmuir-Childs space-charge equation. For completeness of this discussion, Eq. (6) is written as a formula applicable to a diode structure having concentric cylinders with a ratio of diameters of 4 or less.

$$i = K_L \frac{(V_a + \Delta V)^{3/2}}{D^2_e} \left(1 + \frac{1.41}{\left[\dfrac{\mathcal{E}(V_a + \Delta V)}{kT}\right]^{0.475}}\right)^{3/2} . \qquad (6)$$

K = Langmuir Childs Constant which is

$$\frac{4\mathcal{E}_o}{9}\left(2\frac{\mathcal{E}}{m}\right)^{1/2} = 2.335 \times 10^{-6} \text{ amp}/(\text{volts})^{3/2}$$

$\mathcal{E}_o$ = $10^7/4\pi c^2 = 8.85 \times 10^{-12}$ farad/m.

$\mathcal{E}/m$ = Electron charge to mass ratio = 1.76×10^{11} coulomb/kg

V_a = applied anode volts

ΔV = space charge potential minimum in volts and given by

$$\Delta V = \phi \frac{\Delta T}{T_a}$$

where ϕ is the work-factor of Eq. (2) and ΔT is the temperature increment above the critical temperature T_a at which space charge just reduces the field at the cathode to zero

D^2_e = effective spacing squared of the diode and is given in terms of the radii as follows: (r_a = anode radius) (r_c = cathode radius)

$$D^2_e = \frac{(r_a - r_c)^2}{\left(\frac{r_a}{r_c}\right)^{0.85}}$$

Equation (6) shows that as the temperature increases, the current will increase very slightly because of the change in ΔV and because of the way in which the temperature enters explicitly in the last factor of the equation.

General Considerations Relative to Cathode Evaluation

Emission testing is difficult because there are so many properties of the cathode concerning which it is desirable to obtain information. Great care must be exercised in the procedure because the measurement of one property often alters in a significant manner the values associated with other properties which are themselves of comparable importance. It is therefore desirable to minimize the number of readings necessary to acquire the most needed information. A procedure that has been proposed is given as follows:

Proposed Emission Tests

1.1 Condition tube for 5 minutes with the cathode at a temperature of 835 ± 15°C with no electron current drain.

1.2 Take a static emission reading (I_s) with 40V as E_b on the processed diode in the space-charge region. With the present diode the theoretical value of the space charge limited emission current is of the order of 120 ma/cm^2. There is about 0.5 sq. cm. of coating so that the ideal diode should read approximately 60 ma. at 6.3V Ef, 40V E_b.

1.3 Take a static emission reading (i_2) at T_2 (450 ± 20°C) and 40.0V E_b. An automatic timer provides a 3-second reading after the anode voltage is applied. Cathode temperature under these conditions is accurately read and recorded.

1.4 Take a low temperature emission reading (i_1) at 360 ± 20°C cathode temperature (T_1) with an anode voltage of 40.0V D.C. This reading is a static emission reading which will later be used with the $\underset{v}{I}_s$ reading of par. 1.5.

1.5 Take a low-field emission reading ($\underset{v}{I}_s$) at the same temperature (T_1) as used in par. 1.4, but with an anode voltage of 5.0V D.C.

1.6 Heat tubes for at least 5 minutes @ 835 ± 15°C with no electron current drain.

1.7 The exact temperature (T_3) at which this reading is taken will be determined from the data obtained in par. 1.4 and par. 1.3. At this temperature note the current after 3 seconds and after 60 seconds, i.e. i_3 (3 seconds) and i_3 (60 seconds).

1.8 Record the slumping in milliamperes which occurs at the temperature T_3 (par. 1.7) from 3 seconds to 60 seconds of time.

Application of Readings to Problem

2.1 Refer the data obtained from par. 1.4 and par. 1.3 to the graphs (Graphs #1, Sheet 1, 2, 3, 4 and Graph #2, Sheet 1, 2, 3, pages 7 through 13) for $T_1 - i_1$ and $T_2 - i_2$ of emission current vs. cathode temperature and obtain the work-factor for each condition, i.e. ϕ_1 and ϕ_2. Determine the average of these two figures, i.e. $\bar{\phi}$.

2.2 From the average work-factor value obtained in par. 2.1 read off from Graph #3 the temperature, T_3, which is the cathode temperature at which the reading in par. 1.7 is to be taken.

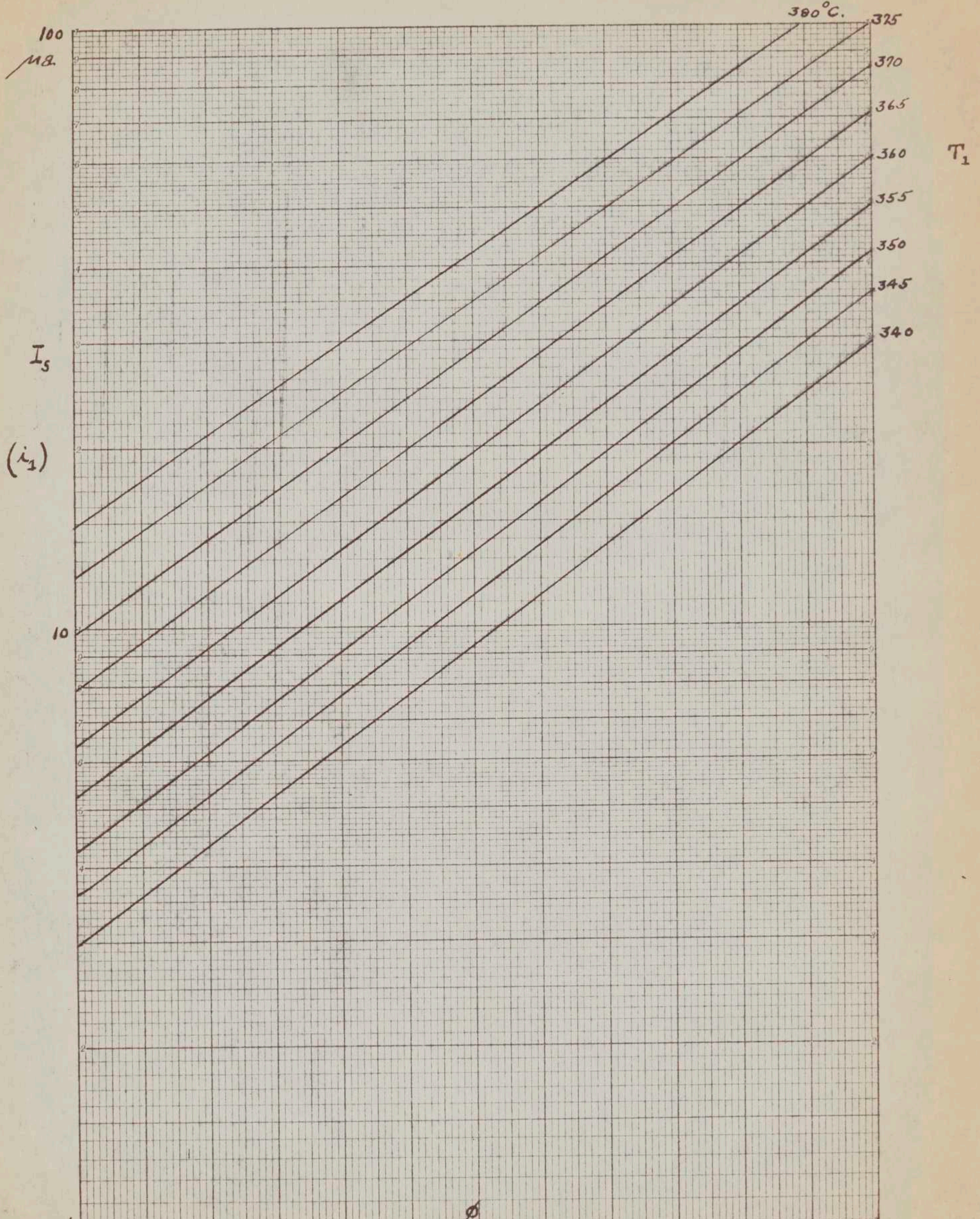
2.3 Take the emission reading (i_3) at a temperature T_3 as per par. 2.2, which is the reading indicated in par. 1.7.

T_1 SHEET 1

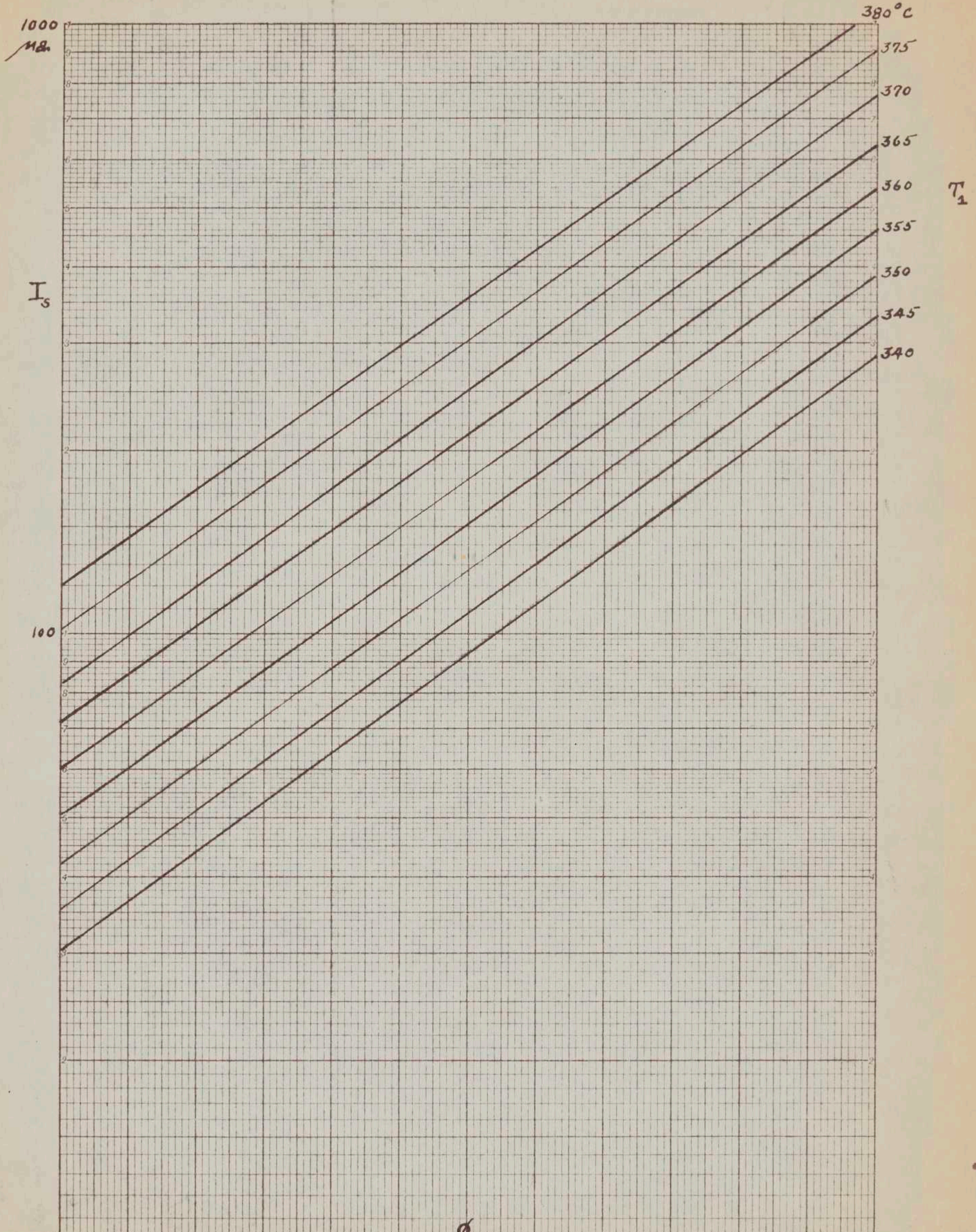
Dec. 3 '53

GRAPH #1

APP. II

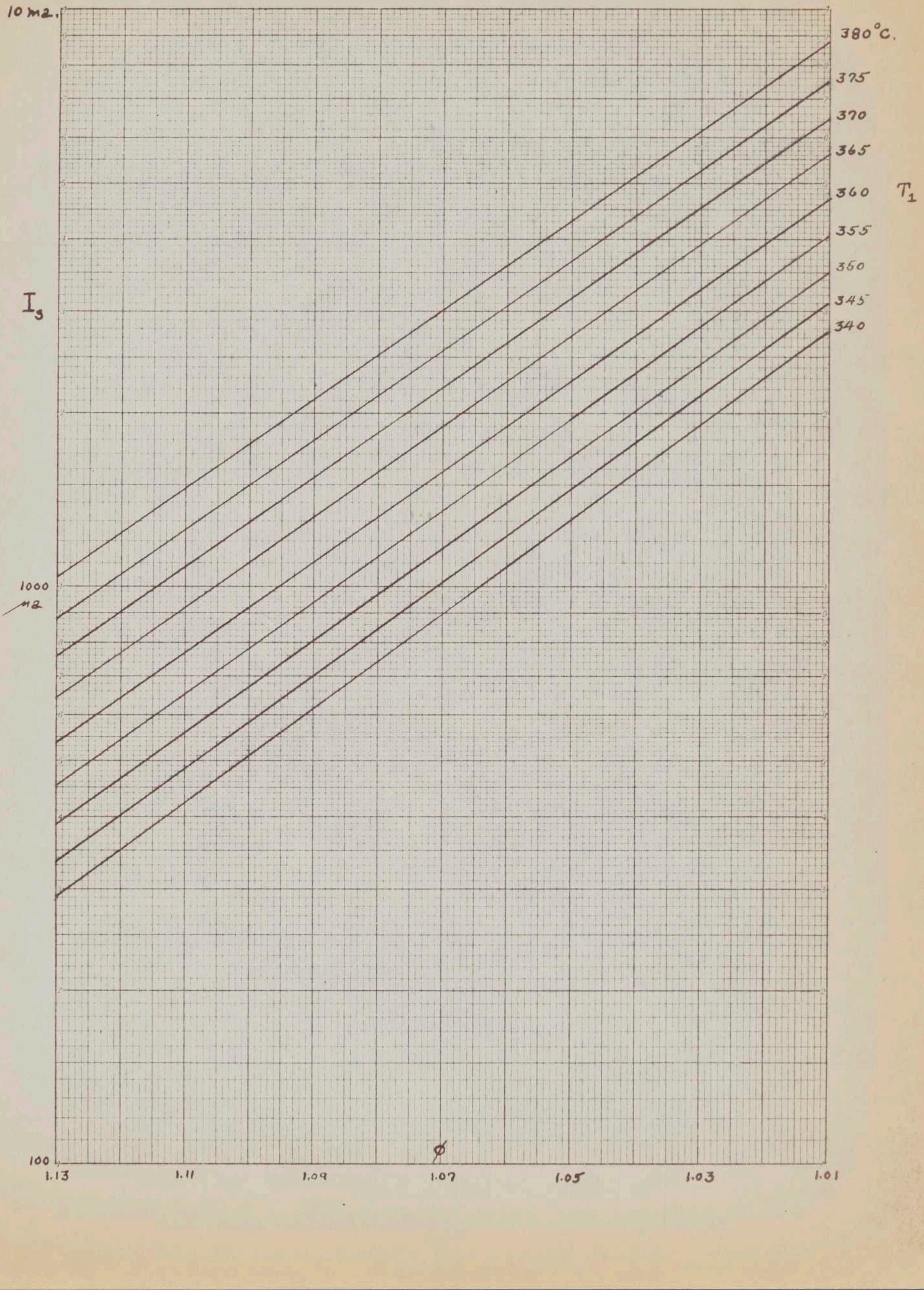


GRAPH #1


1000
μa.
100
10
I_s
1.25
1.23
1.21
1.19
1.17
1.15
1.13
ϕ
380°C
375
370
365
360
355
350
345
340
T_1

GRAPH #1

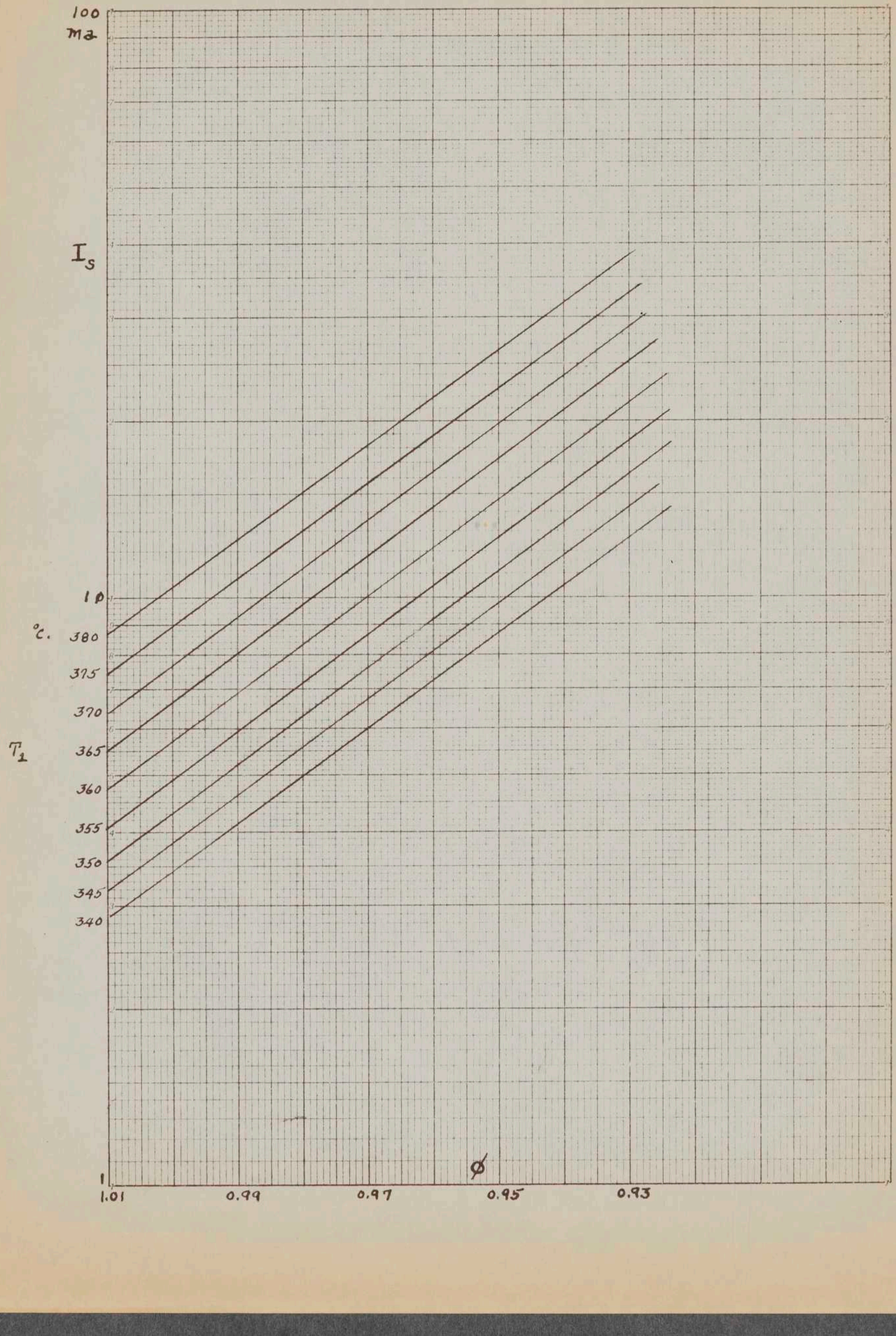
T_1 SHEET 3
Dec. 3 '53



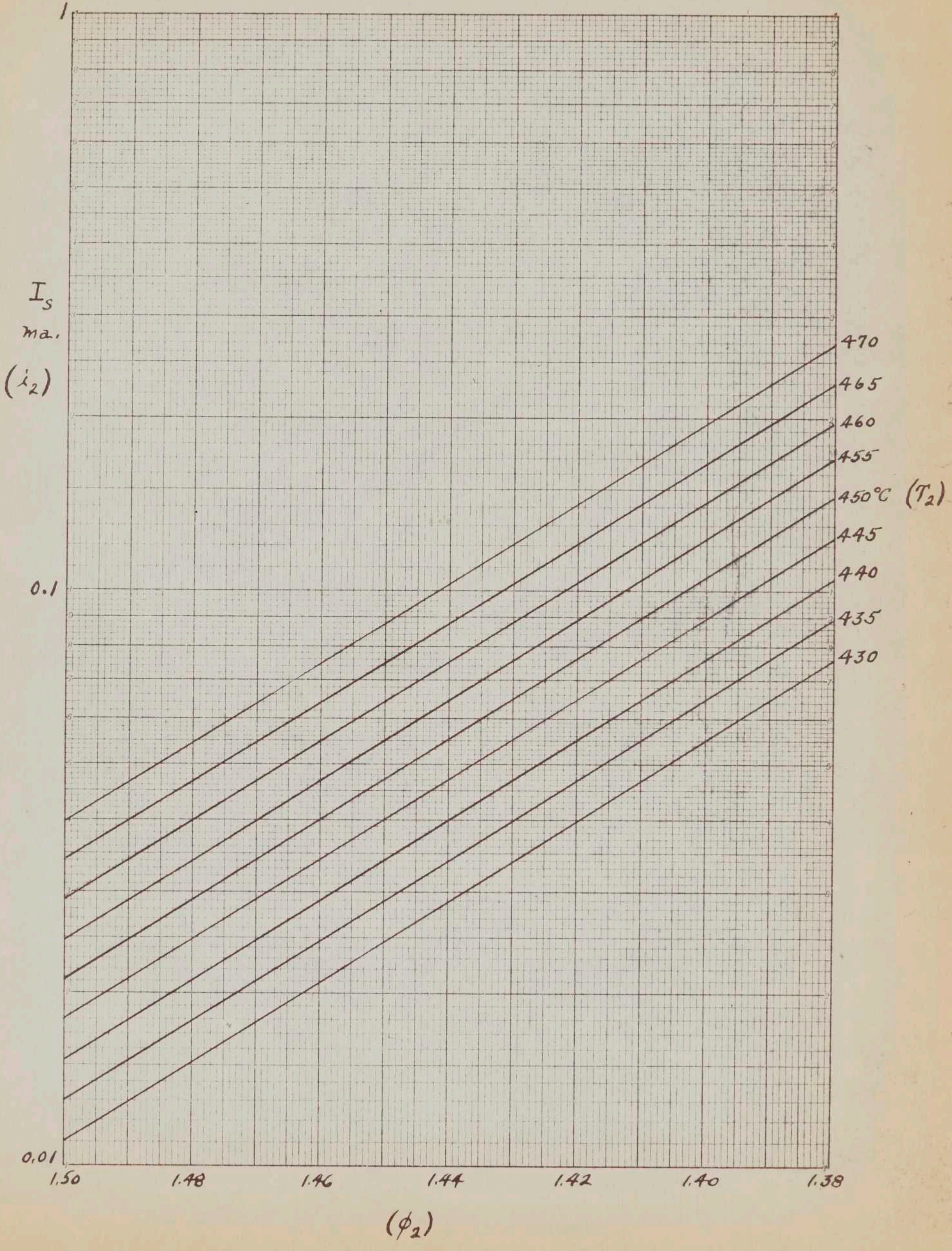
T_1 SHEET 4

Dec. 3 '53

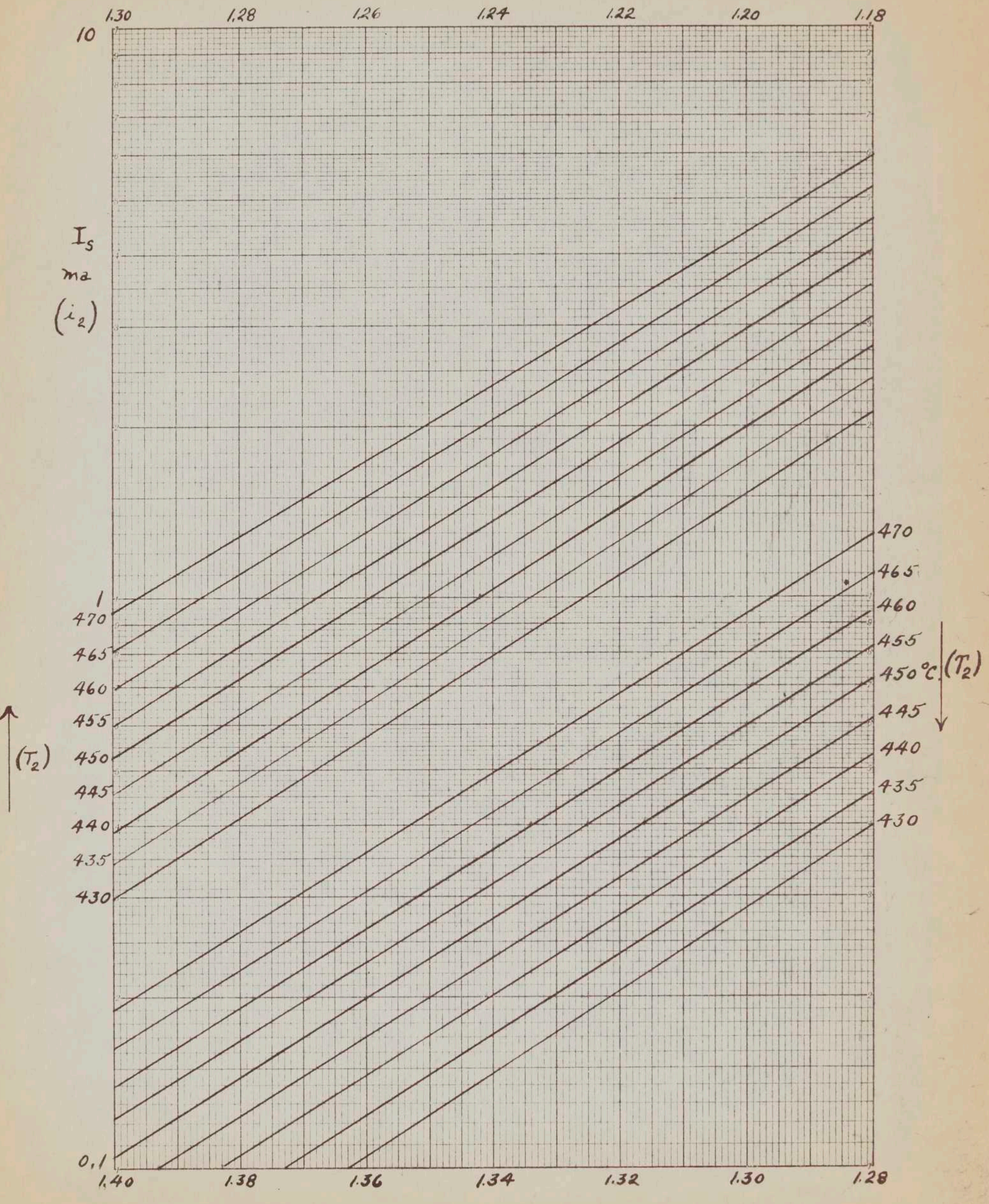
GRAPH #1



GRAPH #2

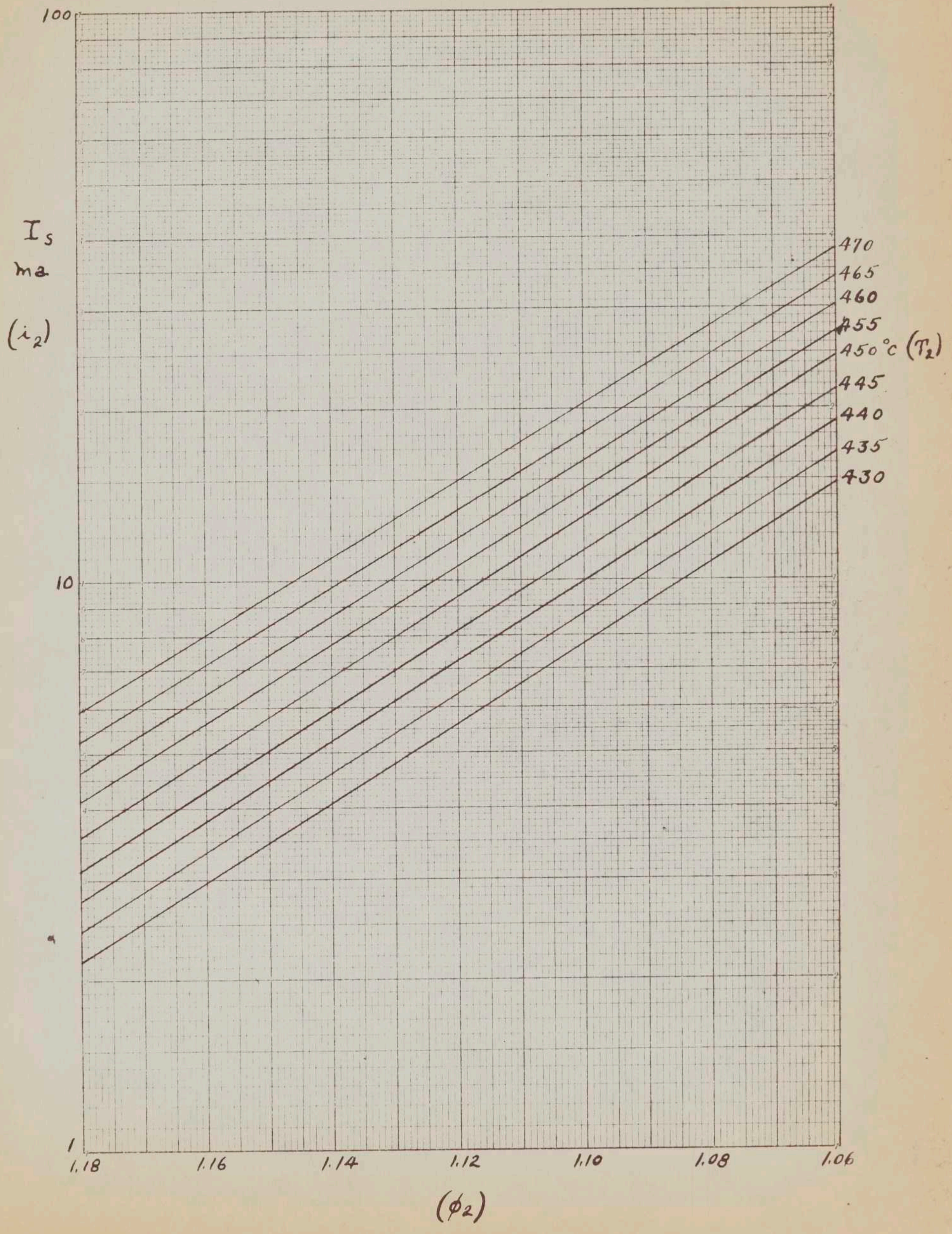

1
I_s
ma.
(i_2)
0.1
0.01
1.50
1.48
1.46
1.44
1.42
1.40
1.38
(ϕ_2)
470
465
460
455
450°C
(T_2)
445
440
435
430

GRAPH #2

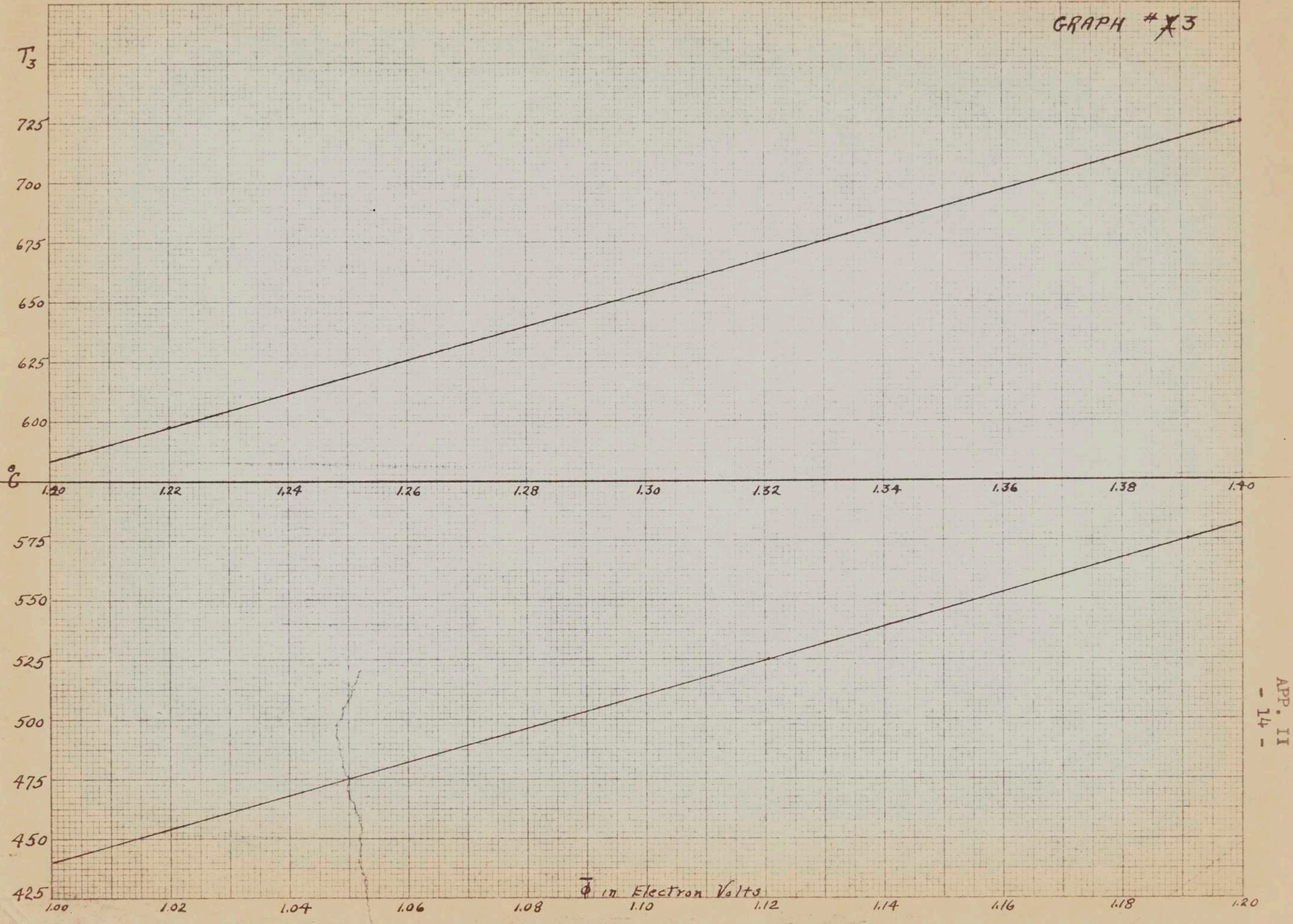

1.30
1.28
1.26
1.24
1.22
1.20
1.18
10
I$_s$
ma
(i_2)
1
470
465
460
455
450
445
440
435
430
(T_2)
0.1
1.40
1.38
1.36
1.34
1.32
1.30
1.28
(ϕ_2)
470
465
460
455
450°C
(T_2)
445
440
435
430

T_2 - Sheet 3

GRAPH #2



GRAPH #3


T_3
725
700
675
650
625
600
°C
1.20
1.22
1.24
1.26
1.28
1.30
1.32
1.34
1.36
1.38
1.40
575
550
525
500
475
450
425
1.00
1.02
1.04
1.06
1.08
1.10
1.12
1.14
1.16
1.18
1.20
Φ in Electron Volts

Calculations

3.1 An emission current which is the highest temperature-limited current at 40V (i_{3Bogie}) for the ideal diode tube has been selected as 53 ma.

3.2 The actual i_3 (3 second) current emission value read on the diode under test at T_3 and 40V, par. 1.7 divided by the ideal value will give a comparison between the tube under test and the ideal tube, and may be expressed in percent, i.e., $\frac{i_3 \text{ (3 sec.)}}{53} \times 100 = f_i$.

3.3 From the 40V E_b static emission reading obtained in par. 1.4 subtract the 5V E_b low-field emission reading obtained in par. 1.5. This difference divided by the 40V E_b reading will give the percentage value of the low-temperature low-voltage to the low-temperature high-voltage condition, i.e.,

$\frac{i_1 - I_{vs}}{i_1} \times 100 = f_v$. This relationship will tell us about field effects and the patchiness of cathodes.

3.4 Divide the difference in emission at T_3 (par. 1.7) which occurs at the stated time intervals by the emission value i_3 (3 seconds) to determine the percent of slump that has occurred, i.e.,

$$\frac{i_3 \text{ (3 sec.)} - i_3 \text{ (60 sec.)}}{i_3 \text{ (3 sec.)}} \times 100 = f_s.$$

Discussion of the Proposed Emission Tests

In the following discussion reference will be made specifically to the various tests and the calculations by referring to the paragraph numbers involved. For easy reference these paragraph numbers introduce each of the discussion paragraphs below.

1.1 Discussion

After a tube has been on life test, it must be transferred to the emission test rack. It is very often true that considerable time may occur between the termination of a life testing period and the emission test itself; that is, times of the order of a few minutes or even a few hours. The proposed warm-up without the application of voltage seems to be the least objectionable way of preparing for emission tests.

The results of a set of experiments to be described here are offered in support of this procedure for the stabilization of a cathode in anticipation of measurements. Four tubes were taken for this study from lot E569 which were diodes having a 499 pure nickel alloy base structure and radio mixture No. 3 as the coating. These tubes had been on life test for 16 hours before the series of 5 tests were carried out. These tests may be identified as follows:

Test 1. Procedure described above was followed immediately after the termination of the 16 hour life test.

Test 2. Tubes were cooled 24 hours and then regular procedure followed.

Test 3. Direct repeat of tests with no interruption.

Test 4. Tubes allowed to stand by at room temperature one hour just before tests were made.

Test 5. Test repeated without interruption.

The actual data are recorded on the typical "standard diode work sheet" and presented here as Table 1. The computations called for in the instructions above are presented in Table 2, headed "standard diode computation sheet." The column headed $(\phi_2 - \phi_1)$ is of particular interest because of the smallness of the numbers listed here and the fact that the distribution of plus and minus signs is almost exactly equal. One can conclude from this result that the choice of the thermionic constant "a" = 1.2×10^6 amp/cm^2 could not be improved upon, and furthermore, the cathodes show excellent uniformity since in general a predominance of plus signs in this column generally means the cathode is not of uniform work-factor.

Still a third table has been prepared on the "computation sheet" form in which the data taken on the five tests for a particular tube are assembled together. It is evident from an examination of these figures that some differences exist between the readings taken on a given tube depending upon its past history. The deviations are far more random than they are systematic.

These data are offered to support the conclusion that the above reading procedure is a satisfactory one and is to be adopted until some better method can be discovered and proven to have advantages.

1.2 Discussion

A suitable cathode loading for observation is taken to be 120 ma/cm^2 space-charge limited. Good cathodes operating at normal temperatures yield this current without difficulty. Under the test conditions specified for the diode structure now in use,

Table No. 1

STANDARD DIODE - WORK SHEET

Series No. E569 Hrs. of Life 16 Date 12/4/53

Tube No.	T°C	Is	T_2	i_2	T_1	i_1	Is v	T_3	i_3 (3 secs)	i_3 (60 secs
E569-1	847	60.8	447	8.5	359	555	358	528	34.0	20.2
3	832	57.2	436	8.5	349	610	370	518	36.3	25.3
4	829	58.9	432	7.3	347	485	310	522	30.9	19.9
7	849	58.9	444	10.1	362	809	434	520	33.5	18.9
TOTAL										
AVE.										
E569-1	843	60.9	447	8.0	365	691	417	530	33.7	19.8
3	831	58.1	439	9.2	358	868	520	517	34.9	21.4
4	822	59.9	428	7.4	350	670	433	510	26.1	16.8
7	844	60.0	446	9.8	364	992	510	517	31.5	17.0
TOTAL										
AVE.										
E569-1	852	60.4	452	7.1	367	610	318	539	37.8	22.5
3	839	58.1	439	8.2	358	714	405	520	35.4	22.4
4	831	60.4	432	6.9	356	530	364	522	30.0	18.8
7	849	59.6	445	9.5	364	690	432	522	35.0	20.3
TOTAL										
AVE.										

Table No. 1

STANDARD DIODE - WORK SHEET

- 2 -

Series No. E569 Hrs. of Life 16 Date 12/4/53

Tube No.	T°C	Is	T_2	i_2	T_1	i_1	Is v	T_3	i_3 (3 secs)	i_3 (60 secs)
E569-1	847	61.0	449	8.2	365	705	398	530	30.3	16.9
3	836	58.7	439	9.3	359	870	507	513	33.9	22.0
4	831	59.2	433	7.9	354	668	414	514	30.0	17.9
7	847	59.5	447	11.4	366	1000	530	514	35.5	19.5
TOTAL										
AVE.										
E569-1	847	60.0	455	9.1	362	620	387	530	34.8	22.0
3	826	57.1	441	8.8	349	504	338	520	32.9	22.3
4	826	59.2	446	8.8	356	605	383	523	32.0	21.9
7	848	59.2	457	11.6	367	810	383	524	33.0	17.0
TOTAL										
AVE.										

Table #2

STANDARD DIODE - COMPUTATION SHEET

Series No. E569 Hrs. of Life 16 Date 12/4/53

Tube No.	ϕ_1	ϕ_2	$\bar{\phi}$	$\phi_2 - \phi_1$	f_i	$i_1 - I_s$ ✓	f_v	i_3 (3 secs) i_2 (60 secs)	f_s	Remarks
E569-1	1.126	1.121	1.124	-5	64.2	198	35.7	13.8	40.7	
3	1.107	1.114	1.111	-7	68.5	240	39.3	11.0	30.3	
4	1.112	1.117	1.115	+5	58.3	175	36.1	11.0	35.6	
7	1.111	1.113	1.113	+2	63.0	375	46.4	14.6	43.6	
TOTAL			4.463		254.0		157.5		150.2	
AVE.			1.116^{-5}_{+8}		$63.5^{-5.2}_{+5.0}$		$39.4^{-9.7}_{+7.0}$		$37.6^{-7.3}_{+6.0}$	
E569-1	1.126	1.125	1.126	-1	63.6	274	39.6	13.9	41.3	Tube
3	1.110	1.113	1.112	+2	65.8	346	39.9	13.5	38.7	No. 3
4	1.099	1.100	1.100	+1	49.3	237	35.4	9.3	35.6	varying
7	1.109	1.111	1.110	+2	59.4	482	48.6	14.5	46.0	
TOTAL			4.448		238.1		163.5		161.6	
AVE.			1.112^{-2}_{+14}		$59.5^{-10.2}_{+6.3}$		$40.9^{-5.5}_{+8.7}$		$40.4^{-4.8}_{+5.6}$	
E569-1	1.136	1.140	1.138	-4	71.4	292	47.9	15.2	40.2	
3	1.111	1.118	1.115	+7	66.9	309	43.4	13.0	36.7	
4	1.124	1.110	1.117	-14	56.6	166	31.3	11.2	37.3	
7	1.124	1.110	1.117	-14	66.0	258	37.4	15.3	43.7	
AL			4.487		260.9		160.0		157.9	
AVE.			1.125^{-7}_{+16}		$65.2^{-8.6}_{+6.2}$		$40.0^{-8.7}_{+7.9}$		$39.5^{-2.8}_{+4.2}$	

Table #2

- 2 -

STANDARD DIODE - COMPUTATION SHEET

Series No. E569 Hrs. of Life 16 Date 12/4/53

Tube No.	ϕ_1	ϕ_2	$\bar{\phi}$	$\phi_2 - \phi_1$	f_i	$i_1 - I_s$	f_v	i_3 (3 secs) i_3 (60 secs)	f_s	Remarks
E569-1	1.125	1.126	1.127	+1	57.2	307	43.5	13.4	44.3	
3	1.101	1.102	1.102	+1	64.0	363	41.7	11.9	35.1	
4	1.107	1.103	1.105	-4	56.6	254	38.0	12.1	40.3	
7	1.107	1.103	1.105	-4	67.0	470	47.0	16.0	45.1	
TOTAL			4.439		244.8		170.2		164.8	
AVE.			1.110^{-8}_{+17}		$61.2^{-4.0}_{+5.8}$		$42.6^{-4.6}_{+4.4}$		$41.2^{-6.1}_{+3.9}$	
E569-1	1.126	1.129	1.128	+3	65.6	233	37.5	12.8	36.8	
3	1.109	1.119	1.114	+10	62.1	202	37.4	10.6	32.2	
4	1.116	1.117	1.117	+1	60.4	222	36.7	10.9	33.1	
7	1.120	1.120	1.120	0	62.3	427	52.7	16.0	48.5	
TOTAL			4.479		250.4		164.3		150.6	
AVE.			1.120^{-6}_{+8}		$62.6^{-2.2}_{+3.0}$		$41.1^{-4.4}_{+11.1}$		$37.6^{-5.4}_{+10.9}$	
AL										
AVE.										

STANDARD DIODE - AVERAGE SHEET

Table #3

Series No. ____________ Hrs. of Life 16 Date 12-4-53

No.	$\bar{\varphi}$	Range	f_1	E	f_ψ	R	f_s	R		
E569	1.120	-6 +8	62.6	-2.2 +3.0	41.1	-4.4 +11.1	37.6	-5.4 +10.9		
E569	1.116	-5 +8	63.5	-5.2 +5.0	39.4	-3.7 +7.0	37.6	-7.3 +6.0		
E569	1.112	-2 +14	59.5	-10.2 +6.3	40.9	-5.5 +8.7	40.4	-4.8 +5.6		
E569	1.122	-7 +16	65.2	-8.6 +6.2	40.0	-8.7 +7.9	39.5	-2.8 +4.2		
E569	1.110	-8 +17	61.2	-4.0 +5.8	42.6	-4.6 +4.4	41.2	-6.1 +3.9		

COMMENTS

E569 - RIV, RM #3, 499 Alloy

(1) Previous Readings 24 Hrs. Before

(2) Tubes Read Regular Procedure

(3) " Repeated Regular Procedure No Rest

(4) " Read Regular Procedure After 1 Hr. @ R.T.

(5) " Repeated Regular Procedure No Rest

a tube constructed normally will give 60 ma. Analysis shows that faulty construction such as misalignment of parts generally results in emission values higher than normal. Thus if the emission measured under these conditions exceeds about 65 ma, the tube should be examined for possible structural irregularity. Emission currents less than approximately 55 ma indicate a very faulty coating condition, or else a very non-uniform distribution of temperature over the cathode. Again tubes that yield at this test emission currents outside of the limits of 60 ± 5 ma should be given special attention to try to discover the specific reason for such an unexpected variation.

1.3 Discussion

Under the test conditions specified at the temperature T_2, the electron emission should not be influenced seriously by space charge. On the basis of the observed reading and the known temperature, it is possible to read directly from the charts or the tables a value of the work-factor ϕ_2 which would give that reading for the normal cathode having an emission constant "a" = 1.2×10^6 (typical value). Although from the theoretical point of view it would be instructive to know the most appropriate value of the thermionic constant "a", the work required to make such a determination is more than it is worth for these particular tests. The work-factor value that one obtains in this manner is a good index of the properties of the emitter. The higher the value of the work-factor, the poorer the emitter, and clearly, if the thermionic constant is low, it is a poor emitter. In this analysis, an abnormality in the thermionic constant modifies the work-factor in the correct manner. To be more specific, a cathode with only 50 percent of the normal thermionic constant will be interpreted as having a work-factor 0.043 ev higher in value than would have been chosen if the true value of the constant "a" had been known.

Because of the fact that the draining of current for this test can possibly alter the properties of the cathode itself, it is important to apply the anode voltage for a very short period of time as suggested here 3 seconds. Further investigations will be made to find out whether or not even 3 seconds is too long a period of time for good cathodes.

1.4 Discussion

After having taken the reading at temperature T_2 as instructed, the observer takes a reading as soon as possible thereafter at the stabilized lower temperature T_1. Charts are provided similar to those used in connection with the observation at T_2 for the determination of that value of the work-factor which in association with the chosen value of "a" = 1.2×10^6 will give the current density observed. If the cathode is perfectly stable and is uniform and characterized by an "a" value close to the one used, then the two work-factor values, namely, ϕ_2 and ϕ_1 will differ by less than 10 units in the fourth figure. It is these differences that are recorded in the various tables associated with this report and headed $(\phi_2 - \phi_1)$.

An examination of the basic physical principles upon which these tests are formulated shows that valuable information can be obtained from a study of the Column headed $(\phi_2 - \phi_1)$. There are two points of interest which are the value of this difference between the work-factors and the sign of the difference. For good stable cathodes that are quite uniform, the value of the difference should seldom exceed ten and the sign should be more or less random. Examples have been found and are illustrated in these tables specifically by those in the C45 group in which all values but one exceed 10 units and all values have positive signs. This result leads to two explanations, one of which may apply and perhaps both. An abnormally low value of the thermionic constant "a" even though the cathode might happen to be uniform might yield a result of this kind. Or else the cathode may be very non-uniform and the "a" value might, therefore, be low because of this non-uniformity. In either case the cathode would certainly be classified as a poor cathode. Since this conclusion applies to practically all of the tubes in that particular lot, this evidence would indicate that the nickel used for the lot in association with the method of processing gave poor results. Whenever the observer obtains a large negative value as entered in this column $(\phi_2 - \phi_1)$ he can generally conclude that the cathode is actually activating during the measuring process and readings should be repeated with special attention to this possibility. Of course, an abnormally large value of "a" would give the same result.

1.5 Discussion

Lack of surface uniformity can be shown to yield an abnormally high variation in emission with applied electric field when the observations are made at such low temperatures that space charge is not playing an important part. While the cathode is operating at the temperature T_1 of 360 ± 20°C, it is suggested that the emission be measured both with 40 volts applied and 5 volts applied, and that the fractional change in emission shall be expressed by noting the actual change and dividing it by the emission observed at the 40 volt point. This fractional change expressed in percent is designated by the letter f_v. It will be noted that fractional changes f_v as great as 60 to 70 percent can occur. The normal change for good cathodes would lie between 30 and 40 percent. Experience with this test is too meager for conclusions to be drawn with respect to it that are well supported by statistical analysis, but it is thought that it may be helpful in distinguishing between non-uniform cathodes and those that have abnormally low values of the thermionic constant "a".

STANDARD DIODE - AVERAGE SHEET

Series No. 18 Hrs. of Life 50 Date 11/9/53

t No.	$\bar{\phi}$	Range	f_1	R	f_v	R	f_s	R		
C45	1.207	- 25 + 67	40.8	- 35.3 + 21.2	42.6	- 7.6 + 16.4	43.7	-21.9 +31.2		
C46	1.288	-59 +61	46.9	-15.0 +14.0	59.0	-32.0 +27.2	19.9	-31.8 +30.5		
C47	1.161	-11 +14	66.7	-11.6 +10.7	42.6	-11.7 +32.4	22.9	- 9.9 +11.4		
C48	1.130	-15 + 7	66.2	-6.0 +6.9	28.1	-10.2 + 7.0	30.7	- 7.6 + 3.8		

COMMENTS 50 Hrs. Life

Lot C45 - RIV, RM #3 coating, Cathode Lot 558 (Purified Ni) Exhausted at 1175°C.

Lot C46 - RIV, RM #3 coating, Cathode Lot 558 (Purified Ni) Exhausted at 1250°C.

Lot C47 - RIV, RM #3 coating, Cathode Lot 499 (Passive) Exhausted at 1175°C.

Lot C48 - RIV, RM #3 coating, Cathode Lot 699 (Active) Exhausted at 1250°C.

STANDARD DIODE - WORK SHEET

Series No. 18 Hrs. of Life 50 Date 11/9/53

Tube No.	Is	T°C	T_1	Is	i_1	T_2	i_2	T_3	i_3 (3 secs)	i_3 (60 secs)
C45-1	?	851	363	171.0	263.0	453	3.2	578	28.3	13.9
3	60.9	830	361	148.0	246.0	451	3.6	568	25.8	20.3
4	51.0	849	351	25.0	49.0	442	0.4	642	15.3	6.8
5	55.5	851	366	169.0	275.0	453	3.5	575	2.9	1.8
6	~~19.2~~	~~827~~	356	5.0	5.0	440	0.1	~~915~~	~~5.8~~	~~10.0~~
7	57.8	837	351	65.0	155.0	440	2.3	578	33.0	26.0
8	49.4	845	370	128.0	197.0	444	1.3	595	24.2	5.5
Total								3566		
Ave.								589^{-21}_{+53}		
C46-1	53.9	817	365	262.0	359.	451	2.9	602	32.3	20.8
2	54.8	817	353	112.0	185	456	2.9	613	31.5	16.9
3	48.9	832	366	14.0	40	452	0.1	688	17.0	15.9
4	50.9	835	351	6.5	47	453	0.6	674	23.9	25.8
5	56.4	830	358	90.0	360	457	3.0	602	28.2	14.0
6	50.9	825	353	7.0	18	460	0.2	687	16.5	18.4
7	--	--	370	0.2	1.5	449	0.003	--	--	--
8	--	--	364	0.2	4.8	440	0.003	--	--	--
Total								3866		
Ave.								644^{-62}_{+24}		
C47-1	60.9	857	370	325	519	459	6.8	550	26.9	18.9
2	57.9	847	350	110	187	443	3.9	560	46.2	36.2
3	61.4	859	358	80	320	453	4.8	557	35.4	34.8
5	58.9	841	350	147	230	447	4.5	555	38.2	30.0
6	60.9	865	351	268	453	444	3.5	546	29.2	19.2
7	60.0	850	355	209	328	451	6.1	548	35.3	30.7
8	58.9	850	364	190	275	458	5.2	564	36.3	28.1
al								3880		
Ave.								554^{-8}_{+10}		

STANDARD DIODE - WORK SHEET

Series No. 18 Hrs. of Life 50 Date 11/9/53

Tube No.	Is	T°C	T_1	$\underset{\vee}{\text{Is}}$	i_1	T_2	i_2	T_3	i_3 (3 secs)	i_3 (60 secs)
C48-2	--	--	365	732	1160	446	10.2	--	--	--
3	59.4	820	355	388	545	435	6.0	528	33.7	22.1
4	60.8	826	370	480	740	449	7.2	536	34.3	23.1
5	58.4	833	366	608	910	449	8.9	521	31.9	22.0
6	~~55.9~~	~~833~~	367	270	389	464	9.3	~~547~~	~~30.9~~	~~20.1~~
7	59.8	826	355	331	395	438	5.9	538	39.1	26.5
8	60.4	822	358	349	475	441	5.9	538	36.4	28.0
Total							2661			
Ave.							532^{-11}_{+6}			

STANDARD DIODE - COMPUTATION SHEET

Series No. 18
Hrs. of Life 50
Date 11/9/53

Tube No.	ϕ_1	ϕ_2	$\bar{\phi}$	$\phi_2 - \phi_1$	f_1	$i_1 - I_s$	f_v	i_3 (3secs) i_3 (60secs)	f_s	Remarks
C45-1	1.180	1.192	1.186	+12	53.4	92.0	35.0	14.5	51.1	Drop
3	1.183	1.180	1.182	-3	48.7	98.0	39.8	5.5	21.3	#6
4	1.245	1.303	1.274	+58	28.9	24.0	49.0	8.1	55.5	
5	1.185	1.185	1.185	0	5.5	106.0	38.6	1.1	37.9	
6	1.383	1.388	~~1.386~~	+5	--	--	--	--	--	--
7	1.195	1.192	1.194	-3	62.3	90.0	58.0	7.0	21.2	
8	1.210	1.230	1.220	+20	45.7	69.0	35.1	18.1	74.9	
Total			7.241		244.5		255.5		261.9	
Ave.			1.207^{-25}_{+67}		$40.8^{-35.3}_{21.5}$		$42.6^{-7.6}_{+16.4}$		$43.7^{-21.9}_{+31.2}$	
C46-1	1.163	1.295	1.229	+132	60.9	97	27.0	11.5	35.6	Drop
2	1.182	1.303	1.243	+121	59.4	73	39.4	14.6	46.3	#7 & #8
3	1.290	1.407	1.349	+117	31.9	26	65.0	1.1	6.5	
4	1.262	1.397	1.330	+135	45.1	40.5	86.2	+1.9	+8.0	
5	1.155	1.303	1.229	+148	53.2	270	75.0	14.2	50.4	
6	1.308	1.377	1.348	+69	31.1	11	61.1	+1.9	+11.5	
7	1.481	--	--	--	--	--	--	--	--	
8	1.403	--	--	--	--	--	--	--	--	
Total			7.728		281.6		353.7		119.3	
			1.288^{-59}_{+61}		$46.9^{-15.0}_{+14.0}$		$59.0^{-32.0}_{+27.2}$		$19.9^{-31.8}_{+30.5}$	
C47-1	1.157	1.154	1.156	-3	50.8	196	37.8	8.0	29.7	
2	1.175	1.163	1.169	-12	87.1	77	41.6	10.0	27.6	
3	1.161	1.166	1.164	+5	66.8	240	75.0	0.6	16.9	
5	1.164	1.160	1.162	-4	72.0	83	36.1	8.2	21.5	
6	1.129	1.171	1.150	+42	55.1	185	40.8	10.0	34.3	
7	1.154	1.149	1.152	-6	66.6	119	36.3	4.6	13.0	
8	1.179	1.171	1.175	-8	68.5	85	30.9	6.2	17.1	
[illegible]			8.128		466.9		298.5		160.1	
Ave.			1.161^{-11}_{+14}		$66.7^{-11.6}_{+10.7}$		$42.6^{-11.7}_{+32.4}$		$22.9^{-9.9}_{+11.4}$	

STANDARD DIODE - COMPUTATION SHEET

Series No. 18   Hrs. of Life 50   Date 11/9/53

Tube No.	ϕ_1	ϕ_2	$\bar{\bar{\phi}}$	$\phi_2 - \phi_1$	f_1	$i_1 - I_s$	f_v	i_3 (3secs) i_3 (60secs)	f_s	Remarks
2	--	--	--	--	--	--	--	--	--	Drop
3	1.126	1.123	1.125	-3	63.6	157	28.8	11.6	34.5	#2 & #6
4	1.137	1.135	1.136	-2	65.3	260	35.1	11.2	32.7	
5	1.109	1.121	1.115	-12	60.2	302	32.2	9.9	31.0	
6	1.167	1.141	~~1.152~~	-16	--	--	--	--	--	
7	1.144	1.130	1.137	-14	73.1	64	17.9	12.6	32.2	
8	1.139	1.135	1.137	-4	68.9	126	26.5	8.4	23.0	
Total			5.650		331.1		140.5		153.5	
Ave.			1.130^{-15}_{+7}		$66.2^{-6.0}_{+6.9}$		$28.1^{-10.2}_{+7.0}$		$30.7^{-7.6}_{+3.8}$	

1.6 Discussion

It is to be expected that a certain amount of time will elapse between the finishing of the measurements under 1.5 and the measurement called for in 1.7 because of the need to determine the two work-factors ϕ_1 and ϕ_2 and their mean value $\bar{\phi}$. With a knowledge of this average value of work-factor $\bar{\phi}$, the most suitable test temperature T_3 can be read off the computation graph 3.

In line with the experience and discussion given here under Para. 1.1, the most suitable standby condition for the cathodes under test is 835°C and no drain.

1.7 Discussion

Detailed analysis as well as experience in this and other laboratories indicates that non-uniform cathodes will fall most notably below predicted current values when the measurements are made at a temperature very close to that for which the current just begins to be limited by space charge. The curve used for the determination of T_3 is constructed so that if the cathode maintains that emission exactly characteristic of the average work-factor ϕ then the measured current would be 53 ma. 75 to 80 percent of this expectation is about the best that has been observed and low values are likely to fall between 30 and 40 percent.

Although all the other readings are taken with the anode applied for only 3 seconds, in this case a 60-second run is permitted. The first reading taken 3 seconds after the application of the anode voltage is used for the calculation of the fraction f_1 which is computed according to the instruction in par. 3.2. In general the emission observed at the end of 60 seconds will be measurably lower than that observed at 3 seconds because of "emission slump." Slump is known to occur for either one or both of the following reasons: first, the flow of electron current through the coating material sets up a resistance drop in potential across the coating which causes the redistribution of the impurity centers so important for the maintenance of high electron emission from the cathode. The redistribution is eventually counteracted by the non-uniform concentration that results. Since some cathodes are more prone to slump than others, the quantitative evaluation of this effect is considered to be important for the evaluation of a cathode structure. The second reason for slumping relates to the fact that certain compounds not clearly defined as to their chemical composition are known to decompose under electron bombardment and produce gases that in turn "poison" the cathode surface. Although at least a certain fraction of the objectionable material on the anode must have come from the cathode, it seems unlikely that the poisoning effect thus produced should be attributed clearly enough to the basic constituents of the cathode to make it necessary to try to evaluate this poisoning effect as an independent quantity.

It is one of the purposes of the proposed triode design to create a structure in which the slump observed will be as free as possible from the poisoning effect. The idea is that with the grid structure a large fraction of the material if not all of it can be caused to be deposited on the outside anode or elsewhere in the tube so that the grid itself which during test will be the main electron collector can be kept free from these objectionable compounds.

General Concluding Discussion

With the above discussion to show the reasons for the measurements made and the method by which they are analyzed, it seems that the paragraphs 2.1 to 3.4 are self-explanatory. Typical data sheets and computation sheets are included with this discussion so that the reader can see the nature of the numerical results obtained. In summary, the following statements may be made.

1. The test with the 6.3 heater volts yields information with regard to the tube structure. The tests at T_2 and T_1 serve as a means of determining the cathode work-factor and give an indication as to the cathode uniformity.

2. The voltage effect at temperature T_1 gives a further index concerning cathode uniformity.

3. Measurements at T_3 yield still further information concerning cathode uniformity, emission efficiency, and the slumping properties of the cathode.

It is anticipated that the accumulation of quantitative evidence according to this plan of study will yield a more accurate evaluation of cathode properties at each stage in the life of the tube than has hitherto been available. Supplementing these data it is anticipated that pulse emission data will also be taken in order to determine the correlation that may exist between pulse data and the data taken under this plan.