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HELIUM RESEARCH CENTER

INTERNAL REPORT

RECALIBRATION OF LEEDS & NORTHRUP COMPANY G-2 MUELLER BRIDGE SERIAL NO. 1603629 AND REDETERMINATION OF THE ICE POINT RESISTANCE OF LEEDS & NORTHRUP COMPANY PLATINUM RESISTANCE THERMOMETER SERIAL NO. 1586182

BY

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BRANCH Fundamental Research

PROJECT NO. 7005

DATE January 1970

AMARILLO, TEXAS

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CONTENTS

Page

Abstract 3

Introduction 4

Mueller bridge calibration 5

Determination of platinum resistance thermometer ice point resistance 12

Discussion 25

TABLES

1. Standard resistor measurements 8

2. Data from comparison of Mueller bridge decades 13

3. Decade step resistance values, legal ohms 16

4. Mueller bridge, serial No. 1603629, dial reading corrections 21

5. Resistance of platinum resistance thermometer, serial No. 1586182, at the triple point of water 23

RECALIBRATION OF LEEDS & NORTHRUP COMPANY G-2 MUELLER BRIDGE, SERIAL NO. 1603629 AND REDETERMINATION OF THE ICE POINT RESISTANCE OF LEEDS & NORTHRUP COMPANY PLATINUM RESISTANCE THERMOMETER, SERIAL NO. 1586182

By

Ted C. Briggs[1/] and Alvin R. Howard[1/]

ABSTRACT

An internally consistent Mueller bridge and a reliable value of the ice point resistance are required for the accurate determination of temperatures with a platinum resistance thermometer.

The decade steps of Mueller bridge, serial No. 1603629 were intercompared and the resistance of a standard resistor was measured. The triple point resistance of platinum resistance thermometer, serial No. 1586182 was measured in a commercial triple point of water cell.

From these measurements, corrections for each dial reading of the bridge were tabulated, and the ice point resistance of the platinum resistance thermometer was computed. The value for the ice point resistance agrees with a value reported by the National Bureau of Standards to 4 parts in 10^6 indicating extraordinary consistency.

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INTRODUCTION

The Thermodynamics Section of the Bureau of Mines Helium Research Center has used a Leeds & Northrup Company (L & N)[2/] model 8069-B,

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2/ Identification of manufacturers does not constitute Bureau of Mines endorsement.

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serial No. 1603629, G-2 Mueller bridge and a L & N model 8163-B, serial No. 1586182, platinum resistance thermometer for several years. The bridge and thermometer are used to accurately determine temperatures in the constant temperature bath of a Burnett compressibility apparatus.

Resistances of the decade steps of a Mueller bridge tend to change slightly with time; therefore, it is desirable to recalibrate the bridge occasionally in order to maintain maximum accuracy. The bridge was calibrated by the manufacturer during August 1962 and has not been recalibrated since that date.

Our platinum resistance thermometer (PRT) was recalibrated during September 1962 at the National Bureau of Standards (NBS). The previous calibration was done at L & N during February 1962. The thermometer ice point resistance was determined at the Helium Research Center by Briggs[3/] in June 1964.

3/ Briggs, Ted C. Temperature Measurement With Leeds and Northrup Platinum Resistance Thermometer No. 1586182. Helium Research Center Internal Report 53, June 1964, 17 pp.

The recent NBS thermometer calibration was carried out with a thermometer current of 1 milliampere while the older L & N calibration used a current of 2 milliamperes. To be consistent with the latest calibration, the ice point resistance was redetermined while using a thermometer current of 1 milliampere.

MUELLER BRIDGE CALIBRATION

A desirable, though not mandatory for PRT measurements, part of calibration of a Mueller bridge is to measure the resistance of a known standard. For this work, a Leeds & Northrup type 8070-B, serial No. 1192371, standard resistor was sent to the National Bureau of Standards for calibration. The NBS provided a value of 10.00965 legal ohms for the resistance at 25.0° C with a resistance uncertainty of 0.0004 percent[4/].

4/ National Bureau of Standards. Report of Calibration. Test No. 211.01/G-39946, Reference P0491399, Dec. 3, 1968. On file at the Bureau of Mines, Helium Research Center, Amarillo, Tex.

Within the 20° to 30° C temperature interval, the change of resistance with temperature for a standard resistor of the type used is accurately expressed by

$$R_{t,s} = R_{25}[1 + \alpha (t - 25) + \beta (t - 25)^2] \quad . \qquad (1)$$

The NBS calibration did not provide values for α and β for equation 1; so the standard resistor was sent to L & N. Leeds & Northrup Company supplied a value of 10.00963 ohms for the resistance at 25.0° C and the values

$$\alpha = +0.000006$$

$$\beta = -0.0000006$$ [5/]

5/ Leeds & Northrup Company. Report of Calibration for Standard resistor, catalog No. 8070-B, serial No. 1192371. April 1969. On file at the Bureau of Mines, Helium Research Center, Amarillo, Tex.

The L & N calibration indicated a resistance uncertainty of 0.001 percent. The two standard resistor calibrations agree within 0.0002 percent at 25.0° C, which is quite good. We use the NBS value for the resistance at 25.0° C and the L & N values for α and β.

Before any standard resistor measurements were made, all bridge adjustments and tests were done as outlined in the manufacturer's manual (L & N No. 77-2-2-1 Issue 6). The ratio dial reading was 18.2 when the ratio arms were adjusted to equality. The bridge zero was measured with the deflections of the null detector and was determined to be -0.00002 ohms. The bridge zero is the average of the values obtained with the commutator in the N and R positions.

A Keithley Instruments model 147 null detector was used with the bridge.

Standard resistor No. 1192371 was connected to the bridge with No. 10 gage copper wire in the manner used for a four lead PRT. Resistance of the standard was measured by setting the 1-ohm decade in the 10 ohm (X) position and adjusting the lower decades to balance the null detector. Measurements of the standard resistor were made with the bridge commutator in the N and then the R positions, and the experimental observations are listed in table 1.

The value of the standard resistor so determined was substituted into the equation

$$X = R_{t,s} + Z - a_t \qquad (2)$$

where

X = sum of the 10 coils in the 1-ohm decade

$R_{t,s}$ = certified value in ohms of the calibrating resistor at temperature t

Z = zero correction of the bridge

a_t = reading of the lower decade settings.

Values of X were computed with equation 2 for the commutator in the N and R positions and the means of these two values for each determination are recorded in table 1.

The method used for the intercomparison of the Mueller bridge decades is outlined in the manufacturer's directions and in NBS

TABLE 1. - Standard resistor measurements

R_N 1/	R_R 2/	t, °C 3/	$R_{t,s}$ 4/	X 5/	Dev. from avg. X
10.00970	10.00956	24.85	10.00964086	9.99999086	-0.00001402
10.00969	10.00956	24.82	10.00963900	9.99999400	-.00001088
10.00969	10.00956	24.79	10.00963712	9.99999212	-.00001276
10.00969	10.00956	24.75	10.00963461	9.99998961	-.00001527
10.00969	10.00956	24.75	10.00963461	9.99998961	-.00001527
10.00970	10.00954	24.75	10.00963461	9.99999461	-.00001027
10.00970	10.00954	24.76	10.00963524	9.99999524	-.00000964
10.00970	10.00954	24.78	10.00963650	9.99999650	-.00000838
10.00971	10.00954	24.82	10.00963900	9.99999400	-.00001088
10.00971	10.00954	24.82	10.00963900	9.99999400	-.00001088
10.00971	10.00954	24.83	10.00963962	9.99999462	-.00001026
10.00962	10.00940	23.55	10.00955029	10.00002029	+.00001541
10.00965	10.00940	23.80	10.00956928	10.00002428	+.00001940
10.00966	10.00943	23.96	10.00958104	10.00001604	+.00001116
10.00967	10.00943	24.00	10.00958394	10.00001394	+.00000906
10.00969	10.00944	24.15	10.00959461	10.00000961	+.00000473
10.00970	10.00946	24.28	10.00960365	10.00000365	-.00000123
10.00970	10.00946	24.34	10.00960775	10.00000775	+.00000287
10.00970	10.00946	24.40	10.00961180	10.00001180	+.00000692
10.00972	10.00947	24.46	10.00961582	10.00000082	+.00000406
10.00971	10.00946	24.50	10.00961847	10.00001347	+.00000859
10.00971	10.00946	24.50	10.00961847	10.00001347	+.00000859
10.00971	10.00946	24.58	10.00962372	10.00001872	+.00001384
10.00973	10.00946	24.62	10.00962631	10.00001131	+.00000643
10.00973	10.00946	24.68	10.00963017	10.00001517	+.00001029
10.00972	10.00946	24.70	10.00963144	10.00002144	+.00001656

Average X = 10.00000488 ± 0.00000223

Standard error of a single X = ± 0.00001137

1/ R_N = bridge reading with the commutator in the N position

2/ R_R = bridge reading with the commutator in the R position

3/ t = temperature of standard resistor, ° C

4/ $R_{t,s}$ = resistance of standard resistor at temperature t, legal ohms

5/ X = computed from equation 2, sum of the 10 coils in the 1-ohm decade, mean of values determined with the commutator in the N and R positions

literature[6-8] and briefly consists of the following:

6/ National Bureau of Standards. Notes to Supplement Resistance Thermometer Certificates, January 1, 1949, 17 pp.

7/ Brooks, Paul P. B. Calibration of Mueller Thermometer Bridges. National Bureau of Standards, October 1965, 39 pp.

8/ _____. Calibration Procedures for Direct-Current Resistance Apparatus. National Bureau of Standards Monograph 39, March 1, 1962, 53 pp.

"The method of calibration is to compare the resistance of each decade step with the resistance of the X (sum of all ten steps) of the next lower decade. This comparison is made by alternately including in the variable arm of the bridge either the step being calibrated or the X of the next lower decade. The lower decades of the bridge are used to make the variable arm balance an external resistance. From these alternate balances, a relation between the step being calibrated and the X of the next lower decade is obtained. The complete calibration consists of repeating this process for each decade step."[6]

The intercomparisons require external resistors that remain constant during the brief period required for each comparison. The absolute values of the external resistors need not be known. A L & N decade box and L & N Kohlrausch slide wire were used for the various external resistors required in the measurements.

For the measurements with the 1-ohm decade, the following equations apply:

$$1_1 + a_1 = 0.X + b_1 \qquad (3)$$

$$1_2 + a_2 = 0.X + b_2 \qquad (4)$$

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$$1_{10} + a_{10} = 0.X + b_{10} \qquad (12)$$

where

1_1 = the 1-ohm coil in the first switch position

1_2 = the 1-ohm coil in the second switch position

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1_{10} = the 1-ohm coil in the tenth switch position

0.X = the sum of the ten 0.1-ohm coils of the 0.1-ohm decade

a_n = the readings of the lower decades (including null detector interpolations) necessary to obtain a balance when the step being calibrated is included in the variable arm of the bridge

b_n = the reading of the lower decades (including null detector interpolations) necessary to obtain a balance when the X position of the next lower decade is included in the variable arm of the bridge.

Equations 3 through 12 are added to obtain

$$X + \sum_{1}^{10} a_n = 10\ (0.X) + \sum_{1}^{10} b_n \tag{13}$$

or

$$0.X = 0.1 \left[X + \sum_{1}^{10} (a_n - b_n)\right] \tag{14}$$

By using the value of 0.X computed from equation 14, we can obtain values for l_1, l_2 ... l_{10} from equations 3 through 12.

The values obtained for l_1, l_2 ... l_{10} are combined to give the total series resistance at each position of the switch; i.e.,

$$1 = l_1$$

$$2 = l_1 + l_2$$

$$3 = l_1 + l_2 + l_3$$

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.

$$X = l_1 + l_2 + l_3 \ldots l_{10} \quad .$$

Similar equations may be written for the lower decades and we obtain:

$$0.0X = 0.1\left[0.X + \sum_{1}^{10} (a_{.n} - b_{.n})\right] , \tag{15}$$

$$0.00X = 0.1\left[0.0X + \sum_{1}^{10} (a_{.0n} - b_{.0n})\right] , \tag{16}$$

and

$$0.000X = 0.1\left[0.00X + \sum_{1}^{10} (a_{.00n} - b_{.00n})\right] . \tag{17}$$

For the 10-ohm decade, the following equations apply:

$$10_1 + a_{10} = X + b_{10} \tag{18}$$

$$10_2 + a_{20} = X + b_{20} \tag{19}$$

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.

.

$$10_{10} + a_{100} = X + b_{100} \quad . \tag{27}$$

We know X and may therefore compute 10_1, 10_2 ... 10_{10} and hence 10, 20, 30 ... X0 .

The complete bridge intercomparisons of decades was done three times and the experimental observations are recorded in table 2. Bridge current was 2 milliamperes, but was only applied long enough to obtain a null detector deflection.

The actual resistance of each decade step was computed for each of the three intercomparisons and the results are listed in table 3.

Corrections for the dial readings of Mueller bridge, serial No. 1603629 are listed in table 4. The corrections are added algebraically to the dial readings to obtain the true resistance in legal ohms.

The 0.0001-ohm decade was checked by deflections of the null detector and no corrections were indicated.

DETERMINATION OF PLATINUM RESISTANCE THERMOMETER ICE POINT RESISTANCE

A commercially available (Trans-Sonics, Inc.) triple point of water cell was used to determine the resistance of platinum resistance thermometer, serial No. 1586182 at the triple point of water.

The manufacturer claims that the triple point of water cell (TPWC) establishes a defining point of the International Practical Temperature Scale with an accuracy of better than 0.0005° C.

An ice mantle was frozen around the TPWC thermometer well with dry ice in accordance with the manufacturer's instructions, alcohol was placed in the thermometer well, the cell was placed in its insulating jacket, and the triple point of water resistance of the PRT was

TABLE 2. - Data from comparison of Mueller bridge decades

Run No. 1

10 ohm decade					1 ohm decade				
10_1	a_{10} = 0.01574		b_{10} = 0.01554		1_1	a_1 = 0.01787		b_1 = 0.01789	
10_2	a_{20} = .01733		b_{20} = .01718		1_2	a_2 = .01807		b_2 = .01808	
10_3	a_{30} = .01350		b_{30} = .01328		1_3	a_3 = .01679		b_3 = .01680	
10_4	a_{40} = .01473		b_{40} = .01461		1_4	a_4 = .01609		b_4 = .01610	
10_5	a_{50} = .01122		b_{50} = .01111		1_5	a_5 = .01607		b_5 = .01607	
10_6	a_{60} = .01467		b_{60} = .01458		1_6	a_6 = .01637		b_6 = .01638	
10_7	a_{70} = .01168		b_{70} = .01151		1_7	a_7 = .01560		b_7 = .01561	
10_8	a_{80} = .01403		b_{80} = .01388		1_8	a_8 = .01578		b_8 = .01579	
10_9	a_{90} = .00868		b_{90} = .00846		1_9	a_9 = .01246		b_9 = .01247	
10_{10}	a_{100} = .03658		b_{100} = .03636		1_{10}	a_{10} = .01552		b_{10} = .01553	

0.1 ohm decade			0.01 ohm decade		
$.1_1$	$a_{.1}$ = 0.00240	$b_{.1}$ = 0.00238	$.01_1$	$a_{.01}$ = 0.00078	$b_{.01}$ = 0.00077
$.1_2$	$a_{.2}$ = .00070	$b_{.2}$ = .00068	$.01_2$	$a_{.02}$ = .00038	$b_{.02}$ = .00038
$.1_3$	$a_{.3}$ = .00247	$b_{.3}$ = .00247	$.01_3$	$a_{.03}$ = .00031	$b_{.03}$ = .00031
$.1_4$	$a_{.4}$ = .00016	$b_{.4}$ = .00016	$.01_4$	$a_{.04}$ = .00067	$b_{.04}$ = .00067
$.1_5$	$a_{.5}$ = .00221	$b_{.5}$ = .00221	$.01_5$	$a_{.05}$ = .00081	$b_{.05}$ = .00080
$.1_6$	$a_{.6}$ = .00176	$b_{.6}$ = .00176	$.01_6$	$a_{.06}$ = .00064	$b_{.06}$ = .00063
$.1_7$	$a_{.7}$ = .00419	$b_{.7}$ = .00418	$.01_7$	$a_{.07}$ = .00081	$b_{.07}$ = .00081
$.1_8$	$a_{.8}$ = .00275	$b_{.8}$ = .00273	$.01_8$	$a_{.08}$ = .00047	$b_{.08}$ = .00047
$.1_9$	$a_{.9}$ = .00297	$b_{.9}$ = .00296	$.01_9$	$a_{.09}$ = .00075	$b_{.09}$ = .00075
$.1_{10}$	$a_{1.0}$ = .00045	$b_{1.0}$ = .00043	$.01_{10}$	$a_{.10}$ = .00068	$b_{.10}$ = .00067

0.001 ohm decade		
$.001_1$	$a_{.001}$ = 0.00006	$b_{.001}$ = 0.00006
$.001_2$	$a_{.002}$ = .00003	$b_{.002}$ = .00004
$.001_3$	$a_{.003}$ = .00007	$b_{.003}$ = .00007
$.001_4$	$a_{.004}$ = .00006	$b_{.004}$ = .00006
$.001_5$	$a_{.005}$ = .00005	$b_{.005}$ = .00005
$.001_6$	$a_{.006}$ = .00006	$b_{.006}$ = .00006
$.001_7$	$a_{.007}$ = .00007	$b_{.007}$ = .00006
$.001_8$	$a_{.008}$ = .00006	$b_{.008}$ = .00006
$.001_9$	$a_{.009}$ = .00006	$b_{.009}$ = .00006
$.001_{10}$	$a_{.010}$ = .00005	$b_{.010}$ = .00005

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TABLE 2. - Data from comparison of Mueller bridge decades
--Continued

Run No. 2

10 ohm decade

10_1	a_{10}	= 0.00671	b_{10}	= 0.00651
10_2	a_{20}	= .00820	b_{20}	= .00807
10_3	a_{30}	= .00479	b_{30}	= .00457
10_4	a_{40}	= .00591	b_{40}	= .00578
10_5	a_{50}	= .00236	b_{50}	= .00226
10_6	a_{60}	= .00576	b_{60}	= .00566
10_7	a_{70}	= .00282	b_{70}	= .00265
10_8	a_{80}	= .06713	b_{80}	= .06698
10_9	a_{90}	= .06210	b_{90}	= .06190
10_{10}	a_{100}	= .09088	b_{100}	= .09068

1 ohm decade

1_1	a_1	= 0.00835	b_1	= 0.00836
1_2	a_2	= .00867	b_2	= .00868
1_3	a_3	= .00758	b_3	= .00760
1_4	a_4	= .00776	b_4	= .00777
1_5	a_5	= .00678	b_5	= .00679
1_6	a_6	= .00720	b_6	= .00721
1_7	a_7	= .00628	b_7	= .00629
1_8	a_8	= .00676	b_8	= .00676
1_9	a_9	= .00317	b_9	= .00318
1_{10}	a_{10}	= .00609	b_{10}	= .00609

0.1 ohm decade

$.1_1$	$a_{.1}$	= 0.00483	$b_{.1}$	= 0.00481
$.1_2$	$a_{.2}$	= .00300	$b_{.2}$	= .00299
$.1_3$	$a_{.3}$	= .00497	$b_{.3}$	= .00497
$.1_4$	$a_{.4}$	= .00288	$b_{.4}$	= .00286
$.1_5$	$a_{.5}$	= .00497	$b_{.5}$	= .00496
$.1_6$	$a_{.6}$	= .00238	$b_{.6}$	= .00236
$.1_7$	$a_{.7}$	= .00509	$b_{.7}$	= .00507
$.1_8$	$a_{.8}$	= .00370	$b_{.8}$	= .00369
$.1_9$	$a_{.9}$	= .00384	$b_{.9}$	= .00383
$.1_{10}$	$a_{1.0}$	= .00153	$b_{1.0}$	= .00152

0.01 ohm decade

$.01_1$	$a_{.01}$	= 0.00058	$b_{.01}$	= 0.00058
$.01_2$	$a_{.02}$	= .00043	$b_{.02}$	= .00043
$.01_3$	$a_{.03}$	= .00066	$b_{.03}$	= .00066
$.01_4$	$a_{.04}$	= .00058	$b_{.04}$	= .00058
$.01_5$	$a_{.05}$	= .00071	$b_{.05}$	= .00071
$.01_6$	$a_{.06}$	= .00063	$b_{.06}$	= .00063
$.01_7$	$a_{.07}$	= .00066	$b_{.07}$	= .00066
$.01_8$	$a_{.08}$	= .00037	$b_{.08}$	= .00037
$.01_9$	$a_{.09}$	= .00057	$b_{.09}$	= .00056
$.01_{10}$	$a_{.10}$	= .00074	$b_{.10}$	= .00073

0.001 ohm decade

$.001_1$	$a_{.001}$	= 0.00006	$b_{.001}$	= 0.00006
$.001_2$	$a_{.002}$	= .00005	$b_{.002}$	= .00006
$.001_3$	$a_{.003}$	= .00004	$b_{.003}$	= .00004
$.001_4$	$a_{.004}$	= .00006	$b_{.004}$	= .00006
$.001_5$	$a_{.005}$	= .00003	$b_{.005}$	= .00003
$.001_6$	$a_{.006}$	= .00006	$b_{.006}$	= .00006
$.001_7$	$a_{.007}$	= .00006	$b_{.007}$	= .00006
$.001_8$	$a_{.008}$	= .00003	$b_{.008}$	= .00003
$.001_9$	$a_{.009}$	= .00006	$b_{.009}$	= .00006
$.001_{10}$	$a_{.010}$	= .00006	$b_{.010}$	= .00006

TABLE 2. - Data from comparison of Mueller bridge decades

--Continued

Run No. 3

10 ohm decade

10_1	a_{10} = 0.00639	b_{10} = 0.00617
10_2	a_{20} = .00771	b_{20} = .00759
10_3	a_{30} = .00384	b_{30} = .00364
10_4	a_{40} = .00477	b_{40} = .00466
10_5	a_{50} = .00127	b_{50} = .00116
10_6	a_{60} = .00471	b_{60} = .00463
10_7	a_{70} = .00160	b_{70} = .00147
10_8	a_{80} = .00397	b_{80} = .00384
10_9	a_{90} = .00196	b_{90} = .00173
10_{10}	a_{100} = .03203	b_{100} = .03182

1 ohm decade

1_1	a_1 = 0.00821	b_1 = 0.00823
1_2	a_2 = .00823	b_2 = .00824
1_3	a_3 = .00696	b_3 = .00697
1_4	a_4 = .00717	b_4 = .00719
1_5	a_5 = .00634	b_5 = .00636
1_6	a_6 = .00620	b_6 = .00621
1_7	a_7 = .00608	b_7 = .00609
1_8	a_8 = .00553	b_8 = .00554
1_9	a_9 = .00261	b_9 = .00263
1_{10}	a_{10} = .00619	b_{10} = .00619

0.1 ohm decade

$.1_1$	$a_{.1}$ = 0.00566	$b_{.1}$ = 0.00564
$.1_2$	$a_{.2}$ = .00440	$b_{.2}$ = .00439
$.1_3$	$a_{.3}$ = .00589	$b_{.3}$ = .00589
$.1_4$	$a_{.4}$ = .00366	$b_{.4}$ = .00364
$.1_5$	$a_{.5}$ = .00564	$b_{.5}$ = .00563
$.1_6$	$a_{.6}$ = .00363	$b_{.6}$ = .00362
$.1_7$	$a_{.7}$ = .00568	$b_{.7}$ = .00566
$.1_8$	$a_{.8}$ = .00463	$b_{.8}$ = .00461
$.1_9$	$a_{.9}$ = .00454	$b_{.9}$ = .00453
$.1_{10}$	$a_{1.0}$ = .00204	$b_{1.0}$ = .00202

0.01 ohm decade

$.01_1$	$a_{.01}$ = 0.00056	$b_{.01}$ = 0.00056
$.01_2$	$a_{.02}$ = .00067	$b_{.02}$ = .00067
$.01_3$	$a_{.03}$ = .00063	$b_{.03}$ = .00063
$.01_4$	$a_{.04}$ = .00070	$b_{.04}$ = .00070
$.01_5$	$a_{.05}$ = .00057	$b_{.05}$ = .00057
$.01_6$	$a_{.06}$ = .00083	$b_{.06}$ = .00083
$.01_7$	$a_{.07}$ = .00066	$b_{.07}$ = .00066
$.01_8$	$a_{.08}$ = .00086	$b_{.08}$ = .00085
$.01_9$	$a_{.09}$ = .00073	$b_{.09}$ = .00073
$.01_{10}$	$a_{.10}$ = .00054	$b_{.10}$ = .00054

0.001 ohm decade

$.001_1$	$a_{.001}$ = 0.00006	$b_{.001}$ = 0.00006
$.001_2$	$a_{.002}$ = .00008	$b_{.002}$ = .00008
$.001_3$	$a_{.003}$ = .00006	$b_{.003}$ = .00006
$.001_4$	$a_{.004}$ = .00007	$b_{.004}$ = .00007
$.001_5$	$a_{.005}$ = .00001	$b_{.005}$ = .00001
$.001_6$	$a_{.006}$ = .00006	$b_{.006}$ = .00006
$.001_7$	$a_{.007}$ = .00007	$b_{.007}$ = .00007
$.001_8$	$a_{.008}$ = .00008	$b_{.008}$ = .00008
$.001_9$	$a_{.009}$ = .00006	$b_{.009}$ = .00006
$.001_{10}$	$a_{.010}$ = .00003	$b_{.010}$ = .00003

TABLE 3. - Decade step resistance values, legal ohms

10 ohm decade

Decade step	Resistance, Run No. 1	Resistance, Run No. 2	Resistance, Run No. 3	Average resistance
10	9.999805	9.999805	9.999785	9.999798 ± 0.000007
20	19.999660	19.999680	19.999670	19.999670 ± .000006
30	29.999445	29.999465	29.999475	29.999462 ± .000009
40	39.999330	39.999340	39.999370	39.999347 ± .000012
50	49.999224	49.999244	49.999264	49.999244 ± .000012
60	59.999139	59.999149	59.999189	59.999159 ± .000015
70	69.998974	69.998984	69.999064	69.999007 ± .000028
80	79.998829	79.998839	79.998939	79.998869 ± .000035
90	89.998614	89.998644	89.998714	89.998657 ± .000030
X0	99.998399	99.998449	99.998509	99.998452 ± .000032

Decade step	Dev. from avg., Run No. 1	Dev. from avg., Run No. 2	Dev. from avg., Run No. 3
10	+0.000007	+0.000007	-0.000013
20	-.000010	+.000010	.000000
30	-.000017	+.000003	+.000013
40	-.000017	-.000007	+.000023
50	-.000020	.000000	+.000020
60	-.000020	-.000010	+.000030
70	-.000033	-.000023	+.000057
80	-.000040	-.000030	+.000070
90	-.000043	-.000013	+.000057
X0	-.000053	-.000003	+.000057

TABLE 3. - Decade step resistance values, legal ohms--Continued

1 ohm decade

Decade step	Resistance, Run No. 1	Resistance, Run No. 2	Resistance, Run No. 3	Average Resistance
1	1.000010	1.000001	1.000007	1.000006 ± 0.000003
2	2.000011	2.000003	2.000005	2.000006 ± .000002
3	3.000011	3.000014	3.000002	3.000009 ± .000004
4	4.000012	4.000016	4.000010	4.000013 ± .000002
5	5.000002	5.000017	5.000017	5.000012 ± .000005
6	6.000003	6.000019	6.000015	6.000012 ± .000005
7	7.000003	7.000020	7.000012	7.000012 ± .000005
8	8.000004	8.000012	8.000010	8.000009 ± .000002
9	9.000004	9.000013	9.000017	9.000011 ± .000004
X	10.000005	10.000005	10.000005	10.000005 ± .000000

Decade step	Dev. from avg., Run No. 1	Dev. from avg., Run No. 2	Dev. from avg., Run No. 3
1	+0.000004	-0.000005	+0.000001
2	+.000005	-.000003	-.000001
3	+.000002	+.000005	-.000007
4	-.000001	+.000003	-.000003
5	-.000010	+.000005	+.000005
6	-.000009	+.000007	+.000003
7	-.000009	+.000008	.000000
8	-.000005	+.000003	+.000001
9	-.000007	+.000002	+.000006
X	.000000	.000000	.000000

TABLE 3. - Decade step resistance values, legal ohms--Continued

0.1 ohm decade

Decade step	Resistance, Run No. 1	Resistance, Run No. 2	Resistance, Run No. 3	Average Resistance
0.1	0.099989	0.099992	0.099993	0.099991 ± 0.000001
.2	.199978	.199994	.199995	.199989 ± .000006
.3	.299987	.300006	.300008	.300000 ± .000007
.4	.399996	.399999	.400001	.399999 ± .000001
.5	.500005	.500001	.500004	.500003 ± .000001
.6	.600014	.599993	.600006	.600004 ± .000006
.7	.700013	.699985	.699999	.699999 ± .000008
.8	.800002	.799987	.799992	.799994 ± .000004
.9	.900001	.899989	.899995	.899995 ± .000003
.X	.999990	.999991	.999987	.999989 ± .000001

Decade step	Dev. from avg., Run No. 1	Dev. from avg., Run No. 2	Dev. from avg., Run No. 3
0.1	-0.000002	+0.000001	+0.000002
.2	-.000011	+.000005	+.000006
.3	-.000013	+.000006	+.000008
.4	-.000003	.000000	+.000002
.5	+.000002	-.000002	+.000001
.6	+.000010	-.000011	+.000002
.7	+.000014	-.000014	.000000
.8	+.000008	-.000007	-.000002
.9	+.000006	-.000006	.000000
.X	+.000001	+.000002	-.000002

TABLE 3. - Decade step resistance values, legal ohms--Continued

0.01 ohm decade

Decade step	Resistance, Run No. 1	Resistance, Run No. 2	Resistance, Run No. 3	Average Resistance
0.01	0.009995	0.010003	0.010002	0.010000 ± 0.000003
.02	.020000	.020006	.020005	.020004 ± .000002
.03	.030005	.030010	.030007	.030007 ± .000001
.04	.040010	.040013	.040009	.040011 ± .000001
.05	.050005	.050016	.050011	.050011 ± .000003
.06	.059999	.060019	.060014	.060011 ± .000006
.07	.070004	.070023	.070016	.070014 ± .000006
.08	.080009	.080026	.080008	.080014 ± .000006
.09	.090014	.090019	.090010	.090014 ± .000003
.0X	.100009	.100012	.100013	.100011 ± .000001

Decade step	Dev. from avg., Run No. 1	Dev. from avg., Run No. 2	Dev. from avg., Run No. 3
0.01	-0.000005	+0.000003	+0.000002
.02	-.000004	+.000002	+.000001
.03	-.000002	+.000003	.000000
.04	-.000001	+.000002	-.000002
.05	-.000006	+.000005	.000000
.06	-.000012	+.000008	+.000003
.07	-.000010	+.000009	+.000002
.08	-.000005	+.000012	-.000006
.09	.000000	+.000005	-.000004
.0X	-.000002	+.000001	+.000002

TABLE 3. - Decade step resistance values, legal ohms--Continued

0.001 ohm decade

Decade step	Resistance, Run No. 1	Resistance, Run No. 2	Resistance, Run No. 3	Average Resistance
0.001	0.001000	0.000999	0.001000	0.001000 ± 0.000000
.002	.002011	.002009	.002000	.002007 ± .000003
.003	.003011	.003008	.003001	.003007 ± .000003
.004	.004012	.004007	.004001	.004007 ± .000003
.005	.005012	.005007	.005001	.005007 ± .000003
.006	.006013	.006006	.006001	.006007 ± .000003
.007	.007003	.007005	.007002	.007003 ± .000001
.008	.008004	.008005	.008002	.008004 ± .000001
.009	.009004	.009004	.009002	.009003 ± .000001
.00X	.010005	.010003	.010002	.010003 ± .000001

Decade step	Dev. from avg., Run No. 1	Dev. from avg., Run No. 2	Dev. from avg., Run No. 3
0.001	0.000000	-0.000001	0.000000
.002	+.000004	+.000002	-.000007
.003	+.000004	+.000001	-.000006
.004	+.000005	.000000	-.000006
.005	+.000005	.000000	-.000006
.006	+.000006	-.000001	-.000006
.007	.000000	+.000002	-.000001
.008	.000000	+.000001	-.000002
.009	+.000001	+.000001	-.000001
.00X	+.000002	.000000	-.000001

TABLE 4. - Mueller bridge, serial No. 1603629, dial reading corrections

10 dial		1 dial		0.1 dial	
Reading	Correction	Reading	Correction	Reading	Correction
10	-0.00020	1	+0.00001	0.1	-0.00001
20	-.00033	2	+.00001	.2	-.00001
30	-.00054	3	+.00001	.3	.00000
40	-.00065	4	+.00001	.4	.00000
50	-.00076	5	+.00001	.5	.00000
60	-.00084	6	+.00001	.6	.00000
70	-.00099	7	+.00001	.7	.00000
80	-.00113	8	+.00001	.8	-.00001
90	-.00134	9	+.00001	.9	-.00001
X0	-.00155	X	+.00001	.X	-.00001

0.01 dial		0.001 dial		0.0001 dial	
Reading	Correction	Reading	Correction	Reading	Correction
0.01	0.00000	0.001	0.00000	0.0001	0.00000
.02	.00000	.002	+.00001	.0002	.00000
.03	+.00001	.003	+.00001	.0003	.00000
.04	+.00001	.004	+.00001	.0004	.00000
.05	+.00001	.005	+.00001	.0005	.00000
.06	+.00001	.006	+.00001	.0006	.00000
.07	+.00001	.007	.00000	.0007	.00000
.08	+.00001	.008	.00000	.0008	.00000
.09	+.00001	.009	.00000	.0009	.00000
.0X	+.00001	.00X	.00000	.000X	.00000

measured with the bridge commutator in the N and then the R positions.

Resistance measurements were made about every ten minutes until the ice mantle began to float. Measurements were made during three days. Results from these measurements are recorded in table 5 where,

R_N = bridge resistance reading (including null detector interpolations) with the bridge commutator in the N position

R_R = bridge resistance reading (including null detector interpolations) with the bridge commutator in the R position

R_T = average of the resistance readings in the N and R commutator positions after these readings have been corrected for bridge zero (the bridge zero is substracted) and the decade corrections of table 4 have been applied, R_T is the true resistance of the PRT at the triple point of water.

A constant current of 1 milliampere was supplied through the thermometer for the triple point measurements, and time was allowed for the reading to become constant before the resistances were recorded.

The thermometer was calibrated at the National Bureau of Standards[9/]

9/ National Bureau of Standards. Report of Calibration. Platinum Resistance Thermometer Serial No. 1586182, Test No. G39579, Ref. No. 221.11/G-39579, September 1968. On file at the Bureau of Mines, Helium Research Center, Amarillo, Tex.

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in terms of the 1948 International Practical Temperature Scale (IPTS-48) for the temperature range -183° to 500° C; therefore, temperatures determined with this PRT will be in terms of the IPTS-48.

TABLE 5. - Resistance of platinum resistance thermometer, serial No. 1586182, at the triple point of water

R_N	R_R	R_T	Dev. from avg. R_T
25.54695	25.54545	25.54592	-0.00001
25.54695	25.54545	25.54592	-.00001
25.54695	25.54545	25.54592	-.00001
25.54695	25.54545	25.54592	-.00001
25.54695	25.54545	25.54592	-.00001
25.54695	25.54545	25.54592	-.00001
25.54696	25.54540	25.54590	-.00003
25.54693	25.54540	25.54589	-.00004
25.54693	25.54540	25.54589	-.00004
25.54693	25.54540	25.54589	-.00004
25.54693	25.54542	25.54590	-.00003
25.54693	25.54543	25.54590	-.00003
25.54693	25.54543	25.54590	-.00003
25.54693	25.54543	25.54590	-.00003
25.54693	25.54543	25.54590	-.00003
25.54693	25.54543	25.54590	-.00003
25.54693	25.54543	25.54590	-.00003
25.54693	25.54543	25.54590	-.00003
25.54695	25.54547	25.54593	.00000
25.54695	25.54545	25.54592	-.00001
25.54695	25.54545	25.54592	-.00001
25.54695	25.54545	25.54592	-.00001
25.54697	25.54545	25.54593	.00000
25.54696	25.54546	25.54593	.00000
25.54696	25.54546	25.54593	.00000
25.54700	25.54547	25.54595	+.00002
25.54700	25.54548	25.54596	+.00003
25.54700	25.54548	25.54596	+.00003
25.54700	25.54548	25.54596	+.00003
25.54700	25.54548	25.54596	+.00003
25.54700	25.54548	25.54596	+.00003
25.54702	25.54548	25.54597	+.00004
25.54702	25.54548	25.54597	+.00004
25.54702	25.54548	25.54597	+.00004
25.54702	25.54548	25.54597	+.00004
25.54705	25.54547	25.54598	+.00005
25.54700	25.54547	25.54595	+.00002
25.54700	25.54547	25.54595	+.00002

TABLE 5. - Resistance of platinum resistance thermometer, serial No. 1586182, at the triple point of water--Continued

R_N	R_R	R_T	Dev. from avg. R_T
25.54700	25.54547	25.54595	+.00002
25.54695	25.54542	25.54591	-.00002
25.54695	25.54542	25.54591	-.00002
25.54695	25.54542	25.54591	-.00002
25.54695	25.54542	25.54591	-.00002
25.54695	25.54542	25.54591	-.00002

Average R_T = 25.54593 ± 0.000004

$R_O = R_T/1.00003984 = 25.54491 \pm 0.000004$ legal ohms

By definition, the ice point of water is 0.01 degree below the triple point; therefore, to obtain the ice point resistance we take

$$R_0 = \frac{R_T}{1.00003984} = \frac{25.54593 \pm 0.000004}{1.00003984}$$

$$R_0 = 25.54491 \pm 0.000004 \text{ legal ohms}$$

where

R_0 = ice point resistance .

The number 1.00003984 is obtained from the interpolation table supplied in conjunction with the NBS calibration for PRT serial No. 1586182.

DISCUSSION

The corrections of table 4 differ significantly from the original L & N calibration[10/] only for the 10-ohm decade, and are roughly double

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[10/] Leeds & Northrup Company. Certificate for Catalog No. 8069-B Resistance Thermometer Bridge, Serial No. 1603629. August 1962. On file at the Bureau of Mines, Helium Research Center, Amarillo, Tex.

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the original corrections or a maximum change of about 1 part in 10^5 for this decade.

We feel that any resistance determined with the bridge will be known with an accuracy equal to, or better than, that originally claimed by the manufacturer, which was 0.00002 ohm for 1 ohm or less and 2 parts in 10^5 for a resistance greater than 1 ohm.

The value determined for the ice point resistance agrees with the value determined at the NBS[9/] to 4 parts in 10^6, which may be partly fortuitous, but does give added confidence in our work.

The ice point resistance determined by this work differs from that of Briggs[3/] by 5 parts in 10^5; however, Briggs used a thermometer current of 2 milliamperes while a current of 1 milliampere was used by us. Also, we note that the precision of our ice point measurements was an order of magnitude better than that of Briggs due, at least in part, to a better null detector.

In summary, we feel that our temperature determinations, made with PRT serial No. 1586182 and Mueller bridge serial No. 1603629, will reproduce the IPTS-48 with an accuracy essentially dependent upon the accuracy of the NBS thermometer calibration.