New Two-Point Calibration Method for Platinum Resistance Thermometers for the Range 75–400 K*

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In this paper we describe a new method for calibrating high quality platinum resistance thermometers to ±0.01 °C over the temperature range 75–400 K. This method requires resistance measurements at only two temperatures (liquid nitrogen and the ice point) in contrast to other methods which require measurements at four temperatures. The method is based on the invariance of Cragoe's Z-functions (resistance ratios) with respect to different high quality platinum thermometers. In addition our method uses the new International Practical Temperature Scale of 1968 (IPT-68). We checked our calibration at two intermediate temperatures (liquid oxygen and the fusion point of mercury) and measured deviations of less than ±0.01 °C from our calibration.

INTRODUCTION

THE platinum resistance thermometer is a versatile and accurate means of determining temperature over wide ranges. Because the electrical resistance of platinum varies reproducibly with temperature, it can be used as a thermometer by measuring its resistance and referring to a calibration chart relating resistance to temperature. A difficulty arises in securing a universal calibration table since each thermometer varies in impurity content and in absolute resistance. High quality thermometers typically have low impurity content, high stability, and are often hermetically sealed in helium filled platinum sheaths.

Many calibration methods have been proposed. Perhaps the best known is the four-point method of Callendar–Van Dusen.[1] Resistance measurements at four fixed points can yield the parameters R_0, α, β, and δ which, when substituted into the Callendar–Van Dusen equation,

$$\frac{R(T)}{R_0}=1+\alpha\left[T-\delta\left(\frac{T}{100}-1\right)\left(\frac{T}{100}\right)\right.$$
$$\left.-\beta\left(\frac{T}{100}-1\right)\left(\frac{T}{100}\right)^3\right], \quad (1)$$

and evaluated at some temperature T (°C), yield the resistance $R(T)$ of the thermometer at that temperature. However, this equation is accurate down to approximately 90 K; all attempts to extend its range below this have been unsuccessful.[2]

Cragoe[3] observed that different platinum thermometers can be characterized by a universal[4] function of tempera-

ture, the Z function, which is defined as follows:

$$Z_{12}(T)=[R(T)-R(T_1)]/[R(T_2)-R(T_1)], \quad (2)$$

where $R(T)$ is the resistance of the thermometer at temperature T, and T_1 and T_2 are fixed calibration temperatures. The subscripts on the Z function emphasize its dependence on the particular calibration temperatures. This observation led to a method for calibrating platinum thermometers. Basically, the method requires that the resistances $R(T_1)$ and $R(T_2)$ be measured for the uncalibrated thermometer and that a table of functions $Z_{12}(T)$ based on those two temperatures also be available. Equation (2) is then used to determine $R(T)$ vs temperature. The accuracy of this method has been shown to be ±0.01°C for high quality platinum thermometers when used over the range 75–400 K.[5] A difficulty arises in that a table of appropriate Z-functions is not generally available, since it is not always known in advance precisely what temperatures T_1 and T_2 will be convenient for a particular calibration.

The purpose of this paper is to describe a general method for determining Z functions based on the ice point and *any* convenient temperature in the vicinity of the boiling point of liquid nitrogen. The experimenter has freedom to choose the latter point at his convenience and yet can calibrate his thermometer to ±0.01°C[6] for temperatures over the range 75–400 K.[7]

I. CALIBRATION METHOD

We make use of three thermometers in this method. Let thermometer A be the one to be calibrated, thermometer B

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[1] G. K. White, *Experimental Techniques in Low-Temperature Physics* (Clarendon Press, Oxford, 1959), p. 109.

[2] *Temperature, Its Measurement and Control in Science and Industry*, C. M. Herzfeld, Ed. (Reinholt Publishing Corp., New York, 1962), Vol. III, Part 1, p. 343.

[3] Cragoe, Procés-Verbaux Comité Int. Poids Mesures 21, T84 (1948).

[4] The invariance of these Z functions for different thermometers is based on Matthiessen's additivity rule which states that the electrical

resistivity of a metal is the sum of a temperature independent impurity resistivity and a temperature dependent resistivity which is not affected by the impurities. This invariance in fact has been verified for a wide range of platinum thermometers [see Ref. 2; also R. J. Corruccini, NBS Tech. Note 147 (1962)].

[5] D. H. Sinclair, H. G. Terbeek, and J. H. Malone, *Cryogenic Temperature Measurement Using Platinum Resistance Thermometers*, NASA TN D-4499 (1968), p. 34.

[6] If low quality thermometers are used, this method should still be accurate to ±0.05°C (see Ref. 5).

[7] Even though our fixed points are at liquid nitrogen and the ice point, extrapolations over the extended range (75–400 K) should give

be any thermometer for which the parameters R_0, α, β, and δ are known, and thermometer C be a particular thermometer which was calibrated for us at the National Bureau of Standards (NBS) over the range 10–92 K. Our procedure is as follows.

(1) The resistance of thermometer A was measured at the temperature of boiling liquid nitrogen as determined by thermometer C. No attempt was made to use pure nitrogen or to reproduce standard pressure. Thermometer C indicated $T_1 = 76.935$ K, after correcting for IPT-68 scale.[8]

(2) The resistances of thermometers A and C were measured at $T_2 = 273.15$ K, the ice point.

(3) The 10–92 K NBS calibration of thermometer C was corrected to the new IPT-68 international scale.

(4) The resistance of thermometer B was computed for all temperatures between 92.0–400.0 K in steps of 0.1°C from the Callendar–Van Dusen equation using a Univac 1108 computer. However, before its resistance was calculated, corrections in temperature were made for the difference between the old IPT-48 scale which was based on the Callendar–Van Dusen equation and the new IPT-68 scale. We then computed Z functions based on $T_1 = 92.00$ K and $T_2 = 273.15$ K from these resistances for this range.

(5) These Z functions were used to compute the resistance of thermometer C from 92.00 to 400.00 K since its resistance was known at $T_1 = 92.00$ K and $T_2 = 273.15$ K. Thermometer C was thus completely calibrated from 10 to 400 K using the new IPT-68 scale.

(6) Next, a Z-function table was computed from thermometer C based on $T_1 = 76.935$ K and $T_2 = 273.15$ K for all temperatures (in steps of 0.1°C) from 75 to 400 K. Between 75 and 92 K the resistance was taken to be the corrected[8] NBS calibrated resistance (included in the computer program) and from 92 to 400 K we used the resistance calculated in step 5.

(7) Finally, the resistance of thermometer A was computed for 75–400 K in steps of 0.1°C using the Z functions from step 6 and the knowledge of its resistance at $T_1 = 76.935$ K and $T_2 = 273.15$ K. This completed the calibration of thermometer A.

To make use of our calibration method one needs the following:

(1) knowledge of R_0, α, β, and δ for any high quality platinum resistance thermometer. For this reason we include in Table I the parameters for the one we used.[9]

(2) a table of differences between the IPT-48 scale cor-

errors less than ±0.01°C for high quality thermometers (see Ref. 5, p. 20).
[8] In October, 1968 the Comité International des Poids et Mesures adopted a new International Practical Temperature Scale (IPT-68). Over the 75–400 K range it differs from the previous scale by as much as 0.035°C, so we have corrected our calibration accordingly.
[9] C. Yet-Chong and A. M. Forrest, J. Sci. Instrum. Ser. 2, 1, 839 (1968).

TABLE I. Data necessary for calibration.

1. Example thermometer (thermometer B) with known Callendar–Van Dusen parameters.[9]

$$R_0 = 25.57664 \quad \alpha = 0.0039267 \quad \delta = 1.4914 \quad \beta = 0.1096$$

2. Differences between IPT-68 scale and IPT-48 scale (used in Callendar–Van Dusen equation). This table is reproduced from Ref. 10.

T_{1968} (°C)	$T_{1968} - T_{1948}$ (°C)	T_{1968} (°C)	$T_{1968} - T_{1948}$ (°C)
−180	0.012	−20	0.012
−170	0.007	−10	0.006
−160	−0.005	0	0.000
−150	−0.013	10	−0.004
−140	−0.013	20	−0.007
−130	−0.006	30	−0.009
−120	0.003	40	−0.010
−110	0.013	50	−0.010
−100	0.022	60	−0.010
−90	0.029	70	−0.008
−80	0.033	80	−0.006
−70	0.034	90	−0.003
−60	0.032	100	0.000
−50	0.029	110	0.004
−40	0.024	120	0.007
−30	0.018	130	0.012

3. Resistance of our NBS thermometer from 75–92 K as determined by NBS[a] and corrected to IPT-68 scale.[11]

T	$R(T)$
75.0–75.5 K	$(T-75.0)(0.11012)+4.54423$ Ω
75.5–76.0	$(T-75.5)(0.11020)+4.59929$
76.0–76.5	$(T-76.0)(0.11026)+4.65439$
76.5–77.0	$(T-76.5)(0.11034)+4.70952$
77.0–77.5	$(T-77.0)(0.11040)+4.76469$
77.5–78.5	$(T-77.5)(0.11051)+4.81989$
78.5–79.0	$(T-78.5)(0.11056)+4.93040$
79.0–80.0	$(T-79.0)(0.11065)+4.98568$
80.0–82.0	$(T-80.0)(0.11079)+5.09633$
82.0–84.0	$(T-82.0)(0.11090)+5.31791$
84.0–86.0	$(T-84.0)(0.11098)+5.53971$
86.0–88.0	$(T-86.0)(0.11101)+5.76167$
88.0–90.0	$(T-88.0)(0.11096)+5.98369$
90.0–91.0	$(T-90.0)(0.11088)+6.20561$
91.0–92.0	$(T-91.0)(0.11084)+6.31649$

4. Measured resistance of our NBS thermometer at the ice point.

$$R(273.15 \text{ K}) = 25.5447 \pm 0.0010 \text{ Ω}$$

[a] Rather than reproduce the entire corrected NBS chart, a linear interpolation good to ±0.00004 Ω (±0.0004°C) is given.

responding to the R_0, α, β, and δ of the Callendar–Van Dusen equation and the new IPT-68 scale. Such a table is also included in Table I.[10,11]

(3) knowledge of the resistance of our NBS thermometer (or any other standard thermometer) in the 75–92 K region and at 273.15 K. This information is contained in Table I, already corrected to IPT-68 scale.

(4) the resistance of the thermometer to be calibrated at the ice point and at the lowest desired temperature (liquid nitrogen or above). The temperature of the low point should be measured to at least 0.01°C since the Z functions will be based on this temperature.

[10] "The International Practical Temperature Scale of 1968," Metrologia 5, 35 (1969).
[11] R. E. Bedford, M. Durieux, R. Muijlwijk, and C. R. Barber, Metrologia 5, 47 (1969).

With this information one can follow a similar procedure to calibrate any thermometer using measurements taken at only two easily accessible temperatures.

II. EXPERIMENTAL CONSIDERATIONS

Accuracy of ±0.01°C was obtained from equipment of simple construction. Two uncalibrated thermometers and the NBS thermometer (all three, Leeds and Northrup model 8164) were mounted in a copper block. Thermal contact to the block was guaranteed by the use of a grease of high thermal conductivity. The block was then simply submerged in a Dewar containing the calibrating bath, allowing at least 1 h to attain equilibrium. Air bubbles were continuously blown through the ice–water solution in order to keep it well stirred. Two standard five-digit potentiometers were used (Leeds and Northrup model K-3) to determine each thermometer's resistance; one K-3 measured the potential drop across a thermometer, while the other monitored the current by measuring the emf across a standard resistor placed in series with the thermometer. Forward and reverse current measurements were taken to cancel out any thermal emf's.

To determine the resistance at the two fixed points, the average of four measurements was taken. In both cases repeatability of ±0.01°C was obtained.

To check the calibration, we measured the resistance of both newly calibrated thermometers at liquid oxygen temperatures (90 K) and then predicted the temperature from their tables. These predictions were compared to the temperature determined by the NBS thermometer and in all cases we found them to differ by less than 0.011°C. This process was repeated at the fusion point of mercury with a maximum deviation of 0.012°C.

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A Live Time Controlled Scanning Rate for a Whole Body Counter

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Scanning whole body counters tend to sacrifice sensitivity and introduce measurement error through the use of constant drive rate mechanisms which do not readily compensate for changes in electronic deadtime. An electronic drive rate control has been developed at Battelle-Northwest Laboratory which largely eliminates this problem. The control automatically adjusts the relative drive rate to correspond to multichannel analyzer live time and is easily programmed for subject height and count duration. Digital circuitry, utilizing integrated circuits, controls the speed of a heavy duty stepping motor by controlling the motor stepping frequency. A scanning whole body counter utilizing the typical constant drive rate tends to underestimate the body or organ burden of a subject whose deposition caused abnormally high analyzer deadtime. A counter utilizing the live time control will spend proportionally more real scanning time over an area of high deposition, resulting in a desired amount of "scanning live time" for which the counter calibrations apply.

INTERNAL Dose Evaluation of Battelle-Northwest operates several whole body counters of the "shadow shield" or scanning design.[1] There are also a number of whole body counters throughout the United States and Europe which utilize variations of the scanning geometry.[2] This type of counter usually employs a constant speed drive to control the scanning rate, and the scanning period is normally adjusted to coincide with a multichannel analyzer live counting duration of a few minutes.

In routine "low level" whole body counting the constant speed method is adequate and the completion of the

analyzer live time count is closely coincident with the scan completion. A problem arises when relatively large radionuclide depositions, say microcurie amounts, are encountered in whole body counting, particularly if the deposition is localized. In this situation there may be a significant increase in analyzer deadtime, where deadtime is the time the analyzer is processing pulse data during which it cannot accept additional pulses. As deadtime increases, the count rate per unit activity decreases and since the localized source is moving past the detector, the total number of counts per total activity is reduced. As a result, the radionuclide deposition in a subject may be underestimated by a variable factor depending upon the

[1] D. N. Brady and F. Swanberg, Jr., Health Phys. **11**, 1221 (1965).
[2] H. G. Mehl and J. Rundo, Health Phys. **9**, 607 (1963).